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HANDBOOK OF CONSTRUCTION COST

BY

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PREFACE

Seventeen years ago the first edition of my Handbook of Cost Data was published; the second edition was published twelve years ago and has not been revised. When the question arose as to whether I should revise the Handbook of Cost Data now or produce an entirely new book on construction costs, I chose the latter alternative, for the following reasons:

Nearly three-fourths of the costs given in the Handbook of Cost Data are still applicable although published more than twelve years ago. This may surprise many people, for cost data are commonly supposed to be ephemeral. But, as stated in the prefaces to the Handbook of Cost Data and to the Handbook of Mechanical and Electrical Cost Data, unit costs can be so stated as to be applicable for a century or more, provided the methods of construction have not changed. If the number of hours of labor of each class and the number of units of materials are given for each unit of construction, then present rates of wages and present prices of materials can be applied to the old data, and the present cost of construction deduced.

Because of this fact I decided not to revise the Handbook of Cost Data for a few years longer, but to produce a new companion book under the title of Handbook of Construction Cost, thus preserving fully 1,800 pages of usable cost data in the old book, and adding thereto 1,700 pages in this new book. The owners of the old handbook will thus find no duplication of data in this new handbook and will not be put to the expense of buying a two volume revised edition.

The World War caused a great rise in prices and wages. So important did it become to know approximately what future price and wage levels would be that I decided to make a very thorough study of the factors that affect price and wage levels. This study was rewarded by the deduction first of a price level formula, and later of a wage level formula, both of which are discussed at some length in this book, where they are shown to be in agreement with the facts for so many years as to leave no doubt as to their substantial accuracy.

Several political economists had previously announced composite price and wage formulas, which purported to give a weighted average of commodity and security prices and of wages. My engineering training enabled me to discern that since the wage level curve had risen almost uniformly for a century, whereas the commodity price level curve had oscillated, no formula giving a composite of wages and prices would be of any value, even if it could be deduced. Accordingly, I devoted myself to deducing two distinct formulas, one for commodity price levels and one for wage levels. The first of these was published in Engineering and Contracting, April 7, 1920, and the second August 3, 1921, together with the proof of their substantial accuracy.

For compiling data for this book I am greatly indebted to James M. Kingsley.

HALBERT P. GILLETTE.

CHICAGO,
Sept. 1, 1922.

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HANDBOOK OF CONSTRUCTION COST

CHAPTER I

ENGINEERING ECONOMICS

This chapter takes up briefly some of the principles and applications of engineering economics. Further matter on this subject is given in Section I of the "Handbook of Cost Data" by Gillette, which contains 112 pages dealing with the principles of engineering economics and cost keeping; and Chapter I of the "Handbook of Mechanical and Electrical Cost Data" by Gillette and Dana, which contains 81 pages on general economic principles. "Construction Cost Keeping and Management" by Gillette and Dana deals at greater length with the particular phases of engineering economics indicated by the book's title.

Engineering is the systematic application of science to problems of economic production and service. The engineer's ultimate aim, therefore, is to effect a desired result at a minimum cost and maximum profit. To this end, where it is feasible, the engineer should formulate a unit cost equation in which all dependent variables and constants are included, and he should then solve for a minimum unit cost. But whether he is able to employ this ideal method or must use cruder methods, he must eventually express all the items in terms of money.

Put differently, every economic problem resolves itself into the determination of quantities to which unit prices are applied. No economic problem can be solved merely by the use of qualitative terms; yet many a poor reasoner attempts to solve the most complex of economic problems without the use of a single item to which a definite cost is assignable. Volubility is vainly made to serve instead of valuation.

Imperfect Cost Data.—The term data is coming more and more to designate statistical facts rather than qualitative facts. Cost data are obviously essential in solving economic problems. Yet there still exists a prejudice against published cost data. If, however, each engineer were to rely solely on cost data gathered by his own meager pickings from his own little crab-apple tree of experience, economic progress would be decidedly restricted. Accordingly each year witnesses more complete and detailed publication of costs in most lines of engineering work. It is true that many of the cost data are incomplete, or insufficiently explained, and are therefore apt to be misleading. It is also true that a man entirely inexperienced in the use of cost data may misinterpret even the most complete data. But neither the deficiences in published data nor defective reasoning in their application should serve as an argument for restricting the publication of such information. In spite of the risk of misuse, "a half-loaf is better than none." Moreover a half-loaf of knowledge on a given subject is almost universally the precursor of a full loaf.

Prices and Costs.—Price is the quantity of money exchanged for property or service. *Cost* is usually, but not necessarily, expressed in terms of money, and, when so expressed, means the money outlay and debits incurred in securing property or service. Cost may also be expressed, at least partly, in terms of hours or days of labor required to produce a given commodity or service. But as materials that have been purchased usually enter into the cost of a product, and as the labor upon those materials is often unascertainable, the known labor-cost of product is rarely all the cost. The labor-cost of a product may be given in hours or days of labor expended upon it. The materials-cost of a product may likewise be expressed in units of each kind of materials used.

Although the money-cost of reproducing a given product or service vary with current prices and current wage rates, the labor-costs and the materials-costs of the given product may remain the same in different localities and in the same locality at different times. Indeed, unless methods of construction or machines change, the average labor-cost and materials-cost per unit of products or service may remain practically unchanged for a generation. When this is the case the present cost of reproducing a given product is ascertainable by multiplying the old labor-cost and material-cost by the present rates of wages and present prices of materials. In other words old money-costs can often be converted into present money-costs by the use of a little knowledge of prices, wages and arithmetic.

The Usefulness of Old Cost Data.—Obvious as all that has just been said may appear, nevertheless there continues to be some criticism of "old" cost data. It is clear, however, that part of this criticism springs from failure to distinguish between prices and costs. Part of the criticism springs from belief in a false generalization which usually takes some such form as this: "Modern progress is so rapid that cost data ten years old are inapplicable." We are rather proud of our industrial progress, and our pride has perhaps concealed from us how slow that progress really is. In Chapter II it is shown that during the years 1900 to 1919 there was practically no increase in per capita productivity in America. Prior to 1900 the annual increase had averaged about 1.5 per cent for 40 years. Surely this is not startlingly great industrial progress even at the best period. In the face of such facts what becomes of any sweeping assertion that modern progress makes useless all cost data that are ten years old?

When a generalization is shown to be false, it is not only natural but proper to narrow it so as to make it convey truth of a more limited sort. Hence the attempt may be made to qualify the generalization by confining it to the construction field. At first sight it does look plausible to say that construction methods and machines are revolutionized every ten years or so; but a little study of engineering literature shows that even this qualified generalization needs further qualification. There are countless instances of present use of very ancient tools and methods in construction work. The pick, the shovel, the cart, the wheelbarrow, the saw, the adz, the ax, the hammer, the block and tackle, the inclined plane, the lever and an almost endless list of primative tools still find an economic use, and most of them probably always will find such use.

The introduction of the method of chuting concrete, and of suitable new devices for chuting it long distances, is scarcely a decade old. But concrete is still handled in ways and by devices that are several decades old. Are we not apt to be so blinded by the latest devices as to ignore the fact that many of the oldest still have special fields of usefulness? A study of engineering literature convinces me that we are. Mere age, therefore, is not a sound reason for not studying old cost data. Frequently the best articles on methods and costs of construction of a given kind are the articles published 20 years or more ago.

Often an old article fails to give rates of wages, but gives the unit cost of labor. In such cases, the reader may still find the old data useful if he knows approximately the prevailing rates of wages at the time the old data were gathered. Accordingly I have left unchanged in every case, the rates of wages that were actually paid, so that the reader can, by searching this book and the Handbook of Cost Data, acquire a knowledge of what were the prevailing wages for different kinds of labor at different times and places. In order further to increase the reader's knowledge of wage rates, I have made a study of "wage indexes" for the past 80 years. This study, together with a formula for "wage levels," will be found in Chapter II.

For a similar reason I have also given prices of materials and "commodity price levels," together with a formula for "price levels."

Efficiency as Affecting Costs.—During periods of rapidly rising wage rates, employees tend to become less efficient. This springs from the fact that employers are bidding for employees to such an extent that employees take advantage of conditions. Hence, during the recent war there was a falling off in labor efficiency. But labor efficiency has returned again to normal. It follows that costs of work done during the years 1916 to 1920 inclusive are not so reliable as prior thereto, because of the unknown extent to which labor efficiency was below normal during those five years.

Engineering Economics.—The following reprint in Engineering and Contracting, May 30, 1917, is from a series of lectures delivered before the students of the School of Engineering, University of Kansas, by J. A. L. Waddell.

General Features of Engineering Economics.—When determining, from the standpoint of economy, which is the best of a number of proposed constructions or machines, one should compute for each case the four following quantities, and their sums:

A. The annual expense for operation.
B. The average annual cost of repairs.
C. The average annual cost of renewals.
D. The annual interest on the money invested.

That one for which this sum is least is the most economic of all the proposed constructions or machines; but this statement is truly correct only when the costs of operation, repairs, and renewals are averaged over a long term of years; or else, for a comparatively short period of time, when the conditions in respect to wear and deterioration at the end of that period are practically the same for all cases.

The principal economic investigation that occurs in engineering practice is that of determining the financial excellence of a proposed enterprise. It consists in showing by proper calculations its first cost, the probable total annual expense of maintenance, repairs, operation, and interest, the advisable allowance for deterioration or ultimate replacement, the probable gross income, and the resulting net income that can be used in paying dividends on the stock or other profits to the promoters. Whether any proposed enterprise, after being thus figured, will prove profitable will depend greatly on the state of the money market, the size of the project, the probabilities of future changes in governing conditions, and the personal equation of the investor. Generally speaking, if the computed net annual profits on the total cost of the investment (over and above all expenses of every kind, including maintenance, repairs, operation, sinking fund, and interest on all borrowed capital) do not exceed 5 per cent of the said total cost, the project is not attractive; if it be as high as 10 per cent, the enterprise is deemed ordinarily good; and if it be 15 per cent or more the scheme is termed "gilt-edged." Small projects necessitate greater probable percentages of net earnings than do large ones; and any possibility of a future reduction of income will call for a high estimate of net earning capacity. Finally, the measure of individual greed on the part of the investor will be found to be an important factor in the determination of the attractiveness of any suggested enterprise.

Such investigations as the economics of an important project should generally be entrusted only to engineers experienced in the line of activity to which the said project properly belongs; for if they be left to inexperienced investigators, it is more than likely that mistakes will be made and money lost in consequence. The professional men who generally do such work are the independent consulting engineers; certain specialists retained on salary solely for this purpose by important organizations, such as railroad companies; and engineers who are regularly in the employ of large banking houses. The work involved is of such importance that it usually commands large compensation—as, indeed, it should; because to do it effectively demands not only long experience but also good judgment and a vast amount of mental labor, both in order to make oneself capable in general and so as to consider thoroughly all the points embraced by the special problem in hand.

This fundamental economic problem is often one of extreme complication, involving, perhaps, a determination of the character of the proposed improvement, a choice of sites or routes, a selection of uses, a consideration of æsthetics, an option on type or style of construction, a question of ultimate durability, a study of greatest possible convenience, a prevision of serious opposition, a prognostication of future conditions, an anticipation of prospective structural modifications, and a safe estimate of cost.

General Features of Economics of Design and Construction

Anticipating the Future.—In all engineering work of both designing and construction, true economy necessitates a thorough consideration of future requirements and possible eventualities, also a provision for meeting the same. For instance, in designing a structure one should consider possible future additions of loading and how to accommodate them; and in construction one should anticipate delays, floods, storms, and other possible difficulties, and should prepare his programme so as to meet them effectively and without any unnecessary expenditure of time, labor, or money. Foresight of this kind is an important element of success in the career of every engineer.

Systemization.—Quoting from the speaker's treatise on "Bridge Engineering," "The systemization of all that one does in connection with his professional work is one of the most important steps that can be taken towards the attainment of success." Moreover, it is one of the fundamental elements of economics in all lines of work.

Time Versus Material.—Some designers in their endeavor to save a small amount of material expend a large amount of time, not only of their own but also of other people's, which time when properly evaluated is often greatly in excess of the cost of the material saved. Such economy as this is false; and its practice is unscientific.

Labor Versus Material.—Similarly some designers in an endeavor to cut down quantities in their structures increase the labor thereon to such an extent that the material saved is worth only a small portion of the value of the extra labor expended. For instance, if one were to make a small pier hollow, the concrete thus saved would not be worth anything like as much as the cost of the forms required to construct the hollow space.

Recording Diagrams.—The study of economics is greatly facilitated by the use of diagrams that record quantities of materials, costs of construction, times of operation, etc., for varying conditions. In general, it may be stated that American engineers do not use graphics for studying economics to the extent which is advisable; and that in this they might learn something from their European brethren.

Economics of Mental Effort.—Almost nothing concerning this important subject is taught in our technical schools; and but little is known about it by practicing engineers. To be a truly successful engineer, one has need to study deeply the matter of how best and most economically to utilize his mental forces; how to accomplish the greatest amount of work with the smallest expenditure of effort; how many hours of work per day for long-continued labor will effect the largest accomplishment; to what extent men in various lines of activity should take vacations, and how these should be spent; what are the effects upon one's working capacity from the use of liquor and tobacco in both small and large quantities, etc. All these are economic questions of great importance; and they need to be given proper attention by every engineer who aspires to efficiency in both himself and his employes. Again, the development of the faculty of concentration is an economic consideration of much importance.

Economics in Office Practice.—There are many conditions in ordinary office practice that are susceptible of considerable improvement from the economic point of view—for instance, unnecessary conversation, useless duplication of labor, and lack of proper checking; but this matter is too complicated and lengthy to warrant more than mere mention in a lecture of this kind.

Economics of Manufacture.—This is a subject of such complication and extent that it can merely be mentioned here; for upon it a large treatise might readily be written. It will suffice to say that the prime requisites are the prompt furnishing at all times of materials and tools; the keeping on hand of spare parts of machinery which are liable to breakage or wear; the proper upkeep of all machinery and apparatus; the systematic arrangement for carrying work through the shops, preferably always in one direction; the avoidance of duplication of labor; the prevention of errors, and the speedy correction of those which unavoidably occur; the development of individual efficiency in all employes; the maintenance of a contented spirit among the workmen; and the constant and intelligent supervision of all work.

Economics of Construction.—This subject like the one last discussed is of great complication, and in general principles the two have much in common.

For instance, there should be prepared for each piece of construction an elaborate programme, indicating the various steps to be taken and how the work should be carried out. Diagrams in this connection are most useful. Again, there should be prepared a time-schedule for the completion of the various divisions of the work; and this should invariably be lived up to when it is possible.

There should be a pre-arranged schedule for the furnishing of all materials and supplies; adequate means for the transportation thereof should be provided; the workmen should be well housed and fed; and should be made comfortable and contented; disagreements between heads of departments should be prevented; all possible difficulties should be anticipated, and means should be at hand to meet and overcome them; ample funds should be provided for paying promptly all bills for labor and materials; liquor should be kept away from the workmen; and strike organizers and other troublesome people should be run off the job.

All these matters are directly concerned with the economics of construction.

Labor.—The scientific handling of labor is an economic prolem of the utmost importance, and a treatise could well be written on the subject. The principal desideratum is to keep the workmen well, happy, and contented; and the best ways to do this are to treat them kindly, make them comfortable, feed and house them well, amuse them in their spare time, don't work them too long hours, pay them by piece-work when practicable, listen patiently to their complaints, right their wrongs, see that they are well taken care of when they are ill or injured, and evolve, if possible, some feasible method of sharing profits with them. On the other hand, though, drive them hard and continuously during working hours, insist upon their putting in overtime when the conditions truly require it, discharge instantly all insubordinate or otherwise troublesome men, dispense quietly with the services of all shirkers, and insist that everybody put forth his best and most intelligent effort to effect the maximum of accomplishment in the minimum of time.

Waste.—In all lines of activity the avoidance of waste or extravagance and the utilization of by-products are today burning questions; and upon their proper solution by American scientists will depend greatly the success of our country in its commercial struggle with the nations of Europe and Asia. This statement is just as true concerning engineering as it is of any other activity; and it is encouraging to see that a number of our leading technical institutions are inaugurating research departments for the furtherance of this object.

Efficiency Experts.—A very new type of specialist in engineering is the efficiency expert—the man who takes hold of moribund factories and other decaying enterprises, studies them thoroughly so as to determine the raison d'etre for their decline, evolves the proper remedies for their troubles, puts them again upon their feet, and starts them upon the high road to success. It is mainly in little matters, apparently of small importance, that such concerns fail; and it requires a high development of unusual talent in an engineer to become a truly successful efficiency expert. Such work as his no one can deny being "engineering economics" in the truest sense of the term; and the specialty is surely destined to become more and more popular and important as the years pass by.

The Art of Making Rapid and Reliable Preliminary Estimates of Cost.—Allen Hazen gives the following in Engineering and Contracting, March 18, 1914. Estimating the cost of constructing proposed or existing structures rapidly and surely is an art. It is a valuable art and deserves cultivation. The success of many undertakings depends upon its use. Some men have the knack of estimating; others can never learn it. But good methods are essential and these can be studied and perfected and applied to special problems.

Estimates made for different purposes, are prepared in quite different ways according to circumstances. They may be conveniently classified under three headings:

(1) Preliminary estimates, being estimates made in advance of the preparation of detailed plans and specifications for the purpose of discussing a project for deciding as to its adoption, and for making the necessary financial arrangements for carrying it out.

(2) Detailed estimates, being estimates based upon detailed plans for the execution of the work, and usually made shortly before bids are asked for the particular work covered, or in advance of undertaking to carry it out by day labor.

(3) Final estimates, being the estimates to the contractor at contract prices for the actual work done. The term "final estimate" may also properly be applied to a statement of the cost of a completed work based upon actual expenditures made for carrying it out.

That which follows relates only to preliminary estimates.

Preliminary estimates are made much more frequently than others because only a fraction of the projects for which estimates are made are carried out. Less precision is expected in preliminary estimates than in detailed or final estimates, but on the other hand all reasonably attainable accuracy is desirable, for many important matters depend upon it. The decision as to which of two or more alternate projects is to be adopted frequently turns upon the preliminary estimates of the respective costs. The decision as to whether or not to undertake a certain enterprise usually turns upon the preliminary estimate of the cost of the work. A certain degree of reliability is, therefore, essential in preliminary estimates. On the other hand, preliminary estimates must be made for many enterprises that will never be carried out, and it is necessary that they should be made rapidly and without undue expense to the client.

Basis for Preliminary Estimates.—There is only one real reliable basis for preliminary estimates. It is, the consideration of final estimates of work previously carried out, of a character and magnitude as nearly as may be similar to that of the proposed work. The more nearly the work represented by these final estimates approaches in all the conditions that for which estimates are being made, the more reliable, in general, are the preliminary estimates based upon it; and the more numerous and greater the points of divergence, the less reliable is the basis and the greater is the probable error in the resulting preliminary estimate.

Estimates in Valuation Proceedings.—When a property such as a water works property is to be valued for the purpose of sale, it is common for engineers to make estimates of the cost of reproduction for the structures. These estimates may be in the nature of final estimates when the structures were recently completed and the actual costs are shown by records. They may be in the nature of detailed estimates when full plans and quantity schedule are available. More often they are in the nature of preliminary estimates because such detailed information and cost are not available. Preliminary estimates made in this way are commonly subject to comparison with like estimates made by engineers representing the other party to the transaction, and it is frequently necessary to harmonize such estimates by arbitration or otherwise. If they are presented as evidence in court the engineers who made them must support them through a searching cross-examination. The criticism of preliminary estimates made in this way is likely to be more searching than that of estimates made in the ordinary course of business, where the estimates are made for the purpose of construction and comparison only. For this reason the experience gained in valuing properties for the purpose of sale and in condemnation cases is more useful than any other experience that an engineer can have in training him in the first elements of sound procedure in making preliminary estimates.

Methods of Comparison.—The problem presented in making preliminary estimates is this: given the final estimates of a certain number of works, more or less comparable to the one proposed, and a general outline of the works for which an estimate is to be made to find the probable fair reasonable cost of construction of the proposed works. The general procedure is to find the elements of cost in the work that is to be carried out, and the actual cost of those elements in the works for which final estimates are available, and to apply the latter to the former. In doing this all known differences that would affect, to an important extent, the probable cost of the work, must be taken into account and allowed for to the best of the estimator's ability.

Basis of Estimate.—An estimate may be said to be low, fair, or liberal, according to the methods used in making it. A fair estimate may be defined as one such that with the work carried out in a business-like way under average conditions, there is somewhat more than an even chance that the work could be completed within the estimate. In the case of structures of types that have been built frequently, and of which the elements of cost have been well determined, experience indicates that it is possible in most cases to approximate, in preliminary estimates, the cost of new structures within 10 per cent of the actual cost. With such structures a fair estimate would be somewhere between the most probable cost and 10 per cent more than this, or, in a general way, 5 per cent above the most probable cost. With an estimate made in this way, it should be possible to keep the actual cost of construction within the estimate three times out of four, and this is figuring as closely as an engineer can be expected to do.

In the case of structures of greater novelty, or structures involving undetermined underground conditions, greater fluctuations must be anticipated and the above-mentioned percentages should be increased.

Erroneous Methods of Reaching Estimates.—In a valuation proceeding, it is frequently surprising that reputable engineers will present on different sides, estimates differing so much for the same item. These differences must frequently grow out of the use of erroneous methods of procedure by the respective engineers. It may be well, therefore, to consider some of the commonest methods that are erroneous, and to point out the reasons why they should not be used.

The Contract Price Method.—The columns of the technical journals contain a record of the prices at which many contracts are awarded. By going through these columns and selecting the low bids and applying them to the proposed work, an estimate may be prepared which will probably be much below a fair estimate for the work. Among the reasons that it would probably be low are the following:

First, many of the low bidders have underestimated the difficulties to the work, and their bid are really too low. That is, they are not sufficient properly to carry out the work and make a fair profit. The contractor may not be able to complete the work under the contract and additional expense to the owner will have to be met.

Second, in applying the bid prices, or contract prices to new work, it is very easy to overlook entirely some items in the work. A price that relates to a part of the work may be taken as applying to the whole of it through ignorance or failure to make a fair and full comparison.

Third, the schedule of quantities prepared by the engineer for use in the specifications on which bids were obtained may be inaccurate and may not correspond with the final quantities when the work is completed.

Fourth, the items of extra work growing out of conditions that either were not anticipated, or that were intentionally excluded from the contract by the engineer as a matter of policy, are overlooked and ignored.

For these and similar reasons, estimates prepared from contract prices or from low bids reported are almost invariably too low and frequently may be too low by a very large percentage. An estimate made in this way is a low estimate. The figures may be arranged to make a very convincing showing in support of it, but it remains notwithstanding a low estimate.

Estimates Based on Averages.—In many municipal and corporate reports one may find records of the monies actually expended in carrying out certain developments. It is easy to find such records and to compile them and to deduce from them a figure which may be used as representing the probable cost of a proposed work of similar character. Some works represented by such figures may have been done in an efficient an economical manner, and the figures so obtained may be reliable and proper ones for use. Frequently, some or all of the work taken for use in this way was done under conditions that were not efficient, and the cost of doing it may include other items than those relating to the construction work. It is easy to select data in this way to back up a high estimate, and to make a showing that is convincing to those not familiar with the methods.

A Fair Basis of Estimate.—A fair basis of estimate does not exclude either of the above methods, but will take into account data secured under either for what it is worth, and will make allowances for the conditions, or supposed conditions, under which the bids were received, or the work was done. A fair basis of estimate will also give much greater weight to final estimates of work as comparable as may be to the work that is proposed where the work was done under conditions known to be careful and economical. The engineer in making such estimates will naturally and rightly give greatest attention to work done under his own direction, and will give second place to work done by his friends and acquaintances with which he is reasonably familiar as to conditions met and methods used in the construction.

The Weighted Price Method.—The number of different kinds of work for which unit prices may be obtained is very great. If an effort is made to keep track of the amount of work of each kind, and to estimate the amount of it in the proposed work, the schedule will be too complicated and the labor of applying the figures will be unduly increased. Moreover, if the schedule used for comparison is too complicated, some items are sure to be overlooked, with the result that too low a final figure will be reached. In order to prevent both of these conditions it is frequently best, in preparing preliminary estimates, to take only a limited number of the main items of work that are involved in the kind of construction that is contemplated, and to weight the unit prices for them in such a way that they will include the whole cost of all the incidental items naturally associated with them.

In proceeding in this way one selects first the items that are to be used. These items should be so selected as to include directly the major part of the work. The final estimates that are to be used as a basis are then taken for analysis. The whole cost of the work represented by each is then distributed among selected items. Considerable judgment is required in the distribution and each part of the construction should be included with the item to which it is most nearly related. The most important point is that every dollar spent should be charged under some one of the selected headings.

The sum of the costs reached in this way, divided by the quantities in the final estimate, gives new unit prices which are weighted to include all the minor items. Applying these unit prices to the main items of the proposed work gives a basis for preliminary estimate.

As illustrations of these methods, take the case of pipe-laying. The trenching, the lead, the cast iron pipe, the teaming and incidental expenses may all be represented by separate items in the final estimate that serves as a basis. These can obviously be consolidated into a single item per lineal foot of pipe of a given size. In this process the price for pipe is weighted to include the other expenses that naturally go with it. The process may be carried further and the pipe still further loaded to include the gates, the hydrants and all auxiliary structures.

In a similar way the cost of the reinforcing and of the forms for concrete construction first stated as separate items, may be consolidated, and all the different classes of concrete may be brought into one so that a unit price for masonry includes reinforcing and forms, and all the appurtenances that go with the masonry structures.

In estimating the cost of sand filters the writer has for years divided the whole cost of the construction into four parts, as follows:

(1) Excavation and earth work.
(2) Masonry.
(3) Filtering materials.
(4) Piping and auxiliaries.

The cost of each plant built worked out in this way on a uniform basis affords a basis for rapid and accurate comparisons, and allows the data to be applied in making preliminary estimates for new work where the prime conditions of cònstruction are known with comparatively little chance of large error.

Weighted unit prices of this kind must be carefully obtained and can only be used with caution. The amount of weighting must always be kept clearly in mind by those who use them. When properly deduced and used, they afford an extremely useful and rapid method of approximating the cost of many structures.

The Ratio Method.—There are many cases where the system of weighted unit prices cannot be used because the schedules in the final estimates that serve as a base are in such form that unit prices cannot be deduced from them. For example, there are many cases where the amount and character of work are known and the total cost of the work is known. but there is no way of sub-dividing it between the different items. To compare the costs of different pieces of work with each other, and to get a basis for estimating the probable cost of other similar work is then much more difficult.

A method of reaching an approximate and useful solution of this problem is one which may be called the ratio method. A schedule is made of a limited number of items of work which represent the greater part of the construction in the several cases. A simple schedule of unit prices is then formed, corresponding to the units. One fixed price is assumed for each kind of work. The price assumed should be a reasonable one, and as nearly as is known an average one, but precision is not to be expected and a round figure may always be used. The amount of work under each item in each job is ascertained and the assumed prices are applied to them. The sum of the amounts for each job represents what that job would have cost at the assumed prices. A comparison between the actual cost and the cost at the assumed prices gives an idea of the relative economy of the work. It may be found, for example, that one piece of work cost 20 per cent more than the amount obtained by applying the assumed prices; another piece of work cost 12 per cent more and a third, 7 per cent less. When the records of a number of known pieces of work are compared in this way it furnishes a basis for making a preliminary estimate for work of the same class. In doing this the quantities for the proposed work are ascertained, the base prices are applied to them and a ratio by which the sum so reached is to be increased or diminished is ascertained by consideration of the ratios actually found to have been obtained in the jobs for which cost records are at hand.

In arriving at the ratio to be used, the engineer will compare, perhaps in his mind and without written schedules, the ease or difficulty of the proposed work as compared with the ease or difficulty of the various works which served as a base; will take into account differences in labor conditions, in freights and deliveries; will take into account the known or assumed efficiency or lack of efficiency in the execution of the several pieces of work from which his basic data were derived, and will reach an estimate of the addition or subtraction to be made to or from the base price in each case.

This method is commonly combined with the preceding. That is to say, the base prices are usually loaded prices.

This method affords a convenient and efficient method of comparing the relative costs of different works where the loaded unit price method cannot be applied and in experienced hands it affords a rapid and reliable method of making preliminary estimates upon many classes of structures.

Extra Cost of Novel Designs.—Work on novel designs commonly costs more than work following standard designs. This is true even when well tried methods are first introduced in new places. Such work may be too small to attract bidders from a distance. The unit cost will then overrun anticipated prices. An under estimate of cost is frequently made on work because the estimator fails to realize what a great effect familiarity with the methods of performing work has upon the cost. To realize this, one has but to think of the difference between present methods and costs of building tunnels and subways and deep foundations, and the methods and costs of only 15 or 20 years ago. Not only is the risk which the contractor takes now less, but methods which have been thoroughly tried out are at his disposal as well as experienced foremen and laborers to do the work more economically. For a structure of new or novel design much caution in using prices that may be standard on other kinds of work must be used.

Small Jobs Cost More in Proportion than Large Ones.—Another common cause of under estimating costs is the use of figures on large pieces of work for estimating small work. The engineer often overlooks the large cost of overhead charges, the waste of labor and the cost of plant caused by organizing a force to perform a small piece of work. He too often forgets that for small work the work must be done by less efficient methods or the cost of plant prohibits the use of expensive machines. Perhaps the most common case of such underestimating is where the job, although a large one in the aggregate, consists of many small pieces of work of widely varied character. Such a job is troublesome and costly for the contractor and the experienced man knows it and puts in a corresponding bid.

It must be remembered that bids follow the law of supply and demand; that general slackness in construction work calls out bidders and low prices. The condition of the money market, the cost of materials and the general opinion of the condition of contract work are of course matters of much importance. It seems scarcely necessary to say that the engineer should know where and how the contractor is to obtain his materials and have a fairly definite idea of the cost either in dollars and cents or as a comparative figure to other work.

The engineer in estimating should try to look at the work from the standpoint of the contractor, should try to remember that no work runs as smoothly along as the contractor wishes, that labor conditions and other matters often spoil the best laid plans. He should endeavor to keep in mind the various work he has watched or performed and the numerous times when unexpected conditions added largely to the cost.

Generally speaking, estimates on proposed work by men of limited experience are too low, yet it is not unusual for an engineer to be so impressed with the difficulty of a piece of work that he overestimates the actual cost and it is more common to find that he has overestimated the bids of the contractors.

It is of much value to have two methods of arriving at estimates. If an independent check method can be made even though a rough one, a failure of the two results to agree often leads to the discovery of serious errors in the application of one or the other method.

Conditions of Success in Estimating.—One of the first requisites for successful estimating is a fair and unprejudiced, and moderately pessimistic mind. The estimator must be alert for new and cheaper processes and methods, and conservatively sceptical concerning their merits. Moreover a successful estimator must have had experience in actual construction. As a general rule an engineer should not make an estimate for a structure that he would not know how to build.

Next, as a requisite to successful estimating, may be mentioned a broad basis of cost records of actual work, more or less similar to that for which estimates are to be made. A good and safe method of using the cost data and adjusting it for application to new conditions is equally important. And, finally, the estimator must have the will to refuse to make estimates for work that he does not understand.

Cost Estimating; A Discussion of Principles with Actual Estimates for Contract Work.—Engineering and Contracting, July 14, 1909, publishes the following by J. B. Balcomb:

General Principles

Engineers rarely make a success of cost estimating. The same may be said of architects, contractors and others, to all of whom a reliable estimate is of the greatest importance. Many even go so far as to assert that it is not possible to do it satisfactorily. Yet it must needs be done, therefore the ability may be attained to do it; provided always, that it is undertaken with a complete understanding, not alone of its importance, but of its requirements and limitations as well.

Certain characteristics are essential: A man must be, (a) a logical thinker, (b) a constructive organizer; he must have, (a) an analytical mind, (b) an active imagination, well under the control of reason; he must acquire, (a) the habit of forming definite judgments and conclusions, (b) the practice of systematizing on paper.

In addition to these, it is imperative to have had shop or field experience, preferably both, and to have accumulated systematic notes and records of cost. A technical education is of advantage and some designing experience is helpful.

If one is to follow estimating professionally, as an architect, estimator or consulting engineer, his practical experience should be broad and diversified. While on field work he should have studied methods and collaborated cost data; both for future use in estimating, and as a guide in using information compiled by others.

In such records, it is not sufficient that quantities of work and their cost be given: he should note the rate of wages, the quality of work, the class of labor, the conditions regarding weather and the arrival of supplies and materials, as well as special conditions either favorable or unfavorable; so that in using this data he may be able to form a rational judgment as to how nearly other work, the cost of which he is called upon to estimate, will be controlled by like conditions.

As an illustration, let us assume that one is recording data on excavation. In such case it would be well to make note of how the work was done; whether with (a) steam shovel, (b) locomotive crane, (c) teams and wheelers, (d) teams and slips, or, (e) men with picks and shovels; whether the hauling was done with (a) locomotive and flat cars, (b) dinkies and dump cars, (c) teams and patent dumpers, (d) horses with carts, or, (e) men with wheelbarrows; and whether it was loosened by (a) men with picks, (b) teams with plows or rooters, or (c) blasting with dynamite or giant powder.

It is also necessary to give: (a) character of excavated material, (b) depth of cut and height of fill, (c) length of haul, (d) condition of roads or tracks, and (e) special features which either facilitated or hindered progress.

If the excavation is in rock, there will be, in addition, (a) method of drilling, (b) method of blasting, (c) method of loading and unloading.

There are other combinations than those suggested, but these cover the usual methods of handling earth. While no other form of construction is susceptible of being handled in so many different ways, yet this serves admirably to illustrate how meagre are the usual cost data as given in the periodicals or technical papers. To say that an excavation cost 40 cts. per cu. yd. means absolutely nothing, for it might have cost anywhere from 5 cts. to $5, and the work still have been handled to the best advantage. What is necessary, is not that we should know one or two but all of the above conditions.

When one is making up an estimate, he should know the relative cost of different methods of operation under like conditions. Then it is possible to select the most economical method, and having determined this, to estimate with a fair degree of probability the cost of the proposed work. To illustrate, where the haul is very short and the excavation shallow, buck scrapers or road graders are often used, while with longer haul and a deeper cut it is advantageous to use elevating graders and patent dumpers. In this latter case, teams with wheel or drag scrapers may be better, especially if the soil is sandy, stony or filled with roots. A locomotive crane presupposes a railroad track and a comparatively short haul, whereas a steam shovel may be used with an engine and cars, where a railroad track is used and the haul is long, or with teams and either dump wagons or scrapers. If the job is large, so that the unit cost of organizing the force and moving the plant is small, it is a safe rule to avoid manual labor wherever possible. The work is always recorded in cubic yards, preferably of excavation rather than of fill. This one kind of construction will serve to illustrate the others, the chief requisite being that all conditions affecting the cost be explicitly stated.

It has been said that the wise business man never ventures on a course of action without first submitting it to a detailed analysis on paper: certain it is that the wise estimator never prepares a bid without doing so. This of course does not apply to dwellings or other structures where the firm has already completed one or more similar buildings under like conditions. In other words, a detailed and itemized estimate is never presumed to be undertaken where identical cost data is available; cases of identical construction, however, occur far less frequently than is generally supposed.

In order to approximate actual costs, it is imperative for an estimator to outline a complete and rational plan of operation, while making an estimate. He should definitely formulate the requirements as to both equipment and men—how much and what kinds of machinery, how many superintendents, engineers, foremen, timekeepers, clerks, mechanics and laborers. In thus mentally organizing his force, he should estimate the size and makeup of each gang, and the time required for different portions of the work. These should be correlated as to their necessary sequence, both as regards the disposition of the working force, and the plant employed on each. That he may thus plan the work in detail, an estimator must have had actual field experience, the broader the better; a portion of the time, preferably, spending his own money. Few estimators, even of those who are without this experience, will question its advantage.

Although his plan may never be carried out, it is worth while to have it typewritten as a guide while making the estimate. Further, it will be helpful should he be called on to superintend the work or as a means of defending his estimate, in case of excessive costs.

It is of especial importance that an estimate be localized—adapted to the particular work in hand and none other—suiting the existing conditions only, because made for them. When another estimate is needed, even for similar work, take this one to pieces and build it up again in accordance with the new requirements and the new conditions. If a job is of sufficient importance to demand an estimate, it is worth a new analysis, an individual synthesis. This does not mean that the estimate shall be elaborate; if the work is simple, make the estimate so, but make it definite and detailed.

The chief items of the usual estimate consist of quotations on material and freight rates from the factory to the work—the theoretical cost of materials at the job. Before the true cost of materials is determined, allowance must be made for: (a) delays in shipment, (b) delays in transportation, (c) switching and demurrage charges, (d) unloading and storage, (e) hauling and reloading one or more times, (f) shortage and broken material, (g) wrong shipments and reordering.

Even then, this is but the beginning of an estimate, and the least difficult part

Frequently sub-contractors are asked for bids, with a view to sub-letting portions of the work, or as a check on the company's own estimate. It is often well to make it serve both purposes, for in many cases small contractors can handle specialized portions of the work for less money than large contractors.

Next to cost records on work practically identical, a man's own experience, properly classified and tabulated, is the most reliable asset of an estimator. In nearly all cases, however, this must be supplemented in order to cover the required field; even specialists finding a diversified knowledge none too broad to embrace the different forms of construction which will at times enter their work.

Since it is manifestly impossible for a man to have had experience in all lines of construction, even in all phases he may be called on to estimate, it becomes necessary to use published data to some extent. Books like Gillettes' "Handbook of Cost Data" are very helpful. Many valuable data are published in the technical journals, although few engineers classify and index them convenient for reference. General conceptions may be formed by noting contract prices, although this is of less value than would at first appear, owing partly to unbalanced bids, but mainly because one knows nothing of the specifications and local conditions.

Test pits are of great value in estimating the cost of excavation work and the necessary depths for foundations. The difficulty being that owners, to whom the work legitimately belongs, will seldom incur the necessary expense; and contractors usually prefer to "make a guess at it" rather than spend money for some one else to profit by. It would often be ultimate economy for owners to show the actual conditions underground rather than let bidders take chances, for the "gambler's chance" means high bidding or unsatisfactory work.

Where a considerable portion of any work is new to a bidding firm, or where its personnel is limited in numbers or experience, a consulting engineer, architect or construction superintendent is frequently called in consultation. This is a commendable practice and could more often be followed to advantage. The chief difficulty is that architects usually estimate by the cubic foot of building or square foot of floor area, thus making an approximation on the assumption of average conditions; construction superintendents have a better knowledge of methods than of costs, so can ordinarily give only general ideas; and comparatively few engineers have systematic cost records at their command. The present growing interest in this, the engineer's weakest point, promises to be of great economic advantage to the building public, and is an opportunity which should be embraced by all engineers who wish to see our profession occupy the preeminent position which rightfully belongs to it, as a result of the marvelous achievements which it has accomplished.

Main Features of Estimating

Materials.—In estimating the cost of machinery, materials and supplies, it is customary to ask for quotations; giving general requirements, approximate date of delivery and point of shipment. Only reliable dealers and manufacturers should be asked to quote. If freight rates are not included with the quotations, they should be secured from transportation companies.

These two items form an important, but by far the easiest, part of an estimate. Exclusive of a firm's reputation for fair dealing and prompt payment, any other company can secure as favorable figures; consequently, can bid equally low, so far as these items are concerned. The opportunity for difference in the bids of two contractors must lie in some place other than the cost of materials and the transportation charges. Usually it is to be found in the estimate of labor or in the question of profits.

Existing Conditions.—Aside from making a guess at the labor cost, which is by no means uncommon, the matter most often overlooked or ignored is that of existing conditions; natural, economic and legal. In forming a judgment regarding natural conditions, the following matters should receive due consideration: (a) amount and frequency of precipitation, (b) amount of surface water, (c) character of drainage, (d) depth to permanent water level, (e) kind of soil, (f) size and depths of excavations, (g) disposition of excavated material, (h) length of time pits will remain open, (i) amount of shoring and sheeting required, (j) effect of climate on materials, (k) effect of climate on plant, (l) effect of climate on labor.

While many of these conditions will be passed over as similar to those on work already done, and eliminated by the use of cost sheets on such work, it is well for an estimator to have such a list before him. On important work, each item should be given at least casual thought, considering fully such as are especially pertinent. The wide variations in these matters between different localities, states and countries, make their consideration imperative where close estimating is desired.

Of but little less importance are the economic conditions, regarding dealers and manufacturers, common carriers, and both skilled and common labor. The difference in service rendered by the same firm or individual in 1892 and the hard times immediately following was very great. Even more marked was the difference between the years immediately preceding and succeeding the Wall street panic of October, 1907, with its resulting aftermath. This should especially be borne in mind regarding the quantity and quality of labor performed both by mechanics and laborers, and the compensation paid therefor. Under this head should be considered the question of commissary and transportation facilities for the force employed, although it is also considered under the headings of plant and labor.

In this connection, the legal requirements should not be overlooked. This is of especial importance in large cities where the obligations imposed are often onerous to say the least. Such matters as not blocking street traffic, keeping the sidewalk clear, supporting adjacent buildings, the many police regulations, as well as the difficulties of not transporting materials, not forgetting the rules of labor unions, are matters which often wipe out the profit and leave a large deficit, when not duly considered in the estimate.

Even in rural communities, there are still the state laws regarding liabilities of employers, mechanic's liens, the collection of money due a contractor, and others, either favorable or unfavorable, which should have due weight in raising or lowering one's bid, before the final estimate is complete.

It is essential to go over the proposed contract carefully, noting the time limit and any burdensome clauses it may contain. Sometimes these may be altered before the bid is submitted, by using tact and diplomacy; if not, proper allowance can be made for them in the estimate.

Contractor's Plant.—The question of plant equipment with which to complete the work according to contract, in case one is the successful bidder, is of far reaching importance. It is an unfortunate custom among engineers and contractors to add a lump sum or a percentage for cost of plant, supplies and maintenance. One might almost as well add a percentage to cover the labor cost, after computing the cost of materials.

The only reliable way is to estimate the cost of plant for each proposed work, considering separately the requirements of each class of construction covered by the specifications. In order to do this, the estimator must outline a complete and rational plan for carrying on the work, as before suggested. Having outlined a plan, he is in position to determine with a fair degree of accuracy, the necessary plant, as well as the cost of supplies and maintenance. These latter will depend mainly on three things: (a) condition of plant, (b) character of work, (c) character of labor employed in operating it. In judging of these, the estimator should consider climatic conditions, facilities for repairs, and the company's attitude toward plant enlargement.

In addition to the tools and machinery with which to do the work, various temporary buildings ought to come under the head of plant equipment. These should embrace construction offices, commissary buildings, sheds and buildings for storage purposes, and such other structures as may be required by the plan of operation.

Labor Cost.—The most difficult, and at the same time most vital element of an estimate, is the labor cost. In order to make a fair approximation, one needs extensive records obtained by a wide and varied personal experience.

The first thing to be considered is the character, and perhaps personnel, of the staff; in other words, the efficiency of the superintendence. Where it is impossible to determine this with a fair degree of accuracy, it necessarily follows that the estimate of labor cost is an approximation only. Next after the general manager of the company, the superintendent will be the main factor in the success or failure of the work. While it is impossible to reduce such matters to mathematical formulas, an illustration by way of percentages will help to emphasize the need of forming a correct judgment on this point. Suppose a percentage of efficiency, giving what might be termed inherent values, is ascribed as follows:

	Illustration No. 1 Per cent.	Illustration No. 2 Per cent.
General Manager	100	70
Superintendent	90	80
Foremen	80	90
Laborers	70	100

At first glance one would assume that each is an 85 per cent organization, taking an average of the different values. This conclusion embraces two errors: first, the percentage value of each grade is affected by the one next above (a good foreman will increase the efficiency of men, a poor one will decrease it; likewise with the superintendent and foremen); second, the efficiency of the organization is the product, not the average of the different values. With a reasonable correction for the first, these would read:

	Illustration No. 1 Per cent.	Illustration No. 2 Per cent.
General Manager	100	70
Superintendent	95	75
Foremen	87½	82½
Laborers	79	91

Taking their products, we have,

Illustration No. 1.: $1 \times 0.95 \times 0.875 \times 0.79 = 66$ per cent organization.

Illustration No. 2: $0.70 \times 0.75 \times 0.825 \times 0.91 = 39$ per cent organization.

These illustrations serve merely to emphasize in a concrete way the importance of good superintendence, and are in no sense suggested as a practical method of arriving at the labor cost. In failing to estimate correctly the human element, especially "the man at the top," more than in all other factors combined, is to be found the reason why careful estimates so often fail utterly to agree with actual costs.

Following superintendence, the next matter to be considered is the quality and quantity of labor. Skilled and unskilled labor should be considered separately.

Superintendence, nationality, quarters and climate are the leading factors in forming an organization, and those which most largely affect the labor cost. The first of these is of prime importance and is usually greatly underestimated. For real economy in handling men and work, a good man is preferable to a poor one, although he demand twice the salary. It is safe to allow liberal salaries in estimating the cost of superintendence. The best contractors seldom permit the question of salary to stand in the way of retaining a really efficient superintendent or foreman.

The effect of commissary, climate and local conditions, as before mentioned, must be kept in mind. The proximity of saloons and dens of vice have a very noticeable effect, at times increasing the labor cost 10 to 25 per cent.

After determining the main features of labor cost, the experienced man knows that numerous items in addition will come to light during actual construction. These are almost impossible to compute previously, except by giving careful thought to every detail, as suggested above. Frequently a percentage is added to cover these contingencies; this is commendable, if each form of construction is considered on its merits, and the percentages varied according to the elements of uncertainty involved. The following are some of the more obvious of these features:

The commissary, which may prove either a debit or a credit, depending on its purpose and management.

Sanitation, including potable water, closets, sewers, drains and baths, and is always a debit.

Medical attendance, which usually produces a debit on small works and a credit on large ones.

Labor insurance, which is always a cost item, directly or indirectly.

Labor agency, which should produce a credit, if undertaken.

Walking delegates, each to be considered on his individual merits if known, otherwise on his reputation.

A Complete Cost Estimate

Losses and Margins of Safety.—In addition to, and supplementing the outline given in the previous sections, a series of items too often overlooked consists of what may be called losses and margins of safety. Among these may be mentioned: (a) lost and broken material, (b) delay in arrival of materials, (c) rehandling materials, (d) storage of materials, (e) cost of organizing the force.

The first item can best be offset by percentages on the labor and material cost, each class of work being considered separately. Regarding the second, it is often best to allow the salary and traveling expenses of a good man (on large works, two or more) to follow up shipments and see that they arrive on time. The unavoidable delay and consequent expense still remaining will be included in the percentage added for general expenses. The rehandling and storage of materials can be estimated only in conjunction with the plan of operation as outlined by the estimator; depending largely on local conditions as to space, buildings and character of the materials. The cost of necessary sheds and buildings will have been allowed for under plant.

The last item will depend largely on the nature of the work, condition of the labor market, character of the laborers, and maximum number employed. Other conditions being equal, it will be nearly a fixed cost, proportional to the maximum working force: the total amount being affected but slightly by the length of time required to complete the job.

Profits.—What constitutes a legitimate profit is an indeterminate proposition, since the number of correct answers is unlimited. A fair profit on one class of work is evident injustice on another. There should be a greater percentage on labor than on machinery; also, a varying per cent on the different classes of labor and the different kinds of machinery. A competent estimator never allows as great a percentage on a single unit that costs a large sum as on a multitude of small items aggregating the same amount; since the latter would be purchased from various manufacturers and dealers and cost much more to handle and install.

The adaptability of the company's plant to proposed work justly weighs somewhat in the element of risk and uncertainty; consequently, it helps determine the profit desired. A further factor is the proportion of the work of which the company makes a specialty. It is evident that a specialty can be handled more economically than general work; yet in so far as it may approach a monopoly, there is a desire for proportionately larger profits.

The aggregate of profit is also determined somewhat by the number and magnitude of contracts on hand; bidding always being higher by a company pretty well loaded up with contracts, and having most of its trained force already in the field. The final element entering into the estimate of profit is the policy of the company—a large amount of work at a low rate, or a few contracts at handsome figures.

Tabulation of Results.—Where a complete estimate is desired, the entire work should be divided into items or classes, each as separate and complete as possible. It is convenient to have a column for each of the following: (a) quotations on materials, (b) freight on same, (c) drayage of same, (d) estimated labor cost, (e) total for material and labor.

Instead of estimating the plant for each item, a better plan is to consider a group of items together; under each group allowing for: (a) repairs and maintenance, (b) supplies, (c) safety margins, (d) profits.

From the plan of operation, already alluded to, the cost of superintendence may now be computed; and than a lump sum or percentage added for general and office expense. This latter will be estimated from the company's monthly expense account, the amount of present and prospective business, and the past experience of the company.

The cost of surveys and expense incurred in the drafting room should be included in the general expense, unless these items are to be estimated separately. If the bid is to be by unit costs: the superintendence and surveying should be distributed proportionally to the labor cost; drafting, general and office expense, proportionally to the cost of both labor and materials.

With the estimate complete, it devolves upon the general manager, who is often the president also, to determine from conditions already mentioned the amount to increase or decrease this final figure before submitting the bid.

Realizing that contracting is an art, not an exact science, he will bear in mind the keenness of competition and the builder's reputation for fair dealing. If the latter is questionable, it is doubtful wisdom even to place a bid.

If the general manager does the estimating himself, it is well to remember that few contractors have become bankrupt because of not securing contracts; many because their work was not handled economically and honestly; while the vast majority who have failed have been able to secure contracts, have handled their work to fair advantage, but have been unable to secure reasonable acceptance and prompt payment; the situation most likely being aggravated by having taken the work too cheaply. For this reason, some managers add a small amount to cover interest on borrowed money to meet expenses while waiting on deferred payments.

With this in mind, two additional columns are sometimes added; one in which to place the percentage of work completed; the other, the cost of same to date. An estimate prepared as here outlined, with costs appended during the progress of the work, helps greatly in borrowing money with which to tide over unforseen emergencies.

These matters call for business ability rather than engineering training, and their successful handling is the final test of a man's ability to secure contracts advantageously. An intelligent estimate will preclude the probability of taking work at a loss, but will never enable a firm to secure work at a maximum profit.

Sewage Disposal Plant.—As an illustrative example, part of an estimate of cost for the sewage disposal plant at Washington, Pa., is given. (See Table I.)

The broken stone was to be quarried and crushed at a quarry belonging to the borough, which accounts for no allowance for rental. It was located at a distance of 500 ft. from, and at an elevation of 50 ft. above, the proposed plant.

A branch line of railroad runs next the site, accounting for the absence of drayage in most cases. General expense was estimated as follows:

	Per cent
Office	8
Drafting room	1
Labor insurance	1
Interest	1½
Adjustments	1½

This percentage, with minor exceptions, is computed on columns 1 to 9 inclusive.

Profit was estimated at from 5 per cent to 10 per cent on materials, including columns 1, 2, 6, 9 and 10, and 10 per cent to 15 per cent on labor, including columns 3, 4, 5, 7 and 8. Exceptions were made on item 45, where 2½ per cent on materials and 7 per cent on labor was used, as the company was desirous of underbidding machinery firms; 25 per cent on the different classes of concrete, as the company felt sure that bidding prices would be high; 30 per cent on the broken stone, as this still kept it below the price at which stone could be shipped in.

It will be noted that the mix is given in each of the concrete items immediately to the left of the ingredients. Where a figure is included in parenthesis, as (1) under freight, it signifies that the freight is included in the amount given in column 1. An x, as in column 3, means that there was no drayage on that item.

TABLE I.—COST ESTIMATE OF A SEWAGE DISPOSAL PLANT

Items and Quantities.	Material 1	Freight 2	Drayage 3	Superintendence 4	Labor 5	Lost and broken material 6	Rehandling material 7	Organizing the force 8	Plant 9	General expense 10	Profit 11	Total 12	Unit bid 13
Excavation, 7,500 cu. yds.							$467	$50	$100	$560	$650	$5,677	$0.76
Plow and scraper, 3,687, at .22				$180	$760								
Pick and shovel, 1.844, at .34				140	590								
Below creek level, 554, at .80				100	416								
Trench for pipes, 415, at .95				320	1,344								
Rolled embankment, 3,200 cu. yds.				250	1,056		106		20	185	210	1,827	0.57
Loam, 675 cu. yds.				65	270		41		5	50	85	516	0.76
Seeding, 17 acres				5	23		2			3	7	40	2.35
Sodding, 100 sq. yds.				4	13		2		5	3	5	32	0.32
Gravel for roads and walks, 560 cu. yds.	$470			45	190	$40	59		325	105	160	1,394	2.50
Concrete, Class "A," 325 cu. yds.				80	341	64	34	65	240	280	700	3,455	10.60
1. Cement, 520 bbls., at $1.58	822	(1)											
2. Sand, 147 yds., at $1.65	243	(1)											
4. Broken stone, 294 yds., at .84	235	(1)											
Forms at $1.08 per cu. yd.	351												
Concrete, Class "B," 1,200 cu. yds.				285	1,200	242	120	20	925	1,160	2,500	12,559	10.45
1. Cement, 1,920 bbls., at $1.58	3,040	(1)											
2. Sand, 592 yds., at $1.65	920	(1)											
4. Broken stone, 1,184 yds., at .84	947	(1)											
Forms at $1.00 per cu. yd.	1,200												
Concrete, Class "C," 1,300 cu. yds.				295	1,235	220	124	30	990	1,120	2,425	12,147	9.35
1. Cement, 1,625 bbls., at $1.58	2,574	(1)											
2½. Sand, 573 yds., at $1.65	956	(1)											
5½. Broken stone, 1,260 yds., at .84	1,008	(1)											
Forms at .90 per cu. yd.	1,170												
Concrete, Class "D," 1,525 cu. yds.				325	1,373	255	137	65	1,080	1,120	2,720	13,610	8.95
1. Cement, 1,906 bbls., at $1.58	3,020	(1)											
2½. Sand, 672 yds., at $1.65	1,111	(1)											
5½. Broken stone, 1,480 yds., at 84	1,184	(1)											
Forms at .80 per cu. yd.	1,220												

Owing to local conditions, the questions of commissary and medical attendance were not considered in this estimate.

The cost of plant is figured for each item, deducting its value as second-hand tools and machinery after the work was done.

The cost of organizing the force falls mainly on those items which would be undertaken in the earlier part of the construction work. The following table will be found helpful, *as a general guide only*, in estimating the cost of organizing a force; the actual amounts in all cases being dependent on many of the conditions previously noted.

	1st mo.	2d mo.	3d mo.	4th mo.
Max. force employed, 100 men.				
1 supt. at $100 per mo.	$ 50	$ 25	....	....
0–6 foreman at $60 per mo.	90	90	....	....
0–50 men at $1.75 a day	415	....	....	....
50–100 men at $1.75 a day	....	300	....	....
Field office help	100	50	....	....
Total, $1,120—$11.20 per man.				
Max. force employed, 500 men.				
1 supt. at $200	$100	$ 65	$ 50	....
0–15 foremen at $75	360	....	....	....
15–20 foremen at $75	....	440	....	....
20–25 foremen at $75	....	....	425	....
0–100 men at $1.75	440	....	....	....
100–300 men at $1.75	....	875	....	....
300–500 men at $1.75	....	....	700	....
1 asst. supt. at $150	100	75	50	....
Field office help	300	200	100	....
Total, $4,280–$8.56 per man.				
Max. force employed, 1,000 men.				
1 gen. supt. at $400	$200	$135	$100	$ 80
0–3 supts. at $175	235	....	....	....
3–5 supts. at $175	....	175	....	....
0–20 foremen at $75	375	....	....	....
10–30 foremen at $75	....	300	....	....
30–50 foremen at $75	....	....	250	100
0–200 men at $1.75	875	....	....	....
200–500 men at $1.75	....	875	....	....
500–800 men at $1.75	....	....	440	....
800–1,000 men at $1.75	....	....	....	440
Field office help	400	300	200	100
Total, $5,580—$5.58 per man.				

In the present instance, the company already had in its employ trained superintendents, foremen and mechanics; so the cost of organizing the force was estimated at a figure considerably less than suggested above. Like all other features of an estimate, it is evident that each case must be determined on its merits and considered accordingly.

Filtration Plant.—The estimate next given is that of a filtration plant at Roanoke, Va., of 4,000,000 gallons daily capacity. It was for a lump sum bid, consequently the arrangement is somewhat different than in the preceding estimate.

Near the end, under "Accessories," the amounts given in the columns for Material and Freight cover "Lost and Broken Material;" under Drayage and Labor, "Rehandling Material" and "Organizing the Force."

Unit bids not being called for, Plant, Superintendence, General Expense and Profit are not distributed, but added at the end to make up the final cost.

TABLE II.—ESTIMATE OF COST OF A FILTRATION PLANT

Coagulating Basin—	Material	Freight	Drayage	Labor
Excavation, 2,800 yds.				
Plow and scraper, 2,500 yds.........	......	...	....	$500
Pick and shovel, 300 yds............	......	...	....	90
Concrete, 596 cu. yds..............	......	...	....	892
Cement, 655 bbls. at $1.85...........	$1,207	(1)	$196	....
Broken stone and sand, 511 yds. at $2.	1,022	...	(1)	....
Forms, 4.6 M f. b. m..............	92	...	(1)	69
Water..............................	15	...	...	10
Reinforcement, 1,000 sq. ft. expand. metal at .04......................	40	2	2	20
Filter Tanks—				
Excavation, 685 yds.				
Plow and scraper, 625 yds...........	......	...	...	125
Pick and shovel, 60 yds............	......	...	...	18
Concrete, 269 yds.				
Materials and forms (as above)........	1,132	...	117	470
Reinforcement, 18,855 lbs. at .02......	377	43	15	204
Wrought iron railing, 80 ft. 180-lb. at .45 per ft........................	36	2	1	7
Clear Well—				
Excavation, 1,100 yds.				
Plow and scraper, 1,075 yds..........	......	...	...	215
Pick and shovel, 25 yds............	......	...	...	8
Concrete, 282 cu. yds.............	......	...	...	353
Materials and forms................	1,154	93	10	...
Reinforcement, none req'd.				
Roof,				
Framing, 25.7 M f. b. m.............	514	...	(1)	180
Sheathing, 9.7 M f. b. m............	194	...	(1)	68
Composition roofing, 81 sqs. at $3.50..	284	...	(1)	81
Building—				
Concrete, 48 yds. (same as filters)....	270	8	24	120
Brick (common), 235,000 lbs., 47,000 at $7.50.........................	352	(1)	176	376
Brick (pressed), 47,500 lbs., 9,500 at $24.............................	228	(1)	36	80
Mill work,				
12 windows at $3.75, 2 doors at $2.50..	50	...	2	35
Roof,				
Framing, 5 M. f. b. m...............	100	...	(1)	75
Sheathing, 3 M. f. b. m............	60	...	(1)	30
Slate, 9 T., 28 sqs. at $8............	224	(1)	14	168
Scaffolding, 3 M. f. b. m............	60	...	(1)	30
Painting...........................	25	...	(1)	50
Hardware,				
Openings, 14 at $1.50...............	21	...	...	...
Ridge, 36 ft. galv. iron..............	9	...	1	3
Conductors, 80 galv. iron............	20	...	1	8
Gutters, 215 galv. iron..............	54	...	2	23
Bearing plates and tie rods, 322 lbs. at .05............................	16	...	1	4
Treating Plant—				
Tanks, 4 req'd. (inc. under "Coag. Basin").				
Orifice boxes, 2 at $15...............	30	1	1	5
Brass pipe and fittings, as per list......	152	1	1	20
Merchant steel pipe and fit., as per list.	22	1	1	8
Depth gauges, 4 at $60..............	240	1	1	10
Brass orifice slides, 2 at $13..........	26	(1)	(1)	2

Machinery—				
Pelton wheel, ¼ ft.				
Centrifugal pump, 1-lb. 10 M.				
Blower, 1-lb. 2; 3.5 T. total..........	810	33	6	50
Pelton wheel, 1- like Lorain Cent. pumps, 2- like Lorain..............	260	9	2	40
Equipment—				
Inlet controller, 1-16 " butterfly valve and float..........................	91	3	1	6
Water manifold and strainers, 14,280 lbs., 1,428 sq. ft. at $1.25............	1,785	32	11	113
Air manifold, 4,450 lbs., 1,428 sq. ft. at .70..............................	1,000	10	3	18
Wash troughs, 8-168 ft., 8,400 lbs., $4.50 per ft......................	751	40	6	38
Gate Valves—				
4–6″ flanged at $8.10................	32	...	...	...
4–10″ flanged at $24.30..............	97	...	...	...
4–10″ angle at $43.50...............	174	...	...	...
3–10″ high pressur at $22.50........	68	...	...	...
4–5″ flanged at $6.75................	27	...	...	...
1–6″ flanged high pres. at $9.........	9	...	...	...
1–10″ flanged foot, at $21.28.........	21	...	...	...
6,700 lbs...........................	...	24	5	66
Sluice Gates—				
4–10″ flanged, at $19.50.............	78	...	...	...
4–12″ flanged, at $26.25.............	105	...	...	...
Valve stands, non-indicating, 20 at $5.	100	...	...	...
1–10″ regulator valve................	231	...	...	...
Loss of head gauges, 4 at $65.........	260	...	...	...
9,200 lbs., total	....	27	7	93
C. I. Pipe—				
B & S, 14,180 lbs.				
Heavy wt. 6″–50′, 1680 lbs...........	29	(1)	1	15
Heavy wt. 10″–200, 12,500 lbs........	219	(1)	10	8
Standard 10″–12′, 720 lbs., 3 pcs.....	58	(1)	1	2
Lead and jute, 22–10″, and 7–6″ joints	33	(1)	1	...
Specials, B & S, 1,330 lbs.				
1–10″ tee, 300 lbs.				
1–10″ ell, 214 lbs.				
1–10″ Y, 370 lbs.				
1–10 × 10 × 6″ Y, 255 lbs.				
2–6″ ells, 190 lbs.				
8–12″ –60 ells......................	69	(1)	3	8
Lead and jute, 4–10″ and 8–12″ joints.	9	...	...	...
Specials flanged, 4,168 lbs.				
1–16″ × 10′ F & F, 1,207 lbs.				
5–10″ × 3′ 3″ FF & S, 1,310 lbs.				
4–12″ × 2′ 9″ FF & S, 1,108 lbs.				
5–10″ × 1′ 3″ F & S, 543 lbs.				
4–6″ × 3′ 3″ F & S................	31	(1)	1	2
4–10 × 10 × 6″ side outlet T's.....	60	(1)	1	4
Bolts and gaskets...................	23	(1)	1	....
Flanged, 9,147 lbs.				
4–10″ × 5′ 2″......................	75	...	...	....
4–8″ × 8′ 9″.......................	63	...	...	....
4–10″ × 3′ 0″......................	54	...	...	....
1–12″ × 16′ 4″.....................	38	...	...	....
2–12″ × 15′ 6″.....................	74	...	...	....
1–12″ × 7′0″.......................	17	...	...	....
4–6″ × 1′ 8″......................	15	21	7	60
Flanged fittings, standard, 3,685 lbs.				
1–12″ ell..........................	12	...	...	....
8–10″ ells.........................	70	...	...	....
4–8″ ells..........................	22	...	...	....
4–6″ ells..........................	13	...	...	....

4–10 × 8 × 8″ tees	58	...	...	...
2–12 × 10″ crosses	41	9	4	36
M. S. Pipe—				
Random lengths, 2,430 lbs.				
6″ × 60′ at .565	34	...	...	...
5″ × 90′ at .435	39	...	...	...
40 ends threaded, at .30	12	5	2	15
Fittings, 469 lbs.				
4–5″ ells at .52	2	...	...	...
2–6″ ells at .72	2	...	...	...
2–6 × 8″ crosses at $1.92	4	...	...	...
1–6″ plug at .29	0	...	...	...
8–5″ flanges at .505	4	...	...	...
4–5″ flange unions at .72	3	...	...	...
2–6″ flange unions at .89	2	1	1	6
Vitrified Pipe—				
Standard, 29,150 lbs.				
24″–170′ at .715	121	...	...	...
15″–70′ at .297	21	(1)	40	45
Fittings,				
2–24 × 10″ crosses	13	...	...	...
2–15 × 12″ crosses	5	(1)	1	...
Channels,				
8″ × 34′ at .05	2	...	...	...
12″ × 20′ at .10	2	...	...	...
Standard,				
12″ × 1030′ at .17	175	...	...	...
8″ × 240′ at .08 ¼	20	(1)	28	6
Miscellaneous—				
Manholes,				
Brick, 4,316 at $9.50	41	(1)	4	38
Cement, 22 bbls, at $1	22	(1)	6	...
Sand, 3 yds. at $1	3	(1)	3	...
Lime, 3 bu. at $1	3	(1)	(1)	...
Covers and frames, 7 at $7	49	(1)	2	7
Filter sand and gravel, 252 T. at .65	164	...	378	126
Excavation, 516 yds	......	...	...	516
Accessories—				
Coagulating basin	120	...	5	240
Filter tanks	75	5	5	120
Clear well	110	5	...	140
Building	135	...	25	100
Treating plant	25	...	...	10
Machinery	20	...	5	20
Equipment	50	10	...	25
Gate valves	5	...	...	10
Sluice gates	10	5	...	15
Cast iron pipe	55	...	5	40
Merchant steel pipe	5	5	5	5
Vitrified pipe	35	...	10	10
Miscellaneous	30	...	40	170
Total				$24,727
Plant				300
Superintendence				500
General expense				2,500
Profit				5,000
Amount of bid				$33,027

Factors a Contractor Should Consider in Estimating.—The average contractor forgets a great many things which should be included in making up his estimate. It is true that many of these items are small and it might seem that they are insignificant, but when several are taken together the cost increases rapidly. In an interesting article in the January Contractor's Atlas, D. S.

Colburn points out certain of these matters that are commonly overlooked in estimating. The article, as abstracted in Engineering and Contracting, Jan. 28, 1920, follows:

It is probable that on an average about 6 per cent of the cost of the job is not taken into consideration when the estimate is made. The following table illustrates this point:

SCHOOL BUILDING 130′ 0″ × 200′ 0″—3 STORIES, NO BASEMENT

467	yds. rock excavation at $2	$ 934.00
880	yds. earth at 30 ct	240.00
9,900	cu. ft. concrete footing at 22 ct	2,178.00
11,880	cu. ft. concrete walls at 25 ct	2,970.00
13,524	sq. ft. reinforced concrete floor in corridors and toilets at 35 ct	4,733.40
13,524	sq. ft. terrazo floors at 25 ct	3,381.00
1,980	lineal ft. terrazzo base at 35 ct	693.00
7,914	sq. ft. plain cement floors at 10 ct	791.40
182,160	face brick at $35	6,375.62
1,339,240	common brick at $18	24,106.30
32,000	sq. ft. partition tile at 12 ct	3,840.00
3,960	cu. ft. cut stone trimmings at $1.75	6,930.00
58,000	enameled brick at $50	2,900.60
16,059	yd. lath and plaster at 40 ct	6,427.60
50	lineal ft. tile flue lining at 75 ct	33.00
6,000	lineal ft. corner beads at 6 ct	338.00
1,800	yd. metal lath at 45 ct	810.00
4,725	sq. ft. slate blackboards at 28 ct	1,325.00
2,160	sq. ft. cork tackboard at 28 ct	604.00
27,000	lineal ft. grounds at 1½ ct	405.00
96	squares steel ceilings at $7	672.00
	Moving picture booth with vent	
	Balcony in gymnasium	1,896.00
66,000	ft. maple floor at $65	4,290.00
500,000	ft. lumber at $45	22,500.00
260	squares roofing at $7.50	1,950.00
500	squares floor deadening at $2	1,000.00
47	tons structural steel at $115	5,405.00
3	iron stairs (sub-bid)	2,600.00
	Hardware trim	1,700.00
	Sheet metal ((sub-bid)	890.00
	Millwork, sash, doors, trim, etc. (sub-bid)	8,197.00
	Labor on millwork	3,278.80
	Painting (sub-bid)	1,890.00
	Usual estimate	$126,585.42
	10 per cent profit	12,658.54
	Usual bid	$139,243.96

FORGOTTEN ITEMS

Bond, 1 per cent	$ 1,490.00
Fire insurance, ½ per cent of $100,000	500.00
Liability insurance, 5 per cent of labor, $48,000	2,400.00
Telephone	160.00
Traveling expenses, board, etc	650.00
Temporary office, locker, sheds, etc	548.00
Water for building uses, temporary piping, hoists, etc	182.00
Lights, fences, barricades	80.00
Watchman, 6 months at $70	420.00
Timekeeper	350.00
Engineer, laying out, batter boards, etc	30.00
Protection of erected work	100.00
Temporary heating 6 months will burn 220 tons coal at $7	1,540.00
Cleaning out building	100.00
Carting debris	25.00
Cutting and jobbing for other trades	430.00
	$ 9,005.00

Bid Should Be

Usual estimate	$126,585.42
Plus items overlooked	9,005.00
Correct estimate	$135,590.42
Plus 10 per cent profit	13,559.04
Correct bid	$149,149.46

It frequently happens that the general specifications are glanced over in a superficial manner, the contractor immediately taking the plans and specific specifications and estimating all materials and workmanship. When the materials and labor have been figured from these, 99 per cent of the contractors think that nothing remains to be done except add the usual 10 per cent for profit. The trouble is that the general specifications are not carefully enough observed and studied.

As an example of this, there was a large contracting concern recently figuring on a drainage job of considerable magnitude. A close study of the specifications revealed the fact that the contractor was responsible in many ways which ordinarily would not involve any responsibility on his part. For instance, he had to guarantee the designer's work and if this job was done according to the plans and specifications, and it didn't work, then the contractor would receive no payment for the job. This happens in many cases.

In another instance, the specifications made the contractor responsible for the work under the specifications and plans as stated. In other words, the plans were prepared by the architect but the contractor was held responsible. One part of the specifications referred to a basement floor and stated that the contractor should guarantee the basement floor slab to stand a certain head of water. The slab has failed and it is a question now who is responsible.

There are certain matters that are commonly overlooked in estimating and these may be chiefly summarized as follows:

(1) Surety Bond—A surety bond guarantees the faithful performance of the contract and payment of all bills in connection therewith. One per cent is the amount commonly charged for this bond no matter how big or how small the job. Many contractors pass this up and think that they can take care of it out of their 10 per cent profit. It may seem that this is rather the exception than the rule and that very few contractors would neglect to take care of this feature. It is surprising how great a number and how many of all classes of contractors neglect to take this factor into consideration.

(2) Liability Insurance—Liability insurance usually amounts to from 5 per cent to 8 per cent of the total labor cost. This can be figured at that amount and should always be taken into consideration.

(3) Temporary Heating—Another item scarcely, if ever, figured in is temporary heating. Heating is required not only in winter work, but also in early spring or fall construction. While the job may start in the summer, it should be borne in mind that it may possibly run into the winter and, therefore, the problem and cost of providing temporary heating should be taken into consideration.

(4) Temporary Enclosures—These are frequently needed, especially in the case of winter work. They are often required to enclose a part of a building so as to afford public protection. Frequently in the case of a building located in the city, roofing is required above the sidewalks. Material sheds are always needed. These items are small but, of course, count up.

(5) Water for Building Use, Temporary Piping and Hoists—It should be taken into consideration that water will be required for various operations connected with the building, for instance, the mixing of concrete, in keeping the concrete wet, and in cleaning. Elevators or hoists are required for elevating the materials to the proper place. This is an item that is many times neglected. The contractor figures that it costs so much to lay so many bricks, but the means of getting them in place is not considered.

(6) Fire Insurance—During the process of construction the building is under joint ownership by the contractor and the individual or company for whom the building is being constructed and, in the event of loss of the building by fire, the loss is prorata. The fact remains that the contractor must pay the premiums on the job until finished.

(7) Engineer, Timekeeper, Watchman—A service engineer is required in connection with the layout and other details. This expense is, however, very slight. But the expense of the timekeeper and watchmen, in case of a large job, amounts to a very appreciable figure.

(8) Telephone Service—Sometimes telephone service is not required, while there are times when it is a great necessity and this item of expense should also be considered.

(9) Traveling Expenses—This item covers the cost of transporting the foremen or other laborers sent out of town away from their homes. The contractor must as a rule pay all of the railroad fares and board for these men as well as his own expenses.

(10) Cutting and Jobbing—Cutting and jobbing for other trades is a large item since the general contractor is usually required to cut all openings for electricians, plumbers and steamfitters and to patch these up after these workemen have finished.

(11) Guarantee—Often the architects require that the contractor guarantee the material and workmanship for two years or maybe more. This is an item of considerable importance and is never taken care of under the general overhead expense. The United States Government figures 1½ per cent depreciation per year on buildings, so it is an easy matter to gain an idea of how much this item alone amounts to.

How to Determine Whether a Crushed Stone Stock Pile Pays.—Engineering and Contracting, July 17, 1918, gives the following: In the production of crushed stone throughout the year it is usually profitable to provide a stock pile, in spite of the extra cost of rehandling the stone. The main reason for this is that a smaller quarrying and crushing plant working continuously will produce the desired annual output at less cost per ton, inclusive of stock pile costs, than the cost per ton incurred by a larger plant, without a stock pile, working below full capacity most of the time.

Electrical engineers use the term "load factor" to denote the ratio of the actual annual output of electricity to the possible full capacity output of a plant. Thus, an electric generator of 1,000 kilowatts capacity is capable of generating 8,760,000 kilowatt hours of current in a year of 8,760 hrs. (i. e., 24 hrs. daily for 365 days). If, then, such a generator is so run as to generate 2,190,000 kw. hrs. in a year, its load factor is 25 per cent.

Since all the annual "fixed charges" on a generating plant are independent of the output, it follows that if the load factor can be doubled, the fixed charges per kilowatt hour will be cut in two. In general, then, the cost of the "fixed charges" per unit of output vary inversely with the load factor. This holds true of all plants, and serves to explain the economy of providing a stock pile for a crushed stone plant that can be operated the year around at a uniform weekly output.

Stone can usually be delivered to and loaded from a stock pile at a cost of 5 to 10 ct. per ton, depending on the scale of operations and the kind of plant used for stock piling and rehandling. Assuming the first cost of a quarrying and crushing plant to be $80 per ton of daily capacity, and that interest, depreciation and taxes are 20 per cent annually, we have 5.3 ct. per ton for fixed charges on a plant when run continuously one shift every day for 300 days. But without a stock pile continuous operation is usually impossible. To meet the "peak demand" for stone the plant must usually be fully twice the capacity required under continuous (one-shift daily) operation. This alone adds 5.3 ct. per ton of stone for fixed charges on the plant, or enough to cover the cost of stock piling and rehandling under ordinary conditions. But this is not the only element of cost affected by the "load factor" or output factor. A plant large enough to take care of peak demands for stone must necessarily have a crew of men capable of running it at its capacity, and most of this crew must be kept on the pay roll when the plant is operating at but a fraction of its capacity. Some of the crew must be paid even when it is not operating at all. So that either failure to secure freight cars regularly or a falling off in immediate demand for the stone results in the paying of full wages to most of the crew, regardless of the low output of the plant.

In the solution of a problem of this character the first step is to estimate the total annual tonnage of stone to be delivered. The next step is to estimate the maximum delivery that will be required for any single day, also for any single week, and for any single month. Then estimate the first cost of a plant that will supply the maximum daily output aided by the storage capacity of the bins, but unaided by a stock pile. Estimate the operating expenses, interest and depreciation charges for such a plant for a year, under the fluctuating daily, weekly and monthly outputs. Divide this total cost by the total annual tonnage and ascertain the cost per ton. Compare this unit cost with the unit cost resulting from operating a smaller plant continuously with the aid of a stock pile, including therein the interest on the average amount of money tied up in the stone in the stock pile. If the smaller plant with the stock pile shows a lower cost per ton (as it usually will) than the larger plant without a stock pile, then it is obvious that the smaller plant is more economic.

Economic Considerations in Municipal Engineering Designs.—Clinton S. Burns gives the following in Engineering and Contracting, April 10, 1918: The designing engineer has for his guidance this motto: "Secure the maximum returns for the funds invested;" and if he be true to his chosen profession he will ever strive to bring his work to that standard, even though it may at times cause him much effort beyond that which may be appreciated by his clients. In many sections of the country with which the writer is familiar, especially in the more recently settled portions of the Middle West, city councils and officers in charge of municipal works have an extremely keen appreciation of the fact that they must accomplish the maximum results from the limited funds at their disposal, and they accordingly begin by engaging the engineer who will do their work for the least money; or else they save the engineering fee entirely by simply engaging some "practical contractor" to build the works and furnish the plans and specifications free of charge. That such a policy as this is directly the opposite to true economy is too well known to engineers to require discussion, but there may be others, some holding official positions, perhaps, who have not given this subject the attention its importance deserves. If public officers but realized the amount of work involved in determining the economic features of any engineering design, they would more readily appreciate the fact that true economy and cheap engineering are not companions.

Many of the municipal works throughout the country are built with so little respect to economic design as to require but a superficial examination to show where enough money has been wasted to more than pay the compensation which would have been required to secure the best engineering talent to prepare the plans and specifications. The firm of which the writer is a member has been called upon to examine plans for a sewerage system in which the plans called for flush tanks at the head of every lateral, regardless of grade or other local conditions of service. The general character of the specifications seemed to indicate that they had been copied largely from what was without doubt originally an excellent set of specifications for a level city in a wet country, where the sewers had to be laid in quicksand and water, for they provided for under-drains and other expensive accessories which could have no utility under any other conditions. It is not surprising to learn that the fee charged for these plans and specifications was about the proper compensation for a stenographer to copy the specifications and for a draftsman to make a few tracings.

The conditions in water works design are even worse than in sewer work, because many cities are unfortunate enough to possess six or eight councilmen, each of whom knows what size water pipe should be located on his own street. After a few hours' discussion they are able to combine their ideas, and the system of mains is adopted; no one dreams that possibly 5 per cent could have been expended for engineering fees, and much better results might have been accomplished with the remaining 95 per cent of the funds.

It is no doubt true that many contractors and practical builders of water works have the ability to plan excellent systems, but even if so, it is not to their interest to work out the economic features, and therefore in the absence of an engineer to look after the city's interest much public money is necessarily poorly invested.

As an illustration of some of the work involved in determining the economic relation between the different parts of a system of water works, the writer ventures to outline one or two of the points that must be considered in this connection. This can best be shown by a concrete example, using the local conditions as to price of fuel, cost of materials for construction, conditions of service, etc., all of which are taken from actual conditions for one particular plant, but which would, of course, be quite different for any other plant. In the case under consideration the rate of pumping is estimated as follows: 2,800 gal. per minute for 6 hours per day, 1,400 gal. per minute for 6 hours per day, 800 gal. per minute for 6 hours per day, and 300 gal. per minute for 6 hours per day. This is a total of approximately 2,000,000 gal. per day, supplied to a manufacturing city of 20,000 population. The pumping station is 4,000 ft. from the branching point of the distribution system. To determine the most economical size of main for this distance it is necessary to make comparison between the various commercial sizes of water pipe. Comparing 12-in. with 16-in. pipe the friction offered by each 1,000 ft. of 12-in. pipe for the above rates of flow is greater than that in the 16-in. pipe by the following amounts: 16.23 ft. for the 6 hours of maximum pumping, 4.06 ft. for the next 6 hours, 1.33 ft. for the next 6 hours, and 0.18 ft. for the 6 hours of minimum pumping. To overcome this friction requires the expenditure of 80 HP.

hours per day, which, with pumps operating at 80,000,000 duty, takes 320 lb. of coal daily, worth in the local market $2 per ton, representing an annual investment of $116.80. This assumes that no additional investment is required for the increased capacity of the power plant nor for attendance and small supplies, because in any ordinary plant of this capacity there is a large reserve power plant chargeable to the fire protection of the city.

At the time when these estimates were made the difference in cost between the 12-in. and the 16-in. pipe was 65 ct. per foot, or $650 per 1,000 ft. The interest and depreciation on this investment with money at 5 per cent, is only $33.45 per year, as against $116.80 for extra coal with the smaller size pipe, thus showing an annual saving of $83.35 in favor of the 16-in. pipe.

Again comparing the 16-in. pipe with one 20 in. in diameter, by a similar detailed calculation, the result shows an annual saving in coal equal to $23.15 per 1,000 ft. of pipe, due to the smaller friction in the larger pipe. But the extra cost of the larger pipe is 87 ct. per foot, or $870 per 1,000 ft. of pipe, requiring an annual investment of $46.11 for interest and depreciation, thus showing $22.96 annually in favor of the 16-in. pipe. Therefore, of these three sizes, the 16-in. is the most economical one to use for this particular service.

After having determined that so far as the domestic service is concerned, there is nothing to be gained by using a main larger than 16 in., a comparison should then be made between the 16-in. and 20-in. pipe with reference to the fire protection of the city. This brings up a question as to whether the city should resort to the use of steamers for this service; but since this point is not now under discussion, it will be assumed that the necessary pressure for ordinary fire service is to be furnished at the hydrants, and that sufficient water is to be provided for 10 streams of 250 gal. per minute each. Then if a fire occurs at the time of maximum domestic consumption, the total quantity of water that the mains must carry is 5,300 gal. per minute.

The difference in friction between the 16-in. and the 20-in. pipe is 12 ft. per 1,000 ft. of pipe, and therefore if the 16-in. be used there is required an additional investment of $300 for boiler plant and $20 for the room that it occupies in the power house. The life of this portion of the plant may be figured as almost indefinite, owing to the fact that it is so infrequently called into service. The maintenance charge, however, must be sufficient to provide for resetting the boiler when necessary and for the small supplies and repairs that are required to keep it in operating condition, a fair estimate for which would be 2 per cent of the cost of the boiler. For the purpose of comparison the life of the cast iron water pipe may be assumed at 60 years, and that of the reserve portion of the boiler plant the same. The two propositions are then compared as follows:

Interest on extra investment for 20-in. pipe	$43.50
Depreciation for a life of 60 years	2.61
Total annual charge against 20-in. in excess of 16-in. pipe	$46.11
Interest on extra investment, boiler and power house	16.00
Depreciation for a life of 60 years	.90
Maintenance, 2 per cent of the cost of the boiler	6.00
Extra coal used for domestic service as above	23.15
Total annual charge against 16-in. pipe for pumping	$46.05

It is thus seen that so far as the fire protection service is concerned there is nothing to be gained from the use of the larger pipe, and therefore the 16-in. is the most economical size to adopt for this particular location.

It will be noticed that in all of these calculations the rate of interest has been assumed at 5 per cent, which is the rate at which the city can secure money on bonds. However, in the matter of depreciation there is considerable uncertainty as to the proper rate of interest to be assumed. The depreciation of any particular machine may be defined as the annual sum that must be laid aside to amount to the cost of the machine at the end of its life. It then depends entirely upon the earning capacity of the funds laid aside annually, and is therefore independent of the rate of interest that is being paid on the original loan. If money can be invested in additional pipe to supply well settled streets it is likely that much more than 5 per cent can be realized on the investment, which will reduce the depreciation charge accordingly.

While such detailed calculations as are illustrated above are essential as a general guide in determining the important features of a system of water works, yet the writer does not wish to be understood as stating that they should always be followed with mathematical precision, because it often happens that the funds are limited by the statutory provisions, so that a city has only a limited amount to invest. In this case it becomes the engineer's duty to take into consideration the question of whether greater returns may not be secured by an increased pipe system rather than by larger and more efficient pipe lines or, in other words, the fact that large revenue may be derived from extending the mains may be sufficient reason for omitting condensers, using small pipes, and various other acts that would be entirely unjustifiable in designing a system for a private water company whose funds are invested for the purpose of securing the maximum rate of interest on the capital invested.

Another point where an attempt at economy is frequently made is in the spacing of fire hydrants. The popular impression seems to be quite general that since hydrants cost about $32 each they should be spaced about 500 or 600 ft. apart, so as to make a small number of hydrants serve as much territory as possible. This popular impression may be accounted for by the fact that the number of hydrants in a system owned by a private water company is universally accepted as the measure of the public tax for fire protection, and naturally, then, they are not closely spaced in such systems, and the precedent is thus established. In a system of water works owned by the municipality, designed to give fire protection without the use of steamers, there can be no possible justification for spacing the hydrants at such great distances apart as they frequently are.

The details will, of course, vary materially with the plan of the pipe system and other local conditions. In one system that has come under the observation of the writer the hydrants averaged from 500 to 600 ft. apart, but by increasing the number by 100 their distances apart could be reduced to 300 ft. This would effect a saving of about 100 ft. of hose for reaching the average fire, and aside from the convenience to the fire company, due to having a hydrant every 300 ft., there results a direct financial benefit to the city as shown below. To overcome the friction in this extra 100 ft. of hose requires an additional pressure of 13 lb. per square inch at the hydrant, and to provide sufficient power to throw 10 streams simultaneously in addition to the maximum daily consumption necessitates the installation of 50 HP. greater boiler capacity and pumps to correspond. This costs $800 for the extra investment in the power station, the annual charge against which is $57.25 for interest, maintenance and depreciation. There is also an increased pressure of 13 lb. per square inch on the pipes throughout the distribution system, which theoretically would require the use of heavier pipe, but for commercial reasons quite probably the pipe system would be of practically the same weight as though it were not called upon to meet this extra pressure. The financial benefits accruing from being able to secure the desired fire protection with less pressure will appear indirectly in the form of reduced maintenance charges, due to less frequency of bursting the mains, less leakage, and consequently greater efficiency of the pumps and quicker response to calls for fire pressure.

Again, the maintenance of the fire department is increased by the long spaces between the hydrants, since each hose cart must be equipped with at least 200 ft. more hose, which requires an investment of $600 for hose, the life of which will not exceed an average of 5 years. Therefore, with interest at 5 per cent the depreciation on the hose amounts to 18 per cent. The maintenance is largely a matter of time and attention of the fire department, and therefore no charge is figured for this item; however, for interest and depreciation the annual tax for the extra hose is $138. This makes a direct annual charge of $195.25 due to the effort to save $3,200 in hydrants, the annual charge against which would not exceed $200, leaving less than $5 to offset the benefits accruing from having twice the number of hydrants. These benefits must include the maintenance of the pipe system under the decreased pressure as mentioned above, the reduced risks in fire insurance, and the greater rapidity with which the fire department can couple the hose and turn on the stream, which means that a smaller fire company can perform the same service. After considering these points, it is clearly apparent that as a business investment it is inexpedient to economize in the first cost of a system by cutting down the number of hydrants, as is frequently done.

This brings up the question of hydrant spacing in systems owned by private companies, and suggests the fact that if a franchise provides for a certain stream to be maintained at the hydrant, it would be to the advantage of both parties concerned to put in more hydrants at a less rate per hydrant. It would be better for the company because it enables it to give the same service for less investment for power; and it is better for the city because it enables it to save in the maintenance of the fire department.

There are many other points that present themselves in planning an economic system of water works, such as the relative efficiency of the different classes of pumping machinery, proper proportioning of the boilers, motors or other machinery, cost of fuel as compared with condensers, etc.; but these are not unlike the points that should be considered in the design of every power plant, and therefore they will not be treated here.

The point that the writer wishes to bring out most clearly is the fact that without careful consideration of every detail there is but little probability that an investment is economically made, and that it should be the duty of those in charge of municipal improvements to exercise the same care in selecting professional advice that they would if they were investing their own capital.

It will be noticed that all of the above calculations of comparative costs are based on average or normal prices rather than upon the present war-time crest. This is as it should be, for any calculation to determine the economics of an engineering problem must be based upon data that will represent a fair average throughout the life of the project under consideration.

CHAPTER II

PRICES AND WAGES

Past and Future Price Levels.—The following discussion, pages 34 to 138, is in large part, very greatly condensed of two articles that I published in Engineering and Contracting, April 7 and May 5, 1920. My object was to deduce a formula for estimating commodity price levels or price indexes. As will be seen later, the formula gives results that agree very closely with the facts for every year since 1889. Data for years prior thereto are less reliable, but even back to 1859 the formula gives approximately correct results.

I know of no prior attempt to deduce a commodity price level formula. In 1907 Prof. E. K. Kemmer published "Money and Credit Instruments in Their Relation to Prices," in which he deduced a formula for the weighted average of three distinct things: (1) commodity prices, (2) wages and (3) prices of corporation stocks. It seemed to me that these three things (commodity prices, wages and stock prices) are not necessarily related one to the other. If this is so, only confusion would be likely to follow an attempt to average such unrelated things. Accordingly I confined my attempt to derive two separate formulas, one for commodity price levels, and one for wage levels. As will be seen later these formulas differ in one very important element, and since each of them corresponds closely with the facts, it follows that any formula that attempts to give a composite average of wages and prices is certain to be incorrect.

Prof. Irving Fisher, in his "Purchasing Power of Money" (1911) adopted Prof. Kemmerer's formula and attempted to bring its results up to date.

Price Indexes.—Before a correct understanding of the present subject can be secured, the meaning of certain terms must be learned. One of the most important of these terms is the expression "price index." Its technical sound, however, merely camouflages a very simple thing, namely, a relative average price.

"Index numbers" are relative numbers in which data for one year (or longer period) are taken as a base of 100, or 100 per cent, and upon which data for other years are computed as percentages. When the index numbers relate to prices, they are called "price indexes." Thus, if the year 1913 is taken as the base year, and average wholesale prices of, say, 300 commodities are taken, that average may be called 100 per cent. Then if the average wholesale price of the same 300 commodities is 1.96 times as high in 1918 as in 1913, the price index for 1918 is 196, or 196 per cent of the average price in 1913.

To take a simple illustration, let us assume that the wholesale price index of the four principal cereals is desired for the years 1914 and 1918. From the U. S. Statistical Abstract for 1918, we find that the average wholesale prices (on the farm) were as follows per bushel:

	1914	1918
Corn	$0.65	$1.37
Wheat	0.99	2.37
Oats	0.44	0.71
Barley	0.55	0.92
Simple average price	$0.658	$1.343

If we add the prices of these four grains and divide by four, we get a "simple average price" of $0.658 for the year 1914, and $1.343 for the year 1918. Hence, if we take the year 1914 as our standard year, we get $1.34 ÷ $0.66 = 203 as the index price for the year 1918, when the corresponding price index is 100 for the year 1914.

This method of calculating price indexes does not take into consideration the relative quantities of each of these four cereals produced in the given years. To give the proper "weight" to the quantities produced, the calculation of "weighted average prices" must be made as follows:

For the year 1914:

Corn	2,673,000,000 bu.	at $0.65 =	$1,737,450,000
Wheat	891,000,000 bu.	at 0.99 =	882,090,000
Oats	1,141,000,000 bu.	at 0.44 =	502,040,000
Barley	195,000,000 bu.	at 0.55 =	107,250,000
Total	4,900,000,000 bu.	at $0.659 =	$3,228,830,000

Dividing the total of $3,228,830,000 by 4,900,000,000, we get $0.659 as the "weighted average unit price" of these four cereals in 1914, as compared with the "simple (or unweighted) average price" of $0.658 previously deduced.

A similar calculation for 1918 is as follows:

Corn	2,583,000,000 bu.	at $1.37 =	$3,538,710,000
Wheat	917,000,000 bu.	at 2.37 =	2,173,290,000
Oats	1,538,000,000 bu.	at 0.71 =	1,091,980,000
Barley	256,000,000 bu.	at 0.92 =	235,520,000
Total	5,294,000,000 bu.	at $1.330 =	$7,039,500,000

This gives a "weighted average unit price" of $1.330 for these four grains, as compared with the "simple average price" of $1.343

Now if we divide the weighted average price of $1.330 (for the year 1918) by that of $0.659 (for the year 1914), we get 202, which is the weighted price index of these four cereals in 1918, as compared with weighted average price index of 100 for the year 1914.

Where several hundred commodities are thus treated, the weighted price indexes do not usually differ greatly from the unweighted price indexes, but the smaller the number of commodities thus grouped to secure an average price, the greater the range of differences between weighted and unweighted index prices. Hence, it is always preferable to use weighted price indexes when they are ascertainable.

Table I shows the weighted wholesale price index in the United States for every year from 1860 to 1920, the year 1913 being taken as 100 per cent.

The Author's Formula for Commodity Price Levels.—The price of every thing sold in competitive market is dependent upon the ratio of the realized demand to the effective supply. The realized demand is of course measurable only in terms of the total money spent; and the effective supply is measurable only in

TABLE I.—WHOLESALE PRICE INDEX OF COMMODITIES

Year	Price	Year	Price	Year	Price
1860	90	1880	93	1900	82
1861	86	1881	95	1901	80
1862	93	1882	96	1902	83
1863	110	1883	94	1903	84
1864	135	1884	92	1904	83
1865	172	1885	86	1905	86
1866	144	1886	86	1906	91
1867	131	1887	87	1907	96
1868	136	1888	88	1908	91
1869	122	1889	89	1909	94
1870	117	1890	84	1910	97
1871	112	1891	83	1911	95
1872	110	1892	78	1912	99
1873	108	1893	78	1913	100
1874	109	1894	71	1914	99
1875	108	1895	70	1915	100
1876	104	1896	67	1916	123
1877	99	1897	67	1917	175
1878	93	1898	69	1918	196
1879	87	1899	75	1919	212
				1920	243

The actual price indexes are those derived from two sources: (1) From 1859 to 1889, the price indexes are those given in Senate Report No. 1394 on "Wholesale Prices, Wages and Transportation," by Nelson W. Aldrich, March 3, 1893. The weighted average price indexes there given are multiplied by 0.9 to reduce them to the same base as the price indexes of the U. S. Bureau of Labor, the latter price indexes being those from 1890 to 1920, using the year 1913 as 100. The Aldrich report price indexes are based on the wholesale prices of 223 commodities, weighted in proportion to family budget expenses. The Bureau of Labor price indexes are based on the wholesale prices of 192 commodities in 1890, as given in Bulletin No. 173, and in the Monthly Labor Review, December, 1919, and January, 1920.

the total number of units of products sold. Hence we have this fundamental price formula:

$$\text{Average Unit Price} = \frac{\text{Demand}}{\text{Supply}} = \frac{\text{Money spent}}{\text{Number of units bought}}$$

In the case of lumber, wheat or any other given product, this formula, if applied to the transactions of a year, gives the average unit price for the year. This is simple enough, and may be called "self evident." But it is not "self evident" that this fundamental average price formula can be so treated as to yield a commodity price level formula.

The money spent in any nation during a year is equal to the average quantity of money in circulation multiplied by the number of times the money is "turned over" during the year (*i.e.* the "velocity of circulation"). Thus the numerator of the fundamental price formula is derived. The denominator of the formula is not so readily perceived to be susceptible of an equally simple analysis. The total number of units of product purchased in any year is practically equal to the total number produced in that year. But the total number of units produced is equal to the total population multiplied by the per capita productivity. Hence we have the following application of the supply and demand formula to a nation's entire annual output of commodities:

$$\text{Average Price} = \frac{\text{Money} \times \text{Vel. of Circulation}}{\text{Population} \times \text{Per Cap. Efficiency}} \times C$$

The factor C is practically a constant percentage, and is the ratio of the amount of money spent for commodities to the total amount of money spent for all things.

We may substitute letters for words in this formula, letting A stand for average price, M for money, V for velocity of circulation, P for population, and E for per capita efficiency of production. Then we may write the formula:

$$A = \frac{M \times V}{P \times E} \times C$$

This formula would give the absolute average unit price of all commodities for any given year, were we able to ascertain the value of E in units. But since this is impracticable, we must try to get the relative average price of commodities, or price index, which we shall indicate by the letter W. It will be seen later that it is practicable to ascertain the relative per capita productivity, or efficiency of production, E. When we insert its values for any given year in the formula, the formula then gives a relative price, or price level, or price index; and then may be written:

$$W = \frac{M \times V}{P \times E} \times C$$

Similarly we need not get the absolute value of V for each year, but only its relative value, and since this will introduce another constant factor analogous to the C, the final formula for commodity price index becomes:

$$W = \frac{M \times V}{P \times E} \times K$$

Based upon the standards for V and E that I shall use, the value of K is ½. Hence we have the following formula for practical use:

$$W = \frac{1}{2} \times \frac{M \times V}{P \times E}$$

This formula gives an average relative price of all commodities sold at wholesale and retail; but since there is at present available only wholesale price indexes, we must test the formula thereby, remembering that in normal times retail and wholesale prices move in unison, whereas in abnormal times wholesale prices change more rapidly than retail, and usually move through a wider range.

Applying the Price Formula.—In order to use the formula it is necessary to secure average values for each of the four variables (M, V, P and E) for each year. Currency in circulation (M) is obtainable from the Comptroller of the Currency, and his reports are abstracted in the annual Statistical Abstract of the U. S. and in the weekly and daily financial papers. Population (P) is reported by the U. S. Bureau of Census. This leaves only velocity of circulation (V) and efficiency of production (E) to be estimated.

Measuring the Rapidity of "Money Turnover."—Everyone is aware that when "business is good," bills are paid more promptly than when it is "poor." A little consideration of this fact makes it clear that "money is turned over" more rapidly in "good times" than in "bad times." It is also known that average prices of commodities rise in "good times." It follows from these two facts that there is a relationship between the rapidity of "money turnover" and average prices of commodities.

In seeking for a simple means of measuring the relative rapidity of "money turnover" I felt at the start of my study of this problem that it should be practicable to eliminate most, if not all, of the effect of speculative transactions upon bank clearings. My first step, therefore, was to take the bank clearings outside of New York City as being a better barometer of trade than the bank clearings in New York City. When I divided the annual bank

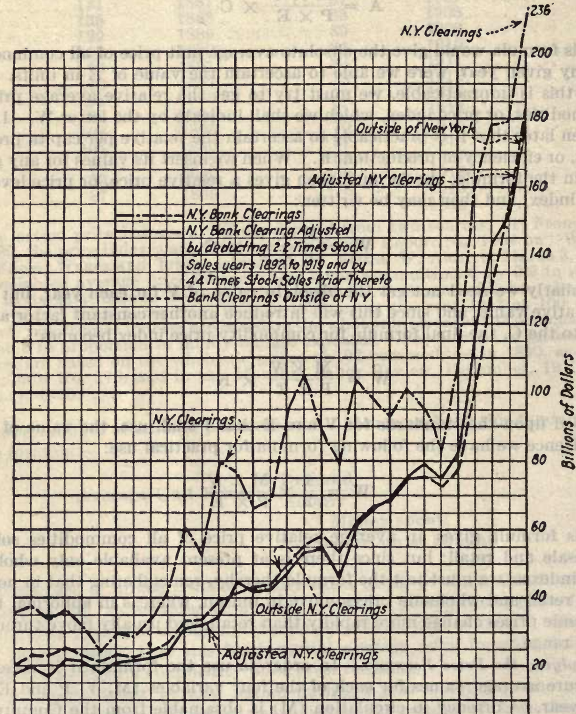

FIG. 1.—Bank clearings.

clearings outside of New York by the total bank deposits in the United States at the middle of any year, I found that the quotient was usually about 4.5 in years when business was "normal," that is, when there was neither a "boom" nor a "depression."

This result encouraged me in the belief that I might be able to "adjust" New York bank clearings, so as to eliminate the effect of stock and bond sales. I reasoned that in the case of an outright purchase of stock, a stock broker would deposit the check or draft received from his client, and would draw his own check for an almost equal amount payable to the person from whom the securities had been purchased. Hence there would appear in New York bank clearings \$2 for every \$1 of outright sales of stocks. In case of a purchase "on margin," a similar result would follow, because the broker would borrow from his bank the difference between the "margin" put up by his client and the purchase price of the stock.

Acting upon this theory, I deducted from the New York bank clearings twice the stock and bond sales for each year, from 1893 to 1919, and I found that the remainder was almost exactly equal to the bank clearings outside of New York City every year. This is well shown in Fig. 1, which is convincing evidence that my method of eliminating the effect of stock and bond sales from New York bank clearings is substantially correct.

It will be noted that when the stock and bond sales on the New York Stock Exchange are not available, all that is necessary to secure substantially correct results for total mercantile and industrial bank clearings in the United States is to double the total bank clearings outside of New York City.

Since the value of bonds sold is ordinarily about 10 per cent of the value of stocks sold on the New York Stock Exchange, and since the stocks usually sell at an average price of about \$90 a share, an approximate adjustment of bank clearings in New York City, to eliminate the effect of stock and bond sales, can be effected thus: multiply the total number of shares sold by \$90, and then multiply this product by 2.2 to get the total bank clearings due to both stock and bond sales. Deduct this product from the total bank clearings in New York City and the remained is the approximate total of New York bank clearings attributable to mercantile and industrial transactions. This is normally equal to the total bank clearings outside of New York City.

To calculate the relative rate of money turnover in a year, or velocity of money circulation, (V), divide the total annual bank clearings (after adjusting for N. Y. stock and bond sales, as above described) by the average bank deposits.

For all practical purposes the individual bank deposits as of July 1 can be used (See Table II). The adjusted bank clearings are given in Table V and Fig. 1 for each year. The resulting velocity of circulation (V) for each year is given in Table VI.

The values of V given in Table VI are relative only, for as a matter of fact only about 40 per cent of the total checks pass through bank clearing houses. Hence to get the actual rate of annual money turnover it is necessary to multiply the values of V given in Table VI by 2.5.

Adjustments of bank clearings for the effect of stock exchange transactions in Chicago, Philadelphia and Boston are unnecessary because of the relatively small volume of their transactions.

The following illustration may serve to make clear the soundness of the above given method of estimating velocity of circulation.

Practically all currency is constantly flowing into the banks and out again, the bank reserves being only part of the total. A bank, therefore, resembles a reservoir or lake into which water is flowing, only to flow out again. We may conceive all the banks in America to be like all the artificial and natural water reservoirs in America. We may conceive the clouds to be like the individual purses that carry the currency to the banks. We may conceive the rivers to be like the "pay envelopes" that carry the currency away from the banks. The average velocity of a given volume of water can be accurately calculated if we know the number of times that a reservoir is filled in a given period by the water In like manner the average velocity of currency circulation can be estimated by ascertaining the number of times the bank reserves are turned over in a year. But since bank deposits are normally about ten times the bank reserves, the relative rate of turnover of bank reserves is ordinarily about the same as the rate of turnover of bank deposits. Hence the relative rate of turnover of bank deposits is practically the same as the relative rate of turnover of all currency.

Productive Efficiency.—Prof. King, in his "Wealth and Income of the People of the U. S.," has given some estimates of the average annual incomes of several different classes of producers, expressed in buying power as well as in dollars. But he does not give the increase in average income per capita or per worker for all those classes of producers combined, and it was this general average that I was seeking. Moreover, I found that through not going to the original sources, Prof. King had made several errors both in the actual data and in his interpretation of them. For example, he did not realize that the statistics as given in the Statistical Abstract relating to the value of agricultural products are not at all comparable for the different census years, a fact that is pointed out in the volumes of the U. S. Census. In several instances Prof. King used incorrect index prices, e.g., simple averages where weighted averages should have been used.

In order to reduce to a minimum any errors that might arise from the use of incorrect price indexes, I decided to secure, as far as practicable, the number of units of product in each of the four grand classes of producers of commodities sold at wholesale, namely (1) Agriculture, (2) Mining, (3) Manufacturing, and (4) Transportation by Rail. I found it possible to secure all the needed data for every year back to 1869, except for manufactured products and for transportation. Steam railway transportation, however, could be carried back to the year 1882, for both the numbers of tons and ton-miles of freight were available.

Table X gives a general idea of the distribution of those engaged in gainful occupations, but too rigorous a comparison between successive census years should not be made, especially between 1899 and 1909, because of differences in the classification rules followed by the census takers in different years.

Since less than 3 per cent of all men engaged in gainfull occupation are classed as steam railway employes (under Transportation) in the U. S. Census, no appreciable error can result by omitting them entirely from consideration in seeking the general average productive efficiency of all workers. Moreover, it should be noted that for every railway employe there is an investment of more than $10,000 in the railway plant, or about four times as much per worker as is found either in manufacturing or in agriculture. All this railway plant has been built by workers classed under Manufacturing and Mechanical, and most of its renewals are made by them also. Hence, viewing the problem broadly, the productive efficiency of railway employes is mainly due to men not classed as railway employes.

The building trades employes must be excluded from consideration because no data as to the value of their total output are available since 1899. For 1899 and prior thereto the building trades output was included by the census with manufacturing output, but I have eliminated it from those years in order to derive a manufacturing output that will be comparable from 1869 to 1914. (Prof. King failed to take into account the above mentioned change in 1899.) The building trades constitute about 4 per cent of the total engaged in gainful occupations. The labor cost of buildings is only 40 to 50 per cent of the total cost, so that the omission of the building trades from the total of productive workers is even less important than the 4 per cent would indicate.

Finally, it should be remembered that we are seeking a productive efficiency factor to use in a wholesale commodity price formula, and the building trades employes have very little influence on this factor.

For similar reasons, workers classed under Domestic and Personal Service and Trade can be omitted from consideration. The same holds true of Professional service, for although a very large part of the increase of productive efficiency is attributable to professional men (educators, engineers, etc.), it finds its measure in the better work done by the workers, which is exactly what we are seeking to determine.

We have left, then, those engaged in Agriculture, Manufacturing and Mining. These occupations comprise about two-thirds of all people engaged in gainful occupations, and they comprise fully 85 per cent of all workers who produce wholesale commodities. Hence if we ascertain the average productive efficiency of these three classes, we shall have a very accurate measure of the productivity of all producers.

The census data for 1859 and earlier years are not comparable with those of later years, because slaves were not counted as being engaged in gainful occupations, although they were counted as part of the population. In 1859 negroes were about 15 per cent of the population.

The Efficiency of Miners.—Practically all the miners in America are engaged in producing seven minerals and metals: Coal, iron ore, copper, gold, silver, lead and zinc. Hence if we ascertain the annual number of units of each of these minerals and metals produced at intervals of 5 or 10 years, and multiply by standard unit prices we shall be able to compare one year's output with another. Then if we divide the total output in dollars for each year by the number of miners engaged in that year, we shall have the gross output in dollars per miner per year. But from this should be deducted the value of new equipment and of materials and supplies used in mining, which, according to the U. S. census, has averaged about 30 per cent of the gross value of the mineral output.

Table XIII gives two typical years, 1869 and 1918, for which I have calculated the gross value of the 7 minerals and metals, using prices that approximate to those of 1913. The gross mineral values for 1869, 1879, 1889, 1899, 1904, 1909, 1914 and 1918 being thus determined (always using the same standard unit prices), 70 per cent thereof was taken (to get the value after deducting raw materials, supplies and additions to plant), and the net values thus derived for each of these years were divided by the number of miners employed during that year. This gave net value produced per miner for each of the years, which is graphically shown in Fig. 2. A similar result is shown graphically in Fig. 3, but there expressed as percentages (instead of in dollars), taking the year 1879 as 100 per cent. Table XIV shows the same results, and the footnotes describe the methods of calculations. The numbers in column A of Table XIV, when multiplied by 70 per cent, give the dollars per miner per year shown in Fig. 2; the numbers in column E (or efficiency per miner) are shown in Fig. 3. It will be seen that the productive efficiency of the miners has more than doubled in 50 years, rising from 91.7 in 1869 to 187.8 in 1918. It is particularly noteworthy that their efficiency has increased more rapidly in the last 30 years of this 50-year period than in the first 20 years. In 1917 the coal miners (and they comprise 80 per cent of all the miners) broke all records for output per miner, mainly because they worked about 20 per cent more days per annum than in normal years. The output for 1918 also was abnormal. Had I used the abnormally high output that actually occurred for 1918, the result would have been a gross equated output of $1,902 per miner

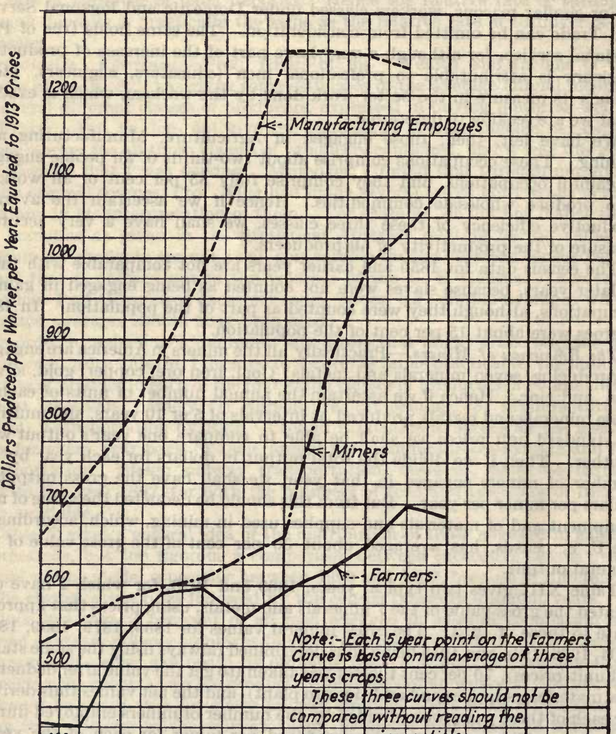

FIG. 2.—"Equated Productivity" per worker (dollars per annum).

instead of the $1,550 given in column A of Table XIV. But since we are seeking the average efficiency of all workers in America, this abnormal output of the coal miners for 1918 would give us a false result, so both in Table XIV and in Figs. 2 and 3, I have scaled down the mining output to that of a normal year.

With the same number of coal miners about 20 per cent more coal was mined in 1917 than in 1914. This achievement shows conclusively what may be accomplished in the way of improving the efficiency of the coal mining industry.

The data of annual output of the mines are to be found in the Statistical Abstract of the United States.

The standard unit prices of coal and iron that I have assumed in Table XIII, are the prices at the mines; but the rest of the prices are those of the

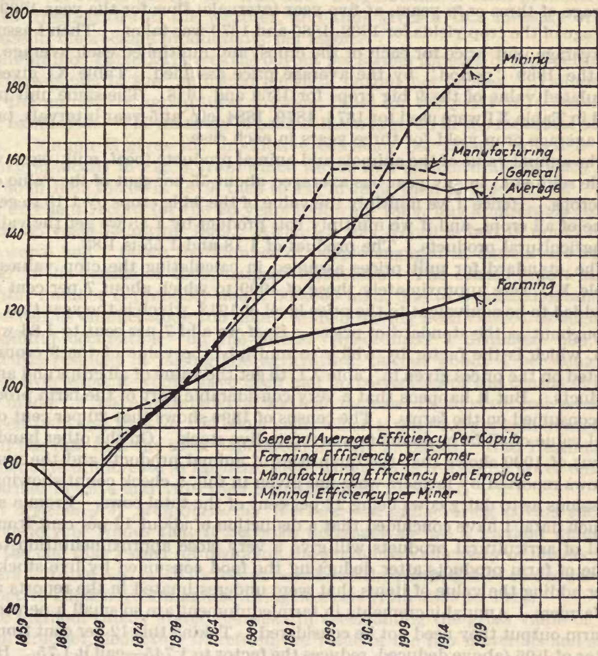

FIG. 3.—Productive efficiency.

metals in the primary wholesale markets. Since these metal prices include the cost of milling, smelting and freight, the resulting total values (Table XIII) for each year are in excess of the bare cost of mining. While this makes it impossible to contrast the dollars produced per miner with the dollars produced per farmer for a given year (Fig. 2), it does not prevent a comparison of the changes in their respective efficiency (Fig. 3), nor does it vitiate the final conclusions as to the per capita productive efficiency of all producers of wholesale commodities, as will be more clearly evident when we come to the discussion of that factor (E). The increased investment in plant per miner has already been taken into consideration, as above described.

Agricultural Efficiency.—In order to measure the productive efficiency of agricultural workers from 1869 to 1918 inclusive, I decided that the most exact method would be to secure the number of units of product of every important crop by years. Upon study of these crop data it became evident that 9 crops comprised 85 per cent of all crop values. Since the other (or minor) crops bear an almost constant ratio in value to the total value of these 9 crops, it is apparent that we need consider only the 9 crops in estimating crop productive efficiency for different years.

Since crops usually vary somewhat from year to year I decided to take the average of three crop years, at five year intervals; thus for the year 1869, the average of the crop yields for 1868, 1869 and 1870 was taken. Then I assumed an average unit price for each of the crops, and multiplied each average crop for the 1869 "period" by the average price assumed. Table XI gives the calculated value of the 9 big crops for 1869 and 1918. The same unit prices used in Table XI were used for 1874, 1879, 1884, etc. at 5-year intervals, taking the average crop yield for three years in each case.

The annual value of the animals and animal products (beef, milk, eggs, wool, cattle sold, etc.) in any year has averaged about 55 per cent of the value of all the crops. Hence if we multiply the value of the 9 big crops by 1.18 to get the value of all crops, and if we multiply this product by 1.55 we get the value of all agricultural products. The product of 1.18 and 1.55 is 1.83.

The standard for unit prices assumed in calculating the crop values (see Table XI) were approximately those of 1909 to which about 7 per cent must be added to be equivalent to the price level of 1913, which is the year that I use throughout as the standard of prices. So if we add 7 per cent to 1.83 we get 1.96, which is the factor by which to multiply the value of the 9 crops calculated on the prices given in Table XI, to get the value of all crops and animal products. But it happens that a very considerable part of the farm products are consumed on the farms. The census of 1899 shows that 20 per cent of the total value of all farm products was fed to live stock. On the other hand, the census of 1909 shows that the quantities of animal products and the number of cows reported by farmers were not given in full, a check count showing the omissions as to dairy cows being 22 per cent of the total cows. From a study of such data, I have concluded that a deduction of about 12 per cent from the total of agricultural products will give a very close approximentation to the value of farm products after deducting the food consumed by live stock and after adding the value of items that were underestimated in the reports made by farmers. Annual increments in farm equipment are so small a percentage of farm output they need not be considered. Taking this 12 per cent from the factor of 1.96 (above deduced, reduces the factor to 1.745—call it 1.75. Hence if we multiply the total values of the 9 big crops (as given in Table XI for 1869 and 1918, and as similarly calculated for intervals of 5 years between those years) we get the equated total value of farm products after deducting the value of food fed to livestock. The resulting totals for each year if divided by the numbers of agricultural workers give the "equated" annual productivity per agricultural worker.

The word "equated" here means reduced to the same standard prices for the standard year, the standard year in this case being 1913.

Fig. 2 shows the output in dollars per year per "farmer," for each of the 5-year points (each "point" being an average for three years' crops, as above explained), from 1869 to 1918 inclusive. Even though I had largely eliminated the effect of fluctuations in crop yield (by taking 3-year averages), it is evident that the effects of very bad crop failures were not entirely "ironed out." Since we are seeking average annual productive efficiency per capita, it is necessary to "iron out" all irregularities. Accordingly, it is necessary to omit the results for the year 1874 and 1894, for exceptionally large crop failures occurred at these "points." To do this "ironing out," draw a straight line on Fig. 2 from the farmer output in 1869 to that in 1879, thence to that in 1889, thence to that in 1918. This line (which is not shown in Fig. 2 but can be drawn by the reader) may be called the "adjusted curve of output per farmer." It serves merely to "iron out" irregularities of farm productivity due to irregularities in the weather, and thus gives a true measure of the increase in the average productivity per farmer.

Column B of Table XII gives the output per farmer for each of the "periods," and corresponds to the "adjusted curve of output per farmer." Column C gives the number of agricultural workers, those for the years 1914 and 1918 being estimated. The meaning of each column is given in the footnotes of the table. Column E gives the productive efficiency per farmer, which is also shown graphically in Fig. 3, from which we see that agricultural efficiency rose from 80 in 1869 to 100 in 1879, then to 111 in 1889, then to 125 in 1918. This in an excellent record for the 20 years following 1869, but a miserable record for the 30 years following 1889. Although this record is bad it would have been worse had I taken the number of people engaged in agriculture as reported in the census of 1909, namely 12,659,000. The census report states that this number is probably about 500,000 high, due to a misunderstanding by the census enumerarors, too many women having been classed as engaged in "gainful occupation" on the farms. Accordingly I deducted 500,000, which has resulted in raising the agricultural output about 4 per cent per worker over what it would have been had no correction of the census figures been made. I have estimated a 900,000 increase in agricultural workers between 1909 and 1918, or 100,000 a year, which is only 0.8 per cent yearly, or at half the rate that the total population usually increases. Had I estimated a higher rate of increase in farmers, there would have resulted a lower output per farmer in 1914 and 1918 then that shown in Table XI.

The Efficiency of Manufacturing Workers.—Manufacturing covers such a vast variety of trades that it becomes necessary to use a method differing from the one that I used for deducing the productive efficiency of miners and farmers. Table XV (with its footnotes) shows the method used to deduce the productive efficiency of manufacturing workers from 1869 to 1914.

The method, briefly stated, consists in ascertaining the gross value of the annual product, deducting therefrom the value of the raw materials and supplies, and dividing the net value thus obtained by the wholesale price index for the given year. The quotient (column E, Table XV) is the "equated" net value produced by the work of all those engaged in manufacture. If great exactitude is required, this result should be reduced by about 3 per cent, to allow for the annual increment in "equated" investment in manufacturing plant, but this refinement is unnecessary.

Dividing the value of a year's output by the price index for the given year gives an "equated" value that is comparable with that for any other year. By such a method we are able to reduce all values to a common basis, arriving at a result similar to that obtained by the method above described for "equating" the output of miners and farmers.

Fig. 2 shows graphically the data given in column H of Table XV; Fig. 3 shows the data in column I.

It will be seen that manufacturing workers' productive efficienct or out-put was 84 in 1869, and rose to 158 in 1899—almost doubling in 30 years. Following 1899 there was no improvement whatever for 15 years (up to 1914), and there is little doubt that some falling off in manufacturing workers' efficiency, per worker, has occurred since 1914. However, the per capita productive efficiency of the nation has not decreased materially since 1914, because farming and mining efficiency have risen sufficiently to offset any loss in manufacturing efficiency. The proof of this conclusion will now be given:

Productive Efficiency Per Capita.—Per capita productive efficiency has, so far as I know, never been ascertained before, yet its economic significance is of extreme importance, entirely aside from its use in my price index formula.

We have already considered the productivity of each of the three great classes of workers who produce raw materials and finished factory commodities. It remains now to secure the combined or composite efficiency of these workers. Before doing so it may be well to point out the economic part of the other classes of workers, namely those engaged in "professional service." "domestic and personal service," "trade and transportation." These three great classes comprise about one-third of all who are engaged in gainful occupations. As will be seen from Table X, this ratio of one-third has been fairly constant for the 40 years, from 1869 to 1909. It is apparent, therefore, that to the cost of producing commodities, there must be added about 50 per cent for transporting and distributing them and for the professional service (educatinal, engineering, etc.) and other services (government, etc.). This explains why retail prices average, on the whole, approximately 50 per cent in excess of wholesale prices, year after year. But the present significance of this constancy of the ratio of the number of "producers" to "distributors, etc.," namely, 2 to 1, is this: If we ascertain the efficiency of the "producers" of commodities sold at wholesale prices, that same efficiency will apply to the "distributors, etc."

Table X shows that the ratio of "workers" (all those engaged in gainful occupations) to total population has increased since 1869. Probably the rate of increase since 1914 has been greater than theretofore, because so many women who were called into gainful service during the war have continued in that service. This should be borne in mind when considering the productive efficiency of the nation as a whole, for it accounts largely for the fact that our per capita efficiency has not decreased during the past five years in spite of a decrease in individual efficiency in many industries and trades.

Table XVI gives my calculation of the per capita productivity and efficiency of the American people, from 1869 to 1918 inclusive.

It will be observed that I have estimated the "equated" value of manufactured products for 1918 at 10 per cent in excess of that for 1914. In arriving at this estimate, I studied all the data of annual production of different commodities, and made a "weighted average" estimate of the resulting percentage increase. Table VIII contains only a small fraction of the data that I used in making this estimate, but it should serve to silence anyone who argues that high prices are attributable to the reduced output of American workers.

Column G of Table XVI shows the per capita productive efficiency of the American people (the E in my index price formula) and Fig. 3 shows the same data graphically, from 1869 to 1918. Observe that per capita efficiency rose from 80 per cent in 1869, to 100 per cent in 1879 (the year taken as a standard for comparison), then to 146 in 1904, then to 152 in 1914, and finally to 153.5

in 1918. It will be seen that since 1909 there has been very little change in per capita efficiency. It will be seen that, contrary to general opinion, the productive output of the nation did not decrease as a result of the war.

The Effect of Exports Upon Price Levels.—There have been only three years since 1875 that out imports have exceeded our exports. During the fifteen years prior to the world war, the excess of merchandise exports over imports was as follows, by five-year periods:

	Millions
June 30, 1899, to June 30, 1904	$2,552
June 30, 1904, to June 30, 1909	2,381
June 30, 1909, to June 30, 1914	2,385
Total, millions of dollars	$7,318

Taking five years preceding the war, we see that out merchandise exports exceeded out imports by an average of 477 million dollars annually. In Table XVI will be seen that our average annual production of wholesale commodities during the same five-year period was 18,400 million dollars. Hence our annual excess of exports over imports averaged about 2.5 per cent of the total commodities that we produced. In my price formula this 2.5 per cent does not appear as a corrective factor, but it is automatically taken care of.

Table IX Column "A," gives the "balance of trade" for each of the last five calendar years in millions of dollars. To reduce these dollars to the same purchasing power as existed in 1913, the total for each year (as given in Column "A") is divided by the average price index for the corresponding year (as given in Column "B"), and quotient (as given in Column "C"). is the number of dollars of "balance of trade" expressed in terms of the buying power of a dollar in 1913. This "equated value" of the excess of exports over imports is 9,764 million dollars for this five-year period, or about 1,953 million dollars per annum, as compared with 477 million dollars per annum prior to the war.

Table XVI shows that the annual production of wholesale commodities averaged 19,770 for the years 1914 to 1918. Hence it follows that the excess of exports over imports during the years 1914 to 1919 averaged about 10 per cent of the total commodities produced during those years, as compared with 2.5 per cent during the prewar years; thus producing an abnormal deficiency of commodities for home consumption amounting to 7.5 per cent of the total annual production.

So far as its effect upon the American average wholesale commodity prices is concerned, this abnormal balance of trade of 7.5 per cent has acted precisely as if there had been a 7.5 per cent decrease in productivity. Hence the per-capita productivity coefficient (the E in the price formula) must be decreased 7.5 per cent for each of the five calendar years, 1915 to 1919, inclusive.

Some Imaginary Causes of High Prices.—Among the imaginary causes of higher average prices are: (1) Profiteering, (2) Extravagance, (3) Inefficiency of workers, (4) Scarcity of commodities in America, (5) High taxes.

"Profiteering," even where it exists, can not affect average prices, however much it may affect the prices of a given class of things. Profiteering merely serves to change the distribution of the total currency, but does not change the total. Profiteering does not change the total buying power of the nation, for that is measured by the product of the total currency and its rate of turnover. Profiteering diverts the currency into pockets and bank accounts that it would not otherwise have reached. Such a diversion may result in a greater buying of certain commodities by the profiteers. But by as much as those profiteers increase the demand for the things they purchase, by an exactly equal amount there occurs a decrease in the demand for the things that would otherwise have been purchased had there been no profiteering.

The very same sort of reasoning holds good as to extravagance. Extravagance diverts money from the purchase of, say, construction materials, to say, diamonds and silks; but extravagance alters not one whit the total annual buying power of a nation. Every nation always spends all that is earned annually.

High taxes have no effect on average prices, unless they cause a stagnation in industry. It is possible that this may yet occur to some extent, because the graduated income tax takes away a large part of the profits in business of a venturesome nature and therefore tends to a restriction of business enterprise. Also if high taxes lead to a permanent and large increase in government activities of an unproductive nature, there results a lowering in productive efficiency per capita (the E in my price formula) and a consequent rise of average prices of commodities.

A general scarcity of commodities in America does not exist. This also is a fictional reason for high prices.

Scarcity of commodities in Europe affects prices in America by: (1) Causing a shipment of gold to America, (2) by increasing the rate of money turnover, and (3) by decreasing the quantity of commodities available for domestic markets.

Modern political economists (with very few exceptions) have hitherto held that bank deposits against which checks may be drawn (often called "credit currency") are essentially the same as money, and that, therefore, an increase in bank deposits tends to raise the level of prices just as does an increase in money. It will be observed that my formula does not support that belief, unless it can be shown to be a fact that bank deposits subject to check have increased in the same proportion that money has increased. Table II shows that the ratio of bank deposits to total currency was 2.2 to 1 in the year 1880, and that it rose to 5.7 to 1 in 1919. The rise was steady and so rapid during those 40 years as to make it clear that, had total bank deposits had the same effect as currency in raising prices, there would have occurred a price increase several fold in excess of what actually did occur. Table VII shows that the ratio of total bank deposits to deposits subject to check has been constant for 30 years, so that it cannot be contended that the more rapid increase in total bank deposits has been offset by a decrease in the proportion of checking deposits to total deposits.

There remains only one other way in which the increase in total bank deposits could be offset, and that would be by a decrease in the rapidity of turnover of checking deposits. This, however, has not occurred. Prof. Fisher states that the contrary has occurred. But we need not use his estimates to prove this contention, for all that is necessary is to refer to Tables VI and VII. In Table VI we see that the ratio of bank deposits to total bank clearings "adjusted" for the effect of New York Stock Exchange transactions has averaged about 9 for the past 30 years oscillating, back and forth from this average. Table VII shows that during the same period the ratio of total deposits to checking deposits has averaged 2 to 1, and that there have been only slight departures from this average at any time. Hence it follows that the ratio of "adjusted" annual bank clearings to checking bank deposits (=

"credit currency") has averaged 18 to 1, and that there have been only relatively small departures from this average.

It is made clear from these facts that the rapid increase in bank deposits, as compared with the less rapid increase in total currency, has not been offset either by (1) a decrease in the ratio of checking deposits to total deposits or by (2) a decrease in the rapidity of annual turnover of checking deposits. This being so, it is conclusively established that average commodity prices would be nearly two times as high as they now are, were it a fact that checking deposits have the same effect as currency upon prices, it being remembered that per capita bank deposits have increased 2 times as rapidly as currency since 1890 (See Table II).

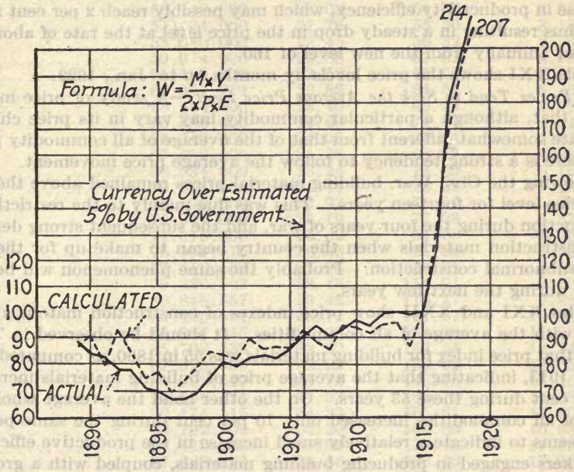

FIG. 4.—Comparison of actual and calculated wholesale price indexes, 1889 to 1919.

Predicting Price Levels by the Formula.—Table XVII and Fig. 4 show the actual wholesale price indexes for every year from 1889 to 1919 compared with price indexes calculated by the formula. The agreement is so close as to verify the accuracy of the formula, especially when consideration is given to the wide range not only of the price level during this period but the great variation in each of the four variables in the formula.

So long as the variables affecting price levels were not known quantitatively, it was impracticable to predict price levels with any degree of accuracy. But by considering the probable changes in each of the four variables in the price formula, it is possible to forecast price movements with considerable accuracy.

It is probable that the 50 per cent increase in gold that America secured during the war will not be materially reduced for several years, because Europe owes America 9 billion dollars, or more than all the gold in circulation in the world.

Table II shows that the per capita currency in circulation was $34.56 in July 1, 1913, and $54.74 six years later, or an increase of about 60 per cent.

There may be some decrease in this currency due to the retirement of Federal Reserve notes, but this shrinkage is likely to be nearly offset by increase in gold. Hence when the velocity of circulation (V) returns to normal, and when exports and imports again reach a normal relation of substantial equality, we shall have left only one factor that has changed, namely per capita currency. Since that has increased 60 per cent, and is not likely to change rapidly, the new price level, or new price plateau, will be about 60 per cent above the pre-war price level. This price plateau will probably slope gently downward as it did after 1867, following the two-year readjustment period when prices declined rapidly (see Table I). The factors that will tend to decrease price levels will be an increase in population (at about 1.5 per cent yearly), and an increase in productivity efficiency, which may possibly reach 2 per cent annually; thus resulting in a steady drop in the price level at the rate of about 3.5 per cent annually from the new level of 160.

Table XXI shows the price levels by months up to Jan., 1922.

All Prices Tend to Seek the Average Price Level.—A study of price indexes shows that, although a particular commodity may vary in its price changes at a rate somewhat different from that of the average of all commodity prices still there is a strong tendency to follow the average price movement.

Following the Civil War, building material prices remained above the general price level for fourteen years. This was due mainly to the restriction of construction during the four years of war, and the subsequent strong demand for construction materials when the country began to make up for the previous subnormal construction. Probably the same phenomenon will be witnessed during the next few years.

Tables XXI and XXII show price indexes of construction materials compared with the average of all commodities. It should be observed in Table XXII that price index for building materials was 55 in 1860, as compared with 100 in 1913, indicating that the average price of building materials increased 80 per cent during these 53 years. On the other hand the average wholesale price of all commodities increased only 10 per cent during the same period. This seems to indicate a relatively small increase in the productive efficiency of workers engaged in producing building materials, coupled with a growing scarcity of timber.

TABLE II.—POPULATION, CURRENCY AND BANK DEPOSITS

Year	Population (June 1)	Currency per capita	Bank deposits per capita (July 1)	Total bank deposits† (millions)
1895	30,822,000	$14.35	$35.80*	$1,098*
1860	31,443,321	13.85	34.60*	1,089*
1861	32,064,000	13.98	35.00*	1,121*
1862	32,704,000	10.23	25.60*	837*
1863	33,365,000	17.84	44.50*	1,488*
1864	34,046,000	19.67	49.20*	1,674*
1865	34,748,000	20.58	51.50*	1,787*
1866	35,469,000	18.99	47.50*	1,684*
1867	36,211,000	18.29	45.70*	1,655*
1868	36,973,000	18.42	46.00*	1,702*
1869	37,756,000	17.63	44.10*	1,664*
1870	38,558,371	17.51	43.80*	1,691*
1871	39,555,000	18.17	45.40*	1,797*
1872	40,596,000	18.27	47.50*	1,928*
1873	41,677,000	18.09	48.80*	2,035*
1874	42,796,000	18.13	50.80*	2,173*

Foot Notes:

* Estimated by multiplying total currency by 2.5 for the years 1859 to 1871 inclusive, then by 2.6 for 1872, by 2.7 for 1873, and 2.8 for 1874.

TABLE II.—POPULATION, CURRENCY AND BANK DEPOSITS—*Continued*

Year	Population (June 1)	Currency per capita	Bank deposits per capita (July 1)	Total bank deposits (millions)
1875	43,951,000	17.16	49.66	2,183*
1876	45,137,000	16.12	47.65	2,151
1877	46,353,000	15.58	44.38	2,057
1878	47,598,000	15.32	39.94	1,901
1879	48,866,000	16.75	37.53	1,834
1880	50,155,783	19.41	42.55	2,134
1881	51,316,000	21.71	49.47	2.539
1882	52,495,000	22.37	52.49	2,756
1883	53,693,000	22.93	54.80	2,876
1884	54,911,000	22.65	52.40	2,874
1885	56,148,000	23.03	54.50	3,061
1886	57,404,000	21.78	55.50	3,186
1887	58,680,000	22.45	56.32	3,596
1888	59,974,000	22.88	57.01	3,704
1889	61,289,000	22.52	61.62	4,025
1890	62,947,714	22.82	64.51	4,361
1891	63,844,000	23.45	65.74	4,482
1892	65,086,000	24.60	71.67	4,944
1893	66,349,000	24.06	69.74	4,834
1894	67,632,000	24.56	68.77	4,849
1895	68,934,000	23.24	71.39	5,167
1896	70,254,000	21.44	70.39	5,122
1897	71,592,000	22.92	71.16	5,245
1898	72,947,000	25.19	77.98	5,874
1899	74,318,000	25.62	91.08	6,964
1900	75,994,575	26.93	95.26	7,527
1901	77,612,569	27.98	109.01	8,817
1902	79,230,563	28.43	114.91	9,501
1903	80,848,557	29.42	118.17	9,953
1904	82,466,551	30.77	121.27	10,288
1905	84,084,545	31.08	134.99	11,735
1906	85,702,533	32.32	142.54	12,546
1907	87,320,539	32.22	150.02	13,553
1908	88,938,527	34.72	143.75	13,166
1909	90,556,521	34.93	155.79	14,687
1910	92,174,515	34.33	165.81	15,658
1911	93,792,509	34.20	169.59	16,332
1912	95,410,503	34.34	178.43	17,480
1913	97,028,497	34.56	180.10	17,905
1914	98,646,491	34.35	187.72	18,955
1915	100,264,485	35.44	191.75	19,628
1916	101,882,479	39.29	224.55	23,319
1917	103,500,473	45.74	254.01	26,776
1918	105,118,467	50.81	265.72	28,511
1919	106,740,000	54.74	309.89	33,065

* For years following 1874 the data given by the comptroller of the currency in the Statistical Abstract of the U. S. are taken, except as to private banks, which (since 1877) have been estimated by multiplying the private bank deposits given in the Statistical Abstract by 4, because only one-fourth of the private banks have reported their deposits. The correctness of this estimate for private banks is confirmed by data given in Mitchell's "Business Cycles." The total deposits in private banks has been only about 0.6 per cent of the total deposits in all other banks for several years past.

These bank deposits are those known technically as "Individual Bank Deposits," which excludes the U. S. Govt. deposits.

TABLE III.—NEW YORK STOCK EXCHANGE SALES

Calendar year	No. of shares of stock	Stock value in millions	Bonds at par in millions
1889	72,014,600	$4,060	398
1890	71,282,885	3,978	379
1891	69,031,689	3,813	391
1892	85,875,092	4,875	503
1893	80,977,839	4,551	301
1894	49,075,032	3,095	355
1895	66,583,232	3,809	503
1896	54,654,096	3,330	386
1897	77,324,172	4,974	545
1898	112,699,957	8,188	918
1899	176,421,135	13,430	768
1900	138,380,184	9,250	645
1901	265,944,659	20,432	917
1902	188,503,403	14,219	951
1903	161,102,101	11,005	596
1904	187,312,065	12,062	1,037
1905	263,081,156	21,296	1,022
1906	284,298,010	23,394	672
1907	196,438,824	14,758	519
1908	197,206,346	15,320	1,052
1909	214,632,194	19,143	1,293
1910	164,051,061	14,126	634
1911	127,208,258	11,004	897
1912	131,128,425	11,563	670
1913	83,470,693	7,171	494
1914	47,900,568	3,899	456
1915	173,145,203	12,662	961
1916	233,311,993	18,870	1,150
1917	185,628,948	15,610	1,047
1918	144,118,469	12,483	1,980
1919	316,787,725	25,905	3,809

TABLE IV.—BANK CLEARINGS IN MILLIONS OF DOLLARS
(Calendar Years)

Year	New York	All U. S.	Year	New York	All U. S.
1889	$35,895	$56,175	1905	$93,822	$143,909
1890	37,458	60,623	1906	104,675	160,019
1891	33,749	56,718	1907	87,182	145,175
1892	36,662	62,109	1908	79,275	132,408
1893	31,261	54,323	1909	103,588	165,608
1894	24,387	45,686	1910	97,275	163,722
1895	29,841	53,348	1911	92,373	160,230
1896	28,870	51,333	1912	100,474	174,914
1897	33,427	57,403	1913	94,634	169,826
1898	41,971	68,931	1914	83,019	155,242
1899	60,761	94,178	1915	110,564	187,818
1900	52,634	86,205	1916	159,581	260,953
1901	79,420	118,579	1917	177,405	306,945
1902	76,328	118,023	1918	178,533	332,351
1903	65,970	109,209	1919	235,802	417,519
1904	68,649	112,621			

Foot Note: The bank clearings given in the Statistical Abstracts of the U. S. are for fiscal years ending Sept. 30. In ordinary times these do not differ greatly from those for calendar years ending Dec. 31, but in times of rapid business changes they may differ considerably.

TABLE V.—BANK CLEARINGS (MILLIONS OF DOLLARS)

Column	A	B	C*	D	E	F
	——New	York——		Adjusted	Clearings	Total
Calendar year	Clearings	Stock sales	Adjustment	N. Y. clearings (A − C)	outside N. Y.	adjusted clearings (D + E)
1889	35,895	4,059	17,860	18,035	20,280	38,315
1890	37,458	3,978	17,503	19,955	23,165	43,120
1	33,749	3,812	16,773	16,976	22,969	39,945
2	36,662	4,874	14,622	22,040	25,447	47,487
3	31,261	4,550	10,010	21,251	23,062	44,313
4	24,387	3,095	6,809	17,578	21,299	38,877
5	29,841	3,808	8,378	21,463	23,507	44,970
6	28,870	3,330	7,326	21,544	22,463	44,007
7	33,427	4,974	10,943	22,484	23,976	46,460
8	41,971	8,187	18,011	23,960	26,960	50,920
9	60,761	13,429	29,544	31,217	33,417	64,634
1900	52,634	9,249	20,348	32,286	33,571	65,857
1	79,420	20,432	44,950	34,470	39,159	73,629
2	76,328	14,218	31,280	45,048	41,695	86,743
3	65,970	11,004	24,209	41,761	43,239	85,000
4	68,649	12,061	26,534	42,115	43,972	86,087
5	93,822	21,296	46,851	46,971	50,087	97,058
6	104,675	23,393	51,465	53,210	55,344	108,554
7	87,182	14,758	32,468	54,714	57,993	112,707
8	79,275	15,319	33,702	45,573	53,133	98,706
9	103,588	19,142	42,112	61,476	62,020	123,496
1910	97,275	14,126	31,077	66,198	66,447	132,645
1	92,373	11,004	24,209	68,164	67,857	136,021
2	100,474	11,562	25,436	75,038	74,440	149,478
3	94,634	7,171	15,776	78,858	75,192	154,050
4	83,019	3,898	8,576	74,443	72,223	146,666
5	110,564	12,661	27,854	82,710	77,254	159,964
6	159,581	18,870	41,514	118,067	101,372	219,439
7	177,405	15,609	34,340	143,065	129,540	272,605
8	178,533	12,483	27,463	151,070	153,818	304,888
9	235,802	25,905	56,991	178,811	181,632	360,443

* The quantities in this column were calculated by multiplying the stock sales (column B) by the following factors: For the year 1891 and prior thereto, 4.4; for the year 1892, 3.0; for all subsequent years, 2.2. Prior to May 17, 1892, the N. Y. Stock Exchange clearings were merged with the N. Y. Bank Clearings, but thereafter there was no merger. If greater accuracy is desired, add the N. Y. stock sales to the bond sales and multiply by 2, instead of approximating the same result by multiplying the stock sales by 2.2.

TABLE VI.—VELOCITY OF CIRCULATION (V)

Year	(V)	Year	(V)	Year	(V)
1889	9.52	1900	8.75	1910	8.47
1890	9.89	1901	8.35	1911	8.32
1891	8.91	1902	9.13	1912	8.55
1892	9.61	1903	8.54	1913	8.60
1893	9.17	1904	8.36	1914	7.74
1894	8.02	1905	8.27	1915	8.15
1895	8.70	1906	8.65	1916	9.41
1896	8.60	1907	8.33	1917	10.18
1897	8.86	1908	7.50	1918	10.70
1898	8.67	1909	8.41	1919	10.89
1899	9.28				

Foot Note: The world war began early in Aug., 1914, and was followed immediately by an abnormal decrease in bank clearings due to failure to pay obligations. Hence the value of V for 1914 is below the real rate of money turnover, and accordingly it leads to an incorrect result for 1914 when used in the price formula.

TABLE VII.—TOTAL BANK DEPOSITS AND CHECKING DEPOSITS OR "CREDIT CURRENCY"

(Millions of Dollars)

Year	Total deposits	Checking deposits	Year	Total deposits	Checking deposits
1891	4,482	2,325	1901	8,817	4,935
1892	4,944	2,615	1902	9,501	5,367
1893	4,834	2,510	1903	9,953	5,853
1894	4,849	2,578	1904	10,288	6,559
1895	5,167	2,731	1905	11,735	6,860
1896	5,122	2,688	1906	12,546	7,103
1897	5,245	2,747	1907	13,553	6,522
1898	5,874	3,198	1908	13,166	6,888
1899	6,964	3,365	1909	14,687	7,713
1900	7,527	4,305	1910	15,658	8,242

Foot Note: Total bank deposits are taken from Table II. Checking Deposits are taken from Mitchell's "Business Cycles."

TABLE VIII.—PER CAPITA PRODUCTIVE EFFICIENCY (E)

Year	(E)	Year	(E)	Year	(E)
1869	0.80	1886	1.16	1903	1.46
1870	0.82	1887	1.18	1904	1.47
1871	0.84	1888	1.21	1905	1.49
1872	0.86	1889	1.23	1906	1.50
1873	0.88	1890	1.25	1907	1.52
1874	0.90	1891	1.26	1908	1.53
1875	0.92	1892	1.28	1909	1.55
1876	0.94	1893	1.30	1910	1.55
1877	0.96	1894	1.31	1911	1.55
1878	0.98	1895	1.33	1912	1.55
1879	1.00	1896	1.35	1913	1.55
1880	1.02	1897	1.37	1914	1.55
1881	1.05	1898	1.38	1915	1.55
1882	1.07	1899	1.40	1916	1.55
1883	1.09	1900	1.41	1917	1.55
1884	1.11	1901	1.43	1918	1.55
1885	1.14	1902	1.44	1919	1.55

Foot Note: During the years 1915 to 1919 our exports exceeded our imports by an amount that was abnormal to an extent that is equivalent to reducing the quantity of goods available for domestic consumption by 7.5 per cent. Accordingly the factor E in this table must be reduced 7.5 per cent or to 1.43 for the years 1915 to 1919 inclusive.

TABLE IX.—EXCESS OF EXPORTS OVER IMPORTS

Calendar year	A Excess	B Price Index	C Column "A" ÷ column "B"
1915	$ 1,776	100	$1,775
1916	3,091	123	2,513
1917	3,282	175	1,818
1918	3,118	196	1,585
1919	4,017	212	1,872
Total	$15,284		$9,764

TABLE X.—GAINFUL OCCUPATION STATISTICS
(Thousands)

Year	1869	1879	1889	1899	1909
Agriculture	5,922	7,714	8,148	10,382	12,568
Professional	372	603	944	1,259	1,825
Domestic and personal	2,302	3,418	4,221	5,581	5,361
Trade and transportation[2]	1,240	1,872	3,326	4,766	7,606
Manufacturing and mechanical[1]	2,670	3,785	5,687	7,085	10,807
Total gainful occupation	12,507	17,392	22,318	29,073	38,167
Total population	37,756	48,866	61,289	74,318	90,557
Fishermen	......	41	60	69	68
Building trades	......	681	1,135	1,212	1,661
Mines and quarries	163	296	531	740	1,177
Transportation[2]	......	587	1,131	1,515	2,465

Foot Notes:

[1] Manufacturing and mechanical includes fishing, building trades, mines and quarries, railway shopmen.

[2] Transportation includes railways (exclusive of shopmen), telegraph and telephone linemen and operators.

TABLE XI.—CROP DATA FOR TWO PERIODS, 1869 AND 1918
Period of 1869

Crop	Millions of units	Unit price	Total millions, dollars
Corn, bu	958	$0.55	527
Wheat, bu	240	1.00	240
Oats, bu	263	0.40	105
Barley, bu	26	0.60	16
Hay, ton	25.70	12.00	308
Potatoes, bu	118	0.60	71
Cotton, bale	2.65	55.00	146
Tobacco, lb	393	0.10	39
Sugar, lb	80	0.025	2
Total			1,454
	Period of 1918		
Corn, bu	2,871	$0.55	1,579
Wheat, bu	784	1.00	784
Oats, bu	1,563	0.43	625
Barley, bu	278	0.60	167
Hay, ton	80.41	12.00	965
Potatoes, bu	422	0 60	253
Cotton, bale	11.50	55.0	633
Tobacco, lb	1,295	0.10	130
Sugar, lb	2,143	0.025	54
Total			5,190

Foot Note: The crop quantities for the "Period of 1869" are the average for the three years of 1868, 1869 and 1870. The crop quantities for the "Period of 1918" are the average for the two years of 1917 and 1918.

TABLE XII.—FARMING EFFICIENCY

"Period"	A Average per year per worker for 9 crops	B Average per year per worker for all products	C Number of workers in thousands	D Equated value of all crops in millions of dollars	E Efficiency per worker
1869	$246	$430	5,922	$2,545	80.4
1879	306	536	7,714	4,130	100.0
1889	340	595	8,566	5,103	111.1
1899	353	613	10,382	6,414	115.4
1904	359	629	11,522	7,238	117.3
1909	365	638	12,159	7,767	119.3
1914	375	647	12,660	8,309	122.5
1918	383	671	13,060	8,754	125.2

Foot Notes:

Column A gives the equated average annual gross output of agricultural workers, for the 9 leading crops per year per worker (see Table XI for two typical "Periods").

Column B is the value in column A multiplied by 1.75, giving the per worker equated value of all farm products.

Column D is one-thousandth of the product of the numbers in columns B and C.

Column E is derived by dividing the numbers in column A by 536, the 536 being the equated value of all farm products per farmer for the "period" of 1879; this year, 1879, being taken as a standard for comparing the output during each of the "periods."

The word "period" is used to designate the average crop for three years, as explained in the article and in Table XI.

TABLE XIII.—MINING DATA FOR TWO YEARS, 1869 AND 1918

Mineral	Millions of units	Unit price	Total millions of dollars
Year 1869			
Coal, long tons	29.38	$ 1.50	44.07
Copper, long tons	0.01	300.00	3.00
Iron ore, long tons	3.03	2.00	6.06
Gold, oz	2.39	20.70	49.47
Silver, oz	9.28	1.00	9.28
Lead, short tons	0.02	100.00	2.00
Zinc, short tons	0.01	120.00	1.20
Total			115.08
Year 1918			
Coal, long tons	581.61	$ 1.50	872.42
Copper, long tons	0.89	300.00	267.00
Iron ore, long tons	75.57	2.00	151.14
Gold, oz	3.31	20.70	68.52
Silver, oz	67.88	1.00	67.88
Lead, short tons	0.54	100.00	54.00
Zinc, short tons	0.58	120.00	69.60
Total			1,550.56

Table XIV.—Mining Efficiency

Year	A Equated output per miner	B Number of miners	C Total equated value, millions	D 70% total equated value, millions	E Efficiency
1869	$ 757	152,107	$ 115	$ 81	91.7
1879	825	234,228	193	135	100.0
1889	915	387,248	354	248	110.9
1899	1,112	563,406	627	439	134.8
1904	1,232	670,562	826	479	149.3
1909	1,393	777,719	1,084	759	168.8
1914	1,479	818,647	1,211	842	179.2
1918	1,550	815,230	1,264	885	187.8

Foot Notes:

Column A gives the equated average annual gross output of all miners engaged in producing the 7 leading minerals. (See Table XIII.)

Column B is the number of miners thus engaged.

Column C is one-millionth of the product of the numbers in columns A and B.

Column D is 70 per cent of column C, and this is the equated value produced by the miners after deducting 30 per cent for raw materials and supplies.

Column E is derived by dividing the numbers in column A by 825, the 825 being the equated value of minerals per miner for the year 1879; this year, 1879, being taken as a standard for comparing the output during each of the years.

Table XV.—Manufacturing Productivity and Efficiency

Year	A Total value of products, millions	B Total value of raw mtls., millions	C Value added by mfg, millions	D Weighted price index	E Equated value added by mfg.
1869	$ 4,232	$ 2,488	$1,744	1.22	$1,430
1879	5,370	3,397	1,973	0.87	2,268
1889	9,372	5,162	4,210	0.86	4,895
1899	13,000	7,344	5,656	0.76	7,442
1899	11,407	6,576	4,831	0.76	6,357
1904	14,794	8,500	6,294	0.84	7,493
1909	20,672	12,143	8,529	0.95	8,978
1914	24,246	14,368	9,878	1.00	9,878

Foot Notes:

Column A gives the total value of manufactured products in millions of dollars.

Column B gives the total value of raw materials and supplies.

Column C gives the difference between the values in columns A and B, or the value added by manufacture.

Column D gives the weighted actual index prices of all commodities, treated as a percentage.

Column E gives the "equated" value added by manufacture, which is derived by dividing the numbers in column C by those in column D.

Table XV.—Manufacturing Productivity and Efficiency—*Continued*

Year	F Employes, thousands	G Value per employe	H Adjusted value per employe	I Efficiency
1869	2,054	$ 696	$ 664	83.9
1879	2,733	830	791	100.0
1889	4,713	1,039	991	125.3
{ 1899	5,670	1,313		
{ 1899	5,077	1,252	1,252	158.3
1904	5,987	1,252	1,252	158.3
1909	7,405	1,212	1,212	153.2
1914	8,000	1,235	1,235	156.0

Column F gives the thousands of employes.

Column G gives the annual value created per employe, but for the years 1869, 1879 and 1889 this includes the buliding trades employes, whereas the years 1904, 1909 and 1914 exclude the building trades. Hence two sets of figures are given in the table for the year 1899; the upper set of figures includes the building trades, the lower set excludes them.

Column H gives the equated value created per employe after "adjusting" for the years 1869, 1879 and 1889 so as to exclude the building trades. This adjustment is made by taking 95.4 per cent of the numbers in column G for the years 1869, 1879 and 1899.

Column I gives the efficiency of manufacturing employes, obtained by dividing the numbers in column H by 791, which is the adjusted value created by the average manufacturing employe in 1879, this year being taken as a standard for comparative purposes.

Table XVI.—Per Capita Efficiency in the Production of Wholesale Commodities

(Column G gives values for E in the author's price formula.)

Year.	A Equated agricultural products, millions	B Equated mfg. products millions	C Equated mining products, millions	D Total of A, B, and C	E Total population, thousands	F Per capita products of A. B and C. efficiency	G Per capita
1869	$2,545	$1,222	$ 81	$3,849	37,756	$102	80.3
1879	4,130	1,937	135	6,202	48,866	127	100.0
1889	5,103	4,181	248	9,532	61,289	156	122.8
1899	6,414	6,357	439	13,210	74,318	178	140.2
1904	7,238	7,493	479	15,310	82,467	186	146.5
1909	7,767	9,241	759	17,767	90,557	196	154.3
1914	8,309	9,878	848	19,035	98,646	193	152.0
1918	8,754	10,866	885	20,505	105,118	195	153.5

Foot Notes:

Column A is taken from column D of Table XII.

Column B is derived from column E of Table XV, by taking 85 42 per cent of the numbers given there for the years 1869, 1879 and 1889, in order to eliminate the value created by the building trades. The $10,866,000,000 for 1918 is estimated in the assumption of a 10 per cent increase over 1914.

Column C is taken from column D of Table XIV.

Column D gives the total of columns A, B and C.

Column F gives the quotient found by dividing the numbers in column D by one-thousandth part of the numbers in column E.

Column G gives the quotients found by dividing the numbers in column F by 127, so as to express the per capita efficiency in terms of that in the year 1879 taken as 100 per cent.

TABLE XVII.—PRICE INDEXES CALCULATED BY FORMULA COMPARED WITH ACTUAL

Year	Calculated	Actual	Year	Calculated	Actual
1889	87	89	1905	86	86
1890	91	84	1906	93	91
1891	80	83	1907	89	96
1892	92	78	1908	86	91
1893	85	78	1909	95	94
1894	75	71	1910	94	97
1895	77	70	1911	92	95
1896	69	67	1912	95	99
1897	74	67	1913	96	100
1898	79	69	1914	86	99
1899	85	75	1915	100	100
1900	84	82	1916	128	123
1901	82	80	1917	163	175
1902	90	83	1918	190	196
1903	86	84	1919	207	212
1904	87	83			

The Relations of Prices of Different Commodities.—Prices of different commodities tend to rise and fall in harmony. But it should be remembered that this harmony of movement occurs only when there is a harmony of supply and demand, that is, when the changes or demand are relatively the same for each of the different classes of commodities. Furthermore (and the fact is rarely considered) the supply of commodities depends upon the productive efficiency of workers. If the productive efficiency in one field remains stationary while that in another field is rising, then we must look for relatively diverging prices in the two fields. Thus, if the efficiency of steel producers is rising while that of lumber producers is stationary, the price of steel will become relatively lower than that of lumber. This, in fact, is exactly what occurred after the Civil War, as shown in Table XVIII.

TABLE XVIII.—WHOLESALE PRICE INDEXES (UNWEIGHTED)
(Aldrich Senate Report)

Year	All commodities	Building materials	Metals	Food	Clothing
1860	100	100	100	100	100
1865	217	182	219	217	299
1870	142	148	139	154	139
1875	128	144	131	131	120
1880	107	131	105	108	105
1885	93	127	80	99	85
1890	92	124	78	105	82

It will be seen that while the four large classes of commodities moved in general harmony, there was a relative divergence between "building materials" and "metals." This was due to a more rapid increase in the average productive efficiency of miners and metal manufacturers than of producers of lumber, brick and other building materials. In the article on price levels in the Nov. 24, 1920 issue of Engineering and Contracting it was shown that the price indexes of "building materials," "metals" and "all commodities" were as follows (taking the average of the year 1913 at 100):

TABLE XIX.—WHOLESALE PRICE INDEXES*

Year	All commodities	Building materials	Metals
1840	89	64	166
1850	83	56	154
1860	90	55	134
1870	117	86	186
1880	93	76	141
1890	84	72	110
1900	82	76	106
1910	97	101	94
1913	100	100	100
1920	243	308	186

* These indexes are those of the Bureau of Labor and the Aldrich Senate Report, and are all weighted averages, except those for "building materials" and "metals" back of the year 1890 which are unweighted averages.

It is worthy of note that between 1860 and 1913, "building materials" increased 80 per cent in price, on the average, whereas "metals" decreased nearly 30 per cent. This could scarcely have occurred unless there had been a far greater increase in productive efficiency in mining and metallurgy than in the production of building materials taken as a whole.

Hence, while there is a general harmony of price movement of different classes of commodities, each class of commodities has its own economic factors that must be considered independently of the factors that affect all commodities in common.

Following our Civil War the pent up demand for building materials was released, and it served to hold the average price to such an extent that in 1880 when the price index of "all commodities" was down nearly to the prewar level (Tables XX and XXII), the price index of building materials never did return to the prewar level. Such facts must be borne in mind when forecasting the probable movement of building material prices.

TABLE XX.—WHOLESALE PRICE INDEXES OF BUILDING MATERIALS AND METALS
(The averages for the year 1860 being taken at 100 per cent)

Year	All commodities	Building materials	Metals and implements
1860	100	100	100
1865	191	182	219
1866	160	187	193
1867	145	179	179
1868	151	174	167
1869	136	166	158
1870	130	148	139
1871	124	151	132
1872	122	167	146
1873	120	172	149
1874	121	155	137
1879	97	115	90

Foot Note:
"All Commodities" is a weighted average wholesale price index of 223 commodities.
The index prices for "Lumber and Building Materials" and for "Metals and Implements" are simple averages.
These index prices are from the Aldrich Senate Report, No. 1394.

Principles upon which Six Different Price Indexes are Based.—Many users of price indexes have felt the need of a more thorough understanding of the details of construction of such tabulations, but have not found it easy to obtain the information desired.

There are radical and confusing differences among the commonly published indexes, leading even to the complete discredit of all index calculations in the minds of some people; and to supply the evident need of information upon this subject we present herewith brief explanations of the construction of each of the five most widely circulated and most commonly used indexes of wholesale commodity prices. Complete explanations including data would require a large amount of space, and readers desiring such information are therefore of necessity referred to the respective publishers.

General Principles of Price Indexes.—A price index is a device for showing the comparative changes in costs of certain groups of commodities over certain periods. Changes in the cost of any single commodity ordinarily require no special treatment or device, but it is often desired to measure an average change of price affecting an entire business—or in its largest sense, the average change in price of all commodities which are traded within a nation. Such an index of all commodities serves to measure the general price level, and thus to show (in reciprocal form) the value of money in terms of the amount of goods which a given quantity of money will buy.

Because of the difficulties in gathering complete data, indexes are usually based upon a limited number of commodities only, the numbers in the best known indexes ranging from 25 to more than 300, but these are selected with the intention that they shall afford a fair criterion of the business in all commodities. In some indexes the commodity prices are weighted according to their importance in the nation's trade: in others they are unweighted.

Indexes are most commonly stated in terms of percentage, the average price on some given date or for some given period being arbitrarily established as 100 per cent. It is now quite common to take the average for the year 1913, as 100 per cent, that being the last year for which prices were unaffected by conditions due to the great war.

A weighted index may be prepared as follows: The total money paid for all the index commodities sold during the base period (usually 1 year) is called 100%. Then the index for any other date or period is given by dividing the above total into the amount which the same quantities of goods would have cost at prices of the new date or period.

Unweighted indexes are prepared by adding together the unit prices of all the index commodities for the date chosen as base, and calling this sum 100 per cent. Then the sum of the unit prices of the same commodities on any other date, divided by the sum on the base date gives the index for the other date in terms of percentage. Since under this system a change in price of a little used commodity, such as pepper, produces an effect equal to a similar change in the price of an important commodity, such as flour, the unweighted index measures the price level much less accurately than does the weighted index.

Dun's Index, which is one of the best, is expressed in terms of dollars per capita consumption instead of in terms of percentage. This is explained later.

Altho indexes are of necessity approximations based upon partial data, when properly made and interpreted they possess sufficient accuracy for practical use, and they should not be criticised or discredited because of their lack of complete mathematical accuracy.

We treat here only of wholesale price indexes, altho the U. S. Bureau of Labor Statistics publishes a retail price index, and others have been computed. The greater difficulty in obtaining the necessary data for retail prices—particularly as affecting the nation as a whole—accounts for the greater attention which has been given to wholesale indexes, and for the general superiority of the wholesale to the retail index.

Index of U. S. Bureau of Labor Statistics.—This index covers each of 9 groups of important wholesale commodities, and a total for all commodities. It is calculated for each year from 1890 to the present, and for each month since January, 1913. It is based upon the sales of about 327 commodities —the number having varied slightly from time to time. The commodities selected cover, as nearly as is practicable, all the most important articles of wholesale trade. Difficulties in obtaining satisfactory units of comparison have kept out of the index such things as machinery and many other, sorts of manufactured goods; but the large proportion of the nations total transactions included in the commodities entering the index, and the tendency of price fluctuations in the omitted manufactured articles to follow the general tendency, leaves the index as a reasonably accurate picture of general variations in wholesale prices. In the figures as now published, the few changes in commodities used have been provided for, so that the figures are consistent for all the years covered.

Since it is necessary to deal with a constant basic quantity of each commodity, some average year's consumption is necessary. The quantities traded in the census year 1909 are at once the most easily obtained and the most accurate available, and are therefore used for multiplication by the prices of each index date or period.

For each commodity group the base is established by multiplying the total quantity of each article marketed in 1909 by the average price of that article in the year 1913, adding all the products so obtained for the group, and calling the total 100. The sum of the totals of the 9 groups gives the base of 100 for all commodities. For all other index dates similar calculations are made with prices as of those dates and total quantities the same as were used for 1913, so that the total of any group divided by the corresponding total for 1913 gives a true weighted average price expressed as a percentage of the weighted average price of 1913.

Information as to prices is obtained from both official and private sources. The same is true of the quantities marketed in 1909. Only products actually sold are used in the estimate, products not marketed, such as produce consumed on the farms where it was raised, or steel ingots made into other forms in the mills where they were produced being distinctly excluded.

The group classification and the number of commodities entering into each is as follows:

1. Farm Products	32 Commodities
2. Food, etc	91
3. Clothes & Clothing	77
4. Fuel and Lighting	21
5. Metal, etc	25
6. Lumber & Bldg. Materials	30
7. Chemical and Drugs	18
8. House-Furnishing Goods	12
9. Miscellaneous	21
Total All Commodities	327

Bulletin No. 269, "Wholesale Prices 1890 to 1919," published by the Bureau of Labor Statistics of the U. S. Bureau of Labor gives the indexes, data, and description of methods in much detail.

U. S. Federal Reserve Board Index.—This also is a weighted index, but as it is prepared primarily for purposes of international comparison, it relates chiefly to articles of foreign trade. It is based upon only 90 commodities as against 327 of the Bureau of Labor Index. Part of its figures are obtained from the Bureau of Labor Statistics, but its purpose is specifically different from that of the Bureau's index, and any comparison of the two should be with this fact definitely recognized.

The base of this index is 100 for the year 1913. It is calculated monthly. The classification of commodities is as follows—Goods produced, Goods imported, Goods exported, Raw materials, Producers' Goods, Consumers' Goods, All.

Dun's Review Index.—This index is based upon about 300 wholesale commodities divided into 7 groups. It is calculated for each year from 1860 to date, and for each month since Jan., 1898. In its preparation wholesale quotations on each commodity are obtained for the nearest business day to the first of each month, and are separately multiplied by figures determined upon as the estimated annual per capita consumption of the commodity. Therefore this also gives a truly weighted index.

The tabulation is on a different plan from the two indexes previously described, for instead of showing 100 per cent for each group of commodities and the total for the year 1913, it shows the worth in dollars of the estimated per capita consumption for the year. Thus the sum of the figures for the 7 groups for any given date gives the total for that date. Fortunately for purposes of the rough comparison of totals, the total per capita consumption of $116.319 estimated for the year 1913 is near enough to $100 to permit of a quick rough comparison with the Bureau of Labor Index with a base of 100% for the same year.

Percentage figures to a base of 100 in 1913 are obtainable by dividing any total from Dun's Index by 1.16319.

The classification is as follows: Breadstuffs, Meat, Dairy and Garden, Other food, Clothing, Metals, Miscellaneous, Total. The index figures from 1860 are published in pamphlet form by Dun's Review, New York. The number of commodities in each class is not stated.

Bradstreet's Index.—This is an unweighted index based upon the prices of 96 commodities at the first of each month. The index numbers are the totals in dollars and cents of the Costs of 1 pound of each of the 96 commodities. The classification and number of commodities used are as follows:

1. Breadstuffs	6 commodities
2. Live Stock	4
3. Provisions & Groceries	24
4. Fresh and Dried Fruits	5
5. Hides and Leather	4
6. Textiles	11
7. Metals	13
8. Coal & Coke	4
9. Oils	6
10. Naval Stores	3
11. Building Materials	8
12. Chemicals and Drugs	11
13. Miscellaneous	7
Total	106*

* 10 articles are omitted from the index computation, but what 10 is not stated.

The Annalist Index.—This is an unweighted index based upon 25 different articles of food only, mean prices for each week being used. These mean prices are converted to relatives of the prices of the period from 1890 to 1899, and simple averages of the relatives are then made. The Annalist is published weekly at New York City.

Canadian Index.—The Department of Labor of Canada publishes an index based upon 271 commodities corresponding quite closely with those of the U. S. Bureau of Labor. This index is not weighted like the Bureau's index, for it is stated that in the opinion of the compiler "an extended list of articles tends to weight itself" if judiciously selected. The method is similar to that of the Annalist but the calculation covers more than 10 times as many commodities. A quite close agreement between the Canadian index and the U. S. Bureau of Labor index indicates that there is some justification for the contention of the Canadian compiler as to weighting.

Table XXI gives wholesale price indexes compiled by U. S. Dept. of Labor, from 1913 to Jan., 1922. Averages for preceding years are given in Table I.

TABLE XXI.—INDEX NUMBERS OF WHOLESALE PRICES 1913 TO JUNE, 1921, BY GROUPS OF COMMODITIES
(1913 = 100)

Year and month	Farm products	Food, etc.	Cloths, and clothing	Fuel and lighting	Metals and metal products	Building materials	Chemicals and drugs	House furnishi'g g'ds	Miscellaneous	All commodities
1913	100	100	100	100	100	100	100	100	100	100
Jan.	97	99	100	103	107	100	101	100	100	100
April	97	96	100	98	102	101	101	100	98	98
July	101	102	100	99	98	101	99	100	101	100
Oct.	103	102	100	100	99	98	100	100	100	101
1914	103	103	98	96	87	97	101	99	99	100
Jan.	101	102	98	99	92	98	100	99	99	100
April	103	95	99	98	91	99	100	99	101	98
July	104	104	99	95	85	97	99	99	97	100
Oct.	103	107	97	93	83	96	105	99	96	99
1915	105	104	100	93	97	94	114	99	99	101
Jan.	102	106	96	93	83	94	103	99	100	99
April	107	105	99	89	91	94	102	99	99	100
July	108	104	99	90	102	93	108	99	98	101
Oct.	105	103	103	96	100	93	124	99	99	101
1916	122	126	128	119	148	101	159	115	120	124
Jan.	108	113	110	105	126	99	150	105	107	110
April	114	117	119	108	147	101	172	108	110	117
July	118	121	126	108	145	99	156	121	120	119
Oct.	136	140	138	133	151	101	150	124	132	134
1917	189	176	181	175	208	124	198	144	155	176
Jan.	148	150	161	176	183	106	159	132	138	151
April	181	182	169	184	208	114	170	139	149	172
July	199	181	187	192	257	132	198	152	153	186
Oct.	208	183	193	146	182	114	252	152	163	181
1918	220	189	239	163	181	151	221	196	193	196
Jan.	207	187	211	157	174	136	232	161	178	185
April	217	178	232	157	177	146	229	172	191	190
July	224	184	249	166	184	154	216	199	190	198
Oct.	224	201	257	167	187	158	218	226	196	204

TABLE XXI.—INDEX NUMBERS OF WHOLESALE PRICES 1913 TO JUNE, 1921, BY GROUPS OF COMMODITIES—*Continued*
(1913 = 100)

Year and month	Farm products	Food, etc.	Cloths, and clothing	Fuel and lighting	Metals and metal products	Building materials	Chemicals and drugs	House furnishi'g g'ds	Miscellaneous	All commodities
1919	234	210	261	173	161	192	179	236	217	212
Jan	222	207	234	170	172	161	191	218	212	203
Feb	218	196	223	169	168	163	185	218	208	197
March	228	203	216	168	162	165	183	218	217	201
April	235	211	217	167	152	162	178	217	216	203
May	240	214	228	167	152	164	179	217	213	207
June	231	204	258	170	154	175	174	233	212	207
July	246	216	282	171	158	186	171	245	221	218
Aug	243	227	304	175	165	208	172	259	225	226
Sept	226	211	306	181	160	227	173	262	217	220
Oct	230	211	313	181	161	231	174	264	220	223
Nov	240	219	325	179	164	236	176	299	220	230
Dec	244	234	335	181	169	253	179	303	229	238
1920	218	236	302	238	186	308	210	366	236	243
Jan	246	253	350	184	177	268	189	324	227	248
Feb	237	244	356	187	189	300	197	329	227	249
March	239	246	356	192	192	324	205	329	230	253
April	246	270	353	213	195	341	212	321	238	265
May	244	287	347	235	193	341	215	329	246	272
June	243	279	335	246	190	337	218	362	247	269
July	236	268	317	252	191	333	217	362	243	262
Aug	222	235	290	268	193	328	216	363	240	250
Sept	210	222	273	284	192	318	222	371	239	242
Oct	182	204	257	282	184	313	216	371	229	225
Nov	165	195	234	258	170	274	207	369	220	207
Dec	144	172	220	236	157	266	188	346	205	189
1921:										
Jan	136	162	208	228	152	239	182	283	190	177
Feb	129	150	198	218	146	222	178	277	180	167
March	125	150	192	207	139	208	171	275	167	162
April	115	141	186	199	138	203	168	274	154	154
May	117	133	181	194	138	202	166	262	151	151
June	113	132	180	187	132	202	166	250	150	148
July	115	134	179	184	125	200	163	235	149	148
Aug	118	152	179	182	120	198	161	230	147	152
Sept	122	146	187	178	120	193	162	223	146	152
Oct	119	142	190	182	121	192	162	218	145	150
Nov	114	142	186	186	119	197	162	218	145	149
Dec	113	139	185	187	119	203	161	218	148	149

TABLE XXII.—WHOLESALE PRICE INDEXES OF BUILDING MATERIALS AND METALS
(The averages for the year 1913 being taken at 100 per cent)

Year	All commodities	Building materials	Metals and metal products
1840	89	64	166
1845	83	59	147
1850	83	56	154
1855	96	57	157
1860	90	55	134
61	86	63	133
62	93	87	155
63	110	103	189
64	135	129	265
65	172	106	293
66	144	109	259

TABLE XXII.—WHOLESALE PRICE INDEXES OF BUILDING MATERIALS AND METALS—*Continued*

(The averages for the year 1913 being taken at 100 per cent)

Year	All commodities	Building materials	Metals and metal products
67	131	104	240
68	136	101	224
69	122	97	212
1870	117	86	186
71	112	88	177
72	110	87	196
73	108	100	200
74	109	90	184
75	108	84	176
76	104	80	158
77	99	73	141
78	93	68	126
79	87	67	121
1880	93	76	141
81	95	76	130
82	96	80	133
83	94	78	126
84	92	75	111
85	86	74	107
86	86	75	105
87	87	74	105
88	88	73	107
89	89	72	105
1890	84	72	110
91	83	70	101
92	78	67	94
93	78	68	85
94	71	66	72
95	70	65	78
96	67	63	81
97	67	62	72
98	69	65	72
99	75	71	109
1900	82	76	106
01	80	73	98
02	83	77	78
03	84	80	97
04	83	81	89
05	86	85	98
06	91	94	107
07	96	97	121
08	91	92	94
09	94	97	93
1910	97	101	94
11	95	101	90
12	99	99	100
13	100	100	100
14	99	97	88
15	100	94	97
16	123	101	149
17	175	124	208
18	196	150	180
19	212	194	161

Foot Note.—The index prices for 1840 to 1889 are from the Senate Report No. 1394 on "Wholesale Prices," by Nelson W. Aldrich, Mar. 3, 1893. Those for "all commodities" (223 in number) are "weighted" in proportion to family budget expenses; but those for "building materials" and for "metals and metal products" are unweighted or simple averages, and therefore not so reliable, down to 1889.

The index prices from 1890 to 1919 are all "weighted" in proportion to annual consumption and are compiled by the U. S. Bureau of Labor. See Tables XXIII and XXIV.

TABLE XXIII.—GROUP 5, METALS AND METAL PRODUCTS, QUANTITIES AND WHOLESALE VALUES IN 1919

	Unit	Quantity (000 omitted)	Value (000 omitted)
Bar Iron:			
Best refined, Phila.	lb.	1,083,265	$ 41,381
Common, from mill, Pitts.	lb.	1,083,265	36,614
Copper:			
Ingot, electrolytic	lbs.	1,312,438	250,807
Wire, bare, No. 8	lb.	278,964	61,930
Iron Ore, Mesabi, Bessemer	Long ton	52,310	327,539
Lead, pig, désilverized	lb.	732,153	42,318
Lead pipe	100 lb.	1,058	7,688
Nails, wire	keg	13,916	48,961
Pig Iron:			
Basio	Long ton	1,742	48,248
Bessemer	do.	1,168	36,362
Foundry			
No. 2 northern	Long ton	2,557	77,512
No. 2 southern	do.	2,557	82,271
Pipe, cast iron, 6 in.	Ton	1,146	65,896
Silver, bar, fine	Ounce	151,969	170,935
Steel:			
Billets, Bessemer	Long ton	4,972	201,557
Plates, tank ¼ in. wide	lb.	5,256,756	142,458
Rails, standard—			
Bessemer	Ton	1,767	83,516
Open-hearth	Ton	1,257	61,925
Structural	lb.	4,996,876	139,413
Tin:			
Pig	lb.	94,248	61,742
Plate, coke	100 lb.	12,968	91,736
Wire:			
Barbed, galvanized	100 lb.	6,471	28,907
Plain annealed Nos. 0 to 9	do.	9,580	29,827
Zinc:			
Sheet	100 lb.	576	5,666
Spelter (pig zinc) western	lb.	464,903	34,403
Total			$2,179,612

This table compiled from Bulletin No. 269, U. S. Bureau of Labor Statistics.

TABLE XXIV.—GROUP 6, LUMBER AND BUILDING MATERIALS, QUANTITIES AND WHOLESALE VALUES IN 1919

	Unit	Quantity (000 omitted)	Value (000 omitted)
Brick, common: Chicago run of kiln salmon	1,000	3,264	$ 29,202
Cincinnati, red, building	1,000	3,264	44,336
New York, red, building	1,000	3,264	52,088
Cement, Portland, Domestic	bbl.	65,435	207,115
Glass:			
Plate, polished, glazing—			
3 to 5 sq. ft.	sq. ft.	24,861	11,498
50 to 10 sq. ft.	sq. ft.	24,861	14,482
Window, American, single, 25 inch:			
A	50 sq. ft.	3,461	24,951
B	50 sq. ft.	3,461	23,439
Lath, eastern spruce, 1½ in. slab	1,000	4,388	28,293
Lime, common	bbl.	23,278	62,224
Lumber:			
Douglas fir—			
No. 1	1,000 ft.	3,642	92,568
No. 2 and better	do.	1,214	48,155
Hemlock	do.	3,051	121,277
Maple	do.	1,107	76,014
Oak White—			
Plain	1,000 ft.	1,471	150,226
Quartered	do.	2,943	461,683

TABLE XXIV.—GROUP 6, LUMBER AND BUILDING MATERIALS, QUANTITIES AND WHOLESALE VALUES IN 1919—*Continued*

	Unit	Quantity (000 omitted)	Value (000 omitted)
Pine—			
White, boards, No. a barn.	do.	3,510	223,909
White, boards uppers.....	do.	390	54,827
Yellow, flooring..........	do.	10,173	801,971
Yellow, siding............	do.	6,104	332,668
Poplar, yellow.............	do.	859	94,490
Spruce, eastern............	do.	1,749	79,798
Paint Materials:			
Lead, carbonate of (white lead)..................	lb.	247,237	32,437
Linseed oil, raw...........	gal.	102,528	181,352
Turpentine, spirits of........	do.	29,765	36,022
Zinc, oxide of (zinc, white)...	lb.	143,550	12,532
Putty......................	do.	63,502	2,959
Rosin, common to good, strained...............	bbl.	3,673	55,831
Shingles, 16 in. long:			
Cypress...................	1,000	1,387	8,375
Red Cedar.................	1,000	12,005	53,882
Total..			$3,418,604

This table compiled from Bulletin No. 269, O. S. Bureau of Labor Statistics.

TABLE XXV.—RELATIVE IMPORTANCE OF WHOLESALE COMMODITIES

	1909		1919	
	Millions	Per Cent	Millions	Per Cent
1 Farm Products.............	$ 4,056	27.58	$ 9,891	28.14
2 Food......................	3,876	26.34	8,592	24.45
3 Cloths & Clothing..........	1,648	11.23	5,014	14.26
4 Fuel & Lighting............	1,518	10.32	3,057	8.70
5 Metals....................	834	5.67	2,180	6.20
6 Building Materials..........	1,685	11.47	3,419	9.73
7 Chemicals.................	184	1.24	398	1.13
8 Furniture..................	65	0.42	184	0.51
9 Miscellaneous..............	844	5.72	2,414	6.87
Total.....................	$14,710	100.00	$35,149	100.00

From Bulletin No. 269, U. S. Bureau of Labor Statistics.

Average Wholesale Prices of Important Commodities, Used in Construction, 1890 to 1920.—Tables XXVI and XXVII are prepared from data given in Bulletin No. 269 of the Bureau of Labor Statistics, U. S. Department of labor and from further information obtained from the Bureau, by letter.

As stated in Bulletin No. 269, the average prices shown in the tables are, in all instances where this information could be obtained, based on first-hand transactions in primary markets. Thus the pig-iron prices are those to foundry operators and large steel makers. Steel prices are to jobbers or large manufacturing consumers.

In collecting prices for inclusion in these tables the aim was to secure quotations on those particular grades or qualities of an article that represent the bulk of sales within the class.

It is obvious that in order to arrive at a strictly scientific average price for any period one must know the precise quantity marketed and the price at which each unit of the quantity was sold. It is manifestly impossible to obtain such detail, and even if it were possible the labor and cost involved in such a compilation would be prohibitive. The method adopted here, which is the one usually employed in computing average prices, is believed to yield results quite satisfactory for all practical purposes.

In computing the averages shown in the tables the net cash price was used for all articles subject to large and varying discounts. In the cases of a few articles, such as steel plates, steel sheets, etc., the prices of which are subject to a small discount for cash within 10 days, no deduction has been made.

The name of city where price quotations were secured is given in every case.

TABLE XXVI.—AVERAGE PRICE OF METALS AND METAL PRODUCTS

Year	Bar iron: Best refined, from store (Philadelphia market) per pound	Bar iron: From mill (Pittsburgh market): Best refined, per pound	Bar iron: From mill (Pittsburgh market): Common, per pound	Copper: ingot (New York): Lake, per pound	Copper: ingot (New York): Electrolytic, per pound
1890	$0.021	$0.018	......	$0.158	......
1891	.019	.017	......	.131	......
1892	.018	.016	......	.115	......
1893	.017	.015	......	.109	......
1894	.013	.012	......	.095	......
1895	.014	.013	......	.108	......
1896	.014	.012	......	.110	......
1897	.013	.011	......	.113	......
1898	.013	.011	......	.119	......
1899	.021	.020	......	.177	......
1900	.020	.022	......	.166	......
1901	.018	.018	......	.169	......
1902	.021	.019	......	.120	......
1903	.020	.018	......	.137	......
1904	.017	.015	......	.131	......
1905	.019	.019	$0.017	.158	......
1906	.020	......	.017	.196	......
1907	.021	......	.018	.213	$0.208
1908	.017	......	.015	......	.133
1909	.018	......	.015	......	.131
1910	.019	......	.016	......	.129
1911	.016	......	.013	......	.125
1912	.018	......	.014	......	.164
1913	.019	......	.017	......	.157
1914	.016	......	.013	......	.134
1915	.017	......	.013	......	.173
1916	.032	......	.026	......	.275
1917	.047	......	.041	......	.294
1918	.048	......	.038	......	.247
1919	.038	......	.034	......	.191
1920	.048	......	.044	......	.180

TABLE XXVI.—*Continued*

Year	Copper: Sheet: hot rolled (base sizes) (New York) per pound	Copper: Wire: bare, (f.o.b. mill) per pound	Lead: pig (New York) per pound	Lead pipe (New York) per 100 pounds
1890	$0.228	$0.188	$0.044	$5,400
1891	.190	.165	.044	5.600
1892	.160	.144	.041	5.183
1893	.150	.135	.037	5.000
1894	.143	.116	.033	4.433
1865	.143	.124	.033	4.200
1896	.143	.106	.030	4.100
1897	.146	.138	.036	4.317
1898	.140	.138	.038	4.600
1899	.218	.183	.045	5.350
1900	.207	.180	.045	5.121
1901	.209	.182	.044	5.048
1902	.178	.133	.041	5.217
1903	.192	.150	.043	5.196
1904	.180	.144	.044	4.795
1905	.199	.170	.048	5.225
1906	.238	.211	.059	6.421
1907	.279	.240	.055	6.705
1908	.179	.152	.042	4.740
1909	.179	.148	.043	4.821
1910	.180	1.44	.045	5.061
1911	.166	.139	.045	5.028
1912	.213	.175	.044	5.201
1913	.212	.167	.044	5.082
1914	.188	.147	.039	4.523
1915	.225	1.185	.046	5.301
1916	.359	.305	.068	7.598
1917	.391	.359	.091	10.068
1918	.338	.276	.074	8.887
1919	.285	.222	.058	7.266
1920	.284	.219	.081	9.782

Year	Pig iron: Bessemer (Pittsburgh) per long ton	Pig iron: Foundry, No. 2, northern (Pittsburgh) per lont ton	Pig iron (Cincinnati): Gray forge, southern, coke, per long ton	Pig iron (Cincinnati): Foundry No. 2 southern, per long ton	Steel Billets: Bessemer (Pittsburgh) per long ton
1890	$18.873	$17.150	$14.500	....	$30.468
1891	15.590	15.396	12.517	....	25.329
1892	14.367	13.773	11.792	....	23.631
1893	12.869	12.440	10.635	....	20.436
1894	11.378	10.846	8.938	....	16.578
1895	12.717	11.675	10.323	....	18.484
1896	12.140	11.771	9.604	....	18.833
1897	10.126	10.100	8.802	....	15.080
1898	10.332	10.027	8.719	....	15.306
1899	19.033	17.350	15.063	....	31.117
1900	19.493	18.506	15.604	....	25.063
1901	15.935	14.719	12.552	....	24.131
1902	20.674	21.240	17.604	....	30.599
1903	18.976	19.142	16.229	....	27.912
1904	13.756	13.625	11.677	....	22.179

TABLE XXVI.—*Continued*

Year	Pig iron: Bessemer (Pittsburgh) per long ton	Pig iron: Foundry, No. 2, northern (Pittsburgh) per long ton	Pig iron (Cincinnati): Gray forge, southern, coke, per long ton	Pig iron (Cincinnati): Foundry No. 2 southern, per long ton	Steel Billets: Bessemer (Pittsburgh) per long ton
1905	$16.359	$16.410	$14.490	....	$24.028
1906	19.544	19.267	16.531	....	27.448
1907	22.842	23.869	20.988	....	29.253
1908	17.070	16.250	14.375	....	26.313
1909	17.408	16.410	14.938	....	24.616
1910	17.193	15.983	14.573	....	25.380
1911	15.713	14.519	12.833	....	21.458
1912	15.938	15.088	14.240	....	22.378
1913	17.133	16.008	14.098	$14.903	25.789
1914	14.889	13.903	....	13.390	20.078
1915	15.783	14.873	....	13.576	22.441
1916	23.888	21.065	....	18.671	43.946
1917	43.608	41.392	....	38.808	69.856
1918	36.663	34.460	....	36.526	47.274
1919	31.132	30.314	....	32.175	40.539
1920	44.459	44.902	....	44.508	56.260

Year	Steel: Rails: Bessemer (Pittsburgh) per long ton	Steel: Rails: open hearth (Pittsburgh) per long ton	Steel: Sheets: box annealed, No. 27 (Pittsburgh) per pound	Steel: Structural (Chicago) per pound	Tin Pigs (New York) per pound
1890	$31.779	....	......	......	$0.212
1891	29.917	....	......	......	.203
1892	30,000	....	......	......	.204
1893	28.125	....	......	......	.200
1894	24.000	....	$0.024	......	.181
1895	24,333	....	.024	......	.141
1896	28.000	....	.022	......	.133
1897	18.750	....	.020	......	.136
1898	17.625	....	.019	......	.155
1899	28.125	....	.027	......	.272
1900	32.288	....	.029	......	.031
1901	27.333	....	.032	......	.262
1902	28.000	....	.029	......	.265
1903	28.000	....	.026	......	.282
1904	28,000	....	.021	......	.280
1905	28.000	....	.022	......	.313
1906	28.000	....	.024	......	.392
1907	28.000	....	.025	......	.388
1908	28.000	....	.024	......	.294
1909	28.000	....	.022	......	.296
1910	28.099	....	.023	......	.342
1911	28.000	....	.020	......	.427
1912	28.000	....	.020	......	.463
1913	28.000	$30.000	.022	$0.016	.494
1914	28.000	30.000	.019	.013	.351
1915	28.000	30.000	.019	.015	.376
1916	31.333	33.333	.030	.028	.433
1917	38.000	40.000	.065	.043	.594
1918	54.000	56.000	.049	.032	.852
1919	47.264	49.264	.044	.028	.655
1920	51.827	53.827	.053	.032	.503

TABLE XXVI.—*Continued*

Year	Tin—Plate: domestic—Coke at New York per 100 pounds	Coke, f.o.b. Pittsburgh per 100 pounds	Wire: fence Barbed: galvanized F.o.b. Chicago, per 100 pounds	Zinc—Sheet (La Salle, Ill.) per 100 pounds	Spelter (pig) (New York) per pound
1890..........	......	......	$3.567	$ 6.054	$0.055
1891..........	......	......	3.219	5.719	..51
1892..........	......	......	2.766	5.490	.047
1893..........	......	......	2.519	4.994	.041
1894..........	......	......	2.175	3.950	.036
1895..........	......	......	2.246	4.522	.036
1896..........	$3.435	......	1.963	4.940	.040
1897..........	3.182	......	1.800	4.940	.042
1898..........	2.850	......	1.838	5.498	045
1899..........	4.191	......	3.170	7.004	.059
1900..........	4.678	......	3.394	6.095	.044
1901..........	4.190	......	3.38	5.558	.041
1902..........	4.123	......	2.954	5.731	.049
1903..........	3.940	......	2.738	6.018	.056
1904..........	3.603	......	2.508	5.609	.052
1905..........	3.707	......	2.383	6.285	.059
1906..........	3.861	......	2.428	7.173	.062
1907..........	4.090	......	2.634	7.486	.062
1908..........	3.890	......	2.022	6.440	.048
1909..........	3.737	......	2.359	6.643	.055
1910..........	3.840	......	2.133	7.019	.056
1911..........	3.865	......	2.180	7.048	.058
1912..........	3.657	$3.456	2.134	7.924	.071
1913..........	......	3.558	2.309	7.245	.058
1914...	......	3.369	2.152	6.919	.053
1915..........	.....	3.242	2.535	16.158	.144
1916..........	......	5.057	3.515	18.783	.140
1917..........	......	8.864	4.527	18.093	.093
1918..........	......	7.727	4.594	14.238	.083
1919..........	......	7.074	.4.467	9.837	.074
1920..........	......	7.558	4.724	11.338	.081

TABLE XXVII.—AVERAGE PRICE OF LUMBER AND BUILDING MATERIALS

Year	Brick: common—Salmon: run of klin, (Chicago) per M	Red: (Cincinnati) per M	Red: domestic (New York) per M	Cement—Portland: domestic (New York)—Series 1, per barrel	Series 2, per barrel
1890..............	......	......	$6.563	......	......
1891..............	......	......	5.708	......	......
1892..............	......	......	5.771	......	......
1893..............	......	......	5.833	......	......
1894..............	......	......	5.000	......	......
1895..............	......	......	5.313	$1.969	......
1896..............	......	......	5.063	2.000	......
1897..............	......	......	4.938	1.967	......
1898..............	......	......	5.750	1.998	......
1899..............	......	......	5.688	2.048	......

TABLE XXVII.—*Continued*

Year	Brick: common — Salmon: run of kiln (Chicago) per M	Brick: common — Red: (Cincinnati) per M	Brick: common — Red: domestic (New York) per M	Cement — Portland: domestic (New Yord) — Series 1. per barrel	Cement — Portland: domestic (New Yord) — Series 2. per barrel
1900	......	......	$5.250	$2.158	......
1901	......	......	5.766	1.890	......
1902	......	......	5.385	1.950	......
1903	......	......	5.906	2.029	......
1904	......	......	7.495	1.460	......
1905	......	......	8.104	1.427	......
1906	......	......	8.547	1.575	......
1907	......	......	6.156	1.646	......
1908	......	......	5.104	1.460	......
1909	......	......	6.385	1.412	......
1910	......	......	5.719	1.448	......
1911	......	......	5.891	1.461	......
1912	......	......	6.760	1.315	......
1913	$4.938	$7.000	6.563	1.580	......
1914	4.872	6.750	5.531	1.580	......
1915	4.780	6.250	6.052	1.453	$1.434
1916	4.783	6.750	8.035	......	1.689
1917	4.947	8.438	8.885	......	2.094
1918	7.449	12.938	11.927	......	2.647
1919	8.947	13.583	15.958	......	3.165
1920	11.441	17.467	21.854	......	4.377

Year	Glass: plate — Polished, area 3 to 5 sq. ft. (New York) — Unsilvered, Per square foot	Glass: plate — Polished, area 3 to 5 sq. ft. (New York) — Glazing, per square foot	Glass: plate — Polished, area 5 to 10 sq. ft. (New York) — Unsilvered, per square foot	Glass: plate — Polished, area 5 to 10 sq. ft. (New York) — Glazing, per square foot	Glass: window — American, single, 25-in., 6 by 8 to 10 by 15 in. (New York) — AA, per 50 sq. ft.	Glass: window — American, single, 25-in., 6 by 8 to 10 by 15 in. (New York) — A, per 50 sq. ft.	Glass: window — American, single, B, 25-in., 6 by 8 to 10 by 15 in. (New York) per 50 sq. ft.
1890	$0.530	......	$0.700	......	$2.228	......	$1.786
1891	.520	......	.690	......	2.213	......	1.770
1892	.420	......	.550	......	1.994	......	1.595
1893	.420	......	.550	......	2.138	......	1.710
1894	.330	......	.450	......	1.992	......	1.633
1895	.300	......	.480	......	1.599	......	1.392
1896	.340	......	.540	......	1.802	......	1.600
1897	.200	......	.320	......	2.199	......	1.963
1898	.270	......	.430	......	2.643	......	2.343
1899	.300	......	.480	......	2.708	......	2.399
1900	.340	......	.540	......	2.699	......	2.319
1901	.320	......	.490	......	4.128	......	3.282
1902	.258	......	.411	......	3.219	......	2.565
1903	.363	......	.431	......	2.640	......	2.160
1904	.228	......	.365	......	2.887	......	2.328
1905	.241	$0.198	.373	$0.305	2.764	......	2.137
1906	......	.227	......	.330	2.920	......	2.256
1907	......	.230	......	.340	2.813	......	2.242
1908	......	.173	......	.275	2.360	......	1.881
1909	......	.202	......	.282	2.320	......	1.849

TABLE XXVII.—*Continued*

Year	Glass: plate — Polished, area 3 to 5 sq. ft. (New York) — Un-silvered, per square foot	Glazing, per square foot	Glass: plate — Polished, area 5 to 10 sq. ft. (New York) — Un-silvered, per square foot	Glazing, per square foot	Glass: window — American, single, 25-in., 6 by 8 to 10 by 15 in. (New York) — AA. per 50 sq. ft.	A. per 50 sq. ft.	Glass: window — American, single, B, 25-in., 6 by 8 to 10 by 15-in. (New York) — per 50 sq. ft.
1910......	......	$0.249	......	$0.348	$2.930	....	$2.338
1911......	......	.225	......	.316	2.253	.....	1.796
1912......	......	.217	......	.297	2.240	.....	1.785
1913	......	.237	......	.318	2.720	$2.274	2.221
1914......	......	.211	......	.291	......	2.274	2.168
1915......	......	.187	......	.253	......	2.550	2.423
1916......	......	.292	......	.338	.....	3.150	2.494
1917......	......	.340	......	.393	......	4.123	3.325
1918......	......	.361	......	.453	......	6.322	5.689
1919......	......	.463	......	.583	......	7.209	6.772
1920......	......	.745	......	.809	......	6.900	6.555

Year	Lath: eastern spruce, 1½-inch slab (New York) per M	Lime: common (New York) — Rockport, per barrel	Lime: common (New York) — Eastern, per barrel	Lumber — Douglas fir: No. 1, common (F.o.b. mill Wash. State) per M feet	Lumber — Douglas fir: No. 2, and better, drop siding (F.o.b. mill Wash. State) per M feet
1890.............	......	$0.979	......	....	....
1891.............	......	.913	......	....	....
1892.............	......	.929	......	....	....
1893.............	......	.929	......	....	....
1894.............	......	.848	......	....	....
1895.............	......	.781	......	....	....
1896.............	......	.694	......	....	....
1897.............	......	.719	......	....	.....
1898.............	......	.742	......	....	....
1899.............	......	.798	......	....	....
1900.............	......	.683	......	....	....
1901.............	......	.774	......	....	....
1902.............	......	.806	......	....	....
1903.............	......	.788	......	....	....
1904.............	......	.825	......	....	....
1905.............	......	.891	......	....	....
1906.............	......	.947	......	....	....
1907.............	......	.949	......	....	....
1908.............	......	1.045	......	....	....
1909.............	......	1.045	......	....	....
1910.............	......	1.045	......	....	....
1911.............	......	1.108	......	....	....
1912.............	......	1.085	......	....	....
1913.............	$4.284	1.078	......	$9.208	$17.333
1914.............	3.904	1.023	......	7.917	14.292
1915.............	3.839	1.167	$1.240	7.875	14.292
1916.............	4.221	......	1.405	10.375	18.583
1917.............	4.938	......	1.760	15.875	23.917
1918.............	5.000	......	2.309	18.250	28.000
1919.............	6.448	......	2.673	25.417	39.667
1920.............	14.354	......	4.322	29.917	54.750

TABLE XXVII.—*Continued*

Year	Lumber (New York) Hemlock per M feet	Maple: hard per M feet	Oak: white, plain per M feet	Oak: white, quartered per M feet	Pine: white, boards—No. 2 barn— Buffalo market, per M feet	New York market, per M feet
1890	$12.583	$ 26.500	$ 37.875	$ 51.458	$16.792	....
1891	12.458	26.500	38.000	53.583	17.000	....
1892	12.292	26.500	38.458	53.000	17.146	....
1893	12.000	26.500	38.750	53.000	18.625	....
1894	11.708	26.500	37.250	51.125	18.167	....
1895	11.146	26.500	36.250	53.250	17.250	....
1896	11.167	26.500	36.250	54.500	16.500	....
1897	11.000	26.500	36.250	53.833	15.833	....
1898	11.750	26.500	36.250	52.500	15.500	....
1899	13.521	26.542	38.958	60.521	18.292	....
1900	16.500	27.500	40.833	64.458	21.500	....
1901	15.000	26.708	36.771	59.167	20.875	....
1902	15.833	28.583	40.875	63.083	23.500	....
1903	16.792	31.667	44.833	74.792	24.000	....
1904	17.000	31.000	46.500	80.750	23.000	....
1905	17.875	30.500	47.333	80.250	24.167	....
1906	21.896	31.000	50.417	79.167	29.750	$33.250
1907	22.250	32.250	55.208	80.000	....	37.417
1908	20.875	31.625	49.292	80.167	....	36.375
1909	20.583	31.000	48.417	84.333	....	37.104
1910	20.625	31.800	54.250	87.450	....	38.052
1911	20.682	34.318	54.682	87.182	....	38.376
1912	21.455	36.455	56.227	86.500	....	37.227
1913	24.227	36.364	60.591	88.318	....	36.864
1914	24.396	38.500	60.042	88.333	....	37.500
1915	21.591	38.500	57.682	86.500	....	37.500
1916	23.542	40.583	61.333	86.500	....	37.500
1917	27.708	49.708	66.292	90.000	....	49.125
1918	33.929	60.125	75.625	104.271	....	60.417
1919	39.750	68.667	102.125	156.875	....	63.792
1920	56.667	143.750	204.667	296.250	....	....

Year	Lumber (New York) Pine: white, boards, uppers. Buffalo market, per M feet	New York market per M feet	Lumber Pine: yellow, flooring per M feet	Pine: yellow, siding (New York) market) per M feet	(Norfolk Va., market) per M feet	Poplar (New York) per M feet	Spruce (New York) per M feet
1890	$44.083	....	....	$20.750	....	$30.500	$16.292
1891	45.000	....	....	19.958	....	30.500	14.218
1892	46.142	....	....	18.500	....	30.604	14.854
1893	48.500	....	....	18.500	....	33.625	13.771
1894	46.417	....	....	18.500	....	31.750	12.708
1895	46.000	....	....	16.917	....	31.000	14.250
1896	46.625	....	....	16.417	....	31.000	14.250
1897	46.333	....	....	16.438	....	30.667	14.000
1898	46.083	....	....	18.625	....	30.000	13.750
1899	50.458	....	....	20.042	....	34.021	15.396
1900	57.500	....	....	20.708	....	37.688	17.375
1901	60.417	....	....	19.667	....	36.708	18.000
1902	74.833	....	....	21.000	....	42.104	19.250
1903	80.000	....	....	21.000	....	49.646	19.188
1904	81.000	....	....	21.417	....	50.329	20.500

TABLE XXVII.—*Continued*

Year	Lumber (New York) — Pine: white, boards, uppers — Buffalo market, per M feet	Lumber (New York) — Pine: white, boards, uppers — New York market per M feet	Lumber — Pine: yellow, flooring per M feet	Lumber — Pine, yellow, siding (New York) market per M feet	Lumber — Pine, yellow, siding (Norfolk Va., market) per M feet	Lumber — Poplar (New York) per M feet	Lumber — Spruce (New York) per M feet
1905	$82.000	....	....	$24.917	....	$48.208	$21.417
1906	84.750	$ 88.250	....	29.333	....	50.958	25.542
1907	....	97.083	....	30.500	....	58.083	24.000
1908	....	96.083	$ 43.917	30.500	....	58.292	20.792
1909	....	93.042	45.833	33.042	....	57.625	25.250
1910	....	98.800	46.300	30.800	....	61.500	24.600
1911	....	100.500	46.546	30.591	....	61.591	24.273
1912	....	101.046	44.546	33.136	....	61.500	26.955
1913	....	103.500	44.591	32.136	....	61.727	27.864
1914	....	103.500	42.750	29.625	....	60.667	27.417
1915	....	103.500	39.591	28.182	....	58.909	27.000
1916	....	103.500	39.375	31.818	$26.917	60.292	28.250
1917	....	112.500	50.909	....	36.208	63.458	35.000
1918	....	130.792	60.750	....	42.917	84.708	39.625
1919	....	140.583	78.833	......	54.500	110.000	45.625
1920	....	....	145.417	....	95.750	195.636	....

Year	Paint materials — Lead, carbonate of (white lead): American, in oil (New York) per pound	Linseed oil, raw (New York) per gallon	Turpentine, spirits of (New York) per gallon	Zinc, oxide of (zinc white) (New York) per pound
1890	$0.064	$0.616	$0.408	$0.043
1891	.065	.484	.380	.042
1892	.066	.408	.323	.043
1893	.061	.463	.300	.041
1894	.052	.524	.293	.037
1895	.053	.524	.292	.035
1896	.052	.368	.274	.038
1897	.054	.328	.292	.038
1898	.054	.393	.322	.040
1899	.057	.427	.458	.044
1900	.063	.629	.477	.045
1901	.058	.635	.373	.044
1902	.054	.593	.474	.044
1903	.062	.417	.572	.046
1904	.059	.416	.576	.046
1905	.063	.468	.628	.047
1906	.069	.405	.665	.051
1907	.070	.434	.634	.054
1908	.065	.438	.453	.051
1909	.064	.580	.491	.052
1910	.069	.847	.683	.054
1911	.071	.879	.679	.054
1912	.068	.673	.470	.052
1913	.068	.462	.428	.054
1914	.068	.502	.473	.054
1915	.070	.562	.459	.067
1916	.093	.751	.491	.092
1917	.112	1.107	.488	.100
1918	.127	1.597	.594	.100
1919	.131	1.769	1.210	.087
1920	.152	1.459	1.734	.089

TABLE XXVII.—*Continued*

Year or month	Shingles: cypress, 16 inches long (New Orleans) per M	Shingles (Buffalo, N. Y.) White pine, 18 inches long, per M	Shingles (Buffalo, N. Y.) Michigan white pine, 16 inches long, per M	Shingles (Wash. State) Red cedar, 16 inches long, per M	Tar (Wilmington, N. C.) per barrel
1890	$3.350	$3.842	......	......	$1.475
1891	3.250	4.000	......	......	1.583
1892	3.150	3.906	......	......	1.300
1893	3.000	3.850	......	......	1.046
1894	2.800	3.750	......	......	1.092
1895	2.650	3.700	......	......	1.142
1896	2.500	3.613	......	......	1.013
1897	2.350	3.542	......	......	1.054
1898	2.500	3.552	......	......	1.098
1899	2.663	3.679	......	......	1.246
1900	2.850	4.000	......	......	1.363
1901	2.850	4.188	$3.263	......	1.282
1902	2.671	......	3.588	......	1.325
1903	2.567	......	3.650	......	1.679
1904	2.600	......	3.575	......	1.679
1905	2.725	......	3.500	$1.688	1.758
1906	3.242	......	......	2.213	1.958
1907	4.225	......	......	2.696	2.329
1908	3.538	......	......	2.013	1.600
1909	3.267	......	......	2.004	1.638
1910	3.492	......	......	2.008	2.254
1911	3.608	......	......	1.813	2.125
1912	3.483	......	......	1.939	2.000
1913	3.542	......	......	1.967	2.225
1914	3.329	......	......	1.713	2.188
1915	3.067	......	......	1.664	1.733
1916	3.446	......	......	1.910	2.254
1917	4.054	......	......	2.818	3.192
1918	5.425	......	......	2.794	3.677
1919	6.039	......	......	4.488	4.452
1920	8.067	......	......	4.723	5.123

Relation of Cast-Iron Water Pipe and Gray Forge Iron Prices.—Figs. 5 and 6, given in the Annual Review Section of Iron Age, published Jan. 6, 1921, show clearly the fluctuations in the prices over a period of 18 years and indicate, as might be expected, that the variations in price of cast iron pipe are largely due to the variations in the price of the pig iron from which the pipe is made.

Prices of Cast Iron Water Pipe During the Past 50 Years.—Interesting statistics on the price of cast iron pipe were presented by Burt B. Hodgman, Chief Engineer of the National Water Main Cleaning Co., in a paper presented at the 1917 annual meeting of the American Water Works Association. In his paper, an abstract of which is given in Engineering and Contracting, Aug. 29, 1917, Mr. Hodgman gives the prices actually paid for cast iron pipe by the city of Boston, Mass., during the past 50 years.

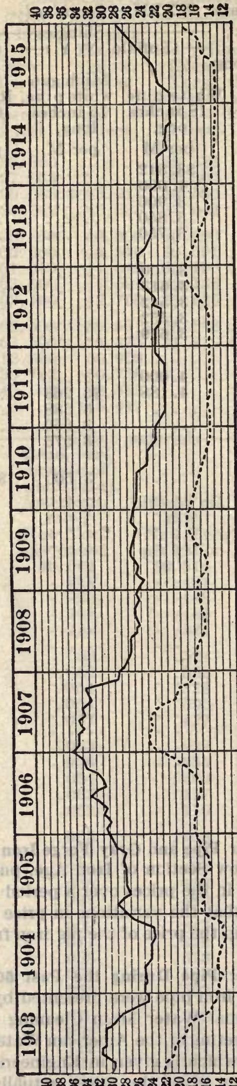

FIG. 5.—Fluctuation of prices of 6-in. cast iron water pipe at New York, per net ton of 2000 lbs. (car load lots) from 1903 to 1915, compared with gray forge pig iron at Philadelphia. Solid line, pipe; dotted line, pig iron.

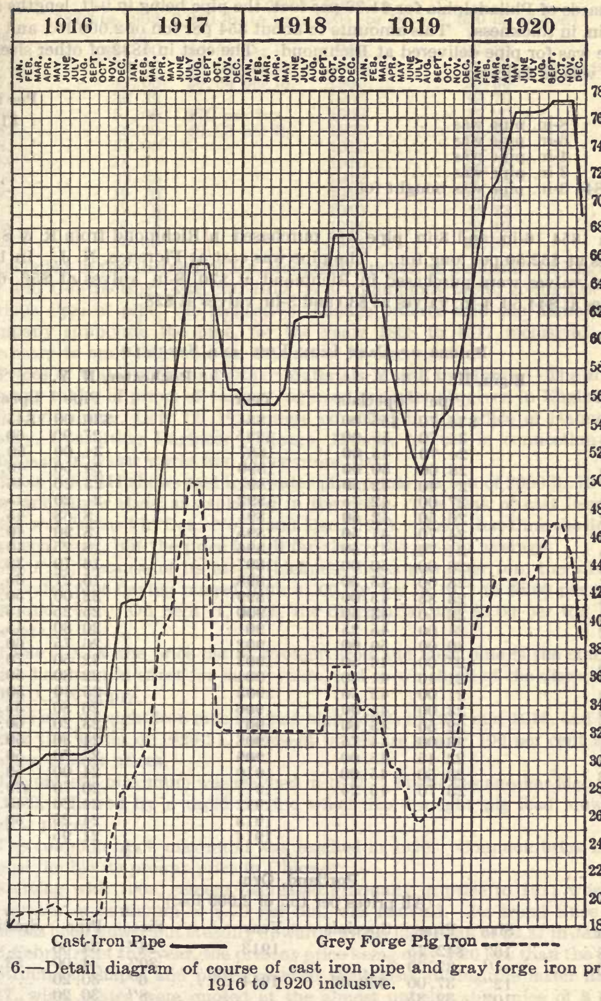

FIG. 6.—Detail diagram of course of cast iron pipe and gray forge iron prices 1916 to 1920 inclusive.

In 1832 Richmond, Va., purchased 10-in. pipe from Samuel & Thomas S. Richards of Philadelphia for $1.38 per foot, the pipe being in 9-ft. lengths and 9/16 in. in thickness. This amounts to about $54 per ton of 2,000 lb., and the price was for pipe delivered at Richmond. The cost in 1832 of other sizes of pipe was as follows:

	Per foot
8-in. pipe was	$1.25
6-in. pipe was	.70
4-in. pipe was	.45
3-in. pipe was	.37
In 1844 3-in. pipe was bought for	.30

In 1854 16-in. and 8-in. pipe was purchased in Richmond from R. & S. H. Jones at $52.50 per long ton. The pipe was cast at Florence, N. J. In 1832 10-in. valves were purchased in Richmond at $70, 8-in. valves at $56, 6-in. valves at $44.50, 4-in. valves at $30 and 3-in. valves at $28.

Prices of Cast Iron Pipe and Specials

Elgin, Ill.

Year	Pipe	Specials
1887	$34.70	$55.00
1888	34.70	55.00
1889	24.70	45.00
1890	28.00	50.00
1891	27.40	42.50
1892	27.00	42.75
1893	26.50	42.50
1894	24.70	41.50
1895	24.70	41.50
1896	28.00	50.00
1897	28.00	48.50
1898	23.85	45.00
1899	23.50	43.50
1902	24.00	45.25
1905	30.00	50.00
1906	27.00	46.50
1907	21.40	41.40
1908	21.00	42.50
1909	23.00	45.00
1910	22.50	45.00
1911	23.00	44.75
1912	23.45	45.00
1913	23.50	45.00
1914	23.70	45.25

Rochester, N. Y.

Year	Pipe	Specials
1884	$30.00	$45.00
1885	27.90	60.00
1887	34.00	60.00
1890	24.50	46.00
1891	23.20	46.00
1892	21.20	45.00
1894	18.68	45.00
1895	18.90	40.00
1896	18.25	40.00
1897	16.70	38.00
1898	15.27	35.00
1899	22.00	50.00
1900	25.25	45.00
1901	20.80	45.00
1902	26.75	60.00
1903	32.50	70.00
1904	22.80	50.00
1905	25.40	50.00
1906	26.80	55.00
1907	23.20	60.00
1908	24.30	50.00
1909	22.70	50.00
1910	24.00	50.00
1911	20.70	49.00
1912	21.20	48.00
1913	24.25	50.00
1914	21.95	......

Portland, Ore

(All prices per ton of 2,000 lbs.)

Year	Size	Pipe	Specials
1908	16″	$42.75	......
1910	4″	37.00	......
	12″	37.00	$60.00
1911	10″	32.35	......
	20″	32.35	48.00
	10″	30.90	......
	20″	30.50	......
1913	6″	34.25	......
	8″	34.50	......
1913	24″	34.00	......
	30″	34.00	53.00
1914	6″	30.20	......
	8″	30.20	......
	12″	30.20	......
	16″	30.20	......
	24″	30.20	......
	30″	30.20	......

PRICES OF CAST IRON PIPE AND SPECIALS
Lowell, Mass.
(1870 to 1902, 2,240 lb. to ton; 1904 to 1914, 2, 000 lb. to ton)

Year	Pipe		Year	Pipe	
1870........	$63.00	$0.04 per lb.	1902........	28.20	
1873........	73.00	$0.04 per lb.	1904........	23.20	$0.05 per lb.
1874........	42.00	$0.04 per lb.	1906........	29.30	
1876........	36.39		1906........	32.70	
1880........	51.00	$70 per ton	1909........	25.20	
1882........	45.00	$0.03 per lb.	1909........	24.20	
1881........	55.00		1010........	22.30	
1889........	28.31		1910........	22.00	
1895........	23.85		1912........	21.45	
1895........	19.70		1912........	22.34	
1897........	18.18		1913........	23.23	
1899........	21.75		1914........	22.49	
1899........	23.00		1914........	21.95	

Included in the abstract of Mr. Hodgman's paper, as published in Engineering and Contracting, Aug. 29, 1917, is a voluminous table, giving prices on various sizes of pipe, the respective tonnage ordered and the name of the company supplying the pipe, for the years 1868 to 1917 inclusive. It is necessary to omit this table on account of its size.

Prices of Waterworks and Other Materials Month by Month.—The accompanying tables of prices of various engineering materials given in Engineering and Contracting, Oct. 12, 1921, were compiled in the office of Dabney H. Maury, Consulting Engineer, Chicago, Illinois, for use in connection with appraisals of water works and other properties.

Table XXVIII shows cast iron water pipe prices per ton of 2000 lb. in 4-in., 6-in. and larger sizes, as explained in the note. The peak of cast iron pipe prices was reached in Oct., Nov., and Dec., 1920. Since that time the decline has been rapid, but the price is still far above the prewar average.

Gas Pipe, because of its lesser thickness, costs more per ton, the advance over water pipe having ranged from $1.00 per ton in 1913 to $4.00 per ton in 1920 and 1921. On Sept. 1, 1921, the differential was $3.00 per ton in all markets.

Table XXIX the price list of wrought iron and steel pipe is the standard which has been in effect for many years, and to which all of the discounts of Table XXX apply.

Steel and wrought iron pipe reached high points in 1917 and 1918, and again during the winter of 1920-21. Present prices are nearly 100 per cent above average prewar prices.

The pig lead maximum was reached in 1917. There was another high point in 1920, followed by a rapid decline which has brought pig lead down to prewar prices.

The common brick maximum was reached in 1920. Common brick is still almost double its prewar price in Chicago.

Starting with 1903, cement decreased gradually in price to 1911 when, in November, a minimum of $.70 per bbl. was reached. Its trend since that time has been slowly but steadily upwards with a high peak of $2.37 in January and February of this year, the present price being only $.20 less than the peak.

Structural shapes and plates reached their peak during the latter half of 1917, when plates were quoted at the almost unbelievable price of $.10 at warehouse, Chicago. Since that time they have declined in price, reaching a point slightly below $.03 in August, 1921.

The range of prices of reinforcing bars has followed rather closely that of structural shapes.

Table XXVIII.—Prices per Short Ton of Cast Iron Water Pipe at Chicago, Ill.

(Quotations are from The Iron Age). See Footnote.

Year	1904	1905	1906	1907	1908	1909
Average	26.42	29.25	32.46	37.75	28.08	27.79
for	25.46	25.96	31.46	36.75	27.08	26.79
year	24.50	27.83	30.46	35.75	26.08	25.46
	28.00	28.50	31.00	37.50	33.00	27.00
Jan.	27.50	27.50	30.00	36.50	32.00	26.00
	.....	.....	29.00	35.50	31.00	25.00
	27.00	28.50	31.00	38.50	30.00	28.00
Feb.	26.00	27.50	30.00	37.50	29.00	27.00
	25.00	.....	29.00	36.50	28.00	25.00
	26.00	28.50	31.00	38.50	30.00	28.00
Mar.	25.00	27.50	30.00	37.50	29.00	27.00
	24.00	.....	29.00	36.50	28.00	25.00
	26.00	29.00	31.00	38.50	28.00	27.50
April	25.00	28.00	30.00	37.50	27.00	26.50
	24.00	.....	29.00	36.50	26.00	24.50
	27.00	29.00	31.00	38.50	27.00	27.50
May	26.00	28.00	30.00	37.50	26.00	26.50
	25.00	.....	29.00	36.50	25.00	24.50
	26.00	29.00	31.00	38.50	27.00	27.50
June	25.00	28.00	30.00	37.50	26.00	26.50
	.....	.....	29.00	36.50	25.00	25.50
	25.50	29.00	32.50	38.50	27.00	26.50
July	24.50	28.00	31.50	37.50	26.00	27.50
	.....	27.50	30.50	36.50	25.00	25.50
	25.50	29.00	32.50	38.50	27.00	27.50
Aug.	24.50	28.00	31.50	37.50	26.00	26.50
	.....	27.00	30.50	36.50	25.00	25.50
	25.50	29.50	33.00	38.00	27.00	27.50
Sept.	24.50	28.50	32.00	37.00	26.00	26.50
	.....	27.50	31.00	36.00	25.00	25.50
	25.50	30.00	34.00	37.00	27.00	28.50
Oct.	24.50	29.00	33.00	36.00	26.00	27.50
	.....	28.00	32.00	35.00	25.00	26.50
	27.50	30.00	34.00	36.00	27.00	28.50
Nov.	26.50	29.00	33.00	35.00	26.00	27.50
	.....	28.00	32.00	34.00	25.00	26.50
	27.50	31.00	37.50	35.00	27.00	28.50
Dec.	26.50	30.00	36.50	34.00	26.00	27.50
	.....	29.00	35.50	33.00	25.00	26.50

Year	1910	1911	1912	1913	1914	1915
Average	27.92	25.75	28.13	29.00	26.21	26.37
for	26.92	24.42	26.17	27.00	24.21	24.37
year	25.92	23.92	25.46	26.00	23.58	23.13
	28.50	25.00	26.50	31.00	27.00	25.50
Jan.	27.50	24.00	24.50	29.00	25.00	23.50
	26.50	23.50	24.00	28.00	24.00	23.00
	28.50	25.00	27.00	31.00	27.00	25.50
Feb.	27.50	24.00	25.00	29.00	25.00	23.50
	26.50	23.50	24.50	28.00	24.00	23.00
	28.50	25.50	27.00	30.00	27.00	25.50
Mar.	27.50	24.50	25.00	28.00	25.00	23.50
	26.50	24.00	24.50	27.00	24.00	23.00
	28.50	25.50	27.00	30.50	26.00	25.50
April	27.50	24.50	25.00	28.50	24.00	23.50
	26.50	24.00	24.50	27.50	23.50	23.00
	28.50	25.50	27.00	29.50	26.00	25.50
May	27.50	24.50	25.00	27.50	24.00	23.50
	26.50	24.00	24.50	26.50	23.50	23.00
	28.50	25.50	27.00	28.50	26.00	25.50
June	27.50	24.50	25.00	26.50	24.00	23.50
	26.50	24.00	24.50	25.50	23.50	23.00
	28.00	25.50	27.50	28.50	26.00	26.00
July	27.00	24.50	25.50	26.50	24.00	24.00
	26.00	24.00	25.00	25.50	23.50	23.50

TABLE XXVIII.—*Continued*

Year	1910	1911	1912	1913	1914	1915
Aug	28.00	25.50	27.50	28.00	26.00	26.00
	27.00	24.50	26.00	26.00	24.00	24.00
	26.00	24.00	25.00	25.00	23.50	23.50
Sept	27.00	26.50	30.00	28.00	26.00	26.50
	26.00	24.50	28.00	26.00	24.00	24.50
	25.00	24.00	27.00	25.00	23.50	.....
Oct	27.00	26.50	30.00	28.00	26.00	27.00
	26.00	24.50	28.00	26.00	24.00	25.00
	25.00	24.00	27.00	25.00	23.50	.....
Nov	27.00	26.50	30.00	28.00	26.00	29.00
	26.00	24.50	28.00	26.00	24.00	27.00
	25.00	24.00	27.00	25.00	23.50	.....
Dec	27.00	26.50	31.00	27.00	25.50	29.00
	26.00	24.50	29.00	25.00	23.50	27.00
	25.00	24.00	28.00	24.00	23.00	.....

Year	1916	1917	1918	1919	1920	1921
Average for year	34.23	57.83	62.85	60.90	79.98	.....
	31.31	54.83	59.85	57.97	76.48	.....
	.....	.....	.....	.....	.....	.....
Jan	30.50	44.50	57.30	69.80	69.80	69.10
	28.50	41.50	54.30	66.80	66.80	64.10
Feb	32.75	44.50	57.30	64.80	72.80	69.10
	29.75	41.50	54.30	61.80	69.80	64.10
Mar	32.75	45.50	57.30	64.80	75.80	69.10
	29.75	42.50	54.30	61.80	72.80	64.10
April	33.75	53.50	57.30	59.80	75.80	69.10
	30.75	50.50	54.30	56.80	72.80	64.10
May	33.75	58.50	57.30	59.80	79.80	69.10
	30.75	55.50	54.30	56.80	76.80	64.10
June	33.75	61.50	63.35	54.80	79.80	57.10
	30.75	58.50	60.35	51.80	76.80	54.10
July	34.00	68.50	65.05	54.80	79.80	52.10
	31.00	65.50	62.05	51.80	76.80	49.10
Aug	34.00	68.50	65.05	56.30	79.80	49.10
	31.00	65.50	62.05	53.30	76.80	46.10
Sept	34.00	68.50	64.80	58.50	82.10	.....
	31.00	65.50	61.80	55.80	79.10	.....
Oct	34.50	68.50	69.80	58.80	88.10	.....
	31.50	65.50	66.80	55.80	83.10	.....
Nov	34.50	53.50	69.80	62.80	88.10	.....
	31.50	50.50	66.80	59.80	83.10	.....
Dec	42.50	58.50	69.80	65.80	88.10	.....
	39.50	55.50	66.80	62.80	83.10	.....

Foot Note: The prices given in the table are arranged according to size of pipe, the top figure for each month representing quotations on 4″ pipe. The sizes represented by the other figures are as follows:

Period	Middle figure	Lower figure
Jan., 1902 to July, 1903	6″	8″ & larger
Aug., 1903	6″ & larger	....
Sept., 1903	6″ & 8″	10″ & larger
Oct., 1903 to Jan., 1904	6″ & larger	....
Feb., 1904 to May, 1904	6″ to 12″	Larger than 12″
June, 1904 to June 1905	6″ & larger	....
July, 1905 to Sept., 1905	6″ to 10″	12″ & larger
Oct., 1905 to Aug., 1915	6″ to 12″	16″ larger
Sept., 1915 to Sept., 1921	6″ & larger	....

TABLE XXIX.—STANDARD PRICE LIST OF STEEL AND WROUGHT IRON PIPE—EITHER BLACK OR GALVANIZED

This list was established prior to 1900, and has since remained in general use throughout the United States.

Standard pipe is furnished with threads and couplings and in random lengths unless otherwise ordered. Weights are in pounds.

	Standard steam, gas and water pipe		
		Weight per foot	
Size, in.	Price per foot	Plain ends	Threads and couplings
⅛	$0.05½	.244	.245
¼	.06	.424	.425
⅜	.06	.567	.568
½	.08½	.850	.852
¾	.11½	1.130	1.134
1	.17	1.678	1.684
1¼	.23	2.272	2.281
1½	.27½	2.717	2.731
2	.37	3.652	3.678
2½	.58½	5.793	5.819
3	.76½	7.575	7.616
3½	.92	9.109	9.202
4	1.09	10.790	10.889
4½	1.27	12.538	12.642
5	1.48	14.617	14.810
6	1.92	18.974	19.185
7	2.38	23.544	23.769
8	2.50	24.696	25.000
8	2.88	28.554	28.809
9	3.45	33.907	34.188
10	3.20	31.201	32.000
10	3.50	34.240	35.000
10	4.12	40.483	41.132
11	4.63	45.557	46.247
12	4.50	43.773	45.000
12	5.07	49.562	50.706

Extra strong pipe for high pressure hydraulic installations, etc., takes a higher price.

TABLE XXX.—DISCOUNTS ON WROUGHT IRON AND STEEL PIPE IN CARLOAD LOTS AT PITTSBURGH, PA.

	Steel pipe							
	Black				Galvanized			
Size—inches	½	¾–6	7–12	...	½	¾–6	7–12	...
1910—								
Jan.	74	78	72	...	62	68	57	...
Feb.–May	74	78	72	...	62	68	57	...
June–Sept	74	78	72	...	62	68	57	...
Size—inches	½	¾–1½	¾–3	2–3	½	¾–1½	¾–3	2–3
1910—								
Oct	75	79	....	80	63	69	....	70
Nov.–Dec.	75	79	....	80	63	69	....	70
1911—								
Jan.–Sept	75	79	....	80	65	69	....	70
Oct	77	80	....	81	67	72	....	74
Nov	78	80	....	81	67	72	....	74
Dec	78	81	....	82	68	73	....	75
1912—								
Jan.–Feb	78	81	....	82	68	73	....	75
Mar.–May	78	81	....	82	68	72	....	75
June–July	77	80	....	81	67	72	....	74
Aug	76	79	....	80	66	71	....	73
Sept	76	79	....	80	66	71	....	73
Oct	76	....	79	...	66	....	71	...
Nov	76	....	79	...	66	....	71	...
Dec	76	....	79	...	66	....	71	...

TABLE XXX.—*Continued*

	Steel pipe							
	Black				Galvanized			
1913—								
Jan.–April	77	....	80	...	66½	....	71½	...
May	76½	....	79½	...	66	....	70	...
June–Aug	76	....	79	...	65½	....	70½	...
Sept.–Dec	77	....	80	...	66½	....	71½	...
1914—								
Jan	77	....	80	...	66½	....	71½	...
Feb.–Apr	76½	....	79½	...	66	....	71	...
May–Oct	77	....	80	...	66½	....	71½	...
Nov.–Dec	78	....	81	...	67½	....	72½	...
1915—								
Jan.–Feb	78	....	81	...	67½	....	72½	...
Mar	77	....	80	...	66½	....	69½	...
April	77	....	80	...	65½	....	69½	...
May	76	....	79	...	64½	....	68½	...
June	76	....	79	...	59½	....	63½	...
July–Aug	76	....	79	...	53½	....	57½	...
Sept.–Oct	76	....	79	...	59½	....	63½	...
Nov.–Dec	75	....	78	...	59½	....	63½	...
1916—								
Jan	74	....	77	...	58½	....	62½	...
Feb	73	....	76	...	56½	....	60½	...
Mar	71	....	74	...	53½	....	57½	...
April	69	....	72	...	49½	....	53½	...
May–July	67	....	70	...	46½	....	50½	...
Aug.–Sept	67	....	70	...	51½	....	55½	...
Oct.–Nov	66	....	69	...	51½	....	55½	...
Dec	63	....	66	...	48½	....	52½	...
1917—								
Jan.–Feb	61	....	64	...	46½	....	50½	...
Mar	59	....	62	...	44½	....	48½	...
April	52	....	55	...	37½	....	41½	...
May–June	46	....	49	...	31½	....	35½	...
July–Nov	46	....	49	...	31½	....	35½	...
Dec	48	....	51	...	33½	....	37½	...
1918—								
Jan.–Dec	48	....	51	...	33½	....	37½	...
1919—								
Jan.–Mar	51	....	54	...	36½	....	40½	...
Apr.–Aug	54½	....	57½	...	40	....	44	...
Sept.–Dec	54½	....	57½	...	40	....	44	...
1920—								
Jan	54½	....	57½	...	40	....	44	...
Feb	51	....	54	...	36½	....	41½	...
Mar.–July	51	....	54	...	36½	....	41½	...
Aug.–Dec	52¾	....	55¾	...	38¼	....	42¾	...
1921—								
Jan.–Feb	54½	....	57½	...	40	....	44	...
Mar.–Apr	54½	....	57½	...	40	....	44	...
Size, inches	½	¾	1–3	...	½	¾	1–3	...
1921—								
May–July	56½	60½	62½	...	42	48	50	...
Aug	58½	62½	64½	...	44	50	52	...

	Wrought iron pipe									
	Black					Galvanized				
Size—inches.	½	¾–6	7–12	....	...	½	¾–6	7–12	....	...
1910—										
Jan	69	73	68	....	...	57	63	53	....	...
Feb.–May	69	73	67	....	...	57	63	52	....	...
June–Sept	70	74	68	....	...	58	64	53	....	...
Size—inches.	½	¾–1½	¾–2½	2–2½	2–3	½	¾–1½	¾–2½	2–2½	2–3
1910—										
Oct	....	....	....	....	...	....	....	....	....	...
Nov.–Dec	71	75	....	....	76	59	65	....	....	66

TABLE XXX.—*Continued*

	Wrought iron pipe									
	Black					Galvanized				
1911—										
Jan.–Sept...	71	75	....	....	76	59	65	....	....	66
Oct.........	75	75	....	....	76	65	67	....	....	69
Nov.........	72	75	....	....	76	62	67	....	....	69
Dec.........	72	75	....	....	76	62	67	....	....	69
1912—										
Jan.–Feb....	72	75	....	....	76	62	67	....	....	69
Mar.–May..	72	75	....	....	76	59		....	....	65
June–July...	72	75	....	....	76	59	64	....	....	65
Aug.........	71	74	....	....	75	58	63	....	....	64
Sept........	69	72	....	....	73	56	61	....	....	62
Oct.........	70	73	....	74	...	57	62	....	63	...
Nov.........	70	73	....	73	...	57	62	....	62	...
Dec.........	70	73	....	....	...	57	62	....	....	...
1913—										
Jan.–April...	70	....	73	....	...	57	....	62	....	...
May.........	70	....	73	....	...	57	....	62	....	...
June–Aug...	69	....	72	....	...	56	....	61	....	...
Sept.–Dec...	69	....	72	....	...	56	....	61	....	...
1914—										
Jan.........	69	....	72	....	...	56	....	61	....	...
Feb.–April...	69	....	72	....	...	56	....	61	....	...
May–Oct....	69	....	72	....	...	56	....	61	....	...
Nov.–Dec...	69	....	72	....	...	56	....	61	....	...
1915—										
Jan.–Feb....	69	....	72	....	...	56	....	61	....	...
Mar.........	69	....	72	....	...	54	....	59	....	...
April........	69	....	72	....	...	54	....	59	....	...
May.........	68	....	71	....	...	52	....	57	....	...
June........	68	....	71	....	...	47	....	52	....	...
July–Aug....	68	....	71	....	...	41	....	46	....	...
Sept.–Oct....	68	....	71	....	...	47	....	52	....	...
Nov.–Dec...	67	....	70	....	...	47	....	52	....	...
1916—										
Jan.........	67	....	70	....	...	47	....	52	....	...
Feb.........	63	66	....	....	...	43	48	....	....	...
Mar.........	61	64	....	....	...	40	45	....	....	...
April........	59	62	....	....	...	36	41	....	....	...
May–July...	57	60	....	....	...	33	38	....	....	...
Aug.–Sept...	57	60	....	....	...	38	43	....	....	...
Oct.–Nov....	56	59	....	....	...	38	43	....	....	...
Dec.........	53	56	....	....	...	35	40	....	....	...
1917—										
Jan.–Feb....	51	54	....	....	...	33	40	....	....	...
Mar.........	49	52	....	....	...	31	38	....	....	...
April........	41	44	....	....	...	23	28	....	....	...
May–June...	35	38	....	....	...	17	22	....	....	...
July–Nov....	28	33	....	....	...	10	17	....	....	...
Dec.........	28	33	....	....	...	10	17	....	....	...
1918—										
Jan.–Dec....	28	33	....	....	...	10	17	....	....	...
1919—										
Jan.–Mar....	31	36	....	....	...	13	20	....	....	...
Apr.–Aug....	34½	39	....	....	...	16½	23½	....	....	...
Sept.–Dec...	34½	30	....	....	...	16½	23½	....	....	...
1920—										
Jan.........	34½	30	....	....	...	16½	23½	....	....	...
Feb.........	34½	30	....	....	...	16½	23½	....	....	...
Mar.–July...	29½	34½	....	33½	...	11½	18½	....	17½	...
Aug.–Dec ...	24½	29½	....	....	...	6½	13¼	....	....	...
1921—										
Jan.–Feb....	20	25	....	....	...	2	9	....	....	...
Mar.–Apr....	24½	29½	....	....	...	6½	13½	....	....	...
Size—inches.	½	¾	1–1½	....	...	½	¾	1–1½	....	...
1921—										
May–July...	27½	33½	35½	....	...	9½	18½	20½	....	...
Aug.........	31½	37½	39½	....	...	13½	22½	24½	....	...

TABLE XXXI.—PIG LEAD PRICES IN CENTS PER LB. IN CARLOAD LOTS AT ST. LOUIS, MO.

	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921
Jan.	4.65	4.35	4.35	4.15	4.10	3.60	5.40	7.35	6.37	5.70	7.50	4.65
Feb.	4.60	4.32	4.17½	4.20	4.05	3.62½	6.00	8.00	6.85	4.75	8.45	4.55
Mar.	4.40	4.25	3.92½	4.20	3.87½	3.85	6.30	9.62½	7.10	5.00	8.75	4.50
Apr.	4.25	4.30	4.12½	4.20	3.70	4.12½	8.00	9.15	7.00	5.00	8.75	4.75
May	4.25	4.27½	4.07½	4.37½	3.80	4.07½	7.37½	9.75	6.62	4.95	8.40	4.90
June	4.22½	4.22½	4.12½	4.20	3.80	4.82½	7.20	11.50	6.92	4.95	8.15	5.25
July	4.25	4.35	4.40	4.22½	3.77½	5.60	6.65	11.25	7.75	5.15	8.00	4.25
Aug.	4.25	4.45	4.57½	4.37½	3.72½	4.90	6.00	10.75	7.75	5.50	8.75	4.20
Sept.	4.30	4.42½	4.72½	4.67½	3.72½	4.75	6.60	10.125	7.75	5.75	8.75	....
Oct.	4.27½	4.32½	4.95	4.50	3.57½	4.42½	6.85	7.825	7.75	5.95	7.75	....
Nov.	4.27½	4.15	4.60	4.20	3.37½	4.80	6.90	5.625	7.75	6.50	6.65	....
Dec.	4.40	4.37½	4.20	3.95	3.67½	5.20	7.40	6.375	6.75	6.55	5.25	....

TABLE XXXII.—PRICES OF REINFORCING BARS FROM MILL—PITTSBURGH, PA.

Prices are in cents per pound in carload lots, and are taken from Engineering News and Engineering News-Record.

Note.—Prices of bars from Chicago warehouse, 1910 to 1916 inclusive, are from .45c to .70c higher than Pittsburgh mill prices. Prices of bars from Chicago warehouse, 1917 to 1920 inclusive, are from .70c to 1.27c higher than Pittsburgh mill prices.

	1910			1911			1912			1913		
	½″	⅝″	¾″ & larger	½″	⅝″	¾″ & larger	½″	⅝″	¾″ & larger	½″	⅝″	¾″ & larger
Jan.......	1.65	1.60	1 55	1.55	1.50	1.45	1.30	1.25	1.25	1.60	1.55	1.50
Feb.......	1.65	1.60	1 55	1.55	1.50	1.45	1.30	1.25	1.25	1.60	1.55	1.50
Mar.......	1.65	1.60	1.55	1.55	1.50	1.45	1.30	1.25	1.20	1.60	1.55	1.50
Apr.......	1.65	1.60	1.55	1.55	1.50	1.45	1.35	1.30	1.25	1.60	1.55	1.50
May.......	1.65	1.60	1.55	1.55	1.50	1.45	1.35	1.30	1.25	1.60	1.55	1.50
June.......	1.65	1.60	1.55	1.40	1.35	1.30	1.40	1.35	1.30	1.60	1.55	1.50
July.......	1.60	1.55	1.50	1.40	1.35	1.30	1.45	1.40	1.35	1.60	1.55	1.50
Aug.......	1.60	1.55	1.50	1.40	1.35	1.30	1.50	1.45	1.40	1.60	1.55	1.50
Sept.......	1.60	1.55	1.50	1.40	1.35	1.30	1.55	1.50	1.45	1.60	1.55	1.50
Oct.......	1.60	1.55	1.50	1.35	1.30	1.25	1.55	1.50	1.45	1.55	1.50	1.45
Nov.......	1.60	1.55	1.50	1.35	1.30	1.25	1.60	1.55	1.50	1.60	1.45	1.40
Dec.......	1.60	1.55	1.50	1.25	1.20	1.20	....	....	....	1.55	1.40	1.35
Average...	1.62	1.58	1.52	1.44	1.39	1.35	....	....	....	1.59	1.52	1.48

	1914			1915			1916			1917		
	½″	⅝″	¾″ & larger	½″	⅝″	¾″ & larger	½″	⅝″	¾″ & larger	½″	⅝″	¾″ & larger
Jan.......	1.55	1.40	1.35	1.30	1.15	1.10	....	....	....	3.10	3.05	3.00
Feb.......	1.55	1.40	1.35	1.30	1.15	1.10	2.05	1.90	1.80	3.10	3.05	3.00
Mar.......	1.45	1.30	1.25	1.35	1.20	1.15	2.50	2.35	2.25	3.10	3.05	3.00
Apr.......	1.40	1.25	1.20	1.35	1.20	1.15	2.70	2.55	2.45	3.45	3.40	3.35
May.......	1.35	1.20	1.15	1.40	1.25	1.20	2.75	2.60	2.50	3.60	3.55	3.50
June.......	1.35	1.20	1.15	1.40	1.25	1.20	2.75	2.60	2.50	....	....	....
July.......	1.35	1.20	1.15	1.45	1.30	1.25	2.75	2.60	2.50	....	....	....
Aug.......	....	....	....	1.45	1.30	1.25	2.60	2.55	2.50	....	....	....
Sept.......	1.40	1.25	1.20	1.40	1.35	1.30	2.70	2.65	2.60	....	....	....
Oct.......	1.40	1.25	1.20	1.50	1.45	1.40	2.70	2.65	2.60	....	....	....
Nov.......	1.40	1.25	1.20	....	....	....	2.70	2.65	2.60	....	....	....
Dec.......	1.35	1.20	1.15	....	....	....	3.00	2.95	2.90	3.00	2.95	2.90
Average...	....	....	....	....	....	....	....	....	....	....	....	....

	1918			1919			1920			1921		
	½″	⅝″	¾″ & larger	½″	⅝″	¾″ & larger	½″	⅝″	¾″ & larger	½″	⅝″	¾″ & larger
Jan.......	3.00	2.95	2.90	3.00	2.95	2.90	2.45	2.40	2.35	2.45	2.40	2.35
Feb.......	3.00	2.95	2.90	3.00	2.95	2.90	2.45	2.40	2.35	2.45	2.40	2.35
Mar.......	3.00	2.95	2.90	3.00	2.95	2.90	2.45	2.40	2.35	2.40	2.35	2.30
Apr.......	3.00	2.95	2.90	2.45	2.40	2.35	3.22	3.20	3.17	2.28	2.22	2.18
May.......	3.00	2.95	2.90	2.45	2.40	2.35	3.22	3.20	3.18	2.20	2.15	2.10
June.......	3.00	2.95	2.90	2.45	2.40	2.35	3.10	3.08	3.05	2.20	2.15	2.10
July.......	3.00	2.95	2.90	2.45	2.40	2.35	3.10	3.08	3.05	2.20	2.15	2.10
Aug.......	3.00	2.95	2.90	2.45	2.40	2.35	3.10	3.08	3.05	2.20	2.15	2.10
Sept.......	3.00	2.95	2.90	2.45	2.40	2.35	3.10	3.08	3.05	....	....	....
Oct.......	3.00	2.95	2.90	2.45	2.40	2.35	3.10	3.08	3.05	....	....	....
Nov.......	3.00	2.95	2.90	2.45	2.40	2.35	2.98	2.95	2.92	....	....	....
Dec.......	3.00	2.95	2.90	2.45	2.40	2.35	2.98	2.95	2.92	....	....	....
Average...	3.00	2.95	2.90	2.59	2.54	2.49	2.94	2.91	2.87	....	....	....

TABLE XXXIII.—PRICES OF STRUCTURAL SHAPES, FROM WAREHOUSE CHICAGO, ILL.

Prices are in cents per pound in carload lots and are taken from Engineering News, Iron Age and Engineering News Record.

	1910			1911			1912			1913		
	Beams 3 to 15"	Angles 3" to 6"	Plates ¼" & larger	Beams 3" to 15"	Angles 3" to 6"	Plates ¼" & larger	Beams 3" to 15"	Angles 3" to 6"	Plates ¼" & larger	Beams 3" to 15"	Angles 3" to 6"	Plates ¼" & larger
Jan.	2.00	2.05	2.00	1.85	1.85	1.88	1.60	1.60	1.60	2.05	2.05	2.10
Feb.	2.00	2.05	2.00	1.85	1.85	1.88	1.60	1.60	1.60	2.05	2.05	2.05
Mar.	2.00	2.05	2.00	1.85	1.85	1.88	1.60	1.60	1.60	2.05	2.05	2.05
Apr.	2.00	2.05	2.00	1.85	1.85	1.88	1.60	1.60	1.60	2.05	2.05	2.05
May	2.00	2.05	2.00	1.85	1.85	1.88	1.70	1.70	1.70	2.05	2.05	2.05
June	2.00	2.05	1.98	1.78	1.83	1.83	1.75	1.75	1.75	2.05	2.05	2.05
July	1.90	1.95	1.95	1.83	1.83	1.83	1.75	1.75	1.75	2.05	2.05	2.05
Aug.	1.85	1.85	1.88	1.83	1.83	1.83	1.90	1.90	1.90	2.05	2.05	2.05
Sept.	1.85	1.85	1.88	1.83	1.83	1.83	1.91	1.91	2.00	1.95	1.95	2.05
Oct.	1.85	1.85	1.88	1.75	1.75	1.83	2.08	2.08	2.05	1.95	1.95	2.05
Nov.	1.85	1.85	1.88	1.65	1.65	1.63	2.05	2.05	2.05	1.95	1.95	1.95
Dec.	1.85	1.85	1.88	1.60	1.60	1.60	2.05	2.05	2.05	1.51	1.51	1.85
Avg.	1.93	1.96	1.94	1.79	1.80	1.81	1.80	1.80	1.80	1.98	1.98	2.03

	1914			1915			1916			1917		
	Beams 3" to 15"	Angles 3" to 6"	Plates ¼" & larger	Beams 3" to 15"	Angles 3" to 6"	Plates ¼" & larger	Beams 3" to 15"	Angles 3" to 6"	Plates ¼" & larger	Beams 3" to 15"	Angles 3" to 6"	Plates ¼" & larger
Jan.	1.75	1.75	1.75	1.80	1.80	1.78	2.40	2.40	2.40	3.70	3.70	4.35
Feb.	1.75	1.75	1.75	1.75	1.75	1.75	2.50	2.50	2.70	3.85	3.85	4.50
Mar.	1.75	1.75	1.75	1.75	1.75	1.75	2.90	2.90	3.15	4.00	4.00	4.75
Apr.	1.75	1.75	1.65	1.75	1.75	1.75	3.10	3.10	3.50	4.50	4.50	5.50
May	1.75	1.75	1.65	1.75	1.75	1.75	3.10	3.10	3.50	4.75	4.75	6.00
June	1.75	1.75	1.70	1.75	1.75	1.75	3.10	3.10	3.50	5.00	5.00	7.00
July	1.75	1.75	1.75	1.75	1.75	1.75	3.10	3.10	3.50	5.00	5.00	7.00
Aug.	1.75	1.75	1.75	1.75	1.75	1.75	3.10	3.10	3.50	5.00	5.00	8.00
Sept.	1.75	1.75	1.75	1.85	1.85	1.85	3.10	3.10	3.50	5.00	5.00	10.00
Oct.	1.75	1.75	1.75	1.90	1.90	2.00	3.25	3.25	3.75	5.00	5.00	10.00
Nov.	1.75	1.75	1.75	2.00	2.00	2.20	3.25	3.25	3.75	5.00	5.00	7.00
Dec.	1.75	1.75	1.75	1.99	1.99	2.30	3.70	3.70	4.35	4.20	4.20	4.45
Avg.	1.75	1.75	1.73	1.82	1.82	1.86	3.05	3.05	3.42	4.58	4.58	6.54

	1918			1919			1920			1921		
	Beams 3" to 15"	Angles 3" to 6"	Plates ¼" & larger	Beams 3" to 15"	Angles 3" to 6"	Plates ¼" & larger	Beams 3" to 15"	Angles 3" to 6"	Plates ¼" & larger	Beams 3" to 15"	Angles 3" to 6"	Plates ¼" & larger
Jan.	4.20	4.20	4.45	4.27	4.27	4.52	3.47	3.47	3.67	3.58	3.58	3.78
Feb.	4.20	4.20	4.45	4.07	4.07	4.27	3.47	3.47	3.67	3.58	3.58	3.78
Mar.	4.20	4.20	4.45	4.07	4.07	4.27	3.97	3.97	4.17	3.58	3.58	3.78
Apr.	4.20	4.20	4.45	3.47	3.47	3.67	3.97	3.97	4.17	3.13	3.13	3.13
May	4.20	4.20	4.45	3.47	3.47	3.67	3.97	3.97	4.17	3.23	3.23	3.23
June	4.20	4.20	4.45	3.47	3.47	3.67	3.97	3.97	4.17	3.23	3.23	3.23
July	4.27	4.27	4.52	3.47	3.47	3.67	3.97	3.97	4.17	3.13	3.13	3.13
Aug.	4.27	4.27	4.52	3.47	3.47	3.67	3.97	3.97	4.17	2.88	2.88	2.88
Sept.	4.27	4.27	4.52	3.47	3.47	3.67	3.97	3.97	4.17	....	....	....
Oct.	4.27	4.27	4.52	3.47	3.47	3.67	3.97	3.97	4.17	....	....	....
Nov.	4.27	4.27	4.52	3.47	3.47	3.67	3.97	3.97	4.17	....	....	....
Dec.	4.27	4.27	4.52	3.47	3.47	3.67	3.58	3.58	3.78	....	....	....
Avg.	4.24	4.24	4.48	3.64	3.64	3.84	3.85	3.85	4.05	....	....	....

TABLE XXXIV.—COMMON BRICK PRICES AT CHICAGO, ILL.

Prices are in dollars per 1,000 in car load lots

Month	1916	1917	1918	1919	1920	1921
Jan	$6.00	$6.00	$ 8.00	$11.00	$12.00	$15.00
Feb	6.25	6.00	8.00	12.00	14.00	15.00
Mar	6.25	6.00	8.00	12.00	14.00	15.00
Apr	6.00	6.00	8.00	12.00	14.00	15.00
May	6.25	6.00	8.00	12.00	14.00	12.00
June	6.00	8.00	8.00	12.00	14.00	12.00
July	6.25	8.00	11.00	12.00	15.00	12.00
Aug	6.00	8.00	11.00	12.00	16.00	12.00
Sept	7.00	8.00	11.00	12.00	16.00	.....
Oct	6.00	8.00	11.00	12.00	15.00	.....
Nov	6.00	8.00	11.00	12.00	15.00	.....
Dec	6.00	8.00	11.00	12.00	15.00	.....
Avg	$6.17	$7.17	$9.50	$11.92	$14.50	......

TABLE XXXV.—PORTLAND CEMENT PRICES AT CHICAGO, ILL.

Prices to and including December, 1913, from Universal Portland Cement Co.; prices January, 1914, to and including March, 1917, from Engineering News; prices April, 1917, to date from Engineering News Record. Prices are, in dollars per barrel, for carload lots, f. o. b. Chicago, and do not include price of bags.

Average yearly price (1903 to 1909, inclusive):

1903	$1.65	1906	$1.55
1904	1.35	1907	1.55
1905	1.30	1908	1.15
		1909	$1.00

Month	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921
Jan	.90	1.05	.75	1.05	1.30	1.02	1.31	1.56	1.81	2.05	2.00	2.37
Feb	.92	1.05	.77	1.12	1.05	1.02	1.31	1.56	1.81	2.05	2.00	2.37
Mar	1.00	1.10	.78	1.22	1.05	1.11	1.36	1.66	1.81	2.05	2.00	2.17
Apr	1.08	1.12	.85	1.25	1.15	1.11	1.41	1.76	1.96	2.05	2.00	2.17
May	1.18	1.05	.88	1.25	1.15	1.11	1.46	1.76	1.96	2.00	2.00	2.17
June	1.28	.95	.88	1.25	1.15	1.11	1.41	1.91	1.96	2.00	2.15	2.17
July	1.30	.85	.96	1.25	1.15	1.11	1.41	1.91	2.05	2.00	2.15	2.17
Aug	1.28	.85	1.05	1.25	1.17	1.11	1.41	1.91	2.05	2.00	2.15	2.17
Sept	1.18	.83	1.20	1.22	1.17	1.16	1.46	1.81	2.05	2.00	2.15	....
Oct	1.15	.74	1.25	1.20	1.15	1.01	1.46	1.81	2.05	2.00	2.35	....
Nov	1.07	.70	1.18	1.12	1.10	1.26	1.46	1.81	2.05	2.00	2.35	....
Dec	1.05	.72	1.09	1.07	1.10	1.31	1.56	1.81	2.05	2.00	2.35	....
Avg	1.11	.91	.97	1.19	1.14	1.12	1.42	1.77	1.97	2.02	2.14	....

TABLE XXXVI.—VITRIFIED SEWER TILE PRICES, 1915–1917, INCLUSIVE

Prices are taken from Engineering News & Engineering News Record and are in dollars per ft. for carload lots, f.o.b. Chicago.

	1915												Avge. price
Size	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1915
3″	.055	.055	.055	.055	.05	.05	.05	.045	.045	.045	.045	.05	.05
4″	.055	.055	.055	.055	.05	.05	.05	.045	.045	.045	.045	.05	.05
5″	.088	.088	.088	.088	.08	.08	.08	.072	.072	.072	.072	.08	.08
6″	.088	.088	.088	.088	.08	.08	.08	.072	.072	.072	.072	.08	.08
8″	.126	.126	.126	.126	.11	.11	.11	.099	.099	.099	.099	.11	.112
10″	.184	.184	.184	.184	.16	.16	.16	.144	.144	.144	.144	.16	.163
12″	.22	.22	.22	.22	.20	.20	.20	.18	.18	.18	.18	.20	.20
15″	.297	.297	.297	.297	.27	.27	.27	.243	.243	.243	.243	.27	.270
18″	.418	.418	.418	.418	.38	.38	.38	.342	.342	.342	.342	.38	.380
20″	.495	.495	.495	.495	.45	.45	.45	.405	.405	.405	.405	.45	.450
22″	.66	.66	.66	.66	.60	.60	.60	.54	.54	.54	.54	.60	.60
24″	.715	.715	.715	.715	.65	.65	.65	.585	.585	.585	.585	.65	.65
27″	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.26	1.26	1.26	1.26	1.35	1.32
30″	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.54	1.54	1.54	1.54	1.65	1.61
33″	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.06	2.06	2.06	2.06	2.18	2.15
36″	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.31	2.31	2.31	2.31	2.45	2.40

	1916												Avge. price
Size	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1916
3″	.045	.045	....	.055	.055	.055	.055	.055	.062	.062	.062	.062	.056
4″	.045	.045	....	.055	.055	.055	.055	.055	.062	.062	.062	.062	.056
5″	.072	.072	....	.088	.088	.088	.088	.088	.10	.10	.10	.10	.089
6″	.072	.072	....	.088	.088	.088	.088	.088	.10	.10	.10	.10	.089
8″	.099	.099	....	.121	.121	.121	.121	.121	.138	.138	.138	.138	.123
10″	.144	.144	....	.173	.173	.173	.173	.173	.20	.20	.20	.20	.177
12″	.18	.18	....	.22	.22	.22	.22	.22	.25	.25	.25	.25	.22
15″	.243	.243	....	.297	.297	.297	.297	.297	.338	.338	.338	.338	.302
18″	.342	.342	....	.418	.418	.418	.418	.418	.438	.475	.475	.475	.422
20″	.405	.405	....	.495	.495	.495	.495	.495	.562	.562	.562	.562	.503
22″	.54	.54	....	.66	.66	.66	.66	.66	.75	.75	.75	.75	.67
24″	.585	.585	....	.715	.715	.715	.715	.715	.812	.812	.812	.812	.727
27″	1.50	1.50	....	1.44	1.44	1.44	1.44	1.44	1.35	1.35	....	....	1.43
30″	1.75	1.75	....	1.76	1.76	1.76	1.76	1.76	1.65	1.65	....	....	1.73
33″	2.15	2.15	....	2.31	2.31	2.31	2.31	2.31	2.19	2.19	....	....	2.25
36″	2.25	2.25	....	2.73	2.73	2.73	2.73	2.73	2.45	2.45	....	....	2.56

	1917												Avge. price
Size	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1917
3″	.075	.075	.075	.075	.075	.075	....	.09	.09	.09	.09	.09	.082
4″	....	....	....	.075	.075	.075	....	.10	.10	.10	.10	.10	.090
5″	.12	.12	.12	.12	.12	.12	....	.135	.135	.135	.135	.135	.127
6″	....	....	....	.12	.12	.12	....	.15	.15	.15	.15	.15	.14
8″	.175	.175	.175	.175	.175	.175	....	.21	.21	.21	.21	.21	.191
10″	....	....	....	.262	.262	.262	....	.315	.315	.315	.315	.315	.295
12″	.338	.338	.338	.338	.338	.338	....	.405	.405	.405	.405	.405	.368
15″	....	....	...	.45	.45	.45	....	.54	.54	.54	.54	.54	.50
18″	....	....	....	.625	.625	.625	....	.75	.75	.75	.75	.75	.703
20″	....	....	....	.75	.75	.75	....	.90	.90	.90	.90	.90	.84
22″	....	....	....	1.00	1.00	1.00	....	1.20	1.20	1.20	1.20	1.20	1.12
24″	1.35	1.35	1.35	1.12	1.12	1.12	....	1.35	1.35	1.35	1.35	1.35	1.29
27″	....	....	....	....	....	....	....	....	....	....	....	....	....
30″	....	....	....	....	....	....	....	....	....	....	....	....	....
33″	....	....	....	....	....	....	....	....	....	....	....	....	....
36″	3.50	3.50	3.50	....	....	....	....	....	....	....	....	....	3.50

TABLE XXXVI.—*Continued*

	1918												Avge. price
Size	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1918
3″	.09	.09	.09	.09	.09	.10	.10	.125	.125	.125	.125	.125	.106
4″	.10	.10	.10	.10	.10	.10	.10	.125	.125	.125	.125	.125	.11
5″	.135	.135	.135	.135	.135	.15	.15	.175	.175	.175	.175	.175	.154
6″	.15	.15	.15	.15	.15	.15	.15	.175	.175	.175	.175	.175	.160
8″	.21	.21	.21	.21	.21	.21	.21	.25	.25	.25	.25	.25	.23
10″	.315	.315	.315	.315	.315	.315	.315	.375	.375	.375	.375	.375	.34
12″	.405	.405	.405	.405	.405	.405	.405	.475	.475	.475	.475	.475	.43
15″	.54	.54	.54	.54	.54	.54	.54	.63	.63	.63	.63	.63	.57
18″	.75	.75	.75	.75	.75	.875	.875	1.00	1.00	1.00	1.00	1.00	.875
20″	.90	.90	.90	.90	.90	1.05	1.05	1.20	1.20	1.20	1.20	1.20	.105
22″	1.20	1.20	1.20	1.20	1.20	1.40	1.40	1.60	1.60	1.60	1.60	1.60	1.40
24″	1.35	1.35	1.35	1.35	1.35	1.58	1.58	1.80	1.80	1.80	1.80	1.80	1.58
27″	....	....	....	....	....	2.25	2.25	2.75	2.75	2.75	2.75	2.75	2.60
30″	....	....	....	....	....	2.75	2.75	3.45	3.45	3.45	3.45	3.45	3.25
33″	....	....	....	....	....	3.25	3.25	4.00	4.00	4.00	4.00	4.00	3.78
36″	....	....	....	....	....	3.75	3.75	4.35	4.35	4.35	4.35	4.35	4.18

	1919												Avge. price
Size	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1919
3″	.125	.125	.125	.125	.125	.09	.09	.09	.09	.105	.12	.12	.111
4″	.125	.125	.125	.125	.125	.09	.09	.09	.09	.105	.12	.12	.111
5″	.175	.175	.175	.175	.175	.135	.135	.135	.135	.158	.18	.18	.161
6″	.175	.175	.175	.175	.175	.135	.135	.135	.135	.158	.18	.18	.161
8″	.25	.25	.25	.25	.25	.21	.21	.21	.21	.245	.28	.28	.241
10″	.375	.375	.375	.375	.375	.315	.315	.315	.315	.368	.42	.42	.362
12″	.475	.475	.475	.475	.475	.405	.405	.405	.405	.472	.54	.54	.462
15″	.63	.63	.63	.63	.63	.54	.54	.54	.54	.63	.72	.72	.615
18″	1.00	1.00	1.00	1.00	1.00	.875	.875	.875	.875	1.00	.875	.875	.938
20″	1.20	1.20	1.20	1.20	1.20	1.05	1.05	1.05	1.05	1.20	1.05	1.05	1.12
22″	1.60	1.60	1.60	1.60	1.60	1.40	1.40	1.40	1.40	1.60	1.40	1.40	1.50
24″	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
27″	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75
30″	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45	3.45
33″	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
36″	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35

	1920												Avge. price
Size	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1920
3″	.12	.135	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.146
4″	.12	.135	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15	.146
5″	.18	.202	.225	.225	.225	.225	.225	.225	.225	.225	.225	.225	.219
6″	.18	.202	.225	.225	.225	.225	.225	.225	.225	.225	.225	.225	.219
8″	.28	.315	.35	.35	.35	.35	.35	.35	.35	.35	.35	.35	.341
10″	.42	.472	.525	.525	.525	.525	.525	.525	.525	.525	.525	.525	.512
12″	.54	.608	.625	.625	.625	.625	.625	.625	.625	.625	.625	.625	.617
15″	.72	.81	.90	.90	.90	.90	.90	.90	.90	.90	.90	.90	.89
18″	.875	1.22	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.21
20″	1.05	1.35	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.45
22″	1.40	1.80	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.27
24″	1.80	1.92	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.18
27″	2.75	3.25	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.42
30″	3.45	3.75	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.39
33″	4.00	4.50	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.67
36″	4.35	5.10	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.37

TABLE XXXVI.—*Continued*

Size	1921 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
3″	.15	.15	.15	.15	.15	.135	.135	.135
4″	.15	.15	.15	.15	.15	.135	.135	.135
5″	.225	.225	.225	.225	.25	.202	.202	.202
6″	.225	.225	.225	.225	.225	.202	.202	.202
8″	.35	.35	.35	.35	.35	.315	.315	.315
10″	.525	.525	.525	.525	.525	.472	.472	.472
12″	.625	.625	.625	.625	.625	.606	.606	.607
15″	.90	.90	.90	.90	.90	.81	.81	.81
18″	1.25	1.25	1.25	1.25	1.25	1.12	1.12	1.12
20″	1.50	1.50	1.50	1.50	1.50	1.35	1.35	1.35
22″	2.00	2.00	2.00	2.00	2.00	1.80	1.80	1.80
24″	2.25	2.25	2.25	2.25	2.25	2.02	2.02	2.02
27″	3.50	4.50	4.50	4.50	4.50	3.75	3.75	3.75
30″	4.00	5.50	5.50	5.50	5.50	4.75	4.75	4.75
33″	4.75	6.75	6.75	6.75	6.75	5.50	5.50	5.50
36″	5.50	7.00	7.00	7.00	7.00	6.00	6.00	6.00

Copper, Spelter, Lead, Tin and Sheet Steel Prices.—Tables XXXVII to XLIII, inc. are given in the Annual Review Section of The Iron Age, Jan. 6, 1921. The prices are the computed monthly averages of the prices of carloads, at New York, for metals and at Pittsburgh for tin plate and No. 28 galvanized and black sheets, given in the metal market reports of the Iron Age week by week.

TABLE XXXVII.—LAKE COPPER.

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.......	16.21	16.90	11.45	12.13	12.62	15.18	18.78	24.41	13.90	14.56
Feb.......	16.25	16.97	12.47	12.80	12.34	15.25	17.94	25.10	13.13	13.37
March....	16.41	17.00	12.12	14.31	12.60	15.25	18.50	23.38	12.85	12.90
April......	17.00	17.00	11.97	14.85	13.19	15.18	18.62	24.62	13.09	12.94
May......	16.80	17.00	12.10	14.75	13.28	15.00	18.70	24.10	12.88	13.21
June......	16.31	17.00	12.23	14.56	12.74	15.00	18.69	23.94	13.00	13.50
July......	16.31	16.97	11.94	13.73	12.62	15.03	18.47	21.95	13.00	13.34
Aug.......	16.55	16.50	11.59	13.35	12.50	16.07	18.65	18.94	13.71	13.56
Sept......	16.75	16.50	11.60	13.58	12.67	16.12	19.31	16.41	13.80	13.50
Oct.......	16.73	16.71	11.71	13.42	13.09	16.62	21.81	13.80	13.81	13.19
Nov......	16.75	16.82	11.44	13.25	14.22	16.90	22 50	13.94	14 44	13.44
Dec.......	16.87	14.71	11.61	12.30	14.87	18.75	23.06	13.48	14.53	13.80

TABLE XXXVIII.—SPELTER, AT

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.......	4.55	4.08	4.28	4.82	4.95	6.17	6.48	6.90	4.54	5.15
Feb.......	4.69	3.94	4.18	5.00	4.95	6.12	6.09	7.00	4.78	4.99
March....	4.60	3.89	4.29	5.36	5.05	6.06	5.96	6.92	4.76	4.81
April......	4.71	3.94	4.41	5.65	5.22	5.97	6.05	6.81	4.68	4.94
May......	4.52	3.97	4.50	5.75	5.14	5.55	5.95	6.51	4.60	5.12
June......	4.27	3.95	4.88	6.00	4.79	5.32	6.14	6.45	4.56	5 39
July......	4.24	3.90	5.23	5.95	4.85	5.38	5.98	6.15	4.46	5.35
Aug.......	4.17	3.92	5.46	5.94	4.85	5.66	6.06	5.71	4.71	5.74
Sept......	4.10	4.02	5.45	6.00	5.06	5.83	6.19	5.28	4.76	5.85
Oct.......	4.10	4.20	5.48	6.05	5.17	6.05	6.18	5.45	4.81	6.09
Nov......	4.20	4.32	5.29	5.68	5.49	6.17	6.36	5.10	5.03	6.32
Dec.......	4.19	4.35	4.91	5.15	5.80	6 50	6 62	4 39	5.17	6.35

TABLE XXXIX.—LEAD, AT

	1900	1901	1902	1903	1904	1905	1906	1907	1808	1909
Jan.......	4.70	4.37	4.02	4.10	4.39	4.56	5.86	6.30	3 73	4.19
Feb.......	4.70	4.37	4.10	4.10	4.40	4.50	5.56	6.31	3.75	4.07
March....	4.70	4.37	4.10	4.44	4.50	4.45	5.35	6.31	3.88	4.02
April......	4.70	4.37	4.10	4.59	4.50	4 50	5.39	6.16	4.02	4.19
May......	4.22	4.37	4.10	4.37	4.48	4.50	5.90	6.02	4.26	4.32
June......	3.90	4.37	4.10	4.25	4.22	4.51	5.94	5 75	4.45	4.36
July......	4.03	4.37	4.10	4.12	4.17	4.56	5 80	5.24	4 50	4.35
Aug.......	4.26	4.37	4.10	4.12	4.15	4.64	5.78	5.12	4.59	4.36
Sept......	4.36	4.37	4.10	4.26	4.20	4.85	5.92	4.84	4.54	4.39
Oct.......	4.37	4.37	4.10	4.40	4.20	5.07	5.94	4.64	4.34	4.39
Nov......	4.37	4.37	4.10	4.25	4.51	5.48	5.97	4.45	4.39	4.40
Dec.......	4.37	4.19	4.10	4.19	4.60	5.96	6.19	3.76	4.24	4.56

TABLE XL.—TIN, AT NEW

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.......	26.00	26.60	23.38	27.76	28.75	29.18	36.36	42.14	27.43	28.19
Feb.......	29.71	26.55	24.73	29.14	27.98	29.49	36.48	42.16	28.74	28.44
March....	32.42	25.95	26.16	30.06	26.19	29.21	36.62	41.29	30.46	28.75
April......	30.85	25.94	27.29	29.69	27.99	30.43	38.86	40.84	31.79	29.35
May......	29.25	26.82	29.26	39.26	27.76	30.04	43.08	43.01	29.84	29.07
June......	30.00	28.22	29.29	28.30	26.14	30.36	38.97	42.65	28.18	29.26
July......	32.76	27.41	28.28	27.60	26.28	31.71	37.18	41.15	28.92	29.05
Aug.......	31.13	26.90	28.14	28.00	26.74	32.85	39.90	37.35	29.99	29.96
Sept......	29.63	25.04	26.55	27.06	27.27	32.21	40.32	37.22	28.91	30.00
Oct.......	28.46	24.62	25.76	25.83	28.53	32.47	42.90	32.33	29.44	30.41
Nov......	28.10	27.47	25.43	25.35	29.00	33.46	42.70	30.81	30.43	30.74
Dec.......	26.84	24.39	25.33	27.53	29.27	35.84	42.62	27.92	29.13	32.91

AT NEW YORK, CENTS PER POUND

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
14.00	12.81	14.50	16.98	14.85	14.02	24.39	29.73	23.50	20.48	19.52
13.78	12.75	14.41	15.55	15.00	15.21	26.85	34.90	23.50	17.86	19.25½
13.75	12.58	14.88	15.05	14.79	15.75	27.10	35.85	23.50	15.46½	18.67
13.31	12.41	16.00	15.67	14.75	18.90	28.27	31.67	23.50	15.55	19.36
13.06	12.33	16.30	15.91	14.40	21.00	28.88	31.42	23.50	16.18	19.05
12.88	12.71	17.53	15.42	14.12	23.38	27.82	32.46	23.50	17.95	19.00
12.66	12.78	17.54	14.78	13.70	21.98	25.84	28.78	25.80	22.07	19.00
12.93	12.75	17.73	15.86	12.85	19.33	26.95	27.24	26.00	23.16	19.00
12.81	12.65	17.77	16.77	12.66	17.97	28.03	24.90	26.00	22.68	18.70
12.84	12.53	17.80	16.85	11.73	17.89	28.48	23.50	26.00	22.13	16.56
12.98	12.80	17.70	16.16	12.00	18.92	32.32	23.50	26.00	20.69	14.67
13.00	13.84	17.69	14.88	13.35	20.24	33.38	23.50	25.40	18.90	13.90

NEW YORK, CENTS PER POUND

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
6.26	5.55	6.52	7.15	5.29	6.59	18.19	9.94	7.88	7.38	9.62
5.89	5.56	6.71	6.45	5.40	8.84	20.13	10.48	7.99	6.70	9.14
5.72	5.65	6.98	6.26	5.28	9.29	18.40	10.77	7.64	6.52	8.92½
5.60	5.51	6.86	5.77	5.18	11.22	18.58	9.85	7.01	6.51	8.63
5.20	5.50	6.86	5.47	5.06	16.14	15.86	9.46	7.32	6.46	8.08
5.19	5.63	6.99	5.18	5.09	22.18	12.75	9.62	8.01	6.93	7.92
5.20	5.79	7.26	5.38	5.02	20.58	9.83	8.95	8.69	7.90	8.18
5.26	6.04	7.19	5.75	5.60	14.11	8.98	8.69	8.96	7.84	8.31
5.53	6.03	7.53	5.82	5.50	14.16	8.22	8.34	9.60	7.57	7.82
5.69	6.20	7.57	5.42	4.97	13.96	9.98	8.24	9.11	7.83	7.51
5.95	6.60	7.48	5.29	5.12	17.15	11.90	7.95	8.70	8.14	6.84
5.80	6.44	7.33	5.18	5.71	16.69	11.13	7.84	8.45	8.59	6.00

NEW YORK, CENTS PER POUND

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
4.70	4.50	4.41	4.35	4.11	3.74	5.93	7.69	6.87	5.56	8.67
4.63	4.46	4.00	4.35	4.06	3.82	6.23	9.13	7.04	5.05	8.88
4.51	4.41	4.08	4.35	3.97	4.04	7.43	9.47	7.24	5.23	9.20½
4.40	4.44	4.20	4.40	3.82	4.20	7.73	9.43	6.95	5.03	8.95
4.37	4.40	4.20	4.37	3.90	4.25	7.45	11.00	6.88	5.05	8.55
4.38	4.46	4.50	4.35	3.90	5.89	6.87	11.68	7.55	5.33½	8.47½
4.40	4.50	4.67	4.37	3.90	5.59	6.34	10.72	8.04	5.65	8.67
4.40	4.50	4.54	4.64	3.87	4.68	6.26	10.72	8.05	5.77	8.98
4.40	4.49	5.04	4.73	3.86	4.62	6.88	8.84	8.05	6.12	8.11
4.40	4.31	5.06	4.52	3.52	4.60	7.00	6.77	8.05	6.45	7.24
4.44	4.31	4.66	4.33	3.68	5.16	7.13	6.44	8.05	6.76	6.33
4.50	4.45	4.32	4.06	3.80	5.33	7.60	6.48	6.71	7.03	4.37

YORK, CENTS PER POUND

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
32.61	41.20	44.58	50.34	39.12	34.13	41.76	44.10	85.13	71.50	62.74
32.65	43.34	43.56	48.71	39.82	37.25	42.60	51.47	85.00	72.45	59.87
32.51	41.10	42.76	46.93	38.03	48.73	50.53	58.38	85.00	72.50	61.92½
32.83	42.05	43.64	49.04	36.10	47.64	51.51	55.82	88.53	72.50	62.12
33.05	43.32	45.98	49.06	33.21	38.79	49.14	63.21	100.00	72.50	54.99
32.79	46.25	47.44	45.01	30.60	40.26	42.07	61.93	91.00	71.83	48.33½
32.99	43.23	44.70	41.32	35.65	37.38	38.25	62.61	93.00	70.11	49.29
33.92	43.38	45.86	41.63	48.34	34.37	38.88	62.53	91.33	62.20	47.60
35.17	39.69	49.16	42.63	31.13	33.13	38.65	61.54	80.40	59.79	44.43
36.76	41.23	50.07	40.38	30.25	33.05	41.10	62.24	78.82	54.82	40.47
37.38	43.08	49.87	39.75	33.28	39.50	44.12	74.18	73.67	54.17	36.97
38.21	45.03	49.86	37.12	34.01	38.53	42.66	84.74	71.51	53.80	34.04

TABLE XLI.—TIN PLATE, AT

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan........	4.65	4.00	4.00	3.60	3.56	3.55	3.47	3.90	3.74	3.70
Feb.......	4.65	4.00	4.00	3.60	3.45	3.55	3.50	3.90	3.70	3.70
March....	4.65	4.00	4.00	3.80	3.45	3.55	3.50	3.90	3.70	3.53
April......	4.65	4.00	4.00	3.80	3.45	3.55	3.57	3.90	3.70	3.40
May......	4.65	4.00	4.00	3.80	3.45	3.55	3.66	3.90	3.70	3.40
June......	4.65	4.00	4.00	3.80	3.45	3.55	3.75	3.90	3.70	3.40
July......	4.65	4.00	4.00	3.80	3.41	3.55	3.75	3.90	3.70	3.40
Aug.......	4.65	4.00	4.00	3.80	3.30	3.55	3.75	3.90	3.70	3.40
Sept......	4.50	4.00	4.00	3.80	3.30	3.55	3.75	3.90	3.70	3.40
Oct.......	4.00	4.00	4.00	3.80	3.30	3.34	3.75	3.90	3.70	3.50
Nov......	4.00	4.00	3.65	3.50	3.39	3.34	3.90	3.90	3.70	3.56
Dec.......	4.00	4.00	3.60	3.60	3.47	3.40	3.90	3.90	3.70	3.60

TABLE XLII.—NO. 28 BLACK SHEETS,

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.......	2.97½	2.90	3.07½	2.75	2.29	2.30	2.40	2.60	2.52	2.50
Feb.......	3.03	2.93¾	3.10	2.75	2.27½	2.30	2.40	2.60	2.50	2.50
March....	3.10	3.22½	3.10	2.75	2.27	2.34	2.38	2.60	2.50	2.25
April......	3.20	3.35	3.12½	2.75	2.25	2.40	2.35	2.60	2.50	2.20
May......	3.20	3.30	3.10	2.75	2.20	2.40	2.35	2.60	2.50	2.20
June......	3.05	3.30	3.05	2.75	2.16	2.30	2.50	2.60	2.50	2.20
July......	3.14¾	3.10	3.00	2.73¾	2.10	2.26	2.50	2.60	2.50	2.20
Aug.......	2.98	3.41	3.05	2.70	2.10	2.26	2.50	2.60	2.50	2.20
Sept......	2.93¾	3.77½	2.97½	2.65	2.10	2.25	2.50	2.60	2.50	2.26
Oct.......	2.90	3.23	2.79	2.62	2.10	2.25	2.50	2.60	2.50	2.30
Nov.......	2.89	3.10	2.75	2.49	2.12½	2.27	2.60	2.60	2.50	2.30
Dec.......	2.96	3.10	2.75	2.32	2.22	2.30	2.60	2.60	2.50	2.40

TABLE XLIII.—AVERAGE PRICES OF NO. 28 GALVANIZED

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.......	3.83	4.36	4.64	3.70	3.36	3.35	3.45	3.67	3.59	3.55
Feb.......	4.09	4.36	4.36	3.70	3.25	3.40	3.45	3.75	3.55	3.51
March....	4.32	4.84	4.36	3.78	3.23	3.45	3.43	3.75	3.55	3.26
April......	4.78	4.84	4.36	3.89	3.23	3.45	3.40	3.75	3.55	3.25
May......	4.66	4.74	4.36	3.88	3.23	3.45	3.40	3.75	3.55	3.25
June......	4.59	4.59	4.23	3.81	3.18	3.35	3.55	3.75	3.55	3.25
July......	4.53	4.48	4.26	3.73	3.14	3.36	3.55	3.75	3.55	3.25
Aug.......	4.43	4.74	4.18	3.66	3.14	3.32	3.55	3.75	3.55	3.25
Sept......	4.33	4.73	3.99	3.66	3.14	3.30	3.55	3.75	3.55	3.28
Oct.......	4.25	4.55	3.87	3.73	3.14	3.30	3.58	3.75	3.55	3.35
Nov......	4.16	4.84	3.85	3.51	3.23	3.32	3.65	3.75	3.55	3.43
Dec.......	4.36	4.84	3.78	3.40	3.31	3.35	3.65	3.75	3.55	3.50

The highest prices realized for galvanized sheets, aside from the war peak in 1917, were obtained in April, 1916, following the spectacular performances of spelter, when prices of that metal soared to an unprecedented height. At that time, No. 28 galvanized sheets sold up to 5.30c. per lb., Pittsburgh, or higher, although the average for the month is placed, in the table, at 5c. It is interesting to know that in 1901, in a period of great activity in the steel trade, No. 28 galvanized sheets were regularly quoted at 5.10c., Pittsburgh, for two weeks, namely, the first half of September.

In making up the above table of prices the compiler has used for January,

PITTSBURGH, DOLLARS PER BOX

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
3.60	3.60	3.40	3.60	3.32	3.10	3.75	7.00	7.75	7.35	7.00
3.60	3.67	3.35	3.60	2.29	3.10	3.96	7.38	7.75	7.35	7.00
3.60	3.70	3.30	3.60	3.30	3.25	4.19	8.00	7.75	7.26	7.00
3.60	3.70	3.30	3.60	3.30	3.25	4.50	8.00	7.75	7.00	7.00
3.60	3.70	3.33	3.60	3.30	3.15	5.30	8.40	7.75	7.00	7.00
3.60	3.70	3.40	3.60	3.30	3.11	5.81	10.50	7.75	7.00	7.00
3.60	3.70	3.43	3.60	3.27	3.10	6.00	12.00	7.75	7.00	7.50
3.60	3.70	3.50	3.55	3.41	3.10	5.95	11.40	7.75	7.00	9.00
3.60	3.67	3.58	3.50	3.35	3.15	5.75	12.00	7.75	7.00	9.00
3.60	3.52	3.60	3.50	3.24	3.15	5.81	.....	7.75	7.00	8.33
3.60	3.40	3.60	3.40	3.15	3.28	5.97	7.75	7.75	7.00	7.50
3.60	3.40	3.60	3.40	3.13	3.52	6.63	7.75	7.55	7.00	7.00

AT PITTSBURGH, CENTS PER POUND

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
2.40	2.20	1.90	2.31	1.87	1.80	2.60	4.50	5.00	4.70	4.47½
2.40	2.20	1.87	2.35	1.95	1.80	2.60	4.69	5.00	4.70	5.00
2.40	2.20	1.80	2.35	1.95	1.80	2.71	4.94	5.00	4.61	5.50
2.40	2.20	1.86	2.35	1.91	1.80	2.85	5.75	5.00	4.35	5.50
2.40	2.20	1.90	2.30	1.85	1.79	2.89	7.00	5.00	4.35	5.50
2.40	2.00	1.90	2.27	1.81	1.75	2.90	7.88	5.00	4.35	5.50
2.23¾	2.00	1.95	2.25	1.80	1.75	2.90	8.50	5.00	4.35	6.75
2.21	1.99	2.02	2.21	1.86	1.85	2.90	8.50	5.00	4.35	7.50
2.15	1.91	2.07	2.14	1.95	1.90	2.93	8.50	5.00	4.35	7.37½
2.20	1.85	2.21	2.04	1.94	2.03	3.23	.....	5.05	4.35	6.69
2.20	1.85	2.25	1.97	1.87	2.25	3.65	5.00	5.00	4.35	5.77
2.19	1.83¾	2.25	1.89	1.82	2.50	4.31	5.00	4.85	4.35	4.35

SHEETS, AT PITTSBURGH IN CENTS PER POUND

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
3.50	3.20	2.90	3.46	2.87	2.79	4.75	6.25	6.25	6.05	5.32½
3.50	3.20	2.87	3.50	2.95	3.16	4.75	6.38	6.25	6.05	6.50
3.50	3.20	2.80	3.50	2.95	3.40	4.75	6.69	6.25	5.96	7.00
3.50	3.20	2.86	3.50	2.91	3.29	5.00	7.00	6.25	5.70	7.00
3.50	3.20	2.90	3.42	2.80	3.50	4.94	8.20	6.25	5.70	7.00
3.50	3.00	2.90	3.38	2.75	4.28	4.69	9.50	6.25	5.70	7.00
3.39	3.00	3.00	3.33	2.75	4.40	4.38	10.00	6.25	5.70	8.25
3.30	2.99	3.12	3.24	2.85	3.71	4.21	10.00	6.25	5.70	9.00
3.21	2.93	3.21	3.16	2.95	3.56	4.18	9.75	6.25	5.70	8.87½
3.20	2.85	3.36	3.08	2.95	3.50	4.41	....	6.25	5.70	8.81
3.20	2.85	3.40	2.98	2.88	3.89	5.18	6.25	6.25	5.70	7.04
3.19	2.89	3.40	2.90	2.78	4.75	6.00	6.25	6.15	5.70	5.70

February and March, 1919, up to March 21, the prices in effect to the latter date, and then used the 5.70c. price in effect all through the year from March 21. Premiums were paid during late November and all of December, but premiums have not been recorded above, as a large percentage of the sheets sold in 1919 were at the prices named in the table.

Pig Iron Steel, and Rail Prices for Twenty-one Years.—Tables XLIV to LV, inc., published in the Annual Review Section of the Iron Age, Jan. 6, 1921, give the monthly average prices computed from the weekly market quotations of the Iron Age.

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TABLE XLIV.—BESSEMER PIG IRON AT PITTS-

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.........	$24.99	$13.15	$16.70	$22.15	$13.91	$16.85	$18.35	$23.15	$19.00	$17.34
Feb.........	24.80	14.43	16.93	21.45	13.66	16.41	18.35	22.85	17.90	16.78
March.......	24.72	16.31	17.37	21.85	14.25	16.35	18.28	22.85	17.86	16.25
April........	24.70	16.75	18.75	21.28	14.18	16.35	18.19	23.35	17.49	15.78
May.........	21.00	16.30	20.75	20.01	13.60	16.16	18.10	24.01	16.93	15.84
June.........	19.72	16.00	21.56	19.72	12.81	16.65	18.23	24.27	16.90	16.05
July.........	16.75	16.00	21.60	18.89	12.40	14.85	18.41	23.55	16.83	16.46
Aug.........	15.60	15.75	21.62	18.35	12.81	15.20	19.00	22.90	16.23	17.03
Sept.........	13.87	15.75	21.75	17.22	12.63	15.91	19.54	22.90	15.90	18.05
Oct.........	13.06	15.89	21.75	16.05	13.10	16.54	20.35	22.00	15.71	19.53
Nov.........	13.48	16.00	21.68	15.18	14.85	17.85	22.85	20.65	16.59	19.90
Dec.........	13.43	16.31	21.75	14.40	16.65	18.35	23.75	19.34	17.40	19.90

TABLE XLV.—BESSEMER STEEL BILLETS AT

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.........	$34.50	$19.75	$27.50	$29.60	$23.00	$22.75	$26.25	$29.40	$28.00	$25.00
Feb.........	34.87	20.21	29.37	29.87	23.00	23.50	26.50	29.50	28.00	25.00
March.......	33.00	22.88	31.25	30.62	23.00	24.00	26.70	29.00	28.00	23.00
April........	32.00	24.00	31.50	30.25	23.00	24.00	27.00	30.12	28.00	23.00
May.........	28.90	24.00	32.20	30.37	23.00	23.50	26.40	30.30	28.00	23.00
June.........	27.25	24.38	32.37	28.87	23.00	22.00	26.63	29.62	25.75	23.00
July.........	21.00	24.00	31.75	27.60	23.00	22.00	27.25	30.00	25.00	23.50
Aug.........	18.20	24.20	31.06	27.00	23.00	24.00	27.80	29.25	25.00	24.13
Sept.........	16.93	24.88	29.50	27.00	20.00	25.00	28.00	29.37	25.00	25.00
Oct.........	16.50	26.70	29.70	27.00	19.50	25.62	28.00	28.20	25.00	26.25
Nov.........	18.95	27.00	28.50	24.00	20.25	26.00	28.88	28.00	25.00	27.13
Dec.........	19.75	27.50	29.12	23.00	21.20	26.00	29.50	28.00	25.00	27.50

TABLE XLVI.—SOUTHERN NO. 2 FOUNDRY PIG

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.........	$20.69	$13.45	$14.55	$21.65	$12.37	$16.25	$16.75	$26.00	$16.15	$16.25
Feb.........	20.50	13.12	14.75	21.50	12.12	16.25	16.75	26.00	15.75	16.13
March.......	20.30	14.00	14.75	21.37	12.10	16.25	16.65	26.00	15.50	15.05
April........	20.19	14.50	16.87	20.15	12.50	16.25	16.63	25.06	15.20	14.25
May.........	19.75	13.85	18.35	18.87	12.25	15.81	16.75	24.25	14.75	14.50
June.........	18.75	13.37	20.19	17.75	11.80	14.65	16.44	24.10	15.25	14.70
July.........	16.81	13.00	20.75	16.15	11.81	13.94	16.06	23.85	15.00	15.75
Aug.........	14.25	13.00	23.06	15.19	12.00	14.40	17.30	23.00	15.25	16.38
Sept.........	13.62	13.06	25.00	14.75	12.00	14.37	18.69	21.50	15.65	17.35
Oct.........	12.87	13.75	25.65	13.50	12.81	15.31	20.00	20.95	15.75	17.88
Nov.........	12.95	14.00	23.62	12.00	15.19	16.60	23.38	19.50	16.00	17.75
Dec.........	13.75	14.25	22.44	12.05	15.85	16.75	25.00	17.00	16.25	17.45

TABLE XLVII.—LOCAL NO. 2 FOUNDRY PIG IRON AT

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.........	$23.85	$15.10	$16.25	$23.45	$14.47	$17.85	$19.60	$25.85	$18.45	$17.35
Feb.........	23.85	14.60	16.85	23.35	13.91	17.85	19.41	25.85	18.16	16.75
March......	23.85	15.60	18.51	23.22	14.05	17.80	19.35	26.10	17.85	16.50
April........	23.72	15.85	18.97	22.87	14.35	17.60	19.10	26.35	17.73	16.50
May.........	22.65	15.85	20.85	20.72	13.85	17.60	18.90	26.85	17.63	16.50
June.........	20.72	15.35	21.85	19.85	13.70	17.00	18.54	26.60	17.73	16.50
July.........	18.60	15.35	21.60	18.25	13.60	16.47	18.60	25.55	17.55	17.00
Aug.........	16.25	15.35	22.10	17.22	13.60	16.60	19.45	24.85	17.35	17.13
Sept.........	15.35	15.35	23.35	16.41	13.85	16.60	20.16	24.10	17.05	18.70
Oct.........	14.85	15.10	23.35	15.70	14.10	17.66	21.48	22.45	16.85	19.00
Nov.........	14.85	15.23	23.35	15.10	15.98	19.15	24.70	20.66	17.10	19.00
Dec.........	15.10	15.85	23.35	14.81	16.95	19.60	25.85	18.80	17.35	19.00

BURGH, DOLLARS PER GROSS TON (2240 LB.)

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
$19.90	$15.90	$15.05	$18.15	$14.96	$14.59	$21.58	$35.95	$37.25	$33.60	$40.00
19.34	15.90	14.90	18.15	15.09	14.55	21.51	35.95	37.25	33.60	42.90
18.60	15.90	15.09	18.15	15.09	14.55	21.75	37.70	37.25	32.54	43.40
18.27	15.90	15.15	17.90	14.90	14.55	21.95	42.20	36.15	29.35	43.60
17.52	15.90	15.13	17.70	14.90	14.59	21.95	45.15	36.15	29.35	44.03
16.60	15.90	15.15	17.14	14.90	14.70	21.95	54.70	36.38	29.35	44.80
16.40	15.90	15.20	16.70	14.90	14.95	21.95	57.45	36.60	29.35	47.15
16.09	15.90	15.46	16.52	14.90	15.95	21.95	54.75	36.60	29.35	49.11
15.90	15.90	16.15	16.65	14.90	16.85	22.26	48.03	36.60	29.35	50.46
15.90	15.44	17.80	16.60	14.84	16.95	24.08	37.25	36.60	29.35	49.16
15.82	15.00	18.02	16.02	14.59	17.51	30.15	37.25	36.60	31.26	41.10
15.90	15.03	18.15	15.77	14.70	19.65	35.68	37.25	36.60	36.65	36.96

PITTSBURGH, DOLLARS PER GROSS TON

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
$27.50	$23.00	$20.00	$28.30	$20.13	$19.25	$32.00	$63.00	$47.50	$43.50	$48.00
27.50	23.00	20.00	28.50	21.00	19.50	33.50	65.00	47.50	43.50	55.25
27.50	23.00	19.75	28.50	21.00	19.70	42.40	66.25	47.50	42.25	60.00
26.75	23.00	20.00	28.50	20.80	20.00	45.00	73.75	47.50	38.50	60.00
26.12	22.60	20.80	27.37	20.00	20.00	45.00	86.00	47.50	38.50	60.00
25.30	21.00	20.87	26.50	19.50	20.50	43.50	98.75	47.50	38.50	61.00
25.00	21.00	21.50	26.60	19.00	21.38	41.00	100.00	47.50	38.50	62.50
24.62	21.00	22.12	26.00	20.25	23.13	44.20	86.00	47.50	38.50	61.00
24.40	20.75	23.62	24.87	21.00	24.10	45.00	66.25	47.50	38.50	58.74
23.75	20.00	26.00	23.30	20.00	24.63	46.25	49.38	47.50	38.50	55.00
23.30	19.50	27.00	21.00	19.25	26.50	52.00	47.50	47.50	41.38	49.70
23.00	19.25	27.00	20.00	19.00	30.60	57.50	47.50	45.50	46.00	43.50

IRON AT CINCINNATI, DOLLARS PER GROSS TON

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
$17.25	$14.25	$13.25	$16.95	$13.88	$12.40	$17.90	$26.10	$35.90	$34.60	$41.80
17.06	14.25	13.31	16.69	13.81	12.40	17.90	27.53	35.90	34.60	43.60
16.30	14.25	13.50	16.31	14.00	12.27	17.90	31.90	35.90	33.54	43.60
15.37	14.25	13.75	15.65	13.75	12.34	17.90	37.40	35.90	30.35	44.00
15.00	13.95	14.15	14.94	13.75	12.40	17.90	41.90	35.90	29.85	45.60
14.85	13.44	14.25	14.06	13.63	12.50	17.34	45.15	36.08	28.39	45.60
14.75	13.25	14.70	13.75	13.30	12.71	16.90	49.90	36.60	28.35	45.60
14.31	13.45	15.06	14.06	13.25	13.71	16.70	49.90	36.60	30.40	45.78
14.25	13.31	15.87	14.25	13.25	14.15	17.28	49.90	36.60	31.25	46.50
14.25	13.25	16.80	14.35	12.90	14.78	18.03	49.38	37.60	31.60	46.50
14.25	13.20	17.25	13.87	12.90	16.15	22.40	35.90	37.60	34.35	42.50
14.25	13.19	17.25	13.95	12.50	17.10	25.90	35.90	37.60	38.60	41.10

CHICAGO (AT FURNACE), DOLLARS PER GROSS TON

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
$19.00	$15.50	$14.00	$17.90	$13.75	$13.00	$18.50	$30.00	$33.00	$31.00	$40.00
19.00	15.50	14.00	17.31	14.00	13.00	18.50	32.00	33.00	31.00	42.25
18.30	15.50	14.00	17.25	14.25	12.95	18.70	36.00	33.00	29.94	43.00
17.50	15.00	14.00	17.00	14.25	13.00	19.00	39.25	33.00	26.75	43.00
17.06	15.00	14.50	16.00	14.06	13.00	19.00	43.80	33.00	26.75	43.00
16.75	15.00	14.50	15.62	13.69	13.00	19.00	51.00	33.00	26.75	43.40
16.56	14.87	14.70	14.70	13.75	13.00	19.00	55.00	33.00	26.75	45.25
16.50	14.50	15.37	15.00	13.69	13.44	18.40	55.00	33.00	26.75	46.00
16.40	14.50	16.00	15.00	13.25	13.90	18.13	54.67	33.00	26.75	46.00
16.00	14.46	17.00	15.00	12.94	14.63	19.63	33.00	34.00	27.75	44.50
16.00	14.09	17.75	14.87	12.56	17.13	25.80	33.00	34.00	31.00	39.40
16.00	14.00	18.00	14.30	13.00	18.10	29.50	33.00	34.00	38.75	34.50

TABLE XLVIII.—STANDARD BRANDS EASTERN PENNSYLVANIA NO. 2 X

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan........	$22.70	$15.50	$16.75	$22.45	$14.69	$17.50	$18.50	$24.80	$18.25	$17.25
Feb........	22.56	15.31	17.19	22.25	14.50	17.50	18.50	25.87	18.25	17.00
March......	22.31	15.12	18.81	22.25	14.80	17.56	18.35	25.00	18.12	16.37
April........	21.75	15.46	19.62	21.87	15.00	17.75	18.44	24.81	17.65	16.20
May........	20.60	15.19	19.75	20.06	14.75	17.81	18.50	25.55	16.94	16.06
June........	18.75	15.06	20.94	19.19	14.50	16.75	18.44	24.62	16.62	16.42
July........	16.37	15.00	22.30	18.10	14.31	16.12	18.25	23.06	16.50	16.50
Aug........	16.15	14.97	22.00	16.87	14.25	16.25	19.00	21.90	16.50	17.00
Sept........	15.56	14.80	22.00	16.12	14.25	16.43	20.44	20.50	16.62	18.05
Oct........	15.00	15.25	22.12	15.20	14.43	17.25	21.12	19.85	16.75	18.69
Nov........	15.35	15.37	23.37	15.00	15.75	18.05	23.30	18.94	17.00	19.00
Dec........	15.62	15.75	23.00	15.00	16.90	18.25	24.00	18.84	17.25	19.00

TABLE XLIX.—SOFT STEEL BARS AT

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.......	2.22	1.25	1.50	1.60	1.30	1.40	1.50	1.60	1.60	1.40
Feb.......	2.21	1.30	1.51	1.60	1.30	1.40	1.50	1.60	1.60	1.35
March....	2.25	1.40	1.60	1.60	1.33	1.50	1.50	1.60	1.60	1.20
April......	2.10	1.47	1.60	1.60	1.35	1.50	1.50	1.60	1.60	1.15
May......	1.91	1.41	1.60	1.60	1.35	1.50	1.50	1.60	1.60	1.19
June......	1.52	1.40	1.60	1.60	1.35	1.46	1.50	1.60	1.45	1.20
July......	1.19	1.40	1.60	1.60	1.35	1.50	1.50	1.60	1.40	1.27
Aug.......	1.05	1.44	1.60	1.60	1.35	1.50	1.50	1.60	1.40	1.32
Sept......	1.12	1.50	1.60	1.60	1.31	1.50	1.50	1.60	1.40	1.39
Oct.......	1.09	1.53	1.60	1.60	1.30	1.50	1.50	1.60	1.40	1.51
Nov......	1.18	1.50	1.60	1.37	1.31	1.50	1.54	1.60	1.40	1.50
Dec.......	1.25	1.50	1.60	1.30	1.34	1.50	1.60	1.60	1.40	1.50

TABLE L.—WIRE ROD PRICES AT

	1903	1904	1905	1906	1907	1908	1909	1910
Jan...........	$34.70	$30.00	$31.00	$33.75	$37.00	$34.30	$33.00	$33.00
Feb...........	35.75	30.00	31.00	34.00	37.00	35.00	33.00	33.00
March........	36.62	30.80	31.70	34.00	37.00	35.00	33.00	33.00
April..........	37.00	31.00	34.00	34.12	37.00	35.00	29.00	32.50
May...........	37.00	30.50	34.00	34.40	37.00	35.00	27.50	32.00
June..........	36.62	29.20	33.30	34.00	37.12	33.50	27.50	30.80
July..........	35.80	28.00	31.87	34.00	36.50	33.00	29.40	29.25
Aug...........	35.00	28.00	32.10	34.00	36.10	33.25	31.00	28.25
Sept..........	34.75	27.00	31.12	34.00	36.00	33.00	31.50	28.00
Oct...........	34.00	26.00	31.75	34.50	35.40	33.00	31.87	28.50
Nov..........	31.62	26.75	32.10	35.50	34.00	33.00	32.50	28.12
Dec...........	30.50	29.80	32.50	37.00	34.00	33.00	33.00	28.00

TABLE LI.—BILLET PRICES AT PITTS-

	1889	1890	1891	1892	1893	1894	1895
Jan...............	$28.15	$36.65	$25.60	$25.00	$21.56	$16.12	$14.90
Feb...............	27.81	35.25	26.00	24.36	21.62	15.75	14.95
March.............	27.25	31.88	26.25	23.00	22.60	15.55	14.84
April..............	27.00	28.38	25.35	22.81	22.44	15.69	15.44
May...............	26.90	27.55	25.50	22.41	21.69	18.00	16.30
June..............	26.75	30.25	25.25	22.97	21.70	18.12	18.63
July..............	27.13	30.70	25.50	23.50	21.06	18.00	20.75
Aug...............	28.20	30.38	25.31	23.81	20.45	17.15	21.75
Sept..............	29.50	30.13	25.00	23.65	19.31	17.19	24.00
Oct...............	33.70	28.70	24.90	23.53	18.06	16.00	21.90
Nov..............	34.00	27.39	24.16	24.94	17.37	15.57	19.13
Dec...............	35.60	26.25	24.20	22.40	16.69	15.12	16.97

* Quotations on wire rods did not regularly appear in market reports until burgh. The quotations for November and December, 1917, and all of 1918,

† The table below gives the average monthly prices of 4 x 4 in. Bessemer steel and are averaged from weekly quotations in *Iron Age*. Prior to 1886 steel

FOUNDRY PIG IRON AT PHILADELPHIA, DOLLARS PER GROSS TON

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
$19.00	$15.50	$14.85	$18.25	$14.65	$14.25	$19.94	$30.10	$34.25	$36.15	$44.10
18.69	15.50	14.85	18.25	14.94	14.25	20.00	31.88	34.25	36.15	45.10
18.00	15.50	14.92	17.77	15.00	14.25	20.05	37.31	34.25	34.39	45.53
17.75	15.50	15.00	17.40	15.00	14.25	20.50	41.38	34.25	31.90	46.85
17.00	15.50	15.18	16.75	14.81	14.25	20.50	43.60	34.25	30.70	47.10
16.55	15.25	15.31	16.19	14.75	14.25	19.94	48.19	34.29	29.50	47.15
16.25	15.00	15.70	15.60	14.75	14.31	19.75	53.13	34.40	29.08	48.15
16.00	15.00	15.87	15.60	14.75	14.94	19.55	53.00	34.40	29.60	51.96
16.00	15.00	16.59	15.83	14.75	16.00	19.50	51.67	34.40	30.70	53.51
15.81	15.00	17.60	15.95	14.63	16.25	20.31	34.25	38.85	32.10	52.53
15.68	14.95	18.25	15.56	14.50	17.12	24.90	34.25	39.15	35.35	44.99
15.50	14.85	18.25	15.20	14.25	19.05	29.25	34.25	39.15	40.10	34.79

PITTSBURGH, CENTS PER POUND

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
1.50	1.40	1.15	1.70	1.20	1.10	2.03	3.15	2.90	2.70	2.75
1.50	1.40	1.12	1.70	1.20	1.10	2.31	3.25	2.90	2.70	3.00
1.45	1.40	1.10	1.85	1.20	1.15	2.65	3.63	2.90	2.61	3.63
1.45	1.40	1.16	1.84	1.15	1.20	2.88	3.75	2.90	2.35	3.75
1.45	1.37	1.20	1.70	1.14	1.20	3.00	4.00	2.90	2.35	3.63
1.45	1.25	1.20	1.60	1.11	1.21	2.75	4.25	2.90	2.35	3.50
1.45	1.23	1.25	1.50	1.12	1.25	2.63	4.50	2 90	2.35	3.50
1.40	1.20	1.30	1.40	1.19	1.30	2.56	4.30	2.90	2.35	3.25
1.40	1.19	1.37	1.40	1.20	1.34	2.60	4.00	2.90	2.35	3.25
1.40	1.12	1.45	1.39	1.15	1.44	2.75	2.90	2.90	2.39	3.13
1.40	1.08	1.55	1.29	1.10	1.62	2.83	2.90	2.90	2.69	2.87
1.40	1.12	1.66	1.21	1.07	1.84	3.00	2.90	2.80	2.75	2.35

PITTSBURGH FOR EIGHTEEN YEARS*

1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
$28.00	$24.37	$30.00	$25.50	$25.00	$43.00	$75.00	$57.00	$57.00	$60.00
28.75	25.00	30.00	26.38	25.00	48.00	77.50	57.00	57.00	63.75
29.00	25.00	30.00	26.50	25.00	54.80	81.00	57.00	55.75	70.00
29.00	25.00	30.00	26.00	25.00	60.00	85.00	57.00	52.00	70.00
29.00	25.00	30.00	25.50	25.00	60.00	86.00	57.00	52.00	72.50
28.25	25.00	29.50	24.50	25.00	53.75	92.50	57.00	52.00	75.00
27.00	25.00	28.30	24.50	25.63	53.75	96.25	57.00	52.00	75.00
27.00	25.80	28.00	25.00	27.00	55.00	94.00	57.00	52.00	75.00
27.00	27.00	27.37	26.20	29.40	55.00	88.75	57.00	52.00	75.00
26.00	28.50	26.60	25.88	31.75	55.00	77.25	57.00	52.00	75.00
25.30	29.75	25.87	25.25	36.25	63.00	57.00	57.00	54.50	66.40
24.50	30.00	25.17	25.00	39.50	68.75	57.00	57.00	59.50	57.00

BURGH FOR THIRTY-TWO YEARS†

1896	1897	1898	1899	1900	1901	1902	1903	1904
$16.80	$15.42	$14.93	$16.62	$34.50	$19.75	$27.50	$29.60	$23.00
17.38	15.25	15.06	18.00	34.87	20.31	29.37	29.87	23.00
17.09	15.44	15.25	24.30	33.00	22.88	31.25	30.62	23.00
19.53	14.60	15.06	25.37	32.00	24.00	31.50	30.25	23.00
19.50	13.82	14.85	26.75	28.90	24.00	32.27	30.37	23.00
19.12	14.06	14.65	30.10	27.25	24.38	32.35	28.87	23.00
18.85	14.00	14 50	33.12	21.00	24.00	31.76	27.60	23.00
18.75	14.00	15.85	35.40	18.20	24.20	31.02	27.00	23.00
19.75	15.60	16.00	38.37	16.93	24.88	29.50	27 00	20.00
19.75	16.44	15.56	38.75	16.50	26.70	29.70	27.00	19.50
20.00	15.57	15.06	36.50	18.95	27.00	28.50	24 00	20.25
17.50	15.00	15.80	33.75	19.75	27.50	29.10	23.00	21.20

late in 1901. Prices above are for Bessemer wire rods, per gross ton, at Pitts-
are Government prices and apply also to open-hearth rods.
billets at Pittsburgh from 1889 to 1920, inclusive. The prices are per gross ton
billets were not a regular merchant commodity.

TABLE LI—

	1905	1906	1907	1908	1909	1910	1911
Jan.	$22.75	$26.25	$29.40	$28.00	$25.00	$27.50	$23.00
Feb.	23.50	26.50	29.50	28.00	25.00	27.50	23.00
March	24.00	26.70	29.00	28.00	23.00	27.50	23.00
April	24.00	27.00	30.12	28.00	23.00	26.75	23.00
May	23.50	26.40	30.30	28.00	23.00	26.12	22.60
June	22.00	26.63	29.62	25.75	23.00	25.30	21.00
July	22.00	27.25	30.00	25.00	23.50	25.00	21.00
Aug.	24.00	27.80	29.25	25.00	24.13	24.62	21.00
Sept.	25.00	28.00	29.37	25.00	25.00	24.40	20.75
Oct.	25.62	28.00	28.20	25.00	26.25	23.75	20.00
Nov.	26.00	28.88	28.00	25.00	27.13	23.30	19.50
Dec.	26.00	29.50	28.00	25.00	27.50	23.00	19.25

TABLE LII.—TANK PLATES AT

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.	2.22	1.40	1.60	1.75	1.60	1.50	1.60	1.70	1.70	1.60
Feb.	2.17	1.40	1.60	1.60	1.60	1.50	1.60	1.70	1.70	1.52
March	2.03	1.47	1.60	1.60	1.60	1.60	1.60	1.70	1.70	1.30
April	1.87	1.57	1.60	1.60	1.60	1.60	1.60	1.70	1.70	1.27
May	1.69	1.60	1.60	1.60	1.60	1.60	1.60	1.70	1.70	1.29
June	1.39	1.60	1.69	1.60	1.60	1.60	1.60	1.70	1.62	1.25
July	1.16	1.60	1.75	1.60	1.60	1.60	1.60	1.70	1.60	1.33
Aug.	1.09	1.60	1.75	1.60	1.60	1.60	1.60	1.70	1.60	1.40
Sept.	1.11	1.60	1.75	1.60	1.44	1.60	1.60	1.70	1.60	1.46
Oct.	1.07	1.60	1.84	1.60	1.40	1.60	1.60	1.70	1.60	1.50
Nov.	1.31	1.60	1.82	1.60	1.40	1.60	1.62	1.70	1.60	1.54
Dec.	1.39	1.60	1.82	1.60	1.45	1.60	1.70	1.70	1.60	1.55

TABLE LIII.—BEAMS AT PITTS-

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.	2.25	1.50	1.60	1.80	1.60	1.50	1.70	1.70	1.70	1.60
Feb.	2.25	1.50	1.60	1.60	1.60	1.50	1.70	1.70	1.70	1.52
March	2.25	1.52	1.70	1.60	1.60	1.60	1.70	1.70	1.70	1.30
April	2.25	1.60	1.70	1.60	1.60	1.60	1.70	1.70	1.70	1.27
May	2.25	1.60	1.60	1.60	1.60	1.60	1.70	1.70	1.70	1.27
June	2.07	1.60	1.60	1.60	1.60	1.60	1.70	1.70	1.62	1.25
July	1.90	1.60	1.84	1.60	1.60	1.60	1.70	1.70	1.60	1.33
Aug.	1.74	1.60	2.00	1.60	1.60	1.63	1.70	1.70	1.60	1.40
Sept.	1.50	1.60	2.00	1.60	1.44	1.70	1.70	1.70	1.60	1.46
Oct.	1.50	1.60	2.07	1.60	1.40	1.70	1.70	1.70	1.60	1.50
Nov.	1.50	1.60	2.05	1.60	1.40	1.70	1.70	1.70	1.60	1.54
Dec.	1.50	1.60	2.00	1.60	1.44	1.70	1.70	1.70	1.60	1.55

TABLE LIV.—WIRE NAILS AT PITTS-

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.	$3.20	$2.22	$1.99	$1.89	$1.89	$1.75	$1.85	$2.00	$2.05	$1.95
Feb.	3.20	2.30	2.05	1.92	1.90	1.80	1.85	2.00	2.05	1.95
March	3.20	2.30	2.05	2.00	1.91	1.80	1.85	2.00	2.05	1.95
April	2.95	2.30	2.05	2.00	1.90	1.80	1.85	2.00	2.05	1.87
May	2.20	2.30	2.05	2.00	1.90	1.80	1.85	2.00	2.05	1.65
June	2.20	2.30	2.05	2.00	1.90	1.74	1.85	2.00	1.97	1.70
July	2.20	2.30	2.05	2.00	1.89	1.70	1.84	2.00	1.95	1.72
Aug.	2.20	2.30	2.05	2.00	1.71	1.70	1.82	2.00	1.95	1.80
Sept.	2.20	2.30	2.03	2.00	1.60	1.74	1.86	2.05	1.95	1.80
Oct.	2.20	2.28	1.89	2.00	1.60	1.80	1.85	2.05	1.95	1.80
Nov.	2.20	2.17	1.85	1.97	1.62	1.80	1.88	2.05	1.95	1.80
Dec.	2.20	1.99	1.85	1.87	1.73	1.80	2.00	2.05	1.95	1.85

Continued

1912	1913	1914	1915	1916	1917	1918	1919	1920
$20.00	$28.30	$20.13	$19.25	$32.00	$63.00	$47.50	$43.50	$48.00
20.00	28.50	21.00	19.50	33.50	65.00	47.50	43.50	55.25
19.75	28.50	21.00	19.70	42.40	66.25	47.50	42.25	60.00
20.00	28.50	20.80	20.00	45.00	73.75	47.50	38.50	60.00
20.80	27.60	20.00	20.00	45.00	86.00	47.50	38.50	60.00
20.87	26.50	19.50	20.50	43.50	68.75	47.50	38.50	61.00
21.50	26.60	19.00	21.38	41.00	100.00	47.50	38.50	62.50
22.12	26.00	20.25	23.13	44.20	86.00	47.50	38.50	61.00
23.62	24.87	21.00	24.10	45.00	66.25	47.50	38.50	58.74
26.00	23.30	20.00	24.63	46.25	49.38	47.50	38.50	55.00
27.00	21.00	19.25	26.50	52.00	47.50	47.50	38.87	49.70
27.00	20.00	19.00	30.25	57.50	47.50	45.50	46.00	43.50

PITTSBURGH, CENTS PER POUND

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
1.55	1.40	1.15	1.75	1.20	1.10	2.25	4.45	3.25	3.00	2.72
1.55	1.40	1.11	1.71	1.20	1.10	2.56	4.88	3.25	3.00	3.50
1.55	1.40	1.12	1.70	1.18	1.10	3.10	5.25	3.25	2.91	3.63
1.55	1.40	1.21	1.68	1.15	1.15	3.56	5.88	3.25	2.65	3.75
1.51	1.39	1.25	1.60	1.12	1.15	3.75	6.60	2.25	2.65	3.75
1.48	1.35	1.25	1.45	1.10	1.16	3.63	8.00	3.25	2.65	3.55
1.41	1.35	1.30	1.45	1.10	1.22	3.44	9.00	3.25	2.65	3.38
1.40	1.34	1.35	1.44	1.18	1.26	3.70	8.80	3.25	2.65	3.25
1.40	1.29	1.47	1.40	1.20	1.34	4.00	8.00	3.25	2.53	3.25
1.40	1.17	1.53	1.36	1.14	1.44	4.00	3.25	3.25	2.61	3.09
1.40	1.13	1.59	1.26	1.08	1.65	4.15	3.25	3.25	2.65	2.81
1.40	1.15	1.60	1.20	1.05	2.04	4.25	3.25	3.13	2.65	2.65

BURGH, CENTS PER POUND

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
1.55	1.40	1.15	1.75	1.20	1.10	1.90	3.25	3.00	2.80	2.47
1.51	1.40	1.11	1.71	1.20	1.10	2.06	3.25	3.00	2.80	2.70
1.50	1.40	1.15	1.70	1.19	1.10	2.40	3.54	3.00	2.71	3.13
1.50	1.40	1.21	1.68	1.15	1.20	2.55	3.88	3.00	2.45	3.25
1.50	1.39	1.25	1.50	1.14	1.20	2.60	4.00	3.00	2.45	3.10
1.48	1.35	1.25	1.45	1.11	1.20	2.53	4.31	3.00	2.45	3.10
1.41	1.35	1.30	1.45	1.12	1.25	2.50	4.50	3.00	2.45	3.10
1.40	1.35	1.35	1.45	1.19	1.30	2.52	4.30	3.00	2.45	3.10
1.40	1.34	1.42	1.41	1.20	1.35	2.64	4.00	3.00	2.45	3.10
1.40	1.21	1.48	1.37	1.15	1.44	2.75	3.00	3.00	2.45	3.05
1.40	1.13	1.57	1.29	1.10	1.60	2.86	3.00	3.00	2.45	2.89
1.40	1.15	1.60	1.25	1.07	1.78	3.25	3.00	2.90	2.45	2.45

BURGH, DOLLARS PER KEG OF 100 LB.

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
1.85	$1.71	$1.57	$1.75	$1.54	$1.54	$2.13	$3.00	$3.50	$3.50	$4.50
1.85	1.75	1.60	1.75	1.60	1.57	2.25	3.00	3.50	3.50	4.50
1.85	1.79	1.60	1.76	1.60	1.60	2.40	3.20	3.50	3.44	4.00
1.85	1.80	1.60	1.80	1.60	1.56	2.40	3.28	3.50	3.25	4.00
1.82	1.80	1.60	1.80	1.56	1.55	2.50	3.50	3.50	3.25	4.00
1.80	1.75	1.60	1.80	1.50	1.55	2.50	3.75	3.50	3.25	4.00
1.75	1.70	1.62	1.70	1.52	1.60	2.50	4.00	3.50	3.25	4.00
1.70	1.69	1.66	1.65	1.56	1.61	2.58	4.00	3.50	3.25	4.25
1.70	1.65	1.70	1.65	1.60	1.69	2.60	4.00	3.50	3.25	4.25
1.70	1.64	1.70	1.63	1.60	1.80	2.63	....	3.50	3.31	4.25
1.70	1.55	1.70	1.59	1.50	1.87	2.85	3.50	3.50	3.50	4.05
1.70	1.53	1.72	1.55	1.51	2.04	3.00	3.50	8.50	4.12	3.25

Table LV.—Bessemer Steel Rails

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Jan.........	$35.00	$26.00	$28.00	$28.00	$28.00	$28.00	$28.00	$28.00	$28.00	$28.00
Feb.........	34.00	26.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
March......	35.00	26.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
April........	35.00	27.30	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
May........	35.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
June........	35.00	28.00	28.00	28.00	28.00	28.00	23.00	28.00	28.00	28.00
July.........	35.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
Aug.........	35.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
Sept........	32.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
Oct.........	26.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
Nov.........	26.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
Dec.........	26.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00

Structural Steel Prices for 15 Years.—Fig. 7, given in Engineering and Contracting, Oct. 31, 1917, shows the average prices of structural steel at

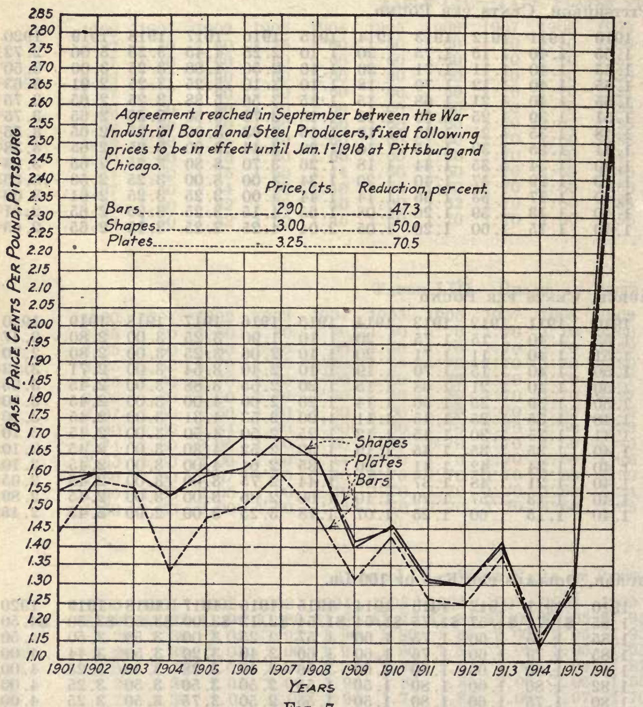


Fig. 7.

Pittsburgh for the years 1901 to 1916. The figures for structural shapes are base for beams and channels 3 in., to 15 in., and ångles 3 in. to 6 in. Prices for plates are f. o. b. Pittsburgh, and are for tank quality. Prices for bars are also Pittsburgh base and are for rounds and squares ¾ in. to $^3/_{16}$ in.

AT MILL, DOLLARS PER GROSS TON

1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
$28.00	$28.00	$28.00	$28.00	$28.00	$28.00	$28.00	$38.00	$55.00	$55.00	$45.00
28.00	28.00	28.00	28.00	28.00	28.00	28.00	38.00	55.00	55.00	45.00
28.00	28.00	28.00	28.00	28.00	28.00	28.00	38.00	55.00	52.50	47.50
28.00	28.00	28.00	28.00	28.00	28.00	28.00	38.00	55.00	45.00	55.00
28.00	28.00	28.00	28.00	28.00	28.00	33.00	38.00	55.00	45.00	55.00
28.00	28.00	28.00	28.00	28.00	28.00	33.00	38.00	55.00	45.00	55.00
28.00	28.00	28.00	28.00	28.00	28.00	33.00	38.00	55.00	45.00	55.00
28.00	28.00	28.00	28.00	28.00	28.00	33.00	38.00	55.00	45.00	55.00
28.00	28.00	28.00	28.00	28.00	28.00	33.00	38.00	55.00	45.00	55.00
28.00	28.00	28.00	28.00	28.00	28.00	33.00	.....	55.00	45.00	55.00
28.00	28.00	28.00	28.00	28.00	28.00	36.00	.....	55.00	45.00	55.00
28.00	28.00	28.00	28.00	28.00	28.00	38.00	.....	55.00	45.00	51.00

Structural Steel Prices, 1898 to 1917.—Fig. 8, reproduced in Engineering and Contracting, April 25, 1917, from the Dec., 1916, Bridge Manual of the Oregon State Highway Commission, shows price fluctuations in steel from year to year at various stages in its progress from furnace to the erected bridge. The lowest line in the diagram represents pig iron (Pittsburgh District), the next two lines steel bars and structural steel in the Pittsburgh District, the second line from the top fabricated steel at site (average for Oregon), and the top line steel in bridge erected in Oregon.

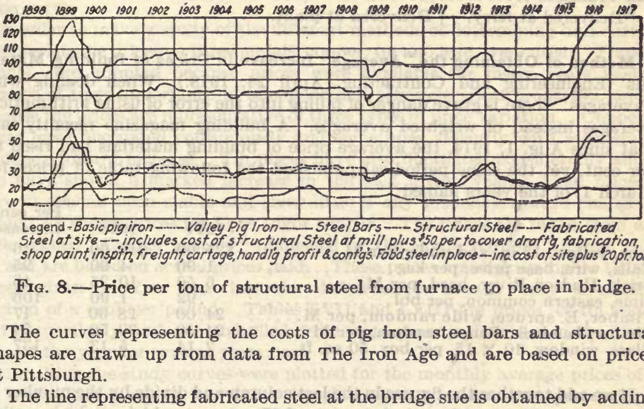


FIG. 8.—Price per ton of structural steel from furnace to place in bridge.

The curves representing the costs of pig iron, steel bars and structural shapes are drawn up from data from The Iron Age and are based on prices at Pittsburgh.

The line representing fabricated steel at the bridge site is obtained by adding $50 to these Eastern prices on structural shapes to provide for: Steel inspection, fabrication, shop inspection, waste in fabrication, draughting, shop painting, freight to Portland district, road haul and handling.

While this assumed figure of $50 is not a maximum, it is stated to be considerably higher than the mean or average cost of the sum of the items it is intended to cover, within the present zone of steel bridge construction in Oregon.

The line representing steel erected in place is obtained by adding $20 to the cost of the fabricated material at the site, to cover all costs of falsework, handling, erection and painting, and is a little better than a fair average price for steel bridge erection in Oregon. This line suggests in a graphical way, for the term of years which it covers, a base line about which, in comparative proximity to it, the prices paid for this work should have ranged themselves.

The costs from mill to site and for erection and painting are based on the cost of a large number of structures built in Oregon. The Manual states that actual costs should run under, rather than over, the figures given.

Teaming rates vary considerably according to the topography of the country and condition of the roads. They also are subject to conditions of supply and demand, but, according to the Manual, a fair average price for teaming throughout the state is 30 ct. per ton mile.

Price of Common Brick.—At the first annual convention of the Common Brick Manufacturers of America at Chicago, information was collected from the delegates regarding the prices of common brick in various cities. The following table shows the trend of prices for the years 1916–1919 in 9 large cities:

	1916	1917	1918	1919
Boston	$12.00	$14.00	$17.00	$18.00
Chicago	7.00	9.00	12.00	12.00
Cincinnati	10.00	13.00	15.00	16.75
Detroit	9.00	11.00	12.00	13.00
Los Angeles	6.00	8.00	14.00	12.50
Louisville	8.50	12.50	20.00	17.50
New York *	7.35	8.15	10.85	14.00
Philadelphia	8.50	12.50	14.00	19.00
San Francisco †	7.50	10.00	11.00	12.50

* Delivered at ferry. † Delivered at plant.

Method of Obtaining the "Average" Increase in Prices of Building Materials (Engineering and Contracting, April 24, 1918.) When dealing with "averages" there is grave danger of falling into the error of using arithmetical averages instead of weighted averages. A building magazine recently said that since Aug. 1, 1914, the average price of building materials had risen 84 per cent, yet the same periodical published the following table of prices for March 1, of the years named:

	1914	1918	Per cent increase
Pine, yellow, 12-in. and under per M	$25.00	$42.00	46
Nails, wire, base price, per keg	1.90	4.00	95
Brick, Hudson River, hard, per M	6.50	10.25	46
Lime, eastern common, per bbl	.92	1.90	106
Timber, E. spruce, wide random, per M	24.00	28.00	17
Timber, hemlock, Penn., random, per M	24.50	30.50	24
Glass, window, 10 × 15, per box, 50 sq. ft	2.14	5.13	137

If we add together the figures in the last column and divide by the number of items, 7, we get an arithmetical average of 67 per cent, which might be called an average increase in the prices of these building materials; but it should be apparent that such an average is really meaningless. Note that the quantities of each of these seven different materials that would be required in most buildings are such that brick and pine would greatly predominate; yet brick and pine have each risen only 46 per cent in price. On the other hand, nails, lime and glass are used in relatively small quantities, and they have risen 95, 106 and 137 per cent in price.

To ascertain the weighted average change in price of building materials in a building of a given class, multiply the quantities of each kind of material by the prices at the two different periods and ascertain the ratio of the two resulting totals. A rough application of this rule leads us to conclude that the average building cost has risen about 50 per cent since the war began.

Determination of Unit Prices of Material for Purposes of Valuation of Plant.—Engineering and Contracting, May 13, 1914, publishes the following article by R. V. Achatz.

One of the first questions which must be decided in making a valuation of a physical plant is what unit costs of material and labor are to be used. In making a valuation on the cost of reproduction basis, it is agreed that these costs should be present costs but there is a question of just what is present cost. In the case of labor present cost is a cost based on the current wage scale, but in the case of material it is quite generally agreed that the market price on a given date, particularly for those materials which are subject to constant fluctuations in price, cannot always be used with justice. Many writers in discussing this question have said that, in case of materials subject to price fluctuations, the market price on a given date should not be used but an average price over a number of years past, usually five or ten, should be adopted. There immediately arises a question as to the propriety of using an average of past prices in a valuation on the cost of reproduction basis, and there is also a large question as to whether such an average actually represents a fair present price. It has been proposed that the present normal price can be determined by plotting the prices for a number of years past and drawing a smooth curve representing an average of the prices as shown by the yearly price curve.

In order to make a study of the different methods of determining unit costs of materials the prices on three metals, copper, tin and lead, were used. These metals were adopted because prices were available for many years past, because of their importance in telephone and other electrical properties, and because the prices are representative of three types of price variation. Copper prices have fluctuated continuously and sometimes violently with a general tendency toward increase. Tin prices have also fluctuated considerably and also have shown a marked increase in the past fifteen years. Lead prices have in general been stable and show little if any tendency toward change. Table LVI shows prices for Lake Ingot copper. The prices are taken from a leaflet called "Copper History" published by the Rome Wire Co., Rome, N. Y., and are based on actual prices paid. These prices are slightly higher than prices given in *Iron Age* but the difference is usually only a small fraction of a cent per pound. Tables LVII and LVIII are prices of tin and lead respectively and are compiled from data given in *Iron Age* in the first issue of the year for several years past.

In making the study curves were plotted for the monthly average prices of the metal (not given in the tables) by plotting at the abscissa representing each month, the average price for that month and connecting the points by straight lines. In a similar way curves were plotted for the average prices for 5, 10 and 15 year periods by plotting at the close of each year the average of the prices for the period preceding and, as before, connecting the points by straight lines. A smooth curve was also drawn representing a mean between the higher and lower changes in the monthly average prices. Theoretically there should be equal areas, above and below, between this curve and the monthly average curve but in practice it can be drawn by eye with sufficient accuracy. This curve has been designated a "normal trend price" curve.

In Fig. 9 are shown the curves of copper prices. These prices extend from 1884, the earliest period that prices were available, to the present. It will be noted that the prices have had peaks at periods of from seven to ten years apart, the highest peaks occurring in 1889, 1899, and 1907, followed by periods of comparatively low prices. The dotted curve represents successive five years averages and was plotted as described in the preceding paragraph. This curve also has peaks coming at the frequency of the peaks in the monthly

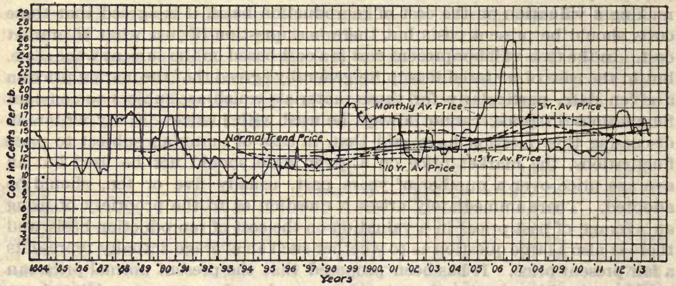


FIG. 9.—Variation and trend of prices for copper for period 1884 to 1913. inclusive.

average curve but displaced so that the maximum points in the five year average curve come later than those of the monthly average and occur during times of low market prices. For example, at the close of 1909 the market price of copper was 13.75 cts. per pound, while the five years average was

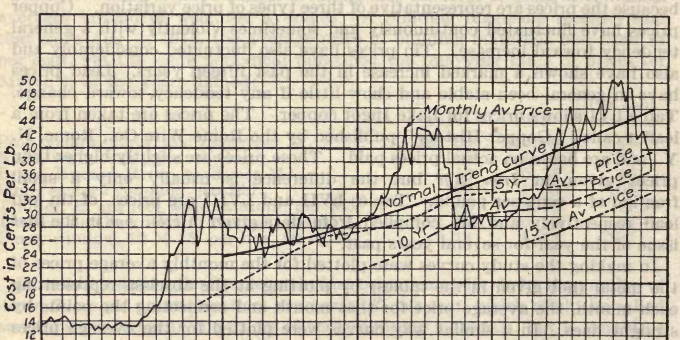


FIG. 10.—Variation and trend of prices for tin for period 1895 to 1913, inclusive.

16.808 cts. per pound. At the close of 1912 the market price was 17.75 cts. per pound, while the five year average was 13.91 cts. The high average for the five years ending with 1909 was due to the influence of the very high peak in the market in 1906–7 and the low average for the five years ending in 1912 was due to the abnormally low prices following the 1907 peak, the influence of that peak on the five year average having passed. It is at once seen that a five year average price at either of these times would be unjust, the price in 1909 being too high to be just to the public and the price in 1912 too low to be just to the utility.

The 10 year average prices of copper are shown in Fig. 9 by the broken line. This curve has peaks in much the same way as the 5 year average curve but the differences from time to time are not so great. The 10 year average at the close of 1911 is 1.1 cts. less than at the close of 1908. The use of this average would be less open to objection than the 5 year average on account of smaller variation from time to time.

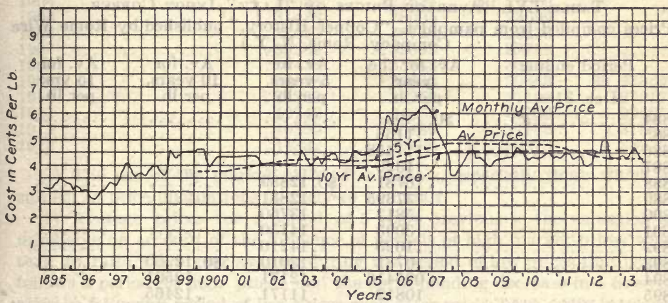


FIG. 11.—Variation and trend of prices for lead for period 1895 to 1913, inclusive.

The 15 year average is shown on Fig. 9 by the dot and dash line. It is entirely free from variation due to the influence of peaks in the market price and shows a general tendency upward. Its use might be objectionable on account of the influence of a period of low prices a long time ago.

The smooth curve which has been called the normal trend price has been drawn to represent an average of the market prices. At any given time the price read from this curve may be considered to be the price of copper under normal conditions. A buyer of copper in the future would expect to find prices following this curve more or less closely. The price as indicated by this curve was 15.2 cts. at the close of 1909, 15.8 cts. at close of 1911 and 16.3 cts. at close of 1913.

Fig. 10 shows the variation in prices of tin. This metal like copper has been subject to considerable fluctuation in price and has also more than doubled in price in the past fifteen years. The curves representing the 5, 10 and 15 year averages and the trend curve have been drawn in the same manner as in case of copper. The average curves are free from the variation from time to time noted in the average curves for copper but it will be noted that, with the exception of a few months in 1904 and the years 1908, 1909 and part of 1910 for the 5 year curve and a few months in 1908 and 1909 for the 10 year curve, the average curves are consistently lower than even the lowest points in the market prices. This brings out more clearly the objection mentioned above in the discussion of the prices of copper that average prices might be too greatly influenced by previous low prices to be used if the basis of the valuation is the cost of reproduction. If the basis is original cost of course this objection disappears. This discussion, however, has been predicated on the use of cost of reproduction. In the case of tin the normal trend curve at the close of 1913 shows a price of 45.9 cts. per pound while the 5 year average, the highest of the average curves, shows 39.468 cts. per pound. It is evident in this case that the use of any average price is unfair.

The variation in lead prices is shown in Fig. 11. The monthly average price curve shows that lead prices have been practically constant since 1899 with the exception of the abnormally high prices in 1906–7. This peak was caused by no particular condition of the lead market at that time but by the general inflation of commercial affairs during those years. The average price curves have been drawn as before. It will be noted that the 10 or 15 year curves

TABLE LVI.—AVERAGE PRICES OF "LAKE" INGOT COPPER
(Prices compiled from pamphlet, "Copper History," published by Rome Wire Company, Rome, N. Y.)

Period ending Dec. 31—	Av. for the year per lb.	Av. for 5 years, per lb.	Av. for 10 years, per lb.	Av. for 15 yrs. per lb.
1884	$0.14031	....	....	....
1885	.11166	....	....	....
1886	.111458	....	....	....
1887	.11323	....	....	....
1888	.16781	$0.12889	....	....
1889	.137395	.12831	....	....
1890	.15812	.13760	....	....
1891	.13093	.14150	....	....
1892	.11625	.14210	....	....
1893	.10781	.13010	$0.12950	....
1894	.095416	.12171	.12501	....
1895	.10812	.11171	.12465	....
1896	.10979	.10748	.12449	....
1897	.11333	.10691	.12450	....
1898	.12062	.10945	.11978	$0.12664
1899	.17802	.12598	.12384	.12533
1900	.16656	.13766	.12468	.12899
1901	.16729	.15116	.12832	.13271
1902	.12135	.15117	.12883	.13325
1903	.13791	.15423	.13184	.13126
1904	.13250	.14512	.13555	.13093
1905	.16093	.14399	.14083	.13122
1906	.19812	.15014	.14966	.13560
1907	.21177	.16825	.15951	.14197
1908	.13540	.16776	.16099	.14381
1909	.13420	.16808	.15660	.14640
1910	.13135	.16217	.15308	.14794
1911	.12750	.14802	.14910	.14912
1912	.16708	.13910	.15368	.15271
1913	.15833	.14369	.15572	.15522

still show that influence of the 1907 high prices while the five year average has passed beyond this influence and has come very near to the normal price. The normal trend curve has not been drawn to avoid confusion in the figure but if it were drawn it would be a straight line parallel to the X-axis at 4.4 cts. This is exactly the same as the 5 year average at the close of 1913. There have been periods in the past, however, when the use of the five year average would have been incorrect. For instance, at the close of 1909 this average was 4.926 cts. per pound while at the close of 1912 it was 4.379 cts., a decrease of about 11 per cent.

From the study of the curves and the above discussion the following conclusions are drawn regarding the use of the different methods of determining unit costs of material for valuation purposes:

TABLE LVII.—AVERAGE PRICES OF TIN

(Prices compiled from *Iron Age* first issue of each year. Prices are on carload lots, New York market.)

Period ending Dec. 31—	Av. for the year, per lb.	Av. for 5 years, per lb.	Av. for 10 years, per lb.	Av. for 15 yrs., per lb.
1895	$0.14033	....	....	....
1896	.13325	....	....	....
1897	.13592	....	....	....
1898	.15613	....	....	....
1899	.24853	$0.16283	....	....
1900	.29579	.19392	....	....
1901	.26326	.21993	....	....
1902	.26633	.24600	....	....
1903	.27973	.27073	....	....
1904	.27658	.27634	$0.21959	....
1905	.31438	.28005	.23699	....
1906	.39666	.30764	.26333	....
1907	.38239	.32995	.28798	....
1908	.29438	.33288	.30180	....
1909	.29678	.33692	.30663	$0.25869
1910	.34239	.34252	.31129	.27217
1911	.42742	.34867	.32780	.29185
1912	.46350	.36489	.34742	.31362
1913	.44332	.39468	.36378	.33276

(1) The use of the market price of materials, especially those which are subject to price fluctuations is likely to be unfair.

(2) Average prices for a period of 5 years previous to the valuation are unreliable on account of the influence of periods of high market prices which tend to raise the 5 year average during the period of low prices that usually follows a period of high prices and the corresponding decrease in 5 five year average following period of low prices even after prices have again increased.

(3) An average of the prices for a period of 10 years previous to the valuation fluctuates in a less degree than the average for 5 years, but may be lower than a fair price or higher than a fair price due to the influence of a period of low or high prices many years before.

(4) An average of the prices for 15 years may be unfair for the same reason as the second given under the ten year average, viz.: the effect of prices of many years previous.

(5) An average smooth curve can be drawn, taking into consideration market prices for a number of years past and also successive average prices for periods of 5, 10 and 15 years, which will represent the normal present price of the material. In general the use of this curve as a basis of unit price of material will be more fair and less open to objection than any average price.

(6) Before unit prices are adopted it is necessary to make a study of the past and present prices of materials, particularly the more important ones which may represent a large portion of the total cost of material in the plant. Such materials would be poles, copper wire, lead covered cable, duct materials and Portland cement in the case of telephone, street railway and other electrical properties, and cast iron pipe in case of gas and water plants.

There may be some objection to a price based on the trend curve on account of the fact that the judgment of the appraiser is brought into its determination, but it must be remembered that a valuation is an estimate of cost to reproduce a given plant and the entire result is based on engineering judgment. Furthermore a result arrived at by the use of well trained judgment after considering all the facts is more likely to be fair than an average over an arbitrary period without further consideration.

The use of such a trend curve as a basis for the unit price of a material is not new although little has been written concerning it. As far as the writer's knowledge goes the most important appraisal that has been made public in which this method was used is the appraisal of the property of the Chicago Telephone Co. made by H. M. Byllseby and Co. and the Arnold Co. in 1911. It is true that Prof. Edward W. Bemis, who was conducting the investigation of rates for the Chicago City Council in this case mentions the price of 16 cts. used in the appraisal as a doubtful point but he accepted the valuation based on this price. Prof. Bemis' comment is as follows:

Among the doubtful points in the appraisal may be mentioned the price of copper used by the appraisers. Copper was taken at 16 cts. a pound, as of Aug. 1, 1911. The following table gives the average price for each of the 19 years, 1893–1911, inclusive, as taken from the Iron Age by the Chicago Telephone Company. These prices are a little lower than those given in the Telephone Directory of the telephone industry, 1912 edition (page 333):

(Table of copper prices omitted.)

The above table would indicate that 16 cts. was high. The company has, however, established an elaborate trend curve of prices of copper to show that

TABLE LVIII.—AVERAGE PRICES OF LEAD

(Prices compiled from Iron Age, first issue of each year. Prices are on carload lots, New York market.)

Period ending Dec. 31—	Av. for the year, per lb.	Av. for 5 years, per lb.	Av. for 10 years, per lb.	Av. for 15 yrs., per lb.
1895	$0.03235	....	....	....
1896	.02971	....	....	....
1897	.03566	....	....	....
1898	.03769	....	....	....
1899	.04469	$0.03802	....	....
1900	.04390	.03833	....	....
1901	.04355	.04110	....	....
1902	.04093	.04215	....	....
1903	.04266	.04315	....	....
1904	.04360	.04293	$0.03947	....
1905	.04898	.04394	.04114	....
1906	.05800	.04683	.04397	....
1907	.05408	.04946	.04581	....
1908	.04224	.04938	.04626	....
1909	.04300	.04926	.04609	$0.04274
1910	.04461	.04839	.04617	.04349
1911	.04436	.04566	.04625	.04453
1912	.04476	.04379	.04663	.04512
1913	.04401	.04415	.04676	.04556

16 cts. a pound is in line with the trend or tendency of prices, at the time of the appraisal. Since the earliest quotations on hand, beginning in 1883, copper has averaged less than 16 cents every year save in 1888, 1899–1901, inclusive, and 1905–1907, inclusive. During those years only 309,433 miles of wire out of 807,571 in use at the close of 1911, or 38 per cent, were laid. It would be easy to show that copper had not from the beginning averaged over 15 cts. per pound, and had not even averaged that for any period of 5 or more years before the appraisal. At the same time, if the test of value is not to be the actual cost or recent costs, but probable costs of material and labor during the next five years, then 16 cts, may be accepted as a probable price.

In advocating the use of the trend curve as a basis for determining the unit prices of material for purposes of valuation, it can not be said that this method will give, in every case, results which are absolutely fair and uniform. Judgment is required in its use and unforseen developments may change the trend of the price of any material but it is believed that the use of this method will give unit costs that are more fair to all parties concerned than any other method that has been used.

Past and Future Wage Levels.—The following is from an article of mine in Engineering and Contracting, Aug. 31, 1921.

In an article at the beginning of this Chapter I showed that average wholesale commodity prices, or price levels, are proportional to the money per capita; and to its velocity of circulation, and inversely to the productive efficiency per capita. In the present article it will be shown that the average wage, or wage level, is proportional to the money per capita and to its velocity of circulation, but that the productive efficiency has no effect upon the average wage except in so far as it may lead to an increase in the per capita money.

It will be shown that the buying power of the average wage (often called the "real" wage) was stationary in England for five centuries, but that beginning about the year 1800 it began to increase rapidly, until in 1914 it was nearly five times what it was in 1800. It will be shown that almost the same percentage of increase in buying power occurred in America during the same period.

It will be shown that the buying power of the average wage varies directly with the per capita efficiency of production, and that no other factor is involved.

It will be shown that in the building trades the average wage of common laborers has risen at the same rate as that of skilled workers and that for six centuries in England the average of common laborers has been almost exactly 60 per cent of the average wage of skilled workers.

It will be shown that per capita money has shown a rapid upward trend for more than a century, and that following a short halt in this tendency after each great war, the upward trend is resumed. Hence it is to be inferred that average wages in America will resume their upward trend, after the present wage readjustment is ended. Since per capita money in America is now 60 per cent above the prewar level of the year 1913, average wages will decline until they reach the new per capita money level. In other words, the average wage will be about 60 per cent above the average wage of 1913, after the present readjustments are completed.

The proof of the truth of the wage formula above mentioned is overwhelming, and the establishment of its truth necessarily demolishes the prevalent theory that inflation of bank deposits has the same effect upon wage levels as inflation of currency. The practical importance of overthrowing such a false theory can hardly be over-estimated, for every modern nation has hitherto acted upon the assumption that inflation of currency is not a serious evil compared with inflation of bank credits, whereas the contrary is true.

Money Wages and "Real" Wages.—Wherever the term wage is used in this article, the daily or weekly wage in currency is meant. The average yearly wage is given in Table LXVII for manufacturing employes, and it will be seen that it has usually varied almost exactly as the daily wage level (Table LIX) has varied.

The wage level (or wage index) is calculated by averaging the wages in different trades, and then taking the average wage during a selected year as a standard for comparison. The year 1913 is here taken as 100 per cent. The Aldrich Senate Report (No. 1394) is my authority for wage and price levels between the years 1840 and 1890. Prior to 1840 there was no published wage level, but from data given in the Annual Report of the Mass. Bureau of Statistics of Labor for 1885, I was able to deduce the wage levels back to 1790.

Fig. 12 and Table LIX give the daily wage level for almost every year for the last 130 years. Table LIX also gives the wage level at five year intervals prior to 1790.

The buying power of the average wage is ascertainable by dividing the average wage by the average commodity price, or, what amounts to the same thing, by dividing the wage level by the commodity price level. For this

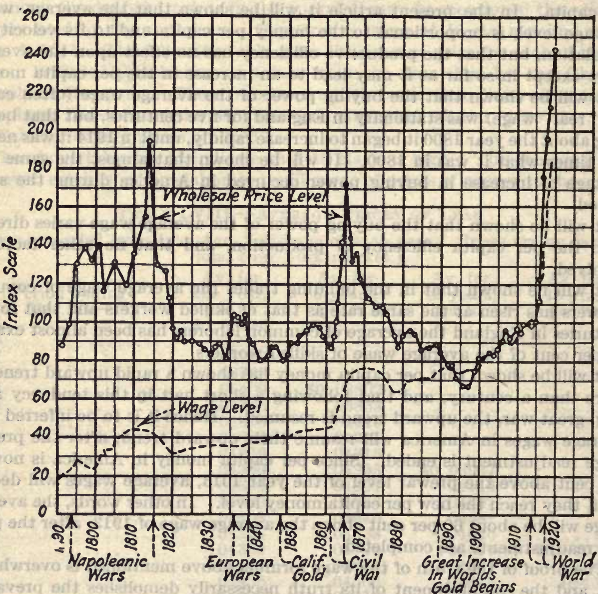


FIG. 12.—Wage and price levels.

(The Wage Levels are from Table LIX the footnote of which gives their source. The unweighted Price Levels from 1791 to 1840 are from an article by H. V. Roelse in the American Statistical Assoc. Quarterly, December, 1917; the weighted Price Levels from 1840 to 1890 are from the Aldrich Senate Report (No. 1394); the weighted Price Levels from 1890 to 1920 are from the U. S. Bureau of Labor).

purpose it would be desirable to use a retail price level, but since none is available, the wholesale price level must be used. Except during periods of very rapid changes in price levels, retail prices change in almost the same proportion as wholesale prices change. Hence, for the purpose of this article, no error occurs from using the wholesale price level.

The last column of Table LX gives the relative "real" wage, or the buying power of the average wage in America for the last 130 years. It is deduced by dividing the numbers in the second column by the corresponding numbers in the third column. The buying power of the average wage being 100 for

TABLE LIX.—WAGE LEVEL OR "INDEX" FOR AVERAGE DAY'S WAGE, THE AVERAGE WAGE IN 1913 BEING 100%

Year	Wage level	Year	Wage level	Year	Wage level	Year	Wage level
1752	15	1846	40	1873	75	1900	76
1755	15	1847	41	1874	74	1901	80
1760	11	1848	42	1875	72	1902	82
1765	16	1849	41	1876	69	1903	85
1770	15	1850	41	1877	66	1904	85
1775	16	1851	41	1878	64	1905	86
1780	19	1852	42	1879	64	1906	91
1785	22	1853	42	1880	65	1907	92
1790	18	1854	43	1881	69	1908	89
1794	25	1855	44	1882	70	1909	90
1795	28	1856	44	1883	72	1910	93
1797	25	1857	45	1884	71	1911	95
1800	25	1858	44	1885	71	1912	97
1802	33	1859	45	1886	71	1913	100
1804	35	1860	45	1887	71	1914	102
1805	40	1861	46	1888	72	1915	103
1810	45	1862	47	1889	74	1916	111
1815	42	1863	54	1890	76	1917	128
1820	52	1864	61	1891	77	1918	162
1830	36	1865	68	1892	77	1919	184
1835	36	1866	71	1893	76	1920	220
1840	37	1867	75	1894	74		
1841	36	1868	75	1895	74		
1842	38	1869	76	1896	75		
1843	38	1870	76	1897	75		
1844	38	1871	76	1898	76		
1845	39	1872	76	1899	77		

Note: From 1752 to 1840 these wage levels have been deduced by H. P. Gillette from wage statistics given in the annual report of the Massachusetts Bureau of Statistics of Labor for 1885, as compiled in "Comparative Wages, Prices and Cost of Living," by Carroll D. Wright, and are based mainly on New England wages paid to farm labor and to construction labor. From 1840 to 1890, the wage levels are those given in the Aldrich Senate Report, No. 1394, and are a weighted average of about 20 trades. According to that report, the average length of the working day was 11.4 hours in 1840; 11 hours in 1860, and 10 hours in 1890. From 1890 to 1920 these day wage levels have been deduced by H. P. Gillette from data in the monthly Labor Review of the U. S. Bureau of Labor, and in the monthly Labor Market Bulletin of the New York State Industrial Commission and in the monthly Crop Reporter of the U. S. Department of Agriculture.

TABLE LX.—BUYING POWER OF AVERAGE DAILY WAGE IN UNITED STATES

Year	Wage level	Wholesale price level	Buying power of wage
1790	18	88	20
1800	28	136	20
1810	45	136	33
1820	52	96	54
1830	36	83	43
1840	37	89	42
1850	41	83	49
1860	45	90	50
1870	76	117	65
1880	65	93	70
1890	76	84	90
1900	76	82	93
1910	93	97	97
1913	100	100	100
1920	220	243	91

Note: The Buying Power of the Wage is deduced by dividing the Wage Level by the Wholesale Price Level.

the year 1913, it was 50 for the year 1860; and 20 for the year 1800. In other words, within 113 years the "real" wage of the average worker in America had increased fourfold, until it was fivefold as great at the end of that period as at the beginning! The same astonishing increase occurred in Great Britain, as will be shown later.

In my price level article, I deduced the per capita efficiency of productiveness in America by 5-year periods, from 1859 to 1919; and it is there shown that this efficiency doubled between the years 1860 and 1910, which is in almost precise accord with the results shown in Table LX, although they were arrived at in an entirely different way.

Table LXI gives the changes in wages and in commodity prices in England, and its footnote gives the sources of the data. In connection it is important to observe that the weight of the pound sterling changed many times between the thirteenth and the nineteenth centuries, and that, therefore it is necessary to multiply English wages and prices prior to 1816 by factors to render them comparable with modern wages and prices. Accordingly, Table LXII has been prepared for this purpose. As silver was the common currency prior to the nineteenth century I have used the factors for silver (last column of Table LXII) in equating ancient English wages and prices. Prior to 1782 there are no British commodity price level or index data, but I have used average prices of wheat for periods of three years as the basis of price levels.

Table LXI shows that for five centuries the buying power of English wages was practically stationary. Then came a marvelous increase, beginning about the year 1800. In 114 years the buying power of the average wage rose from about 36 to 160.

Between the years 1600 and 1800 pure science made enormous strides. Then came its first fruits with the invention of an economic steam engine and scores of other labor-saving devices. The age of pure science dawned about the year 1600. The age of applied science (that is, engineering) dawned about the year 1800. What engineering has accomplished in a little more than a century is truly amazing. Yet the public is so ignorant of both the degree of the accomplishment and the primary cause of it that not one man in ten can name either one.

It was not labor unions that raised average money wages, for that occurred as a result of the increase in per capita money as will be shown later. Nor did labor unions raise "real" wages, for that was the result of applied science. Labor unions reached the apex of their strength in Britain two centuries ago, but without the slightest effect on the buying power of English wages. Skilled labor in England secured an average wage that was about 50 per cent greater than that of common labor as far back as the year 1400, and it has never been able to increase that ratio. In fact, during the recent war, skilled labor fell behind unskilled labor in the race. It is profoundly significant that the most completely organized labor in England has been unable during five centuries to increase its average wage more rapidly than that of unorganized or common labor.

Fortunately for Britain, its free trade policy during the last century has prevented any extensive curtailment of output by trades unions for any extensive period of time. America has always been almost free from such curtailment. Hence these two nations have progressed almost at the same rate in the increased buying power of the average wage.

Since economists are agreed that about three-fourths of all income goes to workers and one-fourth to capital, it is evident that future increases in "real"

TABLE LXI.—ENGLISH WAGES AND THEIR BUYING POWER

Year	Skilled worker	Laborer	Price level	Buying power of wage
1292	$0.36	$0.17	50	34
1400	0.29	0.17	45	38
1494	0.21	0.12	30	40
1601	0.28	0.19	75	26
1699	0.64	0.42	116	36
1778	0.70	0.45	120	37
1788	0.76	0.47	125	38
1797	0.89	0.57	159	36
1801	1.02	0.61	198	31
1803	1.25	0.61	178	34
1826–61	1.20	0.72	...	...
1861–65	1.40	0.85	...	...
1865–66	1.50	0.90	117	77
1866–72	1.60	0.95	...	...
1872–73	1.70	1.05	...	...
1873–78	1.80	1.15	129	81
1914	2.30	1.60	100	160
1920	5.60	5.00	290	172

Note: These wage data are based upon wages given by William Hardy in the London Times, Aug. 31, 1920, but the wages given by him have been multiplied by the factors given in the last column of Table LXII. The wages of "skilled workers" are the average wages paid to carpenters, masons, bricklayers and joiners engaged on public building construction and maintenance in London. The wages of "laborers" relate to the helpers of the "skilled workers." The wages of laborers correspond closely to those given for farm laborers in "A History of Agriculture and Prices in England, 1259 to 1793," by Rogers. This monumental treatise is my source of information as to the prices prior to 1788. The "price level" data from 1292 to 1778 are based upon the average price of wheat, which, as both Rogers and Adam Smith observe, was the greatest staple used by workers. The price of wheat, moreover, varied substantially as the prices of other foodstuffs varied. From 1788 to 1860, the price level is that of Jevons; from 1861 to 1872, that of Sauerbeck; from 1873 to 1920, that of the "Economist."

TABLE LXII.—FACTORS BY WHICH TO MULTIPLY ENGLISH PRICES AND WAGES TO EQUATE TO PRESENT STANDARD

Years	Factor for— Gold	Factor for— Silver
1066–1344	....	3.30
1344–1349	3.55	3.26
1349–1356	3.33	2.93
1356–1421	3.10	2.64
1421–1464	2.80	2.20
1464–1465	2.24	1.76
1465–1527	2.08	1.76
1527	1.73 to 1.95	1.47 to 1.65
1527–1543	1.86	1.47
1543–1545	1.62	1.37
1545–1549	1.55	1.37
1549–1551	1.37	0.92
1551	1.30 to 1.41	1.10
1551–1553	1.41	1.10
1553–1560	1.30	1.10
1560–1600	1.41	1.10
1600	1.28 to 1.39	1.06
1600–1604	1.39	1.06
1604–1626	1.25	1.06
1626–1666	1.14	1.06
1666–1717	1.05	1.06
1717–1816	1.00	1.06
1816–1920	1.00	1.00

Note: These factors have been deduced from data given in "History of Prices and the State of Circulation," by Thos. Tooke.

wages are infinitely more dependent upon increased productivity than upon securing a greater share of the total product. There is no reason why "real" wages can not be increased as greatly during the next century as during the past century. If this is accomplished the average common laborer in the year 2000 will have "real" wages as great as those of the average $6,000-a-year-man of today.

Up to 1824 the working day in America was from "sun up to sun down." By 1840 it had been reduced to an average of 11.4 hours, and by 1890 to 10 hours. It is now probably about 9 hours, possibly 8.5 hours. Since Table LX gives only the increase in the buying power of average daily wages, at least 40 per cent should be added to the buying power in 1913 in comparing it with that in 1800, if both are to be compared on the basis of wages per hour. When this is done, we see that the buying power of an hour's wages in 1913 was fully seven times that in 1800.

The Author's Wage Level Formula.—The average wage paid in any country during any given year would be ascertainable by dividing the total money spent for wages by the total number of workers. This may be expressed thus:

$$\text{Average wage} = \frac{\text{Money Spent for Wager}}{\text{Number of Workers}}$$

But the money spent for wages is a very constant percentage of the total expenditures, as a study of the census statistics indicates. The total annual expenditures are equal to the average number of dollars of currency multiplied by the number of times the money is "turned over" during the year. And the number of workers is a very constant percentage of the population; so if we indicate this percentage by the letter k, and the population by the letter P, the number of workers is $k \times P$. Similarly, if we indicate the wage percentage of the total expenditures by c the number of dollars of money in circulation by M, and the velocity of circulation by V, the total money spent for wages will be $c \times M \times V$. Hence the above given formula for the average wage becomes:

$$\text{Average wage} = \frac{c \times M \times V}{k \times P}$$

Since it is difficult to ascertain the exact value of c and, since we are mainly concerned in ascertaining a "relative wage," or "wage level" (W), we can pass at once to the desired wage level formula by substituting another constant (K) for the quotient of the constant c divided by the constant k. We then have:

$$\text{Wage level (W)} = K \times \frac{M \times V}{P}$$

This is the desired formula for wage levels, and an application of it to actual daily wage levels discloses that the constant K has a value of ⅓ when the wage level is taken at 100 for the year 1913. Hence we have:

$$W = \tfrac{1}{3} \times \frac{M \times V}{P}$$

This gives the annual wage level, but since the number of days worked annually is normally about constant, it also gives approximately the daily wage level.

It will be seen that this wage level formula differs from my commodity price level formula in not containing a factor for efficiency of production (E). The price level formula is:

$$w = \tfrac{1}{2} \times \frac{M \times V}{P \times E}$$

The buying power of the daily wage is measured by dividing the daily wage level (W) by the commodity price level (w). Hence, if we divide the last equation into the equation preceding it we get:

$$\text{Buying Power of Wage} \left(\frac{W}{w}\right) = \tfrac{2}{3} \times E$$

Expressed verbally this last formula means that the buying power of the average wage is proportional to the per capita efficiency of production. If the wage level formula is found to be correct, the conclusion is inevitable that the level of "real" wages rises or falls exactly in proportion to the rise or fall in

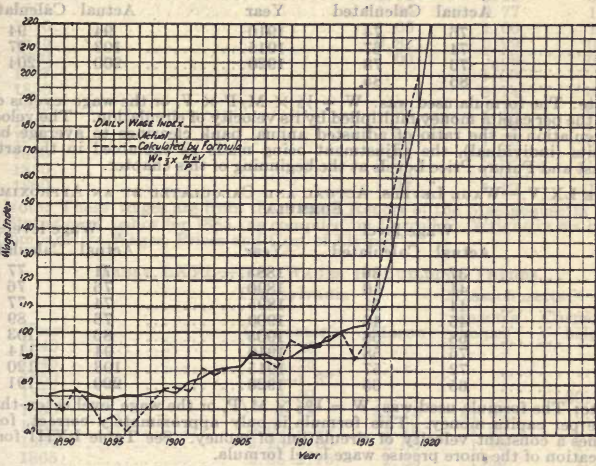


FIG. 13.—Actual compared with calculated wage levels.

per capita efficiency of production. I have established the correctness of the commodity price level formula by showing that it accords closely with commodity price levels. It now remains to prove the correctness of the wage level formula in the same manner. Table LXIII and Fig. 13 show such a comparison for the past 30 years. The agreement is very close. Unfortunately, values for velocity of circulation (V) cannot be very accurately estimated much back of 1889, but, since V has a value that oscillates between 8 and 11, we may assume it to have been 10 every year, and if the value for the wage level derived by substituting 10 for V in the wage level formula agree roughly with the actual wage levels for the past 80 years we may be certain that the wage level formula is substantially correct. Table XLIV shows such a comparison by 5-year intervals from 1840 to 1920. It is, I believe, a complete proof of the substantial truth of the wage level formula. Therefore, we reach this very imporant (and, so far as I know, novel) generalization:

Aside from the relatively minor fluctuations in the velocity of circulation of the currency, the general wage level is proportional to the per capita currency in circulation.

Having this information it becomes possible to forecast the future trend of daily wage levels, or wage indexes. Per capita gold is now 54 per cent above the 1913 level, and per capita currency of all kinds, including gold, is 60 per cent above the 1913 level. If we hold this increase in currency, the new wage level will be 60 per cent above the prewar level. The only question then is as to the probable future trend of our per capita currency.

For the past two years our per capita currency has been nearly constant. The decrease in paper money (Federal Reserve notes) has been offset by the

TABLE LXIII.—WAGE LEVELS, ACTUAL AND CALCULATED BY A CORRECT FORMULA

	Wage level			Wage level	
Year	Actual	Calculated	Year	Actual	Calculated
1890	76	74	1910	94	94
1895	74	67	1915	103	97
1900	76	78	1920	200	204
1905	86	85			

Note: The formula used was: $W = \frac{1}{3} \times M/P \times V$, or the wage level is one-third the per capita money multiplied by its velocity of circulation. The velocity of circulation is the ratio of adjusted annual bank clearings to average bank deposits (individual), the adjustment being made as explained in the article on Past and Future Price Levels at the beginning of this chapter.

TABLE LXIV.—WAGE LEVELS, ACTUAL AND CALCULATED BY AN APPROXIMATE FORMULA

	Wage level			Wage level	
Year	Actual	Calculated	Year	Actual	Calculated
1840	37	36	1885	71	77
1850	41	40	1890	76	76
1855	44	51	1895	74	77
1860	45	46	1900	76	89
1865	68	68	1905	86	103
1870	76	58	1910	94	114
1875	72	57	1915	103	120
1880	65	65	1920	220	191

Note: The formula used was: $W = {}^{10}\!/_{3} \times M/P$, or the wage level is ten-thirds of the per capita money. This formula is only approximately correct, for it assumes a constant velocity of circulation of money. See Table LXIII for an application of the more precise wage level formula.

inflow of gold. The great nations of Europe have issued huge quantities of paper money, which would normally drive out much of their gold to other nations, even were they not debtors to those other nations to begin with. But the victorious allied war nations are debtors to America to an enormous extent—about $9,000,000,000. The payment of the interest on this huge sum would alone increase our per capita currency 6 per cent annually. Although our per capita gold is already 54 per cent above the prewar level, it is almost certain to rise still more in the next few years, not merely because of interest payments from Europe, but because of the economic necessity of restoring the exchange equilibrium.

Every great per capita increase of currency in any nation results in a flow of its gold to countries whose per capita increase has not been so great. During and following our Civil War, most of our gold flowed away to Europe. The same phenomena is now occurring in a reverse direction, but for the same reason.

For these reasons, and based on the history of the flow of gold during and after previous great modern wars, it is safe to infer that our present per capita currency will not decrease materially during the next few years, and that it will ultimately increase.

TABLE LXV.—DAY WAGES IN NEW ENGLAND

Year	Carpenter	Laborer	Farm laborer
1752	.....	$0.33	$0.33
1755	.....	0.33	0.36
1760	.....	0.25	0.25
1765	.....	0.33	0.36
1770	$0.44	0.34	0.34
1775	0.36	0.38	0.34
1780	0.44	0.44	0.42
1785	0.59	0.56	0.41
1790	0.59	0.40	0.38
1795	0.75	0.67	0.57
1800	0.92	0.69	0.42
1805	1.46	0.77	1.00
1810	1.05	1.00	1.00
1815	0.87	0.99	0.87
1820	1.00	0.68	0.75
1827	.....	1.00	....
1830	.....	0.74	0.87
1835	1.30	0.73	0.87
1840	.....	0.78	....
1845	1.29	1.00	0.95
1850	1.50	1.00	....
1855	1.55	1.00	....
1860	1.37	1.10	1.06

Note: These wages are from the Annual Report of the Massachusetts Bureau of Statistics of Labor for 1885, as compiled by Carroll D. Wright in his book on "Comparative Wages, Prices and Cost of Living."

TABLE LXVI.—DAY WAGES IN BUILDING TRADES

	Pennsylvania	Massachusetts		
Year	Carpenter's	Mason	Mason's helper	Carpenter's helper
1840	$1.25	.....	.....	.....
1845	1.25	.....	.....	.....
1850	1.25–1.37	.....	.....	.....
1855	1.50	.....	.....	$0.74
1860	1.75	$1.75	$1.05	0.83
1862	2.00–2.25	1.78	1.09	0.88
1864	2.25–3.00	2.03	1.43	1.00
1865	2.35–2.75	2.35	1.50	1.25
1866	2.50–2.64	2.91	1.75	1.62
1868	2.50–2.67	3.21	1.81	1.39
1870	2.50–2.65	3.62	2.06	1.42
1875	2.36–2.75	2.96	1.68	1.50
1880	2.30–2.75	2.41	1.75	1.18
1885	2.70–2.75	3.59	1.58	1.21
1890	2.70–2.88	3.40	1.56	1.12

Note: These wages are from the Aldrich Senate Report No. 1394.

In answering this important question of the flow of gold between countries, the price formula can be applied to advantage. It can be easily shown that the average prices in two countries that trade with one another on a large scale must become substantially equal. Hence we may deduce that the per capita money in each of two such countries must be proportional to their per capita efficiency of production. Also, it follows that gold must flow from the less efficient nation to the more efficient nation, also that it must flow from the nation that has increased its paper money to the country that has not increased its paper money so greatly. This is a disturbing factor that America has to reckon with for years to come, and it may result in a marked increase in our per capita currency, hence in our money wages within a few years.

Table LXVII.—Average Annual Wages and Salaries in Manufacturing Industries

Year	Salary	Salary level	Wage	Wage level	Salary and wage	Salary and wage level
1849	....	...	....	...	$ 248	37
1859	....	...	....	...	289	43
1869	....	...	....	...	378	56
1879	....	...	....	...	347	52
1889	$ 850	64	$ 444	76	484	72
1899	1,046	78	426	74	469	70
1904	1,103	82	477	82	532	79
1909	1,188	89	518	89	590	88
1914	1,380	100	580	100	671	100
1919*	1,941*	140	1,074*	185	1,178*	176

* For only 15 states.

Note: Prior to 1889 the U. S. Census reports do not give wages and salaries separately. The compensation is supposed to be given in currency throughout the entire period; but judging from the wage levels for 1869 and 1879, it would appear that many manufacturers reported wages paid in gold, which was then at a premium. Excepting for those two census years the wage levels in this table agree very well with those in Tables LIX and LXVIII. The census report for 1919 is not yet completed, so the data in this table for 1919 are merely indicative in a general way, as they apply only to 15 states.

Table LXVIII.—Hourly Wage Index. Year 1913 = 100%

Year	Wage index	Year	Wage index	Year	Wage index	Year	Wage index
1840	33	1860	39	1880	60	1900	73
1841	34	1861	40	1881	62	1901	74
1842	33	1862	41	1882	63	1902	77
1843	33	1863	44	1883	64	1903	80
1844	32	1864	50	1884	64	1904	80
1845	33	1865	58	1885	64	1905	82
1846	34	1866	61	1886	64	1906	85
1847	34	1867	63	1887	67	1907	89
1848	35	1868	65	1888	67	1908	89
1849	36	1869	66	1889	68	1909	90
1850	35	1870	67	1890	69	1910	93
1851	34	1871	68	1891	69	1911	95
1852	35	1872	69	1892	69	1912	97
1853	35	1873	69	1893	69	1913	100
1854	37	1874	67	1894	67	1914	102
1855	38	1875	67	1895	68	1915	103
1856	39	1876	64	1896	69	1916	111
1857	40	1877	61	1897	69	1917	128
1858	39	1878	60	1898	69	1918	162
1859	39	1879	59	1899	70	1919[1]	[1]184
						1920[2]	[2]234

[1] This index number applies to the spring of 1919. Wage rates advanced during the year.

[2] This index number applies to the summer of 1920, and probably represents the wage peak of the year.

Note: Wages are in currency throughout the entire period. This wage level table was compiled by the U. S. Bureau of Labor.

One of the most important conclusions to be drawn from the wage level formula is this: In the past 30 years per capita bank deposits have increased twice as rapidly as per capita money. Since bank deposits are nearly 6 times as great as currency, it would follow that if inflation of bank deposits (or "credit money") acts precisely as inflation of currency acts, then wages should have risen nearly twice as much as they actually did rise in the last 30 years. The failure of wage levels to follow increases in per capita bank deposits, therefore demolishes the theory that "credit currency" (bank deposits) affects wage levels in the same manner that real currency affects wage levels. I had already shown the fallacy of this theory in my article on price levels; but it is now shown again from this wage level study. It can no longer be successfully contended that changes in per capita currency are relatively immaterial so long as changes in the volume of credit occur. The truth is that "credit currency" is of comparatively minor importance as a factor in the changes in wage and price levels, its only effect being the relatively small fluctuations that it causes in the velocity of money circulation.

Table LXIX.—Indexes of Union Minimum Wage Rates and Hours of Labor. Year 1913 = 100%

	Index of—		
Year	Rates of wages per hour	Full-time hours per week	Rates of wages per week, full-time
1907	90	103	92
1908	91	102	93
1909	92	102	93
1910	94	101	95
1911	96	101	96
1912	98	100	98
1913	100	100	100
1914	102	100	102
1915	103	99	102
1916	107	99	106
1917	114	98	112
1918	133	97	130
1919	155	95	148
1920	199	94	189

Note: Based on union minimum wage rates as of May 1 of each year, compiled by U. S. Bureau of Labor.

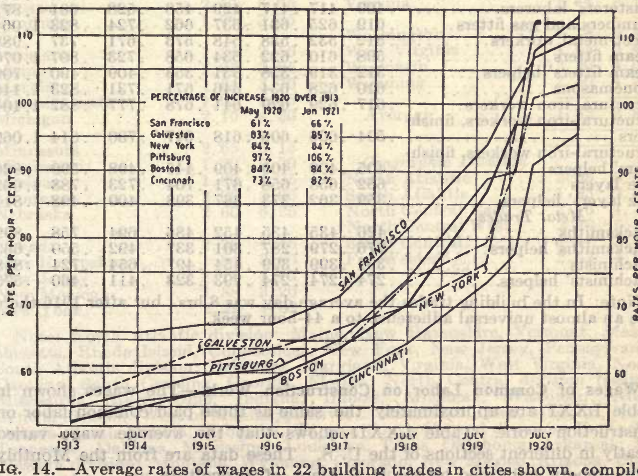


Fig. 14.—Average rates of wages in 22 building trades in cities shown, compiled from schedule of Chicago Builders' Association.

Wages in Building Trades.—W. N. Patten, in Stone and Webster Journal (reprinted in Engineering and Contracting, May 25, 1921) gives the following:

Fig. 14 shows increase in the average rates of wages for twenty-two representative trades in the construction industry for the period between July, 1913, and Jan. 1, 1921, for the cities of San Francisco, Galveston, New York, Pittsburgh, Boston and Cincinnati.

TABLE LXX.—AVERAGE BUILDING WAGES PER HOUR
(According to U. S. Bureau of Labor.)

Year	1913	1914	1915	1916	1917	1918	1919	1920
Building trades								
Bricklayers	.686	.699	.706	.713	.734	.789	.878	1.200
Bricklayers—sewer, tunnel, and caisson	.960	.960	.960	.960	.989	1.065	1.085	1.459
Building laborers	.309	.312	.312	.327	.361	.423	.482	.698
Carpenters	.530	.541	.546	.562	.610	.668	.774	1.034
Carpenters, parquetry-floor layers	.568	.603	.608	.614	.659	.739	.847	1.245
Cement finishers	.552	.557	.563	.568	.602	.662	.745	1.010
Cement finishers' helpers	.360	.364	.364	.367	.382	.447	.508	.814
Cement finishers' laborers	.418	.418	.418	.431	.460	.535	.606	.907
Engineers, portable and hoisting	.586	.592	.598	.604	.633	.727	.797	1.032
Hod carriers	.356	.359	.363	.373	.416	.487	.569	.825
Inside wiremen	.547	.564	.575	.586	.624	.695	.799	1.051
Inside wiremen, fixture hangers	.491	.521	.521	.540	.580	.634	.707	.953
Lathers	.485	.494	.499	.514	.533	.577	.640	.916
Marble setters	.665	.672	.678	.678	.685	.718	.798	1.051
Marble setters' helpers	.404	.408	.408	.408	.432	.453	.517	.873
Painters	.505	.520	.526	.571	.591	.652	.763	1.041
Painters, fresco	.544	.566	.566	.636	.642	.664	.778	1.115
Painters, sign	.629	.629	.629	.648	.674	.736	.888	1.196
Plasterers	.674	.680	.680	.707	728	.761	.883	1.152
Plasterers' laborers	.409	.417	.417	.429	.458	.528	.601	.871
Plumbers and gas fitters	.619	.625	.631	.637	.662	.724	.823	1.064
Sheet-metal workers	.512	.532	.538	.548	.573	.671	.737	.988
Steam fitters	.598	.610	.622	.634	.658	.723	.807	1.070
Steam fitters' helpers	.312	.319	.328	.331	.353	.409	.490	.709
Stonemasons	.610	.628	.634	.646	.671	.731	.823	1.146
Structural-iron workers	.617	.629	.629	.641	.678	.777	.882	1.104
Structural-iron workers, finishers	.594	.606	.606	.618	.647	.730	.814	1.069
Structural-iron workers, finishers' helpers	.405	.409	.409	.409	.445	.498	.599	.826
Tile layers	.652	.658	.658	.671	.704	.723	.788	1.062
Tile layers' helpers	.359	.362	.373	.387	.398	.409	.498	.814
Metal Trades								
Blacksmiths	.426	.435	.435	.452	.486	.694	.758	.899
Blacksmiths' helpers	.276	.279	.287	.301	.337	.492	.550	.663
Machinists	.391	.399	.399	.454	.497	.654	.724	.818
Machinists' helpers	.274	.274	.274	.293	.323	.411	.460	.575

Note: In the building trades the average day was 8 hrs., but after 1916 there was an almost universal adherence to a 44-hour week.

Wages of Common Labor on Construction Work.—The wages shown in Table LXXI are approximately the same as those paid common labor on construction work. Table LXXII shows that the average wage varied greatly in different sections of the U. S. These data are from the Monthly Crop Report, published by the U. S. Dept. of Agriculture.

TABLE LXXI.—AVERAGE DAY WAGES OF FARM LABOR IN U. S.
(Without board and during harvest time)

Year	Wage	Year	Wage	Year	Wage	Year	Wage
1866	2.20	1888	1.31	1898	1.30	1913	1.94
1869	2.20	1890	1.30	1899	1.37	1914	1.91
1875	1.70	1892	1.30	1902	1.53	1915	1.92
1879	1.30	1893	1.24	1910	1.82	1916	2.07
1882	1.48	1894	1.13	1911	1.85	1917	2.54
1885	1.40	1895	1.14	1912	1.87	1918	3.22
....	....	....	....	....	....	1919	3.83
....	....	....	....	....	....	1920	4.36

Note: These wages are for farm labor hired at harvest time; but at other times of the year the wages were less, being about 33% less in 1866, 25% less in 1914, and 20% less in 1919.

TABLE LXXII.—DAY WAGES OF FARM LABOR
(Without board and during harvest time.)

State	1910	1919
Alabama	1.26	2.30
Arizona	2.24	3.65
Arkansas	1.55	3.10
California	2.48	4.69
Colorado	2.47	4.60
Connecticut	2.00	3.75
Delaware	1.55	4.00
Florida	1.46	2.30
Georgia	1.23	2.30
Idaho	2.80	4.95
Illinois	2.30	4.63
Indiana	2.07	4.30
Iowa	2.51	5.20
Kansas	2.57	6.05
Kentucky	1.71	3.35
Louisiana	1.25	2.56
Maine	1.95	3.85
Maryland	1.64	3.70
Massachusetts	1.92	3.75
Michigan	2.10	4.30
Minnesota	2.65	5.15
Mississippi	1.22	2.30
Missouri	1.93	4.35
Montana	2.80	4.95
Nebraska	2.60	6.25
Nevada	2.38	4.45
New Hampshire	1.84	3.80
New Jersey	2.15	4.10
New Mexico	1.88	3.20
New York	2.22	4.02

State	1910	1919
North Carolina	1.28	3.01
North Dakota	3.03	5.85
Ohio	2.07	4.22
Oklahoma	1.97	4.80
Oregon	2.60	4.85
Pennsylvania	1.96	3.71
Rhode Island	2.05	3.50
South Carolina	1.12	2.40
South Dakota	2.95	6.00
Tennessee	1.44	2.70
Texas	1.57	3.68
Utah	2.20	4.10
Vermont	2.25	3.82
Virginia	1.44	3.10
Washington	2.78	5.40
West Virginia	1.65	3.40
Wisconsin	2.20	4.02
Wyoming	2.50	4.70
Average	1.82	3.83
Geographic Division		
North Atlantic	2.08	3.86
South Atlantic	1.33	2.82
North Central East	2.16	4.32
North Central West	2.43	5.33
South Central	1.47	3.14
Far Western	2.52	4.67

Note: North Atlantic division: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania; South Atlantic division; Delaware, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida; North Central division (east of Mississippi River): Ohio, Indiana, Illinois, Michigan, Wisconsin; North Central division (West of Mississippi River): Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas; South Central division: Kentucky, Tennessee, Alabama, Mississippi, Louisiana, Texas, Oklahoma, Arkansas; Far Western division: Montana, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Idaho, Washington, Oregon, and California.

These wages are approximately the same as those paid for common labor on construction work. In the South Atlantic and South Central Divisions the laborers are mostly negroes.

Rate of Wages per Hour for Common Labor on Highway Work, 1912 to 1919.—Engineering and Contracting, March 19, 1919, reprints a committee report to the 1919 convention of the American Road Builder's Association, in regard to labor conditions as regards highway work, from which the following data are abstracted.

A questionnaire was sent out to all state highway departments, to the city engineer of all cities having a population in excess of 100,000 and to many of the large road-building contractors throughout the country. Replies to this questionnaire were received from 39 of the 48 state highway departments, from 54 of the 82 cities to which it was sent, and from 24 road contractors.

Summary of Replies from State Highway Departments.—Thirty-nine state highway departments made replies to the questionnaire. As some of the departments are only 2 years old their replies were not used in figuring average rates of wages.

In 1912 the average rate per hour as reported by 27 states was $ 188, while in the same year Georgia was paying $0.09 and Nevada was paying $.40 Only six states were paying $.25 or more and 10 states were paying $.15 or less—the most of them less. In 1913 the average as reported by 28 states was $.20. In 1914 the same states report an average of $.205, in 1915 of $.225, in 1916 of $.2585, in 1917 of $.303 and in 1918 of $.39. The highest rate for 1918 is reported by Oregon and is $.58. The lowest is by South Carolina and is $.18 per hour.

Summaries of Replies from Cities.—Fifty-four out of 82 cities replied to the questionnaire. Forty-six furnished information as to wages for all years from 1912 to 1918. Taking the year 1912, Spokane, Wash., reports $.37½ per hour, which was the highest, and Birmingham, Ala., with $.14 was the lowest, while the average rate for the year was $.234. In 1913 these 46 cities report an average wage of $.238 per hour. In 1914 the average was $.245; in 1915, $.255; in 1916, $.276; in 1917, $.312; in 1918, $.384. Boston, Mass., reported the highest rate for 1918. It is $.52½ per hour. San Antonio, Tex., had the lowest for the year, $.25, while Atlanta, Ga., and New Haven, Conn., both report a wage of $.28

Summaries of Replies from Contractors.—Twenty-four contracting firms, well distributed throughout the country, make replies, which may be summarized as follows: The average rate of wages they paid in 1912 was $.192; in 1913 it was $.20; in 1914, $.21; in 1915, $.23; in 1916, $.256; in 1917, $.315; in 1918, $.397.

Wages of Skilled and Common Labor Paid by Railroads 1896–1917.—Tables LXXIII and LXXIV have been prepared from the records of daily compensation given in the annual Reports of the Interstate Commerce Commission. These records start with the year ended June 30, 1892. The United States has been divided into territorial districts and all railroads (excepting terminal and switching companies) within each district are included.

From 1892–1910 inclusive the country was divided into 10 districts as shown in Fig. 15.

From July 1, 1910 the country has been divided into three districts and the roads classified as Class I, II or III depending upon the amount of gross earnings.

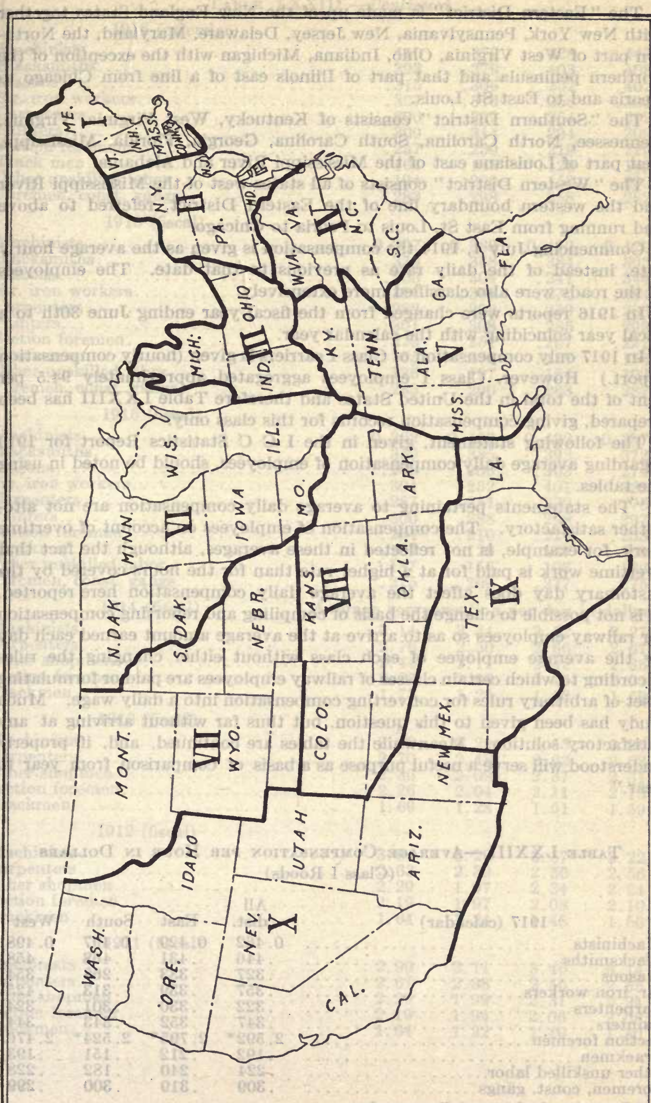


FIG. 15.—Territorial groups as per I. C. C. classification 1892–1910 incl.

The "Eastern District" is made up of the New England States together with New York, Pennsylvania, New Jersey, Delaware, Maryland, the Northern part of West Virginia, Ohio, Indiana, Michigan with the exception of the northern peninsula and that part of Illinois east of a line from Chicago to Peoria and to East St. Louis.

The "Southern District" consists of Kentucky, West Virginia, Virginia, Tennessee, North Carolina, South Carolina, Georgia, Florida, Mississippi, that part of Louisiana east of the Mississippi River and Alabama.

The "Western District" consists of all states west of the Mississippi River and the western boundary line of the Eastern District, referred to above and running from East St. Louis to Peoria to Chicago.

Commencing July 1, 1914 the compensation is given as the average hourly rate, instead of the daily rate as previous to that date. The employees of the roads were also classified more extensively.

In 1916 reports were changed from the fiscal year ending June 30th to a fiscal year coinciding with the calendar year.

In 1917 only compensation of Class I carriers is given (hourly compensation report.) However, Class I employees aggregated approximately 94.5 per cent of the total in the United States and therefore Table LXXIII has been prepared, giving compensation records for this class only.

The following statement, given in the I C C Statistics Report for 1910 regarding average daily compensation of employees, should be noted in using the tables.

"The statements pertaining to average daily compensation are not altogether satisfactory. The compensation of employees on account of overtime work, for example, is not reflected in these averages, although the fact that overtime work is paid for at a higher rate than for the hours covered by the customary day does affect the average daily compensation here reported. It is not possible to change the basis of compiling and reporting compensation for railway employees so as to arrive at the average amount earned each day by the average employee of each class without either changing the rules according to which certain classes of railway employees are paid or formulating a set of arbitrary rules for converting compensation into a daily wage. Much study has been given to this question, but thus far without arriving at any satisfactory solution. Meanwhile the tables are continued, and, if properly understood will serve a useful purpose as a basis of comparison from year to year."

Table LXXIII.—Average Compensation per Hour in Dollars (Class I Roods)

1917 (calendar)	All dist.	East	South	West
Machinists	0.462	0.429	0.497	0.498
Blacksmiths	.446	.431	.468	.458
Masons	.327	.333	.268	.354
Str. iron workers	.357	.339	.313	.425
Carpenters	.322	.330	.301	.324
Painters	.347	.352	.343	.344
Section foremen	2.592*	2.795*	2.524*	2.476*
Trackmen	.192	.212	.151	.193
Other unskilled labor	.224	.240	.182	.228
Foremen, const. gangs	.309	.319	.300	.299

* Items marked * are dollars per day.

TABLE LXXIII.—*Continued*

1916 (calendar)				
Machinists	.410	.379	.428	.447
Blacksmiths	.393	.379	.403	.408
Masons	.315	.306	.252	.402
Str. iron workers	.327	.313	.258	.389
Carpenters	.290	.299	.264	.392
Painters	.309	.314	.294	.308
Section foremen	.237	.259	.219	.229
Track men	.164	.185	.129	.162
Other unskilled labor	.194	.206	.158	.200
Foremen, const. gangs	.283	.298	.258	.282
1916 (fiscal)				
Machinists	0.397	0.369	0.412	0.429
Blacksmiths	.379	.368	.384	.393
Masons	.303	.304	.241	.344
Str. iron workers	.321	.308	.270	.384
Carpenters	.282	.292	.259	.283
Painters	.301	.308	.285	.299
Section foremen	.229	.251	.207	.222
Trackmen	.155	.173	.127	.153
Other unskilled labor	.186	.197	.154	.192
Foremen, const. gangs	.283	.290	.263	.287
1915 (fiscal)				
Machinists	0.362	0.407	0.422	0.387
Blacksmiths	.359	.385	.392	.372
Masons	.290	.209	.363	.279
Str. iron workers	.304	.252	.401	.322
Carpenters	.287	.251	.279	.276
Painters	.300	.288	.298	.297
Section foremen	.254	.210	.226	.233
Trackmen	.167	.125	.147	.150
Other unskilled labor	.187	.156	.193	.182
Foremen, const. gangs	.275	.269	.277	.275
1914 (fiscal)	Average compensation per day in dollars			
Machinists	3.14	3.34	3.52	3.27
Carpenters	2.76	2.50	2.66	2.67
Other shopmen	2.44	2.11	2.42	2.36
Section foremen	2.37	2.08	2.15	2.21
Trackmen	1.73	1.29	1.60	1.59
1913 (fiscal)				
Machinists	3.09	3.29	3.55	3.26
Carpenters	2.70	2.48	2.62	2.63
Other shopmen	2.36	2.09	2.37	2.31
Section foremen	2.26	2.04	2.11	2.15
Trackmen	1.69	1.28	1.61	1.59
1912 (fiscal)				
Machinists	3.04	3.26	3.57	3.22
Carpenters	2.63	2.39	2.56	2.56
Other shopmen	2.29	1.97	2.34	2.24
Section foremen	2.19	1.97	2.08	2.10
Trackmen	1.64	1.24	1.48	1.50
1911 (fiscal)				
Machinists	2.99	3.11	3.46	3.14
Carpenters	2.61	2.38	2.56	2.55
Other shopmen	2.29	1.99	2.31	2.24
Section foremen	2.19	1.94	2.06	2.08
Trackmen	1.64	1.22	1.49	1.50

TABLE LXXIV.—AVERAGE COMPENSATION PER DAY IN DOLLARS

Group I	1910	1909	1908	1907	1906	1905	1904	1903	1902	1901	1900	1899	1898	1897	1896
Machinists	2.64	2.60	2.66	2.61	2.45	2.44	2.41	2.34	2.26	2.31	2.29	2.26	2.26	2.17	2.17
Carpenters	2.46	2.45	2.37	2.25	2.15	2.13	2.11	2.07	2.06	2.06	2.06	2.04	2.03	2.00	1.99
Other shopmen	2.11	2.11	2.14	2.02	1.95	1.93	1.88	1.86	1.85	1.85	1.86	1.87	1.89	1.82	1.79
Section foremen	2.38	2.35	2.35	2.24	2.17	2.14	2.13	2.10	2.07	2.04	2.03	1.96	2.00	2.00	1.99
Trackmen	1.65	1.63	1.63	1.55	1.52	1.50	1.49	1.46	1.44	1.44	1.44	1.43	1.43	1.40	1.38
Group II															
Machinists	2.89	2.79	2.77	2.66	2.55	2.44	2.42	2.34	2.21	2.20	2.19	2.20	2.18	2.14	2.20
Carpenters	2.59	2.48	2.49	2.52	2.42	2.28	2.29	2.21	2.08	2.08	2.04	2.03	2.03	2.01	1.99
Other shopmen	2.18	2.12	2.11	2.06	1.95	1.89	1.89	1.86	1.74	1.75	1.64	1.59	1.57	1.58	1.59
Section foremen	2.08	2.04	2.03	1.96	1.89	1.87	1.87	1.82	1.71	1.69	1.66	1.68	1.69	1.69	1.71
Trackmen	1.52	1.48	1.52	1.48	1.40	1.31	1.30	1.27	1.20	1.20	1.19	1.18	1.17	1.17	1.18
Group III															
Machinists	3.03	2.89	2.85	2.77	2.60	2.56	2.58	2.47	2.35	2.23	2.22	2.17	2.13	2.09	2.14
Carpenters	2.39	2.31	2.29	2.30	2.19	2.21	2.17	2.11	2.02	1.96	1.95	1.93	1.91	1.86	1.89
Other shopmen	2.20	2.09	2.11	2.04	1.91	1.91	1.88	1.85	1.70	1.69	1.68	1.69	1.69	1.64	1.66
Section foremen	1.99	1.94	1.95	1.92	1.79	1.79	1.78	1.75	1.68	1.63	1.60	1.59	1.59	1.61	1.60
Trackmen	1.57	1.46	1.54	1.52	1.43	1.39	1.42	1.37	1.28	1.25	1.22	1.18	1.17	1.16	1.16
Group IV															
Machinists	2.89	2.81	2.83	2.78	2.69	2.57	2.53	2.41	2.26	2.19	2.25	2.22	2.29	2.13	2.18
Carpenters	2.27	2.23	2.19	2.11	2.02	1.94	1.89	1.76	1.54	1.65	1.52	1.57	1.60	1.61	1.69
Other shopmen	1.97	1.90	1.83	1.76	1.69	1.68	1.59	1.55	1.48	1.44	1.45	1.45	1.45	1.37	1.35
Section foremen	1.77	1.73	1.73	1.69	1.64	1.56	1.51	1.48	1.42	1.40	1.35	1.37	1.35	1.39	1.38
Trackmen	1.21	1.16	1.17	1.15	1.09	1.05	0.97	0.90	0.93	0.93	0.90	0.88	0.87	0.88	0.89
Group V															
Machinists	2.95	2.87	2.99	2.91	2.77	2.71	2.62	2.59	2.27	2.29	2.34	2.34	2.26	2.20	2.24
Carpenters	2.21	2.21	2.15	2.18	2.04	2.02	2.01	1.94	1.83	1.80	1.81	1.83	1.74	1.78	1.84
Other shopmen	1.87	1.81	1.84	1.76	1.65	1.63	1.63	1.61	1.58	1.52	1.49	1.50	1.45	1.50	1.44
Section foremen	1.83	1.80	1.76	1.74	1.69	1.65	1.66	1.63	1.57	1.57	1.52	1.56	1.57	1.53	1.53
Trackmen	1.13	1.10	1.13	1.15	1.07	1.03	1.02	0.98	0.96	0.95	0.95	0.93	0.88	0.88	0.88
Group VI															
Machinists	3.06	2.97	2.93	2.88	2.70	2.62	2.58	2.42	2.29	2.18	2.18	2.13	2.15	2.12	2.14
Carpenters	2.48	2.36	2.35	2.30	2.21	2.20	2.24	2.18	2.06	2.01	2.03	1.99	1.97	1.98	2.01
Other shopmen	2.11	2.06	2.07	2.02	1.94	1.96	1.95	1.88	1.79	1.74	1.73	1.73	1.71	1.77	1.73
Section foremen	1.90	1.87	1.86	1.80	1.70	1.68	1.70	1.69	1.64	1.63	1.63	1.63	1.64	1.66	1.65
Trackmen	1.56	1.42	1.51	1.55	1.46	1.41	1.45	1.43	1.34	1.31	1.30	1.23	1.20	1.19	1.20

Group VII															
Machinists	3.80	3.61	3.46	3.43	3.35	3.29	3.16	2.98	2.84	3.00	2.96	2.87	2.86	2.86	2.88
Carpenters	2.82	2.65	2.62	2.62	2.55	2.49	2.40	2.25	2.27	2.41	2.38	2.31	2.37	2.36	2.36
Other shopmen	2.60	2.51	2.47	2.31	2.22	2.19	2.18	2.15	1.90	1.94	1.96	1.96	2.05	2.02	1.99
Section foremen	2.22	2.10	2.10	1.99	1.85	1.80	1.78	1.78	1.74	1.75	1.73	1.72	1.70	1.71	1.72
Trackmen	1.60	1.43	1.57	1.56	1.46	1.42	1.47	1.44	1.41	1.49	1.44	1.37	1.33	1.35	1.37
Group VIII															
Machinists	3.53	3.30	3.31	3.35	3.12	3.12	2.97	2.83	2.73	2.68	2.57	2.53	2.57	2.49	2.50
Carpenters	2.46	2.46	2.34	2.33	2.36	2.41	2.49	2.44	2.36	2.32	2.27	2.22	2.27	2.31	2.32
Other shopmen	2.27	2.21	2.22	2.06	1.99	1.96	1.99	1.95	1.90	1.86	1.89	1.88	1.87	1.90	1.91
Section foremen	1.83	1.81	1.80	1.74	1.71	1.68	1.68	1.71	1.69	1.67	1.68	1.68	1.68	1.67	1.67
Trackmen	1.37	1.31	1.39	1.43	1.37	1.35	1.37	1.41	1.33	1.30	1.26	1.22	1.21	1.21	1.22
Group IX															
Machinists	3.64	3.55	3.47	3.37	3.09	3.03	3.05	3.01	2.87	2.80	2.63	2.86	2.85	2.77	2.80
Carpenters	2.55	2.55	2.56	2.46	2.38	2.46	2.51	2.38	2.31	2.35	2.32	2.31	2.34	2.32	2.29
Other shopmen	2.10	2.12	2.07	2.01	2.01	1.99	1.99	1.88	1.87	1.80	1.83	1.82	1.83	1.81	1.79
Section foremen	1.88	1.87	1.91	1.90	1.80	1.78	1.79	1.80	1.86	1.91	1.86	1.87	1.86	1.87	1.87
Trackmen	1.26	1.28	1.33	1.34	1.26	1.22	1.21	1.22	1.18	1.16	1.15	1.15	1.15	1.17	1.17
Group X															
Machinists	3.93	3.79	3.78	3.52	2.96	3.27	2.07	2.97	2.89	2.89	2.87	2.96	2.91	3.06	3.02
Carpenters	2.98	2.99	2.92	3.00	2.65	2.86	2.78	2.75	2.71	2.73	2.76	2.82	2.77	2.75	2.81
Other shopmen	2.62	2.63	2.54	2.80	2.26	2.36	2.45	2.35	2.23	2.12	2.35	2.33	2.34	2.38	2.35
Section foremen	2.51	2.48	2.55	2.41	2.19	2.34	2.30	2.31	2.28	2.26	2.24	2.22	2.22	2.28	2.24
Trackmen	1.52	1.43	1.60	1.65	1.45	1.40	1.47	1.47	1.41	1.39	1.39	1.38	1.39	1.37	1.39
United States															
Machinists	3.08	2.98	2.95	2.87	2.69	2.65	2.61	2.50	2.36	2.32	2.30	2.29	2.28	2.23	2.26
Carpenters	2.51	2.43	2.40	2.40	2.28	2.25	2.26	2.19	2.08	2.06	2.04	2.03	2.02	2.01	2.03
Other shopmen	2.18	2.13	2.12	2.06	1.92	1.92	1.91	1.86	1.78	1.75	1.73	1.72	1.70	1.71	1.69
Section foremen	1.99	1.96	1.95	1.90	1.80	1.79	1.78	1.78	1.72	1.71	1.68	1.68	1.69	1.70	1.70
Trackmen	1.47	1.38	1.45	1.46	1.36	1.32	1.33	1.31	1.25	1.23	1.22	1.18	1.16	1.16	1.17

NOTE: Due largely to the continuous character of the work, railway trackmen (or section men) receive less than the prevailing wages for common laborers on construction work. Adding 20% to the trackmen's wages gives approximately the wages of construction laborers.

Rental Prices for Construction Equipment.—A schedule, evolved from the records and experiences of contractors, manufacturers and rebuilders of equipment, and designed to furnish contractors with a practical means for estimating equipment expense and determining adequate rental charges has been approved by the Executive Board of the Associated General Contractors. The schedule, which was prepared by the Research Division under the direction of the Committee of Methods of the Association, is given in the Nov. Bulletin of the Associated General Contractors. The schedule and discussion of its application as abstracted in Engineering and contracting, Dec. 15, 1920, follow.

To use the schedule with safety, it is essential to understand how the amounts were obtained, how they are to be applied, and how they are limited for determining rental charges. Knowing these things, no great difficulty should be found in establishing the charges within the bounds of practical accuracy.

For the reason that arithmetical averages as obtained from available records, gave few rational values for depreciation and repairs, such averages were given less weight in establishing the tabular amounts than the practical experience of contractors. In fact, the strongest evidence that these amounts are reasonably safe and accurate lies in the endorsement given them by experienced general contractors.

A tentative draft of the schedule was submitted to members in the Weekly Bulletin of July 31. They were asked to criticise the amounts and offer suggestions. In accordance with the criticism received, which evinced considerable study upon the subject, some of the tabular amounts were changed. As it now stands, the schedule represents the consensus of opinion of many contractors, and with the proper understanding of what the percentage amounts mean, it should offer a safe means of estimating rental charges.

What the Values Mean.—The endless variation of job conditions, such as topography, ground formation and climate, indicate how great may be the error of any fixed equipment charge when applied to the exceptional job. But having figures which represent the mean of many projects, a starting point exists for ascertaining reasonable charges for the exceptional circumstances. Figures given in the standard schedule may be said to show equipment expense when machines are not required to operate continuously under either the worst or the best of operation strain. When no especially favorable or unfavorable circumstances attend a project, the tabular values probably give the expense within a permissible error.

To eliminate error as far as possible by permitting consideration and comparison of the individual items that make up equipment expense, the gross amounts are reduced to their component parts. Thus any item of the expense which is known to be unusually high in specific cases may be adjusted in the schedule to obtain a more appropriate rental rate.

Components of Expense.—Seven items of equipment expense constitute the total rental charge and require consideration in estimating a lump sum contract or in determining fixed rate rentals. An average value for each of these items which represents the expense of a general contractor's outfit as a whole, has been approved by the Executive Board. The items referred to and their annual proportions of the equipment's initial cost are as follows:

Schedule of Typical Rental Charge.—Items of expense are expressed as per cents of original capital investment for equipment having a useful life of 6 years and a salvage value of 25 per cent of the original cost.

	Per cent
1. Average depreciation	12½
2. Equivalent annual interest at 6½ per cent	4
3. Shop repairs	6
4. Field repairs	4
5. Storage and incidentals	3½
6. Insurance	1
7. Taxes	1
Total annual expense	32
Equivalent expense on basis of 8 months' working timer per year	48
Rental rate per month	4

How to Obtain Proper Percentage.—These percentages and those given in the detailed schedule were determined according to the following principles: The economical life of a machine is considered to end when its value has depreciated to 25 per cent of the original cost. The average annual depreciation then amounts to 75 per cent of the initial cost divided by the number of years it may be expected to give service. The initial cost of a machine is represented by the cost of that machine delivered at the contractor's yard.

TABLE LXXV.—RENTAL SCHEDULE FOR CONSTRUCTION EQUIPMENT

Items of equipment	Economical length of life	Annual depreciation	Annual shop repairs	Annual field repairs	Storage and incidentals	Insurance	Taxes	Total annual charge per cent of initial investment
	Yrs.	%	%	%	%	%	%	%
Auto-crane	5	15	6	5	3½	1	1	31½
Auto-truck	3	25	20	20	3½	1	1	70½
Auto-trailer	5	15	6	5	3½	1	1	31½
Backfiller, power	4	18¾	6	7	3½	1	1	37¼
Ballast spreader	8	9½	6	4	3½	1	1	25
Boiler, upright	8	9½	20	5	3½	1	1	40
Boiler, locomotive	8	9½	15	5	3½	1	1	35
Bucket, clamshell	4	18¾	15	6	3½	1	1	45¼
Bucket, orange peel	4	18¾	25	6	3½	1	1	55¼
Bucket, dragline	4	18¾	12	3	3½	1	1	39¼
Cars, steel dump	6	12½	8	4	3½	1	1	30
Cars, wood dump	5	15	7	3	3½	1	1	30½
Cars, flat	8	9½	4	3	3½	1	1	22
Cars, hopper	5	15	8	3	3½	1	1	31½
Compressor, steam	7	10¾	6	3	3½	1	1	25¼
Compressor, gasoline	4	18¾	6	7	3½	1	1	37¼
Compressor, electric	6	12½	3	3	3½	1	1	24
Concrete chutes	2	37½	15	15	3½	1	1	73
Conveyor, belt	2	37½	7	6	3½	1	1	56
Conveyor, bucket	2	37½	10	6	3½	1	1	59
Crusher, rock	6	12½	5	3	3½	1	1	26
Derrick, wood	5	15	4	4	3½	1	1	28½
Derrick, steel	10	7½	4	3	3½	1	1	20
Dragline, steam	6	12½	9	8	3½	1	1	35
Dragline, gasoline	4	18¾	10	10	3½	1	1	44¼
Dragline, electric	8	9½	7	7	3½	1	1	29
Drill, tunnel carriage	5	15	8	8	3½	1	1	36½
Drill, traction well	6	12½	7	10	3½	1	1	35
Drill, tripod	4	18¾	7	10	3½	1	1	41¼
Drill, jack hammer	4	18¾	7	6	3½	1	1	37¼
Engine, gas	6	12½	8	8	3½	1	1	34
Engine, steam	10	7½	5	5	3½	1	1	23

TABLE LXXV.—RENTAL SCHEDULE FOR CONSTRUCTION EQUIPMENT—*Continued*

Items of equipment	Economical length of life	Annual depreciation	Annual shop repairs	Annual field repairs	Storage and incidentals	Insurance	Taxes	Total annual charge per cent of initial investment
	Yrs.	%	%	%	%	%	%	%
Excavator, cableway	6	12½	4	12	3½	1	1	34
Excavator, Keystone	5	15	8	4	3½	1	1	32½
Excavator, trench	5	15	8	6	3½	1	1	34½
Forms, steel concrete	2	37½	20	20	3½	1	1	83
Graders, common road	4	18¾	12	6	3½	1	1	42¼
Graders, elevating	4	18¾	15	7	3½	1	1	46¼
Hoist, steam	10	7½	6	4	3½	1	1	23
Hoist, gasoline	6	12½	7	8	3½	1	1	33
Hoist, electric	8	9½	5	3	3½	1	1	23
Locomotive—								
Industrial steam	9	8½	6	4	3½	1	1	24
Industrial gas	4	18¾	13	10	3½	1	1	47¼
Industrial battery	4	18¾	15	4	3½	1	1	43¼
Standard gage	10	7½	6	4	3½	1	1	23
Crane, steam	8	9½	7	8	3½	1	1	30
Crane, electric	8	9½	6	4	3½	1	1	25
Mixer, steam	5	15	12	4	3½	1	1	36½
Mixer, gasoline	4	18¾	13	8	3½	1	1	45¼
Mixer, electric	6	12½	12	4	3½	1	1	34
Mixer, paving steam	5	15	13	4	3½	1	1	37½
Mixer, paving gas	3	25	16	9	3½	1	1	55½
Motors	6	12½	6	4	3½	1	1	28
Pile driver, steam	8	9½	7	5	3½	1	1	27
Pile driver, track	10	7½	5	3	3½	1	1	21
Pile hammer, steam	7	10¾	7	3	3½	1	1	26¼
Pipe, galvanized	3	25	5	6	3½	1	1	41½
Plows	3	25	15	10	3½	1	1	55½
Pneu. conc. mach	4	18¾	20	8	3½	1	1	52¼
Pump, centrifugal	8	9½	6	4	3½	1	1	25
Pump, piston	6	12½	7	5	3½	1	1	30
Pump, pulsometer	8	9½	2	4	3½	1	1	21
Pump, Emerson	8	9½	2	4	3½	1	1	21
Rails	8	9½	5	3	3½	1	1	23
Riveter, air	5	15	8	4	3½	1	1	32½
Rock channeler	6	12½	7	8	3½	1	1	33
Roller steam road	10	7½	5	3	3½	1	1	21
Saw rigs	4	18¾	10	15	3½	1	1	49¼
Scraper, wheel	3	25	8	4	3½	1	1	42½
Scraper, slip	1	75	25	10	3½	1	1	115½
Scraper, fresno	2	37½	25	15	3½	1	1	83
Shovel, steam	6	12½	7	6	3½	1	1	31
Shovel, gasoline	4	18¾	9	7	3½	1	1	40¼
Shovel, electric	7	10¾	6	5	3½	1	1	27¼
Switches, fabricated	3	25	3	3	3½	1	1	36½
Tower, steel hoist	7	10¾	3	4	3½	1	1	23¼
Tractor, wheel gas	6	12½	9	5	3½	1	1	32
Tractor, caterpillar	5	15	15	10	3½	1	1	45½
Wagons, dump	4	18¾	17	3	3½	1	1	44¼
Wagons, hauling	4	18¾	12	3	3½	1	1	39¼
Wagon loaders, power	5	15	10	6	3½	1	1	36½

Interest should naturally be charged at the prevailing rate. This may be computed in three ways:

1. By charging the prevailing rate each year on the depreciated value of the machine.

2. By charging the prevailing rate each year on the average value of the machine during economical life. For example, when the salvage rate value is 25 per cent the average value equals (100 per cent + 25 per cent) divided by 2 = 62½ per cent.

3. By finding the proportion which the average value is of the initial cost and charging this proportion of the prevailing rate each year. This proportion is called the equivalent annual interest and shows what interest rate on original cost will yield the same interest as the prevailing rate when applied to the depreciating value of the machine. This is the method used in the above schedule. The average value is 62½ per cent of the original; therefore the equivalent annual rate is 62½ per cent of the prevailing rate, or 62½ per cent of 6½ per cent = 4 per cent.

Shop and field repairs are separated by reason of a previous recommendation of the Committee on Methods that field repairs be considered a part of the cost under cost plus contracts and shop repairs be borne by the contractor and covered by the fixed rate rental charge. This recommendation was made on the ground that an owner should not be made to pay the total cost, for example, of re-fluing a boiler which may have been burned out principally on another owner's work.

The other items of cost require no special explanation.

Three Types of Charges.—Owners of equipment find occasion to establish rental rate as follows:

1. For a lump sum or unit price estimate.
2. To owners on cost plus work.
3. To others than client owners.

In these instances charges should be made as follows:

1. The rental charge or equipment expense for lump sum work includes all the items mentioned above.

2. The fixed rate to owners on cost plus work will include all but field repairs, if this item is paid as a cost of the work. To the amount thus determined may be added a service charge depending upon the policy of the contractor, *i.e.*, whether the service of equipment is included in the profit fee or carried in the rental charge.

3. The charge to persons other than client owners includes all of the items of expense and an additional amount for profit or payment for the machine's earning power.

A further consideration in each of these cases is the rate for double shift work, where the percentages for depreciation and repairs should be doubled, or nearly so.

Individual Judgment Essential.—The committee desires to emphasize the fact that the values presented in the table should not be considered absolute in determining a rental charge. A real danger presents itself in using any tabular percentage without investigating the conditions under which the equipment is to work. To illustrate: if the values here given for a standard gage shovel outfit were applied to such an outfit engaged constantly in excavating hard rock, the probability is that the charges allowed would not cover more than half the expense. The frequent dobey shots and the dropping of heavy boulders into cars entails a higher rate of depreciation and repairs than is given in the schedule. On the other hand, if this shovel outfit were steadily engaged in digging sandy loam, the values given in the table would probably cause the equipment charge to contain a fair per cent of profit.

It is with the understanding that individual judgment and experience

TABLE LXXVI.—RENTAL RATES FOR GRADING EQUIPMENT

Class of equipment	Original capital cost	Annual rate of depreciation on original cost, per cent.	Total annual rate of accrued charges on original cost, per cent.*	Total annual charge	Average earning days per year	Daily charge for int., dep., ins. and storage	General shop repairs daily	Daily rental	Est. cost field repairs daily	Total rental charge daily, incl. field repairs
Steam shovel	$12,000	12½	20	$ 2,400.00	200	$12.00	$ 4.00	$ 16.00	$ 4.00	$ 20.00
Steam shovel	20,000	12½	20	4,000.00	200	20.00	6.00	26.00	6.00	32.00
Steam shovel	30,000	12½	20	6,000.00	200	30.00	9.00	39.00	9.00	48.00
Steam shovel	90,000	12½	20	18,000,00	200	90.00	25.00	115.00	25.00	140.00
Drag line excavator	20,000	12½	20	4,000.00	200	20.00	10.00	30.00	10.00	40.00
Drag line excavator	30,000	12½	20	6,000.00	200	30.00	15.00	45.00	15.00	60.00
Standard gage locomotive	12,000	12½	20	2,400.00	200	12.00	5.00	17.00	5.00	22.00
Standard gage locomotive	16,000	7½	15	2,400.00	200	12.00	6.00	18.00	6.00	24.00
Standard gage locomotive	24,000	7½	15	3,600.00	200	18.00	8.00	26.00	8.00	34.00
Dinkey locomotive	4,000	12½	20	800.00	200	4.00	1.50	5.50	1.50	7.00
Dinkey locomotive	6,000	12½	20	1,200.00	200	6.00	2.50	8.50	2.50	11.00
Locomotive crane	20,000	12½	20	4,000.00	200	20.00	6.00	26.00	6.00	32.00
Jordan spreader	9,000	12½	20	1,800.00	200	9.00	3.00	12.00	1.00	13.00
Rail, per ton	48	7½	15	7.20	200	.04	.01	.05	.00	.05
Track throwing machine	6,000	12½	20	1,200.00	200	6.00	2.00	8.00	1.00	9.00
20-yard air dump cars	3,750	12½	20	750.00	200	3.75	.25	4.00	.25	4.25
16-yard air dump cars	2,800	12½	20	560.00	200	2.80	.20	3.00	.25	3.25
12 yard air dump cars	2,000	12½	20	400.00	200	2.00	.15	2.15	.15	2.30
4-yard dump cars	430	12½	20	86.00	200	.43	.07	.50	.10	.60
1½-yard dump cars	110	12½	20	22.00	200	.11	.09	.20	.10	.30
1-yard dump cars	90	12½	20	18.00	200	.09	.06	.15	.10	.25
Flat cars	1,000	7½	15	150.00	200	.75	.15	.90	.10	1.00
Gasoline locomotive	3,200	12½	20	640.00	200	3.20	1.05	4.25	1.25	5.50
1-yard Koppel cars, V-shape	110	12½	20	22.00	200	.11	.04	.15	.05	.20
Motor truck, 5-ton	6,000	22½	30	1,800.00	200	9.00	7.50	16.50	5.00	21.50
Automobile	2,000	31¼	50†	1,000.00	200	5.00	2.50	7.50	2.50	10.00
Caterpillar tractor, gas	5,000	12½	20	1,000.00	150	6.66	8.34	15.00	5.00	20.00
Vertical boiler	900	7½	15	135.00	100	1.35	.65	7.00	.00	7.00
Locomotive boiler	1,500	7½	15	225.00	100	2.25	1.00	3.25	.00	3.25

Steam pump	500	7½	15	75.00	100	.75	.50	1.25	.00	1.25
Centrifugal pump, D. C.	1,500	7½	15	225.00	100	2.25	1.25	3.50	.50	4.00
Belted pump	300	7½	15	45.00	100	.45	.30	.75	.00	.75
Deep well pump	600	7½	15	90.00	100	.90	.60	1.50	.00	1.50
Gasoline engine	1,200	7½	15	180.00	100	1.80	.60	2.40	.10	2.50
Steam engine	1,800	7½	15	270.00	100	2.70	.90	3.60	.15	3.75
Hoisting engine	4,250	7½	15	637.50	100	6.38	2.12	8.50	.50	9.00
Horse pile driver	800	12½	20	160.00	100	1.60	.40	2.00	.00	2.00
Steam pile driver	2,000	12½	20	400.00	100	4.00	.75	4.75	.75	5.50
Track pile driver	10,000	7½	15	1,500.00	100	15.00	3.00	18.00	2.00	20.00
Steam pile hammer	2,500	7½	15	375.00	100	3.75	.75	4.50	.50	5.00
Air compressor	3,000	7½	15	450.00	100	4.50	1.50	6.00	.50	6.50
Electric motor	500	12½	20	100.00	100	1.00	.35	1.35	.15	1.50
Deep well drill	2,000	12½	20	400.00	100	4.00	.50	4.50	.50	5.00
Steam tripod drill	400	12½	20	80.00	100	.80	.20	1.00	.25	1.25
Jackhamer drill	140	12½	20	28.00	100	.28	.22	4.50	.25	.75
Air steel sharpener	2,000	12½	20	400.00	100	4.00	.25	4.25	.25	4.50
Stiff leg derrick	2,000	12½	20	400.00	100	4.00	.50	4.50	.75	5.25
Forrest log loader	400	12½	20	80.00	100	.80	.20	1.00	.25	1.25
Lee wagon loader	225	12½	20	45.00	100	.45	.15	.60	.15	.75
Clamshell bucket	1,500	12½	20	300.00	100	3.00	.25	3.25	.25	3.50
Rock channeler machine	3,000	12½	20	600.00	100	6.00	2.00	8.00	1.00	9.00
Grading machine	1,350	23¼	30‡	405.00	150	2.70	1.30	4.00	1.00	5.00
Pony road grader	200	23¼	30‡	60.00	150	.40	.20	.60	.15	.75
Grading plow	30	23¼	30‡	9.00	150	.06	.04	.10	.00	.10
Dump wagon	180	23¼	30‡	54.00	150	.36	.34	.70	.15	.85
Hauling wagons	120	23¼	30‡	36.00	150	.24	.21	.45	.15	.60
Wheel scrapers	50	33¼	40‡	20.00	150	.13	.12	.25	.00	.25
Slip scrapers	8	43¼	50‡	4.00	150	.03	.02	.05	.00	.05
Fresno	22	43¼	50‡	11.00	150	.07	.08	.15	.00	.15
Switches, complete	150	7½	15	22.50	200	.11	.02	.13	.00	.13
2-in. galv. pipe, per 100 ft.	22	7½	15	3.30	200	.02	.01	.03	.00	.03
2½-in. galv. pipe, per 100 ft.	34	7½	15	5.10	200	.03	.01	.04	.00	.04
3-in. galv. pipe, per 100 ft.	45	7½	15	6.75	200	.04	.01	.05	.00	.05

* Except where noted this rate is made up of the percentage of depreciation, plus 3¾ per cent interest on original investment and 3¾ per cent of original investment allowed for insurance and storage.

† Interest = 3¾ per cent, insurance and storage charge = 15 per cent of the original investment.

‡ Interest = 3 per cent, insurance and storage charge = 3¾ per cent of the original investment.

should adjust the tabular values to meet unusual conditions that this schedule is offered to contractors.

Individual Equipment Rental Schedule.—The component expenses incurred by the ownership and maintenance of construction plant are expressed in this table as percentages of the initial cost for individual items of equipment. They indicate the probable annual expense without profit under ordinary job conditions and should be included in any lump sum estimate or in determining time rate rental charges. The salvage value in all cases is considered to be 25 per cent of the initial cost.

Total percentage amounts in the etreme right-hand column should be applied to the total cost of a machine, including charges for transportation from the factory. This gives the total annual charge which for a lump sum contract covering a full season, is the total equipment expense. For determining a monthly, weekly or daily rental rate the annual amount is divided by the number of such periods in the year during which construction work may be carried on.

Rental Rates for Grading Contractors Equipment.—(Engineering and Contracting, Feb. 18, 1920.)

F. J. Herlihy has compiled the following table (Table LXXVI.) giving the derivation of rental rates for grading equipment. The table shows the original capital cost of his equipment, depreciation charges, average earning days per year, daily charge for interest, depreciation, insurance and storage, and total daily rental charge.

CHAPTER III

HAULING

A fundamental cost entering into nearly every kind of construction is that for hauling. For some work, such as excavation, the cost of removing or hauling away the excavated material is often the controlling factor in arriving at the unit cost; while on practically all work if the transportation end "falls down," progress and costs are "shot to pieces." It is evident, therefore, that time may be well spent in determining the most economic method of hauling for each job.

The material in this chapter is, in general, grouped according to methods of hauling. For further data on this subject, the reader should refer to the index of this volume and also to Gillette's "Earthwork and Its Cost" and "Handbook of Rock Excavation."

Cost of Maintaining City Owned Teams is given in Engineering and Contracting, July 2, 1919, and is from a report by the Rochester Bureau of Municipal Research, Inc., on the collection of refuse in the city of Rochester, N. Y.:

Cost of Maintaining Horses at Columbus, O.—According to the report of Superintendent E. W. Stribling, of the Division of Garbage and Refuse Collection, the cost of maintaining 142 horses by the city of Columbus, O., in 1916 was 83.7 cts. per horse per day. This included a cost of 41.63 cts. for feed; 13.53 cts. for veterinary services, shoeing and supplies; and 28.54 cts. for stable labor. In 1915 the unit cost was 83 cts. per horse per day, including 45.77 cts. for feed, 11.98 cts. for veterinary services, shoeing, and supplies and 25.25 cts. for stable labor. The labor force consisted of 16 men and a night watchman. The cost of feed was about $14 per ton for hay, 75 cts. per bushel for corn and 50 cts. per bushel for oats. Straw cost about $7 per ton. In 1916 each horse consumed daily 30 lbs. of hay, and 13 lbs. of grain, 5.3 lbs. of straw were used in bedding each horse. In 1915 these quantities were 31 lbs., 12.75 lbs., and 6.3 lbs. respectively.

Cost of Horse Maintenance at Cincinnati.—Similar costs for 1916 in the city of Cincinnati, given in the report of Fred Maag, Superintendent of the Department of Street Cleaning, Sewer and Catch Basin Cleaning, indicate that 34.9 cts. per horse per day was the cost of feeding and 39.4 cts. was the cost of "other stable expenses," the total cost being 74.3 cts. per horse per day. Approximately 190 horses and 80 mules were maintained in 17 stables, practically one-half of this number being boarded in one stable. Each horse consumed 14.7 lbs. of hay, 11.5 lbs. of oats and 2.8 lbs. of nutritia daily. Hay cost about $18 per ton, oats 45 cts. per bushel and nutritia $1.50 per hundredweight. (No allowance apparently was made for bedding straw.)

Cost of Feeding Horse at Washington.—In Washington, D. C., according to the report of the Engineering Department for the fiscal year, 1915–16, the cost of feed amounted to 40.2 cts. per horse per day. The daily allowance per horse was 3.3 lbs. of dry straw, 7 lbs. of long timothy, 7 lbs. of mixed clover hay, 12.8 lbs. of oats and 1.7 lbs. of bran. Straw cost at the rate of

$16, long timothy at $20.80 and mixed clover hay at $20 per ton, oats at 54 cts. per bushel and bran at $1.27 per hundredweight. The cost of shoeing was stated to be 2.6 cts. per horse per day.

Cost of Maintaining Horses by New York Street Cleaning Department.—In the annual report of the Department of Street Cleaning of New York, in 1916, Commissioner J. T. Fetherston states that the cost of "labor, materials, supplies and consumable equipment used directly in the care of horses" amounted to $1.087 per horse per day and that this cost represents prices of forage and supplies considerably above normal. About 64 per cent of the total cost represents the cost of forage, 30 per cent the direct labor cost and 6 per cent the cost of maintaining stable equipment. In the 26 stables maintained by the department, 2,400 horses were cared for. One hostler and one stableman were employed for each 13 horses. In 1917, the daily allotment for each horse was 23 lbs. of oats, 18 lbs. of hay, 3¼ lbs. of bran and 3 lbs. of straw. In addition to this each horse was given 1½ lbs. of coarse salt and 2½ lbs. of rock salt per month. When idle the horses were given half ration of oats. In 1916, the daily ration was 21 lbs. of oats, 15 lbs. of hay and 1¼ lbs. of bran. The other items were practically the same as for 1917. This appears to be an unusually heavy ration and the cost of feed alone was practically 70 cts. per horse per day.

Stable Costs at Rochester.—For Rochester it was possible to obtain from James M. Harrison, formerly superintendent for the Genesee Reduction Co., data of the cost of maintaining horses employed in garbage collection from 1908 to 1916. On Jan. 1, 1917, the Department of Public Works took over the operation of the garbage plant stables and the 1917 costs, therefore, are available also.

In 1917 the 68 horses quartered at the garbage plant stables cost about 68 cts. per horse per day to maintain. The approximate cost of feed amounted to 50.7 cts.; the direct labor cost of stable operation, 9.4 cts.; and the estimated cost of barn supplies, shoeing and harness repairs, 7.9 cts. per horse per day. No exact ration allotment was made, but according to the total quantities purchased during the year each horse consumed about 11 lbs. of oats and 22 lbs. of hay per day. The approximate average cost of oats was 80 cts. per bushel and the cost of hay was about $18 per ton. The stable force consisted of one barnman and three helpers, the barnman and one helper working seven days and the other two helpers six days per week. The drivers cleaned and harnessed the horses and gave them their noon feeding.

The foregoing and certain additional data as to the cost of maintaining horses by the Genesee Reduction Co. before 1917, are shown in Tables I and II.

From the foregoing and other data it appears that a horse used in collection work should be fed on the average about 20 lbs. of hay and 14 lbs. of oats per day, in addition to possibly 2 lbs. of other feed, consisting principally of bran, salt, etc. Also each horse should be bedded with approximately 5 lbs. of dry straw daily. On this basis and with hay costing $18 per ton, oats 80 cts. per bushel, other feed $1.50 per hundredweight and straw $12 per ton, the total daily cost per horse of feed and bedding would amount to the following:

20 lb. of hay at $18 per ton	$0.18
14 lb. of oats at $0.80 per bu	.35
2 lb. of other feed at $1.50 per cwt	.03
5 lb. of straw at $12 per ton	.03
Total estimated cost of feed and bedding per horse per day	$0.59

In addition to this the cost of veterinary services, maintenance of stable equipment and supplies, shoeing, and harness repairs should not exceed 12 cts. per horse per day. If one hostler at $800 per year and one stableman at $750 per year were provided for every 20 horses, the direct labor cost of stable operation would amount to about 21 cts. per horse per day. This would include the cost of all work involved in feeding, bedding, cleaning and otherwise caring for horses, and all labor about the stables such as cleaning stables, handling feed and supplies, handling and moving equipment, cleaning equipment, etc.

The total cost per horse per day, therefore, might be estimated at 92 cts. distributed as follows:

Feed and bedding	$0.59
Veterinarian, shoeing, harness repairs, etc	0.12
Direct labor cost of stable operation	0.21
Total maintenance cost per horse per day	$0.92

The annual cost of maintaining horses at this figure would be $336.65 per horse, exclusive of the cost of overhead supervision, fixed charges on first cost of horses, stable sites and stable buildings, depreciation of horses, and depreciation and maintenance of stable buildings.

The annual (purchase) cost of the horses used in garbage collection in Rochester since 1912 has been about $31 per horse, which includes replacements as well as the purchase of three horses during the six years in addition to the number owned at the beginning of the period. (See Table II.)

TABLE I.—COST OF FEEDING HORSES EMPLOYED IN THE COLLECTION OF GARBAGE IN ROCHESTER, N. Y., 1908 TO 1916

Year	Total cost of feed (grain, hay, straw)	Approximate number horses fed	Average cost per horse per day
1908	$ 7,364.08	40	$0.505
1909	6,964.89	40	.477
1910	6,912.67	40	.474
1911	6,827.04	40	.467
1912	7,816.29	65	.330
1913	9,269.83	65	.395
1914	8,771.77	65	.370
1915	10,666.02	66	.443
1916	9,570.47	66	.397

TABLE II.—COST OF RENEWALS OF HORSES EMPLOYED IN THE COLLECTION OF GARBAGE IN ROCHESTER, N. Y., 1912 TO 1917

Year	Total expenditure for horses	Approximate number of horses	Average cost per horse per year
1912	$2,219	65	$34
1913	1,885	65	29
1914	4,205	65	65
1915	1,020	66	15
1916	1,575	66	24
1917	1,125	68	17

Estimates as to the economic life of a horse used in collection work vary from 4½ to 8 years. It is believed, however, that a good horse should give at least six years of useful service in this kind of work. Assuming a first cost of $275 and a salable value of $75 at the end of six years, the annual depreciation would be $33.33 per year per horse.

Depreciation in Value of Horses (Engineering and Contracting, Oct. 17, 1917).—Some interesting data on the depreciation in value of horses are given in a bulletin issued by the U. S. Department of Agriculture. This bulletin deals with the cost of keeping farm horses and the cost of horse labor. It is compiled from a study of records for 316 horses on 27 farms in Illinois, Ohio and New York.

In determining depreciation and appreciation in value of horses a yearly inventory value was placed on each horse on the farm by careful appraisal and a record was kept of each horse bought or sold. In Illinois 11 of the 18 yearly farm records showed a net depreciation of horses. In Ohio 7 of the 16 yearly records showed a net depreciation, and in New York 16 of the 18 yearly records showed a net depreciation.

The average net depreciation of the 316 horses was $4.50 per horse. Of this amount $2.70 per horse was due to the death of 9 horses, valued at $855. Depreciation varied from $11.60 per horse in New York to an appreciation of $2.10 per horse in Ohio.

Table III shows the percentage of horses that appreciated in value, the percentage that did not, and the factors influencing the aggregate depreciation or appreciation, by States.

TABLE III.—PERCENTAGE OF 316 HORSES THAT APPRECIATED IN VALUE, PERCENTAGE THAT DID NOT APPRECIATE, AND THE FACTORS INFLUENCING THE AGGREGATE DEPRECIATION OR APPRECIATION, BY STATES (27 FARMS, 316 HORSES)

	Percentage of horses that showed—							
State and number of horses	Appreciation	No appreciation	No. of deaths	No. bought	No. sold	No. colts bought	No. colts sold	No. colts fed
Illinois (154 horses)	18.75	81.25	3	21	21	2	..	43
Ohio (72 horses)	21.95	78.05	.	9	17	2	1	7
New York (90 horses)	4.95	95.05	6	6	3	1	2	18
The 3 states (316 horses)	15.60	84.40	9	36	41	5	3	68

On the Illinois and New York farms colts became work horses when from 2½ to 4 years of age. The age of work horses that depreciated in value varied considerably, depending on their usage and care. The average age of work horses that appreciated in value was about 4 years. The average age of those that neither appreciated nor depreciated in value was about 8 years, and the average of those that depreciated in value was about 11 years. In Ohio data showing the age of all the horses studied were not obtained; however, the data that were obtained along this line showed about the same results as those in Illinois and New York.

In Illinois about 19 per cent of the horses appreciated in value at the rate of $36.05 per head per year, while the average depreciation for the other 81 per cent was $12.55 per head. At this rate it will be seen that a $36 appreciation of one horse practically would offset the depreciation of three others. Thus the appreciation of one horse out of every 5.34 kept resulted in an average net depreciation for all horses of but $3.46 per head. Of the 154 horses included in the records from this State 3 died, causing a loss of $350. In other words, the death loss was about 1 out of every 51. In considering the reason for the number of young horses on these farms and the low depreciation of work horses it was found that there was an average of one colt for every four work horses kept. Further, no colts were sold, all being developed into work horses, 11 becoming work horses during the time in which data were collected. It also will be seen that the same number of horses was bought as was sold. Three died and had to be replaced, and a part of the farmers enlarged their business, thus requiring more horses. With the continued raising and developing of colts into work horses, however, it is safe to say that ordinarily a greater number of young horses will be developed than will be needed in the farm business.

On the Ohio farms about 22 per cent of the horses appreciated in value at the rate of $56.90 per head. The average depreciation of the remaining 78 per cent was $13.30 per head. At this rate the appreciation of 1 horse would offset the depreciation of more than 4 other horses. Thus the appreciation of 1 horse out of every 4.55 resulted in an average net appreciation of $2.10 per head for the total number of horses. While no deaths occurred in this group, 2 horses were severely injured, entailing a loss of $175.

On the Ohio farms there was an average of one colt for every 10 work horses kept. This was about two-thirds less than on the Illinois farms, and yet the depreciation of horses was $5.56 per head less than in Illinois. By this it will be seen that the net appreciation of horses in Ohio was not so much due to the raising of young horses as in Illinois. A study of the data shows that the reason for this was that on some farms a practice was made of buying young horses, and after working them for a time, selling them at an increase in value. During the years this study was made 9 horses were bought and 17 were sold, 8 of the 17 having been on the farms at the time this work was begun. The horses bought and sold were mostly young draft stock, which accounts for the high appreciation of $56.90 per horse. In following this practice, at times more horses were kept than were needed to do the farm work. Other data in this bulletin show that the average horse worked less hours per year on the Ohio farms than on the Illinois or New York farms.

On the New York farms the relative number of horses that appreciated in value was a great deal less than in each of the other States—less than 5 per cent—at the rate of $44.40 per head. The depreciation per head of the remaining 95 per cent was $14.48. At this rate, the appreciation of one horse would a little more than offset the depreciation of three other horses. Thus, the average net depreciation was $11.56 for all horses. One reason for this depreciation being higher than in the other two States was a loss of $505 due to the death of 6 horses, or about 1 out of every 15. Thus, more than 48½ per cent of the total depreciation was due to deaths. The number of colts on these farms was less than in Illinois. For every work horse sold two were bought. It seems that these farmers have but recently started to replace the old horses by raising colts.

Depreciation figures from other bulletins follow:

Bulletin 341 of the U. S. Department of Agriculture shows that the average depreciation of horses on 378 farms studied in Chester County, Pennsylvania, is $7 per head, and on 300 farms studied in Lenawee County, Michigan, $7.10 per head. These figures are largely determined by the practice of farmers in disposing of horses while they are still salable at a fairly satisfactory price, and would undoubtedly be much greater if all farm horses were kept until their usefulness was at an end.

Cornell University (N. Y.) bulletin 377 shows that the average annual depreciation of horses on 14 New York farms for the year 1912, and on 31 New York farms for 1913, was $14.03 and $12.10 per horse unit, respectively. Of the 45 farms studied, 12 showed an appreciation of horses.

Minnesota extension bulletin 15, covering a period of four years, 1904 to 1907, inclusive, gives figures for farms studied in three different counties. In Rice County depreciation varied from $0.98 in 1905 to $15.48 in 1904, averaging for the four years $5.56 per head. In Lyon County depreciation varied from $4.20 in 1905 to $9.86 in 1904, averaging per year $6.94 per head. In Norman County depreciation varied from $2.60 in 1907 to $7.37 in 1904, averaging per year $5.892 per head.

It is pointed out in the text that depreciation of the horse is an expensive item to farmers who are not able to control this expense by means of clever selling methods and by the use of young horses. Shrewd selling, however, does not affect the general principle of depreciation, since thus the loss is passed on to the buyer.

Minnesota experiment station bulletin 145 gives results of a further study of horse depreciation in the above-mentioned counties. Records for Rice County for the period 1908 to 1912 inclusive shows a variation in depreciation from $0.28 in 1910 to $5.10 in 1909, and an average per year of $3.05 per head. In Lyon County the study covers a period of three years, 1908 to 1910, inclusive. The depreciation varied from $1.47 in 1910 to $5.60 in 1909, averaging per year $3.06 per head. In Norman County the work covered a period of four years, 1908 to 1911, inclusive. The depreciation varied from $0.51 in 1910 to $3.42 in 1911, averaging per year $1.48 per head. It is pointed out in this bulletin that the annual depreciation as shown above is not high enough to represent a proper average charge through a long term of years. Abnormal conditions in the Minnesota horse market were largely responsible for the low depreciation charge.

Health Efficiency of Horses.—In Engineering and Contracting, Sept. 17, 1913, J. W. Paxton states that records are kept by the street cleaning department of Washington, showing the total number of horses cared for in each stable each day and the total number unable to work because of injury or sickness. The health efficiency of the stable is the ratio found by dividing the number of horses capable of working by the total number of horses. The health efficiency of all stables combined has been brought up to 98 per cent, although it was as low as 86 per cent one month shortly after the health records were initiated.

A health efficiency curve is plotted for each stable, and comparisons between different stables can be made at a glance. When in any case there is a drop in the curve, a conference with the stable boss discloses the reason.

In addition to a health record of this sort, it may be suggested that it would be wise, in many cases, to keep a record of all time lost by stock, and to plot curves showing the total "output factor," i.e., ratio of hours actually worked to hours that might have been worked had health, weather, etc., permitted. On construction work it frequently happens that many head of stock are idle for lack of drivers or equipment. Especially is this true when a job is being started. Time is also lost in shoeing, in moving from one camp to another, etc. It is certainly desirable to have daily records of all time losses, and the reasons therefor. Daily "output factor curves" and "health efficiency curves" will focus attention upon time losses and lead inevitably to a reduction of the losses.

Hauling Material with Mules.—The following data are taken from an article by William W. Hurlbut published in Engineering Record, July 19, 1913.

For hauling steel plates from Mojave to the Antelope Valley Siphon, Los Angeles Aqueduct, a distance of 35 miles, three stations were established 10 miles apart. Twelve mule teams were used for this hauling, the average load being 12.9 tons or a little more than 1 ton to the animal.

A team made 20 miles a day, loading at Mojave, arriving at the 10-mile station at noon; at the 20-mile station at night of the first day; at the 30-mile station at noon of the second day; leaving there and discharging the load at the siphon the afternoon of the second day; than returning to the 30-mile station the same night; returning the following day to the 10-mile station; and at noon of the fourth day reloading at Mojave, thus making the round trip in three and one-half days. The cost of this haul averaged 12 cents per ton mile.

Number of Wagons Required for Hauling from Steam Shovels.—The following data are reprinted from the Aug., 1919, issue of Successful Methods:

YARDAGE FOR VARIOUS HAULS

Haul in ft.	Round trips	Cu. yd. per day per team with 1½-yd. wagons
500	105	157
1,000	53	79
2,000	26	40
3,000	17	26
5,000	10	15
10,000	4	6

NUMBER OF TEAMS FOR VARIOUS OUTPUTS

Daily output in cu. yd.	Haul 1,000 ft.	Haul 3,000 ft.	Haul 10,000 ft.
250	3	10	41
300	4	12	50
500	8	20	84

On a road job in Minnesota 5 wagons are serving a ¾-yd. steam shovel on a 300-ft. haul and are kept busy.

At Hamilton, O., a steam shovel with a ¾-yd. bucket, loading gravel on a 3 to 10-ft. face, loaded 480 2-cu. yd. wagons in 9 hours, and 60 teams were estimated as necessary to keep the shovel busy on a 1-mile haul. The same shovel handled clay out of a 6 to 12-ft. face and should be able to load 360 2-yd. wagons in 9 hours. This would require 45 teams to haul the material away on a 1-mile haul, 8 trips to the team.

Average Loads in Team Hauling on Country Highways.—The following data are given in a paper by Seth A. Moulton (Engineering and Contracting, Jan. 4, 1911) before the Association of Cement Users. The observations were made during the construction of a storage dam at Aziscohos, Me., in 1910.

The round trip of 76 miles from Colebrook to the dam and return is made in 4 days, each team making two complete round trips without rest, and laying off the ninth day. Four, five, and six horse teams were employed, averaging 4½ horses to a team, and by a proper arrangement of the time schedule a maximum total of 180 horses could be accommodated on the road, making a total of 40 teams, which, on the basis of 4 days to a trip, gave an average of 10 teams arriving at the dam during each day of the toting season.

During the best period of toting, or for the 6 weeks from Dec. 1 to Jan. 15, the average loads were as follows:

Four horse team	6,650 lbs.
Five horse team	8,600 lbs.
Six horse team	10,400 lbs.

The average load per horse was 1,680 lbs.

During the best period of summer toting the average loads were as follows:

Four horse team	5,750 lbs.
Five horse team	None working
Six horse team	8,400 lbs.

The average load per horse was 1,430 lbs.

During the most adverse condition of toting the average loads were as follows:

Four horse team	4,800 lbs
Five horse team	6,200 lbs.
Six horse team	7,200 lbs.

The average load per horse was 1,220 lbs., or 20 per cent less than could be hauled during the best sledding.

Cost of Hauling with Teams.—Table IV, prepared by E. B. Hiatt, is published in Engineering and Contracting, Dec. 4, 1918. The figures are based on a rate of travel of 2 miles per hour with loads and 3 miles per hour returning empty. Forty minutes is allowed for loading and unloading 3,750 lbs. with shovels. This weight was the average load in Madison County, Iowa, during the 1918 season. The vehicle considered was a common farm wagon.

TABLE IV.—SCHEDULE OF PRICES FOR HAULING ONE TON

	Team rates per day of ten hours					
Miles	$5.00	$5.50	$6.00	$6.50	$7.00	$7.50
0.5	0.288	0.317	0.346	0.375	0.404	0.433
1.0	0.400	0.440	0.480	0.520	0.560	0.600
1.5	0.511	0.562	0.613	0.664	0.715	0.766
2.0	0.622	0.684	0.746	0.808	0.871	0.933
2.5	0.733	0.806	0.880	0.953	1.026	1.100
3.0	0.844	0.928	1.013	1.097	1.182	1.266
3.5	0.955	1.051	1.146	1.242	1.337	1.433
4.0	1.066	1.173	1.280	1.386	1.493	1.600
4.5	1.177	1.295	1.413	1.531	1.648	1.766
5.0	1.288	1.417	1.546	1.675	1.804	1.933
5.5	1.400	1.540	1.680	1.820	1.960	2.100
6.0	1.511	1.662	1.813	1.964	2.115	2.266
6.5	1.622	1.784	1.946	2.108	2.271	2.433
7.0	1.733	1.906	2.080	2.253	2.426	2.600
7.5	1.844	2.028	2.213	2.397	2.582	2.766
8.0	1.955	2.151	2.346	2.542	2.737	2.933
8.5	2.066	2.273	2.480	2.686	2.893	3.100
9.0	2.177	2.395	2.613	2.831	3.048	3.266
9.5	2.288	2.517	2.746	2.975	3.204	3.433
10.0	2.400	2.640	2.880	3.120	3.360	3.600
10.5	2.511	2.762	3.013	3.264	3.515	3.766
11.0	2.622	2.884	3.146	3.408	3.671	3.933
11.5	2.733	3.006	3.280	3.553	3.826	4.100
12.0	2.844	3.128	3.413	3.697	3.982	4.266
12.5	2.955	3.251	3.546	3.842	4.137	4.433
13.0	3.066	3.373	3.680	3.986	4.293	4.600
13.5	3.177	3.495	3.813	4.131	4.448	4.766
14.0	3.288	3.617	3.946	4.275	4.604	4.933
14.5	3.400	3.740	4.080	4.420	4.760	5.100
15.0	3.511	3.862	4.213	4.564	4.915	5.266
15.5	3.622	3.984	4.346	4.708	5.071	5.433
16.0	3.733	4.106	4.480	4.853	5.226	5.600
16.5	3.844	4.228	4.613	4.997	5.382	5.766
17.0	3.955	4.351	4.746	5.142	5.537	5.933
17.5	4.066	4.473	4.880	5.286	5.693	6.100
18.0	4.177	4.595	5.013	5.431	5.848	6.266
18.5	4.288	4.717	5.146	5.575	6.004	6.433
19.0	4.400	4.840	5.280	5.720	6.160	6.600

Similar tables can be prepared using different times for loading and unloadng which would depend upon methods employed and materials hauled. The average load would also vary with the type of wagon employed.

Cost and Service Comparisons of Motor Trucks and Horse-drawn Vehicles

are given by Clinton Brettell in "The School of Mines Quarterly," Columbia University, from which Engineering and Contracting, May 14, 1913, abstracts the following:

There are several ways of making a cost comparison. One is to reduce all costs to a "per day" basis. This method is of little value, for while the motor truck costs more per day, it also does more work per day. Then there is the "cost per mile" basis. This is a little better, but also shows but one phase of the question, as no account is taken of the tonnage moved. The third method, and the best one, considered from all sides, is the "cost per ton-mile." This is the method which will be employed in practically all cases throughout this paper. Data on the subject of transportation costs are abundant, but so many methods of bookkeeping and computation are used that it is not safe to accept any of them off-hand. Before adopting them for comparisons they should be carefully analyzed.

Motor Trucking.—To be accurate, the cost of operation for motor trucks should include the following items:

I. Fixed Charges.—Based on an average number of working days. A figure of 300 working days per year is often used, and approximates quite closely the actual working days for the average case.

A. Driver's Wages.—About $20 per week is a fair charge for this item.

B. Garage.—If the truck is stored in a public garage, about $25 per month is charged. This includes washing, polishing, inspection, heat, light, power, etc. If the owner maintains his own garage, this figure may be somewhat lower. In that case the charge for storage, to compare with the above, would be made up as follows: (*a*) Interest on investment, including building, property and equipment. (*b*) Insurance and taxes on same. (If the building is rented, the above, i. e., interest on investment, insurance and taxes on building, and an additional charge for depreciation on building would all be included in one item, rent.) (*c*) Depreciation on building and equipment, if owned by truck owner; on equipment only, if building is rented. (*d*) Wages of attendants, elevator men, washers and polishers, inspectors, superintendent or foreman. (*e*) Charges for heat, light and power. (*f*) Charges for maintenance of building and equipment.

C. Insurance.—Fire, liability, theft, property damage. These rates vary all over the country. As a rule they are unreasonably high. In most cases the same rates as for pleasure cars are applied to commercial vehicles, without taking account of the lessened liability with slow moving motor trucks. Insurance against fire and theft is generally at some percentage on a partial valuation, say, 2¼ per cent on 80 per cent valuation. Insurance against property damage depends on the horsepower of the truck and is arranged on a sliding scale basis, which is arbitrarily adopted without scientific basis. Liability is usually a flat sum, being greater the more hazardous the occupation. This item should also include taxes for licenses, etc.

D. Interest.—Opinion differs as to what rate of interest to use. One common method is to assume as a basis the rate offered by banks. Whatever the rate finally adopted, it is well to recognize that there is a regular depreciation in the amount of capital invested; so that while interest for the first year is chargeable on practically full value, for the second year it should be on less than full value, for the third year on still less, and so on. The easiest way of taking account of this is to use an average rate of interest, assuming full capital first year and entire dissipation of capital at the end of, say, the tenth year. The average rate will then be ½ the flat rate decided on, say ½ of 5 per cent. This method charges too little interest for the first five years and too much for the last five, the one balancing the other in the final result.

II. VARIABLE OR MILEAGE CHARGES. *A. Depreciation.*—To account for the gradual wearing out of the truck, even with the best possible care and maintenance, a certain amount must be charged off each year, so that at the end of the truck's life there will be a fund sufficient to purchase a new truck, identical with the old one. If a truck receives ordinary care and attention in the matter of upkeep, etc., and is not abused in operation, it will last as much as ten years before it is really worn out, and many will last longer. (*a*) One method of charging depreciation, then, is to write off one-tenth the original value of the truck each year. Opinion differs as to the life, but under present conditions it is not wise to figure over ten years. Naturally a truck which is run 25 miles a day should last longer than one operated 100 miles a day, with equal care and attention in both cases. (*b*) This suggests a second method of charging depreciation, i. e., on a mileage basis, figuring the life of a truck at 100,000 miles under average conditions. The latter method seems the more logical one to follow, since in fixing the rate for the former method it was necessary to consider, among other things, the daily mileage of the truck. Cost per mile is thus equal to total cost divided by total mileage.

B. Tires.—The life of tires is subject to practically the same discussion as given in connection with depreciation. The method generally employed is as follows: The tire maker guarantees his tires for a certain mileage (provided that rated capacities of tires are not exceeded, and in some cases that speeds are limited to certain specified values) usually around 8,000 miles. In addition, the time element is involved, because tires, being made of rubber, deteriorate even when standing idle. The tire maker covers this phase of the situation by stipulating (in most cases) that the guaranteed mileage must be covered within a given time, usually 12 months, to validate the guarantee. Hence cost per mile equals cost per set of tires divided by guaranteed (or actual) mileage, as the case may be.

C. Repairs (exclusive of tires).—This includes labor and material (and profit if work is done in a public garage). It is generally figured on a yearly basis and then converted to a mileage rate, by determining the yearly mileage. For electric trucks, this item includes renewals of plates, electrolyte, etc.

D. Gasoline or Current.—This cost is figured for a year and then reduced to a mileage basis. Cost of gasoline depends on the fuel consumption of the motor and the prevailing price of gasoline. Cost of current depends on type of motors, etc., and cost per kw.-hour for charging batteries. It is best to figure this on a yearly basis and then reduce to a mileage basis. The same discussion applies to oil.

Summary.—The total of items under I gives total cost per day for fixed charges. Assuming a certain daily mileage, and multiplying the rates for the various items under II by this mileage, we get the daily cost for each item. Total of these gives total variable costs per day. Adding daily fixed charges and daily variable charges, we obtain total daily operating cost. Ton-miles per day is the product of the tonnage, by the distance this tonnage was carried. Dividing average cost per day by ton-miles per day, we obtain "Cost per Ton-mile" which is the final result sought. As an example of the foregoing, see Table V, which shows costs for a 5-ton gasoline truck, figured for various daily mileages, and Fig. 1 plotted from these figures.

Horse Trucking.—Following out the same computation for horse drawn trucks, the costs would be determined as follows:

TABLE V.—ESTIMATED YEARLY COST OF OPERATING 5-TON GASOLINE TRUCK

Investment:										
Chassis........	$4,800.	Chassis, with stake body......$5,000.								
Miles per day...		20	25	30	35	40	45	50	60	70
Miles per annum		6,000	7,500	9,000	10,500	12,000	13,500	15,000	18,000	21,000
Fixed charges:	Cost per day.									
Driver........	**$3.466**	$1,040.	$1,040.	$1,040.	$1,040.	$1,040.	$1,040.	$1,040.	$1,040.	$1,040.
Garage........	**1.000**	300.	300.	300.	300.	300.	300.	300.	300.	300.
Insurance......	**.633**	190.	190.	190.	190.	190.	190.	190.	190.	190.
Interest........	**.416**	125.	125.	125.	125.	125.	125.	125.	125.	125.
Total fixed charges.	**$5.515**	$1,655.	$1,655.	$1,655.	$1,655.	$1,655.	$1,655.	$1,655.	$1,655.	$1,655.
Variable expenses:	Cost per mile.									
Depreciation....	**.044**	267.	333.	400.	467.	534.	601.	668.	802.	934.
Tires..........	**.068**	405.	506.	607.	709.	810.	911.	1,012.	1,215.	1,418.
Repairs........	**.033**	200.	250.	300.	350.	400.	450.	500.	600.	700.
Gasoline,.......	**.051**	308.	386.	463.	540.	617.	694.	771.	925.	1,079
Oil............	**.004**	24.	30.	36.	42.	48.	54.	60.	72.	84.
Total variable expense.......	**.200**	$1,205.	$1,505.	$1,806.	$2,108.	$2,409.	$2,710.	$3,011	$3,614.	$4,215.
Total cost per annum.......		2,860.	3,160.	3,461.	3,763.	4,064	4,365.	4,666.	5,269.	5,870.
Total cost per day..........		9.53	10.53	11.53	12.54	13.55	14.55	15.55	17.56	19.60
Total cost per mile..........		.476	.422	.384	.358	.339	.324	.311	.293	.280
Total cost per ton mile..........		.190	.168	.154	.143	.136	.129	.124	.117	.112

Number of working days, 300.
Full load carried half way.
Driver, $20 per week.
Garage, $25 per month.
Insurance: Fire, 2¼ per cent of $4,000; liability, $100.
Interest: The interest charge represents the average yearly interest at 5 per cent on principal.
NOTE.—Mileage costs shown in boldface should not be used in figuring yearly costs under "Variable Expenses," as they are only carried out to three decimal places and are therefore only approximate. The variable expenses shown under the various mileages were worked on yearly totals.

Depreciation (less cost of tires): Life of truck figured at 100,000 miles.
Tires, $540 per set for 8,000 miles guaranteed by tire manufacturer.
Repairs, $500 per annum for daily mileage of 50 miles (for 15,000 miles per annum), exclusive of tires.
Gasoline, 18c per gallon (3.5 miles per gallon).
Oil, 40c per gallon (100 miles per gallon).
NOTE.—The above yearly cost of tires does not take into account the tires on the truck when delivered. Accordingly $540 should be deducted in estimating tire cost for first year.

1. Fixed Charges. *A. Driver.*—In case the driver's wages are paid by the week, it is best to figure this item on the basis of a year and then reduce it to a daily basis. For average figures at Chicago, see Table VI.

B. Stable.—If a truck owner keeps a stable for his equipment the following items should be included in the cost account: (*a*) Feed, hay and straw, water and stable supplies. (*b*) Taxes, insurance, depreciation, interest; if the building is rented, rent includes all of these. (*c*) Light, heat and power. (*d*) Wages of stablemen, helpers, etc.; salary of manager.

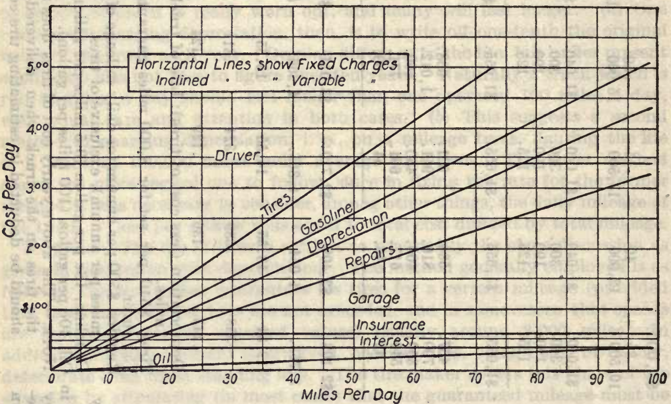


Fig. 1.—Estimated daily cost of operation of five-ton gasoline truck subdivided into its various items

If he boards his horses, a flat figure covers all of the above items. Record of costs should be kept for a year and then reduced to a daily basis by using the average days in service per year.

Table VI.—Costs Incident to Horse Transportation, Chicago

Commodity	1871	1881	1891	1901	1906	1911	1912
Corn, per bu...	$0.39	$0.635	$0.59	$0.675	$0.46	$0.70	$0.90
Oats, per bu...	.33	.468	.334	.483	.358	.474	.40
	1903	1907	1908	1909	1910	1911	1912
Hay, per ton.	$15.00	21.50	14.00	17.00	21.00	25.00	20.00

Chicago Truck Drivers, Wages Per Week

Type of wagon						
Single wagon	1902	1904	1906	1909	1910	1912
One horse............	$11.00	$11.25	$11.25	$11.50	$12.00	$13.50
Two horses..........	12.75	13.00	13.00	13.50	14.00	15.50
Double wagon						
Two horses..........	13.75	14.00	14.00	14.50	15.00	16.50
Three horses.........	15.50	15.75	15.75	16.00	17.00	18.50
Four horses..........	16.50	17.00	17.00	18.00	18.00	19.50
Six horses...........	18.50	19.00	19.00	20.00	20.50	21.50

Overtime (year 1912), 30 cents per hour up to 8 p. m.

D. Interest.—The same methods are applied as in connection with motor trucking. Interest on horses and equipment (harness, wagons, blankets, etc.).

E. Insurance.—No insurance is carried, as a rule.

F. Veterinary and Medicine.—Charges for a year are reduced to daily basis.

II. **Variable Charges.** *A. Depreciation.*—Distinctly a mileage charge, as horses are worn out much quicker by working long hours, and constantly, than by giving them plenty of rest. Under average conditions, horses are unfit for heavy trucking after more than a few years' service. Life of wagons, while somewhat longer, depends on the amount of service; also on nature of service and care as to upkeep. Yearly mileage under average conditions is based on average number of working days, and an average daily mileage (not over 18 miles for light work, considerably less for heavy work). The original cost must thus be divided over the total mileage for the working life of the horse. Cost of wagon is distributed in same way. This gives cost per mile.

B. Repairs.—Repairs on harness and wagons, painting, etc., are figured for a year and then reduced to a mileage basis by applying the total yearly mileage. For any given daily mileage, find total mileage cost per day.

The sum of fixed and variable charges gives total cost per day. Dividing by ton-miles per day gives the final result, cost per ton-mile. The curves shown in Fig. 2 give quite accurately the ton-mile costs for various capacities of trucks, gasoline, electric and horse drawn, figured for various mileages. Table VII shows another method of keeping the cost records for two-horse and three-horse wagons. The final result is cost per ton-mile.

Table VII.—Cost of Operating Horse Wagons
(On basis of five years' operation: loaded both ways.)

Two-horse wagon—	
Price of open express-body wagon	$300.00
Price of two horses	400.00
Price of double set harness	75.00
Total cost of equipment	$775.00
Working days	300
Average miles per day	20
Load in pounds	8,000

Items	Per year	Per working day	Per mile	Per ton mile	Per cent
Wagon expense—					
Maintenance, grease, repairs, etc	$ 125.00	$0.417	$0.0208	$0.0052	6.94
Depreciation, 10 per cent	30.00	.100	.0050	.0012	1.66
Rental value of space	25.00	.084	.0042	.0010	1.38
Horse expense—					
Depreciation, 15 per cent	60.00	.200	.0100	.0025	3.33
Ratio that die, 1 in 20	10.00	.433	.0016	.0004	.56
Feed and bedding	360.00	1.200	.0600	.0150	20.00
Care (hostler)	100.00	.333	.0168	.0042	5.57
Veterinary	15.00	.050	.0026	.0007	.84
Medicine	10.00	.033	.0016	.0004	.56
Rental value, space for horses	125.00	.417	.0208	.0052	6.94
Shoeing	50.00	.167	.0083	.0021	2.78
Water	10.00	.033	.0016	.0004	.56
Blankets	8.00	.026	.0014	.0004	.45
Deterioration to building caused by horses	16.00	.053	.0027	.0007	.89
Rental value of space for storing feed	12.00	.040	.0020	.0005	.66
Harness expense—					
Depreciation	7.50	.025	.0012	.0003	.41
Maintenance and repairs	10.00	.033	.0016	.0004	.56
Rental value of space	5.00	.017	.0008	.0002	.28
General—					
Interest on investment	46.50	.155	.0077	.0019	2.58
Driver's wages	750.00	2.500	.1250	.0313	41.66
Stable supplies	15.00	.050	.0025	.0006	.83
Removing manure	10.00	.033	.0016	.0004	.56
	$1,800.00	$5.999	$0.2998	$0.0750	100.

Three-horse wagon—	
Price of open wagon	$ 375.00
Price of three horses	750.00
Price of harness	100.00
Total cost of equipment	$1,225.00
Working days	300
Average miles per day	18
Load in pounds	12,000

Items	Per year	Per working day	Per mile	Per ton mile	Per cent
Wagon expense—					
Maintenance, grease, repairs, etc.,	$125.00	$0.417	$0.0232	$0.0039	5.20
Depreciation, 10 per cent	37.50	.125	.0007	.0011	1.56
Rental value of space	30.00	.100	.0056	.0009	1.25
Horse expense—					
Depreciation, 15 per cent	112.00	.374	.0208	.0035	4.66
Ratio that die, 1 in 20	10.00	.033	.0018	.0003	.42
Feed and bedding	550.00	1.834	.1019	.0169	22.91
Care (hostler)	150.00	.500	.0278	.0046	6.25
Veterinary	20.00	.066	.0036	.0006	.83
Medicine	15.00	.050	.0028	.0004	.63
Rental value, space for horses	150.00	.500	.0278	.0046	6.25
Shoeing	75.00	.250	.0139	.0023	3.13
Water	15.00	.050	.0028	.0004	.63
Blankets	12.00	.040	.0022	.0004	.50
Deterioration to building caused by horses	25.00	.084	.0046	.0007	1.05
Rental value of space for storing feed	15.00	.050	.0028	.0005	.63
Harness expense—					
Depreciation	12.00	.040	.0022	.0004	.50
Maintenance and repairs	20 00	066	.0036	.0006	.83
Rental value of space	8.00	.027	.0015	.0003	.33
General—					
Interest on investment	73.50	.245	.0136	.0024	3.06
Driver's wages	900.00	3.000	.1666	.0278	37.50
Stable supplies	25.00	.084	.0046	.0007	1.05
Removing manure	20.00	.066	.0036	.0006	.83
	$2,400.00	$8.001	$0.4380	$0.0739	100.

Comparative Economies.—The costs of horse transportation were calculated as follows: A one-horse truck with driver can be hired for $4 per day. Its maximum daily mileage would be 22 miles and its maximum capacity 1 ton. Hence, ton-miles per day (full load half way) = $\frac{1}{2} \times 22 \times 1 = 11$; and cost per ton-mile = $4.00 ÷ 11 = $0.364. Similarly:

Two-horse truck with driver, per day	$ 6.00
Maximum daily mileage, miles	20
Maximum capacity, tons	3
Maximum ton-miles per day = $\frac{1}{2} \times 20 \times 3$ =	30
Cost per ton-mile = $6.00 ÷ 30 =	$ 0.20

Three-horse truck with driver, per day	$ 8.00
Maximum daily mileage, miles	18
Maximum capacity, tons	5
Maximum ton-miles per day = $\frac{1}{2} \times 18 \times 5$ =	45
Cost per ton-mile = $8.00 ÷ 45 =	$0.178

These are the extreme points for the three curves. For lower mileages, the costs will be higher. The daily mileages given are much higher than would be obtained under average operating conditions. Hence, in most cases, the costs would be found further up on the curves.

The figures from which curves in Fig. 2 were plotted, for gasoline trucks, are from figures given in a table (see Table VIII) published in "Commercial Car Journal," Feb. 15, 1912, and are averages taken over a number of years, from records of trucks in actual service. They are based on the assumption that full load is carried half way.

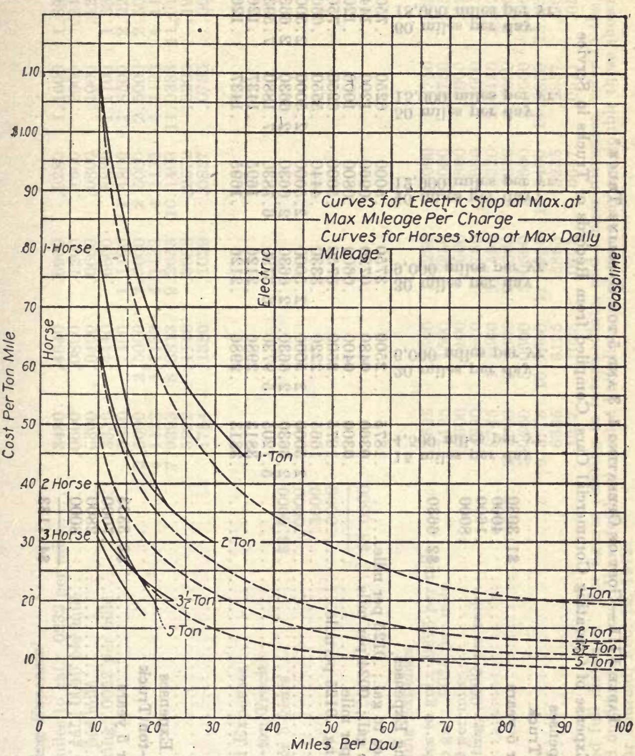


Fig. 2.—Comparative operating costs of gasoline, electric and horse trucks.

The figures for electric trucks of from 1 to 5 tons' capacity (see Table IX) were taken from a table published in February, 1912, by the Commonwealth Edison Co. of Chicago, a company operating a large force of electrics and supplying current to many others. Both these tables are thus from reliable sources.

In Fig. 3 is given another set of curves showing: (1) Horse-haulage costs collected by the National Association of Automobile Manufacturers, from professional truckmen. (2) Probable daily mileages for horse-trucks of various capacities. These are the results of actual practice. (3) Motor-truck speeds recommended by N. A. A. M. for trucks of various capacities.

TABLE VIII.—COST OF OPERATING 1, 3 AND 5-TON GASOLINE TRUCK*

Average Expense of Operating Commercial Cars, Compiled from Records of Trucks in Service

Fixed Expenses	
One-ton Truck	
Dep. on $2,000 at 20 % for 5 years	$1.3030
Interest at 6 %	.4000
Insurance	.1600
Garage	.8000
Total per day	$2.6630

Operating Expenses	15 miles per day; 4,500 miles per yr.	20 miles per day; 6,000 miles per yr.	30 miles per day; 9,000 miles per yr.	40 miles per day; 12,000 miles per yr.	50 miles per day; 15,000 miles per yr.	60 miles per day; 18,000 miles per yr.	70 miles per day; 21,000 miles per yr.
Gasoline at 15 cts.; 12 miles to gal.; .0125 per mile	.1875	.2500	.3750	.5000	.6250	.7500	.8750
Oil at 30 cts.; 125 miles to gal.; .0024 per mile	.0360	.0480	.0720	.0960	.1200	.1440	.1680
Grease and supplies, .002 per mile	.0300	.0400	.0600	.0800	.1000	.1200	.1400
Parts, renewals and painting, .0125 permile	.1875	.2500	.3750	.5000	.6250	.7500	.8750
Tires, .0111 per mile	.1665	.2220	.3330	.4440	.5550	.6660	.7770
Driver, $2.50 per day	2.5000	2.5000	2.5000	2.5000	2.5000	2.5000	2.5000
Fixed expenses	2.6630	2.6630	2.6630	2.6630	2.6630	2.6630	2.6630
Total per day	5.7205	5.9730	6.3780	6.7830	7.1880	7.5930	7.9980
Total per mile	.3813	.2986	.2126	.1695	.1437	.1265	.1142
Total per ton-mile	.3813	.2986	.2126	.1695	.1437	.1265	.1142

Fixed Expenses	
Three-ton Truck	
Dep. on $3,500 at 20 % for 5 years	$2.3333
Interest at 6 %	.7000
Insurance	.2800
Garage	.8000
Total per day	$4.1133

Operating Expenses							
Gasoline at 15 cts.; 6½ miles to gal.; .0232 per mile	.3480	.4640	.6960	.9280	1.1600	1.3920	1.6240
Oil at 30 cts.; 75 miles to gal.; 0040 per mile	.0600	.0800	.1200	.1600	.2000	.2400	.2800
Grease and supplies, .002 per mile	.0300	.0400	.0600	.0800	.1000	.1200	.1400
Parts, renewals and painting, .0022 per mile	.3330	.4440	.6660	.8880	1.1100	1.3320	1.5540
Tires, .0370 per mile	.5550	.7400	1.1100	1.4800	1.8500	2.2200	2.5900
Driver, $2.50 per day	2.5000	2.5000	2.5000	2.5000	2.5000	2.5000	2.5000
Fixed expenses	4.1133	4.1133	4.1133	4.1133	4.1133	4.1133	4.1133
Total per day	7.9393	8.3813	9.2653	10.1493	11.0333	11.6103	12.8213
Total per mile	.5292	.4140	.3088	.2572	.2206	.1935	.1831
Total per ton-mile	.1764	.1380	.1029	.0857	.0735	.0645	.0610

Fixed Expenses

Five-ton Truck

Dep. on $4,500 at 20 % for 5 years	$3.0000
Interest at 6 %	.9000
Insurance	.3600
Garage	.8000
Total per day...$	$5.0600

Operating Expenses							
Gasoline at 15 cts.; 4 miles to gal.; .0375 per mile	.5625	.7500	1.1250	1.5000	1.8750	2.2500	2.6250
Oil at 30 cts.; 40 miles to gal.; .0075 per mile	.1125	.1500	.2250	.3000	.3750	.2500	.5250
Grease and supplies, .002 per mile	.0300	.0400	.0600	.0800	.1000	.1200	.1400
Parts, renewals and painting, .0292 per mile	.4380	.5840	.8760	1.1680	1.4600	1.7520	2.0440
Tires, .0583 per mile	.8745	1.1660	1.7490	2.3320	2.9150	3.4980	4.0810
Driver, $2.50 per day	2.5000	2.5000	2.5000	2.5000	2.5000	2.5000	2.5000
Fixed expenses	5.0600	5.0600	5.0600	5.0600	5.0600	5.0600	5.0600
Total per day	9.5775	10.2500	11.5950	12.9400	14.2850	15.6300	16.9750
Total per mile	.6385	.5125	.3865	.3235	.2857	.2605	.2425
Total per ton-mile	.1277	.1025	.0773	.0647	.0571	.0521	.0485

NOTES.—Load carried full distance. For figures relating to intermediate, and longer distances, refer to the original paper. Costs per ton-mile plotted on Charts II and IV are for load carried half-distance; hence they are double those shown in this table.

*The Commercial Car Journal, Feb. 15, 1912.

Table IX.—Cost of Operating Electric Vehicles

(As published in February, 1912, by the Commonwealth Edison Company of Chicago.)

Item.	1,000-Pound Wagon—Mileage per annum—10,500			2,000-Pound Wagon—Mileage per annum—10,140			2-Ton Truck—Mileage per annum—9,390			5-Ton Truck—Mileage per annum—7,200		
	Per annum	Per day	Per mile	Per annum	Per day	Per mile	Per annum	Per day	Per mile	Per annum	Per day	Per mile
Fixed Charges—												
Amortization	$220.00	$0.7333	$0.0210	$265.00	$0.8833	$0.0262	$340.00	$1.1333	$0.0362	$450.00	$1.5000	$0.0625
Interest	66.00	.2200	.0063	79.00	.2633	.0078	102.00	.3400	.0109	135.00	.4500	.0188
Fire insurance	22.00	.0733	.9021	26.50	.0883	.0026	34.00	.1133	.0036	45.00	.1500	.0062
Liability insurance	100.00	.3333	.2095	100.00	.3333	.0008	100.00	.3333	.0106	100.00	.3330	.0139
Total	$408.00	$1.360	$0.0389	$470.50	$1.568	$0.0464	$576.00	$1.920	$0.0613	$730.00	$2.433	$0.1014
Renewal Charges—												
Batteries	$187.00	$0.6233	$0.0178	$221.00	$0.7367	$0.0218	$289.00	$0.9633	$0.0308	$425.00	$1.4167	$0.0590
Tires	145.60	.4853	.0138	216.30	.7210	.0214	286.60	.9553	.0305	618.80	2.0627	.0859
Chains	25.20	.0840	.0024	32.30	.1077	.0032	37.90	.1263	.0040	58.10	.1936	.0081
Gears and sprockets	46.00	.1534	.0044	54.00	.1800	.0053	59.05	.1964	.0063	79.40	.2646	.0110
Bearings	22.65	.0755	.0022	25.55	.0851	.0025	30.35	.1011	.0032	43.15	.1439	.0060
All other parts	30.00	.1000	.0029	35.00	.1167	.0034	40.00	.1333	.0043	50.00	.1667	.0069
Total	$456.45	$1.522	$0.0435	$584.15	$1.947	$0.0576	$742.90	$2.476	$0.0791	$1,274.45	$4.248	$0.176
Garage Charges—												
Electric power	$122.35	$0.4078	$0.0116	$152.10	$0.5070	$0.0150	$218.80	$0.7293	$0.0232	$330.50	$1.1015	$0.0459
Rent, light and heat	88.00	.2934	.0034	109.05	.3635	.0107	136.15	.4537	.0945	164.05	.5469	.0228
Garage labor	233.00	.7733	.0221	232.00	.7833	.0229	232.00	.7733	.0247	232.00	.7733	.0322
Total	$442.35	$1.475	$0.0421	$493.15	$1.644	$0.0486	$586.95	$1.956	$0.0624	$726.55	$2.422	$0.1000
Driver	750.00	2.500	.0715	750.00	2.500	.0738	750.00	2.500	.0798	750.00	2.500	.1042
Grand total	$2,056.80	$6.857	$0.1960	$2.297.80	$7.659	$0.2264	$2,655.85	$8.852	$0.2826	$3,481.00	$11.603	$0.4834

Note.—300 working days per year. For intermediate capacities, see original article in Power Wagon, February, 1912.

These speeds have been determined after considering all sides of the question, so that depreciation will not be too rapid, due to excessive speeds. (4) The costs shown in this curve for the operation of gasoline trucks of various capacities were plotted from figures published by the Knox and the Hewitt automobile companies. Part of the figures are averages of the two, the remainder being either Knox or Hewitt costs alone.

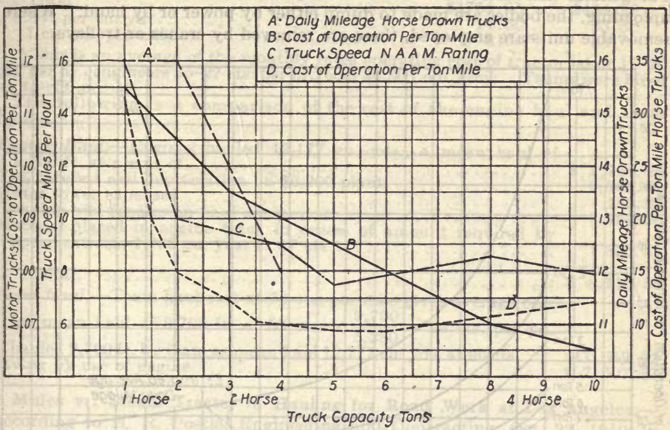


FIG. 3.—Comparative operating costs of motor and horse trucks.

In Fig. 2 truck capacities up to 5 tons were shown. In Fig. 4 additional curves are shown for capacities from 6 to 10 tons. The same rates of increase were maintained in figuring the unit costs in these trucks of larger capacity, the results being checked by estimating the various capacities. In addition, calculations were made, assuming average conditions as to running speeds and working hours, to determine what daily mileages trucks of these various capacities would accomplish under ordinary conditions. Results were compared with figures submitted by the N. A. A. M., and were found to check quite well. A curve was plotted from these values, between daily mileages and truck capacity, on the same sheet with the other curves. This curve cuts the cost curves, thereby marking out the working part of these curves for average conditions. The cost curves approach one another as capacity is increased; increase of daily costs begins to catch up to increase in daily ton-miles, so that it becomes less and less of an advantage to increase from one capacity to the next. This is true even when the mileages per day are kept constant. But in actual changing from seven to ten ton capacity there is practically no decrease in cost of hauling per ton mile.

Referring again to Fig. 2 we find that for low mileages, up to about 18 miles per day, the three-horse truck is the most economical means of transporting goods. This then is the field of usefulness of the horse-drawn vehicle, i.e., where traffic loading, unloading or other conditions are such that the conveyance is forced to remain idle a considerable portion of the day and would therefore be un-economical. Realizing the truth of this argument, the truck manufacturer is designing loading and unloading devices, by the use of which standing time is reduced to a minimum, and the motor truck is thus able to cope successfully with the horse, even in this short haul work. To reduce loading time, several means are resorted to, depending on the nature of the product to be transported. For building materials, coal, etc., cranes, scoops and other mechanical loading devices are employed with great success. For general merchandise, bodies made up of several units are used. For uploading, the bodies are made to dump either by power or by hand. Where removable units are employed, these are removed by cranes or trolleys.

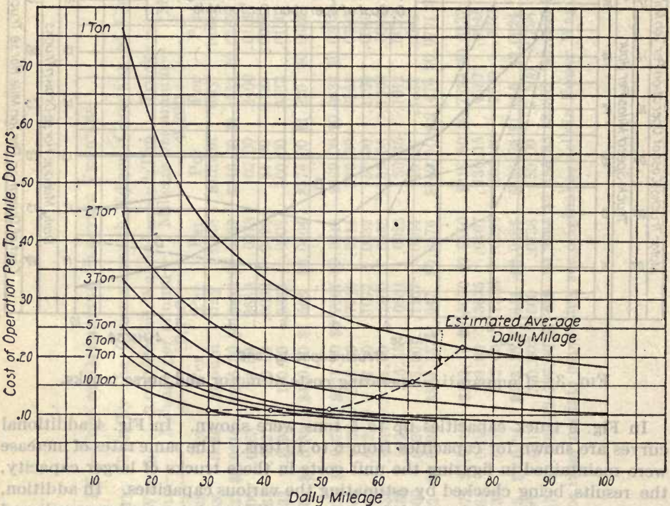


FIG. 4.—Cost of operation per ton-mile for average conditions, various truck capacities and daily mileages.

Comparative Costs of Hauling with Steam Tractor and Teams are given by K. I. Sawyer in Engineering and Contracting, March 13, 1912. The records were taken in 1911 on road extension work of Menominee County, Mich.

Owing to the fact that the steam haulers (75 h. p. Case Traction Engines) were a new part of the county plant a comparison was worked out to show the advantage of using this equipment. This comparison was taken directly from the schedule of actual costs of the road. In the work 12,177 cu. yds. of stone were handled by the engines and 1,912 cu. yds. by team. This work was under identical conditions and gives a good basis of comparison. The team haul rate was 53 cts. per yard-mile. This would be considered high under normal conditions, but it was good under existing conditions. The conditions under which the hauling was done were very stern as is shown by the fact that it was possible to load only about a ton to the load for teams at the start, and even then it was necessary to double the teams over considerable of the road now built. Only good teams weighing 2,900 lbs. to 3,400 lbs. each were used. Further details regarding the hauling are given in Table X.

TABLE X.—COST OF HAULING WITH TRACTOR AND TEAMS

Item	Steam tractor haul	Team haul
Av. haul, ft.	9,700	2,300
Total cu. yd.	12,177	1,912
Cost		
Labor	$ 940.87	....
Coal and oil	$ 814.08	....
Total	$1754.95	$454.26
Av. per cu. yd.	14.5c	23.8c
1 cu. yd. per mile	8.6c*	53.*

* This is an average of the monthly rates operating cost of tractor labor 17–20 cts. per hr., engineers 25–27 cts. per hr., coal $4.50 f.o.b. scow. Teams were hired at 45 cts. per hr.

The following is a comparison of the cost of the engine haul and team haul:

Engine Haul.—Engines hauled 12,177 cu. yds., a mean haul of 9,700 ft. at a cost of	$ 1,754.96
20% interest and depreciation on $6,200 plant	1,260.00
Water tower expenses	140.92
Cleaning and repairs on haul equipment	163.26
Material placed in engine track in excess of amount required by specifications, 1,703 cu. yds. at 47 cts	800.41
Total	$ 4,119.55

Team Haul.—Team haul cost at 53 cts. per mile gives average cost for mean haul of 9,700 ft. of 53 cts. $\times \frac{9,700}{5,280}$ = 96 cts. per yd.

hauled 9,700 ft. by team as mean haul 12,777 cu. yds. at 96 cts.	$11,689.92
Saving by use of engine	$ 7,507.37

Mules vs. Steam Tractor in Hauling for Road Work at Los Angeles.—According to H. R. Postle, Engineering and Contracting, Oct. 22, 1910, in hauling crushed rock from cars to the road, under construction at Los Angeles, Cal., it proved cheaper to haul rock with mules than with a traction engine, using the type of wagon ordinarily manufactured and sold to be drawn in train with an engine. The particular wagon used was the Port Huron 5-yd. or 6 ton wagon; each was fitted with a tongue, two mules being hitched alongside the tongue with three abreast in the lead. With a haul of about ½ mile, each wagon made 10 trips per day of 8 hours, thus delivering on the road 60 tons of rock at a cost of $7.50 (five mules at $1.00 per day and $2.50 per day for the driver) or $0.125 per ton. To have hauled 60 tons of rock with 2-yd. wagons would have required two and a half 2-yd. wagons costing $4.25 each (two horses $2.00, one driver $2.25) or $10.65, which would make the cost $0.177 per ton, which shows a saving of $0.052 per ton by hitching more stock to one wagon and using a large sized wagon. The saving will increase with the length of haul. The coupling of two or three wagons together, or using a wagon of large capacity, with 4 to 8 head of stock is a very common California practice, and is one which the writer has failed to observe in the east. It is the writer's experience that this method of hauling, unless the haul be a long one, will generally be found to be cheaper than hauling by engines for the following reasons:

1. To load a train of wagons quickly requires either a private or specially constructed railroad switch and loading bins, or two trains of wagons, one of which is loading while the other is on the road. Loading wagons continuously one by one does not require so much in the way of switches, bins or wagons.

2. Most contracts demand an equipment easily and cheaply movable from one switch to another. It is seldom that all of the loading can be done at one

switch, consequently expensive equipment which cannot be cheaply and quickly moved, is not justifiable.

3. Horse equipment is better adapted to torn-up and dusty roads, which are sure to be encountered where construction work is in progress.

4. Horse drawn wagons are more easily handled on the sub-grade where the rock is dumped. They pull in on the sub-grade more easily, do less damage, dump and pull out and turn around more quickly.

5. On very few contracts and on very few railroad switches can rock be delivered fast enough to justify the equipment required for engine hauling. The whole equipment, the necessary unloading devices and the number of wagons, more easily fit the general run of contracts where horse drawn wagons are used.

Of the numerous contracts now under construction in Los Angeles County, where $3,000,000 is being expended on macadam road construction, on only one is the rock being hauled by steam engines. They were tried on several others, but quickly abandoned.

Motor Truck Cheaper than Teams on Hauling Gravel.—F. P. Scott in Engineering News-Record, May 16, 1918, gives the following data on cost of hauling gravel for road constructing in Montana.

Teams and a 5-ton (5 cu. yd. capacity) truck were used. Late delivery of the truck prevented it doing its full share of the work.

Labor and supplies were paid for at the following rates: Common labor; $0.375 per hour; team and teamster, $0.75 per hour; foreman, $0.45 per hour, truck drivers, $100 per month; gasoline, $0.27 per gallon; oil, $0.52 per gal.

TABLE XI.—COMPARATIVE COST OF HAULING GRAVEL BY TEAMS AND MOTOR TRUCK

Item	Team hauling	Truck hauling
Total amount hauled, cu. yds.	21,952	2,937
Haul, miles ave.	1.588	2.079
max.	2.125	2.416
min.	0.704	1.805
Cost per yd. mi., ave.	$0.431	$0.235
max.	0.813	0.292
min.	0.349	0.158

The operating costs of the truck upon which the above units are based were as follows:

Operator	$292.05
Repairs	131.59
Fuel	320.63
Int. and Depr.	695.16

Economics and Costs of Motor Truck Operation.—The following matter, from a paper by W. H. Clapp in the Journal of the A. S. M. E., Oct., 1916, is given in Engineering and Contracting, Oct. 18, 1916.

Economics of Truck Operation.—For many kinds of haulage, covering a wide range of operation, the motor truck is distinctly superior to any other method of transportation. Given an active service at full load, with a terminal not definitely fixed and a radius of operation up to 30 miles, it is an exceptional condition which will justify any other method of goods haulage.

There are, however, special considerations which may have considerable bearing upon the employment of a truck. A committee of the Boston Chamber of Commerce, in a detailed report on street traffic in Boston, covering eighteen months of study, reported that "development of motor trucks will tend to relieve congestion by moving all merchandise in larger units and more rapidly," and that "the average speed of motor vehicles in getting into and away from railway terminals is from two to three times that of the horse."

Costs of Gasoline Trucks.—Fig. 5 gives curves of cost, weight and horsepower (average values) for all classes of gasoline trucks as listed by publishers of motor truck publications. The noticeable feature of these curves is the sudden break of each for the lighter trucks of less than 1 ton capacity. These show that the demand for a light truck has been met by making a vehicle which is much lighter for the rated load than the heavier trucks. This is possible because of the higher engine speed, a more simple final drive, torque and thrust taken through the vehicle springs, and by the generous use of

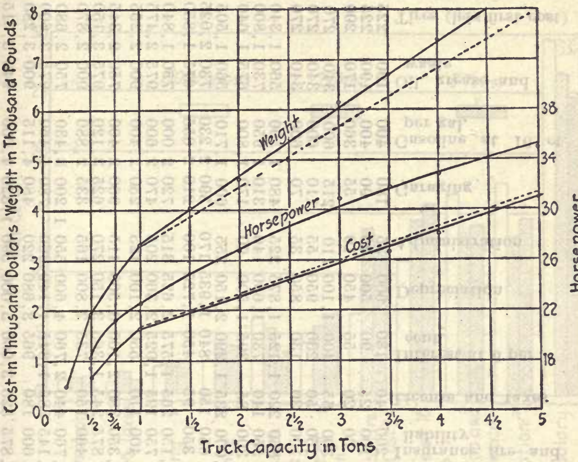


FIG. 5.—Average cost, weight, capacity and h.p. from all classes of gasoline motor trucks.

special alloys and heat-treated steels. The curves suggest that these trucks are too light for the load that they are rated to carry. That this is true is abundantly proved by the records of many light trucks which show that the average life of a light delivery truck is about 35,000 miles, whereas the heavier trucks when properly driven; and cared for can be depended upon to give 80,000 to 100,000 miles, or even more for the better grade of trucks, if they are carefully driven and ordinary maintenance is kept up.

Table XII is an itemized cost statement for various sizes of gasoline trucks under average service conditions on the roads of southern California. That these costs are somewhat lower than averages for other localities may be largely credited to good roads and an equable climate. In making this table three conditions of operation are assumed: the costs for each size of truck are computed for a daily run of 25, 50 and 75 miles, and for each condition the life of the truck is estimated, and depreciation is based on this life. Costs are given in dollars for the entire life of the truck. First costs are average chassis costs in Los Angeles, as follows; Light delivery wagon, 18 h. p., $600.; 1,500

TABLE XII.—TOTAL COST OF OPERATING GASOLINE MOTOR TRUCKS AT VARIOUS DAILY MILEAGES

Capacity of truck	Estimated life, years*	Total mileage	Costs for entire life of truck, in dollars: Insurance, fire and liability	License and taxes	Interest at 6 per cent	Depreciation	Administration	Garaging	Gasoline at 16 ct. per gal.	Oil, grease and waste	Tires (less first cost)	Driver's salary	Inspection and maintenance	Total	Cost per mile, dollars
Light delivery wagon.....	5	37,500	200	40	180	600	35	180	400	190	225	2,400	750	5,200	0.139
	2½	37,500	100	25	90	500	20	90	400	190	225	1,200	655	3,495	0.096
	1½	33,750	60	20	55	450	10	55	360	170	200	900	505	2,785	0.082
1,500 lbs..............	6	45,000	300	65	400	1,100	110	215	600	340	270	3,600	1,010	8,010	0.178
	3	45,000	150	50	230	950	55	110	600	340	270	1,800	900	5,455	0.121
	2	45,000	100	30	130	850	35	70	600	340	270	1,440	790	4,655	0.103
1 ton..................	10	75,000	850	220	1,125	1,875	225	480	1,500	560	1,340	7,200	1,900	17,275	0.230
	6½	97,500	550	140	730	1,690	140	310	1,950	730	1,800	4,680	1,900	14,620	0.150
	4	90,000	300	85	395	1,500	90	170	1,800	675	1,640	3,468	1,800	11,815	0.131
1½ tons..............	10	75,000	1,000	235	1,290	2,150	255	600	1,710	560	1,505	7,200	2,000	18,505	0.247
	6½	97,500	650	150	840	1,935	170	390	2,230	730	2,025	4,680	2,000	15,800	0.162
	4	90,000	350	95	450	1,725	100	210	2,055	675	1,850	3,360	1,900	12,770	0.142
2 tons................	10	75,000	1,150	265	1,575	2,625	315	720	2,000	750	1,840	7,200	2,250	19,440	0.276
	6½	97,500	750	195	1,025	2,360	205	470	2,600	975	2,475	4,680	2,250	17,985	0.184
	4	90,000	400	110	550	2,100	125	250	2,400	900	2,255	3,360	2,100	14,550	0.162
3½ tons..............	10	75,000	1,350	380	2,100	3,500	415	960	2,400	750	2,345	9,600	3,250	25,700	0.361
	6½	97,500	875	245	1,365	3,150	270	625	3,120	975	3,150	6,240	3,250	23,265	0.239
	4	90,000	460	150	735	2,800	165	335	2,880	900	2,870	3,840	3,000	18,135	0.201
5 tons................	10	75,000	1,760	440	2,760	4,600	550	1,200	3,430	750	2,680	10,800	4,000	32,970	0.439
	6½	97,500	1,145	285	1,845	4,140	360	780	4,460	975	3,600	7,020	4,000	28,610	0.297
	4	90,000	600	180	965	3,680	220	480	4,115	900	3,280	4,320	3,600	22,340	0.223
6½ tons..............	10	75,000	1,875	525	3,000	5,000	590	1,320	4,000	940	3,015	10,800	5,000	36,065	0.481
	6½	97,500	1,220	350	1,950	4,500	380	860	5,200	1,220	4,050	7,020	5,000	31,750	0.326

* Based on daily mileage of 25, 50 and 75.

lbs. truck, 22 h. p., $1,100; 1 ton truck, 24 h. p., $1,875.; 1½ ton truck, 25 h. p., $2,150; 2 ton truck 26 h. p., $2,625.; 3½ ton, truck 32 h. p., $3,500.; 5 ton truck, 35 h. p., $4,600; 6½ ton truck, 40 h. p., $5,000.

In California distillate is being used to quite an extent as a substitute for gasoline. The cost per gallon is about half that of gasoline at the present time (1916), and the b. t. u. content somewhat greater. A supply gasoline is carried and used in starting. The consumption of distillate is about the same as that of gasoline. The success which has attended this innovation would seem to justify the claims that the use of distillate does not increase carbon trouble. The question of a lessened volumetric efficiency is a negligible consideration.

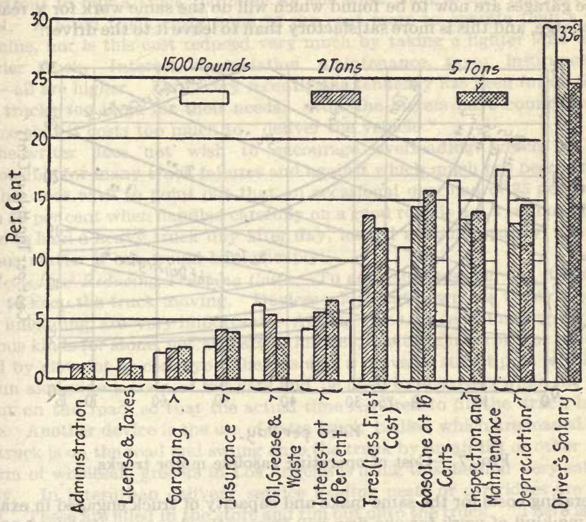


FIG. 6.—Division of truck costs.

Tires will outwear the manufacturers' guarantee at least 25 per cent when used on the good roads of southern California. Smooth roads, dry surfaces and an equable climate all contribute to this result. Overloading and overspeeding are the things that shorten tire life. However, the important consideration is not tire economy, but economy of truck operation per ton of material carried; therefore, durability is only one factor that must be taken into account. Resilience, which prevents the wasting of truck power; cushioning effect, which keeps the maintenance charges low on the whole truck; a good tractive grip and a reasonable cost are all properties which are required in a truck tire.

Operating Costs.—Fig. 6 gives a graphical view of percentage costs for a light, a medium and a heavyweight truck, each averaging 50 miles a day. The higher proportion which the light truck has in the items of labor, depreciation and maintenance is noticeable. Against this increase is the lower percentage of the entire cost charged to fuel and tires.

In discussing motor truck costs it is not possible to neglect the human factor, which here more than in most cases of machinery handling is one of the principal items. It is hardly too much to say that maintenance costs are chiefly driver. An expensive and intricate machine is put in charge of a low-paid employe who is not the owner and who ordinarily has but a limited knowledge of machinery. This is one reason why the life of a light truck is usually about two or three years.

Ownership of eight or ten trucks will justify an owner in employing a mechanic who, with a small outfit of tools and a helper, can keep the trucks clean and in adjustment and make many of the smaller repairs. Reliable service garages are now to be found which will do the same work for a reasonable charge, and this is more satisfactory than to leave it to the driver.

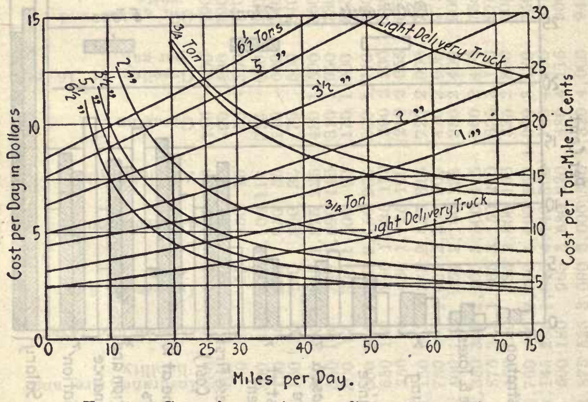


FIG. 7.—Cost of operating gasoline motor trucks.

Operating costs for the same make and capacity of truck engaged in exactly the same kind of work for one firm will frequently show a variation of 40 per cent in the items of gasoline, oil, tires and maintenance. It is easy to see how a poor driver will shorten the life of a truck.

The truck governor has helped to solve the speeding problem. Another aid is the recording speedometer, which gives a graphical log of each day's run—velocity plotted against time: thus every minute of the day is accounted for; the number of stops and time of each, maximum speed, etc. The chart will show, for example, whether it will pay to put on a second man to hasten deliveries or whether a rerouting of existing lines will give a better all-around service. A driver's record sheet, if it is brief and informing and filled out each day, is frequently helpful. It must be drawn off at the office and kept up to date. Records are of little use unless changed conditions can be recognized at once.

Fig. 7 gives curves for gasoline trucks plotted from the data of Table XII. These curves, if continued out to the line of zero miles per day, show the daily fixed charges for each truck. The cost per day increases quite uniformly with the increase in size of the truck, whether the daily run be a large or a small one. The cost per ton mile is based on a full load each way. This chart shows that under such favorable conditions of haulage a heavy truck may reach a ton-mile cost of as low as 5 ct., provided that the nature of the work is such that the truck can be run daily at the rate of 50 or 60 miles a day. This is a heavy mileage for a big truck, and such an ideal service as would be represented by a full haul each way on level roads, with loading and unloading time minimized so that the truck could be under way for six or seven hours each day and with no extra helper required, is not often found.

In deciding upon a truck one of the most important questions to settle is that of size. On the good roads of this section (California) it is more disastrous to buy a truck too large for the work than to buy one that is too small. A 5-ton truck costs some 25 per cent more to operate than a 3-ton machine, nor is this cost reduced very much by taking a lighter load on the heavier truck. Interest, depreciation, maintenance, taxes, insurance and fuel—all are higher. Until very recently the tendency has been for owners to buy trucks too large for their needs. Now the buyers have commenced to realize that it costs too much to "deliver the vehicle."

The writer does not wish to encourage overloading, which has been responsible for many truck failures and against which much has been written, but he does wish to point out that an occasional overload of 25 per cent, or even 50 per cent when handled carefully on a good road is not a serious matter. while to haul a heavy truck day after day, loaded at half capacity, is a very serious matter if one would haul cheaply.

Methods of Reducing Trucking Costs.—To get a low cost per ton it is necessary to keep the truck moving. Devices which cut down the time of loading and unloading are very important. Among these are self-dumping bodies of various kinds for stone, hot asphalt or lumber; loading chutes or bins which are filled by elevator or conveyor; there is also a movable steel tipple which can be run alongside a train of flat cars and be filled by shovelers while the truck is out on the road, so that the actual time required to fill the truck is very little. Another device is the use of extra truck bodies, which are loaded while the truck is on the road and swung onto the truck by an air lift or other hoist. A firm of wholesale grocers in Los Angeles is using this method very satisfactorily. In interurban delivery service loading nests or cartridges are being used. These are filled in the store and run out onto the truck. There is some promise in the extension of this device for relieving the congestion around freight stations and also for interurban service where a heavy truck can bring over all of the orders for an entire community and local deliveries be taken care of by light trucks, each with its especial cartridge. A scheme somewhat similar to this is now being tried out by the city of Los Angeles. The incombustible rubbish is gathered by a house-to-house collection, using wagons. The material is put in large cans which are carried to a central point and a heavy truck is used to haul all of the cans to the city dump.

Comparisons of Operating Costs of Horse-Drawn and Motor Trucks.—The use of an extra man to facilitate deliveries will often save enough time to make a good investment. One of the large department stores in Los Angeles found that on a certain route where one man had averaged 110 stops a day two men were able to make 190 deliveries. The use of self-starters on trucks of this type is also becoming common. These save a little time on each stop and also keep the driver out of the dirt, and particular customers appreciate this feature. At the plant of the Southern California Gas Company the night man unloads the trucks and stores the pipe and old meters that have been collected during the day, and then puts onto the truck the new supplies that have been requisitioned for the coming day.

Fig. 8 and Table XIII show a comparison between the cost of running a light gasoline delivery truck such as is used for close-in delivery work by grocers and the cost of running a one-horse delivery wagon. The costs are

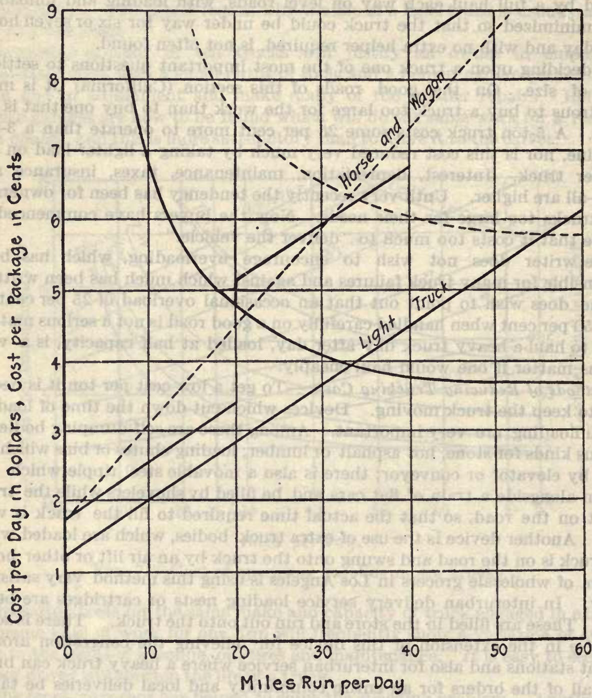


FIG. 8.—Comparison of single horse and wagon and light delivery truck costs.

from actual costs gathered in Los Angeles and vicinity and averaged. For each vehicle the cost is figured for the vehicle idle and again when running at a fair maximum daily average. The figures show that there is no excuse for using a horse for this kind of work, whether the number of deliveries be large or small. Twenty miles a day is a maximum for any delivery horse if used 300 days a year. If more than 20 miles a day are to be covered, it is necessary to duplicate equipment.

Fig. 9 and Table XIV give a similar comparison between the cost of operating a 5-ton gasoline truck and heavy teams used for such work as rock and dirt haulage and heavy transfer work generally. As in Fig. 9, the costs are figured from actual costs based on a maximum of service per day and an assumption as to what the costs would be if the vehicle did no work. The curves show that the truck should have enough work to do to occupy the time of more than one team, if it is to be the cheaper vehicle. The Pacific Electric Railway Co. uses heavy trucks for patching and paving along the line. They find that for work outside the business district the truck will do the work of two or three teams, depending upon the length of haul and the size of the job; for long-distance hauling the truck will do the work of four or five teams.

In paving Vernon Ave. the rock and crushed stone were delivered by teams, the average haul being about two miles. Each team delivered a 3-ton load

TABLE XIII.—COMPARISON OF OPERATING COSTS OF A SINGLE-HORSE WAGON AND A LIGHT DELIVERY TRUCK

Cost of wagon equipment (horse, $250; wagon, $140; harness, $40), $430.
Cost of 700-lb. capacity gasoline truck, $600.

	—Wagon costs—		—Truck costs—	
	Idle	20 miles per day	Idle	60 miles per day
Estimated life, years	10	10	10	2.5
Depreciation	$0.108	$0.156	$0.200	$0.760
Interest at 6 per cent	0.086	0.086	0.120	0.120
Taxes	0.009	0.009	0.012	0.012
Stable and garage rent	0.200	0.200	0.166	0.166
Insurance (fire and theft)	0.030	0.030	0.045	0.045
Driver (1/3 time when idle)	0.666	2.000	0.666	2.000
Feed—				
Hay, 10 lb. and 15 lb	0.102	0.153	......	......
Oats, 10 qt. and 15 qt	0.200	0.300	......	......
Gasoline, at 16 ct. per gal	......	......	......	0.640
Lubricating oil, at 40 ct	......	......	......	0.130
Hostler (1 man to 12 horses)	0.200	0.300	......	......
Cleaning and oiling	......	......	......	0.400
Shoes and veterinary	0.095	0.135	......	......
Tires and tubes	......	......	......	0.625
Repairs to wagon	......	0.090	......	......
Maintenance	......	......	......	1.200
Water, bedding, etc	0.045	0.045	......	0.005
Total cost per day	$1.741	$3.404	$1.209	$6.103

TABLE XIV.—COMPARISON OF OPERATING COSTS OF A 5-TON GASOLINE TRUCK AND A HEAVY TWO-HORSE WAGON

Cost of wagon equipment (2 draft horses, $600; wagon, $300; harness, $100), $1,000.

Cost of 5-ton gasoline truck, $4,800.

	—Wagon costs—		—Truck costs—	
	Idle	16 miles per day	Idle	50 miles per day
Depreciation	$ 60	$ 120	$ 240	$ 480
Interest	60	60	288	288
Taxes	6	6	30	30
Stable or garage	120	120	120	120
Insurance (liability)	....	26	......	140
Driver	250	750	360	1,080
Helper	....	600	......	600
Feed or gasoline	90	135	......	686
Oil, grease, waste, etc	....	5	......	150
Shoes and veterinary, or tires	25	40	......	550
Repairs, maintenance	....	25	......	600
Water, bedding, etc	25	25	......	20
Hostler	100	100	......	......
Total cost { Per year	$736	$2,012	$1,038	$4,744
Total cost { Per day	$2.45	$6.70	$3.46	$15.81

and averaged 5½ trips per day. When work on other contracts took the teams away the work was sublet to another contractor, who took the job at the same price per ton as the teams were figured to have cost. Three 5-ton trucks averaged 12 trips per day eaeh, and carried an average of 54.7 tons per day apiece. This makes each truck equivalent to 3.3 teams, which would represent a considerable saving by the use of trucks, provided they could be kept steadily employed.

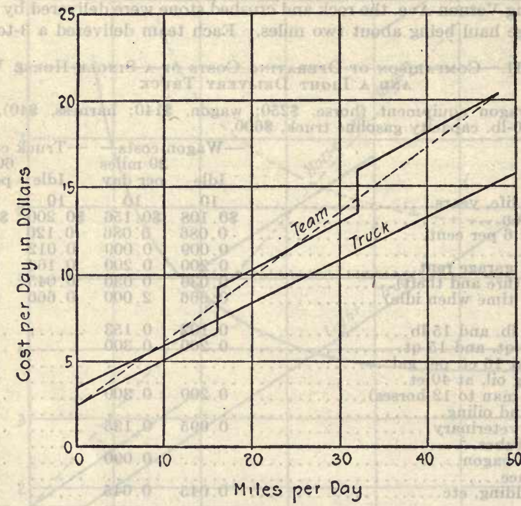


FIG. 9.—Comparison of costs for 5-ton gasoline truck and heavy teams.

The use of electric trucks for delivery service is not so general in Los Angeles as in most large cities. Two of the largest department stores in Los Angeles use no electrics, and other stores which do use them have usually a smaller percentage of the entire fleet of this type. There are two reasons for this: First, a smaller congested area than cities like Boston or Chicago; and, second, a smaller number of stops per mile. For light delivery service where the vehicles carry 1,000 lb. or less the higher first cost of the electrics is a serious objection; for vehicles in the 1,500-lb. class the difference in first cost is not so great, and the electric vehicle will show a lower cost per delivery than the gasoline truck where the latter is held down to the same number of miles per day. Table XV gives the average work and costs for one month for both classes of vehicles for one of the large department stores in Los Angeles. From

TABLE XV.—COMPARISON OF GASOLINE AND ELECTRIC DELIVERY TRUCKS (Averages for 1 month)

Type of truck	Gasoline	Electric
Miles traveled per day	75	36
Stops per mile	1.96	2.74
Stops per day	147	104
Cost per mile, cents	12	15.3
Cost per stop, cents	6.12	5.29

this it will be seen that, where the electric truck gives a cheaper delivery, it has the advantage of more stops per mile. It is probable that in spite of the close-in traffic conditions the gasoline truck would cover the same route in less time or give a larger number of deliveries per day in the same territory. These costs are based on the use of two men with the gasoline truck and one man on the electric. The comparison shows that the advantage in favor of the electric truck is a very small one, and may vanish altogether under comparative tests. On the other hand, there is an advantage for the electric in its quieter operation and greater cleanliness that is worth something in delivery service.

Operating Cost of 5-Ton Dump Truck (Engineering and Contracting, Aug. 6, 1919).—As the result of a questionnaire the Motor Truck Owners' Association of Philadelphia ascertained that the average daily cost of operation for a 5-ton truck of dump body type working under (1919) Philadelphia conditions was $26.09, itemized as follows:

	Per day	Per cent
Depreciation	$ 5.29	20.3
Interest	0.76	2.9
Insurance	1.25	4.8
License	0.11	0.4
Gasoline	3.42	13.1
Oil and grease	0.42	1.6
Repairs	5.11	19.6
Garage fees	0.74	2.8
Overhead expense	1.74	6.7
Driver	4.96	19.0
Tires	2.29	8.8
Total	$26.09	100.0

It also was found out that the fixed charge costs should be based on a 265-day year, and that the average daily mileage was 40½ miles.

Operating Costs of Motor Truck Delivering Sand and Gravel (Engineering and Contracting, March 21, 1917).—A Pacific Coast sand and gravel company is using a 5-ton truck for delivering sand and gravel. The material is nearly always mixed and usually is quite wet. It runs 4 yds. to the load and 3,400 lbs. to the yard, and is hauled over country roads of various kinds, about equally divided between gravel and dirt. There are many hills, some of them quite steep, necessitating going in first and second gears. Most of the trucking was for delivering gravel on county roads, and spreading it with the attachment on the truck. The operating costs, furnished by the company for a 5-months period are given in Table XVI.

TABLE XVI.—OPERATING COSTS, 5-TON TRUCK, 4-YARD CAPACITY

Article used	Amount gal	Miles per gal. or lb.	Av cost article	Total cost	Cost per mile
Distillate	1 655	3.494	11†	$ 182.05	$0.0153
Gasoline	606	3.494	21†	121.20	.023
Motor oil	133	59.4	31†	41.23	.0052
Transmission oil	249*	31.7	5½‡	13.48	.0017
Sprocket oil	144	55	7†	10.8	.0012
Cup grease	100*	79	5‡	5.00	.0006
Tire replacements and depreciation	......	......	.....	154.93	.0196
Repairs and parts	......	......	.....	21.06	.0026
Wages	......	......	.....	508.75	.057
Interest (8 per cent)	......	......	.....	218.78	.0276
Depreciation (20 per cent)	......	......	.....	394.66	.05
	......	......	.....	$1,671.22	$0.2038

* Pounds. † Cts. per gal. ‡ Cts. lb.

For the Season

Average distance of delivery, miles	6.1
Cost per yard mile	$0.1055
Cost per ton mile	.0617
Total mileage	7,900
Yards delivered	5,190
Weight of gravel, 1 yd., lb	3,400
Yard miles hauled	15,800
Ton miles hauled	28,835

The truck was new last year. The driver was paid for an extra hour each day the truck was operated. This extra time he put in screwing down the grease cups and inspecting parts on the truck. The driver was, therefore, held responsible for anything happening that could have been prevented by his inspection. In several instances he discovered that there was a loose nut, missing bolt, cup gone or something of minor importance, which if neglected might cause lost time and more or less expense. These things were immediately attended to and as a consequence no time was lost on account of truck trouble.

Cost of Hauling with Motor Trucks.—The following figures, given by J. A. Broad, Luce County Engineer, in a paper presented at the Michigan Road School (1919). are published in Engineering and Contracting, April 2, 1919.

The cost of hauling with motor trucks in highway work in 1918 in Luce County, Michigan, averaged about 10 ct. per ton mile. Two 5-ton White trucks were employed. The interest on the truck investment was taken at 6 per cent per year and amounted to $288 for each truck. There was no insurance.

The charges for Truck No. 1 were as follows:

Depreciation 100,000 miles (truck value minus tires)	$ 255.16
Total wages of driver	319.74
Gasoline, 1,377 gal. at 25 ct	344.25
Lubricating oil, 117 gal. at 56 ct	65.52
Hard oil, 128.5 lb. at 6 ct	7.71
Waste, 20 lb. at 20 ct	4.00
Tire depreciation—5,316 miles at 3 ct	159.48
Repairs and renewals	160.00
Total operating charges	$1,315.86
Fixed charges (interest)	288.00
	$1,603.86
Average haul in miles	5.54
No. of yds. hauled	1.863
Total number of yd. miles performed, 10,321	$0.155 yd. mile
Total number of ton miles performed, 15,481	0.104 ton mile

The charges for Truck No. 2 were:

Depreciation 100,000 miles (truck value minus tires)	$ 237.40
Total wages paid driver	297.00
Gasoline, 1,235 gal. at 25 ct	308.75
Lubricating oils, 117 gal. at 65 ct	68.88
Hard oils, 128.5 lb. at 6 ct	4.08
Waste, 21.5 lb. at 20 ct	4.30
Tire depreciation, 4,946 miles at 3 ct	148.38
Repairs and renewals	131.00
Total operating charges	$1,199.79
Fixed charges (interest)	288.00
	$1,487.79
Average haul in miles	5.54
No. of yards hauled	1.780
Total number of yd. miles performed, 9,861	$0.151 yd. mile
Total number of ton miles performed, 14,791	0.101 ton mile

Operating Costs for 3½-Ton Truck (Engineering and Contracting, Aug. 6, 1919).—In an address before the Detroit Transportation Association, C. E. Stone gave the following figures taken from the cost records of a Detroit owner for the operation of a 3½-ton stake body truck:

INVESTMENT		
Chassis		$3,800.00
Body		350.00
		$4,150.00
Less tires ($74.25 each, 7,000 miles guaranteed)		445.50
		$3,704.50
Costs are based upon 300 working days in the year		
YEARLY FIXED CHARGES—		
Interest on $3,704.50 at 6 %	$	222.27
Insurance—		
Fire, 75 ct. per hundred		31.13
Collision, full coverage $152, $50 deductible		102.00
Liability (truckman)		135.00
License—		
15 ct. per horsepower (4½ × 5½ − 32.4)		4.86
Weight, 15 ct. per 100 lb., chassis 7,000 lb., body 1,800 lb., total 8,800 lb		13.20
City dray		1.00
Tax 3 % on 70 % of $4,150 ($2,905)		87.15
Garage, $15 per month		180.00
Driver, $5 per day (300 days)		1,500.00
Per year		$2,276.61
300 days $2,276.61, per day cost		$7.58
OPERATING COSTS—		
Fuel (25 ct. per gal., six miles per gal.) per mile	$	0.040
Lubricants (60 ct. gal., 150 miles per gal.) per mile		.004
Tires (7,000 miles set, $445.50) per mile		.064
Depreciation ($3,704.50 on 100,000 miles) per mile		.037
Per mile	$	0.145
Overhauling ($300 per year) per day		1.00
60 miles per day at .145		8.70
Total daily cost	$	17.28
Per ton mile cost	$	0.288

It will be noted that the above figures contain no allowance for the "cost of doing business," which includes general expenses, accidents, bad accounts, etc. To meet these charges this owner charges up $1 a day per truck which he finds about meets the figures. He also has a general sinking fund of 10 per cent of the daily gross receipts of each truck to take care of this matter.

Economic Motor Trucking over very Bad Roads (Engineering and Contracting, Dec. 20, 1916).—The Haskins Dolomite Co., of San Francisco, operates a 5-ton White truck with a Troy trailer from their dolomite quarry to the railway a distance of 10.5 miles, and the truck makes four round trips every 24 hrs., working two shifts. The road is one of the worst of mountain roads, full of chuck holes, covered with dust often 6 ins. deep, with grades up to 10 per cent, one of which (10 per cent) is 1.5 miles long. The truck requires 44 gals. of gasoline and 4 gals, of oil for the day's work of 84 miles. The daily operating expense is about $30, which is equivalent to 7 ct. per ton-mile, exclusive of interest and depreciation, but inclusive of tire renewals and current repairs.

Trailers for Use with Contractors' Motor Trucks.—According to Engineering and Contracting, Dec. 3, 1913, extensive experiments, made by the Troy

Wagon Works Co. in studying the problem of the ability of motor trucks to pull one or more trailers, show that the average truck loaded to its rated capacity, in addition to carrying its rated load, develops a drawbar pull equal to about one-half of its rated load. A team of horses will develop a maximum sustained drawbar pull equal to about one-fourth of their weight. It was estimated from the tests that the drawbar pull required to move a ton of material varies from 50 lbs. on a brick street to 150 lbs. on a hard surfaced country road, no grades of consequence considered. Further variations are in proportion to grades, road conditions, etc. On average roads with average

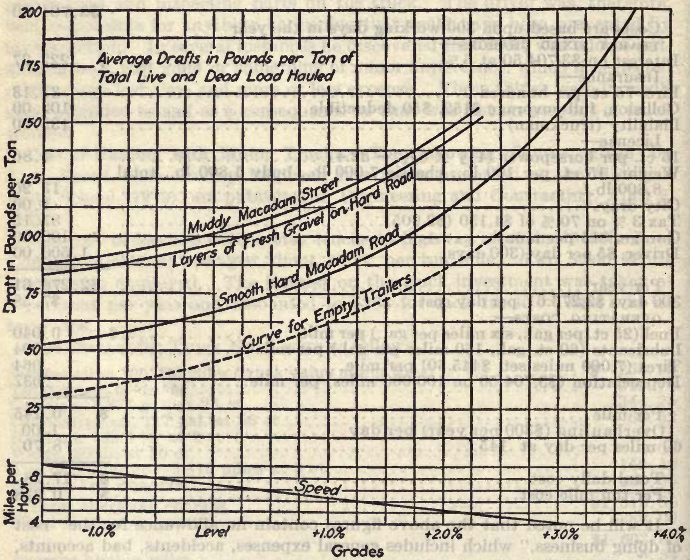


FIG. 10.—Draft per ton curves for various road conditions.

grades the drawbar pull required is about 250 lbs. per ton of live load moved on a properly constructed vehicle. This was another conclusion drawn from the tests. On this basis an average 3-ton truck will pull 10 tons live load in addition to the rated load on the truck proper, in other words the drawbar pull of the average 3-ton truck equals that of three 3,000-pound teams.

Fig. 10 shows "draft per ton curves for various road conditions" from actual tests. In order to take care of possible conditions not obtained in the actual tests, the per ton drawbar pull given in the paragraph above is placed considerably in excess of that shown by the tests.

The Troy Wagon Works Co. decided from the results of their tests that an average motor truck could develop the tractive power necessary to pull one or more loaded trailers. In the tests, in order to keep the motor truck from being delayed the trailer plant was three times the number being pulled, ⅓ of the plant at the loading point, ⅓ in transit and ⅓ being unloaded.

Table XVII shows the results of actual tests in tons delivered, comparing teams with motor alone, with motor hauling one trailer and motor hauling two trailers. In connection with Fig. 11, Table XVIII indicates ton-mile cost for various outfits and shows considerable economy by the use of trailers.

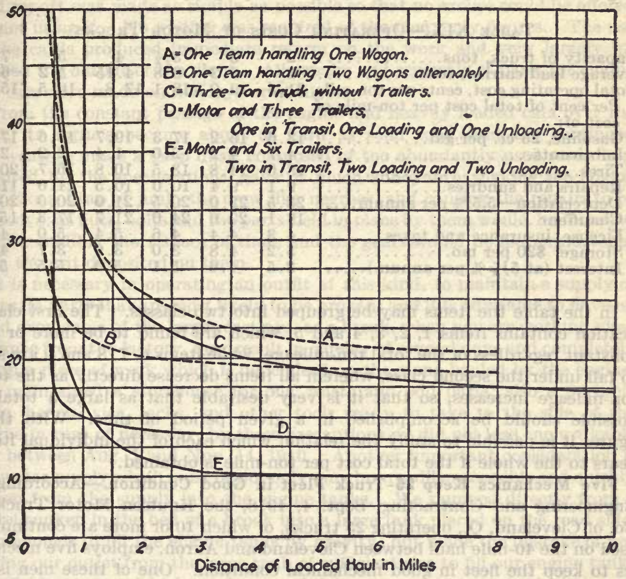


FIG. 11.—Curves showing comparative ton-mile costs for various outfits.

TABLE XVII.—DAILY TONNAGE DELIVERED

Length of haul	One team One wagon	Motor alone	Motor hauling one trailer	Motor hauling two trailers
½ mile	27	42	160	280
1 mile	18	36	140	260
2 miles	12	30	85	160
3 miles	9	21	60	110
4 miles	6	18	50	100
5 miles	6	18	35	70

TABLE XVIII.—COMPARATIVE TON-MILE COSTS

Distance of loaded haul in mines	One team One wagon	Motor hauling: Motor alone	One trailer	Two trailers
½	$0.444	$0.480	$0.210	$0.258
1	0.319	0.319	0.154	0.167
2	0.256	0.240	0.143	0.118
4	0.221	0.200	0.137	0.106
6	0.214	0.186	0.135	0.104
8	0.209	0.179	0.134	0.103
10	.....	0.176	0.134	0.103

Distribution of Average Operating Costs of Gasoline Trucks.—Table XIX, given by Ralph W. Horne in Engineering News-Record, Sept. 20, 1917, is prepared from data collected on the cost of motor-truck operation covering periods of from one to several years, and it is believed that all factors which might be affected by seasonal variations are properly averaged.

TABLE XIX.—OPERATING COSTS OF MOTOR TRUCKS

Capacity of truck, tons	2	3	3½	4	5	7
Average load carried, tons	2	3.3	3.8	4.15	5.2	6.5
Total operating cost, cents per ton-mile	21.5	19.0	18.1	17.8	16.5	15.0
Per cent of total cost per ton-mile of cost of:						
1 Gasoline, 25 ct. per gal	13.6	15.2	17.3	19.7	18.6	17.0
2 Lubricants	4.7	4.2	2.0	1.4	2.2	2.2
3 Tires	18.0	14.8	13.5	10.8	16.7	20.2
4 Repairs and sundries	9.1	9.4	10.0	10.5	11.0	11.1
5 Depreciation—5.5 % per annum	23.5	22.0	20.5	21.0	20.0	20.0
6 Chauffeur	18.1	20.6	24.0	21.7	17.3	15.4
7 License, insurance and taxes	4.3	4.4	4.6	5.4	5.0	4.8
8 Storage, $20 per mo	5.2	4.8	3.0	3.6	3.7	4.0
9 Interest (at 5½ % per annum)	3.5	4.6	5.1	5.9	5.5	5.3

In the table the items may be grouped into two classes. The first classification contains items 1, 2, 3, 4 and 5, which are found to be more or less constant regardless of the total ton-mileage; while items 6, 7, 8 and 9 are seen to fall under the second class, wherein all items decrease directly as the total ton-mileage increases, so that it is very desirable that as large a total as possible should be accomplished in a given period of time. With these figures it is possible to study the relation which each of the individual items bears to the whole if the total cost per ton-mile is obtained.

Five Mechanics Keep 25-Truck Fleet in Good Condition.—According to Engineering and Contracting, Sept. 4, 1918, the Knutsen Motor Trucking Co. of Cleveland, O., operating 25 trucks, of which 10 or more are continually used on the 40-mile haul between Cleveland and Akron, employs five mechanics to keep the fleet in good mechanical condition. One of these men is an expert capable of supervising all kinds of truck repair work, while the other four men are less skilled. The expert and three of the men work at the Cleveland repair shop and warehouse during the day. The other man is kept on duty at night to fix any emergency troubles that might arise, as the company operates a night service between Cleveland and Akron during the summer.

Cost of hauling stone with a 22-h.p. traction engine and stone spreading cars is given by John F. Hammond in Engineering and Contracting, March 27, 1912.

In building the Gatchellville Road, York County, Pa., 14,000 tons of 2-in. stone were required. Because of grades, team hauling was exceedingly expensive and slow, as a team of average weight usually found among the farmers could not move over two tons per day, for a wage of $3.50 or $1.75 per ton. An expert from a prominent traction engine company, who was called in and driven over the route, expressed himself as very doubtful if we could succeed with a traction engine, as the grades on the pitches of some of the hills were 30 per cent, and the traction surface was of a soapy clay nature. He advised us to begin our work at the southerly end beyond New Park and work over the finished road with the traction outfit; this course was finally adopted. The grades of the finished road were approximately 7 per cent on some of the hills for a considerable distance. The records on which this article is based were started on Aug. 1, 1910, after 2 miles, one-half of the road, had been built, and continued up to Nov. 14, 1910, when the road was completed. These records were kept as a means of information and to promote efficiency by compelling daily report of the materials used, wages paid and work done. The card report was made as simple as possible so that no excuse could be offered for not using it. No writing was required of the men, only figures. The use of the cards produced immediate reform on the work and very largely increased the output of the plant. All repairs and renewals of parts for engine and cars were made on holidays or at night.

From the constant passage of the engine and heavily loaded cars over the road, its surface became about as hard as solid rock, and the continued dry weather made a deep dust, composed of too abundantly used screenings required by the specifications, gave us much annoyance, making the engine look like a heap of junk, the crew like negroes, and causing the repairs to be excessive; as nuts, bolts and the parts held in place by them would be loosened in an incredibly short space of time, and the gears would be like grindstones from the grit deposited on them.

It is necessary in operating an outfit af this kind, to maintain a supply of the extra parts that are most likely to be broken; and it is advisable to have on hand even some of the larger castings, as a break, when you are working some distance from the factory, may result in a delay of several days and completely tie up a piece of work which is dependent on the stone hauled by the engine. We maintained a storehouse for oils, waste and odd parts; also a portable forge, bench, vice, jacks, and other tools ready to take to the side of the engine in case of necessity; by these precautions we did not lose one workable day between Aug. 1 and Nov. 14, 1910. Another important consideration is the water supply which must be not only pure but readily accessible and quickly gotten from the supply into the engine tanks. We pumped directly from a barrel sunken in the bed of a brook into a large tank placed on the road side, high enough to fill the engine tanks by gravity; but made the mistake of not having our outlet from the large tank of sufficient size to fill our engine tanks as quickly as we might have done, and delays occured at the tank that were needless and anoying. Water was pumped into the supply tank by a small one-cylinder gasoline pump which operated very cheaply, and only required the services of the engine driver to start and stop it as he passed on his trips. The wages paid to the engine crew was; Engineer, \$3.50 per day; fireman, \$1.75 per day, steady time for ten hours daily; overtime at same hourly rate. The fireman operated the stone spreadnig cars, making the spread of even thickness, which requires considerable experience and should be closely watched by the overseer as the tendency is to spread too deeply, and superfluous stone would have to be removed at an extra expense. Supervision in our case was figured at one-third of the superintendent's time, or \$2.28 per day with no extra time allowance. Interest and depreciation are figured on the new value of the machinery—\$5,050 on June 1, 1909, and on an estimated life of four years, or 25 per cent depreciation per year, with an interest charge on the capital invested of 5 per cent. The sum of the interest and depreciation, however, are figured for the whole year and divided into the days that we actually worked. This is hardly fair to the machine, as it might have done more days' work and thus reduced this item. The life of the machine is also very conservative, and probably should be eight to twelve years instead of four years.

The following tabulations show our conclusions and we think may be considered quite accurate. I have not thought it necessary to make an analysis of the repair account, which consisted of castings, bolts, nuts, valves, pipe elbows, engineer's and fireman's time and many small items:

Total Cost of Operation—93 days.

Operating	$ 945.67
Repairs	310.17
Depreciation and interest	686.15
Supervision	239.40
Total	$2,181.39

Analysis of Operating Account.

4.70 tons coal at $4.50	$ 21.15
3.49 tons coal at $5	17.45
913.4 tons coal at $3.26	297.77
Water	66.27
67 gal. cylinder oil at 30 cts	20.10
30½ gals. black oil at 9½ cts	2.94
333½ lbs. grease at 5½ cts	18.77
71 lbs. of waste at 7½ cts	5.35
Engineer's wages on operation	330.41
Fireman's wages on operation	164.83
3½ gals. kerosene at 10 cts	.35
1 can of tar at 28 cts	.28
Total	$ 945.67

Daily Expense.

Supervision wages	$ 2.28
Engineer's wages	3.50
Fireman's wages	1.75
Coal	3.55
Cylinder oil	.21
Black oil (gears)	.03
Grease (cups and gears)	.20
Kerosene	.003
Tar	.002
Waste	.06
Depreciation	6.417
Interest	0.961
Repairs	3.33
Total	$22.293

Tonnage Hauled.

August 1, 1910	1,681
Sept. 1, 1910	1,525
Oct. 1, 1910	1,176
Nov. 14, 1910	284
Total tons	4,666

Cost Per Ton Hauled.

Operation	$\frac{945.67}{4,666}$	$ 0.202
Repair	$\frac{310.17}{4,666}$	0.066
Depreciation	$\frac{596.78}{4,666}$	0.128
Interest	$\frac{89.37}{4,666}$	0.017
Supervision	$\frac{239.40}{4,666}$	0.051

Total.......$0.464 or 6.4 cts. per ton mile.

Extreme haul, 9.44 miles. Start, 5.00 miles.

Average length of haul, 7.22 miles round trip. 2.24 trips daily; 209 trips, or 1,508.98 miles in 93 days.

Costs of Industrial Railway in Road Building.—The following matter, given by R. P. Mason in a paper presented before the Road School of the University of Michigan (March 1919), is published in Engineering and Contracting, March 5, 1919.

The conditions necessary for the successful operation of an industrial railway in highway construction are as follows:

First fairly level country. We haul 30 car trains over grades up to 3 per cent and have worked over a 1,000-ft. hill of 5.1 per cent by cutting the train in three parts at the foot; in other cases we have used a roller to tow up, but many such hills would make it out of the question. If the hills were not too frequent other power could be provided.

Second, sufficient and continuous supply of material. As such an outfit will handle a large daily volume (at 8 trips per day 300 yd.) and as it requires a considerable crew to keep the work moving, it will not pay if there is much delay in the delivery of road material, or if the loading facilities are inadequate. I am considering the question of stock piling some matreial in order to keep going when deliveries are delayed, but this presents the further problem of loading from the stock pile. Our loader could not be utilized and another rig would have to be provided.

Third, a considerable mileage to be constructed from one set-up to avoid the expense of numerous moves. We figure on at least 8 miles at one set-up 4 miles each way. If the road is continuous and the move is only from the end of a completed section to a point 4 miles beyond, the moving cost will be a completed section to a point 4 miles beyond, the moving cost will be a minimum, but if the outfit has to be moved to a distance, the cost is heavy. Our maximum haul so far has been 4 miles as we have been fortunate in having our work along the railroad with frequent stations. Our outfit consists of a 30-HP. locomotive with underslung tank, 60 1½-yd. side dump steel cars, 1 tracklaying car, 1 hand car and 4 miles of 24-in. gage portable track with curves and switches. The track is 30-ft. rail made up in 15-ft. sections with 7 steel ties to the section.

The outfit cost about $16,000. We depreciate 10 per cent on all the machinery, but only 5 per cent on the track as, at the end of 10 years the salvage value will be at least half the first cost. It is also evident that there will be considerable value in the rest of the outfit at the end of the 10-year period. It is now 5 years old and practically as good as new.

Tracklaying is one of the large items in operating and this will vary considerably according to the character of the soil. In swamp sections where the shoulders have not much stability it is necessary to shim up frequently to keep the track in safe condition, but on a firm soil such as sand or gravel, it does not need much attention after laying. Our cost has varied from $100 to $150 per mile, with an average of about $132.

When the outfit is also used for grading it cuts the tracklaying cost as the track is then in position for the stone work. During a move and while the macadam work is on the short haul, some of the cars and track can be spared for grading without delaying the other work, using a team to haul the train. Especially in soft sections it is very useful and in heavy cuts, working with a small shovel it shows great economy. The fact that the outfit has to be there anyway should be considered as it involves no transportation to and from the job.

Hauling 30 car trains and loading one while the other is making a trip, should admit of an average of 10 trips per day on a haul up to 4 miles—2 miles average haul—and we have made this at times, but various delays, principally in the delivery of stone, have combined to cut the average down to 8 trips. I think the train should average 6 trips on a haul up to 8 miles as the delays in unloading and at the loader would be less and it would only mean an average of 48 miles per day actual running. At this rate, hauling 47 tons per trip would equal 282 tons per day. Speed of train is 8 to 10 miles per hour and time of unloading 10 to 15 minutes. Time of loading is about ½ hour, but of course this does not delay the train. At times when our stone supply was sufficient we have averaged over 400 yd. per day, or at the rate of a mile of road built in 6 days.

The following costs are an average of 3 years, 1914, 1915 and 1916, and cover about 20 miles of 16-ft. macadam construction:

	Per cu. yd.
Tracklaying	$0.055
Engineer	.025
Brakeman	.013
Watchman	.010
Fuel	.010
Oil, grease and waste	.002
Repairs	.015
Moving	.025
Total operating	$0.155
Depreciation	.055
Interest	.035
Total hauling	$0.245
Cost per yard mile	$0.1225
Cost per ton mile	$0.098

Delivering the stone on the road as above affords an opportunity of keeping the other construction costs at a minimum. Loading with an elevator is about the cheapest method and spreading the stone with a road machine is cheaper than by hand and planes the road at the same time, avoiding minor inequalities which so often occur. Rollers and sprinklers are kept up to their full capacity.

The other costs of the macadam construction follow:

	Per cu. yd.
Loading	$0.070
Spreading	.160
Sprinkling	.065
Rolling	.021
	$0.505
Hauling as above	.245
Total	$0.750

Portable Railways for Hauling Materials for Road Construction. — The following information concerning the method and cost of operating a portable railway on road construction near Lockport, N. Y. is given by Orenstein-Arthur Koppel Co., in Engineering and Contracting, March 14, 1914.

The equipment consisted of about four miles of narrow-gage portable track, 40 36 × 24-in. dump cars and two 5-ton dinky locomotives. The cars were hauled in trains of 12 cars each, the arrangement being so made that there was always one train of loaded cars on the way to the site of the work, one train of empties returning for material and one train of cars being loaded.

The cars were loaded from over-head bins at the crusher and the average amount transported was 80 cu. yds. per day.

Item—	Amount	Per cu. yd.
Materials:		
Fuel and oil for locomotives and cars	$ 8.00	$0.100
Labor:		
2 engineers at $2.75	5.50	0.069
2 brakemen at $1.75	3.50	0.044
1 track foreman at $3	3.00	0.037
1 track laborer at $1.75	1.75	0.022
Totals	$21.75	$0.272

As the material was hauled three miles the unit cost was 9 cts. per cubic yard per mile. The average cost of grading the shoulder or berm of the road ready for track laying and laying track was between 2 and 3 cts. per foot of track.

CHAPTER IV

EXCAVATION ECONOMICS

The matter included in this chapter deals with the economics of excavation and does not give costs for particular kinds of work. As most construction work requires excavation at some stage, by referring to the index, under excavation, itemized costs of many different kinds of work may be found.

For further data, on cost of excavation, the reader is referred to Gillette's "Earthwork and Its Cost," Handbook of Rock Excavation" and "Handbook of Clearing and Grubbing."

Rating Table for Excavation with Pick and Shovel.—L. K. Sherman gives the following data in Engineering and Contracting, May 27, 1914.

The accompanying diagram and tables represent the amount of excavation of various materials which will be performed in a ten-hour day by the average laborer working under good supervision. In making this compilation the writer has compared a large number of data from many sources with figures obtained in his own experience on construction. As might be expected there is wide divergence in such published data.

The curves in the diagram based on a rational relation of one class of material to another as regards the amount of work or power required in picking or shovel cutting and the power required in casting up materials of different weights. The output of excavation is proportional to the amount of power or work required to move a cubic yard of the material. Let the amount of work or power to cut into and fill the shovel with sand be called unity. Then for other materials the relative power to cut out and place on the shovel will from experience be as in Table I.

TABLE I.—POWER TO PICK, LOOSEN AND CUT ONTO SHOVEL

Sand	P = 1.0
Gravel, loose	P = 1.5
Earth, medium	P = 2.0
Clay, light	P = 3.0
Clay, dry, hard	P = 4.5
Clay, wet, heavy	P = 5.0
Hard pan	P = 6.0

The work or power to lift or cast up the material after the shovel is filled is proportional to the weight of material and height cost or which is the same, the depth of cut. Then if W is the weight, the relative power to cast up material to different heights H will be as follows:

Sand	W H where W = 1.0
Gravel	W H where W = 1 0
Earth, medium	W H where W = 0.8
Clay, light	W H where W = 1.1
Clay, dry	W H where W = 1.1
Clay, wet	W H where W = 1.3
Hard pan	W H where W = 1.12

The total power to shovel and cast any material is $P + WH$. The output is inversely proportional to the power or work required. The output of any material by hand excavation in cubic yards per man per 10 hours is

$$\text{Cubic yards} = \frac{30}{P + .3WH}$$

The constants 30 and .3 are empirical and like the relative values of P have been selected to correspond with the best data available on excavation of various materials at different depths of cut.

The curves in the diagram Fig. 1 are platted according to the above formula with coefficients P and W as previously noted. The letters represent observations from various published statements and are not equally reliable or comparable. The curves do not attempt to average the data but correspond with the writer's experience and some of the most definite of the published data. Table II shows the number of cubic yards an average laborer should excavate and cast out, at various depths in ten hours while working at the depths stated. Table III shows the average number of cubic yards per 10-hour day than an average laborer should excavate working from the surface to the depth stated. This figure for the same material is naturally somewhat greater than given in Table II. These figures may be increased by 30 per cent for rapid workers and may be decreased 30 per cent for inefficient workmen. The foregoing material may be now definitely classified as follows:

Sand.—Weight, 3,000 lbs. per cubic yard slightly damp. In natural bed. Not over 15 per cent clay.

Gravel.—Weight, 3,000 lbs. per cubic yard. Loose, as excavated material.

Earth.—Weight, 2,400 lbs. per cubic yard. Slightly damp, in natural bed, easily plowed, little or no pick work required. Would require some sheeting in trenches over 6 ft. deep.

Clay (light).—Weight, 3,300 lbs. per cubic yard. Slightly damp, easily plowed. Not stiff or very cohesive, corresponds to yellow clay lying below the black soil and above the blue clay in vicinity of Chicago. Would require some sheeting in trenches over 6 ft. deep. Little pick work required.

Clay (dry, hard).—Weight, 3,300 lbs. per cubic yard. Requires pick work equal to one-third time spent in shoveling and casting. No sheeting required at any depth. Corresponds to material on top of ravines along the lake shore in Lake County, Ill. Hard plowing. Abode in this class.

Clay (wet).—Weight, 3,900 lbs. per cubic yard. Tough and cohesive, has to be cut out in pieces. Slightly sticky, would require substantial sheeting. Corresponds to the underlying "blue clay" of Chicago. Gumbo in this class.

Hard Pan.—Weight, 3,360 lbs. per cubic yard. Requires picking equal to one-half the time spent in shoveling and casting.

The use of the relative coefficient P is suggested as a simple and definite means of describing or designating any class of earth excavation.

The jog in the curves (Fig. 1) at depth of 9 ft. represents an allowance of $P = 1$ on account of extra labor of shovel cutting done to recasting from a platform. As a matter of fact no recasting may be done at the 9 ft. depth or even 14 ft. depth but the output per man will not be increased over the quantity shown by the diagram.

TABLE II.—CUBIC YARDS PER MAN PER 10 HOURS AT STATED DEPTHS

	0 ft. to 3 ft.	3 ft. to 5 ft.	5 ft. to 8 ft.	8 ft. to 10 ft.	10 ft. to 15 ft.
Sand	21.2	14.5	10.7	8.5	5.2
Gravel, loose	15.4	11.8	9.2	7.7	4.9
Earth	12.8	10.5	9.0	7.5	4.9
Light clay	8.9	7.3	6.0	5.2	3.8
Dry clay	6.4	5.3	4.7	4.1	3.2
Wet clay	5.4	4.7	4.2	3.5	2.7
Hard pan	4.6	4.2	3.7	3.3	2.7

Table III.—Average Excavation in Cubic Yards Per 10 Hours for Cuts from Surface to Stated Depths

	0 ft. to 3 ft.	0 ft. to 5 ft.	0 ft. to 8 ft.	0 ft. to 10 ft.	0 ft. to 15 ft.
Sand	21.2	18.1	15.1	13.6	10.7
Gavel, loose	15.4	13.7	11.8	10.8	8.8
Earth	12.8	11.7	10.5	9.7	8.1
Light clay	8.9	8.1	7.3	6.7	5.8
Dry clay	6.4	5.9	5.4	5.1	4.5
Wet clay	5.4	5.1	4.7	4.4	3.8
Hard pan	4.6	4.4	4.2	3.9	3.5

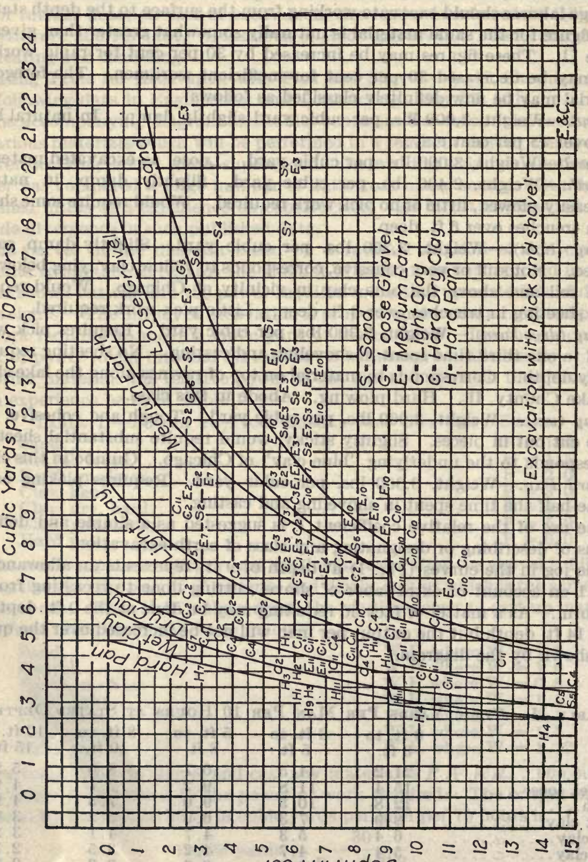


FIG. 1.—Excavation with pick and shovel.

The recorded data platted on Fig. 1 are designated by a letter for the class of material. The number following the letter refers to the source from which the data were obtained, as follows: (1) American Engineers' pocket Book; (2) Cost Data, Gillette; (3) Earth Work Cost, Gillette; (4) L. K. Sherman; (5) Windette. Journal West. Soc. Engrs.; (6) Concrete Costs, Taylor & Thompson; (7) Orrock; (8) Prelini; (9) Engineering and Contracting (December, 1908), Atlantic, Iowa, Sewers, M. A. Hall; Centerville, Ia., Sewers, M. A. Hall; (10) Engineering and Contracting; (11) Engineering and Contracting.

Application of Efficiency Engineering to Shoveling.—The following abstract of a paper, presented before the Feb. 1919 meeting of the A. I. M. E. at New York, by G. Townsend Harley is given in Engineering and Contracting, June 18, 1919.

At the mines of the Phelps Dodge Corporation at Tyrone, N. Mex., the cost of shoveling in all stopes during 1917 amounted to 24 ct. per ton. In the top-slice stopes for the same period shoveling cost 27 ct. per ton, or 16 per cent of the total cost of these stopes. The average wage per laborer shift was $2.67 during the year under review. The tonnage for shovelers from all stoping was 9.3 tons per man, and for top-slicing 8.2 tons per man per day. These stopes were not unduly hot, and there was not more than the usual amount of timber to interfere with the work of the men. The tonnages obtained per shoveler were considered low; first, because of a poor grade of Mexican labor, many of the men having come in from railroad-grading camps; and, second, because of a poor spacing of raises, especially in the top-slice stopes, where, in general, they were spaced 25 ft. by 66 ft. centers.

Preliminary Steps far Determining Shoveling Efficiency.—As a first step toward determining how the general efficiency of underground shoveling could be improved, several weeks were spent in a general survey of the field and making time studies on various men, to see what points would need to be determined for a full consideration of the subject. The following factors were soon recognized: The type, weight, size, and design of shovel giving the greatest shift tonnage without too much wear and tear on the man would have to be determined; a standard of comparison would be necessary if the ill effects of mine air, powder gas and smoke, temperature, humidity and poor light were to be estimated, and the layout and spacing of chutes would have to be studied with regard to their effect on shoveling directly into the chutes, or loading into wheelbarrows or cars and tramming to them. This latter work would determine the proper distance at which shoveling into a chute should cease and loading into a wheelbarrow or car would begin, and the information would also be of great value in planning the development of a stope. Further considerations were: Hindrances to work, such as timber standing in line of throw or closely spaced, and men and supplies passing back and forth through working space; manner of placing the shovelers to obtain maximum results from them, number of men in one working place, and size of working place required per man; the hours of actual work and the cause and amount of delays; capacity of a man for work as the day progresses; proper rest periods for men to maintain maximum efficiency; best means for instructing men and supervising work, and compensation received and manner of payment.

Three types of shovels were in general use at the mines: A No. 2 scoop, a No. 2 or No. 3 square-point D-handle shovel, and a No. 2 round-point long-handle shovel. In determining the average load that the various types and sizes of shovels would handle, so as to be able to decide the best load for the average Mexican laborer of the Southwest, average capacities were obtained by repeatedly shoveling a weighted pile of ore with each of the shovels and counting the number of shovel loads required to move it. It was determined that with Burro Mountain ore a specially made shovel with a 10 by 13-in. blade would hold a 21-lb. load, or 363 cu. in. In practice, however, a No. 4 square-point shovel holding 373 cu. in. and a No. 5 round-point shovel holding 340 cu. in. were used.

A time-study sheet was developed, which was used for all tests. In addition to the data placed on this sheet, an extensive log of the work was carried on, which undertook to explain, in detail, all delays, changes of work, rest periods, changes in conditions that would affect speed, high and low efficiency periods during the day, and other points to be considered.

Motion Studies Establish Standard Time and Performance of Structures.—During the period of preliminary work, it was discovered that the work of a shoveler can be classified into several divisions, each susceptible to comprehensive study and analysis, and to each of which a definite relative time value can be given.

These divisions, in general, may be classified into time spent actually shoveling, time spent other than shoveling, delays and resting periods. By studying each motion separately, it was possible to establish a standard time for each, and, consequently, a standard of performance for the whole. It was possible, also, to discover which were the most tiring motions and how each was affected by length of time worked, length and distribution of rest periods, size of shovel design of shovel, and length of throw.

To obtain some standard of comparison for the underground work, some of the mine shovelers were brought to the surface and a record of their work was made under ideal conditions; that is, with good air, good light, no timber to interfere, steady shoveling for various lengths of time and standard lengths of throw for the muck. In addition to obtaining the comparison standard, it was possible to form definite conclusions, which were later checked satisfactorily under actual conditions in the mine, as to the most advantageous size, type, weight, and design of shovels for general mine use, under the various conditions encountered.

Tests of Shoveling Performance.—Tests were carried on for two months, three different shovelers, taken from the mines, being observed. Each of these men was warned that he had to work at his best speed, all during the job, but that he was not to overtax himself. He was told that when he became tired he was to take a few moments' rest, as it was better for him to rest at intervals than to try to work all the time, at the expense of speed and capacity. Later the rest periods were regulated, to obtain the proper intervals at which they should occur, and their length.

All of the underground shoveling tests may be classified under one of three headings: Shoveling directly into chutes; shoveling into wheelbarrows and tramming to chutes, and shoveling into cars and tramming to chutes. Each of these series was conducted independently of the others, and was complete in itself. The men under observation worked for periods varying from 1 to 8 hours, and for each length of job they threw or trammed the muck over a wide range of distances, with various types and sizes of shovels. In all the underground tests, the work was done under the actual mining conditions, with the one exception that the men were always under observation, and, consequently, were working at a good speed for the full period of the test. In no case did the men overtax themselves, and it is believed that all tonnages recorded are easily obtainable by a good but not exceptional Mexican laborer after he had been properly instructed, and under close and intelligent supervision together with a wage paid in such a manner as to provide an adequate incentive to do good work.

It soon became evident that the great majority of shovels being tested were not suitable for efficient work, and only the work of the No. 4 shovel, which handles the 21-lb. load, together with that of the No. 2 scoop, which was held in high esteem by many of the men in the operating department was plotted on charts. The results obtained during the surface tests were plotted alongside of corresponding results from underground, to accentuate the adverse effects of underground conditions on shoveling capacity.

Effect of Type of Shovel and Length of Throw on Shoveling Speed.—The number of shovels per minute thrown into a chute at a distance of 8 ft. from the ore pile, for jobs varying in length from 1 to 8 hours, is greater with the No. 4 shovel than with the No. 2 scoop. Both on the surface and underground, the speed of shoveling decreases more rapidly with the scoop than with the shovel, as the length of the job increases. A man working with a scoop underground can perform at only 72 per cent at his speed on surface for 8 hours, whereas with a No. 4 shovel he can work at 82 per cent of his surface speed. The percentage reduction in speed between surface and underground work is the measure, in part, of the effect of mine air, powder gas and smoke, temperature, humidity, and poor light. Under the same condition of work, the difference in speed between the No. 4 shovel and the No. 2 scoop is due to the difference in the load handled.

The manner in which the length of throw will affect the speed of the shoveler was worked out for a uniform length of job of 6 hours and 12 minutes, and for varying distances. The decrease in shoveling speed on the surface amounted to an average of 2.5 per cent for every foot increase in distance thrown in the case of the scoop, and 1.8 per cent for the No. 4 shovel. Underground, the working speed was decreased more rapidly, being respectively 4.4 per cent and 3.2 per cent per foot increase in throw. The rate of decrease in shoveling speed, both on the surface and underground, was greater for the heavily loaded scoop than for the shovel.

In determining the amount of rest required for shoveling jobs of various lengths it was found that the scoop again has a negative effect both on surface and underground, causing a man to use up more time in resting than when working with a No. 4 shovel. The rest period, as considered, was made of the time consumed in delays, the time actually spent in resting, during which the man may smoke a cigarette and sit down for a few minutes, and the time used in loosening the muck pile, scraping up the dirt on the shoveling plat, or doing other light work, not actually shoveling, but closely related to it.

Determination of Actual Time Devoted to Shoveling.—Over a long period it was possible to demonstrate the feasibility of accurately determining the percentage of the working day that a man will actually devote to shoveling. The working day at the Burro Mountain mines is 8 hours, ½ hour of which is given up to the lunch period, leaving 7½ hours as the total possible working time. It was found that of this 7½ hours the man actually worked at shoveling for 82.5 per cent of the time. The remainder of the possible working time, or 17.5 per cent, is spent on other work, the man quitting early for lunch or leaving the mine or commencing to work late at beginning of the shift or after lunch. Observations of this character were gathered by some of the shift bosses, on several hundred-man shifts, and it is surprising how little the figures obtained by each have varied from the average finally obtained.

The average tonnage per hour to be expected of a man throwing the muck a distance of 8 ft. over any period of time is shown in Fig. 2. Experiments to determine the total tonnage shoveled for any period over the same distance showed that for a job lasting 5 hours and 30 minutes, with a No. 4 shovel underground, a man would be expected to shovel 26.0 tons a distance of 8 ft. Five representative tests actually gave the following tonnages under average conditions:

	Tonnage
Length of job 5 hours and 40 minutes	28.0
Length of job 5 hours and 10 minutes	23.0
Length of job 5 hours and 25 minutes	26.0
Length of job 5 hours and 50 minutes	34.0
Length of job 5 hours and 30 minutes	25.0
Average, 5 hours and 30 minutes, average	27.4

Comparison of Work Done with Scoop and by Shovel.—A careful study of Fig. 3 shows the following conditions: (1) The difference in tonnage handled by the same shovel, on the surface and underground, for any length of job, is the

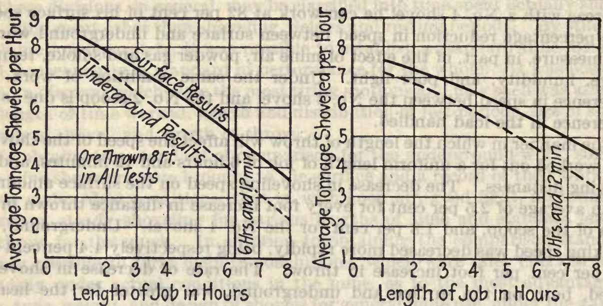


FIG. 2.—Average tonnage shoveled per hour.

measure of the bad effects of underground conditions. For a job of 6 hours and 12 minutes, with a No. 4 shovel, the underground work is 20.5 per cent less than on surface. (2) The difference between the amounts shoveled with the No. 2 scoop and the No. 4 shovel, under same conditions, is the measure of the effect of the difference in load handled by the man. (3) Each line on this chart shows a peak at some particular length of job, and the total tonnage shoveled for any greater period than this is actually less. (4) The presence of this peak accords with the experience of many superintendents and managers, who state that their men do more work in an 8-hour day than they did on the old 10-hour basis. (5) The "economic shoveling day" is about 6⅓ hours, with a No. 2 scoop on the surface, and 5⅓ hours underground. With a No. 4 shovel, on the surface 8 hours is about the proper length of day, whereas underground 6⅔ hours seems to be about correct. As the men actually shovel only 6⅙ hours per day on an average, and as their other work is generally of a light nature, the 8-hour day with the correctly proportioned shovel is probably the best; but with a scoop it is certainly too long. (6) For work on the surface, on jobs lasting longer than 4⅔ hours, the No. 4 shovel is superior to the scoop. Underground the No. 4 shovel demonstrates its superiority for jobs longer than 3⅜ hours. The scoop thus may be considered as a task shovel for short-time jobs, but even here its value is only slightly greater than the No. 4 shovel and it tires the man so that he is unfit for other work when the shoveling task is finished.

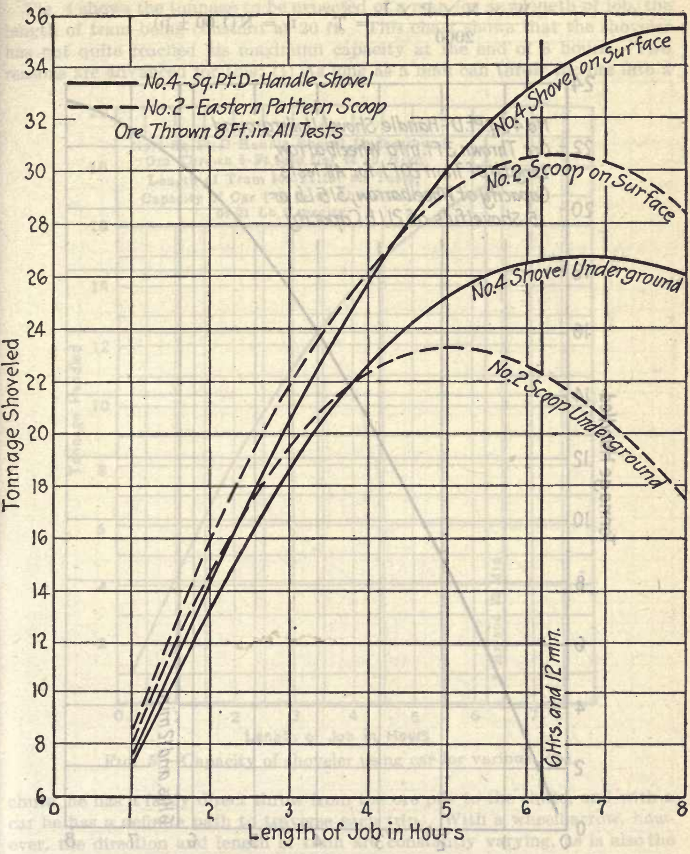


FIG. 3.—Comparison of work of No. 2 scoop and No. 4 shovel.

Effect of Height and Length of Throw on Shoveling Speed.—The following formulas show the manner in which use is made of the figures presented in the preceding diagrams:

Let W = weight of load on shovel, in pounds;

N = number of shovels per minute;

P = per cent time actually shoveling;

L = length of job, in minutes;
T = total tonnage shoveled;
n = number of shovels per minute for an 8-ft. throw;
p = per cent increase or decrease due to various lengths of throw.

$$\frac{W \times N \times P \times L}{2000} = T \qquad n = N(1.00 \pm p)$$

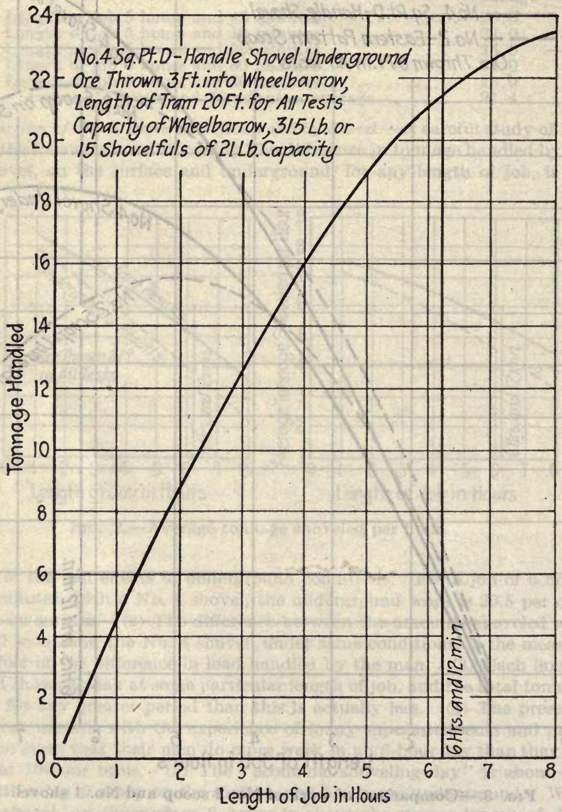


FIG. 4.—Capacity of shoveler using wheelbarrow for various jobs.

In using the No. 4 D-handle shovel it was discovered that a throw of 3 ft. to the wheelbarrow gave the best results as far as number of shovels per minute and rest periods required were concerned, and in all subsequent work the ore was thrown into the wheelbarrow from this distance. For any length of job, the number of shovels per minute is less than when throwing 8 ft. into a chute, and this is due to the fact that the shoveler must place each shovelful carefully to keep the wheelbarrow from spilling its contents and to make it ride easily.

Fig. 4 shows the tonnage to be expected of a man for any length of job, the length of tram being constant at 20 ft. This chart shows that the shoveler has not quite reached his maximum capacity at the end of 8 hours. Two reasons are advanced for this: (1) As long as a man can throw the ore into a

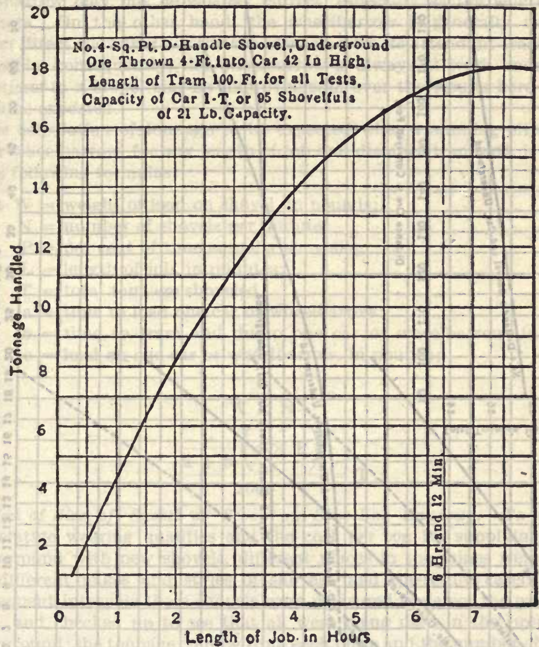


FIG. 5.—Capacity of shoveler using car for various jobs.

chute, he has a fairly direct throw from the ore pile to the chute, and with a car he has a definite path to traverse each trip. With a wheelbarrow, however, the direction and length of tram are constantly varying, as is also the amount of interference from other trammers, timbermen and machine men. The retarding influence of these factors increases as the length of the tram increases. (2) The sequence of operations, shoveling, tramming and dumping, is of such short duration and changes so often from one to the other than it is hard to keep up any pace that may be set, and probably an unnecessary amount of rest is indulged in for all periods.

From a series of tests during which the ore was thrown into a mine car 42 in. high, it was determined that a horizontal interspace of 4 ft. was the best distance to maintain between car and ore pile in order that a man might work to the best advantage. Owing to the height of the car, the capacity of a shoveler is decreased, as compared to his capacity in shovels per minute when loading into a wheelbarrow. This decrease in shoveling speed amounts to about 8 per cent per foot of height. The best type of car for a shoveler to use

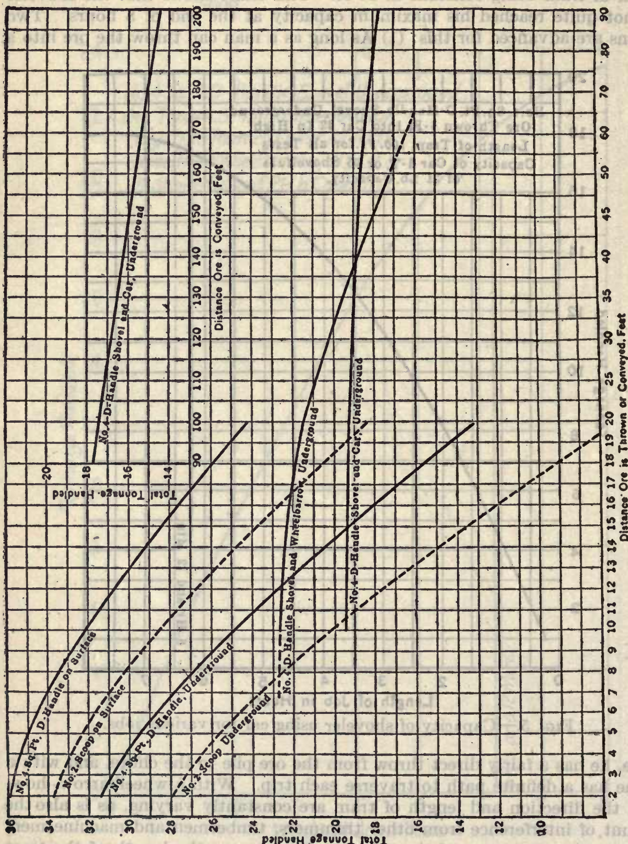


FIG. 6.—Comparative efficiency of different methods of handling ore in stopes with Mexican labor. Length of job constant at 6 hours and 12 minutes.

holds about a ton of ore, is as low as is consistent with good design—certainly not over 45 in. in height—and is equipped with roller bearings, which should be kept in the best of condition. Cars much larger than this are too hard to tram and cars much smaller use up too much of the shoveler's time tramming back and forth.

Tonnage to be Expected under Average Shoveling Conditions.—Fig. 5 shows the tonnage to be expected of a man mucking into a car and tramming a constant distance, for various lengths of jobs. It will be noticed that the economic shoveling day is between 7 and 8 hours long, and that the maximum average results to be expected of a mine shoveler under the given conditions have probably been reached. The tonnage to be expected under average shoveling conditions during a uniform shoveling day of 6 hours and 12 minutes and for any distance that the ore must be thrown or trammed is shown in Fig. 6. The graph representing the tonnage to be expected of a man with a wheelbarrow may not be entirely correct, especially as the length of tram increases. On the other hand, the wheelbarrow is generally used where neither direct shoveling nor the use of a car, with its attendant track expense, is feasible; consequently, the wheelbarrow is always at work under adverse conditions in a stope, and no improvements over the results here tabulated are to be expected.

The calculation of tonnage to be expected when tramming either with a car or wheelbarrow, for any length of job and distance trammed, is expressed in the following formulas:

Let W = weight of load on shovel, in pounds;
N = number of shovels per minute;
P = per cent of time actually shoveling;
L = length of job, in minutes;
T = total tonnage shoveled;
a = time to load one car or wheelbarrow;
b = time to tram and dump one car or wheelbarrow, in minutes;
c = load on one car or wheelbarrow, in pounds;

$$\frac{c}{W \times N} = a$$

$$\frac{\frac{L}{a+b}\left(c \times P\right)}{2000} = T$$

Effect of Size of Shovel or Scoop on Shoveling Capacity.—To determine the relative wearing qualities and the cost per ton for supplying the men underground with new shovels, different places in the mines were equipped with different makes and styles of shovels, and the results carefully noted. At frequent intervals these shovels were measured to detect the wear of each blade, and checked up to see that all were being used in the proper places underground; the tonnage coming from each place and the number of shovelers employed were also noted.

Tests were conducted with square and round-point shovels varying in size from No. 2 to No. 6 and with standard No. 2 scoops, to determine what size of shovel was best adapted to the work. For short jobs of less than 4 hours' duration, the No. 2 scoop and the No. 5 and 6 shovels were slightly superior from the standpoint of tonnage handled; but for jobs requiring more than 4 hours for their completion, the No. 4 shovel was greatly superior. From the standpoint of "number of shovels per minute," work with a scoop is at all times slower than with a No. 4 shovel, and as the day progresses the percentage of time required for resting becomes greater with the scoop than with the shovel. The result is that although, for short work periods, the larger capacity of the scoop brings the total tonnage handled above that of a No. 4 shovel, for long periods the increased amount of rest required when handling the heavier load serves to put the No. 4 shovel considerably in the lead as a tonnage mover. In general it may be said that for shovels smaller than the 21-lb. load shovel, the tonnage handled per shift is approximately directly proportional to the shovel capacity; that is if a man using a No. 4 shovel will handle 26 tons in an 8-hour shift, with a No. 3 shovel, which holds 91 per cent of the load of a No. 4 shovel, he would be expected to shovel about 24 tons a shift. If the increased cost of shoveling with a smaller shovel, or one that has been worn, is balanced against the cost per ton of putting a new shovel underground and discharding the old one, it will indicate economic limit of wear of the shovels in use.

Design of Shovel Best Adapted to Mining Work.—The design of shovel which was considered as being the best adapted to mining work, conforming to conditions under which the tests under review were made, should hold 21 lb. of broken ore as an average load. Both the square and the round-top blades should be of standard shape, of No. 15 gage at the point, and of such composition that the shovel will handle not less than 1,100 tons of medium hard ore when shoveled off a wooden mat. All blades should be of the plain-back type without rivets, the back strap being welded to the blade. Only best-grade, second-growth, northern white ash should be used for the handle, which should be bent to the proper shape and dimensions. On short-handle shovels, the Dirigo, or split D, handle is preferred, as it is much stronger than the ordinary D handle.

How to Obtain Greatest Shoveling Efficiency.—To obtain the highest shoveling efficiency underground, every man hired as a shoveler should be in a particular stope or working place that is directly in charge of a shoveling boss. This boss should have had considerable experience in shoveling.

Economic Choice of Shovels for Construction Work.—C. W. Hartley in Engineering and Contracting, March 31, 1915, gives the results of a study made to indicate the economic choice of shovels for handling different classes of material, from which the following is taken.

It is the custom, or has been in the past, among many large contracting firms and companies in New York City employing a great number of laborers on trench work, to require the men to furnish their own shovels. The principal reason for this is claimed to be that shovels furnished by the employers are very rapidly lost or stolen. While this may be true, it would appear that such procedure is a false economy, as I shall endeavor to show.

Frank B. Gilbreth, in his work on "Motion Study" (page 59) says:

No worker should ever be obliged to furnish his own tools, if large output is expected. When workmen are obliged to furnish their own tools (due to their having too much thrift, lack of money, or fear of having them stolen) they usually use one size only of the same kind of tool. On many kinds of work, greater output can be obtained by using two or more sizes of a tool.

Again, where workmen furnish their own tools, they use them after they are too much worn. A shovel with a worn blade will require several motions to push it into the material to fill it. It is cheaper in this case to cut off the handle of the shovel, so that the men cannot use it. Where no records are kept of their individual outputs, the men always choose the shovel with the small blade.

The statements contained in the last paragraph quoted have been most strikingly forced upon the writer's attention by reason of the following discovery:

In a gang of 38 men, at work in a trench, with shovels furnished by themselves, it was found that 92 per cent were using the smallest size shovel on the market, a No. 2, while the remaining 8 per cent were using the next size larger, a No. 3. These shovels, as will be shown later, are incapable of holding near the amount of material (if it be earth) that should constitute a shovelful. It was further observed that 50 per cent of these men were using shovels, the blades of which were worn down approximately 3 ins. from the point, or until but little over half the original blade remained.

By critical time observations it was demonstrated that the men using the worn shovels worked no faster than those using the good; further, that men will shovel at approximately the same speed whether they are working with a No. 2 shovel, or a No. 4, and, as a general rule, will fill the blade full whenever possible to do so. This being the case, it is self-evident that the use of small or worn shovels will entail the handling of less material, as follows:

A No. 2 shovel, in good condition, was found by many trials to hold, as an average load, 13 lbs., the material being common loam or earth, loose and dry. This same size shovel worn down, as were half of those in use by this aforementioned gang, was found to hold but 7 lbs. of earth or loam, which is, as will be noted, only one-third the amount Taylor has shown to be productive of the greatest shoveling efficiency.

These same data were obtained for shovels of other sizes, namely No. 3, No. 4, and No. 5, and Table IV gives the results of the tests made to determine the average amount of earth, sand, and stone that constitutes a shovelful.

TABLE IV.—SHOVEL LOADS OF VARIOUS MATERIALS IN POUNDS FOR SHOVELS OF DIFFERENT SIZES

		Worn			New		
Number	Dimensions of blade (inches)	Earth	Sand	¾-in. stone	Earth	Sand	¾-in. stone
2......	9¼ by 12¾	7.0	9.0	7.0	13.0	14.5	9.5
3......	9½ by 13¼	...	...	...	15.5	17.0	11.0
4......	9¾ by 13¾	...	...	...	18.0	19.0	12.0
5......	10½ by 14½	...	...	...	22.0	22.5	15.5

It has been my observation that the shovel most used in general contracting work is a No. 2, whether it is supplied by the employer, or by the laborer. That this is the fact is due, probably (in the case of the employer), to lack of consideration of the subject, and also to the fact that the use of this particular size is sanctioned by custom.

It will be noted, from Table IV that the No. 4 and No. 5 shovels approach most nearly, in the amount of material handled, the 21-lb. load. For trench and general shoveling work, however, the No. 5 is a trifle wide and cumbersome, while the No. 4, though appearing large and heavy in comparison with a No. 2, we found to be well adapted to use in the trench. Fortified, therefore, with the data presented at the beginning of this paper, it was decided to equip the laborers in the construction department with the No. 4 shovels, and at the beginning of the season, in April, 1914, this was done.

To quote from a report presented to the chief engineer:

I find that we started the season, on April 15, 1914, with 606 round-pointed No. 4 shovels, and 150 square-pointed No. 4 shovels, or a total of 756.

At the present time, Nov. 10, 1914, there are at the storeyard 311 round and 92 square shovels, leaving 295 round and 58 square, or a total of 353 shovels used during the season. Of these 353 shovels, 57 have been returned as worn out, and there are at present 251 in use on the work. The majority of these shovels now in use show considerable signs of wear, and might well be classed as worn out, so we have a total of 308 shovels worn out during the season. This leaves 45 shovels to be accounted for as lost, stolen, broken, etc.

In a season of 168 working days (up to the first of November) therefore, we have used 353 shovels, or an average of 2.10 per day. These shovels were of two different grades, costing $8.60 and $5.25 per dozen, respectively. The fact that the higher priced shovels outwear the lower has not been apparent, however, at least, not sufficiently so as to warrant the difference in cost.

Assuming, for sake of argument, that all the shovels cost us 72 cts. apiece (or at the rate of $8.60 per doz.) we find that it has cost $1.51 per day to supply our laborers with these No. 4 shovels. The daily average number of laborers at work during the season was 178, and the cost of the shovels per man per day was therefore .85 cts.

It was shown, by my previous reports, that the use of a No. 4 shovel, in place of a No. 2, increased the efficiency, and consequently the output of the shoveler, approximately 27 per cent. While it is practically impossible, on our work, to figure the actual increase in yardage shoveled, the balance seems to be unquestionably in favor of the No. 4 shovel. The cost of these shovels, as shown above, was less than 1 ct. per man per day, and there can be no doubt but that their use effected an increase in output far greater than that amount.

The item of 45 shovels lost, stolen, or unaccounted for is worthy of note. As remarked before, the statement has been made that shovels furnished by the employer are lost and stolen in great numbers. The fact that out of a total of 353 shovels used by 178 men through a season of over five months, only 45, or a percentage of 12.7, were unaccounted for, would tend to refute the argument.

There may be some who might question the practicability of equipping with the No. 4 shovel a number of men who have never used any other than a No. 2. This was done, however, and without the offering of any explanation, or a bonus for increased output. Such a step quite naturally created a great deal of comment and discussion among the men, for a few days, but after that time they apparently forgot that they were using a shovel which would hold half as much again as the one to which they had been accustomed.

A Study of the Application of Scientific Management to Trenching.—The following is a portion of an abstract, of a paper by B. M. Ferguson before the Michigan Gas Ass'n., Sept., 1911, given in Engineering and Contracting, Nov. 29, 1911.

"*High Wages and Low Labor Cost*" is Mr. Taylor's theme of scientific management. To increase the entire working efficiency of any industrial establishment, by putting into the hands of the management exact knowledge of *how long it takes to do work*, and carefully selecting and training men for each particular kind of work, together with improved methods of operation and a reward or bonus going to the operator, workman, mechanic, or laborer for an extra hard day's work, is the essence and direct object of the Taylor System of Scientific Management. "An extra hard day's work" must not be interpreted as meaning that men shall be worked to their limit of capacity or beyond that rate of speed which a man can maintain daily and throughout the year. It simply means a full day's work minus the time lost due to the evils connected with day work or the older and less efficient systems of management and the handling the labor.

The writer was assigned the task of studying the Taylor system with a view of testing its applicability to gas manufacture and distribution. A little study and investigation will develop the fact that *system* and *scientific or efficiency management* find just as big a field of application in the gas business as they do in any other industrial enterprise. What is necessary is a thorough investigation of the working conditions, and a *time study* of all the elements entering into each particular kind of work under consideration.

The Street Department, or more strictly speaking the laying of mains and services, offered the most prolific field of investigation to begin with, since upwards of 400 men were engaged in this kind of work. With the aid of a stop watch and note book the following data were gathered—Table V:

The time for removing this dirt was much too slow, and this for the following reasons:

1. The working capacity of the different men varies greatly due to lack of experience, old age, and a slow natural gait acquired by years of such work.

2. Good men, natural-born workers, and capable of much work, are slowed down or work at the pace set by the men next to them.

3. Men will soldier at every opportunity. They will work at a reasonable gait while the foreman stands over them and watches them, but just as soon as he turns his back and leaves the gang, the men will soldier. The foreman purposely picks a crew of mixed nationalities so as to avoid soldiering and waiting for each other as much as possible.

Two days later, after spending most of the time with the gang, I laid off 14 10-ft. sections, and timed the men on each section, with the results given in Table VI:

The average would be 59.8 minutes. The two men digging sections 4 and 5 are good men and work fast. They could easily earn $2.50 per day on the basis of $2 for

TABLE V—TIME OBSERVATIONS OF FIVE DIFFERENT MEN DIGGING 9-FT. SECTIONS OF 3.23 CUBIC YARDS

	No. 1	No. 2	No. 3	No. 4	No. 5
Time of start	10:00 A. M.	10:00 A. M.	10:15 A. M.	10:25 A. M.	10:25 A. M.
Time of finish	2:35 P. M.	1:50 P. M.	3:15 P. M.	2:50 P. M.	2:50 P. M.
	4:35	3:50	5:00	4:25	4:25
30 min. lunch	:30	:30	:30	:30	:30
	4:05	3:20	4:30	3:55	3:55
Minutes per yard	75.8	62.	83.6	72.7	72.7
Average per yard	73.3		(Average Cross-Section)		

TABLE VI

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13	No. 14
Time taken	3:15	4:05	3:20	2:30	2:15	2:10	3:40	3:40	3:40	3:45	3:45	4:15	4:25	4:10
Time per yard	55.1	69.3	66.5	42.2	38.2	37.0	62.5	62.5	62.5	63.7	63.7	72.2	75.0	71.0

the average man. All the men knew that I was watching them closely, and hence worked more steadily than they would have had I not been there. I marked the sections off for them at the start, and measured them at the finish. Of course, there is always some variation in soil, and temperature conditions have a good deal to do with the manner in which the men can work. It grew hotter in the afternoon, and the men naturally weakened a little.

Similar observations were made with another gang working on the laying of a 4-in. main on Cameron Ave., north of Woodland.

Number of hours digging: 84. Yards of dirt removed: 86.85 = .967 hours or 58 minutes per yard as the average of 17 men digging.

When I came to this job I told the foreman that I was doing some inspecting for the Street Department. When he saw me taking notes in my book and frequently looking at my watch, he began to push the men along, muttering to them in their own language, most of them being Polish. He complained about the short run jobs, and said it was difficult to know how to place his men. The soil here is softer than that on Jefferson Ave., but wet and heavier below the first foot or two. In two different places the banks caved in in the same half block, while nothing like this happened on Jefferson Ave. in about four blocks or more.

Ratio of Time Required to Dig and Throw One Shovelful of Dirt to the Time Required to Backfill One Shovel of Dirt.—Allowing for variation in soil of section by considering the section as composed of $\frac{1}{3}$ soft soil and $\frac{2}{3}$ harder soil, and multiplying observed times by this ratio:

On Jefferson avenue, 1 ft. below surface:
Mean time per shovel..11.5 seconds
Do., 3 ft. below surface:
Mean time per shovel..16.41 seconds

$$
\begin{aligned}
11.5 \times \tfrac{1}{3} &= 3.83 \\
16.41 \times \tfrac{2}{3} &= 10.95 \\
\hline
&\ 14.78 \text{ seconds per shovel.}
\end{aligned}
$$

Mean of 51 other observations taken at random, 13 seconds per shovel. Average of the two (about), 14 seconds:

Time per shovel on backfilling:
8-in. main gang (mean of 180 observations), 5 seconds.
4-in, main gang (mean of 190 observations), 4.8 seconds.

$$\frac{\text{Time required to dig.....14}}{\text{Time required to backfill..5}} = 2.8$$

or a yard of dirt should be thrown back in .357 times required to dig it.

Taking the following as the average cross-section: One cubic yard = 33.4 lin. ins. or .928 lin. yds. Total time required to dig and backfill .928 lin. yds. of ditch of the above section = 59 minutes digging + 16.5 minutes backfilling, or 75.5 minutes per cubic yard.

Soil fairly hard, weather warm but not hot. Nos. 1026, 1031, 1655, 1001 and 1027 received bonus on the basis of 1½ hours overtime ($1.30 on basis of $1) for each 21-ft. section dug. No. 1655 was not a very good worker and it was too much physical exertion for him to keep up his pace. All others showed no special signs of fatigue, and were quite satisfied to apply the extra effort for the bonus offered. (Table VII.)

No. 1031 said he disliked "Piece-work," so took him off. No. 1001 dug two hard sections at a good rate but claimed too much was wanted for the bonus. In the afternoon, he slowed down (Table VIII). His particular sections

TABLE VII.—BONUS TEST ON DIGGING

Number of diggers	1078	1026[1]	1662	1031[1]	1293	1655[1]	1662	1026[1]	1031[1]	1001[1]	1078	1027[1]
Length of section, feet	14	21	14	21	14	21	14	21	21	21	10	21
Area of cross section	5×2	5×2	5×2	5×2	5×2	5×2	*	"	"	"	"	"
Hours digging	4:30	4:15	5:15	4:25	4:45	5:00	5:35	5:15	4:45	4:25	5:25	4:20
Yards dirt removed	5.18	7.78	5.18	7.78	5.18	7.78	4.75	7.15	7.15	7.15	3.38	7.15
Minutes per yard	52.1	32.8	49.2	34.1	55.0	38.6	70.5	43.2	40.0	37.0	96.0	36.4

*"60"×22"

TABLE VIII

	1026[1]	1078	1001[1]	1662	1028	1016	1078	1001[1]	1662	1028	1078	1001[1]	1662	1026[1]
Feet	11	11	11	11	10.5	16.5	11	11	11	9½	12	10	12	12
Hours	3.69	3.69	3.69	4.25	4.54	6.37	4.25	4.93	4.25	4.85	4.73	3.94	4.70	4.85
Minutes per yard	....	....	....	....	....	40.7	51.7	41.8	47.6	38.3	72	72.3	73	72

TABLE IX

Number of digger	1616	1934	1039	861	1028	1293	1835	1001	1655	1662	1626	1078
Hours digging	5	5	5	5	4:15	5:30	5	4:15	5:05	3:45	3:30	4:30
Yards dirt	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	3.14	5.6
Minutes per yard	53.6	53.6	53.6	53.6	45.5	59	53.6	45.5	54.5	40.3	66.8	48.3

[1] These men received bonus as noted.

were harder than the average on account of the many tree roots and this necessitated the use of the pick and axe quite considerably. No. 1026, who is the best worker in the gang, also slowed up in the afternoon, but more on account of the influence of the other men than any other reason. The foreman had always given them 9-ft. sections to dig, and consequently the larger sections were not very popular at the start. For this reason I made the sections smaller temporarily.

Digging of the Average Man Under Close Supervision.—Soil rather hard, and ditch located about 5 ft. from row of trees. Digging in the morning—Table IX.

(1) Average time per yard for good men, 47.3 minutes.
(2) Average time per yard for average men 57.4 minutes.
(3) Average time per yard for good men with bonus, 38.3 minutes.
(4) Average time per yard for good men without bonus, 59.3 minutes.

Amount of work done by bonus men = 1.51 times work done by average man. This is equivalent to $3.03 on a basis of $2 per day. The bonus allowed was three hours overtime, making the day's pay $2.60 instead of $2. On the basis of 60 minutes for the average man and 40 minutes per yard for the bonus man, the men would be doing an excellent day's work. Even allowing this bonus for work at the rate of 45 minutes per yard ($2.66 on the basis of $2) would pay because of the influence of the good men on the other men.

Method of Keeping Cost of Earthwork so as to Show the Daily Unit Cost of Each Gang.—W. A. Gillette in Engineering and Contracting, July 24, 1912, gives the following:

Every dirt moving contractor knows the difficulty of ascertaining the unit cost of excavation during its progress, that is, before he secures his monthly estimate. I venture to say that not one contractor in fifty knows closely the cost per cubic yeard of the earth he moved yesterday or last week, unless it was moved in cars or wagons. Even then few contractors have adequate records of daily output.

Some time ago I conceived the idea that I would have my timekeepers "keep tabs" on the number of loads hauled by each gang during a period of about 20 minutes during the forenoon and for an equal period in the afternoon. Upon these two relatively short-time records, I determined to base an estimate of the full day's work of each gang and to test the accuracy of this method by comparison with the monthly estimates based on the engineers' cross-sections. I was astonished at the accuracy of my estimates of yardage. The first month I moved about 70,000 cu. yds., and my estimate was about 5 per cent higher than the engineers' estimate. The next month I was about an equal amount too low, so that I checked almost exactly with the engineers on the total yardage of the two months.

The timekeeper was given a statement of the estimated size of load of each kind of scraper and wagon. Thus, a No. 2½ wheeler was estimated to hold one-third cubic yard, measured in place. A three-up dump wagon was estimated to average 1¾ cu. yds. Fresnos were estimated at different capacities, according as the pull was up hill, or down hill, or level; and, in some cases, it might be desirable to vary the estimate according as the haul is short or long.

The important new feature of this method of cost keeping is the practice of counting the loads hauled by every gang during at least two periods of the day. One timekeeper can cover a lot of ground if he is provided with a saddle horse; and thus can report the output of a great many separate gangs.

His report is made out daily for each gang, and he also makes a summarized total daily cost report for all the gangs.

By following this plan I was able quickly to discover that my wheeler work was costing more than my fresno work. I also saw at once that for hauls of more than about 150 ft., the cheapest method was to load wagons with fresnos through a trap.

Methods of Analysis of Costs of Steam Shovel Work.—The following matter, published in Engineering and Contracting, Dec. 13, 1911, is an abstract of pages 5 to 30 of "Handbook of Steam Shovel Work" a report by Construction Service Co., to the Bucyrus Co.

There are so many factors entering into steam shovel work that the problem of determining the details of cost seems at first highly complex, but systematic analysis has resulted in so simplifying it that any man of field experience ought to be able, with the help of the data contained in these pages, to put his shovel work on a scientific basis. To determine what the work is costing day by day, is half the problem; to determine what it ought to cost is the other half.

To establish these factors it was necessary to observe a large number of shovels in operation, and the data given are the results of the observation of nearly 50 different shovels at work in various kinds of earth and rock.

The unit costs of working by hand will be nearly the same, field conditions being equal, whether the job is a large one or comparatively small. The steam shovel is dependent for its work upon so many factors, any one of which may greatly help or hinder it, that there is a far greater diversity of results than in the case of handwork. The question of how much work there must be to economically justify the use of a steam shovel is vital in a large percentage of all excavation contracts. To answer it, simply calculate the total cost, including the cost of installing the plant, and divide this by the number of cu. yds. of material to be handled.

General Conditions.—Repair costs should be apportioned to the work rather than considered a function of the age of the shovel. It will be higher for rock than earth and higher for poorly broken rock than for well blasted material. Time alone doesn't affect the unit cost of repairs.

In the item of *depreciation* the reverse of this proposition obtains. If the machine be kept in proper repair the depreciation is effected by time alone, regardless of the work the machine is doing. Many concerns class this item and repairs under one account, but this practice is inaccurate and misleading. There is a great disagreement among accountants as to how depreciation should be figured and there are many so-called depreciation formulae and curves. The simplest to use, and one which for steam shovel work is satisfactory if proper allowance is made for repairs, is the "right-line formula," which is as follows:

$$X = \frac{(a - b)c/d}{a},$$

where
a = original value,
b = value on removal,
c = time in use,
d = estimated life,
X = % of depreciation.

Then X divided by the output for the period c will be the cost of depreciation per unit of performance.

The working life of a shovel may be assumed to be 20 years, and assuming the first cost at $150 per ton, and its scrap value at $10 per ton, the value for X with a 10-year-old shovel, would be

$$\frac{(\$150 - \$10) \times \frac{10}{20}}{\$150} = 46.67\,\% \text{ in the 10 years or } 4\tfrac{2}{3}\,\% \text{ per year.}$$

The *interest* on all money invested in the work must be included in the costs of the work. In this discussion the interest is assumed as 6 per cent.

The *height of bank* to which a shovel can work has an important bearing upon the costs. The reason for this is that the higher the bank the larger amount of material that can be removed without moving the shovel.

Formulæ.—The following analysis of steam shovel work is based on the results of observations of about 50 shovels at work. The wages of the different classes of men were standardized as listed below for purpose of analytical comparison. In connection with this analysis the accompanying curves of cost are useful in enabling a rapid estimate to be made of the approximate cost of steam shovel work in progress or proposed:

d = time in minutes to load 1 cu. ft. with dipper (place measure).
c = capacity of 1 car in cu. ft. (place measure).
f = time shovel is interrupted while spotting 1 car.
e = time shovel is interrupted to change trains.
g = time to move shovel.
L = distance of 1 move of shovel.
N = number of shovel moves.
M = minutes per working day less time for accidental delays.
A or B = area in sq. ft. of section excavated.
R = cost in cents per cu. ft. on cars, for shovel work only (place measure).
LAN = cu. ft. excavated per day.
C = shovel expense in cents in 1 day, not including superintendence and overhead charges and not including preparatory charges.
n = number of cars in train.

(1) Time to load 1 car = dc.

(2) Time to load 1 train = ndc + nf + e.

(3) Number of trains for 1 shovel move $= \frac{LA}{nc}$

(4) Time between beginning of 1 shovel move and beginning of next $= (ndc + nf + e)\frac{LA}{nc} + g.$

$$(5)\quad N = \frac{M}{\left(dc + f + \frac{e}{n}\right)\frac{LA}{c} + g}$$

$$(6)\quad R = \frac{27Cd}{M} + \frac{27C}{M}\left(\frac{f}{c} + \frac{e}{nc} + \frac{g}{lA}\right)$$

This is equivalent to the equation R = md + b.

$$(7)\quad \text{Where } m = \frac{27C}{M}, \text{ and}$$

$$(8)\quad b = m\left(\frac{f}{c} + \frac{e}{nc} + \frac{g}{LA}\right)$$

It appears that the equation $R = md + b$ is that of a straight line. Now since the equation $m = \frac{27C}{M}$ and $b = m\left(\frac{f}{c} + \frac{e}{nc} + \frac{g}{LA}\right)$ all quantities involved in the equation excepting d are, or are assumed to be, constant. The data upon the value of these quantities have been represented in graphic form with all influencing factors by the Figures 7 to 10 incl.

The following standards have been assumed for a shovel valued at, say $14,000:

	Per year
Depreciation, 4⅜ %	$ 653.34
Interest, 6 %	840.00
Repairs, when working one shift	2,000.00
	$3,493.34

	Per day
Assuming year of 150[1] working days	$ 23.29
Shovel runner	5.00
Craneman	3.60
Fireman	2.40
½ watchman at $50 per mo	1.00
6 pitmen at $1.50	9.00
1 team hauling coal, water, etc., ½ day, say, at $5.00	2.50
2½ tons at $3.50	8.75
Oil, waste, etc., say	1.50
	$ 57.04

[1] For various reasons, such as lack of continuous work, weather, etc., 150 working days per year is assumed. This will vary greatly with local conditions.

TABLE X.—DATA FOR USE WITH COST CURVES

Values of e, n, c, f, involved in ordinary contracting work with side dump cars.

e = Average time shovel is interrupted to change trains.
n = Number of cars per train.
c = Capacity of cars in cubic feet (place mueasure).
f = Time to spot one car.
c′ = Capacity of cars in cubic feet (water measure).

	Values of n			Values of c				
	Min.	Avg.	Max.	Min.	Avg.	Max.	f	c′
Brick yard clay	1	1–2	2	54	72	81	Zero	...
R. R. borrow pits	7	11	15	83.7	126	270		151
Rock cuts	7	9	12	54	75	97.2		188
Crushed stone quarries	1	10	10	108	124	189		162
Earth and glacial drift	10	10–11	13	70	108	141		157
Iron ore	3	7	12	270	540	675		540
Sand and gravel pit	1	7	15	67.5	598	891		...

General average of e, n, c, f, c′, as follows

	No. of obs.	Minimum	Average	Maximum
c	35	.25 min.	4.00 min.	13.5 min.
n	35	5.0 cars	10.00 cars	15.0 cars
f	0	0	0	0
c	35	2 yards	4.00 yards	10.00 yards
c′	27	4 yards	5.00 yards	12.00 yards
c/c′	27	0.5	0.8	0.95

Fig. 7 indicates the time to load 1 cu. yd. place measure, in various kinds of material. Fig. 8 deals with the quantities e, average time shovel is interrupted to change trains. For use in plotting the equation above, those

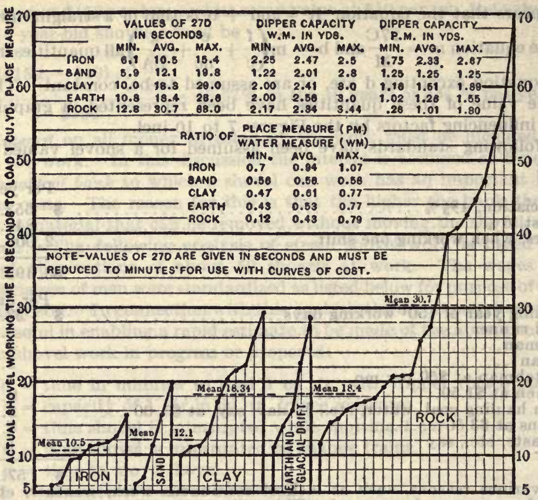


FIG. 7.—Diagram for use with cost curves.
(Value of 27d shown graphically.)

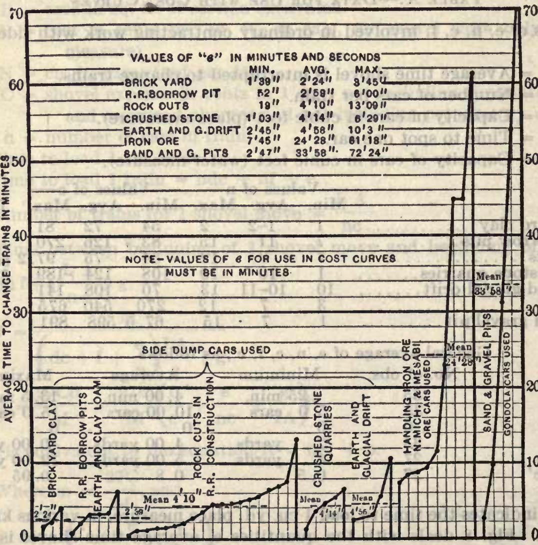


FIG. 8.—Diagram for use with cost curves.
(Value of e shown graphically.)

average values of e, n, c and f involved in ordinary contracting work where side dump cars are used, have been tabulated separately in Table X. It will there be seen that the average value for e, the time between trains is 4 minutes. The average number of cars per train, or n = 10. The commonest form of contractors' dump car is 4 yards water measure or 2.5 yards place measure, and therefore c is taken as 67.5 cubic feet. The ordinary value of f is zero, since the cars are almost invariably spotted while the shovel is swinging and digging. Fig. 9 deals with the value of M or the working

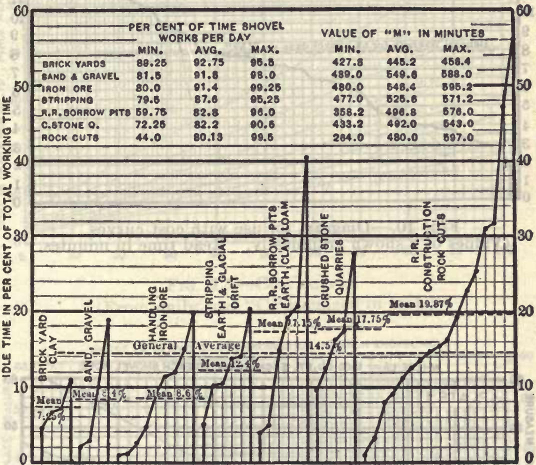


FIG. 9.—Diagram for use with cost curves.

(Idle time shown graphically in per cent of total time per day. Values of "M" to be taken from this diagram. To find "M" take value plotted below subtract from 100 per cent and multiply result by total working time per day (generally 10 hours).

time, including actual shovel time waiting for trains and moving up, but not accidental delays. Fig. 10 deals with the time of moving up, an average value for which is 8 minutes.

The constants having thus been established, three sets of curves have been plotted, Figs. 11, 12 and 13, which are cost curves. Each plate is plotted, with one of the three values of LA 1,500, 3,000 and 6,000 cu. ft. (L being the average shovel move, 6 ft. and A the area of the dug section in sq. ft.) Each of these sets of curves has been plotted for values of M, ranging from 2 hrs. to 10 hrs. by hourly intervals between which intervals the observed values (see Table X) fall.

Estimating.—There are two important uses to which these cost curves can conveniently be put, (1) estimating the cost of proposed work and (2) checking up the cost of work under way. In estimating we may proceed as follows: Assuming that the proposed work is to be a railroad cut in rock, with average equipment, there are then only three quantities to decide upon, namely, LA, 27d, and M. The area of the shovel section being assumed at 250 sq. ft. and

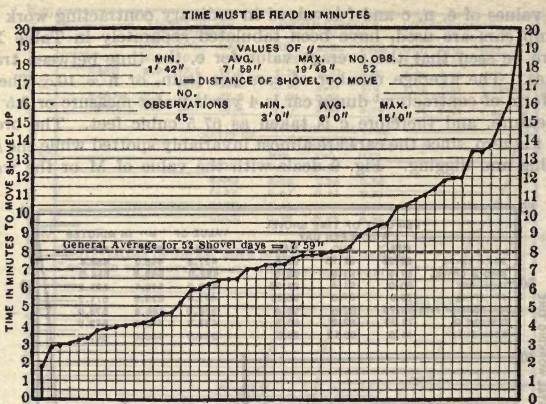


FIG. 10.—Diagram for use with cost curves.
(Values of g shown graphically. Read time in minutes.)

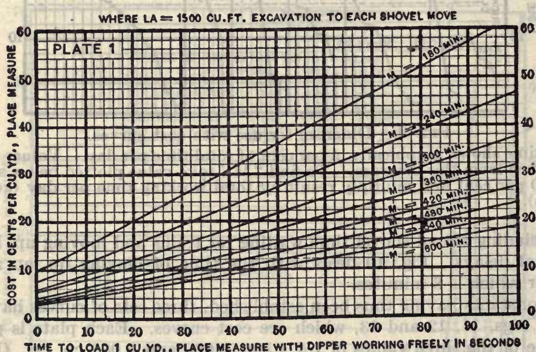


FIG. 11.—Cost curves.

$$\text{Formula } R = \frac{27Cd}{M} + \frac{27C}{M}\left(\frac{f}{c} + \frac{e}{nc} + \frac{g}{LA}\right)$$

Assume—

f = 0, interruption of shovel while spotting cars.
e = 4 min. time between trains.
n = 10, number of cars per train.
c = 2.5 yds. place measure = 67.5 cu. ft.
C = 5704 cents, daily cost.
M = actual working time of shovel.
g = 8 minutes, see Fig. 4.
d = Minutes to load 1 cu. ft. place measure.

the average distance of move being 6 ft., LA will equal 1,500 cu. ft. Now refer to Fig. 7 and select a fair value for the time of loading 1 cu. yd. in rock work. Suppose 30 seconds be chosen. Next refer to Fig. 9 for the proper value of M to use in rock work. The average value is 8 hrs. (80 per cent of 10 hrs.). The cost per yard in cents can now be read directly on cost curves

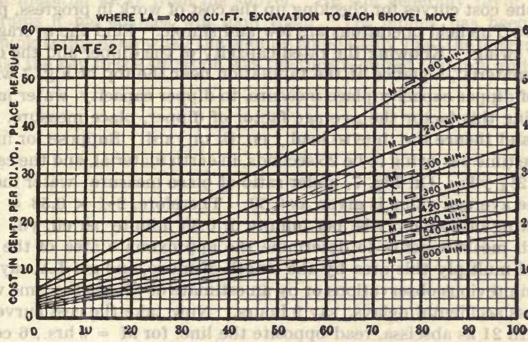


FIG. 12.—Cost curves.
(From daily cost "C" itemized in text.)

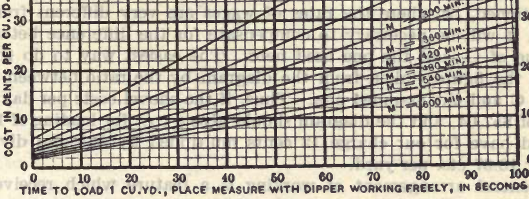


FIG. 13.—Cost curves.
(Values same as Figs. 11 and 12.)

Fig. 11. With abscissa (27d) as 30 seconds glance upward till the vertical line through 30 seconds intersects the 8 hr. M line. Then on the left, opposite this point of intersection read 9½ cents as the cost per cu. yd. loaded, place measure.

It may be noted here that with respect to the two important items of time to load 1 cu. yd. with dipper and values of M, the cost curves are perfectly flexible. Variation in the value of the constants may be allowed for by proper choice of M. In connection with the formula it is interesting to note the effect of decreasing the carrying capacity of each train, other conditions remaining the same. Suppose the carrying capacity be decreased from the average 10×2.5 yds. = 25 cu. yds. to $8 \times 2 = 16$ cu. yds., place measure, what would be the effect upon the cost per cu. yd. The new cost would be 10.6 cts. per cu. yd. as against the former 9½ cts., an increase of 10 per cent.

To use the cost curves for checking up the cost of work in progress, proceed as follows: The field operations are few and simple. Find the average time per dipper swing. Knowing the rated capacity of the dipper and the character of the material, a glance at the tabulation near the top of Fig. 7 will give the ratio of dipper capacity place measure, to dipper capacity, water measure and by using this factor the average factor of dipper, place measure, can be obtained, and thence the time to load 1 cu. ft. or yard. Suppose for instance the average time per swing to be 25 seconds, in earth material, and the capacity of dipper, 2¼ yds. On Fig. 7, under ratio of place measure: water measure, we find the average value is given as 0.53. Therefore, $2\frac{1}{4} \times 0.53 = 1.2$ cu. yds. per swing or 2.88 cu. yds. per minute or 0.35 minute per cu. yd. Make some rough measurements to determine the approximate area of the shovel section and multiply this area by the length of move, and get LA, say 3,000. Then, from previous observations or by an estimate of M, get the time worked per day, less accidental delays, say 9 hours. Now take the cost curves, Fig. 12, and with 21 as abscissa, read opposite the line, for M = 9 hrs., 6 cents as the cost per yard, place measure. If the contents in the formula do not agree close enough with the actual conditions, allow for this by choosing a suitable value of M, or substitute directly in the equation for cost.

It should be noted that the above does not include superintendence or overhead charges and cover only the cost of loading. It should be particularly noted that for plotting the two co-ordinates certain assumptions are necessary because there are a large number of variables in the theoretical steam shovel formula. Thus, the three plates are given—one for LA = 1,500, one when LA is 3,000 and one where it is 6,000. Also an assumption of $57.04 for the value of C is made. Where the shovel differs very much in type from the one mentioned, or where the rates of wages are very different from those assumed, it will be necessary to compensate for the difference between the new value of C, and the one used here. The easiest way to do this is to multiply the figures taken from the diagram by the ratio between the new value of C and the assumed one. Thus, if the shovel costs per day are $65 instead of $57.04, and the diagram should give a cost for loading of 12 cents, we would have for our charge 12 cents multiplied by $65 and divided by $57.04 or 13.67 cts. per yard.

The general arrangement of working is a feature which receives great attention from skillful managers; the "old line" contractor comes on a job and looks it over from the seat of his buggy, deciding on the ground, where he will begin operations and how he will transport the material from the shovels. The modern manager undertakes a job much as a professor attacks a mathematical problem. Sometimes there is only one place to "cut in" and only one way to handle the earth or rock, but generally there are several places to cut in and many ways available for handling the material. If there were only 3 ways—and there are seldom less than 23—he is a bold man who would decide offhand which is unquestionably the best of the three, until an economic study has conclusively established the facts.

The quality and amount of superintendence will greatly affect the unit costs of the work; and by superintendence is meant, not only the man in charge, but his whole directing organization. The work in the iron ore country is an example of the work which may be accomplished in the way of skilled organization. Pure observation alone without actual timing will not show a superintendent whether it is more economical for him to use 9 car or 10 car trains to haul material away from his shovel. He will generally favor the use of long trains if his engines will haul them. Yet money has been saved by shortening trains even when the engines could easily haul the longer ones. In this case the key to the situation was the time required to dump and transport.

CHAPTER V

CONCRETE CONSTRUCTION

This chapter is comprised of articles dealing with the economics of plain and reinforced concrete, in general. For costs on particular types of construction the reader is referred to chapters of this volume covering the subject in question and to the index at the back of the book. Further costs on concrete construction may be found in "Concrete Construction Methods and Cost" by Gillette and Hill and "Handbook of Cost Data" by Gillette.

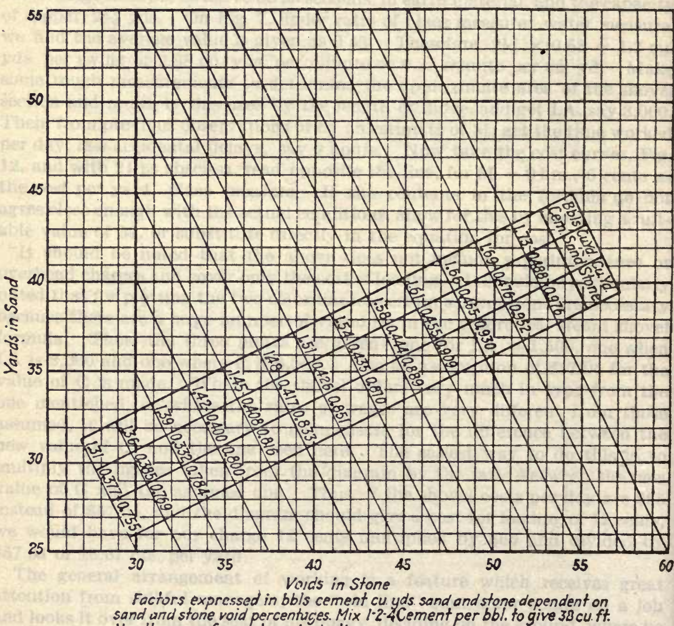
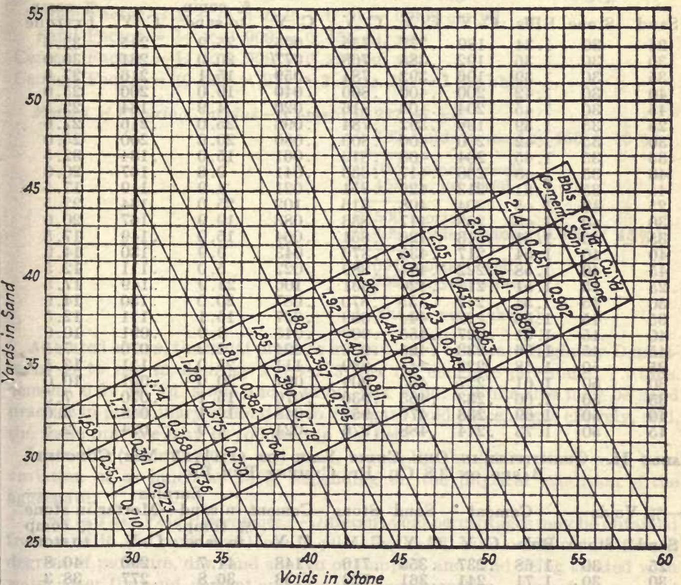


FIG. 1.—Diagram for obtaining interpolated values of factors when the voids in either of the coarse aggregates vary from a multiple of 5 per cent. Mix 1:2:4.

Value of Determining Void Percentages in Coarse Aggregate for Concrete.—W. G. Crandall gives the following discussion in Municipal and County Engineering, Dec. 1919.

In the New York State Highway Department, it has been and is the custom in preliminary estimating of concrete pavement for a mix of 1:1½:3 to figure

1.9 bbls. cement, 0.84 cu. yd. stone, and 0.42 cu. yd. sand as the factors to use in obtaining the cubic yard price of concrete. Inasmuch as the percentage of voids in the aggregates determines the value of the factors, and a variation in the factors means a difference in the cubic yard cost of concrete, it would seem that a field investigation of the voids in the aggregates would warrant itself, to determine whether or not a contractor would increase or decrease his bids on the engineer's estimate of the concrete pavement by varying the



Factors expressed in bbls. cement, cu. yds. sand and stone dependent on sand and stone void percentages. Mix 1-1½-3. Wt. cement per bbl. to give 3.8 cu ft. No allowance for waste or hydration.

FIG. 2.—Diagram for obtaining interpolated values of factors when the voids in either of the coarse aggregates vary from a multiple of 5 per cent. Mix 1:1½:3.

factors, all other items in the analysis being considered equal for the purpose of comparison. Before working out a comparative analysis to show in dollars and cents what this difference means, it is necessary to explain the accompanying tables and curves.

Tables and Curves.—The tables show the quantities in 1 cu. yd. of concrete based on 3.8 cu. ft. cement per barrel for proportions of 1:2:4 and 1:1½:3, the two mixes used by the New York State Highway Department in concrete pavement construction.

The purpose of these tables is to show at a glance what proportions of coarse and fine aggregate to use for either of the above mixes, based on the void percentages in the coarse aggregates. In the tables, the sand voids range from 25% to 45% and the stone voids from 30% to 50% by increments of 5% and the accompanying curves are used to obtain interpolated values of factors when the voids in either of the coarse aggregates vary from a multiple of 5%. The tables and curves show also the cubic yard and percentage excess of cement in sand and mortar in concrete.

TABLE I.—QUANTITIES IN ONE CUBIC YARD OF (1:2:4 Mix) CONCRETE BASED ON 3.8 CU. FT. CEMENT PER BBL.

—Voids—		—Cement—		Sand	Stone	Surplus: Cement in sand		Surplus: Mortar in stone	
Sand	Stone	BBls.	C. Y.	C. Y.	C. Y.	C. Y.	% comp. to sand	C. Y.	% comp. to stone
25	30	1.34	.189	.377	.755	.095	25.2	.245	32.5
30	30	1.36	.192	.385	.768	.077	20.0	.231	30.0
35	30	1.39	.196	.392	.784	.059	15.1	.216	27.6
40	30	1.42	.200	.400	.800	.040	10.0	.200	25.0
45	30	1.45	.204	.408	.816	.020	4.9	.184	22.5
25	35	1.39	.196	.392	.784	.098	25.0	.216	27.6
30	35	1.42	.200	.400	.800	.080	20.0	.200	25.0
35	35	1.45	.204	.408	.816	.061	15.0	.184	32.5
40	35	1.48	.208	.417	.833	.041	9.8	.167	20.0
45	35	1.51	.213	.426	.851	.021	4.9	.149	17.5
25	40	1.45	.204	.408	.816	.102	25.0	.184	22.5
30	40	1.48	.208	.417	.833	.083	19.9	.167	20.0
35	40	1.51	.213	.426	.851	.064	15.0	.149	17.5
40	40	1.54	.217	.435	.870	.043	9.9	.130	14.9
45	40	1.58	.222	.444	.889	.022	5.0	.111	12.5
25	45	1.51	.213	.426	.851	.106	24.9	.149	17.5
30	45	1.54	.217	.435	.870	.087	20.0	.130	14.9
35	45	1.58	.222	.444	.889	.067	15.1	.111	12.5
40	45	1.61	.227	.455	.909	.045	9.9	.091	10.0
45	45	1.66	.233	.465	.930	.024	5.2	.070	7.5
25	50	1.58	.222	.444	.889	.111	25.0	.111	12.5
30	50	1.61	.227	.455	.909	.091	20.0	.091	10.0
35	50	1.66	.233	.465	.930	.070	15.1	.070	7.5
40	50	1.69	.238	.476	.952	.048	10.1	.048	5.0
45	50	1.73	.244	.488	.976	.024	4.9	.024	2.5

TABLE II.—QUANTITIES IN ONE CUBIC YARD OF (1:1½:3 Mix) CONCRETE BASED ON 3.8 CU. FT. CEMENT PER BBL.

—% Voids—		—Cement—		Sand	Stone	Surplus: Cement in sand		Surplus: Mortar in stone	
Sand	Stone	Bbls.	C. Y.	C. Y.	C. Y.	C. Y.	% comp. to sand	C. Y.	% comp to stone
25	30	1.68	.237	.355	.710	.148	41.7	.290	40.8
30	30	1.71	.241	.361	.723	.133	36.8	.277	38.3
35	30	1.74	.245	.368	.736	.116	31.5	.264	35.9
40	30	1.78	.250	.375	.750	.100	26.7	.250	33.3
45	30	1.81	.255	.382	.764	.083	21.7	.236	30.9
25	35	1.74	.245	.368	.736	.153	41.6	.264	35.9
30	35	1.78	.250	.375	.750	.137	36.5	.250	33.3
35	35	1.81	.255	.382	.764	.121	31.7	.236	30.9
40	35	1.85	.260	.390	.779	.104	26.7	.221	28.4
45	35	1.88	.265	.397	.795	.086	21.7	.205	23.8
25	40	1.81	.255	.382	.764	.159	41.6	.236	30.9
30	40	1.85	.260	.390	.779	.143	36.7	.221	28.4
35	40	1.88	.265	.397	.795	.126	31.7	.205	25.8
40	40	1.92	.270	.405	.811	.108	26.7	.189	23.3
45	40	1.96	.276	.414	.828	.090	21.7	.172	20.8
25	45	1.88	.265	.397	.795	.166	41.8	.205	25.8
30	45	1.92	.270	.405	.811	.149	36.8	.189	23.3
35	45	1.96	.276	.414	.828	.131	31.6	.172	20.8
40	45	2.00	.282	.423	.845	.113	26.7	.155	18.3
45	45	2.05	.288	.432	.863	.094	21.8	.137	15.9
25	50	1.96	.276	.414	.828	.172	41.5	.172	20.8
30	50	2.00	.282	.423	.845	.155	36.6	.155	18.3
35	50	2.05	.288	.432	.863	.137	31.7	.137	15.9
40	50	2.09	.294	.441	.882	.118	26.8	.118	13.4
45	50	2.14	.301	.451	.902	.098	21.7	.098	10.9

Method of Figuring Quantities.—Following is the method of figuring quantities in one cubic yard of (1:2:4 mix) concrete based on 3.8 cu. ft. cement per barrel.

Take for instance a 40% sand and a 45% stone

Mix 1		Void %		Void	Swell
2	×	0.40	=	0.8	0.2
4	×	0.45	=	1.8	0.2

Stone Factor = 4 ÷ (4 + 0.2 + 0.2) = 0.909 cu. yd.
Sand Factor = ½ × 0.909 = 0.455 cu. yd.
Cement Factor = ¼ × 0.909 = 0.227 cu. yd.
Cement Factor = (0.227 × 27) ÷ 3.8 cu. ft. = 1.61 bbls.

Method of Figuring Surplus.—Cement 0.227 cu. yd.
0.182 Voids in sand (0.455 × 40%).

0.045 Cement swell.
0.455 cu. yd. sand.

0.500 mortar.
0.409 Voids in stone (0.909 × 45%).

0.091 mortar swell.
0.909 cu. yds. stone.

1,000 cu. yds. (check).

As stated above, the usual practice in the New York State Highway Department is to use in figuring a 1:1½:3 mix for concrete pavement, 1.9 bbls. cement, 0.84 cu. yd. stone and 0.42 cu. yds. sand. While this may be good practice in preliminary estimating to disregard void percentages entirely, still, the same practice may be followed in the field.

In testing voids in stone and sand, especially the latter, there may be a variation of as much as 25%, depending on the physical condition of the aggregate.

Time to Take Void Percentages.—Different void percentages may be obtained from sand in the bank and loose in piles, dry sand, sand containing different degrees of moisture, dry sand shaken or tamped, and sand being treated with water after the sand, cement and stone is mixed together. Therefore, especial precaution should be taken by the engineer on the road to take void percentages at the time directly previous to the actual mixing of the ingredients and in the physical state that the coarse aggregates exist directly previous to their incorporation to form the concrete. These void percentages should be taken every day and also when the character of the aggregate would tend to show a variation, as when a coarse pocket of sand would be evident in a bank from which a fine grade was being taken.

After these void percentages of sand and stone are derived the factors entering into the mixture may be obtained at a glance from the curve.

Example of Value of Void Determination.—Assume the following analysis of cement concrete pavement:

Cement		Stone		Sand	
F. O. B.	$2.35	Bin	$2.25	Royalty	$1.25
Handling	.08	Haul, 1 mi.	.45	Wash, screen,	
Haul, 1 mi.	.08			Haul, 1 mi.	.45
			$2.70		
	$2.51				$1.70

For 1:½:3 mix use 1.9 bbls. cement, 0.84 cu. yd. stone and 0.42 cu. yd. sand.

Cement $2.51 at 1.9	$ 4.77
Stone $2.70 at 0.84	2.27
Sand $1.70 at 0.42	.71
Manipulation	2.50
Water and joints	.30
	$10.55
Profit, 20%	2.11
Waste and overhead, 10%	1.06
	$13.72
	Say $13.75

Suppose a contractor made a void test of the coarse aggregates in the field under approximately the physical conditions the stone and sand would be, when mixed, and determined a sand void of 35% and a stone void of 40%. From the curve the factors entering into the computation would be cement, 1.88 bbls.; sand, 0.397 cu. yd.; Stone, .795 cu. yd.

Applying these factors to the above prices we have

Cement $2.51 at 1.88	$ 4.72
Stone $2.70 at 0.795	2.15
Sand $1.70 at 0.397	.67
Manipulation	2.50
Water and joints	.30
	$10.34
Profit, 20%	2.07
Waste and overhead, 10%	1.03
	$13.44
	Say $13.45

The difference is .30 per yd.

In a road 5 miles long, 18 ft. wide, section 6 in.-8 in.- 6 in., Parabolic, the number of cubic yards, 10,756, at $.30 would mean a saving of $3,226.80, which it seems would be worth a preliminary investigation before submitting bid on a concrete pavement.

Diagram for Cost of Placing Steel Reinforcement.—Labor cost in placing steel is usually estimated in dollars per ton, although it is recognized that such unit costs increase when light steel is being placed. The accompanying diagram Fig. 3, devised by Dan Patch of the Aberthan Construction Co., and published in Engineering Record, Aug. 26, 1916, shows chearly the effect of sizes of rods on the unit cost per ton.

Mr. Patch says:

The unit costs are usually obtained by dividing the labor cost figured from the time-keeper's sheets by the tons of steel reported placed by the quantity man. In order to obtain data for studying the effect of size of bars, only one more item must be recorded—the total length of bars placed. This is easily done by the use of a listing adding machine, by which the total running feet of each diameter of rods placed can be obtained. The daily totals are tabulated in terms of rod sizes and linear feet placed, the total length and total weight computed, and the average weight per running foot easily obtained. Knowing total cost and total tonnage, the cost per ton is found, and plotted on the diagrams as shown in Fig. 3.

The curves *A*, *B* and *C*, which are drawn through the fields of plotted points obtained for costs of placing in wall, columns, stairs, etc., in floor and roof slabs, and of bending and cutting respectively, indicate the large effects of average weight upon the cost of labor per ton.

If additional argument in favor of accounting for the weight variable is necessary it will be found in the curves of Fig. 4. This diagram shows on a larger scale the plotted costs for the same kind of work, but for different dates, the steel growing lighter as the roof is approached. Sections of the typical

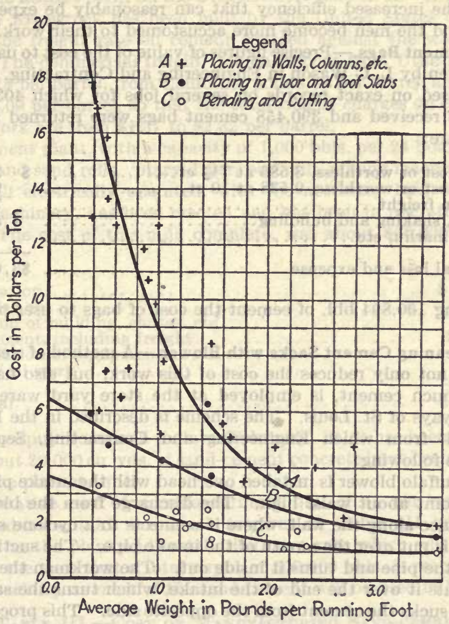


FIG. 3.—Chart for cost of reinforcing steel based on weight per foot.

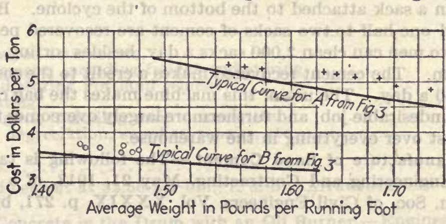


FIG. 4.—Typical examples of costs at various dates compared with curves in Fig. 3.

curves of Fig. 3 to this enlarged scale are shown, the costs of placing in walls, columns, etc. (Curve *A*), giving the clearer illustration.

Use of Typical Curves.—As an example of the value of these curves, consider the figures on the work recorded in Fig. 4. On Nov. 23 the cost per ton was \$4.83. By Jan. 19 this cost had risen to \$5.34 per ton. With these figures only and no knowledge of the weight of steel it would be assumed that the work was being less efficiently done, but with the typical curve as a basis of comparison it will be noted on Fig. 4 that while there has been a 10-per cent increase in the cost per ton, the typical cost curve *A* has been more nearly approached, indicating the increased efficiency that can reasonably be expected as a job progresses and the men become more accustomed to their work.

Cost of Cement Bags.—Precise figures of value of the cost to users of cement sacks are given by L. C Wason in Engineering and Contracting, Feb. 9, 1916. They are based on exact records on several jobs for which 403,576 bags of cement were received and 390,458 cement bags were returned and credited. The figures are:

Bags lost or worthless, 3,586 at 7½ ct	$ 268.50
Bags lost or worthless, 9,538 at 10 ct	953.80
Return freight	725.06
Labor, shaking and bundling	1,590.00
Wire, marlin, etc	66.50
Total loss and expense	$3,603.86

There being 100,894 bbl. of cement the cost of bags to user per barrel was 3.6 ct.

Cost of Cleaning Cement Sacks with Blower.—A method of cleaning cement sacks which not only reduces the cost of this work, but also has resulted in recovering much cement, is employed at the store yard warehouse of the United Railways of St. Louis. The scheme is described in the Electric Railway Journal, from which Engineering and Contracting, Sept. 22, 1920, abstracts the following:

A No. 5 Buffalo blower is installed overhead with the intake pipe extending down to a point about waist high. The discharge from the blower is piped a short distance along the wall, where it connects to a cyclone separator. A cement sack is put over the mouth of the intake pipe. The suction draws the bag up into the pipe and turns it inside out. The workman then pulls it out and again puts it over the end of the intake, which turns the sack the other way out and sucks the cement from the opposite side. This process leaves the sacks cleaner than it is possible to get them by hand. The cement recovered is deposited in a sack attached to the bottom of the cyclone. By this means from one and one-half to two sacks of cement are recovered per 1,000 sacks cleaned. Two men can clean 2,000 sacks a day, besides sorting, counting and bundling them. The cement recovered makes a credit to the cost of handling of about $2.50 a day. The use of this machine makes the bag cleaning not a particularly undesirable job, and furthermore largely overcomes the spreading of cement dust over everything in the warehouse.

Cost of Manufacture of Sand Cement.—The following is taken from an abstract in Engineering and Contracting, May 21, 1913, of a discussion in the Proc. Am. Soc. of Civil Engineers, Vol. XXXIX, p. 271, by Charles H. Paul.

The use of sand-cement in mass work, where the requirements are enough to justify the installation of the necessary grinding machinery, where suitable blending material is available, and where the transportation charges on Portland cement amount to a considerable portion of its cost laid down, will result in a marked saving in construction costs, and will give a product which is at least the equal of the Portland cement from which it was made, in fact, one which, for ordinary requirements, is not open to the least suspicion.

In the construction of the Arrowrock Dam—by the U. S. Reclamation Service to store the flood waters of the Boise River—about 550,000 cu. yds. of concrete will be laid, and the cost of cement is, of necessity, a most important item. The dam is about 22 miles above the city of Boise and 17 miles above Barberton, the nearest point on the Oregon Short Line R. R.. A railroad from Barberton to Arrowrock has been built by the United States Government, over which the freight rate on cement charged against the work is 23 cts. per barrel. The commercial freight rate on cement from Utah mills to Barberton is $1.14 per barrel, from California points $2 per barrel, and from Kansas points $2.09 per barrel, so that the total freight charges on cement to the Arrowrock work are from $1.37 to $2.32 per barrel.

A sand-cement plant, with a capacity of 1,000 bbls. per 24 hours, consisting of a crusher and sand rolls, rotary dryer, ball mill, mixing machine, and three tube mills, all electrically operated, with the necessary bins, hoppers, and conveying machinery, has been erected and has been in operation for about 2 months. The cost of this mill, complete, was about $46,000, itemized as follows:

Excavation	$ 1,500
Foundations	3,750
Erection of building, chutes, etc	8,150
Equipment, including freight	23,000
Installation of equipment	7,850
Electrical work	1,750
Total	$46,000

The total output of the mill to date (February, 1913) has been about 25,000 bbls. and about 20,000 cu. yds. of sand-cement concrete have been placed in the dam up to the present time.

A representative cost of manufacturing 1 bbl. of 45 per cent by weight blend of sand-cement at Arrowrock is given in Table III which includes depreciation on the plant and installation, at a rate which will wipe out the total cost at the time that a total ouput of 500,000 bbls. is reached. It does not include sacking, as most of the sand-cement will be used in bulk.

TABLE III.—COST OF MANUFACTURING SAND-CEMENT

Items	Unit cost of sand-cement per barrel
Granite delivered to crushers	$0.02
* Portland cement, including freight and storing	1.35
Handling and storing Portland cement	0.08
Labor, operating	0.10
Power and lights, including maintenance, etc	0.16
Installation, depreciation, supplies, repairs, etc	0.14
Total cost	$1.85

* Portland cement at $2.36 per bbl., f. o. b. Arrowrock.

Heating Concrete in the Drum with an Oil Burner.—Engineering and Contracting, Jan. 3, 1917, states that a concrete mixer with Hauck Oil Burner attached, designed and built at the request of several contractors engaged on the subway in New York City, gave the following results in the winter work of 1916:

½ cu. yd. batch heated to 50°F. in 2 minutes
½ cu. yd. batch heated to 60°F. in 3 minutes
½ cu. yd. batch heated to 80°F. in 4 minutes

The heater uses fuel oil or kerosene and is made in two types. The compressed air type is equipped with a 25-gal. oil storage tank and air regulating valves, filling pipe with plug and full union. The approximate oil consumption is 1½ gal. per hour.

The other type of heater is designed for use where compressed air is not available. It consists of a 20-gal. oil storage tank equipped inside with a powerful hand pump. The tank can be placed on the ground or on the engineer's platform. It is necessary for operating this vaporizing type of burner to carry oil pressure from 12 to 75 lb., which is obtained from the hand pump placed inside the tank and which requires about 90 seconds of pumping to obtain the above mentioned pressure. No air from the tank is necessary for vaporizing the kerosene in the burner and pressure is only used for forcing the oil to the burner. The burner is attached to a steel pipe, oval shaped at the lower end and bent so that flame shoots diagonally into the mixer. It is fastened to the frame of the mixer.

Additional Cost of Concreting in Winter.— In constructing ore dock No. 2 of the Duluth & Iron Range R. R. at Two Harbors, Minn., the Engineering News-Record, Aug. 9, 1917, states that an item of interest in connection with the winter concrete work on the deck slab was the extra cost of this over concrete placed in more favorable weather. Aside from the initial delay due to very severe cold, no unfavorable conditions were encountered. When started, the concreting progressed at the maximum rate, very smoothly and with an unusually efficient crew of men. Yet the extra cost amounted to about $2.50 per yd. This was due chiefly to the cost of the housing, the fuel and boiler-plant attendants increased concrete labor cost due to decreased production, cost of moving housing and cost of canvas. This is not considered excessive in view of the results achieved.

The heating plant consisted of a 40-hp. return-tubular boiler and two water tanks installed on a flat-car. One tank was for the boiler feed and the other, heated by steam, for hot-water supply for the concrete mixer. A locomotive tender delivered water to the tanks by means of a steam ejector. A steam connection was made to the mixer drum to inject live steam there.

With this equipment it was possible to turn out concrete heated to almost any temperature desired. If concrete is too hot, however, it will set up badly in the mixer, clogging this rapidly, and will also cause checking in the finished slab work. The contractors consider 90 to 100° about as warm as it is desirable to go.

Although a comparatively thin concrete slab on top of a high structure extending into Lake Superior would not seem a very favorable place for cold-weather concrete work, there were several advantages for this work. The bottoms, fronts and dividing walls of the pockets were all in place, thus shutting off the under side of the slab very effectually. The dock was provided with the four railway tracks, and there was also a substantial steel railing on each side of the dock. These points were all used to assist in housing in the deck-slab work.

The housing, 70 ft. wide and 75 ft. long, was mounted on 4 wooden ore cars. The roof and ends of the house were made of 1-in. boards covered with tar paper, the sides being closed with canvas. Steam coils were built completely around the sides of the house and connected to the boiler car.

A move of 72 ft. could be made in 5 min. after the canvas was loosened at the bottom. With weather varying from zero upward, it was found entirely feasible to put in the deck-slab concrete. With weather much below zero it was not found advisable to handle that class of work.

An Inexpensive Method for Testing the Strength of a Reinforced Concrete Floor Slab.—The following abstract, of an article by C. H. Weitz in the "Purdue Engineering Review," is taken from Engineering and Contracting, Jan. 17, 1912.

A number of materials have been tried out for loading floors to be tested; such as pig iron, rubble stone, and bags of cement, gravel or sand. Where cartage charges and wages are high, the cost of a single test, using any of the above materials, will run from $200 to as high as $700. The latter figure may look very high, but a little figuring will show that the amount is not excessive or unusual. In the first place two slabs which measure 18 × 20 ft. each, live load 250 lbs. per sq. ft., will require about 200 tons of material for the test load. Cartage on this material to and from the job will cost

Per ton	$1.00
Unloading and hoisting	1.50
Taking down and reloading	1.00
Total cost per ton	$3.50

This makes a total of $700 for handling the 200 tons of material and is a very low estimate of the cost where laborer's wages are $3 per day, hoisting engineers get $5.60 and teams cost $7 per day.

It was while casting about for some cheaper method for making these tests that the writer hit upon the use of torpedo sand in the bulk. Damp torpedo sand weighs about 110 lbs. per cubic foot as it is shoveled into a bin or pile. A 2-in. plank enclosure was built on the center line of columns, enclosing floor panels. The height of this enclosure in feet was just 9/10 of the hundreds of pounds per square foot of the test load. For instance, a test load of 400 lbs. per square foot requires a bin 3 ft. 7 ins. high.

The sand can be loaded into wheelbarrows and hoisted on a brick hoist, or, more cheaply, in a concrete skip; or, still more cheaply, if conditions permit, by means of a bucket elevator. The sand should be hoisted first to the highest floor to be tested, thrown into the bin and leveled off even with the sides of the bin with a straight edge. The cost of hoisting the sand by the first method will run about 75 cts. per ton; by the second method 30 cts. per ton; and, by the third method 15 cts. per ton. These prices include placing the sand in the bin provided it is located within 30 ft. of the place where the sand is delivered by the hoisting apparatus. There is usually one or more of the above mentioned hoisting mechanisms available on a job, so that it is unnecessary to erect a hoist especially for testing purposes.

As soon as one floor is tested and the load is wanted on a lower floor, it is not necessary to lower the sand by means of a hoist or to carry it down a stairway as is the case when pig iron, rubble, or ballast in bags is used. Instead, all that is needed is to cut a small hole in the slab from beneath and let the sand run through. The hole can then be patched at slight expense.

When as many tests are made as is required the sand may be dropped down a stair or elevator shaft, through a window, or down a rubbish chute directly into wagons. However, there are usually a number of things remaining to be done, such as basement floors, sidewalks, etc., for which a quantity of torpedo sand is needed so that it is seldom necessary to remove any of the sand from the premises.

On a recent job about 150 tons of sand were hoisted by means of a bucket elevator to the third floor and spouted through a window on to the floor. This sand was then shoveled into a bin covering two panels to the required depth. The load was allowed to remain 24 hours for the city inspector to make his observations. A hole was then cut in the slab and the sand allowed to run down to the second floor where a bin had been prepared. After the test of the second floor the sand was dropped to the ground and was all used for cinder concrete and for the first floor which was laid directly on the ground.

The entire cost of these two tests, which involved the handling of 150 tons of material three times, was slightly less than $50.

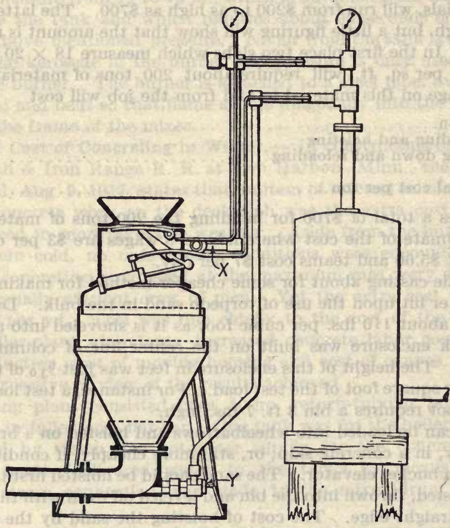


Fig. 5.—How to admit air to pneumatic concrete mixer.

Operating Cost of Concrete Mixer Reduced by Electric Motor.—Engineering and Contracting, May 2, 1917, gives the following:

By attaching an electric motor to a concrete mixer Ryberg Bros., contractors, Salt Lake City, Utah, effected an economy in the first month's operations amounting to more than the cost of the motor. The contractor had a Ransome 10-cu. ft. batch load mixer with a steam engine and boiler. The motor was mounted on timbers extending across the bed frame of the mixer and was connected by a belt to the flywheel of the engine, the piston rod and eccentric of the latter being disconnected from the crankshaft. The boiler was removed. The motor cost $65, and its installation and other work cost $6. The operating cost by electricity for a 25-day month, with the mixer averaging 60 cu. yd. per 8-hour day, was $45. When operating by steam, with coal at $1 per day and engineer at $3.50 per day, the cost was $112.50 per month.

Operation of Pneumatic Mixers.—H. A. Leeuw gives the following discussion and data in Engineering Record, Oct. 9, 1915.

Proper application of an ample supply of compressed air has overcome clogging in the conveying pipe in placing concrete by the pneumatic method.

This clogging has been the most serious drawback to the use of this method for mixing and placing concrete, which has developed until concrete has been placed at a distance of 2,800 ft. at the Mile Rock tunnel in San Francisco, and raised to a height of 60 ft. in building piers for a bridge at Magnolia, W. Va.

Owing to the way in which different aggregates behave in feeding into the conveying pipe, the air has to be supplied differently for stone and gravel. The illustration shows a cross-section of the mixer and inlet pipes, which are designated by *X* and *Y*. To illustrate the above statement, when gravel is used, it has been found that it was necessary to admit air only through the inlet marked *Y*, as an application through both would cause the material to feed too fast into the conveying pipe, and would result in a clogged pipe. When stone is used, however, it is necessary to apply the air through both inlets. If only the inlet *Y* is used, the material will arch and then suddenly all down to the discharge pipe, causing it to clog.

It is very important to have a sufficient volume of air to carry the concrete through the delivery pipe to the forms. When this has not been properly taken care of, the concrete will drop in the delivery pipe and the next batch will stick on this and clog the pipe. The tendency has been to under-estimate the number of cubic feet of free air per minute required. The following table shows the result of three years of study and practical experience. Present satisfactory installations are proving the correctness of these figures.

Cubic Yards of Concrete Per Hour, Mixer Capacity ½ Cu. Yd.

Actual amount of compressed air required. Cu. ft. of free air per minute	Length of horizontal discharge: 100 Lin. ft.	300 Lin. ft.	400 Lin. ft.	600 Lin. ft.	800 Lin. ft.	1,000 Lin. ft.
600	20	15	10	...	..	..
800	30	20	18	12	6	..
1,200	40	30	25	20	12	8

It has been found that the character of the sand plays a more important part, with reference to the speed with which the mixture is carried through the pipe, than does that of the stone or gravel. A sharp, clean sand will require less air to move concrete mixed with it than one in which the percentage of loam or oxide of iron is high.

It has also been found that a pressure of 90 lb. per square inch gives the best results. This pressure, expanding into a 6 or 8-in. pipe, depending on the size of stone or gravel used, is reduced to a pressure averaging about 25 lb.

Hose at Delivery End Reduces Kick.—This high pressure has presented an obstacle to be overcome, as the delivery end must be securely fastened to take care of the kick resulting from this pressure. After considerable experimenting, it has been found that a hose, the lining of which is made of pure rubber to withstand the wear, and reinforced to take care of the thrust, when connected a short distance from the delivery end, acts as a shock-absorber, and allows the discharge end to be handled, so that the concrete is not all deposited in one place, but may be distributed in even layers.

The mixture of the concrete placed in this way has been found to be as perfect as that delivered by any of the mechanical mixers on the market. When, however, the volume of compressed air falls below the amount required, as shown in the table, the mixture shows a tendency toward segregation.

The pneumatic method is well adapted to tunnel lining, as it is possible to secure an increase of at least 50 per cent in speed with a corresponding decrease in labor. Accurate cost data are difficult to get, but the following represents the average case:

	Cents per cubic yard
Labor	12
Compressed air	20
Pipe and equipment	10
Overhead	3
Cost for mixing and placing	45

The usual labor crew consists of six men for an outfit which is placing concrete at the rate of 100 cu. yd. in a 10-hr. day.

Placing Concrete in Wall and Dam of Water Supply Reservoir at Montreal by Compressed Air Method.—Engineering and Contracting, Feb. 10, 1915, gives the following:

Fig. 6 shows the arrangement of material handling plant employed in placing the concrete in the walls and dam of the new reservoir of the Montreal

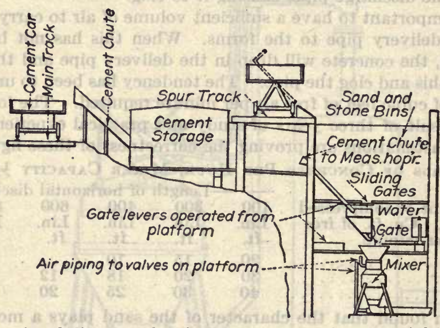


Fig. 6.—Sectional diagram showing arrangement for material handling plant and mixer for placing concrete walls and dam of new reservoir at Montreal by compressed air method.

Water and Power Co. by the compressed air (Mac Micheal) method. The cement used was unloaded from trolley cars on the track as shown. The sacks were unloaded by hand and were placed in the chute which carried them to the cement storage shed. A short siding on a trestle carried the aggregate past the cement shed. The crushed stone was dumped directly into the storage bin, over the mixer, from side-dump cars. The capacity of this bin was 80 and of the cars 6 cu. yds., respectively. The sand was shoveled from box cars into an auxiliary bin, at one side of the pneumatic mixer, of a capacity of 500 cu. yds. The 80-cu. yd. working sand bin, over the mixer, was gravity fed from the auxiliary sand bin mentioned. The sliding gates, hand operated, regulated the discharge of stone and sand into the proper compartments of the measuring hopper shown. Cement was gravity fed from its storage shed into the stone compartment of the hopper. Water was applied to the contents of the hopper as they were discharged into the mixer.

The discharge pipe from the mixer extended to the forms and varied in length from time to time. This was an 8-in. steel pipe provided with flange joints of a special design to facilitate adding or removing sections. The mixed concrete was discharged directly into the forms from the end of the conveying pipe or from a boot at the end of the pipe. At bends the pipe line was firmly secured to resist the side thrust produced by the inertia of the heavy moving mass of concrete. The sections were poured in three lifts of 15, 30 and 37 ft., respectively. The maximum length of discharge pipe was 600 ft., which included the 37-ft. ft. In this line the total curvature aggregated 400°. At this distance pauses were necessary between the discharge of successive batches to allow the air receiver to fill sufficiently. The wall was poured in alternate sections containing about 30 cu. yds. and this necessitated many shifts of forms and discharge piping thus delaying the work. Concrete was placed by the method described in zero weather without difficulty. the aggregate being heated.

TABLE IV.—DATA ON PLACING CONCRETE IN DAM OF MONTREAL RESERVOIR BY COMPRESSED AIR METHOD

No. of shifts	Distances transported, in ft.	* No. hours pouring	Cu. yds. poured	Cu. yds. per hr.	Cu. yds. per shift.	Ratio hrs. pouring to ttl. hrs.	Avg. labor, and power cost cts.
32	180–300	227	4,181	18.5	130	70%	21
22	100–180	126	3,941	31.5	180	58%	17
54	100–300	353	8,122	23	150	65%	19

* Includes pipe repairs and minor changes.

Concreting Dam.—Table IV gives a summary of the progress of the work in concreting the dam of the reservoir. Work was carried on in day and night shifts. In the work on the dam there were 54 shifts to place 8,122 cu. yds., or 150 cu. yds. per shift. The cost of labor on the day shift averaged $19 and on the night shift $27, or an average of $23 per shift. Thus the labor cost was 15½ cts. per cubic yard of concrete placed; the corresponding figure for power was 4.7 cts. per cubic yard. The average gang consisted of six men charging the mixer, including the operator, an extra cement wheeler, a foreman and from two to eight men on the pipe and forms. The best day's run was 436 cu. yds. in 7½ hours. On this run the cost of labor per cubic yard was 6.1 cts. and the cost of power was 1.6 cts.

Concreting Wall.—The wall contained 2,600 cu. yds. and was poured in 26 shifts. The average daily cost for labor was $17.50 and for power $7. This gave a cost for labor and power of 24½ cts. per cubic yard. The average gang on the wall concreting consisted of two men handling cement, three handling aggregate, one mixer operator, one water man, one foreman and one to three men on forms and pipe line. The distance transported ranged from 100 to 600 ft. All wall concrete was lifted 40 ft. Pouring was actually in progress 50 per cent of the time.

Plant.—The compressor used was a W. B. 2 Sullivan, steam driven, 705 cu. ft. machine. There were 1,100 ft. of 6-in. air pipe between the compressor and the mixer. There were two air receivers, one of 150-cu. ft. capacity at the compressor and one of 50 cu. ft. capacity at the mixer. The compressor was run from the boilers of the stone crushing plant and the cost of steam was prorated to the different engines on the basis of the horse-power required. Under this arrangement the power cost for the compressor per shift was $7.

Labor Saving Equipment for Depositing Concrete.—The following data are taken from an article in Engineering Record, Jan. 27, 1917, by W. P. Anderson.

The object of the two installations considered was to reduce the number of common laborers required by doing away with all hand shoveling, charging the mixers by gravity and decreasing the amount of labor needed in handling the chutes used to place concrete directly in the forms. At the plant of the Ubiko Milling Company this was accomplished by dumping the cars of concrete materials into a small bin under the track, from which a bucket elevator carried them to overhead storage bins feeding the mixer by gravity. Both sand and gravel were dumped into the track pit, the material being deflected at the top of the elevator into the sand or gravel compartment of the bins, as the case might be, by a gate between the bins.

At the East Side High School the concrete materials were unloaded from railway cars to overhead bins or into reserve storage piles by a derrick with a clamshell bucket. Stone and sand were drawn from the bins into a small measuring car with two marked compartments which ran along an elevated track in front of the bins and dumped directly into the charging hopper of the mixer. The cement at this plant was unloaded and handled on gravity rollers, and the form lumber, tile and other materials were unloaded in the same way.

Movable Hoppers on Concrete Towers.—At both plants the concrete, after being mixed, was hoisted to movable hoppers, which could be set at any desired height on the tower, and thus spouted to place. The main tower at the East Side High School plant was provided with two hoppers so that concrete could be spouted alternately for long and short distances without materially changing the rigging of the chutes. The amount of rigging required at this plant was further reduced by having drop chutes set in the main chute lines at convenient points. At both plants, the first length were supported from split booms. The upper chute line for the high-school buildings, however, which remained fixed during most of the work, was hung from a guy cable between the main tower and a centrally located tail tower. For supporting the lengths of chute within the lines of the buildings, tripods mounted on iron wheels about 30 in. in diameter were used. The large diameter of these wheels made it possible to roll the chutes around over reinforcing steel already in place, or on the forms or finished surface, with little labor. In addition to the wheeled towers a low "bicycle" frame on two similar wheels was used to carry the delivery end of the chute line at the Ubiko plant.

TABLE V.—LABOR COST OF CONCRETING

	—Ubiko Plant—		
	Mill	Warehouse	East Side High School
Installing and wrecking equipment	$0.426	$0.426	$0.350
Unloading sand, cement and gravel	.265	.265	.171
Mixing concrete	.272	.204	.263
Hoisting and placing concrete and handling chutes	.340	.356	.475
Cleaning up, care of sacks, and miscellaneous	.176	.140	.040
Protection on account of winter work	.003	......	......
Labor cost per cubic yard	1.482	1.391	1.299
Total yardage	2267	907	*4661

* Partial yardage; work not yet completed.

The labor costs given in Table V were realized with common labor at 25 to 30 cents per hour on the Ubiko job, most of the men receiving the lower rate, and at an average of 28.5 cents per hour on the high-school job. The yardage indicated in the table so far placed at the high-school job is considerably below the total quantity of concrete required; but as the total yardage has been considered in estimating the cost for installing and wrecking the equipment and for cleaning up and miscellaneous work, it is expected that the unit figures given will prove approximately correct at the close of the work. It is interesting to note that with the higher unit cost for installation on the smaller contract a lower cost for mixing and placing concrete was realized. The figures make it appear also that the grab-bucket rig has a considerable advantage over the bucket conveyor. It must be considered, however, that it was not always possible to secure materials in bottom-dump cars. Moreover, the design of the conveyor in this plant proved faulty, and a heavier one is now in use on the second contract.

Labor Costs on Foundation Work, Using Portable Plant.—The following data, published in Engineering and Contracting, July 5, 1911, are given in a table appended to a paper by Victor Windett, presented to the Western Society of Engineers on June 7th, 1911.

A portable concrete mixing and conveying plant, which was used by the Great Lakes Dredge & Dock Co. on foundation work for a blast furnace plant near Chicago, is built on a platform 20 ft. square which is mounted on rollers. On the platform a 75 h.p. horizontal boiler is mounted which furnishes steam for the operation of the Ransome mixer and Lidgerwood hoist. The 1-yd. mixer is placed near the rear of the platform and a hopper bin is erected above it, which has a capacity of 10 cu. yds. of stone and 5 cu. yds. of sand. The bins were filled from cars on a parallel track, by means of a locomotive crane and clamshell bucket. Storage is provided for 500 bags of cement on the platform at one side of the mixer. The material from the storage bins is dumped into a 1 yd. batch hopper. From the mixer the concrete is delivered to a Ransome tower bucket which is raised 75 ft. and delivered into the chute. The chute consists of a 12-in. galvanized pipe, supported by two 80 ft. booms. From the ends of the booms lines run to equidistant points on the chute thus supporting it uniformly and keeping it in a straight line. The booms are swung horizontally over the work by hand. The lower 60 ft. of pipe is made in movable lengths of 8 ft. The plant itself is pulled along on its rollers by attaching a line to a deadman and taking it in on the hoist.

The concrete work consisted of foundations for power house and blast furnace buildings. The work was started in 1910 and continued through the winter and spring of 1911.

Table VI gives data on 6 different operations in connection with this work designated as A, B, C. etc. The total work done amounted to 36,146 cu. yds. of concrete. The labor costs given include the placing of 500,000 lbs. of steel reinforcement or about 14 lbs. per cu. yd. of concrete also the labor for erecting and dismantling the plant for handling the concrete.

The rate of wages paid averaged $0.344 per man per hour including the entire force employed.

TABLE VI.—DATA ON CONCRETING FOUNDATIONS

	A	*B*	*C*	*D*	*E*	*F*	General average
Sq. ft. of forms per cu. yd...	7.57	9.74	12.8	14.2	6.1	8.69	9.0
Sq. ft. surface, without forms	8.54	16.1	14.4	.....	.....	14.7	13.0
Total days worked..........	110	79	75	17	24	70	375
Actual concreting time, days.	88	57	36	14	20	62	277
Total labor-days of 9 hours..	5,020	3,977	2,310	922	1,290	3,900	17,419
Cu. yds. of concrete per day (total time).............	98.5	128	49.6	72	139	100	96.5
Cu. yds. of concrete per day (conc. time).............	123	172	103.5	87.5	167.5	113	130
Labor days per cu. yd.......	0.46	0.40	0.62	0.75	0.39	0.56	0.482
Labor cost per cu. yd., dollars	1.43	1.24	1.92	2.32	1.21	1.74	1.49

A. The work on the blast furnace building was massive concrete work the blast foundations consisting of concrete slabs 50 × 70 ft. square, and having a firebrick core averaging 23 ft. in diameter. There were 10,809 cu. yds. of concrete placed at a complete labor cost as given above:

B. The work on the hot blast stove and boiler foundations was massive work, including 10,064 cu. yds. of concrete placed during the summer.

C. The power house foundations consisting of light piers, floors and some massive piers, including in all some 3,733 cu. yds., were placed. This work was done in the winter.

D. The casting machine building foundations were built in the spring. These consisted of light piers and walls amounting in all to 1,225 cu. yds. This concrete contained no reinforcement.

E. The work on the wharf consisted of 3,344 cu. yds. of concrete in massive work. Two rows of piles were capped with concrete forming a base for the walls supporting the rails of the unloading crane. This work was done in the winter and early spring.

F. The construction of the piers for the steel trestle consisted of moderately heavy work amounting in all to 6,971 cu. yds. of concrete. The work was done in the winter and the chuting system was not used. Instead the concrete was delivered in hand pushed Koppel cars of 1 cu. yd. capacity.

Wear of Pipe and Trough Conveyors for Concrete and Concrete Materials.—The following is taken from Engineering and Contracting, March 17, 1915.

In lining pressure tunnels on the Catskill Aqueduct concrete materials were in several places fed down shafts through steel pipe to mixers at the bottom. In one case an 8-in. pipe was used and in another case a 15-in. spiraly rivited steel pipe. In both cases excessive wear put pipe delivery out of competition as an economic means of conveying concrete aggregates great vertical distances. Incidentally clogging occurred so frequently that, putting excessive wear aside, pipe chutes were a failure.

On recent tunnel work in San Francisco, placing concrete lining by pneumatic mixer and conveyor, very interesting studies of pipe wear are reported. An 8-in. steel pipe was used for conveying and 16-cu. ft. charges were forced through the pipe under 120 lbs. air pressure with velocities of 75 to 100 ft. per second. On level straight lines ordinary 8-in. flanged connection steel pipe not quite new had a life of about 6,000 cu. yds. of concrete conveyed. The same pipe on an upgrade of 7 per cent wore through first on the top. Threaded connections proved least durable; the thinning of the section by threading resulted in rapid cutting through at the joints. At bends, 4-ft. radius, ½-in. steel pipe cut through in instances in 12 hours continuous conveying and averaged only 60 hours life.

Records of gravity conveying of concrete in open trough inclined chutes may be summarized about as follows: No. 14 gage blue annealed steel open trough chutes have in instances cut through small holes with 1,500 cu. yds. of concrete conveyed, and there are recorded instances of such chutes having carried 20,000 cu. yds. without wearing holes.

The examples selected, it must be remembered, are purposely examples of failures. They are chosen to show the worst results likely to be experienced in wear of pipe and trough conveyors. Ordinarily the contractor will not experience anything like such adverse conditions. Were this not true these conveying methods would never have attained the extensive use that they have. When excessive wear occurs the records, though they are unfortunately very meager, indicate that it occurs because of exceptional circumstances.

As indicated by the example cited, pipe line wear is greatest at bends, at thin spots like threaded joints and on up-grades. Trough chutes cut through first at dents or bumps or where there are "soft spots" in the rolled plate. Again the character of the aggregates affects greatly the rate of wear. For example pit run gravel will cause least wear, broken stone causes more rapid wear, and slag causes extremely rapid wear. Velocity of travel of the concrete is another factor of importance. Driving a batch of concrete through a closed pipe under crowding pressure at a speed of over a mile a minute is a severe abrasive action for any steel to resist. The wonder is that the destruction is so small as it is. Speed and pressure of flow increase materially the rate of wear of pipes and chutes.

The causes named for excessive wear indicate the possible remedies. At bends in pipe lines, for example, elbow sections of special pipe may be used. Cast manganese steel bends were finally adopted on the San Francisco tunnel work previously named and despite their greater expense proved more economical than ordinary steel elbows. It might even be economical when long use is expected to adopt alloy steel or special steel pipe for the line as a whole. Another remedy is a special joint construction, one which will not produce a thin spot or an irregularity which will intensify the wear locally.

Open trough chutes, inclined so that flow is by gravity, present a different problem. Good uniform quality steel plate shaped smooth and kept undistorted by denting or buckling is the first requisite. Where this will not serve, resort to interlining or to alloy steels is probably the only solution unless change is possible to a smoother aggregate or to reduced chuting speeds. Inquiry of one of the leading makers of concrete chutes, brings out data on relining chutes which contractors will be interested in noting.

For the ordinary job the relined chute is not advisable because of the increased weight. The standard untrussed unlined chute of No. 14 steel weighs from 20 to 30 lbs. per lineal foot so that the ordinary 30-ft. section weighs about 450 lbs. A 50-ft. trussed section without lining weighs 905 lbs. These weights are about as great as the contractor can handle well. No. 14 bottom liner plates 12 ins. wide add about 3½ lbs. per lineal foot or 165 lbs. to a 50-ft. section. Taking into account all the factors causing wear it is probable that a lined chute will wear three times as long as one without lining. Also relined chutes are less liable to become dented and if the plates contain soft spots they are not likely to coincide in locations. For work of considerable volume lined chutes are practically always advantageous.

Depositing Concrete in Bags Under Water.—H. R. Ferriss gives the following data in Engineering and Contracting, Feb. 10, 1915.

A 20-in. cast iron outfall, Fig. 7, was laid from a point on shore to a distance of 720 ft. out from shore, at which point the end was in 18 ft. depth and a swift off shore current. The outfall follows a channel between high rock reefs, and the pipe for its entire distance—with the exception of 120 ft. of the outfall end—is laid in a ditch dredged in clean sand. At the outfall end, the floor of the sea falls away somewhat faster than the grade of the pipe, and advantage is taken of this to hold the end of the pipe line off the floor of the sea. It was considered advisable by the engineer in charge to rest the pipe on concrete deposited in bags, and the outermost end, owing to the swift current and heavy winter storms, is heavily anchored with concrete in bags.

A 1:3:6 mixture was used. A scow was anchored near the outfall end, and aboard it the concrete was mixed and sacked dry. The sacks of concrete were then lowered in a sling, and placed one at a time, by the diver, who afterwards ripped them open with a knife as placed. The concrete showed no sign of setting up for two days. After the seventh day it was fairly well bonded. It is now, after one year, a fairly good mass of concrete, which shows no damage, either from the swift current or from storms, from whose action, except the fiercest, however, it is probably protected by its depth.

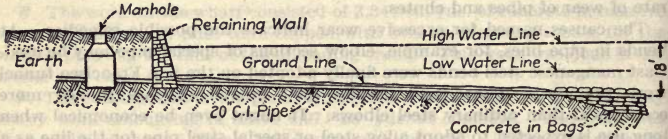


FIG. 7.—Anchorage of concrete in bags for submerged outfall.

It will be noted that the costs of labor only are given, and they depend considerably on locality and weather, which in this instance was exceptionally fine. The costs of materials are easily ascertained for any locality. The costs for the use of scows, engines, etc., will depend entirely on locality and weather conditions. The amount of concrete deposited was 80 cu. yds. and cost as follows:

	Total	Per cu. yd.
Sacking and mixing concrete:		
Foreman, 19 hrs. at 35 cts	$ 6.65	$0.082
Labor, 400 hrs. at 30 cts	120.00	1.500
Placing:		
Diver, 120 hrs. at $1.00	120.00	1.500
Tender, 120 hrs. at $0.50	60.00	0.750
Compressor eng., 60 hrs. at $0.40	24.00	0.300
Labor, 250 hrs. at $0.30	75.00	0.938
Total	$405.65	$5.070

Labor Cost of Forms for Reinforced Concrete Construction.—In a paper read before the American Concrete Institute, Feb. 14, 1916 and abstracted in Engineering and Contracting, Mar. 1, 1916, Sandford E. Thompson gives the following:

In reinforced concrete construction, the greatest discrepancy lies in the cost of forms. It is here that the contractor and also the engineer are apt to be fooled, unless either they are well provided with unit costs or else have handled work previously of an identical nature.

To illustrate the variations in labor costs of different members in form construction, Table VII presents a few values selected from "Concrete Costs" by Taylor and Thompson.

TABLE VII.—LABOR COSTS OF FORMS FOR COLUMNS, BEAMS, GIRDERS, AND SLABS

Costs include 10% for foreman and 15% for superintendence, contingencies, etc., but do not include profit or home office expense. Carpenter labor, 50c per hour; ordinary labor, 25c per hour. Material, 1-in. lumber.

Size	Make form	Place and remove form, first time	Place and re-move form after first time	Remake, place and re-move form
12-Foot Columns—Labor Cost per Member, Iron Clamps				
8-in. by 8-in.	$1.16	$4.68	$3.77	$5.53
16-in. by 16-in.	1.46	5.45	4.40	6.16
24-in. by 24-in.	1.80	6.20	5.14	6.86
36-in. by 36-in.	2.61	7.64	6.33	8.14
20-Foot Beams—Labor Cost per Member, Size Measured Below Slab				
4-in. by 8-in.	$0.92	$2.42	$1.97	$2.79
6-in. by 12-in.	1.09	2.75	2.31	3.23
8-in. by 16-in.	1.26	2.99	2.59	3.64
12-in. by 24-in.	1.75	3.41	3.09	4.29
20-Foot Girders—Labor Cost per Member, One Intersecting Beam				
8-in. by 16-in.	$1.38	$3.27	$2.75	$4.31
12-in. by 24-in.	1.82	3.86	3.20	5.02
Labor Cost of Slab Forms*				
Per 100 square feet of slab surface	$ .81	$2.53	$1.90	$2.06

* Based on slab built two panels per bay.

For inexperienced builders, increase costs 33⅓%.

For special design, add 10% to 50% to "Make Forms."

If no mill saw on job, add 50% to "Make Forms."

If old lumber is used, add 75% to 100% to "Make Forms."

For rectangular columns, select values for square columns having the larger dimension of the rectangle.

For wall columns, add 50% to all except "Make Forms."

Design and Costs of Sliding Forms for a Reinforced Concrete Grain Storage House.—The following data were published in Engineering and Contracting, Oct. 20, 1915, by Wm. Wren Hay and refer to the design, construction and costs of the sliding forms for a large reinforced concrete grain storage house located in Western Canada. The detailed costs of these forms were compiled in the field while the forms were under construction and were checked from the final costs after the concrete was placed and after the accounting had been totaled. The costs are the result of daily observations as to labor and materials in use, these costs being derived in part from the reports turned in by the foremen and in part by personal check of the amount of work completed each day. They were obtained for the purpose of checking the work against the contractor's estimate of cost, and were also used as a guide for the time of completion of the job, as all work was conducted on a rigid schedule to insure against delay in any part of it.

In estimating for such construction it is customary to figure the actual contact surface at so much per square foot, and to figure the flooring over the bins, the yokes, the jacking, and the maintenance of the forms while being lifted, together with their removal, each as a separate item. The cost data given will therefore be grouped in this manner. It is evident that the form surface is a function of the lineal feet of bin walls, and that the number of yokes will vary in a similar manner, although influenced by the contact of the bin arrangement. The flooring will vary as the area of the bins, while the jacking and the maintenance are further influenced by the height of the bins The item of removal depends largely upon the bin arrangement and the story overhead, from which are hung the blocks used for hoisting.

Design Features of Bins.—The bins cover an area of 11,850 sq. ft., their width being 74 ft. 4 ins. and their length 158 ft. 4 ins., including a projecting stairway and elevator tower 12 ft. wide by 17 ft. 10 ins. long. The bins proper consist of 50 circular tanks, each 13 ft. in inside diameter, arranged in five rows spaced 15 ft. 6 ins. on centers by ten rows spaced 16 ft. on centers, forming 23 inner bins and 13 leg openings. The exterior walls are run straight through tangent to the circular bins, these forming 26 additional outer bins The bins are 70 ft. in height, with a nominal capacity of 500,000 bushels. The bin walls are all 6 ins. thick. The contacts of the circular tanks across the structure were widened out, and upon them rest the columns which support the floors of the cupola above. Lengthwise of the bins the tanks are connected by 6-in. contact walls, each 2 ft. long, except where the elevating legs run between the pairs of tanks. This arrangement of bins is that commonly used for houses of this type where there is an additional storage annex.

Forms.—In general, the forms consisted of segments made up of 2-in. planks, spaced 28 ins. vertically, to which were nailed 1-in. sheathing. The large circular forms were braced by means of ½-in. rods bolted through the upper and lower segments at an inclination of 45°, forming a truss arrangement which effectually prevented distortion. The skeleton forms were placed on the bin-bottom girders, being nested together to form the 6-in. wall space. The yokes were then straddled across the opening. As fast as the floor was laid over the forms the latter were cut through at certain lines to provide slip joints, and were then tied horizontally by timbers bolted across the wall space on each side of the joints, by means of toggles at the cuts in the segments and by the rods bolted from one yoke to another across the cut. These joints divided the entire area into eight sections of six tanks each and one section consisting of two tanks and the tower. They were provided for the purpose of enabling each section to be adjusted for levels independent of the others, but the experience on this work did not seem to justify fully the additional expense.

Plant for Constructing Forms and Procedure.—The plant used in constructing the forms was centered in a large carpenter shop, 48 ft. wide by 72 ft. long, in which were set two combination, gasoline-driven saw rigs, with 24-in. gage industrial tracks for handling the lumber in and out of the shed. The lumber was routed from the trackage, where it was unloaded from the cars into the shops for cutting, and out on the opposite side onto a large, open-air platform, upon which the segments were nailed on templates and the sheeting erected. All of the segments were cut to shape on these saw rigs, and all of the sheathing boards were also cut to length on them. This work was done some time in advance of the actual operation of sheathing, and the segments were also nailed ready for the boards, in advance. The sheeting was actually commenced 20 working days before the forms were needed for concreting. To maintain the necessary schedule, and yet not crowd the carpenters, a curve of parabolic form was drawn through the points representing the first three days' unit progress, this curve terminating in the day specified for the total area to be sheeted. By accounting for the area sheeted during each five-hour period, and plotting the points, a very close account was kept of the progress. As a result the last segments were being covered when the first completed forms were started up to the top of the girders.

Detailed Costs of the Forms.—The following data give the unit costs, in the yard, of the forms, as determined from day to day:

Item	Cost per sq. ft. of contact surface
Carpenter labor	\$0.089
Superintendent	0.013
Bolts, etc., including labor	0.010
Oiling forms, total	0.002
Lumber	0.061
Total	\$0.175

The observed rates of labor were as follows:

Item	Labor force	Time required
Cutting segments, 27,500 ft. B. M.	1 carpenter 2 laborers	20 days
Nailing segments	4 carpenters 3 laborers	10 days
Sheathing segments, 18,200 sq. ft.	10 carpenters 2 laborers	20 days

The carpenters were paid 50 cts. per hour and the laborers 30 cts. per hour, working 10 hours per day. There was a total of 5,150 lin. ft. of bin wall, and the staves were 48 ins. in length. The actual contact area was 20,600 sq. ft. Of this amount only 18,200 sq. ft. were built in the yard, the remainder for the exterior perimeter of the storage house being cut and framed on the floor during erection. In the totals considered later, this contact area of 20,600 sq. ft. is used.

The lumber for the sheathing was a special 1 × 4-in. tongue-and-groove pine, with the grooved edge beveled slightly for the circular forms. Its cost was \$28 per M. The cost of the common lumber varied from \$17.50 to \$22 per M, depending upon the size. There was a total of about 11 ft. B. M. per square foot of building used in these forms, divided as follows:

	Ft. B. M.
Segments	2.2
Staves	1.1
Flooring	3.3
Miscellaneous, including gallery, staging, timber for joints, etc.	4.4

Oiling.—The form surface in contact with the concrete was oiled with two coats of light oil. There was no trouble whatever due to sticking or swelling, as the oil penetrated to a considerable depth and prevented the entrance of water. A paraffin oil, from which the small residue of kerosene remaining after "freezing" had not been removed, was used. This oil cost 22 cts. per gallon in barrel lots. One gallon of oil covered 160 sq. ft., two coats, one man applying it at the rate of from 350 to 400 sq. ft. per hour.

Yokes.—The yokes used on the forms were constructed of timber, the legs being 6 × 8-in. pieces, 8 ft. long. The jacks, which were of the pump type, were seated on two 6 × 6-in. pieces, through which ran the 1¼-in. jacking rod. The head piece was a 3 × 8-in. timber. Double ⅝-in. bolts were run across the top and middle, and the forms were hung from the yokes by means of ½-in. rods through both segments and the jack seat. Each yoke contained about 85 ft. B. M. of lumber and 25 lbs. of bolts and iron, and cost slightly over \$5 in place. There were used on this set of forms 244 yokes. In general, there were four yokes to each circular tank. Where the joints occurred a yoke was placed on each side of the joint.

The joints were made by overlapping pieces of 2 × 6-in. timbers where the face of the form was cut, the opening being covered with a piece of tin. The segments were held together by a toggle joint, consisting of a short section of 1½-in. pipe running through four steel plates bolted to both segments, on each side of the cut. There were 80 of these joints, the cost of each being about $12, of which $4.50 was for materials and $7.50 for labor.

Total Costs of Formwork.—The following are the final costs as returned for the various items discussed:

		Per sq. ft.
Forms, labor only:		
Carpenter shop and yard	$2,112	or 10½ cts.
Placing, including floor	1,439	or 7 cts.
Materials, incl. iron, etc	1,470	or 7¼ cts.
Total	$5,021	or 24¾ cts.
Maintenance, leveling, repairing, etc	$ 667	
Yokes, including setting jacks, bolts, plates, etc	1,220	
Joints, including timbers, bolts, plates, etc	960	
Total, no removal	$7,868	
Estimated cost to remove	500	
Total cost of forms	$8,368	

There were 54¼ cu. yds. of concrete per vertical foot of the bins. This concrete was placed at the rate of 10 cu. yds. per hour, in 17½ days of 20 hours each, requiring a vertical movement of 3 ft. 9½ ins. per day. The cost of the jacking gang was about $100 per day, with labor at 30 cts. per hour. The cost of placing and finishing the concrete walls was $1.00 per cubic yard, plus an overhead charge of 30 cts. per cubic yard, or a total of $1.30 per cubic yard. It cost about $10 per ton to place the ⅜-in. rods used for reinforcing and contacts, plus $6.50 per ton for handling in the yard, or a total of $16.50 per ton.

Movable Wall Forms Give Low Cost.—Fig. 8 indicates the type of forms employed in building two heavy concrete walls aggregating some 1,250 cu. ft. at Lock 9 on the New York State Barge Canal. The following costs, for this work, are taken from an article in Engineering and Contracting, Sept. 21, 1910.

The labor of building each form required 3 days' time for 6 carpenters. Two straight forms were built and one curved form. The cost of these, including labor and material used, was $525.00. Spruce dressed lumber was used, at $23 per M. ft. B. M. The labor of moving was accomplished by 6 men, including the foreman, in from 4 to 6 hours. This labor completed the moving and lining-up ready for concrete. The rate of wages for these men and cost of moving were as follows:

6 hrs.—Foreman at $3.52 per 8-hour day	$ 2.64
6 hrs.—2 men at $3.20 per 8-hour day	4.80
6 hrs.—2 men at $2.40 per 8-hour day	3.60
6 hrs.—1 man at $2.00 per 8-hour day	1.50
Total cost of knocking down and setting up	$12.54

The cost per cubic yard of forms and the setting up for the entire work may be estimated as follows:

Cost of material and building of 3 40 ft. forms	$525.00
36 setups at $12.54	451.44
Total	$976.44
Total cu. yds. + neatwork	4,370
Cost per cu. yd. concrete	$0.22

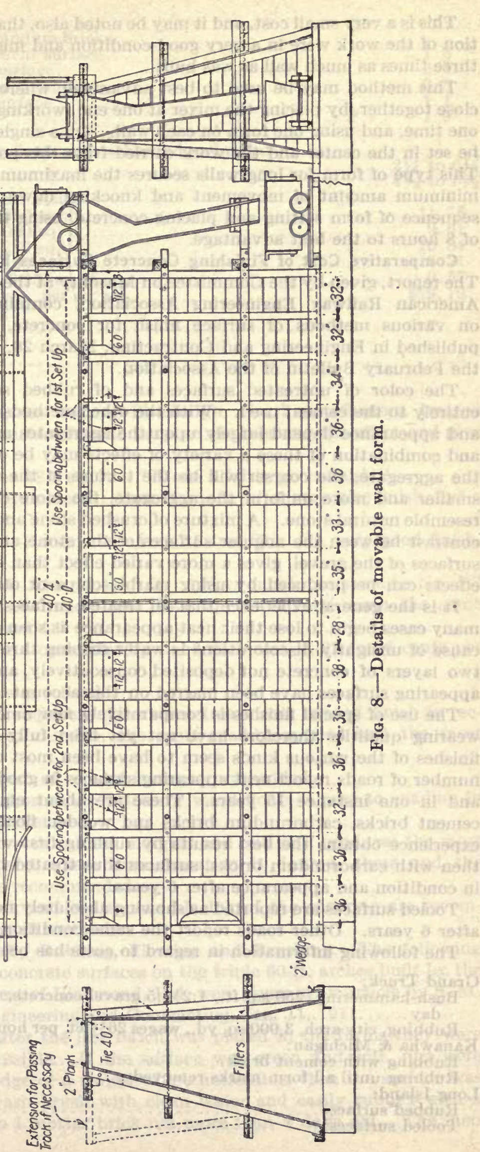


Fig. 8.—Details of movable wall form.

This is a very small cost, and it may be noted also, that the forms on completion of the work were in a very good condition and might have been used for three times as much wall as was built.

This method may be used to best advantage, where walls are parallel and close together, by placing the mixer at one end, working both walls forward at one time, and using one form on each wall. On a single wall the mixer should be set in the center and the work carried from this point in both directions. This type of form for long walls secures the maximum use of forms with the minimum amount of movement and knocking down, and gives the proper sequence of form setting and placing concrete, using the average day's work of 8 hours to the best advantage.

Comparative Cost of Finishing Concrete Surfaces by Various Methods.—The report, given by the Committee on Masonry at the 1917 convention of the American Railway Engineering Association, contained some cost figures on various methods of surface finish for concrete. The following notes published in Engineering and Contracting, March 28, 1917, were taken from the February Bulletin of the Association.

The color of untreated surfaces and of rubbed surfaces is due almost entirely to the cement used. With the other methods of treatment the color and appearance depend largely upon the aggregates and by proper selection and combination of these a variety of effects may be obtained. The coarser the aggregate, the coarser will be the texture of the finished surface. The smaller and more uniform the aggregate, the more closely will the surface resemble natural stone. A mixture of crushed stone and gravel, because of the contrast between the angular surfaces of the stone and the round smoother surfaces of the gravel, gives a more varied effect than either alone. Pleasing effects can be produced by using marble chips or other colored aggregate.

It is the general experience that all treated surfaces darken in time and in many cases begin to lose their neat appearance as soon as finished. A fruitful cause of unsightly discolorations is water seeping through the seam between two layers of concrete not deposited consecutively, and many otherwise fine appearing surfaces have been marred on this account.

The use of special finishes is comparatively new among railroads and their wearing qualities therefore have not yet been fully determined. Rubbed finishes of the various kinds seem to have been most commonly used, and a number of roads report neat appearing surfaces in good condition after 3 to 8 and in one instance 15 years. These are about equally divided between cement bricks, carborundum bricks and wooden floats. One road of large experience obtains the best results by rubbing first with wooden floats and then with carborundum bricks, surfaces thus treated being very satisfactory in condition and appearance after 6 years.

Tooled surfaces are reported as showing absolutely no signs of deterioration after 6 years. Other roads report the same condition after 4 years' service.

The following information in regard to costs has been received:

	Ct. per sq. ft.
Grand Truck:	
Bush-hammering, 250 sq. ft., 1:2½:5 gravel concrete, wages $4 per day	7.2
Rubbing, city arch, 3,900 sq. yd., wages 26½ ct. per hour	5
Kanawha & Michigan:	
Rubbing with cement brick	4
Rubbing until all form marks removed	6
Long Island:	
Rubbed surfaces	1½ to 2
Tooled surfaces	2½ to 3

Michigan Central:	
Rubbing with carborundum bricks:	
1,610 sq. ft. abutment surface	1.6
1,005 sq. ft. pier surface	2.6
4,200 sq. ft. abutment surface	2.8
4,600 sq. ft. pier surface	1.1
Average	1.9
New York Central:	
Rubbing with wooden floats and carborundum bricks:	
Varied from	2¼ to 6⅛
Average	4⅜ to 5½
New York, Chicago & St. Louis:	
Bush-hammering, 1,960 sq. ft	11.75
Bush-hammering, 5,000 sq. ft	9.61
Bush-hammering, 8,280 sq. ft	10.84
Bush-hammering, 3,420 sq. ft	6.21
Rubbing wood floats, 6,250 sq. ft	0.57
Paneled posts, complete, per sq. yd	$19.19
Philadelphia & Reading:	
Bush-hammering	7
Seaboard Air Line:	
Scrubbing	5.5

The Pennsylvania Lines west of Pittsburgh, Northwest System, treated several small areas of surface for the purpose of observing the effect and give the following results:

(1) Tooth-Axed: Area 18.5 sq. ft. "Made a fairly good finish."

(2) Six-Point, Bush-Hammered: Area 16 sq. ft. "A very nice finish, but a little too fine."

(3) Four-Point, Bush-Hammered: Area 15.4 sq. ft. "A very good finish, perhaps the best."

(4) Beam-Hammered: Area 15.4 sq. ft. "Very much the same as No. 1."

(5) Crandled: 10-lb. hammer, area 16.2 sq. ft. "Very much the same appearance at Nos. 1 and 4."

All were done by the stonecutter by hand at a cost of 22 to 26 cents per square foot.

The conclusions were as follows:

1. For all work not requiring decorative treatment, spaded finish is recommended as the most durable, the most readily applied and the most economical.

2. Coating with a wash of cement is not recommended.

3. Rubbing with carborundum bricks or wood floats is next to spading in ease of application and cost.

4. Tooling, alone or with rubbed margins and outlines, produces the most pleasing appearance, and where ornamentation is desired, these and the scrubbing methods are recommended.

5. Careful form work and continuous placing of the concrete are recommended as essential for all methods.

Finishing Concrete by Rubbing, Floating and Brushing.—The following data, on finishing the concrete surfaces on the triple 60-ft. arches built by the Pennsylvania R. R. west of Richmond, Ind. were given in an article by S. M. Klein published in Engineering and Contracting, Jan. 11, 1911.

Forty-eight hours after the last batch was placed in the forms they were removed whenever possible. If the surface was green and soft, fins were scraped off with the edge of a trowel where noticeable, then the surface was wetted with a whitewash brush with clean water and easily rubbed with a 2½ × 2½ × 6-in., 2 to 1 mortar brick not more than 8 days old. The men rubbed the wall with a circular motion which left spots in places. Next day the wall was moistened and floated all over the surface with a wooden float and after that stroked in one direction up and down with a moist, clean whitewash brush. Two men rubbed and finished a section 10 ft. high, 30 ft. long and 3 days old in four hours at 17½ cts. per man per hour.

Where the concrete was a week old and older after forms were removed all fins were removed with a bush hand chisel having five blades. The surface was then wetted with plenty of cold water and rubbed with a 2½ × 2½ × 6-in. 1 to 1 mortar brick not more than 6 days old. One section was rubbed down well, all rod holes were plugged and next day the section was floated down and stroked with a moist, clean whitewash brush. No cement wash of any kind was allowed. Any broken corners had to be carefully repaired by thoroughly cleaning the surface, wetting the patch down well, then if possible driving 20d nails or railroad spikes into the concrete, putting up a form and grouting the broken place. Several patches were thus made and when finished could never be discovered.

The surfaces thus rubbed, floated and brushed bleached out uniformly everywhere, showed neither spots nor blemishes and gave the whole face a beautiful smooth dull finish. One foreman at 40 cts. per hour and 6 laborers at 17½ cts. per hour averaged 25 sq. yds. per man nearly every day rubbing and finishing was done, and they became very efficient at it and took a great deal of pride in their work.

Cost of Waterproofing Concrete Surfaces to Decrease Disintegration by Frost.—J. L. Lytel, project manager of the Strawberry Valley project, Utah, records in the "Reclamation Record" for April, 1915, an interesting experience in waterproofing of concrete surfaces. Engineering and Contracting, April 14, 1915, gives the following abstract of Mr. Lytel's article.

The storage works and tunnel of the Strawberry Valley project are located in the Wasatch Mountains at an elevation of 7,500 ft. There is a wide variation in temperatures in this vicinity and the climate is very severe during the winter months, the lowest temperature on record being 50° below zero. The snow fall ranges from 10 to 24 ft. in depth.

The extreme cold, with alternate thawing and freezing of water in the pores of the exposed faces of the structures, was found to have a very destructive effect on these concrete structures and the waterproofing of the surfaces was decided upon as a preventive against their continued disintegration.

It was decided to treat the vertical surfaces with alum and soap solutions and the horizontal surfaces with paraffine. The alum solution was made by dissolving 2 ounces of alum in 1 gal. of hot water. The soap solution was composed of ¾ lb. of castile soap dissolved in 1 gal. of hot water. The paraffine was boiled to drive off water as the presence of water rendered it hard to apply. Ordinary commercial products were used.

The surface to be treated with paraffine was first thoroughly dried and cleaned of loose concrete, dirt, and other foreign substances. The paraffine was then heated and applied with a paint brush, and was forced into the pores by the heat of a blow torch on the surface. Only one coat of paraffine was applied as the concrete would not absorb more.

The surface to be treated with soap and alum was prepared as above stated. The alum solution was applied at a temperature of 100° F. with a moderately stiff brush and was then worked in with a stiff horse brush. While the surface was still moist from this treatment the hot soap solution was applied in the same manner as the alum solution. One treatment by each solution in the manner described above constituted a coat. If other coats were considered necessary, they were applied in like manner after the preceding coat had been allowed to stand 24 hours or more.

Twelve structures were given this treatment, the surface area covered being approximately 28,000 sq. ft. Four thousand square feet were treated with paraffine, at the rate of 1 lb. for 11¾ sq. ft., and the remainder with soap and alum. It required 1 gal. of alum solution and a ½ gal. of soap solution to cover 50 sq. ft. with two coats. Two coats of alum and soap were applied at an average cost of 76 cts. per 100 sq. ft., and the cost varied from 41 cts. minimum to $1.28 maximum The cost of one coat of paraffine varied from $1.70 to $3.78 per 100 sq. ft., and averaged $2.11. This cost covers everything except general expense. The two men who did this work received $75 and $80 per month. Brushes cost $6.06, Castile soap 12½ cts. per pound, alum 18 cts. per pound, and crude paraffin $4.80 per hundred weight.

The results obtained by this waterproofing are considered very satisfactory. The structures that were repaired and treated have gone through two severe winters and no further disintegration of the concrete on any part has occurred.

CHAPTER VI

DAMS, RESERVOIRS AND STANDPIPES

This chapter besides giving general costs of a large number of well known reservoirs is largely composed of detailed methods and costs of concrete and steel structures. For detailed methods and costs of building earth dams the reader is referred to Gilette's "Earthwork and Its Cost." Further data on the cost of dams is also given in the "Handbook of Cost Data" by Gillette.

Cost of Storage Reservoirs per Million Cu. Ft.—Tables I and II, published in Engineering and Contracting, Sept. 4, 1912, are from a discussion by Seth A. Moulton on power costs and efficiencies contained in the Report of the Maine State Water Storage Commission.

TABLE I.—COST OF AMERICAN STORAGE RESERVOIRS
(From James D. Schuyler)

Name and location	Character*	Cost	Capacity million cu. ft.	Cost per million cu. ft.
Asokan Reservoir, N. Y.	M and E.	$12,669,775	16,030	$ 792
Belle Fourche Dam, S. D.	E.	879,164	9,360	94
Wachusett Dam, Mass.	M.	2,270,116	8,420	269
Ariscohos Dam, Me.	M and E.	1,000,000	8,000	125
New Croton Dam, N. Y.	M.	7,631,000	7,840	973
Buena Vista Lake, Cal.	E.	150,000	7,400	21
Laramie River Dam, Wyo.	E.	117,200	5,230	23
Indian River, N. Y.	M and E.	83,555	4,460	19
Croton, N. Y.	M and E.	4,150,573	4,270	972
Lake McMillan, Pecos River N. M.	R F and E.	180,000	3,880	47
Bear Valley Dam, Cal.	M.	68,000	1,740	39
Windsor, Col.	E.	75,000	1,000	75
Sweetwater, Cal.	M.	264,500	980	269
Titicus, N. Y.	M and E.	933,065	960	972
Bowman, Cal.	R F C.	151,521	920	164
Eureka Lake, Cal.	R F.	35,000	660	53
Sodom, N. Y.	M and E.	366,990	650	565
English, Cal.	R F C.	155,000	650	230
San Leandro, Cal.	E.	900,000	580	1,550
Bog Brook, N. Y.	E.	510,430	550	927
Larimer and Weld, Col.	E.	89,782	500	179
Cuyamaca, Cal.	E.	54,400	490	111
Hemet, Cal.	M.	150,000	460	326
Canistear, N. J.	E.	341,000	322	1,060
Lake Avalon, N. M.	R F and E.	176,000	274	642
Cache la Poudre, Col.	E.	110,266	246	447
Round Hill, Pa.	M and E.	240,548	176	1,367
Glenwild, N. Y.	E.	47,360	160	296
Escondido, Cal.	R F.	100,059	152	658
Cedar Grove Reservoir, N. J.	E.	660,000	94	7,020
Tyler, Tex.	H F.	1,140	77	15
Faucherie, Cal.	R F.	8,000	59	136

* RF = Rock Fill, E = Earth, H F = Hydraulic Fill, M = Masonry, R F C = Rock Fill Crib, S = Steel.

TABLE I.—*Continued.*

Name and location	Character	Cost	Capacity million cu. ft.	Cost per million cu. ft.
La Mesa, Cal	H F	17,000	57	298
Yuba, Cal	H F	38,000	51	745
Pedlar River, Va	M	103,708	49	2,115
Wigwam, Conn	M	150,000	45	3,333
Saguache, Col	E	30,000	41	732
Monument, Col	E	33,121	39	849
Seligman, Ariz	M	150,000	31	4,835
Walnut Canyon, Ariz	M	55,000	21	2,620
Apishapa, Col	E	14,772	20	739
Williams, Ariz	M	52,838	15	3,522
Boss Lake, Col	E	14,654	9	1,628
Ash Fork, Ariz	S	45,776	5	9,155
Hardscrabble, Col	E	9,997	5	1,999
	Average	$ 784,096	1,933	$ 406

TABLE II.—COST OF FOREIGN STORAGE RESERVOIR
(From James D. Schuyler)

Name and location	Character*	Cost	Capacity million cu. ft.	Cost per million cu. ft.
Assouan, Egypt	M	$11,907,000	37,600	$ 317
Ekruk, India	E and M	666,000	3,310	201
Lake Fife, India	M	630,000	3,290	192
Chumbrumbaukum, India	E	312,000	2,780	113
Tansa, India	M	988,000	2,290	432
Vyrnwy, Wales	M	3,334,000	1,950	1,710
Betwa, India	M	160,000	1,600	100
Ashti, India	E	270,000	1,420	190
Liez, France	E	598,418	568	1,054
Villar, Spain	M	390,000	568	687
Talla Res, Edinburgh	E	1,220,000	448	2,720
Gilleppe, Belgium	M	874,000	424	2,060
Mouche, France	M	1,003,657	305	3,290
Lake Oreron, France	E	142,000	257	553
Chartrain, France	M	420,000	159	2,640
Beetaloo, Australia	M	573,300	128	4,480
Ternay, France	M	204,372	106	1,934
Burrator, England	M and E	602,300	105	5,730
Belubula, Australia	B and C	45,000	87	517
Wassy, France	E	138,940	76	1,826
Ban, France	M	190,000	66	2,880
Cousin, France	M	247,600	57	4,340
Furens, France	M	318,000	57	5,580
Pas du Roit, France	M	256,000	46	5,570
Remscheid, Germany	M	91,154	35	2,600
Sand River, South Africa	M	140,000	29	4,830
Lauchemsee, Germany	M	243,750	27	9,020
Patas, India	E	15,925	14	1,137
Burraga, Australia	M	46,500	13.5	3,445
	Average	$ 897,514	1,994	$ 450

* B = Brick, C = Concrete, E = Earth, M = Masonry.

Cost per Acre-foot of Large Storage Dams.—Francis L. Sellow, Project Engineer, U. S. Reclamation Service in a discussion in Proceedings, American Society of Civil Engineers, Vol. XXXIX (reprinted in Engineering and Contracting, May 14, 1913) gives the following costs of reservoirs in the United States and foreign countries. (Tables III and IV.)

TABLE III.—RESERVOIRS IN THE UNITED STATES, BUILT BY THE RECLAMATION SERVICE‡

Location	Type of controlling works		Storage, in acre-feet	Cost—Total	Cost—Per acre-foot
Arizona:					
Roosevelt Dam	Masonry	280 ft.	1,284,000	$3,697,000	$2.90
California:					
East Park	Concrete	139 ft.	45,600	239,000	5.25
Idaho:					
Deerflat	Earth	40 to 70 ft.	186,000	868,800	4.65
New Mexico:					
Carlsbad	Earth and rock	50 ft.	47,000	220,700	4.70
Oregon:					
Cold Springs	Earth	98 ft.	50,000	442,600	8.85
Klamath	Rock fill	33 ft.	462,000*	130,000	0.28
South Dakota:					
Belle Fourche	Earth	115 ft.	209,700	1,123,900	5.40
Washington:					
Bumping Lake	Earth	45 ft.	34,000	410,700	12,10
Wyoming:					
Pathfinder	Masonry	218 ft.	1,025,000†	1,693,000	1.65
Shoshone	Concrete	328 ft.	456,000	1,179,300	2.60
Totals			3,799,300	$10,005,000	$2.63

*Lake storage. †Drainage area, 12,000 sq. miles. ‡Source of information 10th Annual Rept., U. S. R. S.

TABLE IV.—VARIOUS RESERVOIRS

Location	Type of controlling works	Storage, in acre-feet	Cost — Total	Cost — Per acre-foot
In the United States.				
Mississippi Reservoir System (*a*)	Earth and timber dams	2,100,100	$750,000	$0.36
Texas:				
Pecos River				
Upper Reservoir (*b*)	Earth	82,640	170,000	2.06
Lower Reservoir (*c*)	Earth	7,000	86,000	12.29
Colorado:				
Larimer and Weld (*c*)	Earth	7,460	90,000	12.00
Cache la Poudre (*c*)	Earth	5,650	125,000	22.20
California:				
Escondido (*c*)	Rock fill	3,500	110,000	31.44
Cuyamaca (*c*)	Earth	114,755	959,800	8.37
Sweetwater (*c*)	Masonry	22,500	264,000	11.70
Bear Valley (*c*)	Masonry	40,000	75,000	1.88
Totals		2,383,505	$2,629,800	$1.10
Suggested Reservoirs—Gen. Chittenden.				
Wyoming:				
Laramie (*c*)	Masonry 80 ft.	414,000	$1,416,000	$3.42
Sweetwater (*c*)	Masonry 100 ft.	326,900	276,800	0.85
Piney Creek (*c*)	Masonry 3 low dams	85,400	214,600	2.52
Colorado:				
South Platte (*c*)	Masonry 200 ft.	67,200	540,000	8.04
Loveland (*c*)	Masonry	45,700	262,100	5.78
Totals		939,200	$2,709,500	$2.90
Miscellaneous Reservoirs:				
Spain:				
Villar (*d*)	Masonry	13,050	$390,000	$29.90
Belgium:				
Gilleppe (*d*)	Masonry	9,730	874,000	90.00
Wales:				
Vyrnwy (*d*)	Masonry	44,690	3,334,000	75.00
Australia:				
Beetaloo (*d*)	Concrete	2,945	573,300	195.00
Totals		70,415	$5,171,300	$74.00

(*a*) Pittsburgh Flood Commission. (*b*) Chief of Engineers 1898. (*c*) Chittenden Report. (*d*) Buckley.

Location	Type of controlling works	Storage in acre-feet	Cost: Total	Cost: Per acre-foot
Reservoirs in France.				
Furens Dam(*a*)	Masonry 184 ft.	1,300	$318,000	$ 244
Ternay Dam (*a*)	Masonry 119 ft.	2,100	204,372	97
Curzon (*a*)	Masonry	1,297	247,600	190
Ban (*d*)	Masonry	1,499	190,000	127
Pas du Riot (*d*)	Masonry	1,054	256,000	243
Chartrain (*d*)	Masonry	3,647	420,000	115
Lake Oredon (*d*)	Earth	5,894	142,000	24
Mouche (*d*)	Masonry	7,011	1,003,657	143
Liez (*d*)	Earth	13,051	598,418	46
Wassy (*d*)	Earth	1,740	138,942	80
Totals		38,593	$3,518,989	$ 91 ±
Reservoirs in Austria.				
Oder River (*a*)	Six Reservoirs	5,100*	$1,488,000	$ 292
Elbe and Tributaries (*a*)	Four Projects proposed	13,000	2,067,000	159
Wien River (*a*)	Six Projects	19,000	3,661,000	193
	One Project	1,300	1,680,000	1,292
Totals		38,400	$8,896,000	$ 232 ±
*Drainage area, 29 sq. miles.				
Reservoirs in Canada.				
Ottawa River (*a*)	Three Projects. Low concrete dams on numerous lakes	3,800,000	$ 728,000	$ 0.20
Reservoirs in South Africa.				
Cape Colony (*d*)	Earth, six dams	55,422	$1,700,000	$30.80
	Concrete, five dams	44,274	2,800,000	63.20
Transvaal (*d*)	Earth, one dam	95,000	684,000	7.20
	Concrete and weirs, four dams	505,000	4,646,000	9.20
Totals		699,696	$9,830,000	$14.00

Reservoirs in Germany.					
Wupper River:					
Bever Valley (*a*)	Masonry	52.5 ft.	2,700	$ 343,200	$ 127
Lingese Valley (*a*)	Masonry	61 ft.	2,100	256,800	121
Ruhr River:					
12 Reservoirs (*a*)	Masonry	64 to 114 ft.	33,000	3,480,000	105
Rur River:					
Urft Reservoir (*a*)	Masonry	190 ft.	37,000	1,000,000	27
Weiseritz River:					
Malter Reservoir (*a*)	Masonry	115 ft.	7,000	883,000	126
Kleingenburg Reservoir (*a*)	Masonry	128 ft.	12,000	858,000	72
Weser River (*a*)	Masonry	136 ft.	164,000	4,500,000	27
Oder River:					
Glatzer Neisse, proposed (*a*)	Earth	37 ft.	82,500	3,840,000	47
Malapane Reservoir (*a*)	Earth	33 ft.	72,000	2,880,000	40
Tributaries in Silesia (*a*)	13 Reservoirs completed or under construction		75,000	4,317,000	58
Remscheid (*d*)	Masonry		811	91,154	112
Totals			488,111	$22,449,874	$ 46
Reservoirs in India.					
Tansa (*d*)	Masonry		52,670	$988,000	$18.76
Betwa (*d*)	Masonry		36,800	160,000	4.35
Chumbrumbaukum (*d*)	Earth		63,780	312,000	4.89
Bombay:					
20 tanks (*d*)	Earth		372,000	2,090,100	5.62
4 tanks (*d*)	Masonry		250,000	1,700,000	6.80
Totals			775,250	$ 5,250,100	$ 6.77

Cost of Large Concrete Lined Water Works Reservoirs.—The following table is taken from Engineering and Contracting, Dec. 23, 1914.

TABLE V.—COST OF SIX LARGE AMERICAN WATER WORKS RESERVOIRS

Reservoir	Capacity in million gals.	Cost	Cost per million gals
Queen Lane, Philadelphia, Pa.	383	$1,188,000	$3,100
New Roxborough, Philadelphia, Pa.	147	524,000	3,600
Settling Basins, Cincinnati, Ohio	330	1,276,000	3,900
Service Reservoir, Minneapolis, Minn.	93	442,000	4,750
Prospect, Rochester, N. Y.	110	554,000	5,000
Northside, Pittsburgh, Pa.	150	676,000	4,100

Approximate Cost of Reservoirs per 1,000,000 Gal. Water Stored.—Engineering and Contracting, March 14, 1917, publishes the following tabulation from the report of the Water Commissioners of Hartford, Conn., C. M. Saville, Chief Engineer, for the year ending March 1, 1916, which gives comparative figures of size, capacity and cost of various reservoir developments.

TABLE VI.—APPROXIMATE COST OF RESERVOIRS PER 1,000,000 GAL. WATER STORED

Supply	Reservoir	Area flowed, acres	Average depth, feet	Storage, million gallons	Cost per M. G. stored
Hartford	Nepaug	851	34.	9,560	$ 130*
Boston	Wachusett	4,195	46.	63,068	145*
New York	Ashokan	8,180	48.	128,000	155*
Salem and Beverly	Lawrence Station	4,430	7.6	10,900	250†
Hartford	Richards Corner	437	21.	3,000	255†
Salem and Beverly	Topsfield Station	2,480	9.8	7,900	265*
Hartford	Reservoir 4	168	11.1	601	290*
Boston	Reservoir 3	253	14.3	1,180	360*
Boston	Sudbury	1,220	18.2	7,254	395*
New York	Kensico	2,218	40.0	29,000	395*
Cambridge	Hobbs Brk	350	13.1	1,500	400*
Hartford	Reservoir 2	45	19.3	284	420*
Hartford	Reservoir 3	26	17.2	146	460*
Hartford	Reservoir 5	32	7.5	83	570*
Boston	Ashland	167	26.0	1,416	575*
Boston	Hopkinton	185	25.2	1,520	600*
Hartford	Reservoir 6	141	16.1	765	785*
Boston	Reservoir 2	134	12.1	530	880*
Boston	Reservoir 1	143	6.2	288	895*
Hartford	Reservoir 1	32	14.0	146	1590*

* From records. † Estimated cost.

Cu. Yds. of Concrete per Foot of Dam.—Fig. 1, from an article by R. C. Beardsley published in Engineering and Contracting, Feb. 1, 1911, gives the cu. yds. of concrete per foot of dam for four different types of dams and for heads of from 1 to 225 ft.

Estimates of Dams.—The following notes are taken from Smith's "Construction of Masonry Dams" (1915).

Regarding estimates of cost: other things being equal they will carry more weight and conviction in proportion as they show evidence of having been formed after careful analysis; *i.e.*, a reasonable determination of quantities based upon some survey and plan and a subsequent, complete orderly estimate. Thus a mere statement of 100,000 cu. yds. of masonry at $4.50, $450,000, while possibly a very excellent guess is not nearly as valuable and convincing as a plan or profile from which the quantity can be derived, accompanied by a tabulation of all the items entering into the cost, with a sum of $450,000.

The following diagrams may be of some assistance in making up an estimate although they should be used only with some caution and an appreciation of their limits as to accuracy and consequent applicability for the particular estimate. A partial list of existing dams, with dimensions, quantities of masonry, cost and some accompanying pertinent notes, may (aside from its interest) be taken as a very rough indication of what another dam may cost if due regard is given as to whether the particular circumstances of the case are comparable. Such particular circumstances are location, size, accessibility, price and quality of labor, cost of cement, amount of excavation and refill involved, amount expended in beautifying the structure and surroundings, etc.

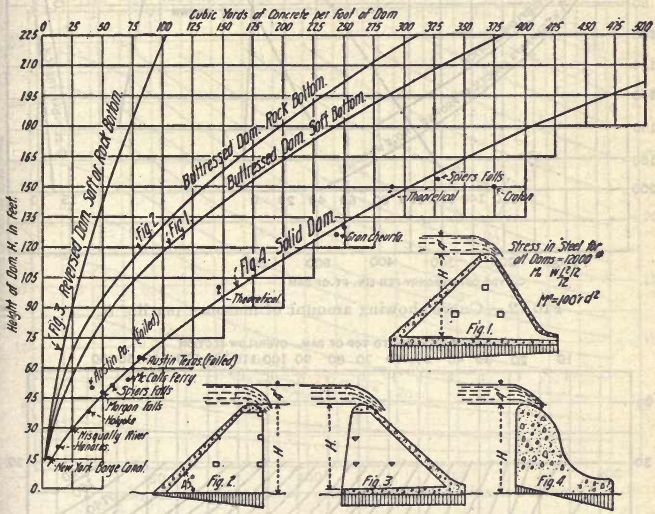


FIG. 1.—Cu. yds. of concrete per foot of dam.

Obviously the length and maximum height as given in the table is only a very crude indication of the amount of masonry involved. For that reason, therefore, it would be much preferable to construct a profile of the dam and from the diagrams (Figs. 2, 3 and 4) arrive at some number of cu. yd. as a basis for comparison. However, such analysis of and comparison with the table can at best furnish only a rough guide toward intelligent guess.

For the purposes of a preliminary estimate, it would be necessary to have a fairly accurate profile across the valley or canyon at the dam-site, together with a fair indication from borings, test pits or otherwise, of the location of the rock surface; also some opinion as to depth to which it will be necessary to go into the rock for a foundation. With such information it should be sufficiently accurate to obtain cu. yd. of excavation and masonry from the diagrams; they are constructed from acceptable masonry sections, and the possible error should be much within that of the then available data. When, however, the project has reached a stage to warrant special studies and designs to meet all

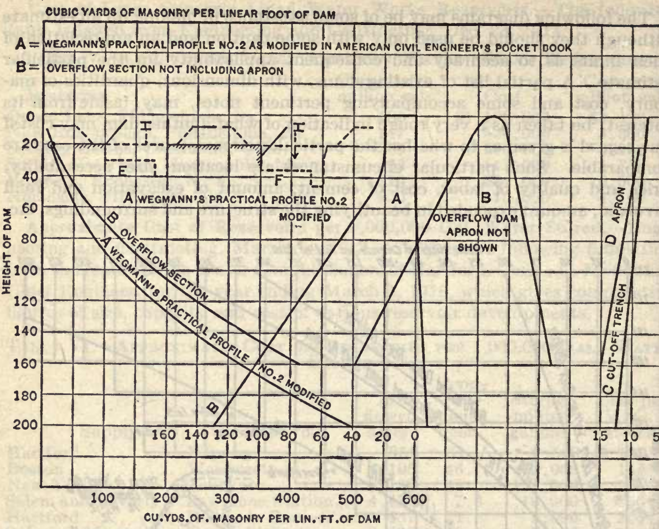


FIG. 2.—Curve showing amount of masonry per lin. ft.

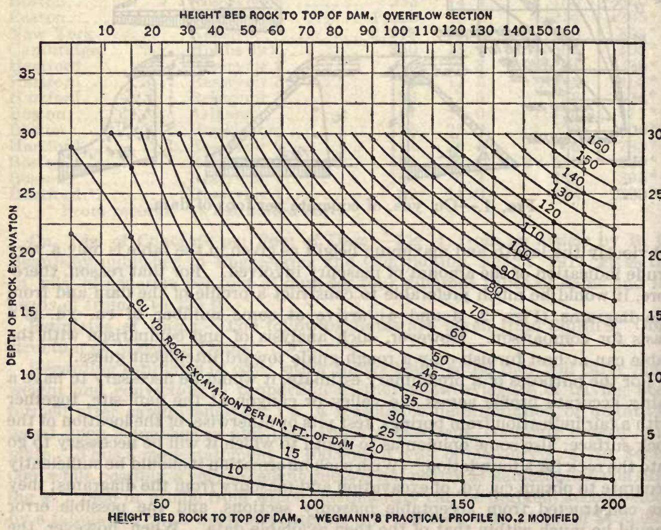


FIG. 3.—Diagram showing cu. yd. of rock excavation.

the particular conditions, much more accurate and detailed data in the way of surveys and borings will be at hand. Such diagrams will then be superseded by sections of the site and the proposed structure.

Diagrams for Preliminary Estimates of Quantities.—For a preliminary estimate of the quantities involved, based upon profiles of earth and rock surfaces across the valley, use accompanying diagrams as follows:

For masonry in a dam without overflow, assume as acceptable, Wegmann's Practical Profile No. 2 as modified on page 616 of the American Civil Engineers Pocket Book. (See section "A" Fig. 2.) For cu. yd. of masonry per lin. ft.

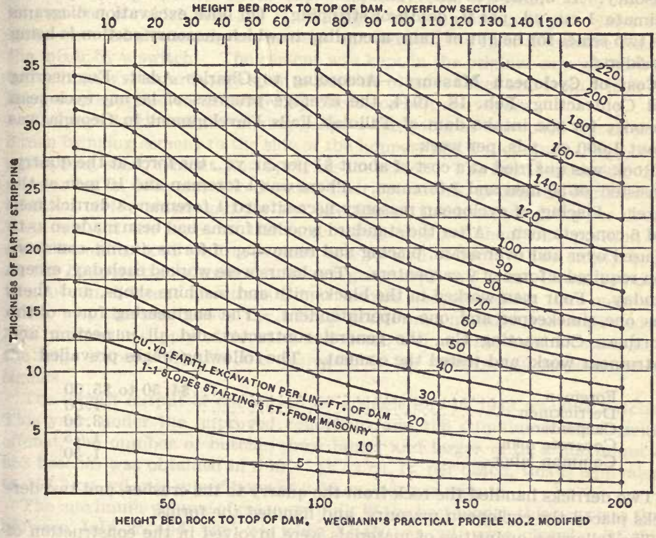


FIG. 4.—Diagram showing cu. yd. of earth excavation.

of dam read curve "A" for neat section to a horizontal base not including masonry in cut off trench.

If the dam is built on surface of rock add for masonry in cut-off trench as per curve "C."

If rock is excavated and masonry slopes can start from the original rock surface, as at "E," read curve "A" for a height above rock surface, and add an amount equal to rock excavation as obtained from diagram Fig. 3.

If masonry slopes must be extended down to a certain elevation below original rock surface, as at "F," read curve "A" for a height of dam above that elevation, and add an amount equal to the rock excavation below that elevation.

For masonry in an overflow dam, proceed precisely as above, reading curve "B" Fig. 2. Then if on account of height of dam, or for another reason, an apron is necessary, add an amount obtained from curve "D."

For rock excavation, read diagram Fig. 3 in which ordinates equal depth of rock which it is assumed necessary to excavate; abscissa represent width of excavation in terms of height of dam, which height should be considered as starting from the elevation where the neat masonry slopes begin. Curves show cu. yd. per lin. ft. and include cut-off trench as per curve "C" Fig. 2. If applied to an overflow dam with an apron, add to rock excavation as thus determined an amount at least equal to curve "D" Fig. 2 masonry in apron.

For Earth Excavation.—Read diagram Fig. 4 similar to rock excavation diagram, observing same rule for height of dam. Curves show cu. yd. per lin. ft. of dam for excavation to 1–1 slopes starting 5 ft. from neat lines of masonry. If applied to an overflow dam with an apron add for tentative estimate 1 cu. yd. per ft. depth of stripping. On both excavation diagrams are two scales for height of dam, according to which masonry section is being considered.

Cost of Cyclopean Masonry.—According to Charles Adsit, Engineering and Contracting, Feb. 18, 1914, the average progress of laying cyclopean masonry for the intake dam of Tallulah Falls Development in Georgia was about 1,000 cu. yds. per week.

Rock was quarried at a cost of about $1 per cu. yd., the force at the quarry, consisted of 50 men and 2 foremen. There was 1 foreman and 10 men at the mixer. Placing of cyclopean masonry necessitated 1 foreman, 3 derrick men and 6 concrete men. After the standard wooden forms had been made so as to be used over and over again, placing and removing of forms during construction required a force of 9 carpenters. Ten hours were worked each day, except Sunday. Four men worked in the blacksmith and machine shops, and there was one timekeeper and one superintendent. The engineering force of the Northern Contracting Co., the general contractor, did all inspection and instrument work, and tested the cement. The following wages prevailed:

Foremen	\$4.50 to \$5.00
Derrickmen	4.00
Carpenters	3.50
Concrete men	1.75
Common labor	1.50

Two derricks handled the rock from the quarry to the crusher, and two derricks placed the cyclopean masonry, and handled the forms.

The following quantities of materials were involved in the construction of the dam: Excavation, 10,600 cu. yds.; Cyclopean masonry, 39,200 cu. yds. The contract price for excavation, including stripping, earth excavation, rock excavation wet or dry, was $1.50 per cubic yard. The contract price, for cyclopean masonry, concrete in the bridge piers, and abutments, was $4.80 per cubic yard. The setting of gates and steel girders, and the reinforced concrete was paid for separately as extra work.

The construction plant consisted of the following equipment:

1 200-HP. Hardie Tynes corliss engine.
1 150-HP. and 2 80-HP. boilers.
1 Allis-Chalmers No. 8 gyratory crusher.
1 Allis-Chalmers No. 5 gyratory crusher.
1 set of 14 × 36-in. sand rolls.
3 American Hoist & Derrick Co. derricks, 115-ft. mast, 100-ft. boom, 15-ton capacity, 30-HP. steam engine.
1 wooden derrick, 65-ft. mast, 70-ft. boom, 18-HP. engine.
18 7 × 2 × 9-ft. steel skips.
3 2½-cu. yd. concrete buckets.
1 2-cu. yd. Austin cube-mixer.
1 Duplex steam pump.

Organization and Output of Gravity Type Mixers Operated at Kensico Dam.—George T. Seabury in Engineering Record, Feb. 13, 1915, gives the following record of the gravity type mixers in use at Kensico Dam.

Three mixers of the Hains-Weaver gravity type, of nominally 2½-yd. capacity, were used in 1914. The average batch, however, had a volume of 52 cu. ft. of fluid concrete. It was the study of the arrangement of these mixers and of their operation that, to a considerable degree, made possible the really remarkable progress attained. Each mixing plant had nearby a large bin for the storage of sand and stone and was also surmounted by a small bin for the same purpose. These bins were connected by belt conveyors, the longest one of which was 340 ft. in length between end pulleys. Sand and stone were fed alternately to the belts and deflected to their respective bins at the mixer by a switch. The cement was kept in the original cars which were brought on a standard-gage spur to the side of each mixer and from which the bags were supplied to the mixer by chutes or belt conveyors.

The organization of the mixing gangs when going at top speed consisted of 6 men bringing cement to the side of the hoppers and 6 more men filling them with stone, sand, cement, and applying the water. The last mentioned 6 men were under an overseer, who directed their operations, giving the word for the addition of the water and for the opening of the measuring hopper doors. Two men cut the tapes on the cement bags and got them into position for quick handling, and two more men were needed to remove the empty bags. At the hoppers below were the three regular men, and when it was required to chute in different directions a fourth man was needed for that operation alone. At the bins above the mixing platform, one man was stationed to look out for the supply of the sand and stone, and another man, located under the large storage bins, fed the aggregate to the conveyor in response to his signals.

The largest output of one mixer for a single day in 1913 was 384 batches. This year, under the improved conditions and the stimulus of the bonuses offered, the number of batches grew larger and larger until a maximum of 653 batches was obtained in 8 hr. At 52 cu. ft. per batch, this is equivalent to 157.2 cu. yd. per mixer-hour or 2.62 cu. yd. per minute.

The maximum volume of masonry built in the best month this year was that between July 25 and Aug. 24, when 84,450 cu. yd. were placed. Of this, 7810 cu. yd. were blocks previously made and placed at night, and 1630 cu. yd. were cyclopean masonry placed in a second shift operated a few nights, and includes a little work done on one Sunday. The remaining 75,010 cu. yd. were placed in the 26½ working days, of 8 hr. each. In this month, therefore, there was placed a daily average of 3125 cu. yd. Considering, however, only the 75,010 cu. yd. of cyclopean and mass concrete placed in the regular 8-hr. day shift, there was an average of 2831 cu. yd. of masonry placed per day, or 353.8 cu. yd. per hour.

Unit Cost of Concrete on Gravity Dam.—The Humpback reservoir is the storage unit in the new Sooke Lake water-supply system for Victoria, B. C. The main dam located at the natural outlet of the reservoir basin has a maximum height of 60 ft. and a total length of 675 ft. The cross-section of the dam is shown in Fig. 5.

Engineering Record, Aug. 15, 1914, gives the following construction costs.

The usual full force employed on the work included 6 foremen, 20 mechanics, 2 blacksmiths and 100 laborers. Concreting began about Sept. 15, 1913, and was continued until about the end of the year. The wages were as follows:

	Per hour
Common labor	$0.34½
Blacksmiths	.45
Carpenters	.53⅛
Foremen	$0.50 to .60

Board and camp charges to all were $1 per day.

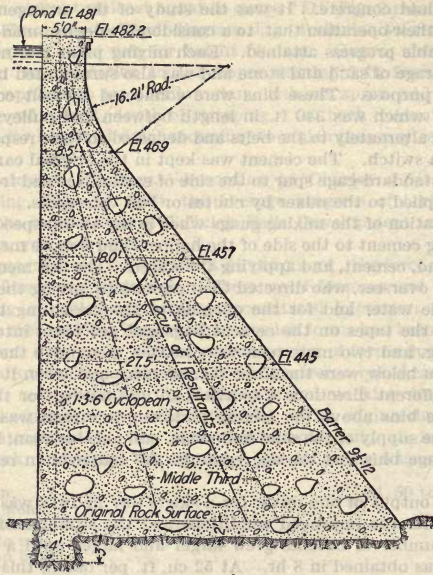


FIG. 5.—Cross-section of dam.

The average cost per yard of all concrete in place was distributed as follows:

Materials	
Cement, 1.01 bbl., at $2.64	$2.664
Sand, 0.285 cu. yd., at $3.13	.892
Gravel, 0.142 cu. yd., at $1.00	.142
Crushed rock, 0.846 cu. yd., at $1.72	1.454
Plums, 0.087 cu. yd. at $1.80	.157
	$5.309
Mixing and Placing	
Labor	$0.747
Supplies	.016
Tools and equipment	.014
Mixer plant	.039
Other plant	.021
	$0.837
Forms	
Total labor	$0.556
Lumber	.096
Plant and supplies	.021
	$0.673
Total cost per cubic yard	**$6.821**

This cost figure, however, includes no charge for rental of plant, which would be cost less salvage divided by 9000.

The usual rate of progress varied from 200 to 250 cu. yd. of concrete placed per nine-hour day, depending on the forms available.

Cost of Las Vegas Arched Masonry Dam.—An arched dam, 250 ft. in radius, of plain concrete, 50 ft. high and only 15.5 ft. wide at the base, was built across the Gallinas River to store 68,000,000 gal. of water for the Agua Pura Company at Las Vegas, New Mexico. Eventually it will be raised to a height of 95 ft. to create a reservoir of 425,000,000 gal. capacity. The structure was completed on Feb. 14, 1911, and in a paper before a meeting of the New England Water-Works Association William T. Barnes, of the staff of Messrs. Metcalf & Eddy, consulting engineers, of Boston, who designed the dam, described in detail the construction methods employed. A summary of his paper is given in Engineering Record, Jan. 4, 1913, from which the following data are taken.

The concrete plant consisted of a ½-cy. yd. Chicago cube mixer. The concrete was delivered to the forms by wheelbarrows. The sand was secured from the bed of the Gallinas River, passed through a ½-in. screen in order to remove occasional gravel, and hauled fully ½ mile up two long and steep hills. The stone was of good quality sandstone, and was crushed locally. In order to supply the stone in sufficient quantity to keep the mixing and placing crews busy throughout the day it was necessary to operate the crushing plant in two shifts of 10 and 12 hours respectively.

When the work was contracted it was expected that the cyclopean form of masonry would be adopted, and with this in view, the contractor erected two small guy derricks, hand-operated, which proved to be entirely inadequate for handling the large stones profitably. Not over 200 cu. yd. of stone were thus utilized, and this amount only in the lower portion of the structure. It is probable, according to Mr. Barnes, that not over 20 per cent of the first thousand yards of concrete was composed of large stones, or not over 8 per cent of the entire structure.

The dam contains 2703 cu. yd. of concrete. The excavation for foundations amounted to 790 cu. yd. of rock and 245 cu. yd. of earth. The cost of the entire work to the contractor was $21,289.89 and to the water company $23,037,93, allowing a contractor's profit of $1748.04. The scale of wages per hour was: Mexican labor, 15 cents; sub-foreman, 17.5 cents; engineer, 25 cents; carpenter, 30 and 20 cents; foreman, 35 cents; double teams, 40 cents.

Cost of the Lost River Multiple-arch Curved Dam.—The following is abstracted from an article by W. W. Patch Engineering News, April 30, 1914. To reclaim farming land being submerged by the rising waters of Tule Lake, which has no visible outlet, a dam was built by the U. S. Reclamation Service to divert a part of the inflowing water, the contract for building the dam being let to Geo. C. Clark, of Everett, Wash, in Dec., 1910.

To save length of diversion channel the dam was placed on indurated volcanic diatomaceous ash instead of on rock. An overflow capable of passing heavy floods being necessary, and this requiring protection against scour below the overflow, a horseshoe-shaped multiple-arch concrete spillway, 289 ft. in length, was adopted, with a low wall or secondary dam thrown between the toes of the horseshoe. The pool so formed was floored with reinforced concrete, covered with plank secured by concrete "toe-holds." The masonry spillway is flanked by paved embankments, held in place at their spillway ends by reinforced-concrete retaining walls, 31 ft. high.

The principal features of the dam are shown in Fig. 6.

The proportions for the concrete used on the work were 1 cement, 2½ sand, and 5 broken basalt rock. The latter was screened into two sizes which afterwards were remixed in nearly equal proportions in order to minimize the percentage of voids. In pier foundations many large rocks were placed in the concrete to save cement. In joining new work to old a mortar coat was applied immediately ahead of the first batch of concrete, but after stripping forms, the exposed surfaces were neither plastered nor coated with cement wash. The arches proved almost absolutely water-tight, even under the maximum head of over 30 ft.

The embankments were constructed in 4-in. layers, wetted and rolled.

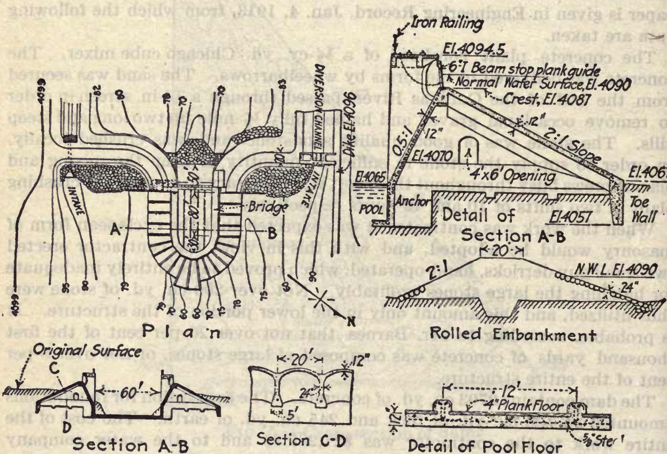


FIG. 6.—Details of dam.

For making concrete of the character required on the dam, sand of proper quality could not be had in the vicinity. Hence, before the contract was let, arrangements were made to ship it in 75 miles by rail and then haul it 8 miles by canal, and 2 miles by wagon to the work. This sand on the job cost $3.75 per cu. yd. During the progress of the work the sand contractor could not supply his material fast enough, and the quality began to deteriorate, so that the United States shipped in quartz sand 300 miles by rail from Marysville, Calif., and delivered it on the siding of the contractor for 10¢. per yd. less than he had been paying for the other sand.

Cost of Work.—The average force on the work comprised 82 men and 36 horses, working for most of the time ten hours per day. Wages were: foremen, $4.38; carpenters, $5; laborers, $2.50; two-horse teams, $6.25. The labor was not efficient as a rule. The accompanying table gives actual, not contract, cost, and includes cost of materials and engineering.

COST OF WORK ON LOST RIVER DAM

Item	Unit	Quantity	Total	Cost per unit
Exc. above Elev. 4067	cu. yd.	9,073	$ 4,743	$ 0.522
Exc. below Elev. 4067	cu. yd.	6,044	10,460	1.73
Embankment	cu. yd.	13,141	8,738	0.665
Rolling, sprinkling and overhaul			305	
Concrete	cu. yd.	5,536	84,510	15.258
Hndlg. reinf. steel	lb.	209,016	7,030	0.033*
Hndlg. structl. steel	lb.	48,254	557	0.012
Stone paving	cu. yd.	1,238	3,386	2.736
Pool flooring	ft.b.m.	25,588	846	33.07
Tool and plank house			2,145	
Five sluice gates and hoists			1,502	
Pump and turbine			1,118	
Stop-plank guides			847	
Stop-planks			330	
Hand rail			282	
Steel rails			342	
Tram car and miscell			786	
Total cost			$127,927	

* Includes cost of steel.

The above includes reasonable allowance for depreciation of the contractor's equipment, which comprised the following:

1—70-hp. Minneapolis traction engine for operating the crushing, screening and mixing plant. This used 4-ft. slabs for fuel.
1—12 × 18-in. Aurora portable crusher, with bucket elevator.
1—rotating 29-ft. screen.
1—1-yd. Ransome concrete mixer.
1—7 × 10-in. double-drum hoisting engine for excavating with drag-bucket.
1—10-hp. gasoline engine with 6-in. centrifugal pump.
1—4-hp. gasoline engine with plunger pump connected.
1—band-saw for form work.
1—bucket elevator for sand hoist.
1—20-in. blower for removing surplus dust from crushed stone and stone dust so that the latter could be added to the sand.
6—9-cu. ft. steel concrete cars with about 600 ft. of 24-in. track.
1—driving team and buckboard.
Blacksmith shop, tools, iron pipe, etc.

All hauling was done with hired teams. In addition to running the plant the traction engine for the last two months of 1911 heated all the water used in making concrete to temperatures of 150° to 204°.

Cost of the East Park Dam, Portland Project, U. S. Recl. Service.—The following data are taken from articles by E. G. Hopson and F. H. Tillinghart appearing respectively in Engineering and Contracting, Oct. 18, 1911, and Engineering Record, June 24, 1911.

Design.—The dam rises to a height of 140 ft. above the foundation rock, and is a solid concrete structure of the gravity type, curved in plan to radius of 275 ft., forming a horizontal arch with abutments in the rock on the sides of the gorge, thus giving it a greatly increased stability. The abutments being somewhat seamy, it was not thought advisable to trust altogether to arch action; hence the combined gravity and arch type. The dam also is located within the so-called earthquake belt. At the top the dam is 10 ft. wide and 249 ft. long, while the maximum thickness at the bottom is 86 ft.

Spillway.—The spillway is located in a saddle in the same ridge about ¼ mile south from the dam, the waste water flowing into a natural tributary to Little Stony Creek and emptying into same at a point about 500 ft. below the dam. Test pits for foundation showed a hard blue shale close to the surface of the ground, conglomerate being encountered only at the north abutment.

The maximum measured flow of Little Stony Creek at the dam site is 8000 sec-ft., but the spillway was designed on the basis of a flow of 10,000 sec.-ft. The distance across the saddle where the spillway is located is only about 300 ft. In order to increase the length of spillway thereby reducing the head, a design consisting of a series of half-circles of arched weirs, butting against piers, was made. The piers are 8 ft. wide and the arches have a radius of 13 ft. 6 in., the whole structure being on a radius of 474 ft. This arrangement gives a total length of 459.9 ft. and after reducing for curvature and incomplete approach there is obtained a total available length of 414 ft., over which the maximum 10,000 sec.-ft. floods should flow 3.7 ft. deep, according to Hazen and Williams' weir formula, as derived from Bazin's. The crest of the spillway is at El. 185, making the high-water elevation in the reservoir 188.7. Small weirs, 2 ft. high and 1 ft. wide, built on a 29-ft. radius and located down stream from the overflow weirs, form a water cushion.

Dikes.—At low points around the reservoir four small earth dikes were constructed ranging in height from 3 to 20 ft. The principal dimensions are 20 ft. width on top, 3 to 1 water slope and 2 to 1 back slope. Rock pitching 1 ft. deep was placed on both slopes.

Costs.—All cement was manufactured at Tolenas, California, cost price f. o. b. cars being $1.55 per barrel. The cost delivered at the nearest railroad station to the work was $2.05 per barrel. Cement and all material brought by rail required hauling over 18 miles of mountain road. The average price of hauling cement, iron work and other materials was 32 cts. per ton mile. The cost of road haul and storage for cement was $1.08 per barrel, so that the net cost delivered at the work was $3.13 per barrel.

In the main dam the total concrete built was 12,202 cu. yds., in which 12,383 barrels of cement were used, or 1.01 bbls. per cubic yard of concrete. The mixture was generally proportioned at 1 volume of cement to 10 of the unmixed aggregates.

In the spillway a richer grade of concrete was used, the total yardage being 1,456, in which were placed 1,758 barrels of cement, or 1.21 bbls. per cubic yard. The mixture was generally proportioned at one of cement to eight of the unmixed aggregates.

The concrete was mixed in standard revolving mixers and handled by cars and track.

The principal item of construction was placing concrete in the dam and spillway as given in Tables VII and VIII.

TABLE VII.—COST OF CONCRETE IN SPILLWAY, 1,456 CU. YDS.

Items	Total cost	Cost per cu. yd.
Cement delivered at R. R. station (1,758 bbls.)	$3,620.99	$ 2,487
Cement—hauling and storing	1,961.25	1.340
Form—Material	373.15	0.260
Form—labor	1,418.50	0.980
Sand and gravel—labor and furnishing	2,438.80	1.670
Mixing and placing	1,388.70	0.960
Finishing	414.40	0.280
Total		$ 7.977
Preparatory expense	$ 161.35	0.111
Interest on investment	1,259.00	0.869
Plant depreciation	318.95	0.218
Miscellaneous and supplies	654.71	0.447
Total		$ 1.635
Superintendence	$1,233.41	0.846
Engineering	913.91	0.628
General administration	1,503.27	1.032
Grand total		$12.118

TABLE VIII.—COST OF CONCRETE IN MAIN DAM, 12,202 CU. YDS.

Items	Total cost	Cost per cu. yd.
Cement delivered at R. R. station (12,382 bbls.)	$25,333.86	$2.076
Cement—hauling and storing	13,394.98	1.097
Forms—Material	2,054.39	0.168
Forms—labor	5,143.45	0.424
Sand and gravel—labor and furnishing	7,074.20	0.580
Mixing and placing concrete	5,304.29	0.434
Finishing	429.60	0.035
Total		$4.814
Preparatory expense	$ 1,817.57	0.149
Interest on investment	4,326.00	0.354
Plant depreciation	3,201.31	0.262
Miscellaneous and supplies	6,700.08	0.550
Total		$1.315
Stream control and unproductive work at quarry	$ 2,611.34	0.213
Superintendence	7,530.02	0.617
Engineering	5,800.14	0.475
General administration	9,540.59	0.782
Grand total		$8.216

Force.—The contractor's average force engaged on this work was 38 men, including 8 teamsters and 20 teams. The engineering and inspection force consisted of 4 men.

The total cost to the United States for the whole work was as follows:

Main dam	$104,358.26
Spillway	15,846.52
Lands for reservoir	86,047.11
Engineering—preliminary and construction	32,076.34
Total	$238,328.23
Cost per acre foot of storage	5.23

Cost of Stony River Hollow Concrete Dam.—G. H. Bayles gives the following data (Engineering News, Jan. 22, 1914) in regard to the construction cost of the dam.

Various rates of wages were paid at the beginning of the work, but these soon settled to the following:

Mechanics, $0.30 to	$0.50 per hour
Carpenters, $0.30 to	0.35 per hour
Helpers	0.25 per hour
Laborers in cutoff trench	0.25 per hour
Other laborers	0.22 per hour

All field costs included, the costs of the parts of the work completed with cableway were as follows:

Cutoff excavation	1,273 cu. yd.	@ $2.93
Earth excavation	3,432 cu. yd.	@ 0.48
Rock excavation	44 cu. yd.	@ 3.43
Crushed stone and sand for 1 cu. yd. of concrete	1 cu. yd.	@ 1.23
Mixing and placing concrete	7,594 cu. yd.	@ 0.72
Forms (not including materials)	7,594 cu. yd.	@ 1.67
Placing steel	366,277 lb.	@ 0.005

The dam as constructed consisted of 56 panels 15 ft. long with buttress supports at each panel point. The maximum height was 51.17 ft. above foundations. A spillway 150 ft. long was provided with elevation 3 ft. below top of the dam. The height of dam at the spillway was 34.75 ft. The width of dam (at foundation line) varied from a minimum of approximately 16 ft. to a maximum of 70 ft.

TABLE IX.—UNIT COSTS OF THE CORBETT DIVERSION DAM, SHOSHONE IRRIGATION PROJECT

Distribution of cost	Excav., class 1, 7865 cu. yd.	Excav., class 2, 2681 cu. yd.	Excav., class 3, 1454 cu. yd.	Puddling, 1712 cu. yd.	Reinforced concrete 4950.59 cu. yd.	Hauling and placing reinforcing steel 319,382 lb.	Hauling and placing cast iron, 39,385 lb.
Interest on investment	$0.044	$0.132	$0.261	$0.042	$0.338	$0.0004	$0.0007
Preparatory expense	.053	.163	.332	.052	.418	.0005	.0009
Plant depreciation	.044	.132	.261	.042	.338	.0004	.0007
Executive	.145	.434	.857	.140	1.122	.0013	.0023
Labor	.948	2.853	5.648	.953	6.632	.0084	.0164
Supplies	.035	.097	.181	...	1.000	....	....
Total contractor's cost	$1.269	$3.811	$7.541	$1.229	$9.848	$0.011	$0.021
U. S. materials	.001	.004	.006	....	4.925	.022	.129
U. S. Engineering	.052	.175	.383	.026	.436	.001	.005
Total actual cost	$1.322	$3.990	$7.930	$1.255	$15.209	$0.034	$0.155

The quantities from which the above figures were derived were made up from the number of batches placed. It was found that it required a little more than the figured yardage to fill the forms, say 5%, and where the concrete came in contact with the earth—the footings and cutoff—as much as 25% more than the neat quantities was required, and the average for footings was a little under 20%.

The dam site is 19 miles distant from the nearest railway station, and all men and material had to be brought in over logging railroads, which materially affected the cost.

Six months after its completion 5 bays or panels of this dam went out due to leakage under the cut-off wall which did not go down to solid rock.

Cost of Corbett Diversion Dam, Shoshone Irrigation Project.—The Corbett Diversion Dam was built by contract during the latter part of 1906, and the forepart of 1907 for the total contract price of $66,750. This dam is located on the Shoshone River about eight miles below Cody, Wyo., and is a part of the irrigation structures pertaining to the Shoshone Project, of the U. S. Reclamation Service.

The following description of the diversion dam and data on its cost are given in the August number of the "Reclamation Record," 1908, and reprinted in Engineering Record, Aug. 22, 1908.

The Corbett Dam is of the reinforced concrete buttressed type, having a deck 30 in. thick on the upper side with a slope of 1 to 1. This deck rests on buttresses two feet thick, spaced 14 ft. on centers. The structure is founded on gravel and shale, and has a reinforced concrete platform two feet thick resting on the foundation and extending from the deck wall downstream to a distance of about 40 ft. Beneath the deck of the dam and this platform are three cut-off walls running lengthwise of the dam and extending down into the shale. The total length of the dam between abutments is 400 ft., and extending at the right abutment of the dam to the bluff is an earth embankment about 450 ft. in length. At the left end of the dam are located the sluiceway and the headworks controlling the entrance to the Corbett Tunnel.

Careful records of cost were kept during the construction of the dam, and the data relating thereto are given in Table IX under the primary heading of distribution of cost and under the secondary heading of the class items of the schedule. Labor conditions were extremely bad during the entire construction period, but the contractor was provided with fairly efficient equipment. Laborers were paid at the rate of $2.50 to $3 per eight-hour day, carpenters at the rate of $3 to $4.50 and teams at the rate of $2.50 per eight-hour day.

There was no suitable sand for concrete in the vicinity of the dam, and it was necessary to establish a crushing plant for manufacturing the same from cobblestones. The crusher and concrete mixer were located at a distance of about 400 ft. from the right abutment of the dam. The concrete was hauled from the mixer to central points on the dam by means of cars of one-half cubic yard capacity drawn by horses. At these central points the concrete was transferred to small hand carts, and thus conveyed to various local points on the dam.

The shore ends of the dam were constructed during ordinary stages of the river without diverting the river from its channel. For the portion of the dam in the channel of the river it was found necessary to construct a temporary dam from the end of the sluiceway wall diagonally across the river, thus diverting the entire low-water flow of the river through the sluiceway.

The total actual cost for all of the items tabulated was $127,277.43.

Cost of Concrete Core Wall, Moline Pool Dam.—J. B. Bassett in "Professional Memoirs" described the methods and costs of construction of the concrete core wall in Moline Pool Dam in the Mississippi River at Moline, Ill. The following is taken from an abstract of that paper published in Engineering and Contracting, July 27, 1910.

The core wall was constructed to make more permanent the loose rock fill dam forming "Moline Pool" which in times of high water acted as a spillway and was therefore subject to disintegration from the top.

The construction details are as follows: A dipper dredge is first employed to dig a trench along the toe of the dam to steepen the slope to its most abrupt angle of repose and to get down through the mud, sand, etc., to the solid rock bottom. Following the dredge a drillboat is employed to drill holes 10 ft. apart along the toe of slope and approximately 3 ft. therefrom. These holes are carefully placed, as the alignment of the wall depends on their proper location. Upright 6 × 8 in. form posts having a 2-in. steel rod, pointed on the lower end, bolted thereto, and allowed to extend about 1½ ft. below the end of the post, are then set, being dropped into the holes by the drillboat crew as fast as the holes are drilled, and left standing. Later the posts are lined up, slanted to a batter of about 1 to 3½, and tied to anchorages in the rock dam by 3 × 6-in. strips bolted to the sides of the posts. The remainder of the form consists of horizontal 6 × 6-in. waling strips spaced by means of sink planks about 3½ ft. between centers, and 2-in. plank sheathing set on end to make as good a contact as possible with the irregular bottom. It will be noted that only the face side of the wall is joined, the rough slope of the dam forming the back side, except near the top, where the section is reduced to a finish to a 2-ft. width of coping.

The concrete plant was erected on a flat barge and consists of a rolling drum mixer and small, stiff-leg derrick with a 40-ft. boom, together with the necessary boilers, hoisting apparatus, etc. This barge is floated alongside the form, with the gravel and cement barges on its other side. A straight sided, bottom-dumping bucket was designed for the work, arranged with two doors joining at the center and held shut by latches that can be tripped at will by latch strings. The concrete is deposited directly in the water with this bucket with very little agitation or loss of cement. For conveying the raw material to the mixer a special arrangement of an automatically dumping skip car was devised. A hinged and counter-weighted track extension allows the car to run out to the center of the gravel barge moored alongside, where it is filled by hand. The car itself is gaged so that the proper quantity may be secured. A small barge containing the cement is moored alongside the gravel barge, the cement being carried a few steps by hand and dumped into the skip car from the containing sacks.

The proportions used average about 1 cement to 6 gravel. For the deeper portions of the wall, the gravel is reduced to about a 1-to-5 mixture to allow for some loss of cement, but the top of the dam is made of proportions of about 1 to 7. The gravel is furnished on United States barges by contract, being pumped direct from the river bed. It is not screened and re-mixed, as is the practice in some localities, since the natural mixture is quite uniform and tests show voids running from 12.5 to 17 per cent. The depth of water in which concrete has been deposited varies from 5.5 to 17 ft. A considerable length of wall was built with the depth at the latter figure. In this case it was found inadvisable to attempt to carry the wall to completed height in one day, due to the excessive pressure on this style of form. It can be readily seen that a continuous contact between the form and the rough rock bottom would not be had. Occasionally, a stone would fall from the dam and, lodging along the line of the form, would prevent the sheathing from reaching to the proper depth, and a hole would be the result. It was found that concrete to a height of 3 or 4 ft. would not run out, but if an attempt was made to carry the section to completion a leak would result, and, once started, it could not be stopped until equilibrium was restored. For this reason the custom was established of building the deeper sections in two layers. Scrap steel rods, etc., in short lengths were stuck into the first layer to assist in bonding.

When the work was started, alternate sections were constructed, the intermediate sections being filled later; but in some cases where the dam behind the wall had quite a strong leakage it was found better to build continuously and push the leak ahead, each day's work being ended at a bulkhead. Later, this practice was followed altogether. Some cement was lost at points opposite the leaks, but not enough to materially weaken the dam. It must be remembered that the upper part of this wall is the vital part, as the dam breaks from disintegration on the crest. For this reason a reinforcing rod of about seven-eighths inch diameter is run longitudinally about 6 ins. below the coping of the wall, tied by 8-ft. rods set vertically near the face of the wall and bent at the top to hook over the longitudinal rod. This is done to hold in place any chunks of concrete which might come loose through shrinkage cracks or from impact of running ice.

The work is being conducted by hired labor, and the wages paid on the concrete outfit are as follows:

One foreman, at $90 per month; 1 derrickman, at $90 per month; 2 firemen, at $40 per month; 1 hoistman on conveyor, at $40 per month; 1 watchman, at $40 per month; 11 laborers, at $1 to $1.25 per day, depending on scarcity of labor. Also, the drillboat crew, of 1 drillrunner, at $60 per month, and 1 fireman, at $40 per month.

Subsistence and sleeping quarters are furnished to all employes in addition to the above wages. Eight hours constitute a day's work, and the usual Saturday half-holidays are allowed at full pay during July, August and September. Full pay is allowed to all employes for all legal holidays. Weather conditions are usually good in the summer season, but about six weeks in the spring and four weeks at the end of the season in November are usually attended by storms and exceedingly high winds.

The cement is taken from the cars and stored in a warehouse and afterwards loaded on the barges by hand. All cement is tested in a laboratory on the office boat.

The dredging and towing expense is also charged for the time put in by the dredge at digging the trench and by the towboat in carrying the various supplies to the work.

A cost statement of the work to date is as shown by the accompanying table:

TABLE X.—COST STATEMENT

13,112.6 cubic yards concrete, 6,301.8 linear feet of wall.

Items	Amount	Cost per cu. yd. of concrete		Cost per lin. ft. of wall
Preliminary expense:				
(plant equipment, warehouse, etc.)	$ 6,530.12		$0.4980	$ 1.037
Quota miscellaneous charges	375.12		.0286	
Superintendence and office:				
Field	5,551.26	$0.4233		
Quota R. I. office charges	2,060.92	.1572		
Total			$0.5805	
Excavation	1,241.56		.0947	
Forms:				
Material	2,752.39	$0.2099		
Labor	2,514.95	.1917		
Drilling	660.67	.0504		
Drilling, coal for	186.53	.0142		
Total			$0.4662	
Materials:				
Cement	17,952.72	$1.3691		8.917
Cement handling	936.02	.0714		
Cement tests	627.39	.0479		
Gravel	7,140.71	.5446		
Reinforcement	290.08	.0221		
Towing	2,889.68	.2204		
Towing, coal for	942.03	.0718		
Total			$2.3473	
Mixing and depositing:				
Labor	7,890.41	$0.6017		
Coal	843.10	.0643		
Total			$0.6660	
Backfilling	766.47		.0585	
Plant repairs	572.92		.0437	
Total	$62,725.05		$4.7835	$9.954
Miscellaneous	283.40		.0216	.045
Plant charge (rental)	4,995.74		.3810	.762
Total, including plant charge	$68,004.19		$5.1861	$10.791

The above statement includes all money spent on the work in plant construction and operation, material, and supplies of all kinds, repairs during season, superintendence, field and main office charges and a plant charge presumed to be equal to its rental charge were it not owned by the United States Government.

Cost of Constructing Small Concrete Dam.—Engineering and Contracting, March 15, 1911, gives the cost of a hollow concrete dam 70 ft. long and 4 ft. high built at East Earl, Pa. by H. L. Bauman using day labor.

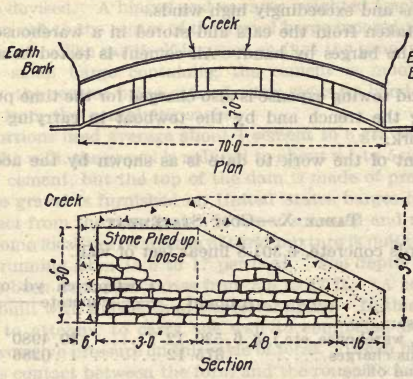


Fig. 7.—Plan and section of concrete dam.

Fig. 7 shows the essential dimensions and it will be noted that the concrete structure is hollow, is divided into compartments by interior cross walls of dry masonry and that the compartments are filled with gravel. The concrete used was a 1:2½:5 mixture plastered with a 1:1 mortar. The amount of concrete is not recorded but estimating from the sketch and from the amount of concrete used it was about 40 cu. yds.

Item	Cost
Hauling gravel (3 men 3 days at $1.75)	$ 15.75
Hauling gravel (2 men and team 1 day at $3.00)	6.00
Hauling gravel (2 men, horse and cart, 3 days at $2.25)	13.50
Screening sand from gravel (1 man 3 days at $1.75)	5.25
Washing gravel (6 men 1 day at $1.75)	10.50
Pump and pumpman (1 day at $5)	5.00
Cofferdam (3 men 4 days at $1.75)	21.00
Cofferdam (2 men, horse and cart, 2 days at $2.25)	9.00
Excavation (6 men 2 days at $1.75)	21.00
2,000 ft. B. M. from lumber at $20 per M	40.00
Delivering lumber	5.00
Settling forms (2 men 2 days at $1.75)	7.00
Placing concrete (7 men 3 days at $1.75)	36.75
2 hp. gasoline mixer engine 3 days	3.00
Removing forms and clearing away (2 men 1 day at $1.75)	3.50
Plastering (4 men 1 day at $1.75)	7.00
Pump 20 hrs. at 40 cts	8.00
Charges on borrowed pump	7.50
10 tons Atlas cement at $8 delivered	80.00
Total	$304.75

A 10-hour day was worked.

Cost of Small Concrete Dam Built by Unskilled Labor.—Fred. J. Wood in Engineering Contracting, March 26, 1913, gives the methods and cost of constructing a small concrete dam at Paris, Maine.

The dam has a total length, on the top, of about 48 ft., of which only 20 ft. are of the full height of 3 ft. The section being so small, a 32-in base, bringing the resultant within proper limits, the dam was made rectangular in section and of that width. No other engineering problems were involved; the foundation was a solid ledge without a sign of a seam, and the location was between two ledge walls which narrowed as they stretched down stream. A man of many years' experience as a contractor's foreman, who had had charge of some concrete construction, composed the whole "expert" force. He was told to build the dam on the lines outlined above and left to his own devices. The dam was built October 2 to 9, 1912, while the river was very low.

First, a diversion dam was built of feed sacks full of sand, placed above the dam site and at a point to turn the river flow through the canal leading to the mill. The canal was cleared of rubbish, all gates opened wide, and the end of the penstock taken off, by all of which means nearly the entire flow was diverted from the new work.

Much difficulty was found in securing laborers and only by offering nearly double wages could a gang of ten men be secured for two days. With the help of one laborer, a handy man with carpenter tools, and a horse, the river had been diverted, the site cleared, and the form built by the night of Oct. 6, and a full gang of ten men reported on the morning of the 7th.

An adjacent pile of old railroad ties was soon transferred into a cob house trestle across the river bed adjoining the form and about a foot above its top. This planked over, formed the mixing platform and the runways. The sand, previously hauled from a bank a mile away, had been dumped on the bank at the west end of the dam, with emery ore (used as aggregate because convenient) immediately behind it. Not enough water ran past the work to provide the amount needed for mixing, so a supply was brought and placed in barrels. Mixing and placing concrete began about 10 o'clock and occupied the rest of the day and about four hours of the next day.

Distribution	Cost	Per cu. yd.
Labor:		
Filling sacks and building diversion dam	$ 14.375	$ 1.65
Cleaning diversion channel	4.50	.52
Clearing site	4.225	.49
Building forms	16.50	1.90
Building mixing platform and runways	6.45	.74
Handling material to the mixing platform	13.60	1.57
Mixing and placing	27.70	3.18
Cleaning up	13.25	1.52
Time lost by rain	2.65	.30
Total for labor	$103.25	$11.87
Material:		
Emery ore (at price quoted for trap rock)	$ 30.00	$ 3.45
Cement, delivered	35.00	4.02
1,500 ft. B.M. boards for forms, delivered	30.00	3.45
10 lbs. 8d. wire nails at 4 cts	.40	.05
20 loads of sand at 5 cts	1.00	.11
Hauling sand, 2½ days at $3	7.50	.86
Total for material	$103.90	$11.94
Total for labor	103.25	11.87
Grand total	$207.15	$23.81

The form was simply built with longitudinal top and bottom stringers, tied across the top at intervals and braced from the outside, with vertical boarding on their inside faces.

Laborers were paid $2.50 per day, one dollar more than the customary rate in that section. The cement a standard brand of Portland was obtained from a local dealer, the sand was also locally secured, and the concrete was mixed in the proportions of 1:2:4.

Life of Equipment Used in Building Dam by the Hydraulic Fill Method.—The following data are taken from an article in Engineering Record, July 11, 1914.

In placing 2,000,000 cu. yd. of material, in a dam 145 ft. in height and 1,700 ft. long, about 95% of the material was moved by water and 5% by Fresnos in building up the dikes.

The material was conveyed a maximum distance of 3,000 ft. with a normal flow of water of 12 sec.-ft. With a normal solid content of water about 10 per cent and with a head of 50 ft. on the pumps, which were 12 × 12 in. centrifugals, operating at 600 r.p.m., the life of the manganese steel runners was about 3 months. The life of the 14 ga. steel distributing pipe with 10 ga. slip joint butts was about 500,000 cu. yd. of material handled. The pipe cost 48.75¢ per ft.

A crew of 6 men for each shift operated 2 pipe systems and deposited 8,000 cu. yd. per 24 hours. Additional men were required for making the dikes and shifting the plant.

Dimensions of Storage Tanks or Reservoirs for Economical Design.—In Engineering News-Record, April 3, 1917, Arthur Jobson gives the following formulæ for obtaining such dimensions that the construction cost of a storage tank or small reservoir will be a minimum. The formulæ were obtained by finding expressions for the cost of the sides and bottom, adding them to get an expression for total cost and equating the first derivative to zero.

The final equations obtained are as follows:

$$R = \sqrt[4]{\frac{V^2 w_1 w_2 c_1}{\pi^2 S c_2}} \qquad (1)$$

and

$$d = \sqrt{\frac{S c_2}{c_1 w_1 w_2}} \qquad (2)$$

in which R is radius in feet; V, capacity in cubic feet; w_1, weight per cubic foot of material in sides; w_2, weight per cubic foot of reservoir contents; c_1, cost per pound of installing sides; c_2, cost per square foot of installing bottom; S, allowable unit stress in pounds per square foot for material in sides, and d, depth in feet.

It is interesting to note in equation 2 that the proper depth for the lowest cost is independent of volume or capacity. For any assumed capacity the depth will be constant for given values of unit stress, costs of installing sides and bottom, unit weight of contents and unit weight of side material Trial computations with equation 1 will show that for the value of R giving the lowest cost the cost of installing the sides and bottom will be approximately equal, as they should be theoretically.

The quantity c_1 is intended to include all expense for labor and material in connection with the cost of installing the sides, and c_2 may not only include the expense for labor and material in laying the bottom, but also the cost of grading and leveling the reservoir site. In the use of these equations, S should be assumed rather small, for two reasons—to allow for efficiency of riveted joints and to proportion properly the thickness of vertical sections of the plate so that the actual net area may approximate the theoretical area used for computing weight and cost. For steel plate with an ultimate strength of 60,000 lb. per square inch, a factor of safety of 4, and a joint efficiency of 70 % the writer found that the value of S to be used was about 1,296,000, or 9000 lb. per square inch.

Sides of Constant Thickness.—If the side-plate thickness is arbitrarily selected without reference to the depth or diameter, the expressions for the most economical dimensions become:

$$R = \sqrt[3]{\frac{tVw_1c_1}{\pi c_2}} \tag{3}$$

and

$$d = \frac{Rc_2}{tw_1c_1} \tag{4}$$

where t is plate thickness in feet.

If the value for R given by equation 3 is substituted in the total-cost formula, it can be shown that the dimensions giving the lowest cost result in making the cost of the sides equal to twice the cost of the bottom, as against these costs being equal where the thickness of the plate is assumed to vary either with the depth or with the diameter of the reservoir.

Cost of Open Concrete Reservoir.—The following unit costs of constructing the 1,300,000 gal. concrete reservoir for Webb City, Mo. are given by E. W. Robinson, in Engineering Record, May 11, 1912. The reservoir was 100 × 200 ft. by 9.5 ft. deep, no roof was provided.

Cost of Concrete Reservoir

	Unit cost	Total
Walls:		
Concrete (634.6 cu. yd.)—		
Materials	$5.053	$ 3,206.62
Mixing and placing	1.217	772.31
Placing steel, labor	0.024	15.23
Forms (634.6 cu. yd.)—		
Making and setting	1.007	639.04
Removing, labor	0.098	62.19
Plastering (980 sq. yd.)—		
Materials	0.170	166.73
Labor	0.145	141.78
Total for walls, 634.6 cu. yd., at $7.885	$7.885	$ 5,003.90
Floor (432.8 cu. yd.):		
Concrete base (323.8 cu. yd.)—		
Materials	2.758	893.13
Labor	1.156	374.43
Finish (109.0 cu. yd.)—		
Materials	5.473	596.52
Labor	1.774	193.37
Asphalting (1972 sq. yd.)—		
Materials	0.431	952.29
Labor	0.052	106.95
Total for floor, 432.8 cu. yd., at	$6.954	$ 3,009.74
General:		
Excavation (3242 cu. yd.)		551.14
Embankment		348.29
Bond and insurance		73.00
Superintendence		700.00
Overhead charges		500.00
Grand total		$10,186.07

Common labor was paid $2, carpenters $3 and $3.50, helpers $2.50 and teams $3.50 per day of 10 hours. The man in charge of placing the steel was paid $2.50, and a few other men received $2.25, $2.50 and $2.75 per day for special reasons. As a whole the labor was fairly efficient, but would have been more so under more competent supervision. The excavation was sub-let to another party at $0.17, which allowed but small profit. The item of superintendence included the time of two members of the contracting firm that was spent upon the job, and one paid superintendent for part of the time. The item of overhead charges, which was partly an estimation and partly taken from statements from the contractors, included traveling and other general expenses, and though excessive was not far from the actual expense incurred.

The aggregate use is what is known as "chats" or "tailings" which is crushed blue and white flint running in size from ⅛ to ¾-in. and is obtained from the various mills of the zinc mines. The mix was 1 part of cement to 2 parts of fine "tailings" to 4 parts of coarse "tailings." Tailings can generally be had for the hauling.

Cost of Covered Concrete Reservoir.—G. Stanley Whitehead gives the following data in Engineering Record, July 1, 1911.

The reservoir, for the town of Brookline, Mass. is circular in form with a capacity of 4,000,000 gals., 180 ft. in diameter and 23.5 ft. deep at the wall. The side walls are of reinforced concrete, 2 ft. thick at the top and 3.5 ft. thick at the bottom, with a batter of ¼ in. per foot on the inside. The bottom slopes toward the center at the rate of 0.5 per cent, with a channel sloping in the opposite direction to drain off the water when emptied. The roof is of mushroom construction, upheld by square reinforced concrete piers, and is covered with 14 in. of cinders and 10 in. of loam; this and the adjoining embankment slopes have been grassed over and treated as a small park.

The reservoir was so located on the hill as to make the cut and fill about equal. After stripping the surface loam the material encountered in the excavation consisted entirely of hardpan, which was hauled largely by carts and dumped between the reservoir wall and retaining wall to form the slopes. The fill thus made was thoroughly rolled with a two-horse grooved roller. After the reservoir wall was closed in, the excavation was removed by the use of a derrick set up just outside the main wall and used later to carry the concrete from the mixing plant.

A concrete retaining wall, 18 in. wide on top, with a batter of ½ in. to the foot on the inside and 1 in. to the foot on the outside, nearly encircles the reservoir. It is of 1:2:4: Portland cement concrete, varying from 2 to 6 ft. in height, and takes the earth embankment graded to a 1½ to 1 slope from the roof of the reservoir. It was built primarily to shorten that portion of the embankment that faces private residences. The foundation is of stone and cinders extending 4.5 ft. below the natural surface of the ground, at the bottom of which is a 6-in. tile pipe, laid to drain the wall and take any possible leakage from the reservoir. No reinforcement was used in the wall; consequently, cracks extending from top to bottom opened up about every 60 ft. after standing through the first winter. This condition, however, was expected, and no effort was made to prevent it, as the wall will be ultimately covered with vines and shrubbery.

The concrete in the main reservoir wall is composed of 1 part Atlas Portland cement, 2 parts sand and 4 parts screened gravel containing stones not larger than 2½ in. The reinforcement consists of 1⅛ and ¾-in. round bars, spaced as shown in the cross section. The bars were held in place by the use of perpendicular steel lattice work supports set 15 ft. apart; the ends of the rods were lapped 40 diameters and wired.

COST OF CONCRETE PER CUBIC YARD

Main Wall	
Labor	$ 2.54
Cement	2.04
Gravel and sand	2.84
Steel	2.26
Lumber	.77
Tools, concrete mixer supplies and miscellaneous	1.00
	$11.45
Credit for sale of material	.34
Total cost per cu. yd	$11.11
Retaining Wall	
Labor	$ 2.54
Cement	2.04
Gravel	2.84
Lumber	.77
Total cost per cu. yd	$ 8.19
Floor, Piers and Roof	
Labor	$ 3.14
Lumber	1.11
Gravel and sand	2.85
Cement	2.54
Steel	1.55
Tools, cars, derrick and miscellaneous	.99
	$12.17
Credit for sale of material	.29
Total cost per cu. yd	$11.88
Waterproofing roof	.99
Plastering bottom and sidewalk	.97

COST OF LABOR AND MATERIALS

Cement	$ 1.62 per bbl.
Sand and gravel	2.10 per cu. yd.
Lumber *	23.00 to $29.00 per M.
Steel	0.015 per lb.
Labor	2.25 per day

* Dimension lumber cost $29.00 per M.

The total cost of the reservoir, including the land purchased and the construction of 1500 ft. of roadway, was $80,212.

Cost of Small Reinforced Concrete Reservoirs.—John W. Ash in Engineering Record, Jan. 25, 1913, gives the following costs of constructing the concrete tanks and reservoir for the waterworks plant, Dalton, Ga.

The main reservoir is 80 ft. in diameter, 21 ft. deep, and has 10-in. walls, with coping floor 6 in. thick. The footing course is 12 in. deep and 2 ft. wide. Concrete was a 1:2:4 mixture. The construction of the main reservoir, which is located on the top of a hill about 300 ft. above the creek level, involved some features a little out of the ordinary. There was no road to the top and to have built one would have required considerable time and money. It was decided, therefore, to put the mixing plant at the foot of the hill and haul the concrete and other materials to the top on a tramway. The tramway ties were poles and stringer pieces and the rails were made of 2 × 4-in. timbers, laid double and well spiked together. The total length of tramway was about 900 ft.

The concrete was carried in two concrete carts; each cart carried one batch. While these were being hauled to the top and returned empty two more would be loaded and ready when the empties returned. At the top the landing platform was nearly on a level with the top of the reservoir walls, but as these walls were carried up in 7-ft. sections, the concrete was dumped down a chute to a platform on a level with the top of the section, where it was rehandled with wheelbarrows. After the work of concreting was well started and each man knew just what he was to do, a round trip could be made very quickly. The best day's run was 74 trips in 8 hours—less than 7 min. to a trip. The average, however, was about 9 min., owing to an occasional derailment or other slight delay. The car made about 800 trips and got away once through some carelessness in letting it get unhooked after landing at the top.

It took about 3 hours to get the track back in shape, rig another car and start running again. This was the only accident and no one was hurt.

Reservoir Costs

	Hauling	Labor	Material	Total
Shanties, tool and cement houses	....	$ 67.00	$ 46.20	$ 113.20
Tramway	....	103.20	53.70	156.90
Excavation, 1650 cu. yd	....	333.00	12.60	345.60
Backfill	....	28.50	....	28.50
Concrete, 282 cu. yd	$213.70	396.75	900.25	1,510.70
Steel	18.00	183.45	1,197.32	1,398.77
Forms	....	252.25	261.81	514.06
Finishing and water-proofing walls	....	42.70	28.60	71.30
Hauling water	30.00	....	....	30.00
Erecting and handling outfit	27.25	84.65	....	111.90
Coal, oil, waste, etc	....	....	67.90	67.90
Depreciation, repairs, etc	....	29.75	232.50	262.25
Operating tramway	....	210.00	....	210.00
Waterproofing compound	....	....	193.00	193.00
Grand total				$5,014.08

The coagulating basin is 40 ft. inside diameter and 10 ft. deep. The walls are 9 in. thick and bottom is 4 in. thick. The basin has four wooden baffle walls built of 2-in. plank and 4 × 6-in. posts. The concrete was mixed in the proportions of 1:2:4.

Coagulating Basin Costs

	Labor	Material	Total
Excavation, 325 cu. yd	$160.25	$ 34.75	$195.00
Concrete, 56 cu. yd	50.60	214.70	265.30
Steel, 3030 lb	24.20	65.90	90.10
Forms	58.10	52.15	110.25
Baffle-walls	12.30	72.00	84.30
Finishing and waterproofing	23.90	12.30	36.20
Pipe connections, etc	8.60	3.70	12.30
Grand total			$793.45

The clear water well is 40 ft. inside diameter, 12 ft. deep, with 9-in. walls, 6-in. floor and a self-supporting concrete roof having a rise of 4 ft. at the center, where there is a 4-ft. man-hole with screen ventilator. The mixture of concrete used was 1:2:4.

CLEAR WATER WELL COSTS

	Labor	Material	Total
Wet excav., 150 cu. yd	$ 65.00	....	$ 65.00
Concrete, 128 cu. yd	146.40	$484.00	630.40
Forms	115.20	128.00	243.20
Reinforcement, 7880 lb	59.10	213.90	273.00
Pipe conn's, ventilator, etc	13.50	12.25	25.75
Coal, oil, waste, etc	....	21.30	21.30
Finishing walls	16.25	8.70	24.95
Grand total			$1,283.60

Cement cost $1.35 per barrel; sand, $1.05 per ton; stone, $1.43 per ton. Labor was $1.35 and $1.50 per day; carpenters, $2.25 to $3.50 per day. The labor item includes foremen and superintendence.

Cost of Concrete-Lined Oil-Storage Reservoirs.—Bulletin 155 of the U. S. Bureau of Mines prepared by C. P. Bowie gives some detailed costs and specifications for constructing reservoirs of the above type. The following matter is taken from an abstract of this bulletin published in Engineering and Contracting, May 15, 1918.

The reservoirs are commonly circular in plan, and are constructed by making an excavation and building an earthen embankment with the excavated material. The area within the inner crest of the embankment is then covered with a wooden roof and the bottom and sides of the inclosed place lined with concrete.

The dimensions of a typical container are as follows: Inside diameter at top, 488 ft.; inside diameter at bottom, 437 ft. 6 ins.; maximum depth, approximately 25 ft. 11 ins. The slopes of the embankment are: Slope of embankment inside reservoir, 1 to 1; slope of embankment outside reservoir, 2 to 1; slope of embankment top of reservoir, 20 to 1. The width of the embankment on top is 15 ft. The roof is constructed of wood, covered with roofing paper.

The cost of such a reservoir would be 10 to 13 cts. per barrel of capacity, dependent on the situation and other governing conditions. On a basis of 11 cts., the cost would be distributed approximately as follows:

Cost of earthwork, cts	3.5
Cost of roof, cts	3.0
Cost of concrete lining, cts	4.5
Total, cts	11.0

An unlined earthen reservoir with the same type of roof construction would cost 7 to 9½ ct. a barrel, and it is estimated that a concrete lined reservoir with a concrete roof on concrete roof supports and covered with 2 ft. of earth would cost about 30 ct. a barrel.

The following figures for labor costs cover the construction of two 750,000-bbl. reinforced concrete lined reservoirs built at Bakersfield, Cal., during the winter and spring of 1913–14:

Earthwork:	
Excavating for embankment, per yd	$0.22
Lining inner slopes with selected material, per yd	.51
Finishing floor, per sq. ft	.005
Excavating for pier footings, trenches, etc., per yd	.70
Trimming slopes, per sq. ft	.012

Roof:	
Hauling lumber from cars (½ mile), per M	1.19
Framing lumber for roof, per M	1.60
Erecting roof, per M	3.80
Sawing sheathing, per M	1.35
Roofing:	
Laying roofing paper, per square	.12
Hauling roofing gravel from cars (½ mile), per ton	.25
Placing asphalt and gravel coating, per square	.32
Concrete lining:	
Hauling cement from cars (½ mile), per ton	.54
Hauling sand from creek bed (2 miles), per yard	.86
Hauling rock (½ mile from cars), per yd	.50
Laying reinforcing metal on slope, per square	.16
Laying reinforcing metal on floor, per square	.08
Pouring concrete piers, per yd	*4.63
Pouring concrete floor, per yd	*2.51
Pouring concrete slope, per yd	*3.46

* Including cost of rock, at $1.60 per ton. All material except sand and gravel was furnished by the owner at the Southern Pacific R. R. ½ mile distant from the work.

The figures given are based on the following conditions:

Situation of reservoir, ½ mile from railroad.
Formation of soil, light sandy clay.
Excavators used, wheel and "fresno" scrapers.
Hours worked a day, 9.
Wage paid laborers, $2.50 a day.
Wage paid carpenters, $3.50 a day.
Wage paid concrete laborers, $2.75 a day.
Wage paid concrete finishers, $4.50 a day.
Wage paid foremen, $6 a day.

Cost of Small Reinforced Concrete Reservoir.—C. A. Bingham in Engineering and Contracting, April 3, 1912, gives the following costs of constructing a small concrete reservoir at Mt. Holly, Pa. The reservoir was built in 1909 by the Cumberland Clay Co. to impound water for various processes in the refining of clay.

The reservoir is 73 ft. long and 53 ft. wide and 5 ft. inside depth, thus holding 140,000 gals. About 3 ft. of the wall is in cut, which was shale and tough clay; and the remainder is above the natural surface. The walls are 6 ft. total height, and 12 ins. thick at top and 18 ins. at bottom, with an inside heel 12 × 15 ins. Batter is all on the outside. On three sides a fill was made to within 18 ins. of top of wall, but on lower side this would have meant an excessive cost so buttresses were built every 10 ft.

The walls were heavily reinforced both horizontally and vertically with light rails and other steel on hand and at the corners heavy steel bent to right angles was placed on 12-in. centers, the arms running from 3 to 6 ft. into each side wall. Keyed expansion joints were used every 30 ft. The floor was constructed by a well puddled mixture of clay and gravel and given a surfacing of 4 ins. of concrete and cut in blocks.

A heavy wire fence was placed on top of the wall. The outlets to the mills are controlled by valves and the overflow is taken care of by a small spillway. After three years of service the reservoir is as good as the day completed; the only maintenance being an occasional cleaning of the clay sediment on the bottom. It doesn't leak at all and the walls haven't cracked.

The work was performed by the company forces under plans of the writer; and the sand and gravel was procured on the property. The cost data follow:

Excavation:	
1 foreman 7 days at $2	$ 14.00
7 laborers 7 days at $1.25 up	75.25
2 carts 5 days at $3	30.00
Total for 360 cu. yds	$119.25
Cost per cu. yd., excavation, 33 cts.	
Concreting:	
Form work: Carpenter and helper (old lumber used)	$ 22.75
Mixing and placing: Foreman 7 days and 7 laborers 7 days	75.25
Materials:	
186 bbls. cement at $1.35	249.75
192 cu. yds. gravel at $0.40	76.80
Reinforcing	16.00
Total for 144 cu. yds. concrete	$440.55
Cost per cu. yd., concrete, $3.06.	
Clay floor, fence, miscellaneous (not including pipes or valves)	84.40
Total cost	$644.20

The cost of the reservoir complete per 1,000 gals. was $4.60.

Cost of Reinforced Concrete Cisterns at Fort Moultrie, Charleston, S. C.— R. A. Boothe gives the following in Engineering and Contracting, Aug. 9, 1911.

This work consisted of three 30,000-gal. and four 8,000-gal. capacity reinforced concrete cisterns for the War Department at Fort Moultrie, Charleston, S. C.

The large cisterns were 24 ft. in diameter and 10 ft. high inside with a 10-in. drain and 10-in. inlet and overflow. They were built with a 12-in. base 28 ft. 4 ins. in diameter, reinforced in the center with No. 10 expanded metal with 6 × 3-in. mesh. The walls were 8 ins. thick and were reinforced with ⅜-in. twisted vertical rods spaced 12 ins. on centers and ½-in. twisted horizontal rods spaced 2.4 ins. for the first 2 ft.; 3 ins. for the next 1 ft.; 4 ins. for the next 2 ft.; and 6 ins. for the last 4 ft. The roof was a 10-in. slab, reinforced with ½-in. rods spaced 3½ ins. centers both ways.

The small cisterns were 13 ft. in diameter and 10 ft. high inside with an 8-in. drain and overflow and 6-in. inlet. They were built with a 12-in. base, reinforced the same as the large cisterns. The walls were 8 ins. thick with ⅜-in. twisted vertical rods, spaced 12 ins. on centers, and ½-in. horizontal rods, spaced 4 ins. centers for the first 3 ft. and 6 ins. centers for the remaining 7 ft. The roof was a 6-in. slab reinforced with ⅜-in. rods, spaced 4 ins. centers both ways.

Each cistern had an 18 × 24-in. trapdoor in the roof. All concrete was a 1:2:4 mix, using Pom-Pom gravel and ¾-in. crushed granite.

The segments for the wall forms were sawed at the mill out of 2 × 12 in. long leaf yellow pine. They were sawed to the exact outside diameter and the inner parts were trimmed on the job with sharp hatchets to fit the inside diameter. There were six segments in each circle for the small cisterns and twelve in each circle for the large ones. The circles were spaced 2 ft. centers and 1⅛ in. long leaf yellow pine was used for sheeting.

On the first cistern that was built, which was a small one, the walls and top were built together but it was found to be too hard to remove the forms through the small trapdoor, so for the others the forms were built in sections extending from the bottom to the top and one segment wide for the inside form. After the complete inside drum was built the vertical rods were placed and the horizontal rods bent around and fastened to them. Every sixth vertical rod was held in place by a block spacer. The horizontal rods were wired to the vertical rods at every other joint, the ties being staggered.

The outside forms were then placed. These were 2 ft. high and one segment wide and were made so that the next section fitted into the one below. As soon as one section was filled with concrete the next was placed, three carpenters being able to keep up with the concrete gang. All of the segments were fastened together at the joints with cleats and were found to be so rigid that no braces were necessary.

After the walls had set the cleats were knocked off and the sections removed. On the inside one of the joints was left wide as it was found to be necessary to cut out one board before the forms could be removed. The sections were then slid out over the top and 2 × 4-in. uprights were placed on the inside, these carried the 2 × 6-in. cross pieces on which the floor for the top was laid. The cross pieces were spaced 2 ft. centers and the uprights 4 ft. centers while the sheeting was the same as that used for the walls. The top was then concreted and after it had set about six days the forms were removed and passed out through the trapdoor.

All of the concrete was mixed by negroes on boards as the cisterns were too far apart for a central mixing plant and each one was too small to pay for the setting up of a mixer.

The laborers were paid 15 cts. per hour and worked 8 hours. The carpenters were also negroes and received 20 cts. per hour with the exception of the head carpenter who was a white man and received 30 cts. per hour. There were no foremen as the superintendent looked after everything with the assistance of a young man who kept the time and account of supplies and occasionally acted as gang foreman on excavation.

The usual routine was to mix and place the base for a small cistern, then while the carpenters were erecting the wall forms, mix and place the base for a large cistern, then come back and fill the forms on the small one while the carpenters were building forms on the large one.

In placing the walls and top of the small cisterns the concrete was mixed on the ground and passed up in buckets by hand as the nature of the surroundings did not allow the use of runways, but in building the large one runways were built and the concrete wheeled into place. Although passing the concrete up in buckets was slow it was not a great deal more expensive than wheeling. The cost of large cistern was as follows:

Concreting

		Per cu. yd.
Base:		
22 laborers 8 hrs. at 15 cts.	$26.40	$1.10
Superintendent	5.00	0.12½
Total	$31.40	$1.12½
Walls:		
15 laborers 9 hrs. at 15 cts.	$23.15	$1.21
Superintendent	5.00	.25
Total	$28.15	$1.46
Roof:		
19 laborers 7 hrs. at 15 cts.	$20.70	$1.38
Superintendent	25.00	.33½
Total	$25.70	$1.71½

BUILDING FORMS FOR WALLS

1 carpenter 62 hrs. at 30 cts	$18.60
2 carpenters 62 hrs. at 20 cts	24.80
2 laborers 39 hrs. at 15 cts	11.70
	$55.10

This gives a cost of $.04 per sq. ft. Removing same $4.00, or $.009 per sq. ft.

BUILDING FORMS FOR ROOFS

1 carpenter 18 hrs. at 30 cts	$ 5.40
2 carpenters 18 hrs. at 20 cts	7.20
2 laborers 18 hrs. at 15 cts	5.40
	$18.00

This gives a cost of $.0355 per sq. ft. Removing the forms cost $7.75 or $.005 per sq. ft.

PLACING STEEL

		Per ft.	Per lb.
Walls:			
8 laborers 8 hrs. at 15 cts	$ 9.60	$0.0029	$0.0038
Superintendent	8.00	0.0005	0.0007
Total	$11.60	$0.0034	$0.0045
Roof:			
11 laborers 1 hr	$1.65	....	$0.001

The cost of two small cisterns was as follows:

	Base	Walls	Roof
Concrete, per cu. yd	$1.29	$1.51	$1.80
Steel, per lb	.....	0.005	0.001
Forms, per sq. ft	.....	0.037	0.04
Removing same	.....	0.005	0.01

The costs are higher than they should be on this class of work. This was caused by the inexperienced labor and because the work was scattered. Also by the engineer insisting on a number of minor details that were unnecessary but caused additional work.

Cost of Underground Concrete Cisterns.—Cisterns of 75,000 gal. capacity were constructed in San Francisco as auxiliary water supply for fire protection. There were 85 new cisterns, built beneath the surface at street crossings their exact position indicated by a distinctive type of pavement over them. A. J. Cleary gives the detailed costs of a typical cistern in Engineering Record, July 26, 1913.

The cisterns were constructed by contract, but very accurate cost data were kept by the city's bureau of engineering. Following is a typical cost account for constructing the cistern shown in Fig. 8.

DETAIL COSTS OF CONCRETE CISTERN

GENERAL EXPENSE

Labor Cost:	
Superintendent, 219½ hours at 87½ cents	$192.06
Timekeeper, 142½ hours at 31¼ cents; 5 hours at 50 cents	47.03
Watchman, 652 hours at 31¼ cents	203.75
Total	$442.84
Material Cost:	
Telephone	$ 28.50
Office rent and horse	21.00
10 gal. coal oil at 20 cents	2.00
Total	$ 51.50

Removing Pavement

Labor Cost:	
Foreman, 15 hours at 43¾ cents	$ 6.56
Laborers, 220 hours at 25 cents	55.00
Team, 8 hours at 75 cents	6.00
Total	$67.56

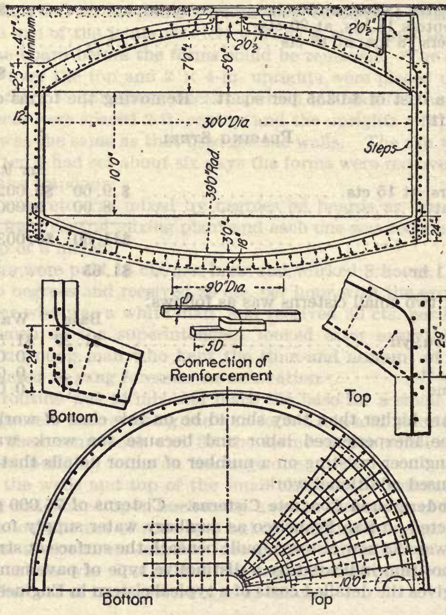


Fig. 8.—Typical reinforced-concrete cistern.

Excavation

Labor Cost:	
Foreman, 169½ hours at 43¾ cents	$ 74.15
Foreman, 46½ hours at 50 cents	23.25
Laborers, 1981 hours at 25 cents	495.25
Team, 317½ hours at 75 cents	238.12
Total	$830.77
Material Cost:	
Motor rent	$ 10.00
Electric power	10.00
Depreciation on equipment	50.00
Total	$ 70.00

Lagging

Labor Cost:	
Foreman, 148 hours at 50 cents	$ 74.00
Foreman, 55 hours at 43¾ cents	24.06
Laborers, 754½ hours at 25 cents	188.62
Laborers, 893¾ hours at 31¼ cents	279.29
Electrician, 77½ hours at 37½ cents	29.06
Total	$595.03
Material Cost:	
4410 ft., 2 × 8 R. P., at 15 cents	$ 66.15
1 keg nails	3.00
Total	$ 69.15

Pumping

Labor Cost:	
Foreman, 11 hours at 50 cents	$ 5. 0
Foreman, 29 hours at 43¾ cents	12.69
Electrician, 88½ hours at 37½ cents	33.19
Laborers, 240 hours at 31¼ cents	75.00
Laborers, 83½ hours at 25 cents	20.87
Total	$147.25
Material Cost:	
7½-hp. motor, 4-in. pump, 105-ft. R. P., at $15 per M	$ 1.60
100-ft. T. & G., at $20 per M	2.00
Motor rent	30.00
Electric power	49.00
Installation fee	10.00
Total	$ 92.60

Bottom Reinforcing Steel

Material Cost:	
Housesmiths, 160 hours at 62½ cents	$100.00
Labor Cost:	
2038 lb. ⅝-in. steel at $0.021	$ 42.80
4566 lb. 1-in. steel at $0.021	95.89
Ties and spreaders	8.00
Total	$146.69

Side Reinforcing Steel

Labor Cost:	
Housesmiths, 72 hours at 62½ cents	$ 45.00
Material Cost:	
1584 lb. ⅝-in. steel at $0.021	$ 33.26
2529 lb. ¾-in. steel at $0.021	53.11
Total	$ 86.37

Dome Reinforcing Steel

Labor Cost:	
Housesmiths, 84 hours at 62½ cents	$ 52.50
Laborer, 8 hours at 31¼ cents	2.50
Total	$ 55.00
Material Cost:	
1623 lb. ¾-in. steel at $0.021	$ 34.09
1829 lb. ⅝-in. steel at $0.021	38.40
3553 lb. 1-in. steel at $0.021	74.61
Ties and spreaders	8.00
Total	$155.10

Bottom Concrete

Labor Cost:	
Concrete foreman, 8 hours at 75 cents	$ 6.00
Concrete laborers, 102 hours at 50 cents	51.00
Foreman, 8 hours at 50 cents	4.00
Laborers, 160 hours at 31¼ cents	50.00
Teams, 8 hours at 75 cents	6.00
Total	$117.00
Material Cost:	
43 yd. rock at $1.40	$ 60.20
54 yd. sand at $1.50	8.10
60¾ bbl. cement at $2.45	148.84
360 lb. Medusa at 14½ cents	52.20
Depreciation on equipment	5.00
Total	$274.34

Side Concrete

Labor Cost:	
Foreman, 18 hours at 50 cents	$ 9.00
Carpenters, 3 hours at 50 cents	1.50
Laborers, 184 hours at 31¼ cents	57.50
Teams, 8 hours at 75 cents	6.00
Total	$ 74.00
Material Cost:	
216 sacks cement at 50 cents	$108.00
300 ft. Medusa at 14½ cents	43.50
33 yd. rock at $1.40	46.20
4½ yd. ocean sand at $1.50	6.38
5 yd. city sand at 50 cents	2.25
Total	$206.33

Dome Concrete

Labor Cost:	
Foreman, 7 hours at 50 cents	$ 3.50
Laborer, 92 hours at 31¼ cents	28.75
Concrete foreman, 8 hours at 75 cents	6.00
Concrete laborers, 94 hours at 50 cents	47.07
Engineer, 9 hours at 37½ cents	3.30
Team, 14 hours at 75 cents	10.52
Total	$ 99.10
Material Cost:	
2 M. H. covers and intake pipe	$ 25.00
270 sacks cement at 60 cents	162.00
6 yd. ocean sand at $1.50	9.00
20 yd. city sand at 50 cents	10.00
50 yd. rock sand at $1.40	70.00
Total	$276.00

Summary of Concrete Cistern Cost

	Labor	Material	Labor and material
General expense	$ 442.84	$ 51.50	$ 494.34
Removing pavement, basalt blocks on 6-in. base	67.56	....	67.56
Excavation (sand)	830.77	70.00	900.77
Lagging (2 × 8 in.)	595.03	69.15	664.18
Pumping	147.25	92.60	239.85
Reinforcing steel	200.00	388.16	588.16
Concrete	317.24	779.62	1096.86
Forms	187.33	59.55	246.88
Backfill (sand)	47.06	....	47.06
Pavement and curb	102.93	75.50	178.43
Catch basin	16.87	14.40	31.27
Sidewalk	5.00	51.10	56.10
Total	$2959.88	$1651.58	$4611.46

UNIT COSTS

Removing pavement	800 sq. ft.	$ 0.084 per sq. ft.
Excavation sand	690 cu. yds.	1.305 per cu. yd.
Lagging (2 × 8 in.)	4,410 ft. b. m.	150.61 per M.
Reinforcing steel	9.79 tons	60.08 per ton
Concrete	146 cu. yd.	7.513 per cu. yd.

Hours of Labor Required on Concrete Cisterns.—The following miscellaneous costs on the construction of the foregoing reinforced concrete cisterns are taken from an article in Engineering and Contracting, March 30, 1910, by Benjamin Brooks who was employed by the city of San Francisco to inspect the work and keep cost data on the erection of the cisterns.

The mixture was 1 of cement to 5 of broken stone, with enough sand to fill the voids, which meant a 1:2½:5 or a 1:3:5 mixture, according to the run of materials and judgment of the engineers. Six pounds of some approved water-proof compound was to be mixed dry with each barrel of cement used in the sides and bottom (but not in the domes), and this necessitated at least one extra man to mix it with a hoe, measure it into boxes and pass it to the man on the mixer platform. On completion of the concrete the bottom received a regular sidewalk finish, and the sides and top a brush over with grout.

Cost of Forms.—Cistern A forms cost as follows:

Man hrs. making per M lumber, 12.4; per sq. ft. surface, .03.
Man hrs. setting per M lumber, 47.4; per sq. ft. surface, .24.
Which at $.62½ per hour is equivalent to:
Making $7.75 per M, or $.02 per sq. ft. surface.
Setting, 29.62 per M, or $.15 per sq. ft. surface.

On cistern B, forms already made for another cistern were used and cost for placing and removing as follows:

	Per sq. ft.
Man hrs. at $.62½ placing 17.25 per M	.069
Man hrs. at $.28 placing 12.25 per M	.049
Man hrs. at $.28 removing 12.75 per. M	.014

which is equal to:

Placing forms	$14.21 per M or $.057 per sq. ft.
Removing forms	3.57 per M or .014 per sq. ft.
Total	$17.78 per M or $.071 per sq ft.

For cistern C, wall forms were already made for another cistern and required only a little patching.

Patching and placing required 44 man hours at 25 cts. plus 73 man hours at 62½ cts., which equals 4½ cts. per sq. ft., including the placing of chutes.

Removing forms and clearing cistern required 61 man hours at 25 cts. and 21 man hours at 62½ cts., which equals 2.8 cts. per sq. ft.

For cistern D, wall forms were already made and required for—

Placing (125 man hrs. at 62½c, 20 man hrs. at 25c) equals $22.46 per M, or 11⁷⁄₁₀c per sq. ft.
Removing (12 man hrs. at 62½c, 37 man hrs. at 25c) equals 1½c per sq. ft.

Cost of Reinforcing Bars per Ton, Cistern A.—To bend and place 1 in., ¾ in. and ⅝ in. twisted square bars required 38 man hours per ton, which at 62½ cts. = $23.75.

Cistern B.—Bending and placing 1 in., ¾ in. and ⅝ in. bars required 52 man hours per ton at 62½ cts. = $32.50 per ton.

Cistern C.—Reinforcing bars required 41⅓ man hours per ton to bend and place, which at 62½ cts. = $25.83.

Cost of Concrete, Cistern A.—Concrete was mixed about 1:2½:5 in a Chicago Improved cube mixer, turning out about 7 cu. yds. per hour with a trained crew, and was wheeled and dumped in concrete "buggies." For the bottom of the cistern the man hours per yard required were:

Chutes and runways	....
Measuring and wheeling materials	0.96
Mixing	.13
Wheeling and chuting concrete	.41
Placing and tamping	.27
Total	1.77

which at 50 cts. per hour = 88½ cts. per cu. yd.

Pumping during excavation, lagging, concreting, etc., cost as follows: 162 man hours (exclusive of night watchman), 0.27 man hours per yard of excavation at 28 cts. = 7½ cts. per cu. yd.

Cistern B.—Concrete handled by same outfit and crew as for Cistern A cost as follows:

For the bottom:	Man hrs per yd.
Wheeling and measuring materials	1.16
Mixing materials	.17
Wheeling and chuting concrete	.45
Placing and tamping concrete	.35
Total counting delays*	2.13
Total actual running	1.80

which at $.50 = $1.06 or $.90 per yd., not counting superintendence.

* Ran out of materials.

For the walls:	Man hrs. per yd.
Wheeling and measuring materials	.82
Mixing concrete	.13
Wheeling and chuting concrete	.37
Placing and tamping	.37
Total	1.66

Which at $.50 per man hour equals $.95 per yd. exclusive of superintendence.

Cistern C.—Concrete for the bottom and sides was mixed in a Smith mixer 2 cu. ft. of cement to the batch and run directly from mixer through portable chutes to the bottom, but wheeled in buggies to the side walls. The crew was untrained and poorly managed. The cost was as follows:

	Man hrs. per cu. yd.
Wheeling and measuring materials	1.55
Mixing materials	.30
Wheeling and chuting concrete	.42
Placing concrete	.60
Installing mixer	.74
Total	3.61

Which at 28c equals $1.01, including foreman.

Plastering bottom required 24.6 man hours at 75 cts., which gave a cost of 2⁶⁄₁₀ cts. per sq. ft.

Brushing the sides required 11 man hours at 25 cts. which gave a cost of ³⁄₁₀ cts. per sq. ft.

Cistern D.—Concrete for the bottom was handled as in Cistern C except that on account of a breakdown 44 cu. yds. were machine mixed and 8 cu. yds. were hand mixed, first the cement and sand dry and wet, then the grout and the rock being turned three times. For the machine mixing the costs were:

	Per cu. yd.
Wheeling and measuring materials, 1.50 man hrs. at 28c	$0.420
Mixing materials, .32 man hrs. at 28c	.089
Chuting and placing concrete, .74 man hrs. at 28c	.207
Building chutes, .55 man hrs. at 62½c	.344
Setting mixer, .34 man hrs. at 45c	.153
Total	$1.213

For the hand mixing the costs were:

	Per cu. yd.
Wheeling and measuring materials, 1.50 man hrs. at 28c	$0.42
Mixing materials, 5.12 man hrs. at 28c	1.43
Placing concrete, 1.25 man hrs. at 28c	.35
Building chutes, 1.38 man hrs. at 45c	.62
Total	$2.82

Concrete for the walls cost as follows:

	Man hrs. per yd.
Wheeling and measuring materials	1.97
Mixing materials	.26
Wheeling and chuting concrete	.65
Placing concrete	.62
Setting mixer	.49
Total	4.00

This gives 4 hrs. × 28 cts. = $1.12 per cu. yd.

Concrete for the dome cost as follows:

	Man hrs. per yd.
Wheeling and measuring materials	1.02
Mixing materials	.23
Wheeling concrete	.47
Placing concrete	.32
Setting mixer*	1.02
Total	3.059

* This item seems very high, but often included carting the mixer back and forth from one cistern to another. It could have been reduced by better management.

This gives 3,069 × 28 cts. = 80.85½ cts. per cu. yd.

Finishing the floor with ½ in. of sidewalk finish required 21 man hours at 75 cts. and 8 man hours at 25 cts. = $17.75, or 2½ cts. per sq. ft.

In the above data, costs of getting materials on the jobs are not considered nor is superintendence except in cases where it is specially mentioned.

Cost of Concrete Reservoirs at Brockton, Mass.—Two 4,000,000 gal. reservoirs were constructed in 1911. Charles R. Felton, in the Water Commissioners Annual Report gave the essential features of the design with some notes on their construction and cost. The following is taken from an abstract of Mr. Felton's report published in Engineering and Contracting, Sept. ?, 1912.

Design.—The reservoirs are of concrete, reinforced with plain round bars, except for a few twisted bars where the sides and bottom join. The concrete is of very rich mixture, to render it impermeable, the bottom courses being 1 cement, 1 sand, and 2 stone, to a height of 10 ft., with a 1:1½:3 mixture above this point; both mixtures containing hydrated lime in the proportion of 5 per cent of the cement by weight. The walls are 30 ins. thick at the bottom and 15 ins. at the coping course, which is 19 inches square.

The floor layer consists of two courses of concrete, 6 ins. thick; the lower one of 1:2:4 concrete, and the upper one of 1:1½:3 concrete, reinforced with ½-in. bars 1 ft. apart in both directions. The horizontal reinforcement consists of plain round bars from 1¼ ins. in diameter at the bottom to ⅝ in. in the coping.

The maximum strain upon the metal, considering the stresses as applied to a cylinder 160 ft. in diameter, are 13,000 lbs. per sq. in., with the reservoir overflowing, or 12,000 lbs. at the proposed high water mark, 18 ins. below the top.

Vertical, square twisted rods, ⅞ in. in diameter and 1 ft. apart were introduced into the foundation and also bent into the floor. These rods were extended to the top of the reservoir, but spaced 2 ft. apart after the first three courses. The bottom was also connected with the foundation by ⅞-in. twisted rods.

Sand and gravel were obtained from a large hill three miles distant from the location, and were very expensive, both on account of the length of haul and the large amount of material handled to get stone, about ⅛ of the total being stone of the required size, viz.: That which would pass a 1⅛-in. screen. The screen was of the revolving type, run by a gasoline engine, and under ordinary conditions would pass about 175 cu. yds. of material in eight hours. The resulting product was excellently graded.

The greatest care was taken to make the concrete impermeable, an entire course being run when once started. These courses were 30 ins. in height, except the bottom one, which was 36 ins. and contained about 110 cu. yds. No departure from this plan was found necessary, the concrete being placed continuously in courses 6 ins. thick, from three and one-half to six hours being consumed on a 30-in. course. After the concrete had partially set, usually in about 7 hours, it was thoroughly scraped with wire brushes and kept wet until the next course was ready, usually covered with wet bagging and carefully swept just before placing.

A steel dam, 4 ins. by ⅜ in., was imbedded 2 ins. deep in the top of each course, and about 1 ft. from the inside of the reservoir. This dam was lapped and bolted with five ¾-in. bolts, and figured in the design for its full tensile value as metal. In addition to the dam a triangular groove about 1.5 in. deep was placed in the top of each course. Before beginning a new course the joint was washed with neat cement grout.

No waterproofing or brushing of the surface was required or allowed, and less than a quart of cement was required to remedy any defects of appearance.

Construction Plant.—The plant consisted of an elevated tank of 5,000 gals. capacity, into which water was pumped by gasoline engine a distance of about 1,300 ft. Two Smith concrete mixers, set at an elevation corresponding substantially in level to the top of the reservoirs and operated by 15-h.p. electric motors. The mixers were fitted with side charging apparatus, and the material elevated to the mixers.

The concrete was placed, usually, at the rate of from 24 to 30 cu. yds. per hour with ordinary wheelbarrows, the greatest care being taken to have the material thoroughly tamped.

Cost.—The labor was all paid at the city rate of $2.50 per day of eight hours; carpenters $4.80 per day; foreman $5.00 per day; masons $0.72 per hour; teams $5.50 per day of eight hours. One of the greatest obstacles in accomplishing work of this character economically is the difficulty of employing all the labor to advantage between pourings, especially when it is necessary to conform to the present drastic eight-hour laws.

The total cost of the reservoirs exclusive of the engineering was almost exactly $80,000, or about one cent per gallon. The cost of the engineering and inspection, not including Mr. Felton's time, was about $2,200.

Labor Costs of Reinforced Concrete Tanks for Storage of Storm Water.—W. G. Cameron, in Engineering and Contracting, Jan. 26, 1916, gives the unit-time data for constructing the temporary storage tanks at Toronto, Ont., shown in Fig. 9.

Design.—The tanks are rectangular in shape, and approximately 104 ft. × 112 ft. On the north side, there is a channel 3.5 ft. deep for the Bloor west sewer, separated from the tanks by a weir. On the east side, there is a section 4 ft. deep, separated from the tanks by a weir, and from the storm water outlet by another weir. Into the north end of this section the storm water from the Keele St. sewer flows. The bottom of this section is graded back towards the north end and a gate valve is provided which can be opened to allow the section to drain into the storm water outlet. The tanks proper are divided into three parts, 17½ ft. deep, by two weirs. These three divisions are graded towards the east side, where they drain into an open 18-in. sludge channel, which runs south along the inner side of the east wall and into the 18-in. tile sewer under the storm water outlet. A gate valve is provided at the end of the sludge channel at the south wall.

Eight rows of columns were used in the tanks for the support of the roof. These columns were 18 in. square in section, 12 ft. apart center to center in the rows and 12-ft. centers between the rows. Two rows of columns were in each tank, and one was used as support for each of the two dividing weirs. The tanks were built of all reinforced 1:2:4 concrete. The walls were 12 ins. wide at the top, while the sides had a batter 1 in 7.6. The width at the bottom varied as the height. There was a footing provided 2 ft. deep and 12 ft. 6 in. wide. The reinforcing for the walls was 1-in. square twisted rods on the outside and 0.30 sq. in. mesh on the inside. The columns were reinforced with 1⅛ sq. in. twisted rods, 2 ft. 6 in. long, as dowels into the footing, one 1⅛ sq. in. rod in each corner, the full height of the column, and ⅜ in. round hoops, spaced vertically 12 in. apart. The roof slab was 6 in. thick, reinforced with 0.5 sq. in. mesh.

The girders and beams for the support of the roof slab were 24 in. × 16 in. and 21 in. × 16 in, respectively. They were reinforced with 1 sq. in. twisted rods and ¾ in. square twisted rods, respectively. The weir walls between the tanks were 8½ ft. high, 9 in. wide at the top, and 18 in. wide at the bottom, reinforced with ¾ sq. in. bars.

Construction.—The ground on which the tanks were built was composed of sand on the surface, which, in small areas, formed pockets. The subsoil was hard, blue clay. Trenches were excavated by hand for the west wall and the western third of the north wall. This part was built first because the ground was low at this side. When these walls were built, and the concrete sufficiently hardened, they were used as a retaining wall for the next material excavated. This material was taken from inside the lines of the future tanks and next the west wall. Enough material was taken out to allow for the erection of a portion of the tanks on the west side. This portion was com-

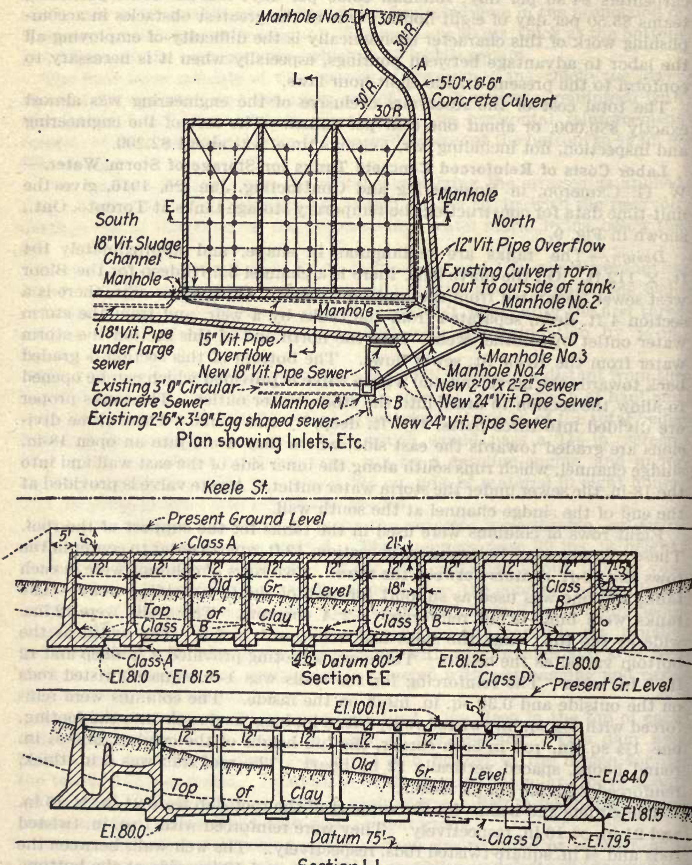


FIG. 9.—Plan and principal sections of reinforced concrete tanks for the temporary storage of storm water, Toronto, Ont.

pleted floor, columns, weirs and roof and allowed to harden. The next material excavated was then deposited on the roof of this finished portion. Thus the excavation and construction proceeded alternately from the west. A clam shell was used for excavating in the body of the tanks, but the clay was so hard that the most of it had to be loosened with picks before it could be gathered up by the clam.

The concrete was all mixed by a drum mixer very conveniently placed at the top of the bank on Keele St. The concrete was dumped into a chute which carried it down the bank to a funnel-shaped box. This box was provided with a slot which slid up and down so that concrete could be taken away in any quantity desired. The concrete was carried in concrete barrows along runways so built that they might easily be taken down and erected quickly again wherever they were required. The forms used for the concrete were all of the panel type. They were built near the work and the same sections used several times. They were made before the work was begun and grouped according to size, so that when they were needed they could easily be found and quickly erected. They were fastened together with bolts.

When the work on the tanks was completed the soil which had been excavated, and soil brought from other work, was spread over the top of the tanks to a depth of 4 ft. The bank on Keele St. was extended and neatly graded, and an easy slope was made from Bloor St. The ground over the tanks and the slopes will probably be sodded and planted, and possibly tennis courts, etc., arranged on it, making in all a very great improvement to this corner of High Park.

Unit Time Data.—The time-costs, in hours' labor on this work, as kept by S. K. Ireland, resident engineer, are as follows:

Excavation.—7,000 cu. yd., 10,472 hours, or 1.496 hours per cubic yard.

Placing Steel.—102 tons, 1,471 hours, or 14.4 hours per ton (85 tons of this were bars and 17 tons mesh).

Building and Erecting Forms.—52,899 sq. ft. took 8,452 hours, or 0.159 hours per square foot.

Removing Forms.—0.0202 hours per square foot.

Mixing and Placing Concrete.—2,522 cu. yds. took 6,394 hours, or 2.53 hours per square yard.

Foreman, 1,658 hours; engineer, 1,098 hours; fireman, 1,133 hours; team, 107 hours; single horse, 451 hours.

Cost of Lining a Reservoir with Gunite.—E. Court Eaton gives the cost of lining a small "balancing reservoir" in Engineering News-Record, July 24, 1919.

The reservoir with a depth of about 9 ft. covered about two acres and was used to store a surplus of water during part of the day and supply the shortage during the balance. Due to the fact that the reservoir was necessarily confined to a certain area close to an old stream bed and the reservoir was excavated in a gravel deposit the seepage amounted to two to three acre-feet per day.

It was decided to line this reservoir with a gunite lining. The total area to be lined was 114,000 sq. ft., and specifications called for a gunite lining 1 in. in thickness, with a mix of one part of cement to 5½ parts of sand; no lime was used in the mixture. The lining was reinforced with galvanized poultry netting, 1½-in. mesh, No. 19-gage wire, placed in the center of the concrete to confine cracks due to expansion to hair cracks, and no expansion joints were used.

This work was let by contract at a price of 10½c. per square foot, including the trimming and preparation of the banks. Work was commenced Jan. 14, 1919, and completed Mar. 19. Because the work had to be done during the winter months the actual number of working days in this time was only 39.

The cement gun used was what is known as the N2 size. It was kept on the upper bank of the canal at a maximum distance of 600 ft. from the compressor, to which it was connected with a 2-in. iron pipe. The compressor was of the portable type, direct-connected to a semi-Diesel type of engine; it was 12 × 12 in. and ran at a speed of 300 r.p.m. A pressure of 42 lb. per square inch was maintained at the compressor, giving about 32 lb. at the gun. A 2-in. rubber hose 200 ft. in length was used from the gun to the nozzle, and the rubber tips in these nozzles lasted nearly one week before requiring replacement. The depreciation on the hose for the period of the job was $200.

In lining the 114,000 sq. ft., 2904 sacks of cement were used, or nearly 39 sq. ft. of lining per sack of cement. The average rate of progress throughout the work was 2900 sq. ft. per working day. The maximum day's run was about 5000 sq. ft., though better average progress would have been made in the dry season, as the principal delays were due to wet sand clogging in the hose and necessitating frequent cleaning out of the machine. A certain amount of moisture is necessary in the sand for this class of work, and the best results were obtained when sufficient water was present so that the sand just failed to hold its shape when squeezed in the hand.

The total quantity of sand used on the work was 600 tons, and the total cost of sand per ton was as follows:

	Per ton
Loading charge at sand pit	$0.30
Freight	.60
Unloading	.12
Hauling to site	1.50
Total	$2.52

The hauling over the wet roads a distance of two miles was the biggest item. The weight of a cubic yard of sand, which was wet, was 2500 pounds.

The cement was $3.45 per barrel delivered at the site, after an allowance of $1 per barrel was made for sacks. The poultry netting delivered at the site cost $1.17 per 100 square feet.

The construction crew employed was as follows:

	Per day
1 Compressor engineer	$ 7.00
1 Nozzleman	5.00
1 Man placing wire	5.00
2 Mixers at $4	8.00
1 Man loadaing gun	4.00
1 Nozzlemn helper	4.00
1 Gun operator	4.00
1 Man cleaning off rebound	4.00
Total payroll	$41.00

One man was kept continuously close to the nozzleman, his duties being to brush back the rebound at the junction of new and old work and to raise the reinforcement by means of a hook to insure its being placed in the center of the lining.

The fuel used consisted of a fuel oil having a gravity of 27 +. Ten drums of this oil of 104-gal. capacity per drum were used. The cost of the oil was $6.55 per drum, delivered to site. The loss by rebound in percentage of the sand used was 8½; this was not wasted, however, as it was collected, screened and used over again with good results, except that only 30 sq. ft. of lining per sack of cement, or 23% less than with new sand, could be gotten when rebound was used, due to the material being coarse and requiring more cement to fill the voids.

Particular attention was paid to the curing, by sprinkling, of the newly completed lining for a period of two days, and up to this time no cracks other than fine hair cracks have developed.

Costs of Grouting Dam Foundations.—Engineering and Contracting, Aug. 19, 1914, publishes the following comparison of the costs of grouting the foundations of the Estacada and Lahontan Dams given by S. H. Rippey in Proc. Am. Soc. of C. E. Vol. XL.

TABLE XI.—COST OF DRILLING AND GROUTING AT ESTACADA AND LAHONTAN DAMS, PER LINEAR FOOT OF COMPLETED WORK

	—Estacada Dam—		Lahontan Dam
Labor and materials	Fisher	Rands	Cole
Labor, drilling	$0.58	$0.59	$0.93
Labor, grouting	0.18	0.18	0.29
Cement	0.12	0.12	0.31
Repairs and supplies	0.17	0.17	0.23
Plant	0.30	.....	.....
Plant depreciation	.....	0.15	0.35
Power	0.05	.....	0.03
Other items	.....	.....	0.94
	$1.40	.....	.....
Salvage on plant, credit	0.17	.....	.....
Direct cost	$1.23	$1.21	.....
Total field cost	.....	.....	$3.08
General plant, etc	0.32	0.45	0.12
Coffers and pumping	.....	0.15	.....
Engineering and superintendence	.....	0.19	0.27
Clerical and office	.....	.....	0.10
Total cost per foot	$1.55	$2.00	$3.57

In regard to the grouting of the Lahontan Dam, D. W. Cole in Engineering News, April 3, 1913, states that:

Drills were worked continuously in 8-hr. shifts, thus employing six crews of two men each for operating the drills, with one daylight crew of two to four men for grouting and testing.

Drillrunners were selected mainly from the men of good mechanical bent available on the job, with one or two importations of experts who had been previously trained. Runners were paid 40c., and helpers 30c. per hr.

Daily bulletins were posted showing output of the several crews and thus a wholesome rivalry was developed.

The maximum depth drilled by one machine in 8 hr. was 19 ft., in rather soft material. The average 8-hr. penetration of a drill was only 6 ft. Omitting the earlier period of work, which was largely experimental, the average performance of each 8-hr. shift was about 7 ft. of hole.

Air pressure of 25 lb. was employed for first batches, as higher pressures sometimes resulted in appearance of air bubbles and even cement color rising from the bed of the river at some distance from the boring; and violent displacement of the formation was not desired.

As the grouting advanced the later batches were driven in at a higher pressure, gradually increasing to 100 lb. per sq. in. at the finish of each hole.

In some of the tighter holes the extreme pressure was required for an hour or more to drive home the grout, but ordinarily the flow of grout was nearly continuous and as fast as the alternating process with the double-cylinder machine could be performed.

Costs of Groined Arch Roof for Minneapolis Reservoir.—W. N. Jones in Engineering Record, April 19, 1913, gives the methods and construction costs of covering with groined arch vaulting the clear water basin of the Minneapolis filter plant. The reservoir is 877.5 ft. long, 413.5 ft. wide and from 21 to 23 ft. deep. Very careful detailed costs were recorded with a view of securing not only the cost of the work but also an index of the efficiency of the labor employed. The following is taken from Mr. Jones article.

Equipment.—The quantity of equipment used has been very small and of the simplest type. No complicated machinery of any kind was employed on the work, and when the site was visited by a prominent engineer of Chicago, he said, "The thing that appeals to me most is the lack of elaborate equipment, such as expensive towers, cable-ways, etc." In fact, about all the machinery used outside of hand tools and a small woodworking shop for use in turning out forms, was a 1¼-cu. yd. concrete mixer, six 1¼-cu. yd. side-dump cars, about 1500 ft. of 24-in. gage track, and a traveling crane designed by the writer for the special use of handling groined arch forms. This crane cost about $500 complete.

For hauling earth, etc., common dump wagons of 1¼-cu. yd. capacity were used. All earth was handled by hand, both in loading and spreading. These wagons were not claimed to be conducive to economy, nor was the handling of the earth by hand, but the prime consideration was the employment of as many citizens and teams as it was possible to employ and still do the work at a reasonable cost.

Construction.—The groined arch concrete vaulting over the reservoir was supported by concrete pedestals and piers spaced 18-ft. centers. Over the roof a 2-ft. covering of earth was deposited. The pedestals were 6.5 ft. square at the base, 3.5 ft. high and each contained 2.85 cu. yd. The pedestal forms cost about $6 each for labor and material and each was used ten times on the average.

The rates paid for labor employed on the work were as follows:

Occupation	Time, days	Rate
Foremen	.....	$4 & $5
Assistant foremen	22⅛	3.00
Timekeepers	3	4.50
Steam engineers	9⅝	4.00
Watchmen	2⅞	2.25
Handy men	190⅝	2.40
Carpenters	24⅜	3.00
Millwrights	3⅜	3.00
Blacksmiths	2⅛	3.00
Concrete men	9⅛	3.25
Water boys	7⅝	1.25
Teams	56⅞	4.72
Single horses	6+	3.00
Laborers	738⅛	2.25

Table XII gives the cost in detail of all the most important items entering into the construction of the groined arch covering of the clear water basin during the season of 1911. The figures for 1910 are omitted, as it was found upon investigation that a number of reports had been lost. Items which were peculiar to this piece of work or were too small to classify are omitted also, as they are of no great consequence in the total cost or desirable for comparisons with similar work elsewhere.

TABLE XII.—CLASSIFIED UNIT COSTS FOR COVERING CLEAR WATER BASIN

Type of work	Quantity	Unit cost	Total cost
Concrete	11,475 cu. yd.	$0.967	$11,080.82
Making groined arch forms	39,595 sq. ft.	0.057	2,243.45
Setting groin forms and braces	348,954 sq. ft.	0.020	6,867.01
Dropping forms	330,541 sq. ft.	0.017	5,761.13
Transporting forms to derrick	298,344 sq. ft.	0.005	1,590.89
Hauling forms from yard	83,841 sq. ft.	0.008	658.34
Building column forms	7,120 sq. ft.	0.017	121.75
Setting and wrecking column forms	102,566 sq. ft.	0.056	5,690.85
Setting and wrecking 4 × 6-in. posts	3,382 units	0.485	1,639.55
Setting and wrecking column supports	810 units	0.747	605.85
Making manhole forms	350 sq. ft.	0.163	57.03
Tearing up forms	492 ft. b.m.	0.602	295.00
Oiling, repairing and notching forms	23,210 sq. ft.	0.034	704.67
Cutting stringers	861 units	0.053	45.60
Earth cover (1,000 to 2,000 ft. haul)	37,024 cu. yd.	0.478	17,714.30
Pointing up rough arches	....	......	176.90

The estimated cost of the work complete was $135,000. While the actual construction cost, including materials, was within $2000 of this amount, the actual costs cannot be exactly determined on account of lumber, etc., being used on the filter plant proper, and no credit being given the clear water basin for it, and also on account of the joint use of machinery, etc.

Cost of Wooden Form Work for Groined Arch Reservoir and Conduits, Pittsburgh Filtration Works.—The following data are from a paper by J. D. Stevenson read before the Society of Western Engineers, published in the Oct., 1910, Proceedings, and reprinted in Engineering and Contracting, Dec. 14, 1910.

Description of Piers.—Fig. 10 shows the form work for a 21.5 ft. circular pier 27 ins. in diameter, being one of 720 piers supporting the roof of the reservoir. The sketch is fully dimensioned. The forms are in three sections each 7 ft. 2 ins. long, each section consists of two semi circular pieces of No.16 galvanized steel, flanged on the vertical edge, the flanges of the two halves being bolted together between two pieces of 2 × 4-in. lumber. The sections are clamped at top, bottom and middle point by a wooden collar made in four pieces and held by bolts.

The pier forms contain 488 ft. of lumber and 688 sq. ft. of metal. The bracing contained 507 ft. of lumber. The cost as compiled by the writer for form work on four piers, 12.68 cu. yds. is given in Table XIII. This is an average from a number of observations taken at random and extending over a period of 8 months.

TABLE XIII.—COST OF FORMS FOR PIERS SUPPORTING GROUND ARCH RESERVOIR ROOF; TOTAL 12.68 CU. YDS. OF CONCRETE IN FOUR PIERS

Item	Total	Per cu. yd.
Stripping, 13 hrs. carpenter at 25 cts	$ 3.25	$0.27
Cleaning, 15 hrs. labor at 15 cts	2.25	0.18
Making:		
15 hrs. carpenter at 30 cts	$ 4.50	.....
15 hrs. labor at 15 cts	2.20	.....
Total	$ 6.75	$0.53
Setting:		
¾ hr. carpenter at 30 cts	$ 0.23	.....
1¼ hr. laborer at 15 cts	0.19	.....
¼ hr. cableway at 50 cts	0.12	.....
Total	$ 0.54	$0.04
Plumbing and bracing, 15 hrs. carp. at 30 cts	4.50	0.35
Grand total	$17.29	$1.37

Barrel Arch.—Fig. 10 shows the design of what was known as the barrel arch form. This form was for that portion of the wall from the springing line of the arch to the center of the first bay. The inside shape was a quarter of a 12 ft. circle and the outside an arc of a 15 ft. circle. These forms caused more trouble than any others on the reservoir. The inside was built in three equal sections, each 9 ft. long and 5 ft. 10 ins. wide on the chord. The ribs, 2 × 12 ins., were placed on 21-in. centers and lagging was 1 × 3 in., southern pine, tongue and grooved and dressed on both sides.

The outside forms were built in three sections, the first section being 3 ft. of the wall form which was left wired to the wall when removing the back wall

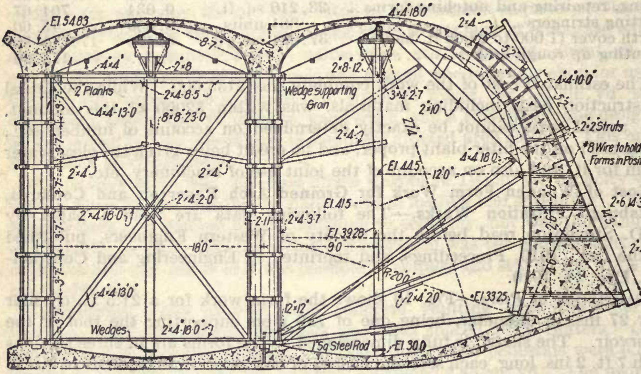


Fig. 10.—Forms for filtered water reservoir showing in elevation piers, walls and groined arch vaulting.

form; this gave a solid base upon which to build. The second was placed before filling and fastened to the inner form by wires and wooden interior struts and held on the outside by an outrigging extending up from the wall. The third was placed after the filling had reached the top of the second form and was wired to the inner form.

The remainder of the arch or a little over one-third of it was screeded, no form being useded on the outside.

Some trouble developed after the third using and was entirely due to the manner of removal. The bracing extending from the top to bottom, shown in Fig. 10, was not removed and the forms were not taken down in three sections, but the entire form was removed at one time. The method of removing was to hitch a set of falls to one of the upper corners to break the bonds and at times twelve men broke the rope before the form left the concrete. It was not uncommon to pull off several ribs in an attempt to break this bond. The result was that this pulling greatly distorted the form. This first showed up in the inability to make a good joint between forms and finally necessitated rebuilding the forms. The trouble could have been eliminated by removing the forms in three pieces rather than in one. The barrel arches on the filters were similar, but one-half the length. On these there was no particular trouble.

The barrel arch in filtered water reservoir contained 0.92⅓ cu. yd. per running foot and the units placed were 36 ft. long or 33¼ cu. yds. The cost of forms is given in Table XIV.

The cost is an average from a number of observations made by the writer. The cost of hauling out is rather high and unusual, the forms, however, were of awkward shape and very large, and had to be hauled on a truck by hand a distance as great as 300 ft. The floor over which they were hauled consisted of inverted groins with piers every 18 ft. The trimming and trueing at 58 cts. a yard is due to the trouble previously explained.

TABLE XIV.—COST OF FORMS FOR BARREL ARCH FILTERED WATER RESERVOIR, PITTSBURG, PA.

	Total	Per cu. yd.
Fabrication at mill:		
240 hrs. at 35 cts.	$84.00*	$0.31
Taking Down:		
1 foreman 2 hrs. at 30 cts.	0.60	
9 laborers 18 hrs. at 20 cts.	3.60	
Total	$ 4.20	$0.13
Hauling Out:		
1 foreman 1½ hrs. at 30 cts.	$ 0.40	
12 laborers 16 hrs. at 20 cts.	3.20	
Total	$ 3.60	$0.11
Cleaning and Repairs:		
1 foreman 5 hrs. at 35 cts.	$ 1.75	
4 carpenters 20 hrs. at 30 cts.	6.00	
2 helpers 10 hrs. at 20 cts.	2.00	
Total	$ 9.75	$0.30
Placing:		
Cableway ⅓ hr. at $2	$ 0.66	
1 foreman ⅓ hr. at 40 cts.	0.13	
3 carpenters 1 hr. at 35 cts.	0.35	
5 laborers 1⅔ hrs. at 15 cts.	0.25	
Total	$ 1.39	$0.04
Trimming and Trueing:		
1 foreman 10 hrs. at 35 cts.	$ 3.50	
4 carpenters 40 hrs. at 30 cts.	12.00	
2 helpers 20 hrs. at 20 cts.	4.00	
Total	$19.50	$0.58
Grand total	$48.94	$1.47

* Used 8 times.

Walls.—The wall forms shown in Fig. 10, are in accordance with the general practice in such work. All forms were made in 9-ft. sections and from top to bottom in one unit. The method for preventing the forms from raising is shown in the illustration and consisted of hooks set in the first layer of concrete and wires tying the forms to these hooks.

The forms were used on an average of 10 times and the only repairs made were a board now and then, where the bar in removing had splintered or broken the forms. The edges of the forms become more or less frayed and this was cared for by a metal strip tacked over the joint. This practice was permissible in this work as the face would not be exposed. In finished surfaces it should never be used, as the metal leaves a surface entirely different from the wood and very readily noticed.

The regular wall in the reservoir contained 2.33½ cu. yds. per running foot and as a rule the wall was built in 36-ft. sections or 84 cu. yds. This amount varied within a yard as the point where the wall ceased and the barrel started was not closely defined. The cost of forms is given in Table XV. This cost is a weighted average as in this work there was a great amount of variance. Often the cable way was used in removing forms and the cost cut down, then again the forms would be in bad shape and require much repairing. As an example, on the

21st wall forms cost	$0.73 per cu. yd.
23rd wall forms cost	.53 per cu. yd.
24th wall forms cost	.55 per cu. yd.
25th wall forms cost	.42 per cu. yd.
26th wall forms cost	.49 per cu. yd.

TABLE XV.—COST OF WALL FORMS, FILTERED WATER RESERVOIR, PITTSBURG, PA.

	Total	Per cu. yd.
Fabrication in Mill:		
110 hrs. carpenters at 35 cts	$38.50*	$0.038
Taking Down:		
1 foreman 10 hrs. at 35 cts	$ 3.50	
2 carpenters 20 hrs. at 30 cts	6.00	
4 laborers 40 hrs. at 20 cts	8.00	
Total	$17.50	$0.208
Setting Up:		
1 foreman 10 hrs. at 35 cts	$ 3.50	
6 carpenters 60 hrs. at 30 cts	18.00	
4 helpers 40 hrs. at 20 cts	8.00	
Total	$29.50	$0.350
† Grand total	$50.20	$0.596

†This does not include cost of material. * Used 12 times.

Groined Arch Forms.—Fig. 10 shows groined arch forms in elevation. Each pier top was molded on forms built in four triangular sections, the joints between sections being on centers of arches and on diagonal lines between piers. The ribs were 2-in. white pine placed on the diagonal line and on 2-ft. centers between the diagonals, the decking was 1-in. southern pine tongue and grooved. The forms were well oiled before filling.

The pier edge of each form rested on a collar bolted to the piers. The piers, having been built 2 ins. higher than the springing line of the arch, prevented any horizontal movement in the form. The four corners were supported by 8 × 8-in. posts and midway between corner posts were placed 4 × 4-in. posts. The proper elevation on the top of arch was first secured by placing wedges between the top of post and form. Later it was found that dumping the concrete disarranged these wedges and their use was discontinued and 0.5-in. boards were used and toenailed. This allowed only an adjustment of 0.5 in. which was considered close enough.

The joint between forms on the top was made by a crown strip which varied from 2 to 4 ins. wide. The corner joints were finished by a 1-in. triangular strip which relieved the rough corner. The forms being square and piers round required a filler in the corners. This filler was first made of plaster paris mixed with excelsior, but was unsatisfactory as the breakage was high and it was impossible to use it a second time. The cost of the fillers in plaster paris was about 27 cts. each. Later wood was used and the work was finished using wood. On Contract 11 the contractor used a metal filler cut from No.

16 gage sheet iron. This filler was used over and over, the first cost being 10 cts. each.

On Contract No. 1, the filters, the total amount of arch centering placed was 2,130,012 sq. ft. There were 240,000 sq. ft. of forms actually made to complete the work, an average of ten times use for each form. The actual cost was $0.0435 per sq. ft. placed; this cost includes plant charges, administration charges, material, etc.

On Contract No. 2, the reservoir, there were placed 243,390 sq. ft. of vaulting forms and there was actually made about 20,000 sq. ft. The cost was $0.096 per sq. ft. placed, or about $3.50 per cu. yd. of concrete placed. This cost is a final cost including everything chargeable to the forms.

For a detailed cost Table XVI was prepared from information gathered by the writer:

Four forms made one pier top or	8.1864 cu. yd.
Lumber in one pier top	1,000 ft.
Lumber in posts and bracing	400 ft.
Lumber in shoring on piers	150 ft.

To the above cost must be added a charge for hauling the forms from the place of removal to the place of setting. This varied greatly and from observations cost 15 man hours per 100 ft. hauled.

Table XVI.—Cost of Vaulting Forms for Filtered Water Reservoir, Pittsburg, Pa.

Making of Groins at Mill:	Total	Per cu. yd.
120 hrs. at $0.35	$42.00*	$0.42
Setting Groins:		
1 foreman ¼ hr. at 35 cts	$ 0.09	
3 carpenters ¾ hr. at 30 cts	0.225	
6 laborers 1½ hr. at 20 cts	0.30	
1 cableway ¼ hr. at $2.00	0.50	
	$ 1.115	$0.14
Setting Corner Posts:		
Cableway 0.1 hr. at $2.00	$ 0.20	
3 carpenters 0.3 hr. at 30 cts	0.09	
	$ 0.29	$0.03
Intermediate posts, 3 carpenters 1½ hr. at 30 cts	$ 0.45	$0.05
Shoring piers, 2 carpenters 3 hrs. at 30 cts	0.90	$0.11
Trimming and trueing, 4 carpenters 3 hrs. at 30 cts	1.20	$0.15
Taking Down Groins:		
1 foreman 1⅓ hrs. at 30 cts	$ 0.40	
5 laborers 6⅔ hrs. at 20 cts	1.35	
5 laborers 6⅔ hrs. at 15 cts	1.00	
Total	$ 2.75	$0.33
Grand total	$10.20	$1.22

* Used 12 times.

Cost of Bending Reinforcing Steel.—In the equalizing chamber the steel required careful bending. There were 27 different shapes. A record kept by the writer on the bending of 10,325 lbs. extending over a period of 10 days showed a cost of: 0.88 man hours per 100 lbs. for blacksmith and of 1.66 man hours per 100 lbs. for helpers. At the prices paid, or 25 cts. per hour for blacksmith and 16 cts. for helper this cost was 48.9 cts. per 100 lbs. In addition to this was chargeable 0.24 man hours per 100 lbs. for the layer out, which work was done by the boss carpenter at a cost of 20 cts. per 100 lbs., the total cost being 68.9 cts. per 100 lbs. In bending the steel a large platform was built and all shapes laid out full size, cleats were nailed at points of curvature and the rods bent to fit.

Conduit.—The construction of conduit forms was governed greatly by the place they were to be installed and the surroundings. A conduit in a trench offers different requirements than conduit in the open. The inner form or barrel is generally first placed. This is held to the proper elevation by piers, or saddles, separately cast, and the tops set to grade. The steel is next placed and then the outer forms.

Care must be exercised to prevent the form floating or rolling and in filling the bottom. The bottom is sometimes cared for by placing grout tubes, or by simply smoothing up after the removal of the forms. In a number of conduits on the reservoir work a board was left off the outside forms just above the invert and through this opening the bottom was successfully filled by tamping. The filling of one side and allowing the concrete to run under and seek its level on the opposite side, thus assuring filling in the bottom, is rather dangerous practice as there is great chance of moving the inside form or barrel.

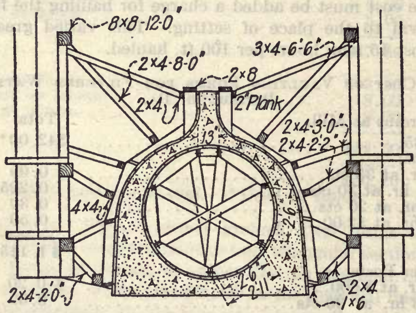


FIG. 11.—Forms and bracing for by-pass conduit.

The by pass conduit, shown in Fig. 11 is 7 ft. in diameter and about 1,200 ft. long, built in 36-ft. sections, contained 48.8 cu. yds. and 3,600 lbs. steel per section, and was built after the roof of the reservoir was in place, the piers and roof being used to brace against. The barrel was placed on concrete saddles and painted with cold water paint. The reinforcement was next placed and then the outside forms. The braces were all fitted and marked and they together with all except the bottom outside form were removed and stored conveniently for easy access. The barrel was held down by braces to the roof and held laterally by braces to stringers placed along the piers. When the concrete reached the level of the top of the bottom form, the second form was placed and so on until the top was reached. After the concrete was placed to a depth level with the top of the barrel it was found that there was no tendency to rise and the braces to the roof were removed.

The forms in this conduit were all bolted together; the inside or barrel form collapses by dropping the top section. The time required to build one section was three days and the time to fill it was seven hours.

The forms including bracing contained 6,350 ft. of lumber. The lagging was 1 in. southern pine and the ribs 2 in. white pine. The cost of a 36-ft. section, including taking down, placing steel, etc., as compiled from a number of observations was:

	Time	Rate	Cost	Times used	Cost per cu. yd.
Building forms at mill..............	489	$0.35	$171.15	10	$0.36
Carpenter work in field—					
Carpenter........................	227¼	.35	....	..	.....
Helpers..........................	19¼	.20	83.39	1	1.70

The forms for the seven foot filtered water conduit shown in Fig. 12 is a good example of form work for a conduit in a trench. In this conduit no outside forms except one on either side of the top was necessary. The sections were 30 ft. in length, contained 22 cu. yds. of concrete and 2,600 lbs. of steel. One foreman, 4 carpenters and 4 helpers took down the back forms, set them up ahead and placed the steel ready for filling at the rate of one section a day. Two sets of forms were used and they were removed the following day as early as 10 o'clock; thus while filling one section another

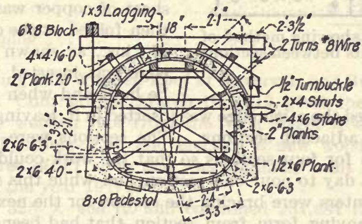


FIG. 12.—Forms and bracing for 7-ft. filtered water conduit.

was being prepared. The cost of setting up the forms and placing steel was $1.15 per cu. yd. and the cost of bending steel 40 cts. per 100 lbs.

The 48-in. conduit was a plain circle inside with perpendicular sides and semicircular top outside. The drain was located in a 21-ft. fill, placed in sections varying from 20 ft. to 50 ft. in length and contained 0.387 cu. yd. of concrete and 35 lbs. steel per lineal foot of conduit. The forms were built in the mill and used six times in the field:

	Per cu. yd.
Lumber..	$0.72
Mill work...	.30
Bending steel...	.26
Carpenter work in field.................................	2.13
Total...	$3.41
Total, cu. ft. of drain.................................	1.59

Cost of Relining a Brick-lined Reservoir with Concrete.—Thomas Fleming, Jr. gives the following data in Engineering and Contracting, April 3, 1912.

The Bellevue reservoir of the Ohio Valley Water Co., which supplies a large suburban territory west of Pittsburg, consists of an earth embankment with a vertical lining of brick masonry 2 ft. thick. The reservoir is 130 ft. in diameter and 20 ft. deep. It rests on solid rock foundation which several years ago was covered with a concrete floor. It has a capacity of 2,000,000 gals.

During the winter season the joints between the bricks opened up enough to allow as much as 400,000 gals. per day to leak out. While the leakage was was not seriously threatening the stability of the reservoir, yet it was a serious proposition financially. The cost of pumping water at this plant against the high head (480 ft.) prevailing, was at that time 3 cts. per 1,000 gals. This cost includes only fuel and labor. It was estimated that the leakage averaged 100,000 gals. per day per annum, which amounted to a financial loss of $3 per day, or $1,095 per year. This capitalized at 8 per cent would represent an investment of $13,688.

Several schemes were proposed to stop this leakage, but it was finally decided to reline the reservoir with an 8-in. concrete lining. This lining was designed to be constructed in sections 29 ft. long horizontally and extending the full vertical height of the reservoir. The sections were connected by a metal expansion joint. This was made of thin sheets of copper of No. 28 gage 12 ins. × 20 ft. The sheet of copper was corrugated and then folded at the center for a width of 4 ins., as shown in Fig. 13. One edge was inserted in the section to be built and when the adjacent section was constructed the other edge was inserted in it, leaving the fold between the faces of the adjacent sections. The sections were built alternately. There were forms for four sections so that the work could progress continuously. It took a day to pour one section and while this section was being poured, the carpenters were bracing the section for the next day's work and laborers were removing form from section that had been poured two days before and were setting this form for work to follow two days later.

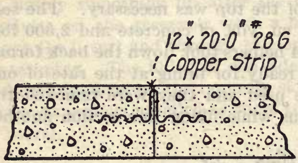


FIG. 13.—Sketch showing method of making copper joints between sections of concrete.

The form for each section was constructed in one piece with vertical struts and horizontal nailing pieces. These nailing pieces were 2 ins. × 12 ins., cut to the arc of the circle and spaced 2 ft. c. to c.; 1-in. sheeting was nailed to these vertically and 2-in. × 10-in. struts also vertical were spaced on the back of the form 5 ft. c. to c. The braces were nailed to these struts. The specifications stated that the contractor must not cut any holes in the concrete floor for supporting or bracing form work. Heavy pieces of timber were therefore laid on the floor of the reservoir entirely across it and braced against the wall on the opposite side. The form braces were then nailed to these timbers. Each section was poured in one day. The concrete was a 1:2:4 mixture and was placed wet and thoroughly spaded. The filling was made slowly so that the concrete in the lower part of the section would attain its initial set before the pressure from above could cause a deformation of forms. Upon the completion of a section it was allowed to stand two days before removing the form. The surface was then gone over with tools, imperfections removed, and a thin coat of liquid cement grout was applied. Upon the completion of the work, the test showed that the reservoir was absolutely water tight. The work had to be completed in 24 days.

The following costs do not include overhead charges, nor do they include 10,000 ft. B. M. of old lumber which was used for form work in addition to the lumber itemized in the list given. The cost of material was much higher than usual, due to the fact that it was necessary to haul it all several miles up a very steep grade where it was necessary to use extra teams for a part of the distance. Prices quoted for hauling were 25 cts. per barrel for cement and $2.10 per 1,000 for brick. There was a total of 201⅔ cu. yds. of concrete used.

Cost of Relining Brick-lined Reservoirs with Concrete

Item		—Per cu. yd. concrete—
260 bbls. cement at $1.25, deliv'd	$ 325.00	.....
123 tons sand at $1.65, delivered	202.95	.....
276 tons gravel at $1.45, delivered	400.20	.....
Total concrete material	$ 928.15	$4.60
4 M. ft. of 1-in. boards at $22	88.00	.....
Tools and lumber	55.00	.....
Nails, oil, supplies and incidentals	18.50	.....
Total form mat'l and incidentals	$ 161.50	$0.80
Foreman, 20 days at $5	100.00	.....
Carpenters at $3.50 per man per day	310.14	.....
Labor at $1.85 per day	297.30	.....
Finishing and cleaning up	54.16	.....
Total for labor	$ 761.60	$3.77
Total cost of lining	$1,851.25	$9.17

Cost of Removing Old Wooden Roof of Reservoir and Building New One.—Engineering and Contracting, March 19, 1919, gives the following costs of removing an old wooden roof from the Villa Street reservoir of the Water Department of Pasadena Cal. and erecting a new wooden covering. The roof covers an area of 3.7 acres and was originally built in 1899. The new roof was built in the year 1917.

The roof was 325 × 495 ft. and contained 251,681 ft. B.M. of lumber. The total cost of removing and salvaging the materials was $781, detailed as follows:

	Total	Cost per M. ft. B.M.	Cost per 100 sq. ft. of roof
Preparing yard for receiving lumber:			
Labor	$ 19	....	....
Auto	4	....	....
Total	$ 23	$0.0917	$0.0143
Removing lumber from reservoir:			
Labor	162	.6484	.1014
Hauling and stacking lumber in yard:			
Labor	139	....	....
Auto	20	....	....
Material	64	....	....
Total	$223	.8883	.1390
Removing 2-in. pipe posts:			
Labor	16	.0632	.0100
Engineering and other supervision:			
Labor	78	....	....
Auto	20	....	....
Total	$ 98	.3889	.0608
Sale and other disposal of materials:			
Labor	119	....	....
Auto	67	....	....
Total	$186	.7407	.1159

Overhead	71	.2821	.0441
Grand total		$3.1033	$0.4855

The value of the materials recovered was:

Broken and split lumber sold as kindling at $2.50 per truck load, 49,663 ft.	$ 82
Serviceable lumber sold at $9 and $10 per M. ft., 119,844 ft.	1,189
Lumber taken into stock, 82,174 ft.	821
Total value of lumber recovered	$2,093
Pipe posts sold (9,373 ft. 2-in. screw pipe)	350
Appraised value of hardware cloth (2,334 sq. ft. at 3 ct.)	70
Total	$2,513

The new roof is the same size as the old one. Its details are as follows: Roofing, 1 in. × 8 in., 1 in. × 10 in., and 1 in. × 12 in. R. W. boards; joists, 2 in. × 8 in. O. P. 16 ft. long spaced 40 ft. c. to c. (west tier 2 in. × 10 in.—20 ft., 4 ft. c. to c.). Girders, 2—2 in. × 12 in. O. P.—18 ft. long spiked together, spaced 15 ft. 9 in. c. to c. Posts, 6 in. × 6 in. R. W. 18 ft. and 20 ft. long with 6 in. × 6 in. × 3 ft. R. W. corbels. Work was begun on Jan. 8, 1918, and was completed March 9, 1918. The detailed costs were as follows:

	Total	Per M. ft. B.M. in roof	Per sq. ft. roof
48 concrete footings on slope:			
Labor, 11⅝ man days at $3.523	$ 41	....	....
Material	6	....	....
Total	$ 47	$ 0.158	$0.0003
Construction of wooden roof:			
Labor, 390⅝ man days at $3.459	$ 1,352	4.500	0.0084
Auto	12	.039	....
Material, 300.4 M. ft.	10.150	33.788	.0631
Total	....	$38.327	$0.0715
Hauling lumber:			
Labor, 44⅜ man days at $2.857	127	0.423	....
Auto	57	.190	....
Total	....	$ 0.613	$0.0011
Other hauling:			
Labor, 1 11-16 man days at $3.342	6	....	....
Auto	3	....	....
Total	$ 9	$ 0.030	$0.0001
Engineering and supervision, 30 man days at $4.952	149	.495	.0009
Disposal of surplus and waste material	25	.083	.0002
Overhead	1,193	3.971	.0074
Grand totals	....	$43.679	$0.0814

Cost of Concrete Wave Protection for Earthen Dams.—The costs of placing concrete linings on the earth dikes of the North Laramie Land Co., Uva, Wyoming is given by W. D'Rohan in Engineering and Contracting, Nov. 27, 1912.

The principal features of the concrete linings are indicated in Figs. 14 and 15.

In the reconstruction of the system, it was necessary to increase the capacity of No. 1 reservoir, by raising the height of the dams. Owing to the scarcity of any suitable material, it was decided to increase the height of the North dyke by means of a parapet wall and as the dyke is exposed to the greatest wind storms, the opportunity of putting a wave break on the top of the wall could not be neglected. The East dyke is of horseshoe form about 2,500 ft. long; 1,300 ft. of it being faced with plain concrete slabs, and the two ends with

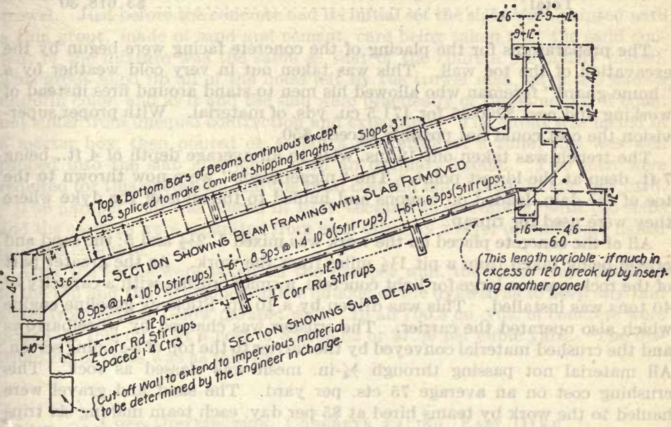


Fig. 14.—Reinforced concrete beam and slab-facing for dams and reservoirs Nos. 1 and 3, North Laramie Land Co.

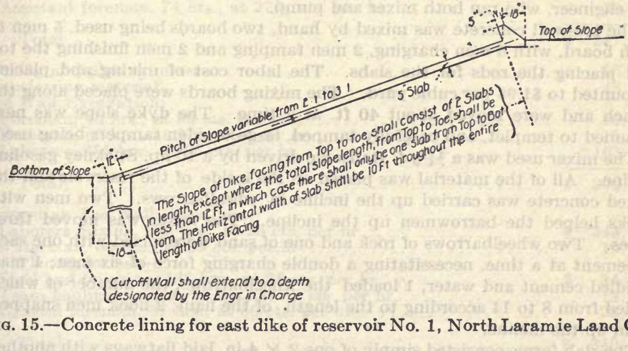


Fig. 15.—Concrete lining for east dike of reservoir No. 1, North Laramie Land Co.

hand laid riprap. This dyke being favorably suitated as regards material, 15,624 cu. yds. of dirt were placed on it. The dyke was first plowed and the fill placed in 3 ft. layers by means of wheelers and scrapers. All of this material was taken from the outside of the dam with an average haul of 300 ft. and cost $3,618.30 or about 23 cts. per yard. The detailed cost of this was as follows.

EARTH WORK, EAST DYKE DAM

Foreman, 360 hrs., at 35 cts. per hr.	$ 126.00
Laborers, 1,020 hrs., at 25 cts. per hr.	255.00
Laborers, 750 hrs., at 30 cts per hr.	225.00
Teams, 4,395 hrs., at 45 cts. per hr.	1,977.75
Teams, 2,178 hrs., at 47½ cts. per hr.	1,034.55
Total	$3,618.30

The preparations for the placing of the concrete facing were begun by the excavation of the toe wall. This was taken out in very cold weather by a "home-guard" foreman who allowed his men to stand around fires instead of working and cost $200.25 for 171.5 cu. yds. of material. With proper supervision the cost could not possibly exceed $50.

The trench was taken out 18 ins. wide to an average depth of 4 ft., being 7 ft. deep at the lowest point. The "niggerheads" were now thrown to the toe of the dam, loaded on wagons and hauled to the ends of the dyke where they were used for riprap.

All of the concrete placed on the work was mixed 1, 2½ and 5; the sand and gravel being taken from a pit 1½ miles from the work. As the greater part of the rock was too large for light concrete, a small crusher with a capacity of 40 tons was installed. This was driven by a 10 hp. Stickney gasoline engine which also operated the carrier. The crusher was charged by wheelbarrows and the crushed material conveyed by the carrier to the top of a sloping screen. All material not passing through ¼-in. mesh was classed as rock. This crushing cost on an average 75 cts. per yard. The sand and gravel were hauled to the work by teams hired at $5 per day, each team making six trips and hauling 10 cu. yds. The water for mixing was pumped by a 3 hp. Stickney gasoline engine through ¾-in. pipe, the delivery at 1,500 ft. with 10-ft. lift being 30 gals. per hour, necessitating storage in barrels and overtime for the engineer, who ran both mixer and pump.

The toe-wall concrete was mixed by hand, two boards being used, 5 men to each board, with 6 men charging, 2 men tamping and 2 men finishing the top and placing the rods for the slabs. The labor cost of mixing and placing amounted to $1.98 per cubic yard. The mixing boards were placed along the trench and were moved about 40 ft. at a time. The dyke slope was next trimmed to templet, and carefully tamped, large wooden tampers being used.

The mixer used was a ¼-yd. Ransome driven by a 10 hp. Stickney gasoline engine. All of the material was placed on the inside of the reservoir and the mixed concrete was carried up the incline in wheelbarrows. Two men with hooks helped the barrowmen up the incline. The mixer was moved three times. Two wheelbarrows of rock and one of sand were mixed with one sack of cement at a time, necessitating a double charging force of six men; 1 man handled cement and water, 1 loaded the wheelbarrows, the number of which varied from 8 to 14 according to the length of the haul; 2 hook men snapped them up the incline.

The slab forms consisted simply of one 2 × 4-in. laid flatways with another one on edge nailed to it and held in place by stakes. For the ends of the slabs the top 2 × 4-in. had holes bored in it for the tie rods; 1 carpenter and 1 helper attended to the moving and placing of the forms, rods and rubberoid. The concrete was run into the slabs by means of troughs made of galvanized sheet iron. These chutes were 7 ft. long in a light frame and as they weighed only 75 lbs. were very easily moved.

Two slabs were placed at a time, the placing gang consisting of 1 man cleaning the wheelbarrows and chutes, 2 men placing the concrete, 2 men on straight edge, and one man troweling. In placing the concrete the men were careful to turn their shovels upside down with every shovelful. In this way, rich mortar that usually sticks to the shovel was on top, making it possible for the trowel man to put a good finish on the slab, using an ordinary 9-in. plasterer's trowel. Just before the concrete had its initial set the slabs were painted with a thin grout, made of sand and cement, care being taken that the sand content of the mixture was the same as that of the conrete previously placed. This grout filled up all of the holes left by the trowel man, gave the slabs a uniform color, and as it and the slab were practically of the same mix it could not suffer from unequal contraction and expansion. The grout was mixed in a mortar box, then poured on a slab a bucketfull at a time; this was well rubbed into the slab and joints with an ordinary broom. Two men were required for this operation, and the total cost did not exceed 10 cts. per yard.

The parapet wall was placed in 10 ft. sections to correspond with the slabs and the sections were separated from each other by a layer of rubberoid nailed into the concrete.

After the forms were taken off the parapet wall, the latter was backfilled to the top and the dirt sloped to the outside of the dyke so as to keep any rain water from getting below parapet wall. In all 790.8 cu. yds. of concrete were placed on this dyke at a cost of $5,983.62 or $7.56 per cubic yard. The distribution of costs was as follows:

COST DISTRIBUTION, CONCRETE FACING, EAST DYKE

Excavation and Leveling:		
Laborers, 910 hrs., at 25 cts. per hr.	$	227.50
Assistant foreman, 74 hrs., at 27½ cts. per hr.		20.35
Total	$	247.85
Moving and placing mixer		65.00
Transferring material		48.00
Toe Wall Excavation:		
Foreman, 40 hrs., at 50 cts. per hr.		20.00
Foreman, 60 hrs., at 27½ cts. per ar		16.50
Laborers, 655 hrs., at 25 cts. per hr.		163.75
Total	$	200.25
Concreting Toe Wall (hand mix):		
Laborers mixing, 980 hrs., at 25 cts. per hr.	$	245.00
Waterman, 66 hrs., at 35 cts. per hr.		19.80
Placing forms—		
Steel and finishing, 138 hrs., at 25 cts. per hr.	$	34.50
Team hauling cement, 25 hrs., at 50 cts. per hr.		12.50
General foreman, 57 hrs., at 50 cts. per hr.		28.50
Total	$	340.30
Materials Used:		
Cement, 567 sacks, at $2.60 per bbl	$	368.55
Gasoline for pump, 30½ gals., at 25 cts. per gal.		7.60
Steel, 1,246 lbs., at 3 cts. per lb.		37.40
Sand, 63 cu. yds., at $1.25 per cu. yd.		78.75
Gravel, 126 cu. yds., at $1.25 per cu. yd.		157.50
Total	$	649.80

Backfilling	$ 76.15
Placing Slabs and Parapet Wall.	
East Dyke:	
Laborers mixing 3,505 hrs., at 25 cts. per hr	$ 876.25
Waterman, 143 hrs., at 35 cts. per hr	42.90
Carpenters, 289 hrs., at 45 cts. per hr	130.05
Placing steel and finishing, 436 hrs., at 25 cts. per hr	109.00
Team hauling cement, 39 hrs., at 50 cts. per hr	19.50
Mixer feeder, 124 hrs., at 27½ cts. per hr	34.10
General foreman, 133 hrs., at 50 cts. per hr	66.50
Extra waterman, 79 hrs., at25 cts. per hr	19.75
Total	$1,298.05
Material Used, Facing East Dyke:	
Cement, 2,835 sacks, at $2.60 per bbl	$1,843.40
Steel, 3,600 lbs., at 3 cts. per lb	108.00
Gasoline for mixer, 100 gals., at 25 cts. per gal	25.00
Gasoline for pump, 55 gals., at 25 cts. per gal	13.75
Lumber (estimated)	25.00
Sand, 263 cu. yds., at $1.25 per cu. yd	328.75
Gravel, 530 cu. yds., at $1.25 per cu. yd	662.50
Rubberoid	52.00
Total	$3,058.40
790.8 yds. of concrete placed for	$5,983.80

A total of 350.2 yds. of rip-rap placed on the outer ends of the East dyke at a cost of $492.05, which also includes the picking up of the rock. A small trench 18 ins. wide and 15 ins. deep was first dug along the toe of the dyke and from this the rock was laid at right angles to the slope. The gang consisted of 5 men laying rip-rap, with 3 helpers passing rock, 2 teams with 2 helpers picking up and loading rock. The costs distribution was as follows:

Gathering and Placing Rip-Rap, East Dyke.	
Laborers, laying rock, 1,053 hours at 25 cts. per hour	$263.25
Foreman, 83 hours at 27½ cts. per hour	22.80
Team hauling rock, 241 hours at 50 cts. per hour	120.50
Men loading rock, 342 hours at 25 cts. per hour	85.50
350.2 cu. yds. placed for	$492.05

The greater part of the concrete of the North dyke was placed in the fall of 1911, and before the writer was connected with the work. The toe wall was dug to a depth of 5 ft., and all of the concrete placed by means of chutes, the mixer being moved along the top of the dam. In this way 554.8 cu. yds. of concrete were placed at a total cost of $8,478.43, or $15.28 per cubic yard. The writer, however used the stationary mixer and wheeled the concrete, making faster time and much cheaper work, placing 576.1 cu. yds. of concrete at a cost of $5,658.17 for labor and material or $9.82 per cubic yard.

The forms for the parapet wall were built at the bench in 16-ft. sections and were held in place by No. 9 soft wire tied to the reinforcement, the inside form being also braced to loops of wire previously bedded in the beams and allowed to stick out. All of the reinforcing was placed by union structural iron workers. It is not usual to employ union men on such work, but from previous experience with laborers on similar work, the writer is of the opinion that the union men are the cheapest in the end. They understand the work and know how to go about it, and allow the foreman to devote his time to the execution of the work.

The forms being in place the concrete was dumped into mortar boxes and shoveled into the forms, 2 men shoveling and 1 tamping from each box, of which there were three, made 100 cu. yds. as the best day's run. The charging gang always remained the same.

The detailed costs of this work including that previously placed were as follows:

Concreting Face of North Dyke

Work Done Previous to May, 1912

Foreman, 480 hours at 50 cts. per hour	$ 240.00
Teams, 294 hours at 45 cts. per hour	132.30
Laborers, 10,154 hours at 25 cts. per hour	2,538.50
Laborers, 276 hours at 27½ cts. per hour	75.90
Carpenters, 793 hours at 45 cts. per hour	356.85
Carpenters, 190 hours at 50 cts. per hour	95.00
Ironworkers, 819 hours at 50 cts. per hour	409.50
Total	$3,848.05
Material Used:	
Lumber, 1,000 ft. at $31.00 per M	$ 31.00
Cement, 850 bbls. at $2.60 per bbl	2,210.00
Gravel, 550 cu. yds. at $1.25 per yd	687.50
Sand, 278 cu. yds. at $1.25 per yd	347.50
Gasoline, 480 gals. at 25 cts. per gal	120.00
Steel, 40,812.8 lbs. at 2 cts. per lb	1,224.38
Wire (estimated)	10.00
Total	$4,630.38
554.8 cu. yds. for	8,478.43

Work in May, 1912

Laborers mixing, 3,085 hours at 25 cts. per hour	$ 771.25
Waterman, 109 hours at 30 cts. per hour	32.70
Carpenters, 342 hours at 45 cts. per hour	153.90
Carpenter helpers, 234 hours at 25 cts. per hour	58.50
Union steelmen, 392 hours at 50 cts. per hour	196.00
Team on cement, 48 hours at 50 cts. per hour	24.00
Mixer feeder, 100 hours at 27½ cts. per hour	27.50
General foreman, 113 hours at 50 cts. per hour	56.50
Assistant foreman, 11 hours at 30 cts. per hour	3.30
Helpers on steel, 218 hours at 25 cts. per hour	54.50
Total	$1,378.15
Materials Used—	
Cement, 747 bbls. at $2.60 per bbl	$1,942.20
Sand, 280 yds. at $1.25 per yd	350.00
Gravel, 554 yds. at $1.25 per yd	692.50
Lumber, 3,000 ft. B.M. at $31.00 per M	93.00
Steel, ½-in., 38,941 ft. at 2 cts. per ft	778.82
Steel, ¾-in., 8,100 ft. at 4½ cts. per ft	364.50
Gasoline, 136 gals. at 25 cts. per gal	34.00
Wire, nails, etc	25.00
Total	$4,280.02
576.1 yds. placed for	$5,658.17

No. 3 reservoir is a natural depression surrounded by almost level land, with an opening at the south end where the dam is located. The facing of this dam was of the beam and slab type. As the chief engineer was desirous of obtaining a good idea of the actual costs of construction of this design, everyone put his best foot forward. The toe-wall was excavated by a competent foreman to an average depth of 9 ft., the deepest part being 17 ft. and the shallowest 5 ft. It was taken out 2 ft. wide at a cost of 47 cts. per cubic yard; which was some improvement over $1.16 per cubic yard, the cost of excavating the East dyke toe-wall. The beams were dug out for 23.6 cts. per cubic yard. The beam forms were put together in sections, being wired at the bottom and slotted at the top to receive the reinforcement, which was also put together at the bench, a lap of 10 ins. being allowed. For the placing of the toe-wall, the mixer was on the inside of the reservoir in the center, and the concrete wheeled each way a distance of 550 ft. The same organization was used throughout.

This dam is 5½ miles from the gravel pit, and the sand and gravel haul was let to the teamsters as piece work, $1.82 per cubic yard being the price agreed on. The teams made two trips one day and three the next, hauling on an average 1½ cu. yds. to the load. Owing to the heavy roads, two snap teams had to be provided, and this, with the heavier stripping at the pit, brought the sand and gravel price up to $3.05 per cubic yard.

For the beams, slabs and parapet wall, the mixer was placed at each end of the dam, 600 ft. of the dyke being faced from one end and 350 ft. from the other. The beam concrete was run into a mortar box placed in the center of a slab. Two men shoveled this concrete into the surrounding beams, one tamper being used for each shoveler; in this way the concrete was thoroughly spaded and placed around the steel.

The system used in placing the slabs and parapet wall was the same as that for the East and North dykes. The edges of the beams and slabs were rounded with an ordinary side-walk edger, and this wonderfully improved the general appearance of the whole work. The slabs were washed with a sand and cement grout about 1 to 3 being similar to the concrete mix, sand content. The trowel finish on the beams and slabs took 440 hours of labor at 25 cts., or $110, and the grout wash was placed by two laborers who used 80 sacks of cement and spent 200 hours on the work, that is, the total labor and material cost was 10 cu. yds. of sand at $3.05, 80 sacks of cement at $2.70 per bbl., 200 hours labor at 25 cts., making a total of $134.50.

During the progress of this work, the Colorado & Southern R. R. tracks washed out, so that the cement had to be hauled from Wheatland, making an extra cost of haul $70. The itemized costs of facing No. 3 dam are as follows:

Leveling Dyke—	
Laborers, 588 hours at 25 cts. per hour	$ 147.00
Foreman, 48 hours at 35 cts. per hour	16.80
Teams, 10 hours at 50 cts. per hour	5.00
981 cubic yds. moved for	$ 168.80
or 17.5 cts. per yd.	
Filling in Slabs and Tamping Dirt in Place—	
Laborers, 1,151 hours at 25 cts. per hour	$ 287.75
Foreman, 41 hours at 35 cts. per hour	14.35
950 cu. yds. moved for	$ 302.50
or 31.8 cts. per yd.	
Excavating Toe-Wall—	
Laborers, 711 hours at 25 cts. per hour	$ 177.75
Foreman, 95 hours at 35 cts. per hour	28.50
Teams, 15 hours at 50 cts. per hour	7.50
453.1 cu. yds. moved for	$ 213.75
or 47 cts. per yd.	
Beam Excavation—	
Laborers, 440 hours at 25 cts. per hour	$ 110.00
Foreman, 49 hours at 35 cts. per hour	14.70
395 beams 12 ft. long and 2 ft. deep for	$ 124.70

Backfilling Toe-Wall—	
Laborers, 153 hours at 25 cts. per hour	$ 38.25
Foreman, 12 hours at 50 cts. per hour	6.00
	$ 44.25
Concreting Toe-Wall—	
Carpenters, 222 hours at 45 cts. per hour	$ 99.90
Helpers, 122 hours at 25 cts. per hour	30.50
Laborers mixing, 1,810 hours at 25 cts. per hour	452.50
Waterman, 62 hours at 30 cts. per hour	18.60
Steelmen, 40 hours at 50 cts. per hour	20.00
Team on cement, 62 hours at 50 cts. per hour	31.00
Mixer feeder, 62 hours at 27½ cts. per hour	17.05
General foreman, 62 hours at 50 cts. per hour	31.00
Assistant foreman, 30 hours at 30 cts. per hour	9.00
356 yds. of concrete for a labor cost of	$ 709.55
or less than $2.00 per yd.	
Material Used—	
Cement, 1,477 sacks at $2.70 per bbl	$ 996.97
Gasoline for mixer, 61 gals. at 25 cts. per gal	15.25
Gasoline for pump, 32 gals. at 25 cts. per gal	8.00
Sand, 164 yds. at $3.05 per yd	500.20
Gravel, 328 yds. at $3.05 per yd	1,000.40
	$2,520.82
Concreting Face and Parapet Wall, No. 3 Reservoir—	
Carpenters, 1,410 hours at 45 cts. per hour	$ 624.50
Carpenters' helpers, 958 hours at 25 cts. per hour	239.50
Laborers mixing, 5,362 hours at 25 cts. per hour	1,340.50
Waterman, 212 hours at 30 cts. per hour	63.60
Steelmen, 970 hours at 50 cts. per hour	485.00
Steelmen helpers, 112 hours at 25 cts. per hour	28.00
Team on cement, 94 hours at 55 cts. per hour	51.70
Feeder for mixer, 191 hours at 27½ cts. per hour	52.50
General foreman, 171 hours at 50 cts. per hour	85.50
Assistant foreman, 93 hours at 35 cts. per hour	33.25
862 yds. placed for	$3,004.05
or $3.48 per yd.	
Material Used—	
Cement, 4,567 sacks at $2.70 per bbl	$3,082.72
Gasoline for mixer, 184 gals. at 25 cts. per gal	46.00
Gasoline for pump, 110 gals. at 25 cts. per gal	27.50
Gravel, 832 yds. at $3.05 per yd	2,537.60
Sand, 416 yds. at $3.05 per yd	1,268.80
Steel (½-in. 98,105 ft., ¾-in. 3,483 ft.), 71,167 lbs. at 3 cts. per lb	2,135.01
Lumber, 6,000 ft. at $27.00 per M	162.00
Cement haul extra	70.00
	$9,329.63
Moving and Placing Mixer—	
Laborers, 90 hours at 25 cts. per hours	$ 22.50
Teams, 6 hours at 55 cts. per hour	3.30
Carpenters, 12 hours at 45 cts. per hour	5.40
General foreman, 4 hours at 50 cts. per hour	2.00
Assistant foreman, 2 hours at 35 cts. per hour	.70
	$ 33.90

The total cost of placing 1,218 cu. yds. of concrete was $16,451.55, or $13.50 per cubic yard. To mix and place toe-wall cost $2 per yard, the beams cost $4.10, the slabs $3 and head-wall $3.60 per yard.

As the work on No. 1 reservoir progressed, water was gradually let into it, and four days after the completion of the work, when the reservoir was at its full capacity, a terrific windstorm arose from the northeast creating waves

3 ft. high and blowing them almost directly on to the facings of the dams; this storm lasted five hours and in the ensuing two weeks three similar storms came in the same direction. The writer, in company with Mr. Shelburne, engineer for the Land Company, visited the dams. We found them in excellent shape. The East dyke showed no signs of settlement or cracks of any description and very little seepage; the North dyke showed a slight parting along the line of the slabs about two-thirds of the height from the top, and the parapet wall had three small cracks straight across, about ⅛ in. wide at top and disappearing toward the bottom of the wall. These came from settlement and were to be expected. In all probability, several more will develop within the next year. when the cracks can be poured full of grout or repaired in some other manner.

Cost of Concrete Standpipes in Mass.—William S. Johnson in the Journal of the New England Water Works Association June, 1914 gives the following data. The standpipes were constructed "recently" according to the author.

Town	Size, diam. height, ft.	Capacity, gals.	Cost including foundations	Cost per 1,000 gals.
Ashland	40 × 32	300,000	$5,812	$19.35
East Douglass	45 × 18	214,000	4,524	21.15
Leicester, Chester Valley and Rochdale)	40 × 21	197,000	4,976	25.25

Cost of Concrete Water Tower at Victoria, B. C.—A. Kempkey in the Proc. Am. Soc. C. E., Vol. XXXVI, gives in detail the methods and costs of construction of the above tower. The following data are taken from an abstract of Mr. Kempkey's paper published in Engineering and Contracting, March 9, 1910.

The tower, as built, consists of a hollow cylinder of plain concrete, 109 ft. high, and having an inside diameter of 22 ft. The walls are 10 ins. thick for the first 70 ft. and 6 ins. thick for the remaining 39 ft., and are ornamented with six pilasters (70 ft. high, 3 ft. wide, and 7 ins. thick), a 4-ft. belt, then twelve pilasters (12 ft. high, 18 ins. wide, and 7 ins. thick), a cornice, and a parapet wall. A steel tank of the ordinary type is embedded in the upper 40 ft. of this cylinder. To form the bottom of this tank, a plain concrete dome is thrown across the cylinder at a point about 70 ft. from the base, the thrust of this dome being taken up by two steel rings, ½ in. by 14 ins. and ⅜ in. by 18 ins., bedded into the walls of the tower, the latter ring being riveted to the lower course of the tank. The tank is covered with a roof of reinforced concrete, 4 ins. thick, conical in shape, and reinforced with ½-in., twisted steel bars.

The tower is built on out-cropping, solid rock. This rock was roughly stepped, and a concrete sub-base built. This sub-base consists of a hollow ring, with an inside diameter of 20 ft., the walls being 5 ft. thick. It is about 2 ft. high on one side and 7 ft. high on the other, and forms a level base on which the tower is built. The forms for this sub-base consisted of vertical lagging and circumferential ribs. The lagging is of double-dressed, 2 × 3-in. segments, and the ribs are of 2 × 12-in. segments, 6 ft. long, lapping past one another and securely spiked together to form complete or partial circles. These ribs are spaced 2 ft. center to center.

Similar construction was used for form the taper base of the tower proper, except, of course, that the radii of the segments forming the successive ribs decreased with the height of the rib. Tapered lagging was used, being made by double dressing 2 × 6-in. pieces to 1¾ × 5$^{13}/_{16}$ ins. and ripping on a diagonal, thus making two staves, 3 ins. wide at one end and 2¾ ins. wide at the other. This tapered lagging was used again on the 4-ft. belt and cornic forms, the taper being turned alternately up and down.

The interior diameter being uniform up to the bottom of the dome, collapsible forms were used from the beginning. These forms were constructed in six large sections, 6 ft. high, with one small key section with wedge piece to facilitate stripping, as shown in Fig. 16. There were three tiers of these, bolted end to end horizontally and to each other vertically.

Above the taper base and except in the 4-ft. belt and cornice, collapsible forms were used on the outside also. There were six sections.

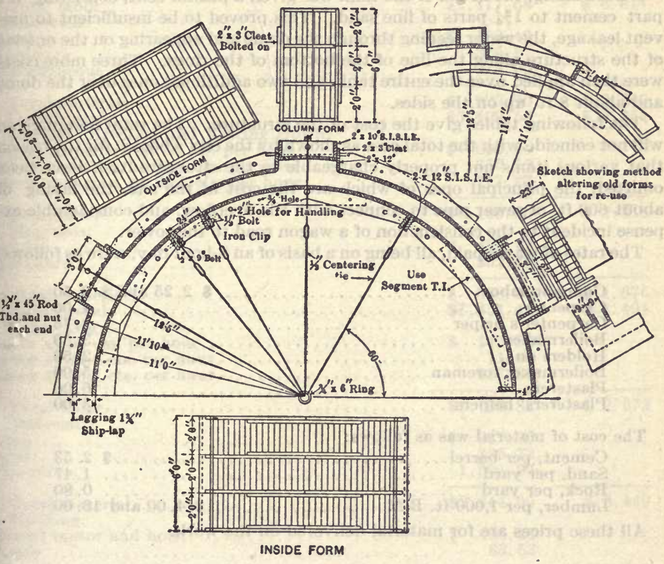


FIG. 16.—Movable forms for shaft of concrete water tower.

The concrete used was as follows: 1:3:6 for the sub-base and taper base; 1:3:5 for the barrel of the tower and tank casing; and 1:2:4 for the dome and roof. The dome was put in at one time, there being no joint, the same being true of the roof.

In order to insure a perfectly round tank, each course was erected against wooden templates accuratedly centered and fastened to the inside scaffold. The tank is the ordinary type of light steel, the lower course being 3/16-in., the next, No. 8 B. W. gage, the next, No. 10 B. W. gage, and the remaining four, No. 12 B. W. gage.

Work on the foundation was started on Aug. 15, 1908, and the tower was not completed until April 1, 1909. Much time was lost waiting for the delivery of the steel, and also owing to a period of very cold weather which caused entire cessation of work for about one month.

The tower as completed presents a striking appearance. In order to obliterate rings due to the successive application of the forms and to cover the efflorescence so common to concrete structures, the outside was given two coats of neat cement wash applied with ordinary kalsomining brushes, and, up to the present time, this seems to have been very effective in accomplishing the desired result. Irregularities due to forms are unnoticeable at a distance of 200 or 300 ft., and the grouting gave a very uniform color. The application of two coats of cement wash cost, for labor, $97.68, and for material, $15.18, or $1.32 per 100 sq. ft., labor being at the rate of $2.25 per 8 hours and cement costing $2.53 per bbl. delivered on the work.

Before filling, the inside of the tank was given a plaster coat, consisting of 1 part cement to 1¾ parts of fine sand. This proved to be insufficient to prevent leakage, the water seeping through the dome and appearing on the outside of the structure along the line of the bottom of the rings. Three more coats were then applied over the entire tank, and two additional ones over the dome and about 8 ft. up on the sides.

The following tables give the cost of the structure. The total herein given will not coincide with the total cost as shown by the city's books, for the reason that various items not properly chargeable to the structure itself have been omitted, the principal ones of which are the cost of the site, the laying of about 600 ft. of sewer pipe to connect with the overflow, and considerable expense incident to the construction of a wagon road to the tower.

The rates of wages paid, all being on a basis of an 8-hour day, were as follows:

Common labor	$ 2.25 and $ 2.50
Carpenter	4.00
Carpenter's helper	2.75
Boilermaker	3.50
Holders on	2.50
Boilermaker foreman	5.00
Plasterers	6.00
Plasterers' helpers	3.00

The cost of material was as follows:

Cement, per barrel	$ 2.53
Sand, per yard	1.47
Rock, per yard	0.80
Lumber, per 1,000 ft. B.M	$14.00 and 16.00

All these prices are for material delivered on the work.

An examination of the cost data, as given, will show that for the most part the unit costs are very high. This is due chiefly to the continued interruption of the work, during its later stages, owing to bad weather, particularly in the case of the erection of the steel tank. The material cost in this case was also exceedingly high. In the case of the concreting, inability to purchase a hoist and motor and the high cost of renting the same, together with the delays mentioned, added greatly to the unit cost. When it is considered that the cost of plastering covers that of four coats over the entire inside of the tank and three more over about one-third of it, it does not appear so high, especially in view of the high rate of wages paid. The cost per yard for concrete alone was $25.126, and this is probably about 25 per cent in excess of the cost of the same class of work executed under more favorable conditions as to location, weather conditions, etc.

The following costs have been rearranged and further analyzed by the editors of Engineering-Contracting from the tables given by the author:

Preliminary work:	Total	Per cu. yd.
Labor, carpenter at 50 cts. per hour	$ 11.00	
Labor, common, at 34.4 cts. per hour	64.94	
Labor, common at 28.1 cts. per hour	249.67	
Total labor	$ 325.61	$ 0.790
Materials	133.62	0.324
Total labor and materials	$ 459.23	$ 1.114
Forms: Building, Shifting, Stripping:		
Labor, carpenter, at 50 cts. per hour	$1,832.99	
Labor, common, at 34.4 cts. per hour	80.85	
Labor, common, at 28.1 cts. per hour	563.84	
Total labor	$2,477.68	$ 6.014
Materials:		
Lumber	$ 583.49	
Hardware	325.51	
Miscellaneous	13.90	
Total material	$ 922.90	$ 2.240
Grand total	$3,400.58	$ 8.254
Scaffold: Erecting and Tearing Down:		
Labor, carpenter, at 50 cts. per hour	$ 693.00	
Labor, common, at 34.4 cts. per hour	350.59	
Labor, common, at 28.1 cts. per hour	117.27	
Total labor	$1,160.86	$ 2.818
Materials:		
Lumber	$ 487.77	
Hardware	202.79	
Total materials	$ 690.56	$ 1.676
Grand total	$1,851.42	$ 4.494
Concreting:		
Labor at 50 cts. per hour	$ 142.00	
Labor at 34.4 cts. per hour	11.00	
Labor at 28.1 cts. per hour	947.81	
Total labor	$1,100.81	$ 2.672
Material:		
Rock	$ 317.30	
Sand	335.72	
Cement	1,591.97	
Total material	$2,244.99	$ 5.449
Hoisting:		
Rental motor and hoist	$ 406.56	
Power	83.53	
Total power	$ 490.09	$ 1.189
Grand total	$3,737.89	$ 9.316
Grand total concrete	$9,449.12	$23.178

These figures do not include apparently any charge for superintendence which with perhaps some other items may account for the difference between the final total and the cost of $25.126 for concrete given by the author of the paper.

The cost of plastering 3,000 sq. ft. was as follows:

Labor:	Total	Per sq. ft.
Plasterers, at 75 cts. per hour	$ 116.50	
Labor at 46⅞ cts. per hour	15.00	
Labor at 37½ cts. per hour	198.52	
Labor at 28.1 cts. per hour	105.66	
Total labor	$ 435.68	$0.1452

	Total	Per sq. ft.
Materials:		
Sand	$ 8.64	
Cement	66.10	
Alum and potash	16.00	
Total material	$ 90.74	$0.0302
Grand total	$ 526.42	$0.1754

The cost of washing 8,560 sq. ft. with cement wash was as follows:

Labor:	Total	Per sq. ft.
Common at 43¾ cts. per hour	$ 50.00	
Common, at 28.1 cts. per hour	47.68	
Total labor	$ 97.68	$0.0114
Material:		
Cement	$ 15.18	$0.0018
Grand total	$ 112.86	$0.0132

The itemized cost of the steel tank, 20,000 lbs., was as follows:

Labor:	Total	Per lb.
Carpenter at 50 cts. per hour	$ 124.24	
Helper at 34.4 cts. per hour	2.75	
Boilermakers	382.57	
Holders on	147.33	
Labor	40.61	
Foreman at 62.5 cts. per hour	186.25	
Total labor	$ 883.75	$0.0441
Materials:		
Tank, rivets, etc	$1,740.69	$0.0875
Grand total	$2,624.44	$0.1316

The various miscellaneous items of cost were as follows:

Windows, Doors, Etc.:	Total
Labor	$ 49.00
Material	47.26
Total	$ 96.26
Equipment, 40% of $461.46	$ 184.58
Ironwork: (Spiral stairway, inlet and overflow pipes, radiator, reinforcing steel, etc.):	
Labor:	
Machinists at 50 cts. per hour	$ 89.50
Helper, at 34.4 cts. per hour	240.16
Labor, at 28.1 cts. per hour	100.79
Total labor	$ 430.45
Material	$ 1,814.71
Grand total	$ 2,245.16
Grand total (tower, and tank complete)	$16,578.29

Construction of Reinforced Concrete Water Tower Using Steel Forms and Movable Staging.—In constructing the 650,000 gal. reinforced concrete standpipe at Westerly, R. I., the contractor used sectional steel forms and special reinforcement as described in Engineering-Contracting, Oct. 5, 1910.

The standpipe is 40 ft. inside diam. with 14-in. walls and is 70 ft. high. The wall reinforcing consists of 12 vertical 1½ pipe columns made in 3-ft. sections, connected by ordinary pipe couplings, spaced equidistant and extending from the bottom of the floor slab to the cornice. These pipe columns have drilled in them ¼-in. holes spaced the proper distance apart for attaching the horizontal reinforcing rods. These rods consist of fifty

1½-in. bars in the first 10 ft. from the base, thirty 1½-in. bars in the second 10 ft., then twenty-five 1½-in., thirty-four 1⅛-in., twenty-five 1⅛-in., fifteen 1⅛-in. and ten 1⅛-in. in each succeeding 10 ft.

The horizontal reinforcing bars are bent around the outside of the pipe columns and attached to them by ¼-in. round clamps. In the first 5 ft. 8 ins. from the bottom, the bars are doubled, being clamped to the inside and outside of the pipe column.

The steel forms are made up of 3 × 3 × ¼-in. angles and ⅜-in. boiler plate. The inside form is 6 ft. high and has a key section in which the plates

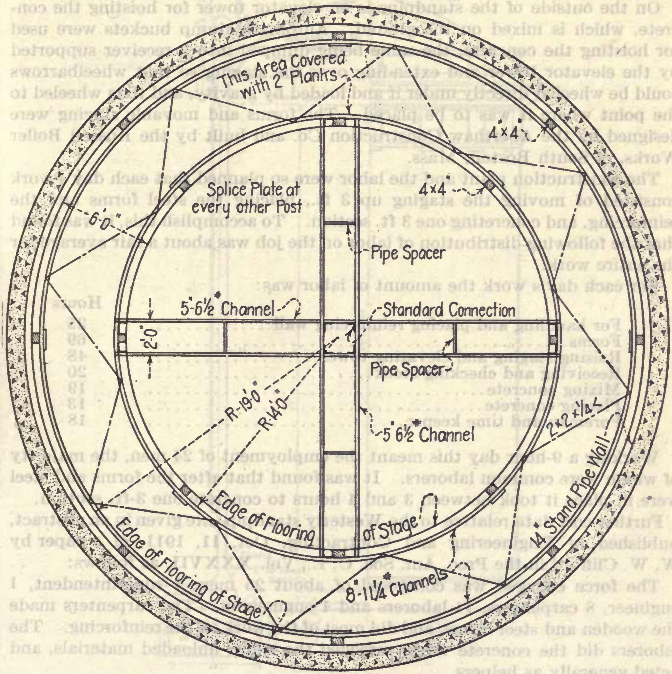


FIG. 17.—Plan showing erection staging.

lap about 6 ins., and on either side of the joint angles are securely riveted to the plates and connected by short turnbuckles, so that the whole form can be sprung in and reduced in diameter so as to make it possible to raise it when necessary. The outside forms are made in seven segments to the circle in sections 3 ft. high. Two complete sections are all that are used, as when one 3-ft. section has been erected and the concrete placed, the next section is placed on top of this, and by the time the concrete is placed in this section the lower form can be removed and placed on top. On the outside forms all the rivets are countersunk, and the face of the angles making joints are machined so as to secure a perfectly smooth fit, thereby securing a practically smooth finished surface.

The movable steel staging is located on the inside of the tower, Fig. 17. It consists of four 5-in. channels in the form of a cross joined at the center with a standard connection. Around these channels are bent two channels in concentric circles of 14 and 19 ft. radius braced with $2 \times 2 \times 1\frac{1}{4}$-in. angles. The floor of this staging is covered with plank, giving a platform 5 ft. wide around the inside of the standpipe. This platform was raised as the work progressed and held in place by 4×4-in. guide posts spaced 45° apart.

On the outside of the standpipe is an elevator tower for hoisting the concrete, which is mixed on the ground. Automatic dump buckets were used for hoisting the concrete, the same being dumped into a receiver supported by the elevator tower and extending over the staging so that wheelbarrows could be wheeled directly under it and loaded by gravity, and then wheeled to the point where it was to be placed. The forms and movable staging were designed by the Aberthaw Construction Co. and built by the Russell Boiler Works, of South Boston, Mass.

The construction plant and the labor were so planned that each day's work consisted of moving the staging up 3 ft., placing the steel forms and the reinforcing, and concreting one 3 ft. section. To accomplish this, it was found that the following distribution of labor on the job was about a fair average for the entire work.

For each day's work the amount of labor was:

	Hours
For handling and placing reinforcing wall	25
Forms	69
Raising staging and elevating tower	48
Receiving and checking stock	20
Mixing concrete	19
Placing concrete	13
Foreman and time keeper	18

Working a 9-hour day this meant the employment of 24 men, the majority of whom were common laborers. It was found that after the forms and steel were in place it took between 3 and 4 hours to concrete one 3-ft. section.

Further cost data relative to the Westerly standpipe are given in an abstract, published in Engineering and Contracting, Oct. 11, 1911, of a paper by W. W. Clifford in the Proc. Am. Soc. C. E., Vol. XXXVII, as follows:

The force engaged was composed of about 25 men: 1 superintendent, 1 engineer, 8 carpenters, 14 laborers and 1 engineman. The carpenters made the wooden and steel forms, and did most of the work on the reinforcing. The laborers did the concrete work, screened the stone, unloaded materials, and acted generally as helpers.

The lower section of the wall and the floor were put in on June 15 in 20 hours of continuous work. Each of the first few sections above the floor took 2 or 3 days. When well started, however, a 3-ft. section was poured in a day. This meant placing the steel and moving up the forms, in which all the men were used, the laborers as helpers, cleaning and greasing the forms, etc., then the stage was raised, usually about noon, and the concrete was poured in the afternoon. It was allowed to set for a few hours while the men were clearing up and getting ready for the next day's work, then in the early evening the concrete foreman and three or four laborers cleaned the top surface. The concrete was finished and ready for the dome 10 weeks after the floor was put in.

The cost of the work is given in Table XVII. In considering these costs note should be taken of the fact that certain parts of the work were done under pressure; namely, those parts for which the whole work waited. Other parts were done in a more leisurely manner, owing to the fact that men cannot work continuously at their maximum speed. For example: In the morning the first thing done was to place the steel, secondly, to raise the forms, and thirdly, to raise the stage. All these had to be done before concreting could begin.

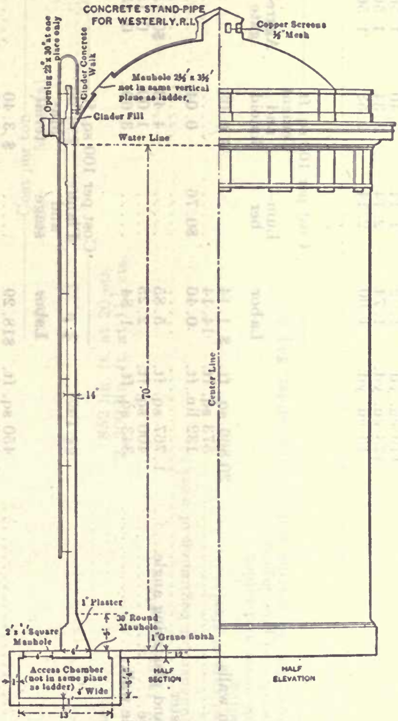


Fig. 18.—Elevation and section of reinforced concrete stand-pipe, Westerly, R. I.

This work was done by the carpenters working at maximum speed, some of the laborers acting as helpers. During this time the other laborers were screening stone, washing down the walls, etc., under no great pressure. Later in the afternoon the laborers were working at top speed on the concrete, while the carpenters were placing the necessary bracing on the staging, and getting ready for the next day's work, all at a less forced speed. Consequently, the labor costs for reinforcement, forms and concrete show up much better than those for staging, screening stone, finishing the wall, etc.

TABLE XVII.—COST OF REINFORCED CONCRETE STAND-PIPE AT WESTERLY, R. I.

Items	Quantities	Labor	Plant and stage	Cement and limoid	Aggregate	Total unit cost	Total cost
		Cost per cubic yard					
Concrete:							
In foundation	337 cu. yd.	$ 0.90	$1.44	$ 1.43	$2.09	$ 5.86	$ 1,975
In floor	119 cu. yd.	1.52	1.44	3.40	1.56	7.92	942
In walls and cornice	423 cu. yd.	1.74	2.14	3.34	1.56	8.78	3,714
In parapet	13 cu. yd.	1.00	2.14	2.53	1.56	7.23	94
In walk around roof							60
		Cost per 100 sq. ft.					
		Labor	Lumber	Cement and limoid	Aggregate		
Finish:							
Rubbing and wash on walls	20,866 sq. ft.	$ 1.14	.....	$ 0.03	.....	$ 1.17	$ 244
Packing on plinth	573 sq. ft.	14.14	.....	.....	.....	14.14	81
Plaster on plinth	132 lin. ft.	0.46	$0.76	0.04	.....	1.26	166
Picking angle for plaster	....	.....	.....	.....	.....	.....	33
Granolithic on floor and plastering angle	1,767 sq. ft.	5.85	.....	4.43	$0.15	10.43	184
Granolithic on cornice	400 sq. ft.	2.25	.....	1.00	0.15	3.40	14
Granolithic on outside walk	343 sq. ft.	1.84	.....	3.60	0.15	5.59	19
		Cost per 100 sq. ft.					
		Labor	Plant and stage	Material			
Forms:							
Foundation	450 sq. ft.	$18.29	.....	$ 3.40	.....	$21.69	$ 98
Plinth	1,249 sq. ft.	12.50	.....	2.20	.....	14.70	184
Walls	16,733 sq. ft.	4.40	$3.36	5.46	.....	13.22	2,212
Walls, triglyphs	1,208 sq. ft.	18.00	3.36	20.24	.....	41.60	502
Floor	247 sq. ft.	5.08	.....	2.20	.....	7.28	18
Cornice	1,163 sq. ft.	38.22	3.36	13.58	.....	55.26	643
Parapet	1,225 sq. ft.	13.63	.....	8.41	.....	22.04	269

	Quantity	Labor (cost per ton)	Stage (cost per ton)	Material (cost per ton)	Total per ton	Amount
Steel Reinforcement:						
Rods	68 tons	$ 9.73	$ 4.50	$39.00	$53.23	$ 3,619
Crosby clips						171
Pipe standards for steel	852 lin. ft. at 20 cts.					169
Hook spacers	2,200 lin. ft. at 1¼ cts.					28
Office and General:						
Telephone, stationery, traveling, etc						$ 200
Board						320
Travel and superintendence (at beginning of work)						56
Watchman and lights						50
Delay (waiting for lost cars of steel)						104
Clearing site and grading						120
Setting pipes, manhole cover and tablet						17
Miscellaneous extra work and pipe laying						196
Material for steel ladder, $90.50; setting and painting ladder, $44.25						135
Guastavino tile dome						1,200
Trap door in dome						9
Weatherproofing (test blocks)						10
Bond (surety)						105
Total						$17,961

The materials were delivered by a granite company, on a side track about 100 ft. from the site of the work, for 35 cts. a ton, the additional costs being for the labor of unloading and carrying the materials to the site of the work. The steel was carried by hand, and the cement in wheelbarrows. The stone and sand were delivered in piles beside the mixer by carts. The following prices were paid for labor:

	Cents per hour
Foreman carpenter	48
Foreman carpenter	43¾ and 45
Carpenter's helper	35
Engineman	35
Labor foreman	50
Laborers	22½ and 25

The following prices were paid for materials:

Cement per bbl. (less 30 cts. for bags returned)	$ 1.52
Sand, per yd., delivered at site	1.15
Stone, per yd., delivered at site	1.07
Limoid, per bag (100 lbs.)	1.00
Plaster of paris, per bbl	2.00
Steel, per ton, plus the freight	38.00

In Table XVII the cost of the stage is divided between concrete, forms, and steel, in the proportions of ¼, ½ and ¼. In the labor costs for the wall steel, about one-third is charged to bending and two-thirds to placing. In the secondary reinforcement, the cost of bending was a negligible quantity.

Cost of 300,000-Gal. Reinforced Concrete Standpipe. — The following data are taken from an article by L. R. Hanson published in Engineering and Contracting, Dec. 13, 1911.

The standpipe was built for the city of Norway on the upper Peninsula of Michigan near the Wisconsin state line. The walls are 12 ins. in thickness, 43 ft. high, and have an internal diameter of 35 ft. The forms were built in sections 5 ft. in length by 3 ft. in height, and two complete inside and outside rings were used. The concrete was a 1:1:2 mixture. The stone, specified as between ⅛ and ¾ in. size, was shipped from a point 300 miles distant and this item materially raised the concrete cost. Sand was obtained near the standpipe site. The cement was mixed with 10 per cent by volume of hydrated lime for waterproofing. Bending and placing the steel cost $5 per ton.

SUMMARY OF COST DATA FOR 300,000 GAL. REINFORCED CONCRETE TANK
(Prices do not include overhead charges or profit)

Walls—1 : 1 : 2 mixture, 235 cu. yds.

	Total cost	Cost per cu. yd.
Forms:		
Material	$ 422.00	$ 1.80
Labor	404.00	1.72
Total	$ 826.00	$ 3.52
Steel:		
Material	$ 906.00	$ 3.86
Labor	118.00	.50
Total	$1,024.00	$ 4.36
Concrete:		
Material	$1,377.00	$ 5.85
Labor	627.00	2.67
Total	$2,004.00	$ 8.52

Plaster:		
Material	$ 77.00	$ 0.33
Labor	265.00	1.12
Total	$ 342.00	$ 1.45
Doors, ladder, drains, etc	$ 237.00	$ 1.00
Removing debris, etc	80.00	.34
Total for floor and circular wall	$4,513.00	$19.22
Roof—1 : 2 : 4 mixture—20 cu. yds.:		
Forms	$ 54.00	$ 2.70
Material	140.00	7.00
Labor	38.00	1.90
Total	$ 232.00	$11.60
Total cost reservoir	$4,745.00	

Wages:	
Common labor, per hr	$0.25
Foreman, per day	8.00
Sand, cu. yds., delivered	1.00
Stone, cu. yd., delivered	2.65
Cement, bbl	1.75
Steel, lb., delivered at tank	0.02

After the entire tank was complete it was given three coats of plaster inside, mixed in the proportions of 1 part cement, 1½ parts sand, ¼ part hydrated lime and hydratite. The first coat of ¼ in. thickness was applied rough, and while still wet was covered with a second coat about ⅛ in. thick which was brought to a wood floated surface; this was next gone over with a brush coat and brought to a very smooth troweled finish. The plaster was applied in circumferential strips 6 ft. in height, and the cost of the three coats per sq. ft. of surface was 7¼ cts.

Upon the completion of the entire tank, it was filled and allowed to stand 48 hrs. and no change in the water level could be detected. For the first week, however, some sweating was noticeable, but in only one place was it of enough consequence to gather and flow, and this evaporated before it was 3 ft. below where it first appeared. No attempt was made to remedy the sweating other than emptying the tank and refilling in two days, but within ten days all discoloration disappeared and no sweating has since been apparent. The tank received a severe winter's test during the past winter when ice over 2 ft. in thickness covered the top and extended around the side walls of the tank as well.

The more successful waterproof construction effected in this tank using a 1:1:2 mixture than in others built under the same supervision and care but of 1:2:4 mixture, seems to justify the additional expense for cement. The plaster is also an effective "waterproofing aid" although how large a part of the good results here obtained, are due to the plaster and the 1:1:2 mixture respectively is a matter of personal opinion. Results secured by plastering other large tanks of 1:2:4 mixture would seem to indicate that the mixture was more important than the plaster face.

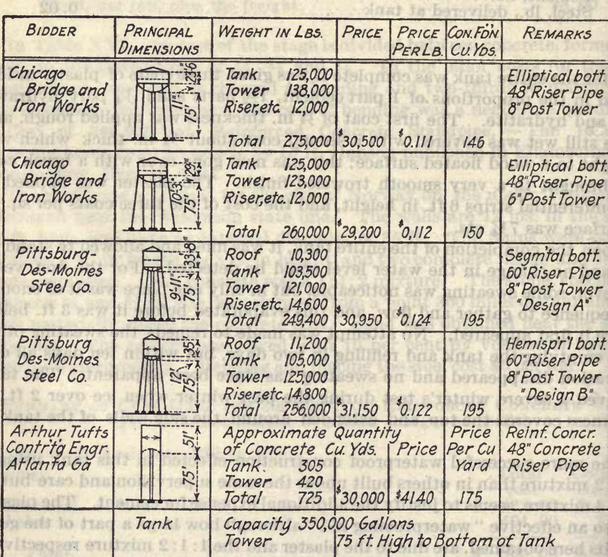
Cost of Steel Standpipes in Mass.—Table XVIII is taken from a paper by William S. Johnson published in the Journal of the New England Water Works Association, June, 1914, and reprinted in Engineering and Contracting, Sept. 30, 1914. According to the author the standpipes were constructed "recently."

TABLE XVIII.—COST OF STEEL STANDPIPES IN MASS.

Town	Size, diam. height, ft.	Capacity, gals.	Cost of foundation	Cost including foundations	Cost per 1,000 gals.
Bedford	20 × 100	235,000	$1,030	$6,640	$28.25
East Brookfield	25 × 50	184,000	300	3,550	19.30
Littleton	35 × 40	288,000	700	4,638	16.10
Marion	20 × 100	235,000	......	5,883*	25.00*
North Chelmsford	22 × 125	355,000	......	9,772	27.50
Oxford	27 × 50	214,000	400	5,060	23.60
Pepperell	45 × 40	476,000	839	6,707	14.10
Plainville	25 × 67	246,000	710	4,979	20.25
So. Hadley (Fire Dist. No. 2)	35 × 60	432,000	......	6,165*	14.30*
Wareham	20 × 100	235,000	......	6,835*	29.10*
West Groton	30 × 40	212,000	613	4,021	18.95
Wrentham	30 × 50	264.000	800	6,000	22.70
Wrentham State School	22 × 50	142,000	368	2,596	18.25

*Without foundation.

Cost and Weight of Steel Water Tank of 350,000 Gal. Capacity.—Fig. 19 from Engineering and Contracting, Oct. 31, 1917, gives a rèsumè of the bids



BIDDER	PRINCIPAL DIMENSIONS	WEIGHT IN LBS.	PRICE	PRICE PER LB.	CON. FDN. CU. YDS.	REMARKS
Chicago Bridge and Iron Works	23'-6" 11' 75'	Tank 125,000 Tower 138,000 Riser, etc. 12,000 Total 275,000	$30,500	$0.111	146	Elliptical bott. 48" Riser Pipe 8" Post Tower
Chicago Bridge and Iron Works	29' 10'-3" 75'	Tank 125,000 Tower 123,000 Riser, etc. 12,000 Total 260,000	$29,200	$0.112	150	Elliptical bott. 48" Riser Pipe 6" Post Tower
Pittsburg-Des-Moines Steel Co.	33'-8" 9'-11" 75'	Roof 10,300 Tank 103,500 Tower 121,000 Riser, etc. 14,600 Total 249,400	$30,950	$0.124	195	Segm'tal bott. 60" Riser Pipe 8" Post Tower "Design A"
Pittsburg Des-Moines Steel Co.	35' 12' 75'	Roof 11,200 Tank 105,000 Tower 125,000 Riser, etc. 14,800 Total 256,000	$31,150	$0.122	195	Hemispr'l bott. 60" Riser Pipe 8" Post Tower "Design B"
Arthur Tufts Contr'tg Engr. Atlanta Ga	51' 75'	Approximate Quantity of Concrete Cu. Yds. Tank 305 Tower 420 Total 725	$30,000	Price $4140	Price Per Cu Yard 175	Reinf. Concr. 48" Concrete Riser Pipe
	Tank	Capacity 350,000 Gallons				
	Tower		75 ft. High to Bottom of Tank			

FIG. 19.—Bids received by Akron, O., for elevated steel water tank.

received by the city of Akron, Ohio, Sept. 27, 1917 for constructing, furnishing and erecting an elevated steel water tank of a capacity of 350,000 gal., the tower to be 75 ft. high to bottom of tank.

Cost of Steel Standpipe at Youngstown, Ohio.—N. E. Hawkins in Engineering and Contracting, March 17, 1915, gives the contract price of a steel standpipe constructed in Youngstown, Ohio as follows:

2,400 cu. yds. earth excavation, at 40 cts.	$ 960.00
1,700 cu. yds. granulated slag fill, at 90 cts.	1,530.00
830 cu. yds. concrete, at $6.50	5,395.00
4-in. drain pipe	1.40
Brick valve house complete (10 ft. × 12 ft.)	516.32
Total masonry contract	$ 8,402.72
Standpipe proper	35,960.00
Total	$44,362.72

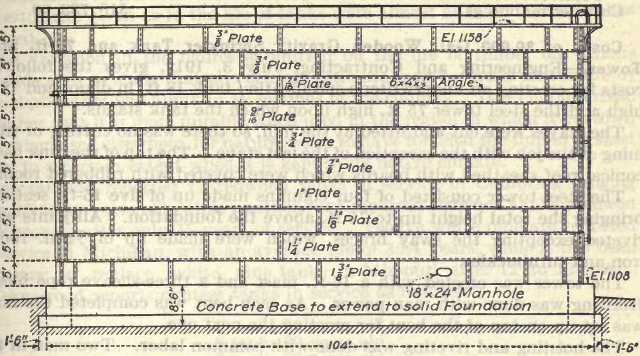


FIG. 20.—Elevation of new steel standpipe at Youngstown, Ohio.

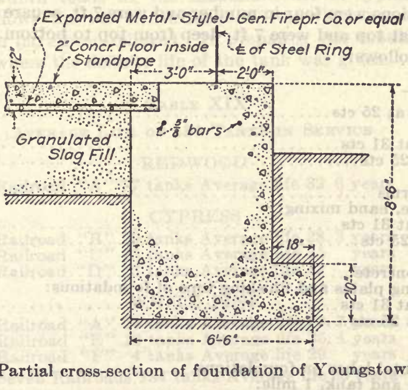


FIG. 21.—Partial cross-section of foundation of Youngstown standpipe.

The tank is 100 ft. in diameter and 50 ft. high and provides a storage of about 2,855,000 gals. making the cost per million gals. about $15,500.00. Figs. 20 and 21 show the principal features of the design.

Cost of 2,500,000 Gal. Steel Standpipe at West Roxbury, Mass.—Engineering and Contracting, Aug. 11, 1915 gives the contract prices to the Metropolitan Water and Sewerage Board of Mass. of the standpipe as follows:

COST OF STANDPIPE, ERECTED IN 1914

Excavation and concrete base 117.5 ft. diam., 2 ft. 8 ins. thick for width of 7 ft. at circumference, 3 ft. thick under 6 columns which support the roof, 12 ins. thick under remainder of tank	$ 6,382.28
Steel reservoir, 100 ft. in diameter, bottom ⅜ ins. thick, sides 44.25 ft. high from ⅞ to ⅜ ins. thick	19,397.00
Grouting under tank bottom 1 : 1 mixture requiring 222 bbls. of cement and 33 cu. yds. of sand	1,053.67
Total	$26,832.95
Cost per million gal	$10,733.00

Costs of 30,000 Gal. Wooden Gravity Sprinkler Tank and 75-ft. Steel Tower.—Engineering and Contracting, July 3, 1912, gives the following costs for erecting an underwriter's specification tank 18 ft. in diam. and 18 ft. high and the steel tower 75 ft. high upon which the tank stands.

The staves were cut and fitted at the mill, so there was no cutting or trimming at the job with the exception of the last stave. The top of the tank had a conical roof sheathed with boards which were covered with rubbered roofing.

The steel tower consisted of four columns made up of five 15-ft. sections, bringing the total height up to 75 ft. above the foundation. All joints were riveted excepting the sway braces, which were made up of ⅞-in. round iron and turnbuckles.

The tower was erected with a 16-ft. mast and a three-sheave rope block. Hoisting was done with man power. As each bent was completed the mast was set up on top of the bent for erecting the next one.

The hoisting and riveting was done with common labor. Two men in the gang were experienced in this work. The others of the gang were picked up locally.

The foundations were four in number and were 7 ft. square at the base and 30 ins. square at top and were 7 ft. deep from top to bottom. The itemized costs were as follows:

Excavation—	
221½ hrs. at 25 cts	$ 55.37
Forms:	
29½ hrs. at 31 cts	$ 9.15
33 hrs. at 25 cts	8.25
Total forms	$ 17.40
Laying concrete, hand mixing:	
19½ hrs. at 31 cts	$ 6.05
91 hrs. at 25 cts	22.75
Total concrete	$ 28.80
Grouting bearing plates and finishing tops of foundations:	
13½ hrs. at 31 cts	$ 4.03
2½ hrs. at 25 cts	0.68
Total	$ 4.71
Grand total labor on foundations	$106.28
Teaming tower and tank, 1 mile:	
Team, 19 hrs. at 60 cts	$ 10.80
Laborers, 37 hrs. at 30 cts	11.10
	$ 21.90
Erecting tower and tank and painting two coats:	
643 hrs. at 30 cts	$182.00
	$204.80
Grand total	$311.08

Superintendence is not included in the above figures. The superintendent spent 198 hours on the job.

Life of Wooden Water Tanks in Railway Service.—The following data published in Engineering and Contracting, Nov. 13, 1918, are given by C. R. Knowles, Superintendent Water Service, Illinois Central R. R., in a paper presented at annual convention of the American Railway Bridge and Building Association. In collecting the information letters of inquiry were sent to 45 railroads and 27 answers were received.

While much valuable information was obtained from the replies, the figures and estimates given as to the life of tanks were almost as many as the replies received.

The variation in the figures submitted on the life of timber on various railroads goes to show that no accurate estimate may be made on the life of tank timber that will apply to all sections of the country. It is characteristic of timber that it is more durable when used in the region in which it is grown than when used elsewhere, for nature seems to have fortified the timber against decay to a certain extent when it is kept in its native climate.

One railroad reported 77 redwood tanks in service in California ranging from 26 to 48 years old, while another road reported redwood tanks renewed in Wisconsin after only 15 years of service. Twelve white pine are reported in service in Michigan, with an average life of 35.4 years, while it has been necessary to replace white pine tanks in Missouri after 12 to 13 years. A Texas road reports cypress tanks in service as follows:

5 tanks 31 years old,
8 tanks 30 years old,
3 tanks 29 years old,

while several eastern roads fix the maximum life of cypress at 25 years.

Table XIX shows the life of 310 tanks, 184 of which are still in service, and 126 of which have been relieved. In preparing this tabulation only figures were used where the definite life of the tank was given.

TABLE XIX

AVERAGE LIFE OF 184 TANKS IN SERVICE

REDWOOD			
Railroad "A"	77 tanks	Average life	32.6 years
CYPRESS			
Railroad "B"	29 tanks	Average life	28.3 years
Railroad "C"	25 tanks	Average life	25 years
Railroad "D"	3 tanks	Average life	32 years
WHITE PINE			
Railroad "A"	24 tanks	Average life	29.7 years
Railroad "E"	12 tanks	Average life	35.4 years
Railroad "F"	4 tanks	Average life	29 years
Seven Railroads	184 tanks	Average life	30 years

AVERAGE LIFE OF 126 TANKS RELIEVED

CYPRESS			
Railroad "B"	24 tanks	Average life	27.3 years
Railroad "G"	16 tanks	Average life	30 years
Railroad "D"	3 tanks	Average life	32 years
	43		29 years

WHITE PINE

Railroad "H"	27 tanks	Average life 27.5	years
Railroad "B"	22 tanks	Average life 25.8	years
Railroad "I"	14 tanks	Average life 23	years
Railroad "F"	4 tanks	Average life 29	years
Railroad "D"	3 tanks	Average life 33	years
Railroad "E"	3 tanks	Average life 38.3	years
Railroad "C"	5 tanks	Average life 27	years
	78	Average life 27	years
YELLOW POPLAR			
Railroad "C"	3 tanks	Average life 30	years
RED CEDAR			
Railroad "C"	1 tank	Average life 28	years
YELLOW PINE			
Railroad "C"	1 tank	Average life 29	years
Eight Railroads	126 tanks	Average life 28	years

It will be noted that the white pine tanks show a higher average life than the cypress tanks in the table of tanks still in service while the opposite is true in the table of tanks relieved. This may be explained by the fact that cypress tanks were not used as extensively as white pine tanks up to 20 years or so ago, and on the roads shown there are probably many white pine tanks which were in use before cypress tanks were constructed, although there is apparently very little difference in the durability of the two woods.

It is interesting to note that a yellow pine tank is shown with a life of 29 years while the life of a yellow pine tank as constructed today would probably not exceed 12 years. This difference in life can probably be explained in the fact that the trees from which the tank mentioned was cut had not been bled of the rosin and preservative oils natural to the wood. It should be explained that the life of 28 years given the red cedar tank did not represent the extreme life of the timber as when the tank was taken down the best of the timber was used in the construction of a smaller tank which is still in use. The original tank was constructed in 1870, which makes the timber in the smaller tank 48 years old.

In the letters received many records were given showing a life of only 10 to 15 years for cypress, white pine and redwood tanks. This was unfair to the timbers mentioned as the short life obtained was undoubtedly due to poor selection of timber, poor construction, the tank not being kept filled with water or some one or more of a number of faults that would cause early decay.

Conditions of Steel Water Tank After 30 Years' Service.—Walter E. Miller gives the following notes in an article published in Engineering News-Record, March 31, 1921.

The water tank with supporting and inclosing masonry tower of the water-works of Madison, Wis., was erected in 1890. Its demolition was completed early in January, 1921. It was removed because (1) the daily consumption of water and the pumping rates had so greatly increased since the tank was erected that the size of the tank became too small to be of material value, and (2), because the tower and tank obstructed an important street. The history of this structure shows how greatly the allowances for depreciation might differ, depending upon whether they include or exclude the functional as well as physical depreciation.

The structure consisted of a steel tank, 12⅓ ft. in diameter by 60 ft. high, supported and enclosed by a cylindrical brick wall above a one-story square structure of stone masonry. The bottom of the tank was 72 ft. and its top was 132 ft. above the street.

The tank rested on a grillage of steel rails laid upon four 16-in. I-beams carried by the heavy brick wall. Above the bottom of the tank the wall had three thicknesses, nominally 8, 6 and 4 in. The lower third of that portion was laid in conact with the tank and had a thickness of the widths of two bricks laid flat. For the middle third of the tank the wall consisted of two rings of brick, one laid flat and one on edge, and was 2 in. from the tank. Around the top third of the tank 4 in. from it was a wall one brick width in thickness.

Examination of the structure before and during its removal revealed but little deterioration; so little as to make it appear that its thirty years of actual service would be but a small part of its possible physical life. The most noticeable and important deterioration was incipient disintegration of the outer brickwork near the level of the bottom of the tank, but this might have been repaired at moderate expense had the continued use of the structure been desired. Notwithstanding the apparent fact that the tank plates had never been cleaned and repainted the greater part of their surfaces was still well preserved and smooth, although in places the paint was gone and rust had formed. In a few places there was a noticeable pitting of the metal, but in no case had this gone far enough to warrant any apprehension as to weakening of the plates.

Data on Life of Iron Water Tank and Cost of 537,000 Gal. Elevated Steel Tank at Princeton, N. J.—The following notes are given in an article by R. W. Becker in Engineering News, Jan. 27, 1916.

In 1883 the firm of Tippett & Wood, of Phillipsburg, N. J., fabricated and erected an elevated water tank at Princeton, N. J., for the Princeton Water Co. The capacity of the tank was 141,000 gal. The growth of the town since has made it inadequate and it was replaced by a 537,000-gal. tank, built by the same firm early in 1915.

Recent inspection of the old materials (iron tank and tower) showed that the tower was exceptionally well preserved. Rust had not caused sufficient deterioration in the tank plates to be perceptible by calibration. The tank received two coats of paint when it was erected and had been painted once every 3 to 4 years since. It had always been filled with water. The only repair required was the replacing of the oak timbers under the tank by 6-in. steel I-beams, 5 yr. ago. The wood was decaying rapidly and appeared unsafe to carry the load much longer after 25 yr. of use.

The old tank and tower were torn down carefully, so as not to injure the plates, by cutting off and backing out the rivets, Each piece as it was cut off was carefully lowered to the ground. As the tank was in such good condition, it was reërected on a concrete foundation at Lawrenceville, N. J., where it is now in service. The tower was reërected at New Brunswick, N. J., where it is supporting a wooden tank of 100,000 gal. capacity. The cost to Tippett & Wood of taking down the old tank and tower was $1,000.

The new tank is 45 ft. in diameter, 30 ft. high from the top to the beginning of the curved bottom, and 58½ ft. high overall. The steel tower supporting the tank is 87½ ft. high from the column foundations to the balcony. The distance from the base of the columns to the peak of the roof is 133 ft.; and from the ground to the top of the finial about 135 ft.

Although the columns are vertical, the tower is very stable on account of the large diameter of the tank. Each column is anchored to a massive concrete pier by four 1½-in. round anchor bolts. The total cost of the structure was about $26,000.

CHAPTER VII

WATER WORKS

This chapter, while touching upon the general subject of waterworks, lays special stress upon the particular phases of construction costs usually allotted to the field of civil engineering. Additional data on pipe costs are given in the chapter on Irrigation and data on operating and construction costs of water treatment plants are given in the following chapter.

For further data the reader is referred to: Gillette's "Handbook of Cost Data" Section VII, Waterworks; Gillette's "Earthwork and Its Cost" and "Handbook of Rock Excavation" for trenching costs and to Gillette and Dana's "Handbook of Mechanical and Electrical Cost Data" for costs of pumps and pumping.

Construction and Operating Costs.—The following matter is abstracted from Hazen's "Clean Water and How to Get It" (1914)

In America water works receipts average about $2.50 per capita for the population supplied, but figures ranging all the way from $2.00 to $4.00 are common, and some figures are outside of this range. These are for publicly owned works. Private companies average to make about the same collections for domestic rates, and in addition they are paid for fire service, so that their total receipts average about $3.00 per capita. Publicly owned works as a rule receive no separate payment for fire protection.

There seems to be no well marked tendency to either higher or lower collections per capita in the larger cities, as compared with the smaller ones. Large cities usually have to go farther for water. Small sources near at hand are not available to them, and it would seem reasonable to suppose that the relative cost would be greater. But it seems that the savings which are made by operating on a larger scale offset this tendency, and on the whole, the expense of securing water is just about the same on an average in proportion to population in small cities and in large ones.

The disposition of the $2.50 per capita collected on an average in America is about as follows: First, in works where the supply is from a gravity source, and no purification is used, about $0.50 per capita annually is used for paying the general expenses of administration, of taking care of services, meters, etc., of making repairs, and of maintaining the works generally. The $2.00 remaining pays 4 per cent interest, and 1 per cent depreciation, or together 5 per cent capital charges on a cost or value of works averaging $40 per capita. The $40 is about equally divided between the distribution system, which includes the pipes in the streets of the city, the services, meters, etc., and the source of supply, which includes all the works for securing the water and bringing it to the city.

Second, in works where the supply is pumped from a river or lake near at hand, with or without purification, about $0.50 is used for the general expenses as above mentioned. Another $0.50 is used for pumping and purification (rather more when the water is purified; less when it is not); and the remaining $1.50 pays 5 per cent capital charges on an average investment of $30 per capita, of which $20 is in the distribution system and $10 in the source of supply.

Gravity sources of supply cost more to secure, but are cheaper to operate.

The above mentioned figures are general approximations, given to show general water works conditions in America at the present time, but wide fluctuations will be found in individual cases.

Some cities are so located that no good, adequate source of supply is near at hand; and where water is brought from long distances and is pumped and purified, it is clear that it cannot be delivered at the cost or sold at the price that is fair for a water drawn from a pure and ample source near at hand.

Then the cost of distribution differs. In a city on level ground where one service or one system of pipes does for all, the cost both of construction and of operation is less than on a hilly site where separate high service districts must be maintained, involving additional pipe systems and additional pumping stations. And a city that is compactly built up, so that it can be served with a pipe system having a mile or less of pipe per thousand of population, can be more cheaply served than a scattered city with long lines of pipe running out where there are but few houses, and where, taking it right through, two or even three miles of pipe are required per thousand of population.

Cities that waste large amounts of water have to pay for it. The cost of the works is greater, and this cost is sure to be represented sooner or later in the assessments.

Matters of these general natures largely explain why some cities can be supplied for less than \$2 per capita while others must collect over \$4 per capita.

The service of water is one of the cheapest. The average American family pays far more for gas, for ice and for milk, than for water. In my own household in New York, taking the cost of Croton water at \$1, the average cost of other household supplies is as follows: Ice \$3, Light \$4, Telephone \$5, Coal \$13, Milk \$15. Taking into account the nature of the water service, which has become absolutely indispensable, the low cost is very remarkable.

Rates Charged for Water Service.—Berlin, Germany, collects twelve marks, equal to about three dollars per annum, for each service, and in addition collects payment for all water recorded by the meters. Milwaukee has similarly collected one dollar per annum for each service, but this is clearly too low a figure. It will not pay for the maintenance of the services and meters.

A better way is to base the payments upon the size of the service. Most of the services of a system are domestic services, that is to say they serve residences. These services are commonly five-eighths of an inch in diameter. The assessment on these may be placed at \$3.00 per annum, let us say. Some takers insist on a larger service because they wish to draw water more rapidly. Many discussions take place because the prospective taker is insistent on a larger service, while the water works superintendent believes the usual size to be sufficient. Why not let the taker have a service as large as he likes and charge him for it in proportion to its size, or, let us say, approximately in proportion to its ability to deliver water?

Starting with a charge of \$3.00 for a five-eighth inch service, and using round figures, the charge for larger services, not including the charge for water would be

For ¾-inch	\$ 5.00 per annum
For 1-inch	10.00 per annum
For 1½-inch	20.00 per annum
For 2-inch	30.00 per annum
For 3-inch	70.00 per annum
For 4-inch	125.00 per annum
For 6-inch	300.00 per annum
For 8-inch	500.00 per annum

This arrangement has the practical advantage of making a substantial charge for a substantial service, and for a service that too often is not adequately paid for, where large pipes lead from the mains into mills, warehouses, etc., for fire purposes only, and from which pipes ordinarily no water is drawn.

These pipes cause more trouble to water departments, and the privileges granted are subject to more gross abuse, than those from any other class of service; and it is right and proper that substantial payments should be made for them.

Such large fire services should always be metered and they should not be allowed to exist on any other condition. This has not been possible until recently, but it can be done now, for a type of meter has been invented which is satisfactory from a water works standpoint, and which does not interfere materially with the value of the pipe for fire service. With this meter the water ordinarily passes through a by-pass on which there is a small meter. But in case of need, that is in case of fire, a valve on the main line opens automatically and the full quantity of water that the pipe will carry flows through it unobstructed for use. Even in this case an approximate idea of the amount of water drawn is registered by some extremely ingenious devices which are only brought into play when the main valve is opened.

The general idea of charging in proportion to the areas of the service pipes has been expressed in the form of minimum rates at Cleveland and other places. I do not know that it has been followed anywhere to its logical conclusion, as above outlined.

Another way to divide the sum to be taxed on services is in proportion to fixture rates. This method is applicable especially in cities which are gradually changing from fixture charges to the meter system. In this case the fixture rates are known for each house. Supposing it is decided to assess one-third of the whole amount to be raised upon fixtures then when a meter was installed on a given service the charge for that service would be one-third of the previous fixture rate, and in addition all water used would be charged for.

For these conditions this system has much to recommend it. But it is a transition system. When all services are metered it is not to be supposed that it will be worth while to continue making fixture rates.

In the case of an excess of revenue being demonstrated, the charge for water could be reduced to six cents or to five cents as the business would stand, or the charge for services might be lowered. Practical experience with the general method would be available to indicate where the cuts could be best and most equitably made.

The use of a sliding scale, that is to say, or making lower rates to large takers, is firmly fixed, and it will be hard to do away with the idea. But the writer believes that such a scale as that suggested contains all the provisions of this kind that are necessary or wise.

In the first place this kind of scale is in reality a sliding one. The small cottage pays, let us say, $3 per year for the service, and in addition uses water charged at $0.10 per 1000 gallons, let us say, amounting to $3 per year in addition. The total payment is $6 per year and the average cost of water to the taker is $0.20 per 1000 gallons.

A larger taker pays, let us say, $12 per year for his service, and uses at the same rate water worth $120 per annum. The whole bill is then $132 and the average cost of water to him is $0.11 per 1000 gallons, against the $0.20 paid by the smaller taker.

The basing figures of course are to be fixed to meet local conditions, and when so fixed they will give all the slide that is desirable. There is no reason why the man in a cottage, who lets his plumbing get out of order and wastes an extravagant quantity of water, should be asked to pay a larger price per thousand gallons for the water wasted by his neglect than is paid by the largest establishment.

Manufacturers are often supplied by cities at special rates which are less than cost. This is most frequently done on special pleas, and is comparable to giving exemption from taxation. The practice is not a wise one and should not be encouraged.

Low rates are also often made to secure customers who would not otherwise use water or who would not use so much. This is most apt to be done in the early days of operation of a system when the capacity of the works built in anticipation of growth is beyond present requirements. Hydraulic elevators and motors are most common and objectionable subjects for such special rates. As long as the capacity of the works is really in excess of the demand, a little financial help is received by the department from such rates; but as soon as the capacity of the plant is approached such rates become a drag and a source of loss. Experience shows that they are not, and cannot possibly be shut off promptly when they cease to be profitable. It is, therefore, better and safer to charge the regular rates for water used for these and all other special purposes, and to take good care that all water so used is paid for. Some revenue will be lost; some elevators and printing presses will be driven by electricity instead of by water power, but electricity is a better way of transmitting power than water under pressure, and in the end all will be better off.

American cities having high service systems make precisely the same charges for water from them as for water from the low service pipes. The man on the top of a hill with high service water pays no more than the man in the valley, though to supply him costs the city usually from two to five cents more per thousand gallons, and where the high service districts are small and isolated the extra cost may greatly exceed these figures. There seems to be no well-founded reason for this equality in charge with clearly defined difference in cost of service.

It would seem rational and wise to charge more for high service water than for low service water, and to establish the differential carefully at so many cents per thousand gallons, to pay as nearly as it can be computed for the additional cost of the high service water; and the differential should be subject to revision from time to time as the conditions of service change. Usually it would be higher at first, with few takers, and less as the quantity sold became greater.

The present method is unfair to those on low ground. They pay their share (usually the largest share) of the excess of supplying water to those located on the hills. And this is the more unfair, as the hill sites are usually more desirable for residences, and those who live on them are well able to pay the added cost which their service entails on the water department.

I have described this meter rate question at some length, because I feel strongly that present methods of charging are in general unfair and unreasonable, and because I believe that the adoption of the general principles here outlined will do a great deal to improve the situation.

The sooner arbitrary and unreasonable methods are abandoned, and more reasonable methods are adopted, the better it will be for both consumers and

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for water departments, and the easier it will be to supply clean water and to make the financial arrangements for doing it.

The Required Sizes of Filters and Other Parts of Water Works.—The following matter is given in Hazen's "Clean Water and How to Get It" (1914).

One of the most perplexing questions to a beginner is to find the reasons for the apparent discrepancies in the sizes of the different parts of a well designed water works system. If a system is capable of supplying 15,000,000 gallons per day, it would seem at first thought that all parts should be of this capacity and that nothing beyond it would be necessary. But this condition is never realized. The pumps have one capacity, the pipes another, the filters still another, and the plant is declared to be too small while the average consumption of water is below any of the figures given for the capacities of the component parts.

In laying out a system of works there is no matter which calls for more careful study than the most advantageous sizes of these component parts. To some extent these sizes are not capable of calculation, but are matters of judgment. The judgment to be valuable must be based on extended experience, and must take into account all the particular conditions in the case in hand.

Let us take a particular case to illustrate in a general way the method of getting at these sizes.

The city under consideration has a present population of 80,000, we will say. The works now built should be large enough so that no addition will be required for ten years. In some parts it may be worth while to anticipate growths for a longer period. The rate of growth to be anticipated is judged from the past rate of this particular city, and of other cities similarly situated, taking also into account any special conditions likely to make it grow either more or less rapidly than it has done, or than its neighbors. In this case we will say that, all things considered, 25 per cent per decade seems a reasonable allowance. Adding 25 per cent to the present population brings us to a population of 100,000, which must be provided for in the first construction.

The amount of water per capita is next to be considered. This depends somewhat upon the habits of the people as to the use of water for domestic purposes, and for watering lawns and streets; somewhat upon the amount of water sold now or likely to be sold for manufacturing, railway, and trade purposes; and still more upon the amount of water that is wasted by takers and the amount lost by leakage from the pipes.

The present consumption we will say is 100 gallons per capita daily. A greater manufacturing use is to be anticipated, but on the other hand, it is proposed to install more meters upon the services which will reduce the waste. This will offset the increase in actual use per capita, and we will consider 100 gallons per capita daily as the probable consumption ten years hence.

The quantity of water to be provided is thus 100 gallons per capita for a population of 100,000, or 10,000,000 gallons per day.

Ten million gallons per day is the average daily amount for the year. Sometimes the use will be less and sometimes more than the average. There are few cities where the maximum month does not exceed the annual average by 15 per cent. There are some where it is 50 per cent greater. In this case 25 per cent is assumed.

The maximum monthly consumption will thus be 25 per cent above the average, or 12,500,000 gallons per day.

The maximum daily consumption must be taken as 10 per cent more than this figure, or 13,750,000 gallons per day.

During some hours of the day the rate of consumption is far greater than at other hours. The excesss of the maximum hourly rate over the average daily rate is more nearly in proportion to the population supplied than it is to the average amount of supply. In other words, the use of water fluctuates, while the waste does not fluctuate, and where waste is large in proportion the fluctuations expressed in percentage of the whole are less. In this case a rate of 80 gallons per capita is taken as representing the excess of maximum rate of consumption over the average of 100. The maximum rate of use, therefore, will be at the rate of 180 gallons per capita, or 18,000,000 gallons per day.

This does not include the water required for fire service, which must still be added. For ordinary fires which are quickly put out, no very heavy drafts are made. But for the larger fires, which occur at long intervals, a liberal supply must be furnished.

In this case, taking into account the nature of the situation and value of the property, we assume that water to supply 30 standard fire streams should be available. Such streams use 250 gallons of water per minute, or at the rate of 360,000 gallons per day for each fire stream. Thirty streams will require water at the rate of 10,800,000 gallons per day.

If this was added to the maximum rate of use, 18,000,000 gallons per day, it would give the extreme maximum rate to be provided for of 28,800,000 gallons per day.

Actually there is so little probability of the occurrence of the maximum fire at precisely the time of the maximum use of water for other purposes that we can afford to take a few chances on it, and this figure may be cut somewhat. With an average use of 100 gallons per capita, rates exceeding 130 gallons per capita would not occur for more than a small percentage of the time. This would be 13,000,000 gallons per day. Adding our 30 fire streams, or 10,800,000 gallons per day, to this, we have 23,800,000,or say 25,000,000 gallons per day, as the amount which the works must be capable of supplying when there is demand for it in case of a heavy fire.

It is only necessary to prepare to supply water at this highest rate for three or four hours, but the works must be able to supply water at the maximum daily rate of 13,750,000, or say 14,000,000 gallons per day, when required, for a number of days in succession.

We can now take up the sizes required for the different parts of the works.

If an impounding reservoir and its catchment area are sufficient to maintain a constant supply in a dry year equal to the annual average contemplated use, that will suffice. The reservoir will take care of fluctuations in the rate of draft, and no computation need be made of the effect of such fluctuations.

The pipe line leading from the impounding reservoir to the distributing reservoir near the city must have a capacity equal to the maximum daily use of 14,000,000 gallons per day, or 40 per cent above the average annual use.

The hourly fluctuations will be balanced by the distributing reservoir. The storage capacity required to balance the fluctuations of ordinary use will be about 15 per cent of the average daily use or 1,500,000 gallons. In addition to this, enough capacity to maintain the maximum fire draft for four hours should be added. This will require:

$$\tfrac{4}{24}\,(25 - 10) = 2{,}500{,}000 \text{ gallons capacity.}$$

This makes the required capacity of the distributing reservoir 4,000,000 gallons.

It is not usually convenient to so operate a plant as to keep the distributing reservoir always full, and a fire might occur when it was somewhat drawn down. To provide for this a further allowance should be made, bringing the capacity to 5,000,000 gallons, or one-half a day's average supply. And if the fire risk is large, the site suitable, and the financial conditions warrant it, a larger reservoir, up to at least a full day's supply, will be safer and better.

Purification works and pumps, if used, located between the impounding reservoir and the distributing reservoir, must have capacities equal to the maximum day's use, and, in addition, reserve units or capacity must be provided to cover the time lost in cleaning filters and in repairing pumps; and it is customary to have a reserve unit of each kind, so that the supply would not be crippled by having one pumping or filtering unit out of service for some time.

As a general rule, where the distributing reservoir balances hourly fluctuations and provides for fire service requirements, the filters should have a capacity a half greater than the average rate of consumption, and the pumps should have a nominal capacity twice as great as the average rate of pumping.

The average rate of the filters will thus be two-thirds of the maximum rate, and the pumping machinery will operate equal to one-half its nominal capacity when the capacity of the plant is reached. At all other times the ratio of use to capacity will be less.

The pipes from the distributing reservoir to the city, and through it, must have a capacity up to the maximum rate of use of 25,000,000 gallons per day.

If the water is pumped from the reservoir to the city, the pumps must have this capacity with one unit in reserve. This means practically that the pumps for direct service must have a capacity equal to three times the average rate of use. In small works the pumps must be even larger than this in proportion.

It never pays to build filters and purification works to meet the maximum rate of consumption. Even in case of a river supply and direct pumping of the filtered water into the distribution pipes, it pays to provide a pure water reservoir at the filters to balance the hourly fluctuations in rate. This permits the purification plant to work at a constant or nearly constant rate throughout the twenty-four hours, which is advantageous.

The figures used in this illustration are representative, but there are reasons in particular cases why higher or lower values must be used. But in every case there are certain ratios that must be met. With pumps capable of lifting 10,000,000 gallons per day, and filters capable of filtering, and pipes capable of carrying this quantity, it has never been possible, and it never will be possible, to deliver under the required conditions of practical service 10,000,000 gallons of water per day, nor even an approximation to this amount.

This matter, although very simple, is mentioned at length because it is one of the most common matters to be misunderstood, and a perfectly clear understanding of it is essential.

Some most important projects have been seriously defective and incapable of their supposed capacities because of inadequate allowances of this kind.

Waterworks Data for Small Towns and Villages.—Prof. D. D. Ewing gives the following in Engineering and Contracting, April, 14, 1920.

The data for the accompanying statistical graphs and empirical equations were drawn from the descriptions of waterworks plants contained in "Municipal Water Supplies of Illinois," by Edward Bartow, Bulletin of the University of Illinois, Water Survey Series No 5,1907 and "Water Supplies of Kansas," by C. A. Haskins and C. C. Young, Engineering Bulletin No. 5, University of Kansas, 1915.

In Fig. 1 are plotted the relations between water consumption in gallons per capita per day and population for small towns in Indiana, Illinois and Kansas. As is indicated in the figure the points through which the graphs are drawn are averages for a number of communities of about the same size. The water consumption of a town depends on a number of factors, some of the most important being:

Industrial development.
Social characteristics of the people.
Climate.
Character of the water supply.
Sewerage development.
Percentage of metered services.

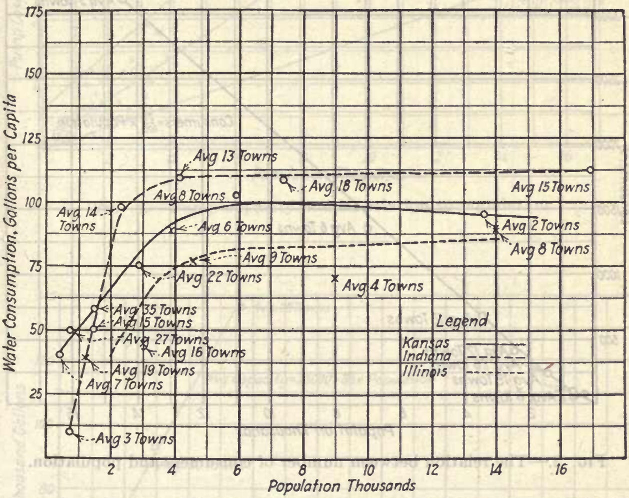


FIG. 1.—The relation between water consumption and population.

As the graphs represent average values it is to be expected that in specific cases there may be wide deviation from the figures indicated by the graphs. For example, in a small country town of the poorer type with nothing in the way of sewer systems and industries the consumption may be as low as 5 gal. per capita per day. On the other hand in a small city containing a number of fairly large water using industries the consumption may reach 500 gal. per capita per day.

A study of the graphs indicates that for ordinary middle west towns of less than 4000 population the average daily water consumption may be expressed by

$$\text{Gallons per capita per day} = \frac{\text{Population}}{40}$$

For towns of more than 4000 population the average consumption is independent of the population and is about 100 gal. per capita per day. In passing it may be stated that reliable water consumption data are very hard to obtain since in only a very few of the plants of the country is the water pumpage metered.

The relation between number of consumers and population for small Kansas communities is shown in Fig. 2. Mathematically the relation is approximately expressed by.

$$\text{Number of consumers} = 21 \times \frac{\text{Population}}{100},$$

or roughly the average number of consumers is one-fifth of the population.

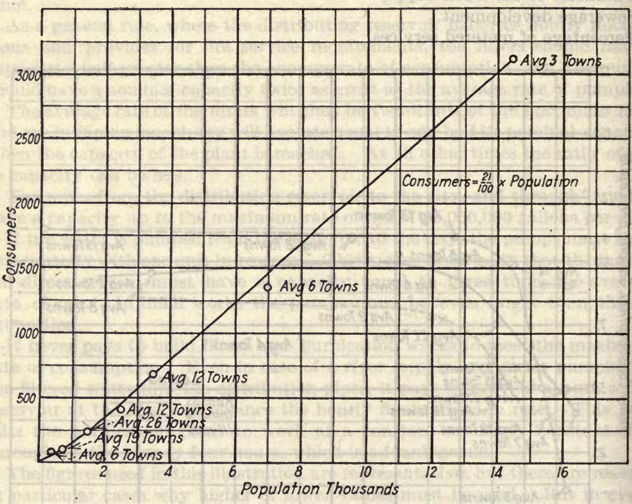


FIG. 2.—The relation between number of consumers and population.

Fig. 3 shows the relation between pump capacity in gallons per minute and population and indicates the method used in determining the relation. The figures plotted are for Kansas towns and the equations of the graphs are:

$$\text{Pump capacity (maximum)} = 600 + 43 \times \frac{\text{Population}}{100}.$$

Pump capacity (average) = 100 + $\frac{1}{8}$ × Population.
Pump capacity (minimum) = $\frac{1}{6}$ × Population.

Similar studies of pump capacity data for Illinois and Indiana plants give the following equations:

Illinois plants:
Pump capacity (maximum) = $\frac{5}{8}$ × Population.
Pump capacity (average) = $\frac{26}{100}$ × Population.
Pump capacity (minimum) = $\frac{1}{8}$ Population.

Indiana plants
Pump capacity (maximum) = $\frac{11}{12}$ × Population.
Pump capacity (average) = $\frac{43}{100}$ × Population.
Pump capacity (minimum) = $\frac{1}{10}$ × Population.

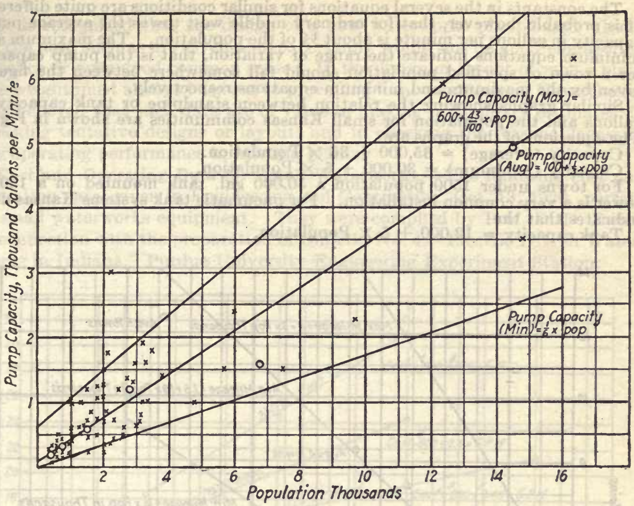


FIG. 3.—Pump capacity and its relation to population.

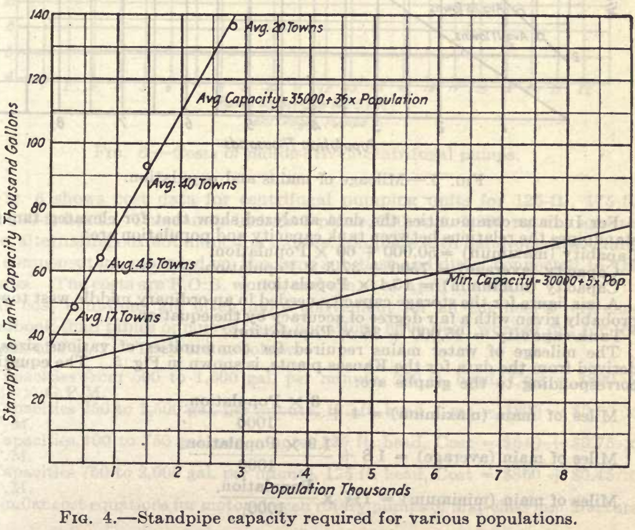


FIG. 4.—Standpipe capacity required for various populations.

The constants in the several equations for similar conditions are quite different. It is probable, however, that for ordinary middle west towns the average pump capacity in gallons per minute is about $\frac{1}{3}$ of the population. The maximum and minimum equations indicate the range of variation, that is the pump capacity for a town of specified population should fall somewhere between the figures given by the maximum and minimum equations respectively.

Similar graphs showing the relation between standpipe or tank capacity in gallons and the population for small Kansas communities are shown in Fig. 4. The equations of the graphs are:

Capacity (average) = 35,000 + 36 × Population.

Capacity (minimum) = 30,000 + 5 × Population.

For towns under 1500 population a 50,000 gal. tank mounted on a 100-ft. tower is a very common installation. For pneumatic tank systems Kansas data indicates that the

Tank capacity = 12,000 + 5 × Population.

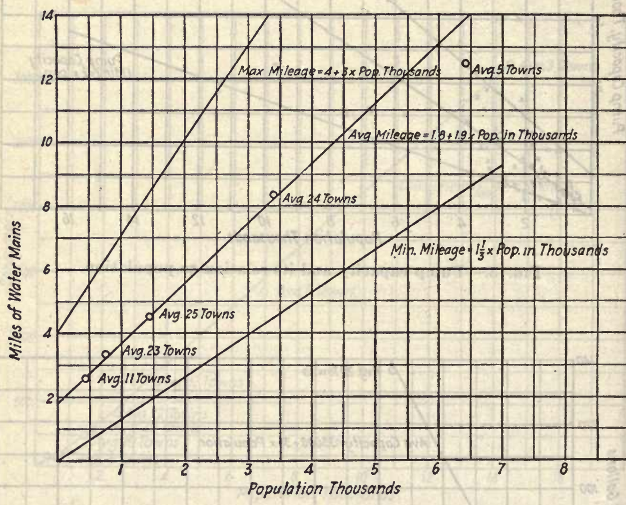


FIG. 5.—Mileage of mains and population.

For Indiana communities the data analyzed show that for elevated tanks or standpipes the relations between tank capacity and population are:

Capabity (maximun) = 50,000 + 60 × Population.

Capacity (average) = 7500 + 37.5 × Population.

Capacity (minimum) = 15.4 × Population.

A fair figure for the storage capacity needed in an ordinary middle west town is probably given with a fair degree of accuracy by the equation.

Tank capacity = 25,000 + 35 × Population.

The mileage of water mains required for communities of various sizes, as derived from the data for the Kansas plants, is shown in Fig. 5. The equations corresponding to the graphs are:

$$\text{Miles of main (maximum)} = 4 + \frac{3 \times \text{Population.}}{1000}$$

$$\text{Miles of main (average)} = 1\ 8 + \frac{1.9 \times \text{Population.}}{1000}$$

$$\text{Miles of main (minimum)} = 1\tfrac{1}{3} \times \frac{\text{Population.}}{1000}$$

It is recognized that the design of a new waterworks plant based wholly on the data such as are given above, certainly would not be good engineering practice or even good common sense. In the design or layout of such a plant due weight must always be given to prevailing local conditions. Nevertheless it is believed that such data are of value in making preliminary estimates, in checking tentative designs or layouts and in checking the reasonableness of the operating performance in existing plants.

Cost and Operating Data for Small Waterworks.—The following cost and operating data, given in Engineering and Contracting, Oct. 13, 1920, pertain to small waterworks equipment. They were compiled by Prof. D. D. Ewing in connection with the preparation of Bulletin No. 4, "Electric Driven Waterworks in Indiana," Purdue University Engineering Experiment Station.

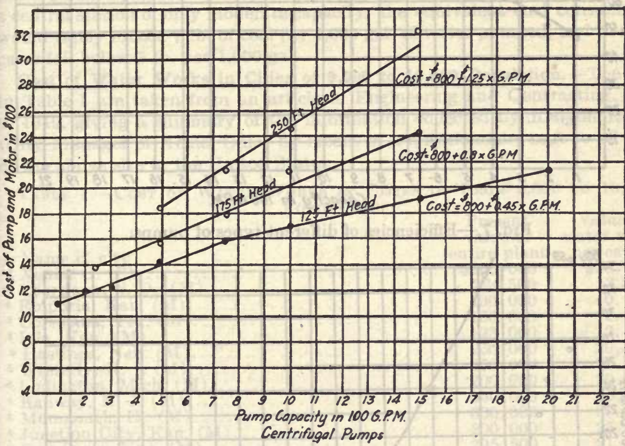


FIG. 6.—Costs of motor-driven centrifugal pumps.

Fig. 6 shows cost data for centrifugal pumping units for 125-ft., 175-ft. and 250-ft head. These units include 3-phase, 220-volt, 1,800 r.p.m., squirrel cage, alternating current induction motors, complete with hand-operated starting compensators, mounted on the same sub-base and direct connected to the pumps. The costs are F.O.B. works, and are as of April 1, 1919.

As cost equations are often more convenient for an engineer's reference handbook than tables or curves, such equations have been worked out for the graphs of Fig. 1. They are as follows:

Capacities from 500 to 1,500 gal. per minute, 250-ft. head, Cost = \$800 + \$1.25 × G.P.M.

Capacities 250 to 1,500 gal. per minute, 175 ft. head, Cost = \$800 + \$0.80 × G.P.M.

Capacities 100 to 750 gal. per minute, 125 ft. head, Cost = \$640 + \$0.75 × G.P.M.

Capacities 750 to 2,000 gal. per minute, 125 ft. head, Cost = \$860 + \$0.45 × G.P.M.

Similar cost equations for motor-driven rotary pumps of first-class manufacture are:

Capacities 100 to 400 gal. per minute, 125 ft. head, Cost = $4.50 × G.P.M.
Capacities 500 to 2,000 gal. per minute, 125 ft. head, Cost = $1,300 + $1.60 G.P.M.

For air pumps with motor-driven compressors the equations are:
Capacities up to 500 gal. per minute, 50-ft. lift, Cost = $500 + $4 × G.P.M.

For motor-driven deep well reciprocating pumping units the equations are:

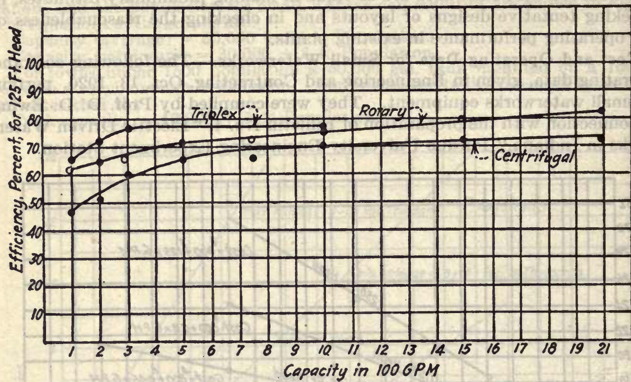


FIG. 7.—Efficiencies of different types of pumps.

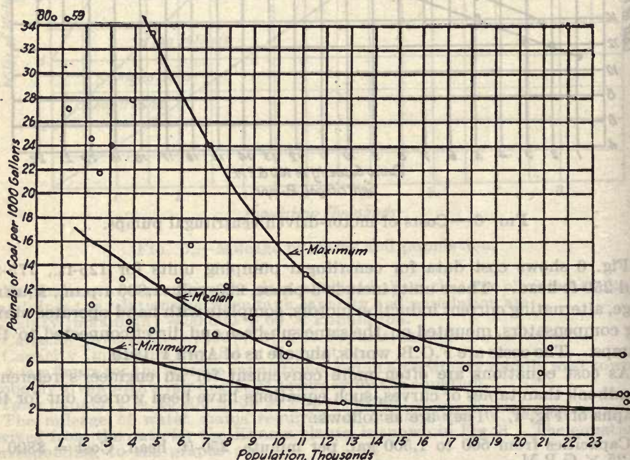


FIG. 8.—Coal consumption in small waterworks plants.

Capacities up to 200 gal. per minute, 50-ft. lift. Cost = $600 + $6 × G.P.M
Capacities up to 200 gal. per minute, 160 ft. head, Cost = $600 + $9 × G.P.M.

For elevated tanks, height to top of tank 100 ft., tank capacities, 25,000 to 200,000 gal., Cost = $3,200 + $45 × capacity in 1,000 gal.

The tank costs are for the tanks erected complete and include everything except freight charges. The weights of these tanks and their towers are given by,

Weight = 14 tons + ¼ × capacity in 1,000 gal.

In Fig. 7 are shown the efficiencies of triplex, rotary and centrifugal pumps. These curves do not represent the efficiencies of just one pump of each of the different types operated under various discharge conditions, but are the efficiencies of lines of pumps of the several types, the efficiency of each pump in a given line being the best operating efficiency of that pump.

Fuel consumption and conservation are matters of prime importance today and in Fig. 8 is shown an analysis of the fuel consumption of a number of small steam operated waterworks plants in Indiana. It will be noted that in the small plants the fuel consumption reaches an almost prohibitive figure. Were these plants operated by electric motors receiving their energy supply from a central station of only moderate capacity, the equivalent coal consumption would rarely exceed 7 lb. of coal per 1,000 gal. of water pumped, and in many cases fall below 5 lb. per 1,000 gal.

Cost of Water Works in Cities of 9,000 to 10,000 Population.—The data in Table I are taken from an article in Engineering and Contracting, April 9, 1919, giving a summary of the information collected by Kenyon Riddle, (City Manager of Xenia, Ohio) by means of a questionnaire sent to all cities of the above size in the United States.

Table I.—Cost of Water Works in Cities of From 9,000 to 10,000 Population

Name of city	Present value of entire plant	Value of water works per capita
[1] Xenia, O. (P)	$260,000	$29.00
[2] Aberdeen, S. D. (M)	224,500	13.50
[4] Emporia, Kan. (M)	400,000	40.00
[2] Corsicana, Tex. (M)	160,000	12.00
[4] Iola, Kan. (M)	123,000	12.30
[5] Hastings, Neb. (M)	250,000	20.00
[5] Westerly, R. I. (M)	350,000	35.00
[6] Ludington, Mich. (M)	200,000	20.00
[4] Rahway, N. J. (M)	350,000	35.00
[8] Monmouth, Ill. (M)	300,000	30.00
[5] Junction City, Kan. (M)	200,000	25.00
[9] Fort Scott, Kan. (M)	295,500	21.00
[8] Kewanee, Ill. (M)	395,000	23.00
[5] Delaware, O. (P)	300,000	33.00
[1] Owosso, Mich. (P)	150,000	19.00
[3] Tyler, Tex. (M)	285,000	19.00
[4] Defiance, O. (M)	150,000	16.60
[4] St. Charles, Mo. (M)	150,000	15.00
[10] Abilene, Kan. (M)	80,000	16.00
[10] Herington, Kan. (M)	90,000	19.00
[5] Albuquerque, N. M. (M)	400,000	22.00
[5] Pomona, Cal. (P)	500,000	31.00
[4] Clarksville, Tenn. (M)	200,000	20.00
[5] Arkansas City, Ak. (M)	200,000	18.00
[4] Chickasha, Okla. (P)	240,000	16.00
[5] Goshen, Ind. (M)	220,000	22.00
[4] Billings, Mont. (M)	500,000	28.00
[6] Ashland, Wis. (P)	480,000	24.00
[8] Barre, Vt. (M)	390,000	39.00
[12] Menominee, Mich. (M)	284,000	28.00
[4] Ottawa, Kan. (M)	130,000	14.40
[11] Adrian, Mich. (P)	150,000	12.50

Source of Supply: [1] Wells and springs. [2] Artesian wells. [3] Reservoir. [4] Rivers. [5] Wells. [6] Lake. [8] Deep wells. [9] River and two deep wells. [10] Springs. [12] Green Bay, Michigan.
(P) Private ownership. (M) Municipal ownership.

Cost Data on Small Water Works Systems.—William Artingstall gives the following data in Municipal and County Engineering, Oct., 1919.

The expenditure incurred for water supply for small cities is dependent on the locality and varies in the per capita cost due to the local conditions peculiar to each city. This variation is due not so much to the cost of the water mains and feeders as it is to the cost of the pumping plant and the difficulty (or ease) with which the necessary amount and kind of water is obtained. For this reason it is customary to let separate contracts covering these two phases of the work and in the majority of cases the cost of the supply is not reported for public information. In Table II the cost of the distribution system is all that is given unless otherwise noted. To this cost must be added an amount per capita of from $15 as a minimum to $40 or $50 as a maximum. In cities where there are no deep wells nor expensive pumps to install, the cost would run in the neighborhood of $15 or $20.

TABLE II.—COST OF SMALL WATER DISTRIBUTION SYSTEMS IN 1919

Town State	Population	Expenditure, per capita
Oneida, S. D	150	$200.00*
St. Clair Beach, Mich	200 approx.	50.00
Ladora, Iowa	260	58.50
Waconda, S. D	326	92.50*
Garber, Okla	382	59.00
Pretty Prairie, Kans	327	97.50
Menno, S. D	621	56.30
Foley, Minn	710	56.30
Hettinger, N. D	766	35.00
Dexter, Ia	767	47.00
Townsend, Mont	759	39.60
Wendell, N. C	759	47.30
Orem, Utah	800	125.00*
Markesan, Wis	892	61.50
Walker, Minn	917	27.80
Fairmount, Neb	921	37.00
Grand Junc. Ia	1,012	40.00
Ferndale, Mich	1,070	79.00*
Spearfish, S. D	1,130	44.00
Spirit Lk., Ia	1,162	45.50
Roundup, Mont	1,513	25.70
Aiken, Neb	1,638	24,00
What Cheer, Ia	1,720	29.00

Note that as the size of the city increases, the cost per capita becomes less due to a greater density of population. *Complete.

Costs of Small Water Works Systems in Massachusetts.—The following data are taken from an article by Harry R. Crohurst published in Engineering and Contracting, May 26, 1915.

TABLE III.—COST PER CAPITA OF SMALL WATER WORKS SYSTEMS

	Population	Total cost of water works	Cost per capita
Ashland	1700	$ 46,034	$27
East Brookfield	2204	23,927	11
Littleton	1229	45,896	37
Medway	2696	100,032	37
Pepperell	2953	105,451	36
Oxford	3361	57,539	17
Wrentham	1743	50,683	29

The system at Ashland was constructed in 1911 and consists of twelve 2½-in. driven wells varying in depth from 25 to 32 ft. with an average depth of 30 ft., a small field stone pumping station 25 × 33 ft. in plan with a red asbestos shingled roof, and a pumping plant consisting of two 17-HP. oil engines and two 7 × 8-in. Smith-Vaile triplex pumps.

The distribution system consists of a covered, reinforced concrete standpipe 40 ft. in diameter and 32 ft. high with a capacity of 300,000 gals., and 6½ miles of cast-iron mains varying from 12 to 6 ins. in diameter. On the system there are 66 gates and 52 hydrants, and the number of services connected at the end of the year 1913 was 250, all of which were metered.

In laying out the system no unusual conditions were encountered, and no large amount of rock was found with the exception of the main leading to the standpipe.

The cost of constructing the system to the end of the year 1913, not including service connections, as given in the 1913 report of the Board of Water Commissioners was as follows:

Bond issue		$ 55 22
Land		1,710.38
Legal expenses		122.65
Office expenses		74.76
Wells		1,266.80
Pumping station		2,122.95
Pumps and engines		4,358.20
Standpipe		5,812.00
Mains:		
Pipe	$15,116.38	....
Gates, hydrants, specials	2,579.32	....
Laying pipe	9,369.86	....
Freight, express and miscellaneous	1,160 62	28,226.18
Engineering		2,285 20
		$46,034 34

During the year 1913 the average daily consumption of water was 20,000 gals., or about 12 gals. per capita, one of the lowest consumption figures in the state.

The cost of operating the works during 1913 was as follows:

Pumping plant	$ 77.95
Service repairs	27.74
Pipe repairs	262.17
Fuel	198.73
Wages	865 00
Office expense	62.91
Interest on bonds	2,000.00
Miscellaneous	27.37
	$3,521.87

From the above consumption and cost of operation the cost of supplying 1,000 gals. of water was 48 cts.

The source of supply of East Brookfield is from the shore of Lake Lashaway, or Furnace Pond, just north of the village. The wells are located on the westerly shore and the water which is taken from a stratum of coarse water-bearing gravel is pumped through 1,325 ft. of 6-in. main to the standpipe from which it is distributed by gravity.

The system installed in the fall of 1908, consists of twelve 2½-in. tubular wells varying in depth from 19 to 24 ft., a small brick pumping station 24 × 30 ft. in plan with a slate roof, and a pumping plant consisting of two 8-HP. oil engines and two 5½ × 8-in. triplex pumps each having a capacity of 100 gals. per minute, The distribution system consists of a covered wrought-iron standpipe 25 ft. in diameter and 50 ft. high with a capacity of 185,000 gals., and about 2.6 miles of cast-iron mains 12 to 6 ins. in diameter. On the system at the time of examination there were 80 services and 32 hydrants.

The cost of constructing this system, not including service connections, was as follows:

Wells		$ 567.72
Pumping station		1,627.70
Pumping plant		3,050.00
Standpipe		3,150.00
Mains:		
Pipe	$8,480.40	....
Hydrant, gates, specials	1,357.60	....
Laying pipe	3,009.90	12,847.90
Engineering and inspection		1,384.07
Bills payable		1,300.00
		$23,927.39

The water works system of Littleton was constructed in 1911 and consists of nine 2½-in. driven wells varying in depth from 17 to 27 ft., a brick pumping station with a slate roof 35 × 25-ft. in plan, and a pumping plant consisting of a 25-HP. oil engine, a 25-HP. motor and a 7½ × 10-in. triplex pump.

The distribution system consists of a covered steel standpipe 40 ft. high and 30 ft. in diameter having a capacity of 275,000 gals., and 5.7 miles of 12 to 6-in. cast-iron mains. On the system are 17 gates, 37 hydrants, and 130 metered services.

The cost of installing the system, not including the cost of service connections, is given in the 1912 report of the Board of Water Commissioners as follows:

Wells		$ 431.31
Pumping station		2,929.00
Pumping plant		3,735.00
Standpipe		3,938.00
Land and right of way		1,575.83
Mains:		
Pipe	$19,036.88	....
Gates and hydrants	1,175.00	....
Express and freight	93.42	....
Laying pipe	8,728.04	....
Setting hydrants	74.00	....
Rock excavation	1,225.00	....
Miscellaneous	954.47	31,286.81
Engineering		2,000.00
		$45,895.95

The cost of operating the Littleton works for the year ending March 1, 1913, was as follows:

Salaries	$ 580.00
Supplies	116.66
Fuel oil	219.77
Expenses	8.15
Freight	39.15
Repairs	25.38
Miscellaneous	42.85
Rent	36.00
	$1,067.96

The water works system of Medway was built in 1911 and 1912 and consists of 30 2½-in. wells varying in depth from 32 to 75 ft., each provided with a 3-ft. strainer point, a pumping station 40 × 20 ft. in plan of terra cotta blocks with cement plastering inside and out and having a wooden truss roof covered with slate, and a pumping plant consisting of two 32-HP. oil engines and two triplex single acting pumps. This plant was tested Sept. 11, 1911, by running both engines together for 11 hours successively. The economy test showed nearly 8,000 gals. pumped to 1 gal. of oil. The cost of oil taken at 6 cts. per gallon at the station shows a fuel cost of ¾ ct. per 1,000 gals. pumped into the standpipe.

The distribution system consists of a steel standpipe 30 ft. in diameter and 80 ft. high with a capacity of 437,000 gals., and 12.35 miles of cast-iron mains 12 to 4 ins. in diameter. On the system there are 87 gates, 111 hydrants and 338 service connections which are only a part of the final number.

The cost of these works up to Feb. 1, 1913, not including service connections, was as follows:

Preliminary examination		$ 2,750.00
Legal bond issue		944.95
Land		1,303.65
Wells and connections		4,650.00
Pumping station		3,632.00
Pumps and engines		7,550.00
Standpipe		8,800.00
Standpipe foundations		2,325.00
Mains:		
Pipe and laying	$52,142.85	
Gates	1,454.00	
Hydrants	3,885.00	
Freight	92.12	
Rock excavation	5,000.00	
River crossing	1,000.00	
Repairs to roads	1,500.00	65,073.97
Engineering		3,002.40
		$100,031.97

The above figures were taken from the engineer's final estimate of the cost of all of the works.

At the present time record of the quantity of water supplied cannot be obtained. The cost of operating the works during 1912 was as follows:

Administration	$ 631.98
General expense	71.17
Interest on bonds	4,325.40
Pumping sation—	
Fuel oil	379.43
Cylinder oil	37.81
Labor	818.90
Coal	56.55
Supplies	94.49
	$6,415.73

The water works system of Pepperell was constructed during the summer of 1910.

The source of supply is from wells located near Gulf Brook just south of the Massachusetts and New Hampshire State line about three miles north of the town.

The works consist of 34 2½-in. wells having an average depth of 25 ft., a brick pumping station 30 × 20 ft. in plan with a slate roof, and a pumping plant consisting of two 25-HP. oil engines and two 8 × 10-in. triplex pumps each having a capacity of 250 gals. per minute.

The distribution system consists of a covered steel standpipe 45 ft. in diameter and 40 ft. high having a capacity of about 475,000 gals., and 16.42 miles of 12 to 6-in. cast-iron mains. On the system are 130 hydrants.

The cost of these works, not including service work, taken from the special 1910 report of the water commissioners, was as follows:

Bond issue		$ 154.35
Wells		2,544.37
Pumping station		2,852.38
Land for station and wells		750.00
Standpipe		6,728.98
Land for standpipe		600.00
Engines and pumps		6,062.52
Mains—		
Pipe and fittings	$49,069.34	
Laying	24,877.13	
Hydrants	3,033.80	
Valves, gates, specials	2,288.69	
Freight	1,099.65	
Inspection of pipe	270.86	
Miscellaneous	1,188.44	81,757.91
Engineering		4,000.00
		$105,450.51

The total consumption of water for the year 1912 was 40,282,000 gals, which is equivalent to an average daily consumption of 110,000 gals. or 37 gals. per capita.

The cost of operating the system for 1912 is given as follows:

Maintenance	$2,728.36
Services	657.84
Piping system	341.15
Meters	65.73
Interest	5,080.00
	$8,873.08

The source of supply of the Oxford Water Works is from driven wells near a small brook flowing into the French River near North Oxford.

The water works system was constructed in 1906 and consists of 8 2½-in. wells varying in depth from 23 to 28 ft., a brick pumping station 25 × 25 ft. in plan and a pumping plant consisting of two oil engines and two triplex pumps.

The distribution system consists of a steel standpipe 27 ft. in diameter and 50 ft. high having a capacity of 220,000 gals., and 9.7 miles of cast-iron mains 10 to 2 ins. in diameter. On the system are 60 hydrants and 405 service connections.

These works are privately owned and the following cost figures are taken from the 1906 report of the company:

Preliminary engineering		$ 250.00
Wells		581.25
Station		1,720.00
Pumping machinery		3,200.00
Standpipe		4,564.95
Foundations		500.00
Mains—		
Pipe	$28,424.60	
Hydrants, valves, specials	5,098.07	
Laying	8,077.87	
Rock excavation	927.95	42,528.49
Land		1,425.00
Engineering		1,769.59
Miscellaneous		1,000.00
		$57,539.28

The cost of operating the Oxford plant for the year 1912 was as follows:

Labor	$ 884.34
Oil and gasoline	710.32
Interest on notes	913.53
Coupons on bonds	1,250.00
Dividends	1,717.50
Salaries	200.00
Repairs	164.27
Miscellaneous	268.07
	$6,108.03

The Wrentham water works were constructed in 1907. The source of supply is from driven wells near the "Trout Ponds," so-called, about a mile south of the village.

The system consists of 9 2½-in. tubular wells having an average depth of 29 ft. The pumping station is a brick structure with a slate roof, 25 × 36 ft. in plan, containing two 25-HP. oil engines and two 8 × 10-in. triplex pumps each having a capacity of 250 gals. per minute.

The distribution system consists of a steel standpipe 30 ft. in diameter and 50 ft. high having a capacity of 265,000 gals., and 5.6 miles of cast-iron mains 10 to 2 ins. in diameter.

The cost of the system, not including service connections was as follows:

Wells		$ 1,048.22
Pumping station above foundation		1,646.97
Engines and pumps		5,933.55
Standpipe above foundation		5,204.63
Foundations (station and standpipe)		1,556.50
Mains—		
Pipe	$21,002.62	
Hydrants	969.68	
Specials	1,215.57	
Laying	9,410.39	
Bridge crossing	195.18	32,793.44
Engineering		2,500.00
		$50,683.31

The above figures are compiled from the 1907 report of the water commissioners.

Reports from 66 Cities on Pumpage, Meterage, Repairs and Renewals, and Depreciation.—Information on certain phases of water works operation, concerning which there is considerable diversity of opinion, has been collected by Engineering and Contracting and published in the issue of May 8, 1918. Table IV contains a summary of the replies to a questionnaire sent to water works superintendents. Of the 66 cities represented in the table, 63 report on pump capacity and output of pumps. The total daily pumping capacity of these cities is 1,500,000,000 gal. and the daily average output averages about 823,000,000 gal. or a ratio a little less than 2 to 1. Excluding Chicago with its daily pump capacity of 923,000,000 gal. and the remaining 62 cities have a daily pump capacity of 583,000,000 gal. and a daily average output of 192,000,000 gal., or a ratio of 3 to 1. Of the 66 cities 57 reported the per capita water consumption. The arithmetical average consumption for 37 cities having more than 69 per cent of their services metered was slightly less than 70 gal. per capita. The average per capita consumption for the 22 cities with less than 56 per cent of their services metered was 133 gal.

Fifty-seven cities reported on maintenance expenses of their water works. The total investment was $133,600,000 or about $30 per capita and the total maintenance expense for the last recorded year was $2,236,000 or about 1.7 per cent. The average depreciation annuity for 34 plants was 2.9 per cent.

TABLE IV

City	Daily capacity of pumping plant, gal.	Average daily output of pumps in 1917, gal.	Population served	Average daily per capita consumption	Per cent of services metered	Average annual expense of repairs and renewals for entire water works	Approximate investment in entire water works	Depreciation annuity per cent of plant maintenance in excess of average expenses, per cent
Akron, Colo	45,670	44,000	1,200	36	75	$ 1,000	$ 32,500	½
Americus, Ga	5,500,000	659,831	10,000	66	100	3,750	156,800	½
Atchison, Kan	4,000,000	1,300,000	14,000	90	20	1,500	425,000	1½
Atlanta, Ga	50,000,000	20,000,000	250,000	80	100	48,000	4,000,000	2
Attleboro, Mass	7,500,000	1,086,000	17,800	61	100	....	949,800	....
Belding, Mich	2,000,000	176,548	4,500	39	98	152	100,000	....
Beloit, Kan	1,000,000	200,000	750	50	100	....	....	....
Bluffton, Ind	2,000,000	250,000	5,000	50	100	15,890	54,246	10
Boone, Ia	3,000,000	1,000,000	12,500	60	100	40,900	355,000	4
Brockton, Mass	6,000,000[1]	3,058,000	75,900	40	100	9,653	2,354,468	....
Burlington, Ia	6,000,000	2,237,131	24,324	90	4	45,997	970,000	....
Cambridge, Mass	30,000,000	9,614,971	114,000	84	35	185,000	6,700,000	....
Cherokee, Ia	300,000[2]	200,000	3,200	...	...	600	45,000	....
Chicago, Ill	923,000,000[3]	631,000,000	2,571,941	245	7.4[4]	1,272,606	74,908,614	....
Council Bluffs, Ia	8,000,000	3,250,000	30,000	93	94	28,000	1,002,500	....
Dodge City, Kan	3,000,000	600,000	5,000	120	48	1,500	125,000	3
Danvers, Mass	4,000,000	1,559,200	12,000	130	44	20,000	544,000	....
Dowagiac, Mich	2,500,000	319,600	5,000	62	100	1,653	60,000	4
Easthampton, Mass	1,000,000	1,000,000	14,000	300	90	....	....	5
Eureka, Cal	1,500,000	687,000	13,125	40	96	2,975	326,250	2
Fairmount, Ind	288,000	158,827	2,506	63	...	96	19,359	8
Fenton, Mich	1,500,000	200,000	3,000	...	...	500	30,000	1
Fort Scott, Kan	4,000,000	1,500,000	12,000	85	90	2,000	215,000	1
Franklin, Mass	1,500,000	324,584	5,000	65	100	8,000	250,000	....[5]
Framingham, Mass	6,000,000	1,071,204	15,200	70	100	2,100[6]	615,210	2
Grinnell, Ia	500,000	250,000	6,000	...	90	2,105	111,661	5
Highland Park, Mich	20,000,000	9,139,000	38,000	240	10	2,000	1,250,000	....
Hopkinsville, Ky	1,500,000	435,000	7,350	59	55	....	200,000	....[7]
Horton, Kan	600,000	80,000	4,000	...	100	1,000	105,000	....
Indianapolis, Ind	112,000,000	26,000,000	300,000	87	11	60,000	11,000,000	1
Jackson, Mich	9,300,000	3,750,000	47,500	76	100	8,000	750,000	1

Lagrange, Ga	2,000,000	350,000	7,000	55	100	723	190,000	½[8]
Lake Forest, Ill	3,500,000	670,000	4,000	168	100	2,305[6]	178,027	2
Larned, Kan	1,700,000	300,000	3,500	85	99	790	75,000	1[9]
LaPorte, Ind	12,000,000	1,904,000	13,500	141	9	1,002	414,410	1
Lincoln, Ill	3,750,000	980,309	12,164	80	98	....	250,000	....
Lynn, Mass	34,000,000	7,200,000	110,000	65	53	....	....	....
Manistee, Mich	7,000,000	825,554	12,000	67	53	5,270	279,813	3
Marquette, Mich	10,500,000	2,164,383	13,000	166	50	8,815	302,880	....
Merced, Cal	5,760,000	900,822	4,000	225	...	....	350,000	....
Middletown, Conn	2,300,000	1,250,000	16,000	78	99	10,000	....	....
Mishawaka, Ind	8,000,000	1,130,000	16,000	68	100	3,693	290,000	1
Mt. Vernon, Ind	2,400,000	700,000	12,000	58	80	4,400	260,000	4
Muscatine, Ia	6,000,000	1,036,584	15,000	65	75	20,000[6]	475,000	....[10]
New Bedford, Mass	20,000,000	9,287,000	113,485	82	100	147,700[6]	4,483,800	....
Newburyport, Mass	6,000,000	1,197,993	15,000	71	4	4,000	775,000	....
Oakland, Cal	58,000,000	19,000,000	335,000	58	95	78,000[6]	15,000,000	....
Ottawa, Kan	1,500,000	735,000	6,000	120	53	....	....	....
Osage City, Kan	1,000,000	52,500	2,000	...	100	1,462	110,000	5
Oxnard, Cal	2,000,000	875,519	4,000	218	...	257	105,000	....
Pasadena, Cal	14,000,000	....	48,000	92	99	60,000	1,580,000	3.6[4]
Palo Alto, Cal	1,500,000	540,000	5,770	93	100	1,850	185,000	2½
Pepperell, Mass	720,000	155,000	3,000	44	90	183	195,602	....
Phoenix, Ariz	12,000,000	4,131,868	30,000	138	20	28,000[13]	602,025	3[14]
Pine Bluff, Ark	8,000,000	1,044,548	30,000	...	...	4,572[6]	525,000	....
Quincy, Ill	6,000,000	1,607,000	38,000	42	70	5,700	1,080,000	1
Rockford, Ill	7,000,000	3,308,795	70,000	47	100	2,773[6]	1,026,720	3[15]
Sacramento, Cal	39,000,000	16,523,319	57,000	290	...	71,220[6]	2,008,307	....
San Luis Obispo, Cal	532,000[16]	400,000	8,000	150	95	4,000	350,000	2
Sheridan, Ind	400,000	77,750	2,000	39	...	12[6]	40,000	3
South Bend, Ind	24,000,000	5,113,214	70,967	72	33	10,030[6]	1,17,605	....[17]
Streator, Ill	8,000,000	2,365,000	16,000	148	50	2,321	600,000	1½[18]
Talladega, Ala	75,000	....	7,000	110	70	....	....	....
Thompsonville, Conn	....	400,000	8,500	47	99	1,000	246,500	2
Waukegan, Ill	10,000,000	4,526,756	22,000	206	20	....	500,000	5
Wellesley, Mass	3,000,000	543,000	6,900	79	100	1,509	488,000	....

[1] Has two units of 6,000,000 gal. each. [2] In 10 hours. [3] Maximum capacity [4] 7.4 per cent of service pipes metered; 23.1 per cent of consumption metered. [5] Thinks plant will depreciate $10,000 per year. [6] For 1917. [7] 1 per cent to 1½ per cent. [8] ½ per cent to 1 per cent. [9] 1 per cent on mains; 4 per cent on stand-pipe, and 5 per cent on buildings and pumps. [10] Depreciation fund 2 per cent to 4 per cent put into renewals. [11] Individual rates of depreciation for different portions of plant and equipment; 1917 depreciation 3.6 per cent. [12] Capacity of reservoirs. [13] Operation and maintenance. [14] 3 per cent or 4 per cent. [15] 3 per cent on mechanical equipment, and 2½ per cent on buildings, etc. [16] Main supply gravity. [17] Depreciation in 1917 was $10,000. [18] For main and renewals.

Per Cent of Water Works Plant Charged to Fire Protection.—Curves based on public utility decisions have been found useful by Chester & Fleming, Consulting Engineers, Pittsburgh, as a guide to show what portion of water charges should be allocated to fire service. The diagrams prepared by the above mentioned firm were reproduced in Engineering and Contracting, May 14, 1919, from which paper the following is taken. Each curve is platted from 24 decisions for plants having a value above $50,000 and gross revenues from $5,000 to $100,000 per year. The decisions from which these curves were prepared are shown in the table, each division's place in the diagram being indicated by its number given in Table V.

The diagrams are self explanatory. For instance, in Fig. 9, there appears at the bottom the gross revenue from plant operation. At the left of the diagram appears the annual revenue from fire protection in dollars, which permits the location on the face of the diagram at its proper point each

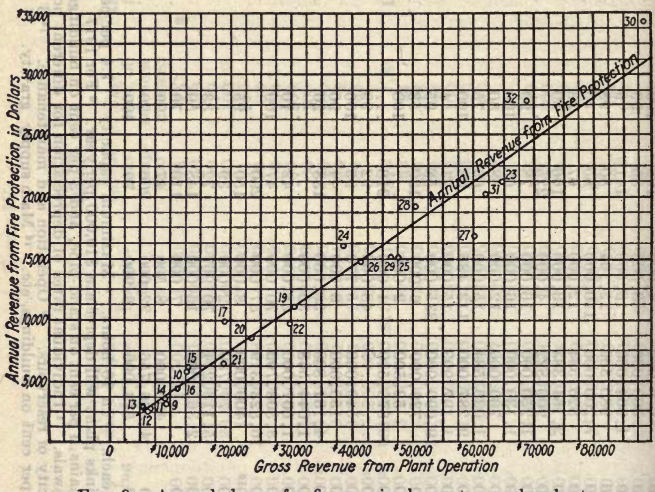


FIG. 9.—Annual charge for fire service by water works plant.

decision and through these decisions the line of average is drawn, and so knowing the gross revenue from plant operation one may readily obtain what the decisions plotted would indicate would be the fair amount of the gross to be derived from the municipality as compensation for fire protection.

Fig. 10 instead of stating the annual revenue from fire protection in dollars, tabulates the percentage of gross revenue.

Fig. 11 deals with the value of the plant as fixed by the Commission in its relation to the revenue from fire protection in dollars.

Fig. 12 deals with the value of the plant as fixed by the Commission with relation to the percentage of the plant chargeable to fire protection.

By plotting the curves which represent the average of the decisions, the average result may be found within the limit of these decisions, and by utiliz-

TABLE V.—FIRE PROTECTION CHARGES MADE AGAINST THE MUNICIPALITY BY PUBLIC UTILITY COMMISSION

	Date of decision	City and state	Population, 1910	Per cent of water works charged to fire service	Value of plant	Gross revenue	Revenue from fire	Per cent of gross revenue from fire
1	1913	Elkhart Lake, Wis	950	59	$ 8,425	$.......	$ 600	....
2	1912	Sharon, Wis	1,100	52*	....	....	1,000	....
3	1914	Waterloo, Wis	1.106	60	30,500	....	1,500	....
4	1913	Fennimore, Wis	1,275	55*	23,046	....	1,500	....
5	1914	Elroy, Wis	1,450	47.4	32,215	....	1,500	....
6	1915	Barron, Wis	1,674	....	35,000	....	1,392	....
7	1912	Evansville, Wis	1,963	64.1	37,122	4,813	2,500	52
8	1914	Vaughn, Wis	......	53	38,000	6,860	2,800	40.8
9	1917	River Falls, Wis	2,300	54.6	56,000	9,429*	3,240*	34.4
10	1913	Delevan, Wis	2,450	64	42,291	6,700	2,800	41.8
11	1913	Columbus, Wis	2,523	53.2	53,696	6,499	2,600	40
12	1910	Jefferson, Wis	2,582	75	51,524	6,208	2,560	41.2
13	1915	Prairie du Chien, Wis	3,179	....	78,400	5,418	2,800	51.7
14	1913	Ft. Atkinson, Wis	3,300	51	73,424	9,156	3,600	39.3
15	1910	Ripon, Wis	3,811	65.2	103,101	12,923	6,082	47.1
16	1913	Sparta, Wis	3,973	55	98,599	11,047	4,400	39.8
17	1911	Oconto, Wis	5,629	57.5	125,000	19,031	9,800	51.5
18	1912	Neenah, Wis	5,734	54.5	117,038	12,850	5,850	45.5
19	1916	Merrill, Wis	8,689	47	200,000	30,415*	11,000	36.2
20	1914	Watertown, Wis	8,829	47.2	202,677	23,394	8,500	36.3
21	1915	Brazill, Ind	9,340	70	128,383	18,987	6,361	33
22	1917	Lincoln, Ill	10,892	43	215,000	29,850	9,651	32.4
23	1914	Ashland, Wis	11,594	54.5	480,000	65,000	21,000	32.3
24	1911	Janesville, Wis	13,894	54	250,000	38,725	15,800	40.8
25	1911	Marinette, Wis	14,610	38.5	326,759	47,630	14,800	31.1
26	1911	Beloit, Wis	15,125	48	289,512	41,565	14,687	35.3
27	1915	Beloit, Wis	15,125	48	402,000	60,323	16,659	27.6
28	1915	Appleton, Wis	16,773	45	525,000	50,616	19,000	37.5
29	1912	Eau Claire, Wis	18,310	48.5	314,987	46,655*	15,000	32.2
30	1913	Green Bay, Wis	25,236	48.7	683,229	88,665*	34,000	39.8
31	1910	Madison, Wis	25,531	49.6	650,000	62,260	20,000	32.1
32	1914	Sheboygan, Wis	26,398	46	[507,739	69,176	27,500	39.8
33	1912	Superior, Wis	40,384	46	838,242	110,146	27,900	25.3

*Estimated.

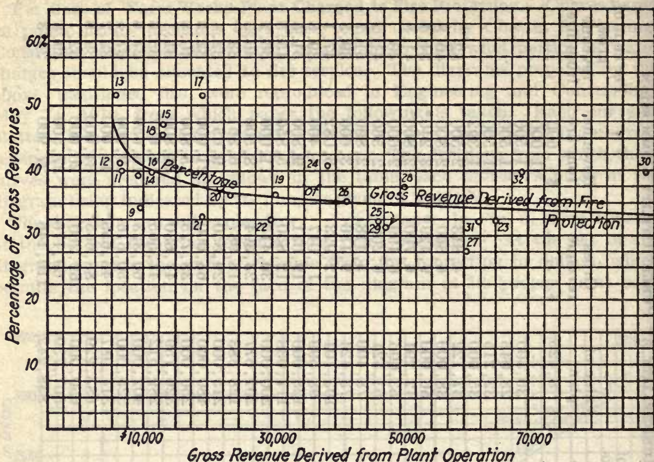


FIG. 10.—Percentage of revenue to be derived from fire protection by water works plant.

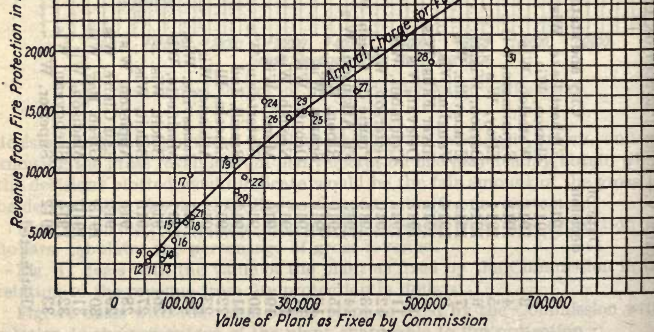


FIG. 11.—Comparison of value of water works plants and revenue from fire protection.

ing the line of average extended in either direction, the results may be made useful beyond the limits embodied in the decisions.

Subdivision of Cost of Water Works in Per Cent of Total Cost.—The following data are from a paper by J. M Bryant presented in 1914 before the Illinois Water Supply Association, and reprinted in Engineering and Contracting, Mar. 25, 1914. The data are taken from an average of 22 cities in Wisconsin

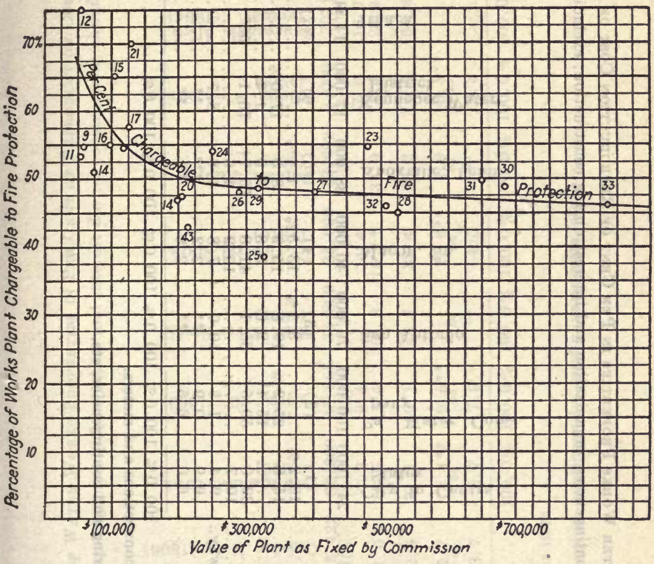


FIG. 12.—Percentage of water works plant chargeable to fire protection.

from the reports of the Wisconsin Railway Commission (7W. R. C. R. 301; 8W. R. C. R. 341).

	Per cent of total cost new
1. Land	3.10
2. Wells, intakes and suctions	8.39
3. Filters, reservoirs, standpipes	6.28
4. Distribution system	63.75
5. Power plant equipment	8.86
6. Buildings and miscellaneous structures	6.37
7. Office furniture, appliances, tools, etc.	0.80

Tables VI, VII, VIII and IX are from a paper by Leonard Metcalf, Emil Kuichling and William C. Hawley presented at the American Water-Works Association Convention June 6–10, 1911.

TABLE VI.—SUBDIVISION OF COST OF WATER WORKS PROPERTIES IN PER CENT OF REPRODUCTION COST OF PROPERTY

(Including therein engineering and contingencies, organization and interest during construction; excluding going value and franchise and other intangible values.)
Based upon experience of L. M.

City	City in Centra States	Pa. Water Company	San Antonio	Macon, Ga.	Knoxville, Tenn.	Kennebec Water District	Ithaca	Livermore Falls	Kittery
Population	241,000	100,000	79,000	40,000	38,000	17,000	14,600	3,100 gravity	2,900 gravity
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. Supply	18.2%	....	3.1%	13.5%	1.4%	....	....	50.0%	‡
2. Pumping	15.8	25.2%	19.8	15.9	8.5	17.0%	....	....	....
3. Reservoirs	....	15.4	2.0	5.8	5.0	4.2	....	....	....
4. Distribution system	39.0	50.5	65.1	41.8	75.7†	70.1	53°	50.0	§
5. Filter, etc	10.7	....	....	10.2	4.6	....	....	....	....
6. Real estate water rights and rights of way	9.4	1.5	10.0	7.8	4.8	8.7	....	....	....
7. Organization	0.9	0.9	**	2.2	**	**	....	....	....
8. Interest during construction	6.0	6.5	**	2.8	**	**	....	....	....
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	....	100.0%	100.0%

†Of this amount 20% covers service connections and meters.
°Water company testimony.
**Included in general per cent engineering and contingencies, etc.
‡Nearly 10%.
§All 90% piping.

Table VII.—Subdivision of Cost of Water Works Properties in Per Cent of Reproduction Cost of Property

(Including therein engineering and contingencies, organization and interest during construction; excluding going value and franchise and other intangible values.)
(Courtesy of Mr. J. W. Alvord)

Location	Omaha, Neb. (1906)	Des Moines, Iowa (1910)	Peoria, Ill. (1909)	Miss. River States (1902)	So. Central State (1910)	Topeka, Kan. (1900)	Middle West. State (1909)	Saugatuck, Mich. (actual) (1904)	Middle West. State (1906)	Miss. River State (1905)
Population	115,422 (10)	86,300 (11)	65,865 (12)	36,809 (13)	35,099 (14)	33,608 (15)	9,000 (16)	707† (17)	8,420† (18)	4,102† (19)
1. Supply	....	7.3	8.4	....	14.4	....	7.6	16.7	....	....
2. Pumping	41.0%	8.5	11.4	51.3	15.1*	31.9	11.8	28.4	29.7	39.4
3. Reservoirs	....	....	....	....	....	....	....	....	9.1	....
4. Distribution systems°	52.6	71.1	59.1	48.7	38.4	66.2	76.5	54.9	61.2	60.6
5. Filters, etc	....	....	....	....	....	....	....	....	....	....
6. Real estate, rights of way, etc	2.7	4.4**	9.6**	....	27.6**	1.9	0.8**	....	....	....
7. Organization	°°	°°	°°	°°	°°	°°	°°	....	....	....
8. Interest during construction	3.7	8.7	7.9	°°	4.5	°°	3.3	....	....	....
	....	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

°Includes meter, stock and tools, etc.
**Interest during construction on this item.
*Includes filters.
°°Included in general per cent engineering, contingencies, preliminary costs, etc.
†1900.

TABLE VIII.—SUBDIVISION OF COST OF WATER WORKS PROPERTIES IN PER CENT OF REPRODUCTION COST OF PROPERTY (Including therein engineering and contingencies, organization and interest during construction; excluding going value and franchise and other intangible values)

Based upon reports of the Railroad Commission of Wisconsin.

City	Madison, Wis. (1909)	Fond du Lac, Wis.	Appleton, Wis.	Ashland, Wis.	Chippewa Falls, Wis. (1908)	Antigo, Wis.	Jefferson, Wis.	Darlington, Wis. (1909)	Washburn, Wis. (1910)	Lake Geneva, Wis.
Population	24,894	19,500	18,900	11,594	8,700	7,000	2,500	2,000	4,924+	2,900
	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(25a)	(25b)
1. Supply	9.1	7.0	5.2	16.4	3.8	7.2	6.8	1.6	4.8	12.3
2. Pumping*	13.1	17.1	21.1	10.3	11.3	10.9	14.0	11.3	15.3	21.0
3. Reservoirs	4.7	3.4	5.1	....	5.9	6.4	8.9	6.0	6.7	6.7
4. Distribution system°	63.8	70.7	65.7	60.0	78.9	63.6	67.8	80.7	73.0	59.1
5. Filter, etc	....	....	....	12.0	....	....	....	....	....	....
6. Real estate, rights of way, etc	9.3	1.8	2.7	1.3	0.1	8.9	2.5	0.4	0.2	0.9
7. Organization	**	**	**		**	**	**	**	**	**
8. Interest during construction	**	**	**		**	3.0	**	**	**	**
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

†1905.
*Pumping includes buildings and miscellaneous structures.
°Includes office furniture, tools, horses and wagons, etc. Non-operative property not included.
**Included in general per cent engineering and contingencies, etc.

TABLE IX.—SUBDIVISION OF COST OF WATER WORKS PROPERTIES IN PER CENT OF REPRODUCTION COST OF PROPERTY

(Including therein engineering and contingencies, organization and interest during construction; excluding going value and franchise and other intangible values.)

(Courtesy of Mr. Morris Knowles)

	Greater city—All 3 divisions combined	Pittsburgh proper	Allegheny, or North Side	South Side, or formero Monongahela W. Co.
1. Supply	540,372	301,919	132,283	106,170
2. Pumping	(28)	(29)	(30)	(31
3. Reservoirs	0.3	....	1.5	1.2
4. Distribution system	18.7	14.2	30.6	22.2
5. Filter, etc	8.5	11.0	1.5	5.2
6. Real estate, water rights and rights of way	36.8	34.8	38.5	49.6
7. Organization	29.6	36.8	13.5	19.4
8. Construction	6.1	3.2	14.4	2.4
	100.0%	100.0%	100.0%	100.0%

Cost of Baltimore High-pressure Fire Service System.—The following table giving the construction costs of the Baltimore high-pressure fire service system is taken from an abstract in Engineering and Contracting, April 16, 1913, of a paper by James B. Scott before the American Society of Mechanical Engineers.

TABLE X.—CONSTRUCTION COST OF THE BALTIMORE HIGH-PRESSURE FIRE SERVICE SYSTEM

Portable Equipment.	
2 automobile hose wagons at $5,000	$ 10,000
8,000 ft. 3-in. hose at $1	8,000
30 portable heads and regulators at $385	11,550
Total	$ 29,550
Pipe System	
Material delivered Baltimore	
Hydrants, 226 at $100	$ 22,600
8-in. pipe, 7,137 ft. at $2.35	16,700
10-in. pipe, 28,229 ft. at $3.10	87,700
16-in. pipe, 17,052 ft. at $5.25	89,600
24-in. pipe, 1,275 ft. at $10	12,750
8-in. gate valves, 6 at $100	600
10-in. gate valves, 193 at $130	25,000
16-in. gate valves, 90 at $210	18,900
18-in. gate valves, 2 at $300	600
24-in. gate valves, 3 at $1,000	3,000
Air and relief valves	200
Low pressure gates, 2 30-in.	500
Suction pipe, 400 ft. cast iron, 30-in., at $4	1,600
Steel air chambers, 2 30-in., at $500	1,000
Venturi meter	500
Cast steel specials	17,500
	$ 298,750

Installation	
Laying pipe, including placing valves, fittings, hydrants, etc.	
8-in. pipe, 7,137 ft. at $0.70	$ 4,996
10-in. pipe, 28,229 ft. at 0.75	21,200
16-in. pipe, 17,052 ft. at 1.15	19,600
24-in. pipe, 1,275 ft. at 1.75	2,230
Pump connections in station	6,000
Laying 30-in. c. i. suction	3,400
Tapping 40-in. main	1,500
Concrete valve boxes, 293 at $30	8,790
Excavation, back filling and rubble paving	
41,318 ft. open trench, at $3.84	158,600
12,375 ft. tunnel, at $4.08	50,400
Improved paving, 6,650 sq. yds., at $1.50	10,000
Superintendence, use of tools, etc	50,000
	$ 336,716
	$ 635,466
Pumping Station	
Site and preliminary work	$ 37,730
Building, including machinery foundations and men's quarters	124,800
Harbor intake and screen chamber	10,000
Equipment	
Four 4,000-gal. pumps	$ 82,000
One 1,000-gal. pump	3,500
Auxiliary pumps	4,250
Feedwater heaters and purifiers	4,750
4 boilers and settings, 27,200 sq. ft. heating surface	33,000
16 underfeed stokers, blowers, air piping, etc	18,000
4 steel stacks and supports	8,000
Coal handling apparatus	7,000
Turbo-generators and switchboard	4,500
Electric crane	4,000
Steam and auxiliary water pipping	30,000
	$ 199,000
	$ 371,530
Miscellaneous	
Signal system, cables, etc	$ 1,500
Furnishings for men's quarters	500
Incidentals	5,000
	$ 7,000
Engineering	50,000
Total cost of construction	$1,093,546

The following analysis of operating expenses, for electric pumps and steam pumps, was an additional argument for the use of steam pumps for the Baltimore installation.

Electric Pumps (New York Type)	
Investment	
5 motor driven pumps (rated capacity 3,000 gals. per min.), switchboard, etc	$112,500
Building and pump foundations	84,000
	196,500
Operation	
Maintaining pressure continually 8,760 hr. less 100 hr. = 8,660 hr. at 100 kw	866,000 kw-hr.
Fire service, 100 hr. per annum 3,150 kw. demand	315,000 kw-hr.
	1,181,000 kw-hr.

Service charge, maximum demand = 3,150 kw.		
Central station investment, 3,150 kw. at $75		$236,000
Underground cable (Baltimore conditions)		40,000
Cash requirements		236,000
Underwriting at 90		31,000
Total investment		$307,000
Fixed charges on $307,000		
Interest	at 5 per cent	
Depreciation	at 5 per cent	
Profit	at 5 per cent	
Total	15 per cent	$ 46,000
Underground conduits, duct rental (Baltimore conditions)		1,300
Total service charge		$ 47,300
Operating expenses		
Service charge		$ 43,700
Meter charge, 1,181,000 kw-hr. at 1 ct		11,810
Salaries, station operating force		10,650
Supplies, lubrication and repairs		1,000
		$ 67,160
Fixed charges on $196,500		
Interest at 4 per cent		$ 7,860
Depreciation at 5 per cent		9,825
		$ 17,685
Total annual expense, electrical plant		$ 84,845

Steam Pumps

Investment		
Four 4,000-gal. pumps and auxiliaries		$ 86,000
Boilers and auxiliaries		70,000
Piping, steam and auxiliary water		30,000
		$186,000
Building and machinery foundations		125,000
		$311,000
Operation		
Coal consumption		
Banking fires, 8,760 hr.—		
100 hr. = 8,660 hr. = 360 days at 6 tons per day		2,160 tons
Fire service. 100 hr. per annum at 5 tons coal per hour		500 tons
Total		2,660 tons
Operating expenses		
Coal, 2,660 tons at $3.30		$ 8,778
Salaries, station operating force		13,350
Supplies, lubrication and repairs		2,000
		$ 24,128
Fixed charges on $311,000		
Interest at 4 per cent		$ 12,440
Depreciation at 5 per cent		15,550
		$ 27,990
		$ 52,118

Summary

Total annual expense, electrical plant	$ 84,845
Total annual expense, steam plant	52,118
Total annual saving	$ 32,727

This saving capitalized at 9 per cent represents an investment by the city of $363,630, considerably more than the first cost of the steam plant in the above comparison.

Operating Costs of Water Works Per Million Gals. and Per Capita.—Engineering and Contracting, Jan. 28, 1914, gives the following from a report on an investigation of the municipal water works at Lorain, Ohio, by Philip Burgess.

TABLE XI.—ANNUAL OPERATING COSTS OF 16 WATER WORKS PROPERTIES

City	Dates	Total population	Annual operating cost Per 1,000,000 gals.	Per capita
Ashland, Wis.	1904–09	12,150	$36.23	$1.25
Manitowoc, Wis.	1907	13,400	47.76	1.32
Janesville, Wis.	1909	13,800	49.96	1.30
Beloit, Wis.	1908	14,100	23.35	1.02
Chillicothe, O.	1908–12	14,500	.....	1.00
Marinette, Wis.	1909–10	14,650	26.17	1.09
Private Water Co. in Arkansas	1908–12	15,400	.....	1.57
Elyria, O.	1910–12	15,500	34.88	1.47
Appleton, Wis.	1909	16,700	36.73	1.29
Fond duLac, Wis.	1907	17,800	20.31	0.77
Eau Claire, Wis.	1907	18,650	18.24	0.71
Private Water Co. in Western Pa.	1905–10	22,570	40.45	1.17
Green Bay, Wis.	1907	24,000	48.56	0.90
Battle Cr., Mich.	1908–12	25,270	26.20	0.72
Madison, Wis.	1908–12	25,460	49.70	1.28
Sheboygan, Wis.	1908	25,500	24.74	0.77
Lorain, O.	1900–10	22,070	23.72	1.17
Average of 16 cities above	....	18,090	34.51	1.10

The costs shown include true operating costs exclusive of extraordinary expenses such as are incurred by extensions or replacements.

Cost of Setting 25,000 Water Meters at San Francisco.—The following data are given by George W. Pracy, Ass't. Sup't. Spring Valley Water Co. in Engineering News-Record, May 9, 1918.

During portions of 1916 and 1917 the Spring Valley Water Co., which supplies the city of San Francisco with water, installed 24,993 meters, practically all of ⅝-in. size, with marked effect in reducing water consumption. Careful records of cost were kept.

In 1915 the average daily water consumption of San Francisco was 42,-635, 014 gal., which was in excess of the developed supply and 3,261,229 gal. over that for 1914. As 1915 was the exposition year, with attendant extraordinary water uses, it was confidently expected that 1916 would see a decrease in the use of water. When instead the first four months of that year showed a substantial increase the problem of adding to or restricting waste was squarely put before the company.

On May 1, 1916, water was supplied through 65,000 service connections of which about 22,000, or 34%, were metered. These meters were all on business houses. All dwellings were on a flat-rate basis. The company felt that the metering of these flat-rate services was not only the most economical but also the best way of meeting the situation. Accordingly in May, 1916, an order was placed for 15,000 ⅝-in. meters, with the option of purchasing a second 15,000 at a later date, a total of 30,000 meters being purchased.

For local reasons it was decided to meter only those consumers whose monthly bills were $1.80 or more. This made the work of setting the meters harder and more costly than metering all houses. All meters were set at the curb.

Organization.—The field work was done by two crews. For the first month each crew consisted of a foreman and about 30 men. The crews were later cut down to 12 to 15 men. The two foremen were under the general foreman of the service and meter department. A Ford truck and a Ford wagon delivered the meters, boxes and other material on the ground.

Method of Setting.—The meters were delivered to the meter shop by the manufacturers. There they were taken out and tested. A testing machine of six-meter capacity was used. Each meter was tested for a 10-cu.-ft. flow at the rate of 15 gal. per minute. Meters reading from 99 to 100% correct were set. Those reading under 99 or over 100% were sent to the bench for adjustment. After testing, the meters were piled up ready for delivery to the job.

The meter boxes were delivered f.o.b. cars at San Francisco. Thence they were hauled to the yard, where they were stacked. The other material was delivered at the yard by the various manufacturers.

A large tool box mounted on wheels was kept in the locality at which each crew was working. At this tool box was kept about half a day's material for the crew. This enabled the crews to start work at 8 a.m. and continue till the truck arrived.

The Fords were sent out each morning with the material needed for the day. They also moved the tool boxes along as the work progressed. The material was delivered from the tool boxes to the houses by one man using a wheelbarrow. Meterset orders were written in the main office and given to the general foreman, who routed them and gave them to each gang foreman. The gang foreman in turn had a man who took these orders and went ahead of the crews measuring up and marking out the services that were to be metered. The marking was done by chalk on the sidewalk or curb. This man was followed by the laborers, who excavated down to the service and stopcock. If the meter was to be set in the concrete sidewalk a piece about 2 ft. square was first broken out. In lawns the sod was carefully taken out and set aside. The laborers were followed by the servicemen, who set the meter. The servicemen were then followed by other laborers who set the concrete boxes and filled in. In concrete sidewalks the laborers just filled in, the repaving being done by a contractor. A team followed to clean up and haul away the debris.

For each hole made in a paved sidewalk an order was filled out and sent to the paving contractor. This order specified the location, kind of paving and size of opening.

Each serviceman was provided with a pad on which he wrote the number and location of the meter as it was set, using a new sheet for each. These were collected by the foreman, who checked each one and entered the information on the orders. The servicemen could not make the original entry direct into the meter-set orders, as it was necessary to keep them clean. The orders were then sent to the clerk at the yard, who made out the paving orders. They then went to the main office, where an account was opened for each meter.

The speed of the crews varied from day to day, depending on various conditions. In the old part of the town, which was burnt over in the fire of 1906 and where the service records were not always correct and the services in poor condition, the least headway was made. In the new residence districts the work went along rapidly. The crews as a whole averaged 4¼ meters per man per day, though on some days they set as many as 8 per man. Each serviceman set an average of 15 meters a day. A record was kept of the number set by each man, and if any serviceman could not keep up with the rest of the gang he was dropped. The cost data for the job are given in Tables XII to XV.

TABLE XII.—AVERAGE COST OF INSTALLING 24,993 ⅝-IN. STYLE 2 TRIDENT METERS ON OLD SERVICE CONNECTIONS AT SAN FRANCISCO, CAL. AUG. 1, 1916, TO APRIL 30, 1917*

	Cost — Total	Per meter	Percentage
1. Labor	$ 21,013.84	$ 0.840	7.90
2. Teaming	2,088.89	0.083	0.79
3. Paving	45,488.48	1.820	17.17
4. Permits	8,934.00	0.357	3.37
5. Material	180,750.16	7.232	68.30
6. Tools	1,202.47	0.048	0.45
7. Miscellaneous	970.96	0.039	0.37
8. Supt., warehouse, etc	4,354.37	0.170	1.65
	$264,803.17	$10.589	100.00

1. Labor: Sub-Foreman, $4.25. Fitters, $3.75. Laborers, $2.50. Eight hours. Average crew consisted of sub-foreman, five fitters, ten laborers and one Ford. Set about 63 meters per day. Meters set per man day, 4.25.
2. Teaming: Horse-drawn vehicles, $1,238.89. Ford auto trucks, $850.
3. Paving: Replacing sidewalks and setting plates at 25c. per square foot. This charge applies only to 19,524 meters set in sidewalks and becomes, per meter paved, $2.33.
4. Permits: Permit to open paved sidewalks at 50c. each. Applies to meters set in paved sidewalks only at 50c. each.
5. Materials:

24,993 meters f.o.b. yard at $5.95		$149,238.55
Concrete boxes	.88	5,197.80
Cast-iron plates	.60 and .65	10,677.74
Meter couplings	.16 to .19	8,244.27
Pipe and fittings		7,391.80
Total		$180,750.16

6. Tools: New tools purchased, $1,149.39. Tools repaired, $53.08.
7. General:

Miscellaneous	$346.44
Carfares	63.65
Machine shop	114.60
Stationery	186.40
Repair sewer vents	170.83
Clean carpets	27.22
Replace lawns	61.82
Total	$970.96

8. Superintendence, employees, insurance, foreman, yard office (proportion), warehouse expense (proportion), auto (proportion of assistant superintendent's and foreman's and all of two sub-foreman's autos, $4,354.37).

* A few larger meters are included as well as a small amount of street paving due to having to shut off at main in some cases. These amounts are practically negligible.

TABLE XIII.—DETAILED COST OF SETTING A ⅝-IN. METER

	Paved sidewalks		Unpaved sidewalks
Labor	$ 0.840 (including testing)		$0.840 (including testing)
Teaming	.083		.083
Paving	2.330		
Plate	.625	Box	.880 (including 0.03 handling car to yard)
Permit	.500		
Material*	6.590 (including meter)		6.590 (including meter)
Tools	.048		.048
Miscellaneous	.039		.039
Superintendent, etc†	.170		.170
Total	$11.225		$8.650

* Meter at $5.95 f.o.b., Bryant St. Yard. † Departmental overhead only as far as assistant superintendent.

Approximately 19,524 meters were set in paved sidewalks and 5,473 meters in unpaved sidewalks. In paved sidewalks there occurs a charge for permit to open sidewalk ($0.50), replacing pavement at $0.25 per square foot, amounting in this case to $2.33 per meter paved, and the cost of a cover either concrete or iron varying from $0.60 to $0.65 each, say $0.625. In unpaved sidewalks these costs do not occur, but there is the cost of a concrete meter box ($0.88). In lawn sidewalks the removal and replacement of sod is equivalent to the cost of breaking up concrete walks.

In the following cost segregation only the difference in paving, materials and permits has been taken into consideration.

TABLE XIV.—SEGREGATION OF LABOR COSTS FOR METER SETTING

Hauling concrete boxes and covers from railroad to yard	$27.62
Unloading meters from wagon to warehouse	16.92
Testing meters	542.11
Installation of meters	19,215.74
Replacing lawns and gardens	28.42
Miscellaneous yard work	118.62
Services of clerks	562.09
Repairs to sewers broken in setting meters	238.92
Cleaning out sewers	44.68
Locating services with wireless pipe finder	105.40
Rearranging services	79.74
Machine shop	33.58
Total	$21,013.84

TABLE XV.—CLASSIFIED RATES OF PAY AND TIME FOR LABOR USED IN SETTING METERS

	Rate	Days	Hours	Amount
Foreman	$4.25	447	..	$ 1,899.75
Fitters	3.75	1,732	..	6,495.00
Helpers	2.75	230	.	632.50
	3.00	220	3	661.12
Laborers	2.50	2,347	6	5,869.37
	2.75	1,198	4	3,295.88
Teamsters	3.00	56	2	168.92
	2.75	63	4	174.63
	4.00	2	3	9.50
Miscellaneous	3.50	2	1	7.44
	3.25	.....	4	1.63
Total		6,299	3	$19,215.74

Cost of Outdoor Meter Installations at Terre Haute, Ind.—The Terre Haute, Ind., Water Co., for outdoor meter installations, has been using recently a pit made of two 2½-ft. 20-in. vitrified sewer pipes with a slot in the bottom of the lower one to fit over service pipes laid some years ago before the present rules concerning the depth of the services were in force. These pipes are provided with a Clark cover and coupling yoke. The cover is 6 in. high, making the total depth of the installation 5½ ft. The average cost in 1918 of an installation of this type including service pipe from the main to the curb was $42.27, according to a paper by Dow R. Gwinn, president of the company, in the January, 1920, Journal of the American Materials Association and abstracted in Engineering and Contracting, Feb. 11, 1920. The itemized cost of the installation as given by Mr. Gwinn is as follows:

Corporation cock, ⅝ in	$1.09
Curb cock, ⅝ in	1.66
Brass tail piece, ¾ in	.38
Extra strong lead service pipe, 3 lb. per foot, 17.1 ft., ⅝ in	3.72
Service box with 2½ in. shaft	1.50
Labor, 10.9 hours at 35 ct	3.82
Labor, 2.2 hours at 40 ct	.88
Drayage $	1.25
City permits	.87
Overhead on tools and equipment	1.30
Total for services	$16.47
Empire meter, ⅝ in	$12.00
Tile, 2	3.70
Clark cast iron cover	2.75
Meter yoke	1.50
Pipe and fittings	.93
Cement	.37
Labor, 5 hours at 35 ct	1.75
Labor, 2 hours at 40 ct	.80
Drayage	2.00
Total for meter and installation	$25.80

Number of Meters Read Per Man Per Day.—The following data are taken from Engineering and Contracting, July 9, 1919.

Judging from a recent tabulation given in the Municipal Journal, there is a wide range of effectiveness of meter readers, even where conditions seem to warrant no such variation. Thus in Los Angeles, with 100,000 "outside" meters, 50 per hour is said to be the average; whereas in Washington, D. C., with 61,000 "outside" meters, 22 per hour is given as the average. The ratio is almost 2½ to 1. Even greater differences exist in other cities as to the number of "inside" meters read per hour.

The number of meters read per hour obviously depends not only upon the efficiency of the men, but upon other conditions such as: (1) The distance from the office to the place where meter reading begins. (2) The distance apart of meters. (3) Whether the meters are inside or outside the building. (4) Whether the readers walk or ride.

The following are typical examples selected from the above mentioned tabulation:

Cities Having Outside Meters

	Number of meters	Average number read per man-hour
Alhambra, Calif	2,100	29
Los Angeles, Calif	99,600	50
San Diego, Calif	15,169	41
Pasadena, Calif	12,547	38
Whittier, Calif	1,951	20
Washington, D. C	61,107	22
Atlanta, Ga	33,000	30
Augusta, Ga	7,500	20
Gadsden, Ala	2,030	60
Lewiston, Ida	1,200	38
Atlantic City, N. J	7,398	40
Oklahoma City, Okla	13,000	28
Portlant, Ore	17,588	30
Memphis, Tenn	19,734	30
Knoxville, Tenn	13,908	67

Average for these 15 cities, 36.

Cities Having Inside Meters

	Number of meters	Average number read per man-hour
Hartford, Conn.	15,451	12
Middleton, Conn.	2,300	11
Concord, N. H.	2,576	20
Elmira, N. Y.	10,032	18
Syracuse, N. Y.	28,133	20
Solvay, N. Y.	990	*15–†20
Worcester, Mass.	20,715	14
Grand Rapids, Mich.	24,530	8
Duluth, Mich.	12,144	15
Minneapolis, Minn.	60,930	10
Akron, O.	26,000	28
Cincinnati, O.	55,000	20
Dayton, O.	30,438	23
Meadville, Pa.	3,376	31
Wilkinsburg, Pa.	15,686	25

Average of these 15 cities, 18.
*Residence. † Business.

Comparing the averages in these two tables, it would appear that twice as many outside meters can be read daily as inside meters.

Cost of Meter Reading at Terre Haute, Ind.—In Engineering and Contracting April 11, 1917, Jay A. Craven describes the methods employed in meter reading at Terre Haute, Ind.

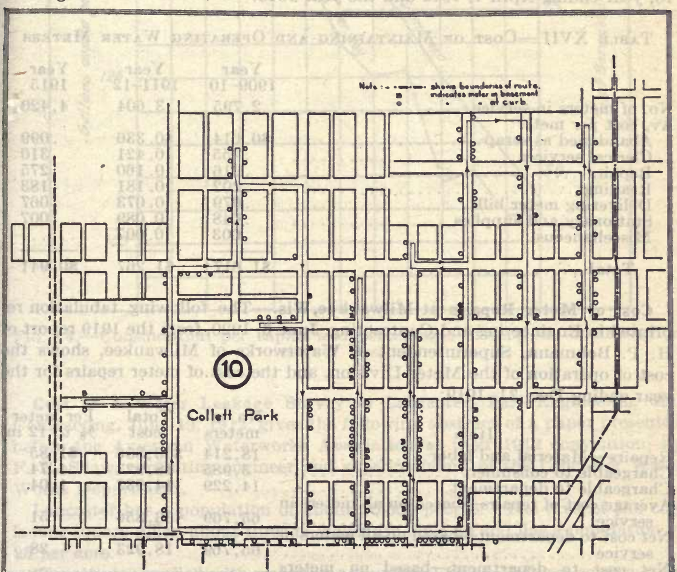


Fig. 13.—Section of large routing map, showing typical route.

A brief outline of the method is as follows. The city is divided into routes with about 200 meters (to be read) on each route. Individual cards for each meter are arranged in proper order in a loose leaf book for each route. At the time the meters are read, a spirit of competition is aroused by having a blackboard record kept showing each reader and the time for completing each book taken out. This record is also transferred to a more permanent form.

The following table is made up of data given by Mr. Craven.

TABLE XVI.—A SUMMARY OF METER READING RECORDS

Month	Total hrs.	Number meters read	Not read	Read per hr.	Cost per meter in cents
Sept	288.25	6,617	297	23	1.7
Oct	254.25	6,805	235	27	1.1
Nov	243.00	6,676	220	27	1.1
Dec.*	347.10	6,703	258	19	3.7*
Jan	291.45	6,672	235	23	1.6
Feb	243.60	6,660	289	27	1.3

* Time shown only represents the time the book was out, and on most of the books, a man accompanied the reader to sweep snow and assist in locating the meters. The cost for this month was exceptionally large.

The best record made was an average of 54 per hour for 4 hours.

Cost of Maintaining and Operating Water Meters.—Table XVII gives the annual cost per meter for the meter system at Reading, Pa. for the years 1909-10, year ending April 1, 1912 and the year 1915.

TABLE XVII.—COST OF MAINTAINING AND OPERATING WATER METERS

	Year 1909–10	Year 1911–12	Year 1915
No. of meters in service	2,795	3,604	4,420
Av. cost per meter:			
Abandoned as scrap	$0.614	$0.336	.099
Clerical services	.455	0.421	.310
Repairs	.216	0.160	.275
Reading	.202	0.181	.183
Delivering meter bills	.079	0.073	.067
Stationary and supplies	.048	0.089	.007
Miscellaneous	.003	0.007	......
Total	$1.617	$1.267	$0.941

Cost of Meter Repairs at Milwaukee, Wis.—The following tabulation reprinted in Engineering and Contracting, June 6, 1920, from the 1919 report of H. P. Bohmann, Superintendent of Waterworks of Milwaukee, shows the cost of operation of the Meter Division, and the cost of meter repairs for the year ending Dec. 31, 1919:

Item	No. of meters	Total cost	Per meter ⅝ to 12 in.
Repairs—Material and labor	18,214	$33,856	$1.85
Chargeable to consumer	3,985	18,923	4.74
Chargeable to department	14,229	14,932	1.04
Average cost of repairs—based on all meters in service	65,769	33,856	.51
Net cost to department—based on all meters in service	65,769	18,923	.28
Net cost to department—based on meters repaired	18,214	18,923	1.03
Total cost of operation for all meters in service	65,769	62,676	.95
Less revenue received	......	28,505	.....
Net cost of operation for total number of meters in service	65,769	34,170	.51

Effect of Meters on Consumption of Water.—The effect of meters upon the consumption of water is too well know to need further comment. This effect is graphically illustrated in Fig. 14 which shows the daily number of gallons used per capita in the city of Boston and the percentage of unmetered taps for each year, 1904 to 1916 inclusive. The figure is taken from a paper by Samuel E. Killam, Sup't. of Pipe Lines and Reservoirs of the Metropolitan Water works presented at the 1917 convention of the New England Water Works Ass'n.

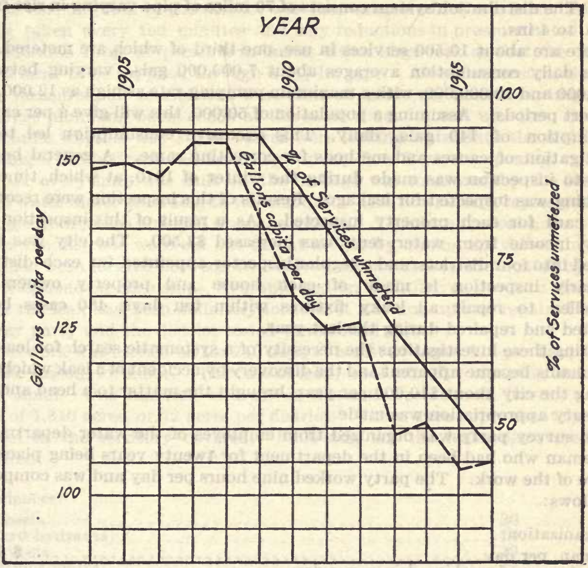


FIG. 14.—Consumption per capita and percentages of services unmetered in city of Boston.

Cost of A Water Leakage Survey at Lancaster, Pa.—Engineering and Contracting, June 19, 1912, gives the following abstract of a paper presented before the American Waterworks Association at their 1912 convention, by F. H. Shaw, consulting engineer and superintendent of the Lancaster Water Works Department.

Lancaster has a population of about 50,000 people. The area of the city is four square miles, about three of which are built up and has a population of 25 per acre.

The city is supplied with water by a municipal plant, the first construction dating back to 1836. The water taken from the Conestoga Creek, a tributary of the Susquehanna River, is filtered and pumped into the city against a head of 250 ft., the supply being measured by a Venturi meter located between the filter plant and the pumping station. The distribution system is connected with the pumping station by two force mains, one 30 in. and one 36 in., each being about one mile in length.

The distribution system is divided into high and low service districts. The low service district contains about 0.4 of a square mile and is supplied from the old reservoir constructed in 1836 and in 1850, which has a capacity of 6,000,000 gals. These reservoirs are filled at night by pumping through the 36-in. main.

The high service district is supplied through the 30-in. main by direct pumping. The water passes through a standpipe having a capacity of 400,000 gals. The distribution system consists of 70 miles of pipe varying in size from 24 ins. to 4 ins.

There are about 10,500 services in use, one-third of which are metered.

The daily consumption averages about 7,000,000 gals., varying between 5,000,000 and 10,000,000, with a maximum pumping rate as high as 12,000,000 for short periods. Assuming a population of 50,000, this will give a per capita consumption of 140 gals. daily. This excessive consumption led to an investigation of causes and methods for correcting same. A general house-house-to inspection was made during the winter of 1910, at which time all plumbing was inspected for leakage. Results of this inspection were recorded on a card for each property inspected. As a result of this inspection the yearly income from water rents was increased $3,500. The city was then divided into four districts, and a regular inspector appointed for each district. A yearly inspection is made of each house and property owners are compelled to repair all leaky fixtures within ten days, 480 cases being reported and repaired during the last year.

During these investigations the necessity of a systematic search for leakage from mains became apparent and the discovery by accident of a leak which was costing the city about $10,000 per year, brought the matter to a head and the necessary appropriation was made.

The survey party was organized from employes of the water department, a foreman who had been in the department for twenty years being placed in charge of the work. The party worked nine hours per day and was composed as follows:

Organization:	
Foreman, per day	$ 3.00
Single team and working driver, per day	2.50
Three laborers, at $1.80 per day	5.40
Total cost per day	$10.90

Outfit:
One 4-in. meter with 2½-in. connections on truck.
One ⅝ in. meter.
One pressure gauge.
Two 25-ft. lengths 2½-in. fire hose.
250 ft. 2½-in. galvanized pipe.
One small tool box.
Picks, shovels, wrenches, caulking tools, lead, wool, etc.

The first step in preparing this work was an inspection of all valves and repairs to same, placing them in working order and replacing some which could not be operated. This work was done by the men in the distribution department in advance of the survey. The survey was started on March 6th, 1911, and stopped for the winter on December 13th. The method of procedure was as follows:

The 4-in. meter was mounted on a small 4-wheeled truck and the connections bushed down to 2½ ins., with a 2½-in. valve at inlet and outlet. The large meter was by-passed by a ⅝-in. meter for use on small flows. A pressure gauge was attached to the outlet end of the large meter. The districts tested had an average area of 12 acres, containing about 80 houses. The district to be tested was shut off from the remainder of the system by closing all valves on street mains. The meter was then connected with a hydrant outside the district by means of a 25-ft. length of fire hose. The 2½-in. pipe line was laid from the meter to a hydrant inside the district, being connected with it by another short length of hose.

The consumption of the district was then measured for one hour, readings being taken every ten minutes and any reductions in pressure noted. Any considerable drop in pressure indicates either large leak or that the district is too large to be supplied through a 2½-in. pipe. After the consumption had been measured, all connections were shut off inside the houses, an inspection of house plumbing being made at the same time. A test was then made to determine whether any street valves were leaking water into the district by opening a fire hydrant and watching for any flow from the opening.

After everything was shut off the leakage was measured by the large or small water meter according to the amount. This flow, if any, represented the leakage from mains and also from the service. To locate the leaks, the streets inside the districts were cut out one at a time by closing the valves until the leak had been located between two valves, after which it was located by using the telephone on curb stops, hydrants and on drills driven down to the main. After the leak had been definitely located, it was dug up and repaired by the survey party and the district tested until found tight.

The work was carried on for 240 days at a cost of about $11 per day, $2,640 for the season, for labor. The cost of lead, wool, etc., for repairing leaks was very small. One hundred and eleven districts were tested, having a total area of 1,310 acres, or 12 acres per district. There were approximately 9,000 houses in the territory covered. Following are the leaks discovered and repaired:

Residences:		
Closets	20	
Yard hydrants	10	
Faucets	19	
Service mains	17	
		66
Street valves	12	
Fire hydrants	35	
Street mains	29	76
Total		142 leaks

The leaks varied from 1 to 19 cu. ft. per minute. The largest leak found was a 3-in. elbow split wide open and running at the rate of 205,200 gals. per day. This line had been by-passed around the meter outside the building and was supplying four buildings. In this case the survey not only stopped the leak, but detected the illegal use of water. This leak amounted to 75,000,000 gals. per year, the actual cost of furnishing which was $2,812.50, or $172.50 more than the cost of the entire survey.

The total mileage of mains inspected was 40.8, varying in size from 4 ins. to 24 ins. The total leakage record was 118 cu. ft. per minute, or 1,271,000 gals. per day. Using $37.50 per 1,000,000 gals. as the actual cost of furnishing water exclusive of interest, the total leakage was costing the city about $17,000 per year.

About one-quarter of the system remains to be tested, also the 20-in. supply main which runs directly across the city. One mile of 36-in. force main laid in 1888, was tested by closing the valves at both ends, and supplying it from the other force main through a smaller meter. Leakage was found amountting to $2,000 per year.

A comparison of the consumption before and after the survey shows a decrease of 10,000,000 gals. per month during March and April, an equal consumption from May to September, a decrease of 8,000,000 gals. per month during October and November, a decrease of 24,000,000 gals. during December and an increase of 20,000,000 gals. during January, February and March. While the present consumption is about equal to that before the survey began, the consumption for 1911 is slightly less than for 1910.

Mr. Shaw considers the decrease of 24,000,000 gals. per month shown in December a fair indication of the results of the survey, as abnormal conditions existed before and after this time, which had a tendency to increase the consumption.

As an investment he believes a survey of this kind, which not only locates but repairs leaks, is a good one and well worth following up until one is assured that the distribution system is reasonably tight.

Cost of Concrete Siphon on the Los Angeles Aqueduct.—D. L. Reaburn, Engineer Saugus Division, Los Angeles Aqueduct gives the following data in an article in Engineering and Contracting, July 3, 1912.

Whitney Siphon, about 28 miles north of Los Angeles, has a slant length of 955 ft. and a maximum head of 70 ft. The pipe is 10 ft. interior diameter, with a uniform thickness of 9 ins. The reinforcement consisted of round rods. The circumferential rods were spaced 4 ins. apart, and varied from ⅝ in. to ¾ in. in diameter. A working strength of 15,000 lbs. per square inch was used, and the rods were designed to carry the total stress, regardless of the strength of the concrete. The longitudinal rods were ¾ in. in diameter and they were spaced about 2 ft. c. to c.

The trench was excavated with teams and trimmed to shape by hand. It had a bottom width of 14 ft. with slopes of about 1 on 1. Care was taken to have most of the dirt placed on one side of the trench. This was leveled off for about 30 ft. from the edge of the trench, so as to give sufficient elevation to the mixer for delivery of the mixed concrete by gravity, to provide room for gravel and cement storage near by, and also to allow the mixer to be moved along as the work progressed.

After the trench was excavated to line and grade the first operation in the construction of the siphon was setting the concrete blocks to support the inner forms. These blocks, which were 4 ins. thick, 10 ins. wide and about 12 ins. high, had been made a few weeks previous to allow ample time for hardening. The tops were cast to fit the curve of the inner forms. They were spaced 6 ft. apart in two parallel rows, so that each pair supported a 6 ft. length of the inner forms. They were set in mortar a few days before the forms were placed on them. This arrangement not only insured correct alignment and grade, but permitted the concrete to be readily poured and thoroughly spaded. The concrete blocks became a part of the concrete shell of the siphon.

The next step was the setting of the inner forms, which were of wood and not very satisfactory, as it was difficult to maintain them in a circular shape after they were once moved. Each 6 ft. length of forms was made up of eight sections, three below the horizontal diameter and five above it, braced and bolted in such a way that they could be collapsed for moving ahead (See Fig. 15). Each section was made of four ribs cut to the proper curve, on which the 2 in. lagging was nailed. The lagging was dressed on the outer side. The arrangement of the cross braces which held the sections in place permitted the dismantled sections to be moved ahead through those already erected, by means of a platform car on a track which rested on the cross ribs of the bottom section. The car was pulled back and forth with a rope.

In conjunction with the setting of the inner forms the reinforcement rods were placed on them, having been previously bent to the required circle with a small bending machine, and properly spaced, wired and blocked away from the forms. After the inner forms were assembled, circular ribs were placed to support the outside lagging. These were spaced 4 ft. apart and braced against the side of the trench. The outside lagging was 2 × 6 × 4 ins. The concrete work was commenced near the middle and carried first toward one end and later toward the other. There were 120 lin. ft. of inner forms used. They were set up by a crew of 8 men.

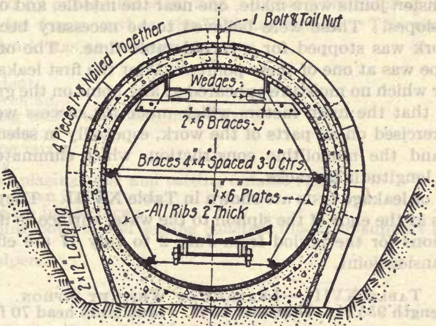


FIG. 15.—Section showing forms used in constructing Whitney Siphon.

When everything was in readiness one of the regular tunnel concrete crews of 26 men and a foreman was detailed to the work. From 36 to 40 men were required to keep the work going continuously. The concrete was delivered on top of the forms through a chute, and flowed to the bottom over them. The outside lagging was placed about 2 ft. high at the start, to allow room for inspection and spading on the bottom. As the concrete rose in the forms, more lagging was placed. The bottom of the trench was filled for the whole length of the day's run and the complete pipe was finished the same day, whether it was 30 ft. or 50 ft. A rough connection was made by means of a sand bag bulkhead, and particular pains were taken to ensure a good bond at this point. About three days were required to complete the 120 ft. of pipe. About noon of the second day the work of taking down the inner forms and moving them ahead was begun, without interfering with the progress of the concreting. In about 24 hours the outer forms were removed and the pipe was immediately backfilled and thoroughly flooded for about a week. When the foot of the steep slope was reached the mixer was moved to the top of the slope and the work continued in the same way until the top was reached. At each end of the siphon a manhole 30 × 36 ins. was constructed.

Electrical energy was used for light and power and water was supplied under pressure from a large tank on the adjacent hill. Sand and gravel were obtained from the adjacent creek without screening. All stone larger than 3 ins. was rejected. The mix was 1:4 or 1 bbl. of cement to 16 cu. ft. of concrete. About 20 per cent of water was used, which insured a very wet mix.

No serious difficulties were encountered in carrying out the work. As the work was done during flood season, Whitney Creek carried considerable water and the excavation was a little more costly owing to the construction of the necessary protecting dams to prevent flooding the trench. At the lowest point, where the creek crosses the siphon, the top was paved with cobble while the concrete was soft, as a precaution against scour in flood season.

At the lowest point on the siphon a special cast iron pipe with a flange moulded to fit the inner side of the pipe was placed. This connected through a 10 in. valve in the blow off chamber to the blow off pipe which consisted of second-hand 12 in. vent pipe embedded in concrete. The inside of the pipe was finished with two coats of neat cement wash put on with a brush.

Three expansion joints were made, one near the middle, and one at the foot of the steep slopes. These were believed to be necessary because at these points the work was stopped for a considerable time. The only noticeable leak in the pipe was at one of these points. After the first leakage test it was repaired, after which no moisture appeared at any point on the ground surface. It is believed that the main factors which made for success were the painstaking care exercised on all parts of the work, especially in selecting the sand and gravel, and the monolithic construction, which eliminated the danger of developing longitudinal cracks.

The results of leakage tests are shown in Table XVIII. They are based on measurements at the ends of the siphon to the water surface as it was lowered. The observations for the period from July 2 to July 17 are effected by the defective expansion joint.

TABLE XVIII.—LEAKAGE OF WHITNEY SIPHON.
(Length 955 ft. Diameter 10 ft. Maximum head 70 ft.)

Period.	1910.	Leakage, gals. per day
16 days	July 2—July 17	4,146
32 days	Sept. 30—Nov. 1	165
10 days	Nov. 1—Nov. 11	135
20 days	Nov. 11—Dec. 1	132
44 days	Dec. 1—Jan. 13	356

Remark.—The leakage shown for the last period indicates that someone had tampered with the blowoff. This is borne out by the fact that the padlock on the cover of the blowoff chamber was found broken.

TABLE XIX.—COST OF WHITNEY SIPHON.

Item	Per lin. ft.
Excavation	$ 5.47
Concrete lining	8.33
Steel in place	3.82
Backfill	2.63
Engineering	0.13
Anchorage proportion	0.14
Blowoff proportion	1.28
Average cost per lin. ft. completed section	21.80
Average labor cost mixing and placing per lin. ft	2.14
Average labor cost placing steel per lin. ft	0.83
Average cost per ft. for forms	1.20

(As there are about 0.78 cu. yd. of concrete per lineal foot of this siphon any of the above items multiplied by this sum gives cost per cubic yard of concrete.)

South Antelope Siphon.—The Antelope Valley Siphon is about four miles long with a maximum head of 200 ft. It is a composite structure, composed of 3,446 ft. of 10 ft. reinforced concrete siphon on the south end and 2,734 ft. on the north end, while the middle portion is of steel. The maximum head on the concrete pipe is about 75 ft. The ground slope is very uniform and level transversely, making an ideal condition for construction.

The excavation for the pipe was taken out to a depth of 8 or 9 ft. with a model No. 20 Marion steam shovel. About two-thirds of the dirt was placed on one side and the remaining one-third on the side from which concreting was carried on.

Construction on the south end was commenced July 7, 1911, at the conduit end and completed Sept. 2, 1911.

The average progress was 44 ft. per day. After the first week a rate of 40 ft. was maintained for about 20 days, after which a uniform rate of 49 ft. per day was made until completion.

The inner forms were of wood built up in sections about 20 ins. wide and 4 ft. long, supported by collapsible steel ribs. These were much more satisfactory than the wooden forms used on the Whitney siphon. The working force on the concrete work was as follows:

1 superintendent.
1 concrete foreman.
6 men charging mixer with wheelbarrows.
1 man on cement.
1 man running mixer.
5 men placing.
6 bending and placing steel and setting outside ribs.
4 men taking down inside forms.
4 men setting up inside forms.
1 man trimming bottom and setting concrete blocks to support inner forms.
2 plasters.
2 plasters' helpers.

32 men, total.

The average rate of pay for this force was about $2.75 per day, or a labor cost of $2 per lineal foot on the basis of 44 ft. progress for mixing and placing, moving and setting forms and finishing.

Rock for a large part of the work was hauled 7½ miles from a plant in the hills and the average haul for sand was 1½ miles. Cement and steel was hauled by teams from Lancaster on the Southern Pacific R. R., a distance of 36 miles. Monolith Tufa cement manufactured by the city of Los Angeles, was used in the ratio of 7 sacks per cubic yard of concrete. The details of cost for the 3,446 ft. of pipe are as follows:

	Per lin. ft.	Per cu. yd.
Excavation	$ 0.94	.....
Sand and gravel	0.606	$0.45
Rock	3.07	2.32
Cement	5.80	4.37
Mixing and placing	0.91	0.69
Moving forms	0.62	0.47
Plastering	0.26	.....
Steel in place	4.30	.....
Backfill	0.39	.....
Engineering (instrument work)	0.04	.....
Superintendence	0.26	.....
Total per lin. ft.	$17.20	.....

The above does not include the cost of forms, which will be distributed at the completion of all work on which they are used. It will approximate $1 per ft.

Cost of Reclamation Service Concrete Siphons.—The following data are taken from Engineering and Contracting, March 15, 1916.

No record is had of the number of siphons constructed by the Reclamation Service. Including those of small size it is large. The siphons of major size are few, however, and those selected as examples represent construction practice adequately.

Belle Fourche Siphons.—There was built three siphons on this project: One 8 ft. in diameter and 477 ft. long; one 6 ft. in diameter and 395 ft. long, and one 5 ft. in diameter and 3,565 ft. long. Fig. 16 shows a section of the 8-ft. siphon the sections for the smaller siphons were similar. A 1:2:4 machine-mixed concrete was used; sand being screened to pass a ¼-in. screen and stone being

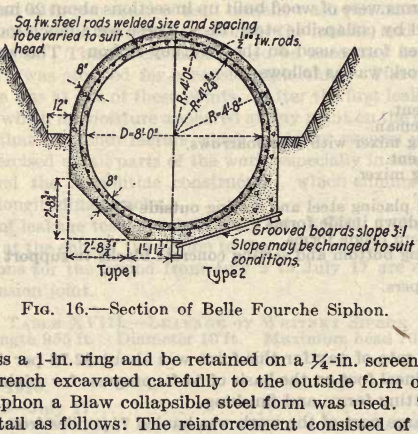


Fig. 16.—Section of Belle Fourche Siphon.

screened to pass a 1-in. ring and be retained on a ¼-in. screen. All siphons were built in trench excavated carefully to the outside form of the siphons. For the 5-ft. siphon a Blaw collapsible steel form was used. This siphon is recorded in detail as follows: The reinforcement consisted of 304,956 lb. of twisted steel bars; cost per pound Belle Fourche 2.4 ct., plus cost for hauling and storing of ½ ct. per pound. Cement at Belle Fourche cost $2.15 and $2.43 per barrel; hauling and storing cost, $1.28 per cubic yard of concrete. Cement hauled 16 miles; gravel hauled 1 mile. Wages per 8-hour day averaged $2.44 one foreman at $2.25 and one at $100 per month. Weather conditions favorable. Costs of concrete work alone were:

Item:	Per cu. yd.
Preparatory expenses	$0.30
Plant depreciation	0.43
Administration	1.03
Engineering	0.29
Superintendence	0.42
Inspection	0.06
Camp maintenance	0.32
Water work	0.28
Blacksmith and carpenter shop	0.26
Total general	$3.39

Item:	Per cu. yd.
Crushing and screening	$1.40
Hauling gravel and sand	0.50
Building (including lumber) wood forms	0.84
Hauling lumber for forms	0.18
Erecting steel forms	0.47
Miscellaneous	0.32
Cleaning reinforcement	0.08
Bending and welding	0.30
Mixing concrete	0.53
Placing concrete	0.42
Finishing and watering	0.22
Total labor	$5.26
Cement	$3.67
Steel	3.26
Hauling and storing cement	1.28
Hauling and placing steel	0.73
Miscellaneous	0.30
Total	$ 9.24
Rent of steel centering	0.86
Miscellaneous supplies	0.17
Total concrete	$18.92

The distribution of labor and materials costs it will be noted is not precise and totals for these items are therefore slightly in error; final total is accurate. The total cost of the concrete work proper was $41,929; the total cost of the siphon, including excavation, filling equipment, etc., was $59,310. Costs recorded in 1908; reported by U. S. Reclamation Service.

Sun River Siphon.—This work was a reinforced concrete siphon 1,568 ft. long, inside diameter 5 ft. 3½ in., with concrete piers and intake built for Sun River project U. S. Reclamation Service. Concrete, 613 cu. yd. in siphon and 272 cu. yd. in piers and intake, 1-2-4 mixtures. Wages were per eight-hour day for laborers, $2.24 to $2.74, two foremen at $125 per month, one carpenter foreman at $5.50 per day and carpenters at $3.50 per day. Cement cost $5.60 per barrel and reinforcing steel 4.12 ct. per pound, delivered. Work done by day labor; weather favorable. Sand and gravel hauled 2 miles; cement and reinforcing steel hauled 27 miles. Forms collapsible steel; progress 18 lin. ft. per day. Costs covering concrete work only were:

Item:	Per cu. yd.	Per cu. yd.
Amount of concrete, cu. yd	Pipe, 613	Piers, etc., 272
Engineering	$ 2.09	$1.57
Superintendence	1.26	0.95
Preparatory expenses	0.38	0.67
Administration	3.47	2.61
Camp maintenance	0.96	1.09
Total general	$8.16	$6.89
Hauling sand and gravel	2.91	2.85
Handling cement and steel	0.27	0.30
Hauling, wood, water and miscellaneous	0.26	0.40
Pumping	....	1.85
Making forms	1.85	2.03
Bending and placing steel	1.43	0.31
Mixing and placing concrete	3.32	2.35
Moving forms	1.40	0.41
Building trestle	0.25	.....
Total labor	$11.69	$10.50

Item:	Per cu. yd.	Per cu. yd.
Lumber	1.41	1.59
Steel	4.10	4.06
Cement	6.35	4.90
Total materials	$11.86	$10.55
Steel forms and supplies	0.81	.....
Installing and removing plant	0.28	0.21
Depreciation	0.47	0.52
Miscellaneous	1.32	1.49
Corral expenses	0.40	0.45
Total supplies	$ 3.28	$ 2.67
Total concrete	$34.99	$32.16

There were 1,254 ft. of tile underdrain which cost 81 ct. per lineal foot, and charges for excavation, backfilling rip-rap, survey and design, depreciation of buildings aggregating about $7,000, making the total cost of the siphon $23.49 per lineal foot. Costs recorded in 1907–8; reported by U. S. Reclamation Service.

Salt River Siphons.—Two twin-tube siphons were constructed, one under Pinto Creek 2,130 ft. long under 35 ft. head and one at Cottonwood Canyon 250 ft. long under a head of 76 ft. A cross-section of one of the Pinto Creek tubes is shown by Fig. 17. The concrete was a 1:2½:4 mixture, mixed wet by hand. The novel feature of the work was the use of a traveling form.

The forms consisted of an outside form constructed as shown by Fig. 17, by inserting 2½-in. × 5½-ft. lagging strips in the metal ribs. The inside form was designed to permit continuous work by moving the form ahead as the concreting progressed. It consisted as shown by Fig. 17, of an invert form on which an arch form was carried on rollers. The invert form was pulled along by cable from a horse power whim set ahead, being steered, aligned and kept to grade by being slid on a light wooden track. It had the form of a long half cylinder, with its forward end beveled off to form a scoop-like snout. The arch center consisted of semi-circular rings 2 ft. long, set one at a time as the work required. Each ring, when set, was flange-bolted to the one behind, and each was hinged at three points on the circumference to make it collapsible. In operation, the invert form was intended to be pulled ahead and the arch rings to be placed one after another in practically a continuous process. So that the arch rings might continue supported after the invert form was drawn out from under them, invert plates similar to the arch plates were inserted one after another in place of the shell of the invert form. The plan provided very nicely for continuous work, but continuous work was found impracticable for all but about 2,500 ft. of the 6,000 ft. of conduit built. The reason for this seems to have been at least in a great measure, the slow setting cement made at the cement works established by the Government, at Roosevelt. In building the first 300 ft. of conduit, a commercial cement was used and a progress of 120 lin. ft. of pipe per 24 hours was easily made. This work was done in June. Later, but still in warm weather, using the Government cement and 70 ft. of arch plates, not more than 70 ft. of pipe could be completed in 24 hours; if the plates were taken down sooner, patches of concrete fell out or peeled off with them. As the weather grew colder, this difficulty increased, until finally, the idea of continuous work was abandoned and for some 3,500 ft. of conduit only one 8-hour shift per day was worked. In December and January the plates had to remain in place three days, so that the progress was only 24 ft. per day; in warm weather this rate was increased to 40 ft. per day.

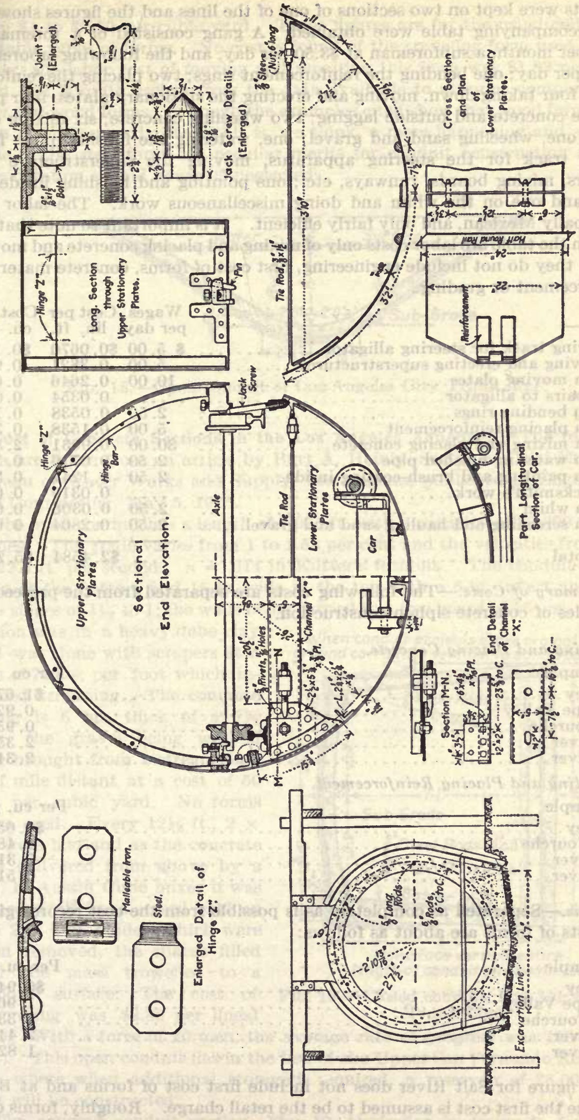


FIG. 17—Section of and detail of traveling form for Salt River Siphon.

Costs were kept on two sections of one of the lines and the figures shown in the accompanying table were obtained. A gang consisted of a foreman at $175 per month, a subforeman at $3.50 per day, and the following laborers at $2.50 per day; one bending the reinforcement rings; two placing the reinforcement; four taking down, moving and erecting the stationary plates; four placing the concrete and outside lagging; two wheeling concrete; six mixing concrete; one, wheeling sand and gravel; one, watering the finished pipe; four, laying track for the steering apparatus, moving the superstructure and hangers, mixing boards, runways, etc.; one pointing and finishing inside the pipe; and one on the whim and doing miscellaneous work. The labor was principally Mexican, and only fairly efficient. It is important to note that the costs in the table are labor costs only of mixing and placing concrete and moving forms; they do not include engineering, first cost of forms, concrete materials, reinforcement or grading.

	Wages per day	Cost per lin. ft.	Cost per cu. yd.
4 men—			
Laying track for steering alligator	$ 5.00	$0.0670	$0.16
Moving and erecting superstructure	5.00	0.3821	0.93
4 men moving plates	10.00	0.2646	0.65
Repairs to alligator	......	0.0354	0.08
1 man bending rings	2.50	0.0538	0.13
2 men placing reinforcement	5.00	0.1538	0.38
12 men mixing and placing concrete	30.00	0.9631	2.34
1 man watering finished pipe	2.50	0.0716	0.17
1 man painting and brush-coating inside	2.50	0.1241	0.31
Blacksmith's work	....	0.0319	0.08
1 man whim	2.50	0.0306	0.07
1 man screening and hauling sand and gravel	2.50	0.2804	0.68
Total	....	$2.4584	$5.98

Summary of Costs.—The following costs are separated from the preceeding examples of concrete siphon construction.

Mixing and Placing Concrete.

Example	Per cu. yd.
Whitney	$1.67
Antelope Valley	0.92
Bell Fourche	0.95
Sun River	2.35
Salt River	2.34

Bending and Placing Reinforcement.

Example	Per cu. yd.
Whitney	$0.65
Belle Fourche	1.48
Sun River	0.31
Salt River	0.51

Forms.—Separated as completely as is possible from the cost records given the costs of forms are about as follows:

Example	Per cu. yd.
Whitney	$0.94
Antelope Valley	1.96
Belle Fourche	1.33
Sun River	2.44
Salt River	1.82

The figure for Salt River does not include first cost of forms and at Belle Fourche the first cost is assumed to be the retail charge. Roughly, forms cost from $1 to $2.50 per cubic yard. These figures are for the usual collapsible portable types of forms. No cost is found of the traveling form used at Salt River; the labor cost of moving and repairing this form was $1.82 per cubic yard. It is quite useless from the data available to attempt comparison of steel and wood forms. Though the examples cited show that wood forms have been most frequently used, this is, we think, a mere happening and signifies little. The steel form has peculiar merits for conduit construction and its consideration should never be neglected.

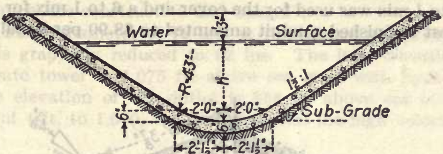


Fig. 18.—Open conduit of Los Angeles City Trunk Line.

Cost of Concrete Sections in the Los Angeles Aqueduct.—The following data are taken from an article by Burt A. Heinly, Secty. to Chief Engineer, Bureau of Water Works and Supply, Los Angeles, published in Engineering and Contracting, May 5, 1915.

The open conduit has a length of 7,975 ft. with a capacity of 20,000 miner's inches. The grade varies from 1 to 2.58 per cent and the velocities from 15.6 to 22.3 ft. per second. $n = .014$ in Kutter's formula. The conduit is 4 ft. wide at the bottom and 15 ft. wide at the top with a 6-in. invert and with side slopes of 1½ to 1; the walls being carried to a free board of 15 ins. Excavation was in a heavy dobe clay and was done with scrapers at a cost of 70 cts. per foot which included trimming. The concrete lining is 6 ins. thick of a 5½ mix, the gravel being washed and brought from a stream one-half mile distant at a cost of 50 cts. per cubic yard. No forms were used. Every 12½ ft., 2 × 6's were laid and as the concrete was delivered from above by a No. 11 Austin Cube mixer it was screeded off by a screed held on the 2 × 6-in. guides, which were then removed, the spaces filled and the mass trowelled to a smooth surface. The cost of concreting was $2.80 per lineal foot. With a force of 20 men, the average rate of progress was 150 ft. per day. This open conduit lies in the bed of the Upper San Fernando Reservoir site, where when additional storage is required, a reservoir of 23,000 acre-feet will be constructed.

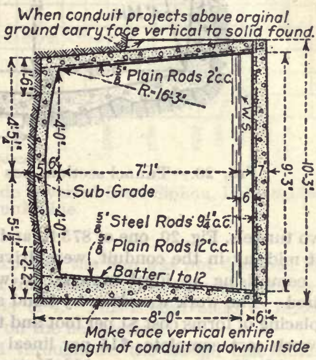


Fig. 19.—Closed conduit, Los Angeles City Trunk Line.

The covered conduit section, Fig. 19, is similar in design to Aqueduct covered conduit sections but is smaller. The depth is 8 ft. 1 in. and the width 8 ft. at the bottom to 9 ft. 3 ins. at the top, with a batter of 1 to 12. On the reservoir side of the conduit, the outer face of the lining was made vertical. Side walls are of a minimum thickness of 6 ins., the bottom 9 ins. and the cover from 6 ins. at the sides to 7 ins. at the center. Reinforcement of sidewalls on the hill side is of ⅝-in. plain rods spaced 2 ft. center to center, and on the reservoir side, ⅝-in. rods spaced 1 ft. center to center. The cover is reinforced by ⅝-in. square twisted rods, placed 9 ins. center to center, and is designed to carry a load of 300 lbs. to the square foot with a factor of safety of 4. A 5½ to 1 mix was used for the cover and a 6 to 1 mix for side and bottom. The cost of finished conduit amounted to $8.90 per lineal foot.

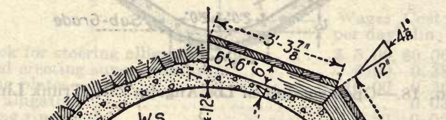


FIG. 20.—Tunnel section, Los Angeles City Trunk Line.

Two tunnels, Fig. 20, one of 875 ft. and the other of 700 ft. which are located about midway in the conduit, were driven through an indurated gravel and clay, comprising an ideal material in which practically no timbering was required. The work was done by hand at a cost of $7.50 per foot. Making and placing of forms cost $1 per foot and the concreting $6.50 per foot, making this work cost complete, $15 per lineal foot. The tunnels have a slope of .0009, with V = to 5.8, n = .014 Kutter's formula. The sidewalls are on a batter.

Construction Quantities.—Per linear foot of tunnel normal section: Excavation, (timbered) 3.10 cu. yds., (untimbered) 2.73 cu. yds.; concrete, (timbered) 0.83 cu. yds., (untimbered) 0.69 cu. yds.; timbers, 15 B. M.; spreaders, 5 B. M.; shoulder braces, 7 B. M.; lagging, 48 B. M.

The regular rate for day labor on this work was $2.50 per 8 hour day.

Cost of the San Fernando Inverted Steel Siphon, Los Angeles Aqueduct.—The following data are taken from an article in Engineering and Contracting, May 5, 1915, by Burt A. Heinly.

The San Fernando Inverted Steel Siphon carries the aqueduct across the San Fernando Valley a total distance of 63,327 ft. under a maximum working head of 260 ft. to the crest of the Santa Monica mountain range which hems the valley on the south. This siphon, a profile of which is shown in Fig. 21, comprises the most difficult and expensive part of the City Trunk Line. It required 8,260 tons of steel for its fabrication and is a noteworthy example of pipe line construction and design.

From an inside diameter of 72 ins. at the inlet, the siphon, as diversions are made, is gradually reduced to 62 ins. The inlet elevation at the San Fernando gate tower is 1,075 ft. above sea level with hydraulic grade at 1,134. The elevation of the outlet is 854 ft. above sea level. With the steep slope of 4 ft. to 1,000, the siphon carries the high velocity of 8 ft. per

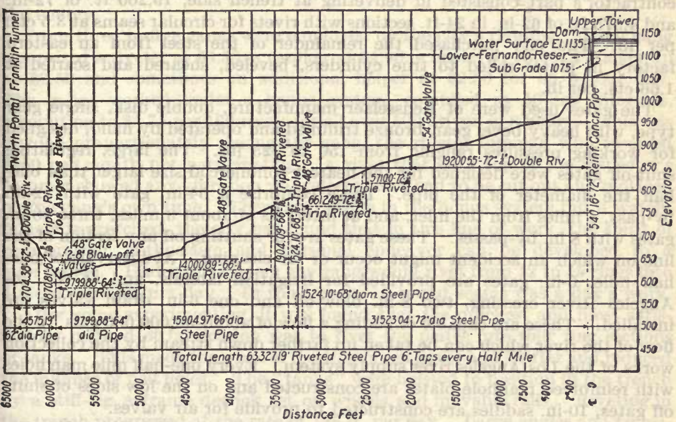


FIG. 21.—Profile of the San Fernando Inverted Steel Siphon, Los Angeles City Trunk Line.

second. On account of the high expense, the line was not designed for full static pressure but is constructed for full pressure up to the maximum hydraulic grade line with a maximum safety of 4. This is equivalent to 15,000 lbs. per square inch maximum pressure on the net section.

Single sheet construction is used throughout, the design and fabrication following the methods employed on the 21 steel siphons of the Los Angeles Aqueduct. The line was designed and built of lap joints of alternate inside and outside sections, the plates being 69 ins. long. All rivets were cone headed: ⅝-in. rivets were used on the ¼-in. and 5/16-in. plates with 11/16-in. open holes; and ¾-in. rivets for the ⅜-in. plate with 13/16-in. open holes. Riveting followed the Hartford Boiler Standard specifications with the efficiency of the joints having a maximum of 72 per cent.

The steel for both plates and rivets was all made by the basic, open hearth process, the quantities, diameters, riveting, etc., being as follows:

Length, ft.	Diameter, ins.	Thickness, ins.	Longitudinal riveting
19,200.55	72	1/4	Double
5,710.00	72	1/4	Triple
6,612.49	72	5/16	Triple
1,524.10	68	5/16	Triple
1,904.09	66	5/16	Triple
14,000.89	66	3/8	Triple
9,799.88	64	3/8	Triple
1,870.81	62	5/16	Triple
2,704.38	62	1/4	Double
63,327.19			

As the time was an important element, the work was divided so that a local contracting firm did part of the work, and the city the remainder. The contractor's part consisted in delivering at trench side, 19,200 ft. of 72-in. and 4,575 ft. of 62-in. in 24-ft. sections with rivets for circular seams at 3.5 cts. per lb. The city purchased the remainder of the steel from an eastern factory in plates rolled to true cylinders, beveled, sheared and scarfed at 1.66 cts. per lb.

The gates used were of Rensselaer manufacture, double disk, single gear type, with heavy bevel gear, bronze trimmed and operated by hand, designed for working pressures ranging from 150 to 225 lbs. The large, regulating shut-off gates were designed for the nearest commercial size larger than one-half the diameter of the pipe. These comprise a 54-in. gate with 12-in. by-pass, 4 miles from the inlet, and at intervals of about 3 miles, three 48-in. gates with 8 in. by-passes. These gates are for shutting off any section of the line on which an accident might occur or for cleaning. At intervals of one-half mile, 6-in. gates are provided for irrigation laterals, and at the Los Angeles River crossing, two 8-in. blow-off and one 6-in. drain valves are installed. These are capable of adding a flow of about 50,000,000 gals. to the flow of the river which can be taken up farther down stream by the collection works of the Los Angeles river supply system. Every one-half mile man holes with reinforced manhole plates are constructed and on the low sides of shut-off gates, 10-in. saddles are constructed to provide for air valves.

The work of construction, as is the rule of the Los Angeles Water Department, was accomplished by its own laboring force under the direction of its own engineers.

The excavation was done with two Model 40 Marion steam shovels of 3/4-cu. yd. and 1 1/4 cu. yd. capacity. Each was equipped for this particular kind of work with an extra long boom 25 ft. in length. The aim was to have the top of the pipe a minimum of 3 ft. below the surface of the ground. This made the depth of ditch range close to 9 ft., the width being as narrow as the shovel could dig, or from 10 to 11 ft. Excavation was in an ideal formation of sandy loam that stood without cribbing excepting in a few instances. Shovel crews in an eight hour day accomplished from 85 to 190 lineal feet, the average cost of trenching ranging from 25 to 30 cts. per foot. Shovel runners were paid $150 per month; cranemen, $115; firemen, $75 per month, and pit-men $2.50 per day. The shovels worked 6 days per week, the crews over-hauling the shovel on the seventh without allowance for overtime. Back-filling was with Fresnos at the rate of 150 ft. per day for each gang, teamsters being paid $2.50 per day. The cost of this item averaged 18 cts. per running foot.

As stated, the contractor was required to deliver the pipe in 24 ft. sections at the side of the trench. He found it cheaper to rivet into single sections in his shop, then rivet four sections into a tank, or 24 ft. length of pipe, on the ground, air being sold to him for this purpose by the city. With the city it was necessary to unload the nested, unriveted plates and do all the work of riveting, both circular and longitudinal at the side of the trench. For this purpose the equipment comprised three compressor stations situated at points near the inlet, middle and outlet of the siphon with air lines of 2-in. and 4-in. inside diameter standard screw pipe. The longest delivery was one of 26,000 ft., through 4-in. pipe. Air compressors used were one Clayton 2-stage tandem of a capacity of 200 cu. ft. of free air per minute under 100 lbs. pressure, driven by a 75 hp. Westinghouse motor, and two 2-stage Ingersoll Rand No. 10 Imperials, each of a capacity of 700 cu. ft. of air per minute under 100 lbs. pressure driven by 100 hp. General Electric motors. Transmission lines of the Southern California Edison Co. in the vicinity were tapped to supply the energy.

From three to five gangs were employed on the city's riveting. Each gang comprised a riveter at $3.50, a caulker at $4.00. a heater at $3.00, a bucker-up at $2.50 and sometimes an additional helper at $2.50 for an 8-hour day. The gangs worked under a bonus system, compiled at 10-day intervals, amounting to $1.75 per 100 rivets for all over 500 driven in 8 hours. This was divided proportionately among the gang, the riveter foreman who received $150 per month not participating. A rivet that on a tap of the inspector's hammer showed any vibration was rejected and had to be cut out and replaced on the gang's own time. There are defects in the bonus system but if watchfulness is exercised, the city has found that in this line of work, the spirit of co-operation, enthusiasm and personal endeavor can be developed to a high degree. Under this system one gang would rivet from 12 to 15 rings into 4-piece sections in a day. In the trench, 10 round seams was a day's work.

After some experimenting, it was found that the quickest and most satisfactory method of fabrication was to rivet the plates into four ring sections or tanks. This made the work of riveting much easier and swifter and reduced the number of bell holes. The "tanks" were hoisted to position in the trench by a stiff-leg A-frame derrick set on wheels and movable rails. Riveting in the trench progressed at the rate of 125 ft. per day. Large angles and transitions were shop made but on small bends, no special construction was required, the plates being simply cut and beveled. On curves where the radius was equal to or larger than a 6° railroad curve, it was found that the situation could be handled by a little reaming of the rivet holes. The pipe was all laid with the longitudinal seams uppermost, as it has been found by experience that most of the leaks occur where the three thicknesses of steel come together and they are thus made easy of access for recaulking.

In painting, coal gas and water gas tars were used. A coating of the latter which is much thinner than coal tar and of high penetrating qualities was first applied and then on succeeding days, two coats of coal tar both inside and out. No heating was required in the summer months but was necessary with the approach of autumn and winter temperatures. Painting was done at trenchside with brushes. After the pipe was laid, another coat was applied to all round seams and to any abrasions. Comparison of expense with patented preparations is to be noted from the fact that coal tar cost 11 cts. per gallon and gas tar 10 cts. per gallon laid down on the ground in carload lots.

The department after having had three years of tests of these materials on the exposed aqueduct siphons finds them an effective substitute for the higher priced coatings.

The transitions at both ends of the siphon consist of blocks of heavily reinforced concrete, covering the pipe to a depth of 2 ft. on all sides for a lineal distance of 8 ft. which serve as anchorages to hold the pipe in place.

Cost of Steel Section of Antelope Valley Siphon, Los Angeles Aqueduct.—The followig data are from an article by William W. Hurlbut published in Engineering Record, July 19, 1913.

The steel, or middle portion of the Antelope Valley siphon, was furnished by the Riter-Conley Manufacturing Company, rolled and punched at a cost of $1.50 per hundredweight f.o.b. factory at Leedsdale, Pa., or $2.30 per hundredweight laid down at Mojave, Cal., the distributing point for this work. The plate was shipped nested in order to obtain the minimum rate for carload lots. The plate is of the lap-joint type, the inside rings being 10 ft. in diameter.

Table XX gives lengths and weights and safe heads of each thickness of metal.

TABLE XX.—STEEL-PLATE DATA

Thickness	Safe head, feet	Length feet,	Weight, pounds
¼-in. double-riveted	100	2,690	938,810
¼-in. triple-riveted	144	4,559	1,609,440
5/16-in	180	3,698	1,626,920
⅜-in	210	4,650	2,648,970
Total		15,597	6,648,970

Table XXI gives the schedule for siphon work for a typical riveting crew of four men.

The world's record for field-driven rivets was made on the erection of this pipe, one man driving 1650 ⅝-in. rivets in one eight-hour shift.

TABLE XXI.—BONUS RATE FOR RIVETING CREW

Mechanic, Each per shift	Size of rivet, in.	Wages, per day	Base rate, per shift	Crew bonus, cents per rivet	Per cent of bonus per man per shift
Riveter	⅝ ¾	$3.50	500 400	1½ 1¾	30
Heater	⅝ ¾	3.00	500 400	1½ 1¾	30
Bucker	⅝ ¾	2.75	500 400	1½ 1¾	20
Sticker	⅝ ¾	2.50	500 400	1½ 1¾	20

The compressor plant was located in the center or 1½ miles from each end of the pipe. The plant consisted of four 40-hp. Aurora gas engines, all belted to a line shaft, the line shaft in turn being belted directly to an Ingersoll-Rand air compressor. Two lines of 4-in. O. D. casing delivered air at a pressure of 110 lb. Erection of this siphon commenced in the middle and was worked both ways from this point. All rivets were cone-headed and of full-diameter shank; ⅝-in. rivets were used on the ¼ and 5/16-in. plate and ¾-in. rivets on the ⅜-in. plate.

Table XXII gives direct field charges of costs for the steel pipe.

TABLE XXII.—FIELD COSTS FOR STEEL PIPE

Description	Length, feet	Unit cost	Cost per cwt.
Trench excavation	15,597	$ 0.33	.....
Anchorages, proportion	15,597	.48	.....
Steel pipe:			
Cost rolled and punched at Mojave	15,597	9.84	$2.30
Loading and hauling	15,597	1.46	.34
Placing	15,597	.52	.12
Riveting	15,597	1.19	.28
Calking	15,597	.24	.06
Painting	15,597	.15	.04
Equipment	15,597	.87	.21
Superintendence	15,597	.11	.03
Engineering	15,597	.04	.01
Backfill	15,597	.19	.....
Bell hole, proportion	15,597	.11	.....
Dismantling camp, proportion	15,597	.01	.....
Manholes, proportion	15,597	.01	.....
Blow-off valves, proportion	15,597	.03	.....
Total		$15.58	$3.39

To the cost shown in the table should be added 10 per cent for overhead charges. The average cost of driving 645,957 rivets was 2.9 cents per rivet, and the average cost per pound of erecting was 3.39 cents.

The erection of steel commenced in April and was completed in September, 1912. The greatest progress was made during the month of August, when 5940 ft. were erected.

Weight and other miscellaneous data of steel pipe are given as follows in Moritz's "Working Data for Irrigation Engineers" (1915).

Fig. 22 gives the thickness of steel pipe for three different efficiencies of joint, single riveted at 55 per cent, best double riveted at 72 per cent, and lock-bar pipe at 90 per cent. The lock-bar joint is capable of developing 100 per cent efficiency; but, due to occasional defects in material or workmanship on the lock-bars, an efficiency of 90 per cent is recommended for calculating the thickness. The thickness given in the diagram is the net thickness of steel required to withstand the given pressure at a unit stress in the steel of 16,000 lbs. per sq. in. It is customary to allow a slight excess of thickness to take care of weakening by corrosion.

The following table (from "American Civil Engineers' Pocket Book") gives the greatest allowable depth of earth cover over steel pipe in feet. If a pipe is to be subjected to a greater pressure of earth than indicated in the table, the thickness must be increased or the pipe shell reinforced with angle irons or other suitable shapes.

DIAMETER OF PIPE

Thickness	30 ins.	36 ins.	42 ins.	48 ins.	54 ins.	60 ins.	72 ins.
3/16	5	..	..	..	..	..	..
1/4	8	5	4	3	..	..	..
5/16	12	9	6	5	4	3	2
3/8	18	12	9	7	6	4	3
7/16	25	17	12	9	8	6	4
1/2	..	22	16	12	10	8	6
5/8	..	..	..	..	15	12	9

Example of Use of Diagram (Fig. 22).—Given a 72-in. steel pipe for a power plant static head of 200 ft.; an allowance of 50 per cent is to be made for water-ram and 10 per cent for corrosion, making the total head (200 × 1.60) = 320 ft.

Enter the diagram at a head of 320 ft., thence horizontally to the line for 72-in. pipe, then vertically down and read thickness slightly more than $\frac{9}{16}$-in. for single-riveted joint, slightly less than $\frac{7}{16}$-in. for double-riveted joint, and slightly more than $\frac{11}{32}$-in. for the lock-bar. Single riveting is seldom used

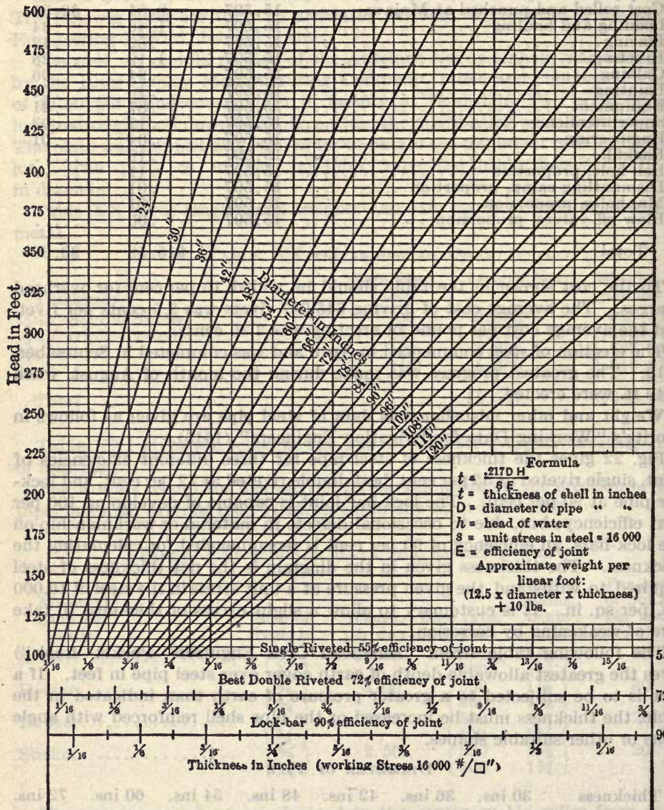


Fig. 22.—Thickness and weight of steel pipe.

for any but unimportant and temporary structures. Carrying the above example further, we note from the foregoing table that the $\frac{7}{16}$-in. shell will withstand a back-fill of 4 ft., and the $\frac{11}{32}$-in. shell will withstand between 2 and 3 ft. The approximate weight of the pipe is given by the formula in the diagram.

Maintenance of Steel Pipe Line, 350 Miles Long.—The following data are taken from an abstract in Engineering Record, Oct. 21, 1916, of the 1914–15 Annual Report of P. V. O'Brien, engineer for the Goldfields areas of the Water Supply, Sewerage and Drainage Department of Western Australia.

The pipe line and pumping project, was completed in 1902. After having been in service a few years the pipe showed signs of serious corrosion. The steel of this conduit was manufactured in Australia from material supplied from England. The thickness of the plates is ¼ in. for all pipes under pressure up to 390 ft. head and 5/16 in. thick for pressures above that amount. The material employed was open-hearth basic steel. When completed and tested the pipes were heated to 300 deg. Fahr. and immersed in a mixture of coal tar and Trinidad Asphalt. Over the outside coating sand was sprinkled to make the material resistant to the sun's heat.

Maintenance Costs.—Mr. O'Brien presents the following figures on the cost of maintenance since the pipe line was completed in 1902:

TABLE XXIII.—COST OF MAINTENANCE OF 30-INCH STEEL MAIN 351½ MILES LONG

Year	Cost	Year	Cost
1902–3 } 1903–4 }	$83,500	1909–10	83,000
1904–5	37,600	1910–11	61,200
1905–6	38,000	1911–12	83,000
1906–7	68,700	1912–13	111,000
1907–8	96,600	1913–14	192,600
1908–9	74,500	1914–15	248,000

The corrosion on the exterior of the pipes took three distinct forms—rusting, pitting and scaling. It appears that the greatest deterioration has occurred where the pipe has been buried in the ground, while sections lying above the surface show comparatively slight damage.

TABLE XXIV.—HOLES DUE TO EXTERNAL CORROSION

Financial year	No. of holes	Financial year	No. of holes
1904–5	2	1910–11	131
1905–6	27	1911–12	124
1906–7	54	1912–13	774
1907–8	55	1913–14	966
1908–9	91	1914–15	2,078
1909–10	177		

The great increase in the number of holes in 1914–15 is partly accounted for by the large amount of work done in scraping the pipe preparatory to recoating. In this way many holes appeared that ordinarily would not have been noticed for several years later.

The method adopted for dealing with external corrosion consists of uncovering the pipes wherever they are found to be badly pitted and continuing the opening up in both directions till they are found to be in good condition. In this way all those parts of the main in the vicinity of places where corrosion is known to be bad have been opened up, and in addition, other portions which were likely to be similarly bad have been opened up during the past year. The length opened up and left open for the financial year 1914–15 was 36½ miles, making a total of 80 miles uncovered at the close of the year. Judging by the condition of the pipes that have been opened up during the past year, it is anticipated that the work of dealing with the external corrosion of the pipes can be satisfactorily dealt with for some years in the same manner as hitherto, and at no greater cost. Although almost the whole of the coating on the pipes where they are underground is more or less perished, and has been so for many years, the condition of the steel plates is, apart from the pitting and scaling already referred to. almost uniformly good.

Life of Cast Iron Water Pipe.—The following data are taken from an article in Engineering and Contracting, Dec. 15, 1915 which gives the substance of replies to a questionaire conducted by Thomas H. Hooper, Sup't of Water Works, Winnipeg, Manitoba.

Baltimore.—Cast iron pipe was laid in Baltimore as early as 1805. The old pipe has been found in good condition. Electrolysis has been found the worst enemy of cast iron pipe. Reported by Robert L. Clemmitt, Acting Water Engineer.

Boston.—The oldest cast iron pipe was laid in 1848. The condition of this pipe depends upon the soil in which it was laid. Have taken out pipe in practically perfect condition, as far as condition of iron goes, after 60 years use. In other cases, in bad ground, or where electrolysis exists, pipe has been destroyed in half that time. Reported by F. A. McInnes, Div. Eng., Pub. Works Dep't.

Chicago.—The first cast iron pipe was laid in 1852. Some of the oldest pipe has been found in excellent condition when examined. Very little deterioration has been observed unless pipe has been attacked by cinders or slag filling or electrolysis. These cases are comparatively rare. Reported by John Ericson, City Engineer.

Hamilton, Ont.—The first pipe was laid in 1859 which on examination is shown to be in good condition. The only deterioration has been from electrolysis. Reported by Thomas Towers, Sup't. of Water Works.

Minneapolis.—The earliest records of cast iron pipe are about 1874. Old pipe when exposed appears to have suffered no depreciation. A piece of 12-in. pipe, 32 years in service, cut out to pass under a 48-in. pipe, looked like new. The coating even had its original lustre. Reported by J. A. Jensen, Sup't of Water Works.

Montreal.—First cast iron pipe was laid in 1852–4. In replacing 4 and 6-in. pipes, which had been in use over 55 years, with pipes of larger diameter, to meet increased demands due to growth of city, it was found that the cast iron was in good condition and the outside appearance almost perfect. In places, the area was much reduced by tubercules of rust or calcareous deposit and silty matter. On the whole, with the nature of Montreal soil, and leaving out the particular cases where electrolysis (due to electric tramways) may effect condition, it is safe to say that the cast iron pipes last as long as their usefullness will warrant. Reported by T. W. Lesage, Eng.—Sup't. of Water Works.

New York City.—Cast iron pipe was introduced in 1815. In 1915, in connection with an investigation of a break on a 30-in. main some of the old pipe was examined. It was found that the material was in good condition and showed hardly any depreciation. It was estimated that this main was made of, what is known as, Scotch iron and was laid about 1830. Reported by Merrit H. Smith, Chief Eng. Bureau of Water.

Philadelphia.—The first cast iron pipe was laid in 1817. Pipes recently taken up, laid in 1817 and 1827, were removed for obsolescence rather than because it could no longer perform its service. Of course tubercles and incrustations were found on the interior but the iron showed no evidence of deterioration. Reported by Carlton E. Davis, Chief of Bureau of Water.

Rochester.—The first pipe was laid in 1872. The pipe examined at frequent intervals has been found to be practically in as good condition as at time of laying. Reported by B. C. Little, Sup't of Water Works.

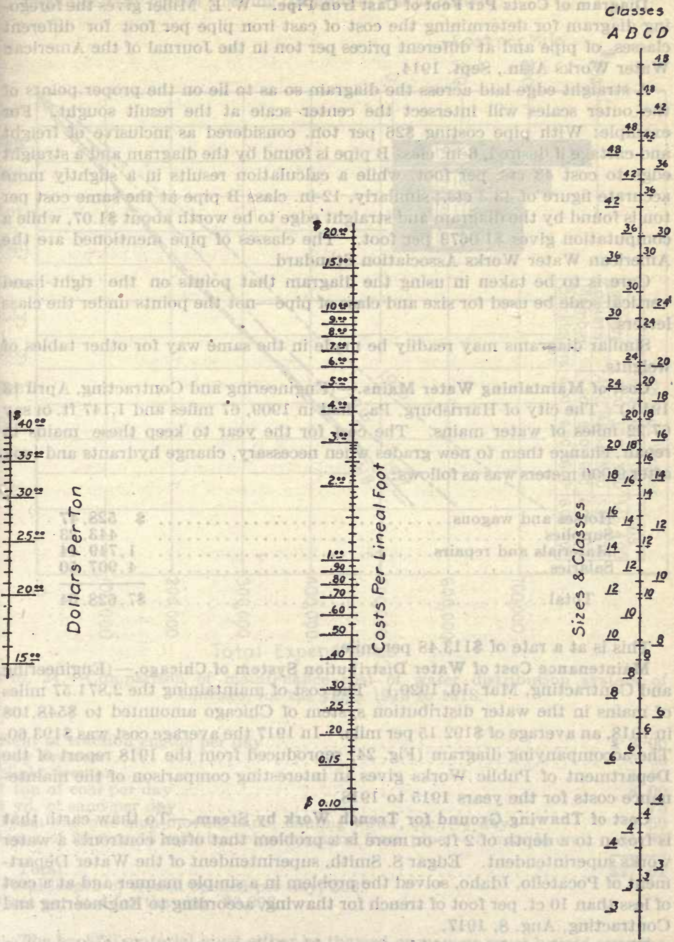


FIG. 23.—Diagram for determining cost of cast iron pipe per foot from price per ton and class of pipe.

St. Louis.—Physical condition of pipe in ground over 60 years in almost every instance has been found good. Reported by Francis T. Cutts, Asst. Water Commissioner.

Toronto.—Cast iron pipe laid in 1854 is still in use and upon examination shows little depreciation except where electrolysis has taken place. Reported by R. C. Harris Commissioner of Works.

Diagram of Costs Per Foot of Cast Iron Pipe.—W. E. Miller gives the foregoing diagram for determining the cost of cast iron pipe per foot for different classes of pipe and at different prices per ton in the Journal of the American Water Works Assn., Sept. 1914.

A straight edge laid across the diagram so as to lie on the proper points of the outer scales will intersect the center scale at the result sought. For example: With pipe costing $26 per ton, considered as inclusive of freight and cartage if desired, 6-in. class B pipe is found by the diagram and a straight edge to cost 43 cts. per foot, while a calculation results in a slightly more accurate figure of 43.3 cts.; similarly, 12-in. class B pipe at the same cost per ton is found by the diagram and straight edge to be worth about $1.07, while a computation gives $1.0673 per foot. The classes of pipe mentioned are the American Water Works Association Standard.

Care is to be taken in using the diagram that points on the right-hand vertical scale be used for size and class of pipe—not the points under the class letters.

Similar diagrams may readily be made in the same way for other tables of weights.

Cost of Maintaining Water Mains.—(Engineering and Contracting, April 13 1910.) The city of Harrisburg, Pa., had in 1909, 67 miles and 1,147 ft. or say 67.22 miles of water mains. The cost for the year to keep these mains in repair, change them to new grades when necessary, change hydrants and look after 9,000 meters was as follows:

Horses and wagons	$ 528.47
Supplies	443.23
Materials and repairs	1,749.44
Salaries	4,907.50
Total	$7,628.64

This is at a rate of $113.48 per mile.

Maintenance Cost of Water Distribution System of Chicago.—(Engineering and Contracting, Mar. 10, 1920.) The cost of maintaining the 2,871.57 miles of mains in the water distribution system of Chicago amounted to $548,108 in 1918, an average of $192.15 per mile. In 1917 the average cost was $193.60. The accompanying diagram (Fig. 24) reproduced from the 1918 report of the Department of Public Works gives an interesting comparison of the maintenance costs for the years 1915 to 1918.

Cost of Thawing Ground for Trench Work by Steam.—To thaw earth that is frozen to a depth of 2 ft. or more is a problem that often confronts a water works superintendent. Edgar S. Smith, superintendent of the Water Department of Pocatello, Idaho, solved the problem in a simple manner and at a cost of less than 10 ct. per foot of trench for thawing, according to Engineering and Contracting, Aug. 8, 1917.

The ground was frozen 4½ ft. deep and in 24 hrs. was completely thawed to a depth of 2½ ft. The remaining 2 ft. were softened sufficiently to be easily picked. The method of thawing consisted in laying a double line of 1½-in. pipe over the trench and covering it with 6-in. of fine sand. Steam was fed into the pipe from a traction engine boiler, and a block 300 ft. long was thawed at one setting of the engine. It took about 2 hrs. to shift to the next block, haul the sand and cover up the pipe, using 2 men and 2 teams.

The total daily cost of thawing the ground was as follows:

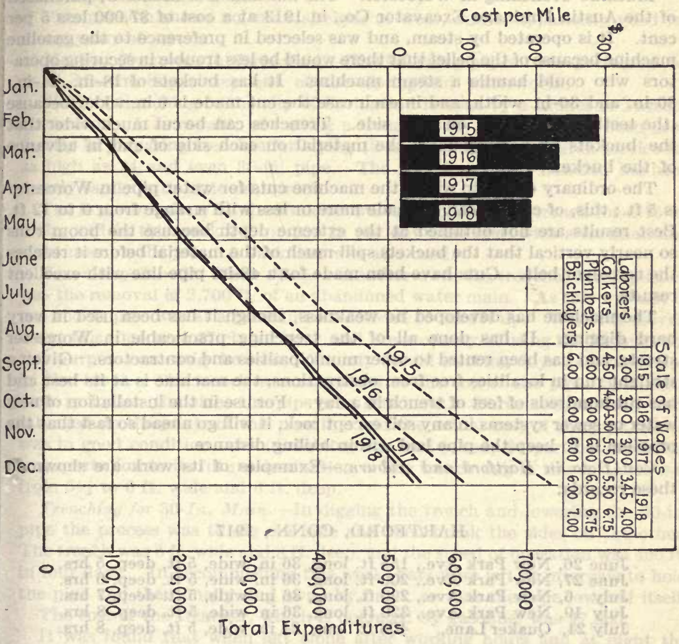


FIG. 24.—Comparison of maintenance cost of water distribution system of Chicago, for the years 1915 to 1918.

Rent of traction engine per day	$ 3.00
Day fireman	5.00
Night fireman	4.50
1 ton of coal per day	8.00
1 yd. of sand per day	.75
Team and one man moving sand, hauling water, etc., ½ day	4.50
Gang of 20 men 15 minutes removing sand from pipe = 5 man hours	1.87
Total	$27.62

Total length of trench opened per day, 300.
Cost per foot for thawing, $0.092.

The backfill material must either be thawed or manure must be laid over the water pipe before back-filling with frozen earth.

Experience with Trenching Machines in Massachusetts.—At the annual (1920) convention of the New England Waterworks Association a general discussion about the use of trenching machines for excavating waterworks trenches brought out some valuable information. George W. Batchelder, Water Commissioner of Worcester, opened the discussion with a paper, the substance of which, as given in Engineering and Contracting, Nov. 10, 1920, follows:

Machine Trenching in Worcester.—The machine is a Model O, purchased of the Austin Drainage Excavator Co., in 1913 at a cost of $7,000 less 5 per cent. It is operated by steam, and was selected in preference to the gasoline machine because of the belief that there would be less trouble in securing operators who could handle a steam machine. It has buckets of 18-in., 24-in., 30-in. and 36-in. width, and in each case the cut made is 6 in. wider because the teeth project 3 in. on each side. Trenches can be cut much wider that the buckets by barring down the material on each side of and in advance of the buckets.

The ordinary depth to which the machine cuts for water pipe in Worcester is 5 ft.; this, of course, can be made more or less with a range from 0 to 12 ft. Best results are not obtained at the extreme depth because the boom runs so nearly vertical that the buckets spill much of the material before it reaches the conveyor belt. Cuts have been made for a 48-in. pipe line with excellent results.

The machine has developed no weakness, though it has been used in very hard digging. It has done all of the trenching practicable in Worcester streets, and has been rented to other municipalities and contractors. Given a straight run in localities free from obstructions, the machine is at its best and has cut hundreds of feet of trench in a day. For use in the installation of new water or sewer systems in any soil except rock, it will go ahead so fast that the problem is to keep the pipe laid within hailing distance.

Cost Data in Hartford and Auburn.—Examples of its work are shown in these records:

HARTFORD, CONN., 1917

June 26,	New Park Ave.,	155 ft. long,	36 in. wide,	5 ft. deep,	5 hrs.
June 27,	New Park Ave.,	200 ft. long,	36 in. wide,	5 ft. deep,	6 hrs.
July 6,	New Park Ave.,	220 ft. long,	36 in. wide,	5 ft. deep,	7 hrs.
July 19,	New Park Ave.,	320 ft. long,	36 in. wide,	5 ft. deep,	8 hrs.
July 24,	Quaker Lane,	408 ft. long,	24 in. wide,	5 ft. deep,	8 hrs.

AUBURN, MASS., 1920

Aug.—					
18, Very coarse gravel	410 ft. long,	24 in. wide,	5 ft. deep,	8	hrs.
19, Loam, hard pan & gravel	250 ft. long,	24 in. wide,	5 ft. deep,	5	hrs.
20, Hard pan, clay & sand	380 ft. long,	24 in. wide,	5 ft. deep,	6½	hrs.
21, Sand & fine gravel	165 ft. long,	24 in. wide,	5 ft. deep,	3	hrs.
23, Filled land, very rocky	384 ft. long,	24 in. wide,	5 ft. deep,	6½	hrs.
24, Coarse gravel & sand	438 ft. long,	24 in. wide,	5 ft. deep,	8	hrs.
25, Very rocky and wet	445 ft. long,	24 in. wide,	5 ft. deep,	8½	hrs.
26, Fine gravel & hard pan	295 ft. long,	24 in. wide,	5 ft. deep,	5½	hrs.
27, Gravel, clay & hard pan	472 ft. long,	24 in. wide,	5 ft. deep,	8	hrs.
28, Filled land, rocky	180 ft. long,	24 in. wide,	5 ft. deep,	3½	hrs.

This total excavation amounts to 34,190 cu. yd. The costs of this work are:

Operator, $88; fireman, $66; freight, $38; coal, $48; oil, etc., $20; repairs and depreciation, ex. labor, $50. Total, $330.

Cost per cu. yd., excl. rental	9.65 cts.
Cost per cu. yd., including rental price	17.2 cts.
Cost per cu. yd., hand labor (estimated)	63.0 cts.

In addition to the work done in Worcester the machine has brought in a revenue for rentals of $9,011, not including the job now going on at Auburn Mass. The total cost of replacements and repair parts since the machine was purchased has been $3,864.

The machine shows no unusual signs of wear, and is apparently good for many years of service.

Machine Trenching in Springfield.—The following paper was presented by A. L. Martin, Superintendent of the Springfield waterworks.

Work of trenching in the city of Springfield is done by a Model 24 Parsons Excavator. It is capable of cutting a trench 26 in. wide, and has been used mostly in preparing trenches for laying 12-in. pipe, but has been in service for as high as 24 and even 30-in. pipe. The soil that it has handled has been mostly sandy with little or no rock.

The first work done by the trencher was the digging of a trench for a 16-in. main, and in this work 300 or 500 ft. per day were laid, with a foreman and eight men on the job. A backfiller was also used.

Excavating Over Old Water Main.—Another work the trencher accomplished was the removal of 2,700 ft. of an abandoned water main. As this was not in use and as pipe was at a premium we decided to take it up. Wages of shovelers at this time were 67 ct. per hour, and the economy of using the trencher for this purpose can easily be seen. Twenty actual working days were consumed in the labor. The trench was excavated to the top of the pipe, then, with men to loosen the side, the pipe was lifted out. Three tons of lead were salvaged on the joints of this pipe line and the actual cost of the pipe, which was in good condition, was (deducting the lead saved) $1 per foot including transportation to its future destination. The trench dug in this instance was from 5½ to 6 ft. wide and 6 ft. deep.

Trenching for 30-In. Main.—In digging the trench and lowering the 30-in. pipe the process was to dig one side and then break the sides on the other. The trench was 6 ft. wide and 8 ft. deep, and the speed of operation was 400 ft. in four days. In accomplishing this work, bars were left at intervals to hold the pipe and then finally dug away by hand, so that the pipe lowered itself.

The cost of the trencher, which is operated by gasoline, was $7,800.

It was found that when left alone after working hours and at night the trencher was apt to be tampered with by curious persons or mischievous boys. A watchman would cost $35 per week. A cage, placed entirely around the machine and made of strong steel wire, much like that used in the cages around the cashier's offices in banks, fulfilled the object it was devised for and cost about $400.

The operator of the trencher is paid 80 ct. per hour, and the assistant 70 ct.

Cost of Machine Trenching for Water Mains at Erie, Pa.—By using a trenching machine the Water Department of Erie, Pa., has overcome difficuities incident to the labor shortage and at the same time has effected a large saving in excavating for water main extensions. A report on the work of the machine, prepared by E. W. Humphreys, Superintendent of Waterworks, and abstracted in Engineering and Contracting, May 8, 1918, shows that it has dug trenches 5½ and 6 ft. deep at a cost as low as 0.9 ct. per lineal foot. This particular trench was dug in hard clay. The figure covers the wages of operator and helper and the cost of gasoline, oils and grease. In laying 10,000 ft. of 6 in. main in 1917 the cost of hand digging alone was 19 ct. per lineal foot, with common labor at 27½ ct. per hour. The hand dug trench was in clay with shale at the bottom.

The accompanying tabulation shows work done by the machine at various times from May 1, 1917, to Jan. 3, 1918:

	—Trench—				Cost per lin. ft. of trench
	Le. ft.	De. ft.	Wi. ft.	Kind of material excavated	
Rankine Ave., N.	1,000	5½	2	Running sand and gravel	$0.065
Rankine Ave., S.	800	5½	2	Hard shale	.036
22d W. Cranberry	665	6	2	Hard clay	.010
28th W. of Sigsbee	652	6	2	Clay loam	.010
Cherry N. of 30th	360	5½	2	Clay and gravel	.012
5th W. Raspberry	400	5½	2	Sandy	.014
27th W. Cascade	420	5½	2	Hard clay	.009
Old French Road	230	6	2	Hard clay	.009

The costs given in Table XXV are the actual operative costs, exclusive of overhead, depreciation and repairs, and pay of watchman. The costs in detail for each of these jobs follow:

TABLE XXV

	Per lin. ft. trench
Rankine Ave., N. (1,000 lin. ft. trench)	
Operator, 62 hr. at 32½ ct.	$0.0200
Helpers, 115 hr. at 30 ct.	.0345
Gasoline, 39 gal. at 24⅓ ct.	.0090
Oils, 4 qt. at 9½ ct.	.0004
Grease, 2 lb. at 7½ ct.	.0001
Total (1,000 lin. ft.)	$0.0640
Ranking Ave. S. (800 lin. ft. trench)	
Operator, 26 hr. at 35 ct.	$0.0114
Helper, 38 hr. at 28 ct.	.0130
Gasoline, 35 gal. at 25 ct.	.0109
Oils, 4 qt. at 11½ ct.	.0006
Grease, 1 lb. at 9 ct.	.0001
Total (800 lin. ft.)	$0.0360
22nd W. of Cranberry (665 lin. ft. trench)	
Operator, 4 hr. at 35 ct.	$0.002
Helper, 4 hr. at 32½ ct.	.002
Gasoline, 15 gal. at 25 ct.	.006
Oils, 3 qt. at 11⅓ ct.	......
Grease, 1 lb. at 9 ct.	
Total (665 lin. ft.)	$0.010
28th W. of Sigsbee (652 lin. ft. trench)	
Operator, 3 hr. at 35 ct.	$0.002
Helper, 3 hr. at 27 ct.	.002
Gasoline, 12 gal. at 25 ct.	.005
Oils, 4 qt. at 11½ ct.; grease, 1 lb. at 9 ct.	.001
Total (652 lin. ft.)	$0.010
Cherry N. of Cranberry (360 lin. ft. trench)	
Operator, 2 hr. at 35 ct.	$0.002
Helper, 2 hr. at 27½ ct.	.002
Gasoline, 10 gal. at 25 ct.	.007
Oils, 3 qt. at 11⅓ ct.; grease, 1 lb. at 5 ct.	.001
Total (360 lin. ft.)	$0.012
5th W. of Raspberry (400 lin. ft. trench)	
Operator, 3 hr. at 45 ct.	$0.003
Helper, 3 hr. at 33 ct.	.002
Gasoline, 12 gal. at 27 ct.	.008
Oils, 1 gal. at 10 ct.; grease, 1 lb. at 5 ct.	.001
Total (400 lin. ft.)	$0.0014

27th W. of Cascade (420 lin. ft. trench)	Per lin. ft. trench
Operator, 2 hr. at 45 ct	$0.002
Helper, 2 hr. at 35 ct	.002
Gasoline, 8 gal. at 25 ct	.005
Oils, 1 qt. at 10 ct	....
Grease, 1 lb. at 5 ct	....
Total (420 lin. ft.)	$0.009
Old French Road (230 lin. ft. of trench)	
Operator, 1 hr. at 45 ct	$0.002
Helper, 1 hr. at 35 ct	.002
Gasoline, 4 gal. at 25 ct	.005
Oils, 1 qt. at 10 ct	....
Total (230 lin. ft.)	$0.009

The figures on the last six jobs represent the actual time the machine was engaged in trenching. On the old French Road work 230 lin. ft. of trench was excavated in one hour, while in the 27th St. work 210 ft. of trench was dug in one hour. A summary of the operating costs on the six jobs shows the following:

6 jobs trenching (2,727 lin. ft.)	Per lin. ft. trench
Operator, 15 hr. at 39 ct	$0.0021
Helper, 15 hr. at 31½ ct	.0017
Gasoline, 61 gal. at 25.1 ct	.0060
Oils, 13 qt. at 11 ct	.0005
Grease, 5 lb. at 6½ ct	.0001
Total (2,727 lin. ft.)	$0.0104

The trenching machine, a Pawling & Harnischfeger, was purchased by the Water Department early in 1917 at a cost of $5,650 f. o. b. Erie.

Cost of Excavating and Backfilling Trench by Machines.—Engineering News-Record, May 24, 1917, gives the following. The excavating was done by a municipally owned Austin excavator which will dig a trench 72 in. wide and cost $10,000.

The cost of operating this excavator 66 working days for a 54-in. force main, at an average depth of 11 ft., was $3665, divided as follows: Repairs, $808; coal and oil, $549; labor, $2308. The volume of material excavated, based on daily reports, was 39,200 cu. yd., or by computation on approximate sections, 43,700 cu. yd. The cost per cubic yard, based on the daily reports, was 9.3 cents.

Labor was paid as follows: Foreman, $4.50; timekeeper (one-fourth of his time, as he was on four jobs), $1; engineer, $4; watchman, $3; fireman, $2.75; laborers, $2.50; team, $5. The cost of repairs was thus divided: Labor, $358; repair parts, $352; repair work at local shop, $98.

Cost of Backfilling by Steam Shovel.—Backfilling was done by means of a small steam shovel. The job was in the outskirts of the city, and the excess dirt was easily disposed of. Cost figures are not available, but on another job in a built-up part of the city the backfilling of a 48-in. main 9520 ft. long cost $1146, or 4.8 cents per cu. yd. The cross-section averaged 75.3 sq. ft gross, or 62.8 net, for backfill, after deducting 12.5 sq. ft. for the 48-in. pipe. There were 22,143 cu. yd. in the trench and 1590 cu. yd. in bell holes, making a total backfill of 23,733 cu. yd. against a total excavation of 29,757 cu. yd.

The cost of the backfilling, plus the hauling away of excess material (6024 cu. yd.) and the refilling of the street surface, was $6302, or a unit cost of 21.2 cents. The cost of removing excess material and refinishing the street surface was $0.839 per cu. yd., a high cost due to long haul.

The steam shovel engineer was paid $6 a day. Other daily wages, all for 8 hours, were: Foreman, $2.75; watchman, $3; assistant foreman, for hauling material away, $3; teams, $5; and two pitmen, $2.50 each.

Saving Effected by Using Excavating and Pipe Laying Machinery.—The following data are taken from Engineering and Contracting, Feb. 12, 1919.

Trenching and backfilling machines were first employed by the Detroit Water Department in 1916, and in 1917, and their value was so fully demonstrated that more equipment was purchased.

In his report for the year ending June 30, 1918, Geo. H. Fenkell, General Manager of the Water Department, gives the following table showing the saving effected by the use of machines:

	All hand labor			Dug and backfilled by machine			
Size—Ins.	Feet laid	Total labor cost	Cost per ft.	Feet laid	Total labor cost	Cost per ft.	Saving by machine per ft.
6	59,238	$35,095	$0.59	60,407	$21,118	$0.35	$0.24
8	33,161	19,108	.58	31,007	12,550	.40	.18
12	4,628	5,159	1.11	5,863	2,845	.49	.62
16	797	1,291	1.62	13,011	12,852	.99	.63

On the 42-in. and 48-in. pipe lines a material saving was effected by the use of mechanical appliances to replace hand labor. The following are some of the most striking instances, the figures being based upon the prevailing scale of wages:

Labor per foot in laying 42-in. and 48-in. pipe will average $8.70 by hand, and $3.50 by machinery; caulking averages $1.32 per joint by hand and $0.49 using pneumatic hammers; handling and lowering each pipe by hand labor averages $6.70 and $1.88 using the steam crane. Backfilling ditches on small lines costs about 9 ct. per lineal foot by hand and 3½ ct. per foot by machine.

A Scraper for Backfilling Trenches.—S. Leonard Cyphers gives the following data in Engineering and Contracting, July 23, 1913.

The "Go-Devil" as it was called by the originator, was used on the 154-mile oil pipe line near Los Angeles to minimize the cost of back-filling the ditch. This ingenius device was designed and first used by James R. Kelly, Superintendent for Mahoney Brothers, Contractors, San Francisco, on the construction of the 8-in. oil pipe line built by the General Petroleum Co. from Shale in the Midway oil fields of California to San Pedro on the coast. It was found to be such a success and money saver that it was adopted by other contractors in similar work.

The appliance illustrated was made of a share taken from a Little Western Road Grader and a handle was attached in the manner shown. Chains were attached to each end of the share by means of hooks designed to shorten or lengthen the chains when it became necessary to reverse the action of the blade on return work upon the ditch. It is drawn by four head of stock attached as shown. The stock are hitched in pairs, one pair being driven on the dirt to be turned into the ditch, the other pair on the opposite side of the ditch and pulling at an angle of 20° to 30° away from the center line of the ditch.

The labor required consisted of a teamster and one other man whose duty it was to guide the share by means of the handle. In operation the share runs at an angle of 20° to 40° to the center line of the ditch, so that in effect its action is similar to a plow in throwing a furrow.

From data kept by the writer, covering a period of several months, and from such sections of the previously mentioned line where the use of this "Go-Devil" was practicable the following facts appear:

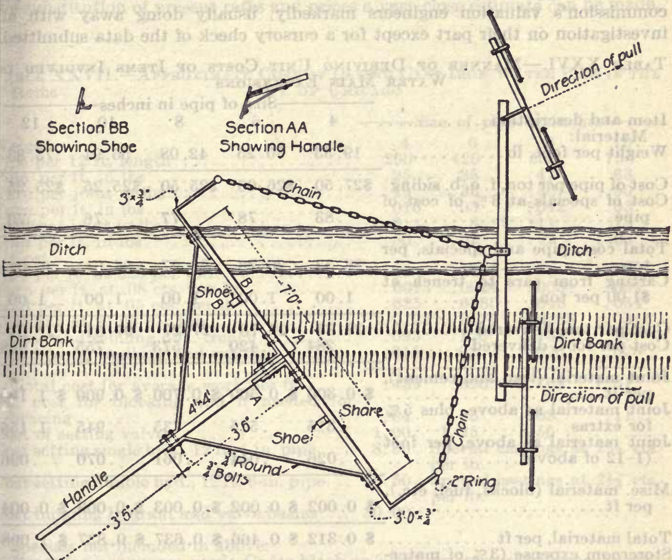


FIG. 25.—Scraper for backfilling trench.

By means of this device, two men and four head of stock were able to fill approximately 5,000 ft. of ditch, 3 ft. deep and 1½ ft. wide in a day of nine hours at a cost as follows:

4 head of stock	$10.00
1 teamster	4.00
1 laborer	3.50
Total	$17.50

This shows a cost of about 0.2 ct. per cubic yard. These figures were taken where runs were at least one mile long. Under different circumstances, the figures would necessarily vary.

The difficulty encountered in the use of the Go-Devil has usually been because of an attempt to move too much dirt at one time, and also because of inability to properly handle the stock. Four to six rounds are necessary to fill and crown a 3 or 4 ft. ditch. Upon the completion of this number, the ditch should be rounded up as well as can be done by hand.

Table for Estimating Water-Main Extension Costs.—Allen F. Brewer gives the following data in Engineering News-Record, May 9, 1918.

Table XXVI shows how an itemized calculation for unit costs of water mains may be prepared. The figures quoted have been assumed arbitrarily, merely to serve as an example.

Such a tabular estimate is of much value where affirmative action is required of a State Public Utility Commission before the company may legally charge for water supplied by any new extension. It will lessen the work of the commission's valuation engineers markedly, usually doing away with all investigation on their part except for a cursory check of the data submitted.

TABLE XXVI.—MANNER OF DERIVING UNIT COSTS OF ITEMS INVOLVED IN WATER MAIN EXTENSIONS

Item and description	Size of pipe in inches 4	6	8	10	12
Material:					
Weight per foot, lb.	19.33	30.25	42.08	55.91	73.83
Cost of pipe per ton, f. o. b. siding	$27.50	$26.00	$25.50	$25.25	$25.25
Cost of specials at 3% of cost of pipe	.83	.78	.77	.76	.76
Total cost, pipe and specials, per ton	28.33	26.78	26.27	26.01	26.01
Carting from cars to trench at $1.00 per ton	1.00	1.00	1.00	1.00	1.00
Cost per ton, delivered	29.33	27.78	27.27	27.01	27.01
Cost per foot, delivered	.284	.420	.573	.755	.998
Joint material (lead and cement), per jt.	$ 0.300	$ 0.500	$ 0.700	$ 0.900	$ 1.100
Joint material as above, plus 5% for extras	.315	.525	.735	.945	1.155
Joint material as above, per foot (1–12 of above)	.026	.044	.061	.070	.096
Misc. material (blocks, fuel, etc.), per ft.	$ 0.002	$ 0.002	$ 0.003	$ 0.003	$ 0.004
Total material, per ft.	$ 0.312	$ 0.466	$ 0.637	$ 0.837	$ 1.098
Storeroom expense (3% of material cost)	.009	.014	.019	.025	.033
Total material cost	$ 0.321	$ 0.480	$ 0.656	$ 0.862	$ 1.131
Labor:					
Average width of trench, ft.	1.5	1.66	1.75	1.83	2.0
Total depth of trench, ft.	3.42	3.57	3.75	3.91	4.08
Contents of trench per foot, cu. ft.	5.13	5.95	6.57	7.17	8.16
Contents of trench per foot, cu. yd.	.19	.22	.243	.265	.303
Trenching and backfilling (at 60c. per yd.), per ft.	.114	.132	.146	.159	.182
Laying, calking, setting valves, etc.	.023	.027	.030	.035	.040
Total, labor laying pipe	$ 0.137	$ 0.159	$ 0.176	$ 0.194	$ 0.222
Tools, carting, lost time, overhead, etc. (10% of above)	$ 0.014	$ 0.016	$ 0.018	$ 0.019	$ 0.022
Total labor cost	$ 0.151	$ 0.175	$ 0.194	$ 0.213	$ 0.244
Total labor and material costs, per ft.	$ 0.472	$ 0.655	$ 0.850	$ 1.075	$ 1.375

Cost of Laying Cast Iron Water Pipe in the City of Chicago.—Table XXVII, published in Engineering and Contracting, Oct. 11, 1911, is a result of the compilation of the cost of laying cast iron water pipe in the city of Chicago for a period of 10 years. The costs were compiled in the City Engineer's office from careful records of contract work. The table has since been used as a check on later work and has been found to be very close. The rates of wages for all men, and the prices of all kinds of material are given so that by the substitution of present rates and prices a very close estimate can be made.

TABLE XXVII.—APPROXIMATE COST OF LAYING CAST IRON WATER PIPE IN THE CITY OF CHICAGO

Items	Size of pipe in inches 4	6	8	10
Weight				
Pipe per 12 ft. length	290	420	555	756
Pipe per ft. in lbs	25	35	47	63
Yarn per joint in lbs	.19	.36	.50	.50
Yarn per ft. in lbs	.016	.03	.042	.05
Lead per joint in lbs	6	8	11	13
Lead per ft. in lbs	.50	.67	.92	1.08
Cost				
Pipe per ft. at $23 per ton	.29	.4025	.54	.73
Yarn per ft. at .08 cts. per lb	.0013	.0024	.0034	.004
Lead per ft. at .05 cts. per lb	.025	.0335	.046	.054
Teaming at $1.00 per ton	.0125	.0175	.0235	.0315
Excav. and refilling 6-ft. trench	.095	.120	.130	.16
Pipe laying, caulking and cutting	.015	.02	.025	.028
Total cost for average work per ft	.439	.596	.768	1.01
Ad. cost for blocking and if needed for bracing	.04	.05	.08	.11
Cost of setting valves	1.00	1.25	1.50	......
Cost setting single hyd., 12 ft. 4-in. pipe	8.50	Special castings at 2½ cts. per lb.		
Cost setting double hyd., 12 ft. 6-in. pipe	13.50	Special castings at 2½ cts. per lb.		
Cost building hydrant and valve basins	30.00	......	......	......

Specials not included in above.

Repaving per square yard: Cedar block on plank or on crushed stone, 50 cts.; brick on concrete, $2.00; macadam, 9 ins. deep, 40 cts.; 12 ins. deep, 50 cts.; granite block, $1.50; asphalt, $3.00.

Rock requiring blasting will cost an average of $3.00 per cu. yd.

Items	12	14	16	18	24	30	36	42	48
Pipe per 12 ft. length	1,000	1,224	1,500	1,824	3,000	4,230	5,400	7,944	9,350
Pipe per ft. in lbs	83	102	125	152	250	352	450	662	780
Yarn per joint in lbs	.75	.84	1.00	1.10	1.50	1.80	2.16	2.50	3.00
Yarn per ft. in lbs	.063	.07	.083	.092	.125	.150	.180	.21	.250
Lead per joint in lbs	16	20	24	28	38	60	80	126	144
Lead per ft. in lbs	1.33	1.67	2.00	2.34	3.17	5.00	6.70	10.50	12
Pipe per ft. at $23 per ton	955	1.17	1.4375	1.75	2.875	4.05	5.175	7.61	8.97
Yarn per ft. at .08 cts. per lb	.005	.0056	.0066	.00736	.010	.012	.0144	.017	.02
Lead per ft. at .05 cts. per lb	.067	.0835	.10	.117	.160	.250	.335	.525	.60
Teaming at $1.00 per ton	.0415	.051	.0625	.067	.125	.176	.225	.331	.39
Excav. and refilling 6-ft. trench	.200	.21	.220	.24	.30	.40	.45	.48	.50
Pipe laying, caulking and cutting	.03	.045	.07	.09	.20	.25	.30	.40	.50
Total cost for average work per ft	1.30	1.565	1.90	2.28	3.67	5.14	6.50	9.36	10.98
Ad. cost for blocking and if needed for bracing	.12	.13	.15	.20	.25	.30	.40	.45	.50
Cost of setting valves	2.20	......	3.00	......	4.40	6.15	8.40	.....	12 00

The costs (Table XXVII) are based on the following rates for labor and material.

8 hrs. = day's work.
Foreman, $3.75 per day.
Caulker, $2.50 per day.
Timekeeper, $2.75 per day.
Laborer, $2.25 per day.
Watchman, $2.00 per day.
Mason, $4.00 per day.
Helper, $2.50 per day.
Brick, $6.50 per M.
Timber, $16 per M.
Cement, $2.25 per bbl.
Sand, $1.25 per cu. yd.
Hydrant covers, $6.75 ea.
Valve covers, $7.50 ea.
Bottoms, $1.50 ea.
4-in. valves, $14.00 ea.
6-in. valves, $18.00 ea.
8-in. valves, $ 35.00 ea.
Hydrants, ea. Dbl., $38.00; Sgl. $26.00

Cost of Water Mains at Los Angeles.—Table XXVIII from the last annual report of Thos. Brooks, Assistant Superintendent and published in Engineering and Contracting, March 12, 1919, shows the cost of laying 4-in. and 6-in. cast iron pipe in 6 months' periods from July 1, 1911, to July 1, 1918:

TABLE XXVIII

Year	Av. cost of pipe per ton	Av. cost of labor per foot	Average per foot	Total cost per ton
	4-inch			
1911	$32.70	$0.0967	$0.519	$51.90
1912	33.88	.0995	.548	51.46
1912	35.05	.1189	.607	56.05
1913	36.22	.1144	.603	55.62
1913	32.42	.107	.553	51.10
1914	32.42	.109	.544	50.27
1914	33.13	.122	.647	59.77
1915	30.17	.145	.620	57.18
1915	28.85	.145	.626	57.68
1916	31.96	.145	.660	60.83
1916	38.40	.161	.741	68.33
1917	43.66	.174	.807	74.42
1917	55.60	.175	.93	85.52
1918	75.17	.173	1.14	105.51
	6-inch			
1911	31.60	.133	.775	48.98
1912	33.71	.127	.782	49.43
1912	33.04	.163	.859	51.56
1913	33.93	.1595	.855	51.42
1913	31.24	.164	.822	49.34
1914	31.24	.170	.836	50.18
1914	31.20	.149	.833	50.05
1915	28.60	.160	.799	48.01
1915	31.09	.171	.878	52.71
1916	33.72	.171	.941	56.54
1916	34.65	.182	.977	58.71
1917	40.11	.212	1.07	64.23
1917	41.43	.221	1.11	66.71
1918	44.92	.242	1.26	75.23

It will be noted from the table that the increased labor cost, as might be expected, keeps pace with the increasing cost of material. The day wage has been raised from $2.25 to $2.50 to $2.75 and $3, but while wages have been increased, the efficiency shows a decrease of possibly one-third from old standards. Foremen with gangs of less than half the normal number, and many small instead of long straight-away jobs also show their effect on unit costs which in the last year reached the maximum.

Owing to the war conditions the tonnage of cast iron pipe laid in the fiscal year 1917–18 by the Construction Department was the smallest of any year in the history of the Department. Only 1,435 tons were laid as against 4,036 tons for the year preceding and 6,420 tons for the year 1915–16. Of this tonnage, approximately two-thirds was in 4 and 6-in. sizes. The tonnage represents a footage of 75,799 ft., or 14.36 miles, laid at a total expenditure of $103,464. In 1915–16 the average cost of cast iron pipe laid, including resurfacing costs was $50.93; in 1916–17 this had increased to $60.60 per ton and for the year ending July 1, 1918, the charges had mounted to $72.10 per ton.

Cost of Laying Water Mains at Hartford, Conn.—During the 1919 season the Water Commissioners of Hartford, Conn., laid 37,400 ft. of 4-in. to 4.2-in. main pipe. Of this, 3,234 ft. were renewals and 34, 166 ft. were extensions. The force employed consisted of two foremen and a total average gang of 42 men. The following table given in Engineering and Contracting, Dec. 8, 1920, is from the report of the Commissioners for the year ending March 1, 1920, and shows the average costs of main pipe work in 1919, and a comparison with previous years:

		Cost per linear foot						
		1919						
Size, inches	Length laid 1919, feet	Labor	Mat'l incl. transportation	Total	1918 Total	1917 Total	1916 Total	1915 Total
4	411	$0.74	$1.06	$1.80	$....	$1.20	$0.81	$....
6	3,560	0.88	1.72	2.60	2.43	.....	1.46	1.26
8	10,160	0.92	2.20	3.12	3.45	2.41	1.66	1.62
10	3,773	1.31	3.22	4.53	*4.72	3.00	2.15	1.93
12	539	1.72	3.71	5.43	4.15	4.12	2.82	2.43
16	547	1.38	8.17	†9.55	6.17	4.92	4.58	.....

* Includes some macadam. † Two special bridge crossings.

Labor....................	$ 3.55 for eight hours
Pipe....................	60.00 per ton
Specials....................	110.00 per ton
Lead....................	0.09 per pound

No overhead charges.

Only a small amount of pipe laying was done during 1918 by the Water Department of Hartford, Conn., due to lack of building and absence of requests for extensions. The cost of this work was very much in excess of any previous figures of the department, due to high wages, excessive cost of materials and difficulty in obtaining proper labor. The following table given in Engineering and Contracting, May 12, 1920, is from the report of Caleb Mills Saville, Manager and Chief Engineer of the Department, and shows the average figures for costs in 1918.

		Cost per lin. ft.		
Size, in.	Length laid 1918, ft.	Labor	Material including cartage	Total, 1918
6	1,736	0.83	1.31	2.14
8	5,431	1.45	2.14	3.59
10	3,561	1.37	3.56	4.93
12	336	1.11	3.04	4.15
16	570	1.29	4.88	6.17

The 1918 costs are based on the following: Unskilled labor, average $3.50 for 8 hours; pipe, $60 per ton; specials, $110 per ton; lead, 9 ct. per pound; no overhead charges.

The following table shows relative costs before the war and during 1918.

	1918	1915	Increase pct.
Labor, average of 45 permanent employes, per 8-hour day	$ 4.30	$ 3.00	44
Cast iron pipe per ton	65.00	23.00	183
Lead per 100 lbs	7.15	3.95	82
Meters (¾ in.)	18.00	12.00	50
Valves, 6 in	20.00	10.00	
Valves, 8 in	31.40	15.75	100
Valves, 10 in	49.00	22.50	
Hydrants 2-way	49.90	25.06	
Hydrants 2-way steamer	54.75	33.40	100
Hydrants 4-way	66.10	33.10	

Cost of Laying 16 miles of 20-in. Cast Iron Water Pipe.—M. V. Moulton in Engineering and Contracting, Oct. 26, 1910, gives the cost of laying the 20-in. supply main for the city of Cheyenne, as follows:

LABOR COST OF LAYING 83,328½ FT. OF 20-IN. CAST IRON WATER MAIN

Item	Total	Per lin. ft. cts.
192¼ dys. No. 0 excavator at $10	$ 1,922.50	*5.24
146 dys. No. 1 excavator at $16	2,336.00	†5.84
2,910 dys. E. & C. bell holes at $2.50	7,275.00	8.73
949.8 dys. laying pipe at $2.50	2,374.50	2.84
199 dys. yarning at $3.50	696.50	0.79
190 dys. lead heating at $2.75	522.50	0.68
174½ dys. pouring at $2.75	479.87	0.58
219 dys. caulking at $3.50	766.50	0.92
237½ dys. helper at $2.50	593.75	0.71
116 dys. testing at $3	348.00	0.42
304½ dys. refilling at $7.50	2,284.00	2.74
453 dys. foreman at $4	1,812.00	2.18
410 dys. teams and teamsters at $5	2,005.00	2.40
147 dys. blacksmith, at $4	588.00	0.70
Pumpmen	119.00	‡99.2
Total	$24,123.12	

* Figured on 36,700 lin. ft. † Figured on 39,600 lin. ft. ‡ Figured on 1,200 lin. ft.

EXTRA WORK IN LAYING 83,328½ FT. OF 20-IN. CAST IRON WATER MAIN

Item	Total
Rock excavation near intake	$ 48.00
Rock excavation west of Round Top	877.80
Cutting off 176 pipe	70.40
Extra fill near intake	162.30
Extra depth of trench	698.59
Diverting creek	38.85
Replacing broken pipe	330.00
Hauling pipe	131.43
Total	$2,357.32

Adding these two totals gives $24,123.12 + 2,357.32 = $26,480.44, which divided by 83, 328.5 lin. ft. gives a cost of 31.8 cts. per lin. ft. The contract price was 39 cts. per lin. ft.

The wages paid did not always correspond to the scale adopted therein, but in most cases the average wages paid will be about the same as those given. An exception is the cost of teams for backfilling, the actual cost of teams for refilling during May and June being $9.50 for a team and two men. Final estimate, including all previous estimates and extras allowed Messrs. Bash and Gray, was $35,246,62, making the actual cost to the City of Cheyenne a little more than $.42 per lin. ft. The average weight of the 20-in. pipe was 1,631 lbs., and the cost of the pipe delivered on the line, including hauling, transportation and cost of material, was $29.70 per ton, or $2.02 per lin. ft., making the total cost of the line when completed $2.44 per lin. ft.

So far as possible, the trench excavation was done by a No. 0 and a No. 1 Municipal Trenching Machines. The former was driven by a 4-cylinder gasoline engine and was capable of digging a trench 28-ins. wide and 7 ft. deep. The No. 1 was a steam driven machine capable of digging a trench 28-ins. wide and 10-ft. deep.

This machine-dug trench had to be widened and deepened at the bell points to allow free access for yarning and calking, considerable hand grading and straightening of the trench had to be done also before the pipe could be properly laid. All this was hand work and is included in cost data under hand grading and bell holes.

The pipes were lowered and entered by means of a derrick, formed by two A-shaped forms connected by a beam, each end equipped with a rope windlass and two single blocks; one man at each windlass lowered a pipe and the pipe last laid was driven home with the pipe that was still swinging from the derrick. This derrick was pulled ahead by a pony. From 15 to 20 pipes an hour could thus be placed by a gang of 7 men, though the average daily progress did not equal this rate.

The calking was done with a pneumatic hammer, a small gasoline compressor, maintaining a pressure of not less than 65 lbs. per sq. in., supplied the hammer. This compressor was mounted on an ordinary wagon truck.

The pipe was tested in sections of variable length, the maximum pressure being 150 lbs. per sq. in.

Cost of Constructing Two 18-in. Cast Iron Water Mains by Day Labor for the Fort William, Ontario, Water Supply.—The following data, published in Engineering and Contracting, May 18, 1910, are from a paper by H. Sydney Hancock, Jr., presented to the Canadian Soc. of Civil Engs.

Supply Main to Reservoir.—The line, which was 10,200 ft. in length, was located to avoid solid rock as far as possible; 8,400 ft. was in a marly clay with occasional boulders, 6,000 ft. in muskeg and 1,200 ft. in solid rock. The grade line was kept at a minimum depth of 4 ft. 6 ins. to insure at least 3 ft. of cover. In the muskeg sections clay, on which the pipe was laid was found at a depth of about 4 ft.

One 18-in. gate valve was placed near the middle of the line and a second close to the reservoir. A check valve was also placed 50 ft. back from the reservoir and two 18-in. valves in the two bye pass lines leading from the supply main parallel to the east wall and past the reservoir to the two 18-in. pressure mains. A cluster of three 1-in. Brook's air valves at every summit and a 6-in., off 18-in., blow off at every depression, a drainage ditch on a 5-10ths grade being executed at each. Manholes of dry rubble were built over each air valve cluster and over the gate valves. The pipes were of standard specification, the limits of weight being from 1,800 to 1,950 lbs. per 12-ft. lengths.

The entire work was done by day labor. Wages paid were as follows:

Superintendent, per mo	$150.00
Sub-foreman, per hr	.40
Blacksmith, per hr	.35
Calkers, per hr	.30
Laborers, per hr	.25

The cost of the work was as follows:

Item	Total	Per lin. ft.
Cleaning and grubbing	$ 460	$0.045
Trenching and backfilling rock, labor	1,698	......
Materials	193	......
Total	$ 1,891	$0.186
Earth, labor	4,504	......
Tools and materials	725	......
Total	$ 5,229	$0.512
Pipelaying, labor	1,065	0.105
Lead, yarn, tools	1,632	0.160
Total	$ 2,697	$0.265
Cast Iron Pipe:		
760,858 tons at $40	$30,691	......
13,812 sleeves, specials at 3 cts	414	......
Total	$31,105	......
Less credits	183	......
Net total	$30,922	$3,030
Hauling pipe	2,130	0.209
Manholes, labor	162	......
Materials	54	......
Total	$ 216	$0.021
Valves	652	0.064
Grand total	$44,198	$4,332

Pressure Main From Reservoir.—This line was 12,520 ft. long, including bye-passes. Six inch, off 18-in., "blow-offs" were placed every half mile, as well as at depressions. Three clusters of three 1-in. Crispin automatic air valves were placed about 4,000 ft. apart.

The pipe used was 18-in. diameter cast-iron pipe of standard specification, from 1,900 lbs. to 2,000 lbs. for all heads over 200 ft., and 1,800 lbs. to 1,900 lbs. for all heads less than 200 ft., excepting across the property of the Grand Trunk Pacific Ry., where no pipe of less than 2,050 lbs. was used. The line was cut into three sections by two 18-in. geared gate valves.

As there was greater possibility of the territory through which this line passed becoming inhabited, the minimum depth for the invert of the pipe was fixed at 6 ft., but in deference to the wishes of the Grand Trunk Pacific Railway Co. the grade line across their property averaged a depth of 12 ft. A 12-in., off 18 ins., cross was placed for the future water requirements of the Grand Trunk Ry.

It was decided that the sand and swamp portions of the line could be laid more economically during the winter, as at that season the movement of the sub-soil water is more sluggish and the depth of frozen ground obviated the use of sheet piling. These advantages were considered to more than compensate for the cost of shoveling snow and the difficulty of excavating frozen ground.

Seven thousand feet of pipe were laid south from the river in February and March at an average rate of 372 ft. per day. The upper section of the pipe was laid during May and June.

No unusual features developed during the progress of the work, the cost of which was as follows:

	Per lin. ft.	Total
Clearing right of way	$0.008	$ 103.50
Excavating trench labor	0.423	5,294.10
Tools	0.028	356.25
Backfilling and tamping	0.104	1,297.34
Total		$ 7,051.19
Cast iron pipe (18-in.)	$3.060	$38,310.87
Inspection at foundry	0.021	267.63
Pig lead	0.147	1,832.90
Yarn	0.003	37.45
Specials	0.041	541.56
Hauling material	0.048	607.20
Total		$41,570.61
Skidding and laying pipe, labor	$0.258	$ 3,228.02
Tools, lumber, plant	0.043	537.19
Accident	0.004	52.00
Total		$ 3,817.21
Culverts and road repairs	$0.021	$ 262.81
6 gate valves	0.080	1,007.00
8 blow off valves	0.015	186.43
9 air valves	0.012	151.08
Total		$ 1,344.51
Manholes, fountain, head walls, etc	$0.057	$ 702.76
Engineering and supt	0.090	1,131.20
Total cost of pipe line	$4.463	$55,880.29
Repairs and alterations at river crossing		$ 1,015.40
Total cost, Section IV		$56,895.69

In the above work common labor was paid 22½ to 25 cts. per hour, calkers 30 cts. per hour and a superintending foreman $150 per month. Cast-iron pipe cost $36.75 per ton at the local foundry, and specials $65 per ton. Pig lead cost $3.80 per 100 lbs., and yarn 8½ cts. per lb. Nearly half a mile of the line was inaccessible to teams, and as a consequence the cost of skidding and handling pipe was high.

Cost of Laying 10,137 Ft. of 12-in. Water Pipe by Day Labor at Tuscaloosa, Ala.—The following data were published in Engineering and Contracting, July 6, 1910.

The work consisted in laying 10,187 ft. of 12-in. pipe and erecting thereon two hydrants with 92 ft. of 4-in. pipe. Prior to starting the work all the pipe had been placed along the line of trench. For laying the pipe five Mueller tripod derricks and equalizers were set and 10 lengths or 120 ft. of pipe were connected, calked and handled at once. The trench was 3 ft. deep. With an average gang of 40½ men and two teams the work was accomplished in 19 working days and 23 days total time. The average length of pipe laid per 10-hour day was 533.5 ft.; the maximum day's work was 1,059 ft. of pipe laid. After completion the pipe was tested to 125 lbs. hydrostatic pressure and only two leaks developed. These were at joints whose pipe had been laid one length at a time in crossing another pipe line and where the ground was too rough to permit lining up 10 lengths at once. There were no leaks in any of the joints caulked on the surface.

The wages paid, working a 10-hour day, were: Laborers, $1.25; yarners and calkers, $1.50 and $2; foreman, $2, and team and driver, $3.50 The cost of the work was as follows:

Labor	$1,051.69
950 lbs. oakum at 3½ cts	33.25
15,864 lbs. lead at 5.15 cts	817.00
1,800 lbs. coal at $2 per ton	1.80
15 gals. coal oil at 17 cts	2.55
Lanterns, nails, etc	11.95
Total	$1,918.24

This gives a cost of 18.9 cts. per lin. ft. of pipe laid. A bid received for the work asked 30 cts. per lin. ft. for laying the 12-in. pipe, 10 cts. per lin. ft. for laying the 4-in. pipe, and $3 each for setting the hydrants or a total of $3,056.30.

Cost of Laying 12-in. Pipe in Deep Trench with Quicksand Bottom.—L. R. Howson, who was Resident Engineer in charge of the construction of the gravity water supply for Norway, Mich. gives the following data, in an article describing this work, in Engineering and Contracting, Dec. 13, 1911.

The system as planned comprises a 12-in. cast iron pipe connection between the lakes, an inlet in Forest Lake, a concrete screening chamber on the shore of Forest Lake, a 12-in. cast iron gravity pipe line 23,000 ft. in length, a reinforced concrete reservoir and connections with the present distribution system and pumping station.

No exceptional difficulties were encountered until the "deep cut" section of 4,000 ft. nearest the lake was reached. This section had an average cut of about 14 ft. with a maximum of 21 ft., and the amount of water in the ditch varied from 4 to 9 ft. in depth when the pumps were closed down. The original contractor removed the top 6 ft. of material with teams and slip scrapers, then started his sheathing and hand excavation. For the first few hundred feet the water was taken care of by two diaphragm pumps, the ditch being dammed with sod behind each bell to prevent flow from behind. Progress became continually slower, and it was apparent that power pumps and other methods must be used and the contractor defaulted.

The National Surety Co. as bondsmen, sublet the contract to a Chicago contracting firm, who started on the deep cut after numerous delays. They tried two No. 2 Nye vacuum pumps to handle the water, but as the entire trench was in a sand carrying a great deal of water, the vacuum pumps on open suction cared for only a short length of ditch, and progress was still very slow. An Emerson vacuum pump with well points was next tried. Four manifolds of well points each 20 ft. long and carrying 16 1¼-in. points 36 ins. in length were purchased, and in this way 80 ft. of ditch could be opened and pipe laid at one pump setting.

Contractor No. 2 also handled his top material differently, using a 30-ton steam shovel with 30-ft. boom and 1-yd. dipper. Owing to the quicksand bottom, the necessity for tight sheathing and the presence of large boulders, this proved to be an impracticable way of removal. This contractor too became discouraged after laying only 500 ft. in three months of experimenting and also defaulted.

The city of Norway was in great need of water at this time (July, 1910), and decided to complete the work under the supervision of the engineers by force account. The steam shovel was dismantled and the top material removed by scraper as before, at a considerable reduction in cost due to the excessive amount removed by the steam shovel to cut out its running benches. The Emerson pump and well points were now operated day and night, and in this way effectually lowered the ground water level below the grade. Lead wool had been used in the joints, but when the trench was dried by continuous pumping the poured joint was again adopted. Sixteen foot planks were used for sheathing, and three or four sets of 4-in. × 8-in. stringers were required. In some places the bank was so heavy that braces were necessary at 3-ft. intervals and 6 ft. was standard. Bell holes were kept dry with diaphragm pumps where necessary.

Progress and Cost.—Proceeding in this way, an average of 50 ft. per day was laid at a cost of $2.57 per ft. Deducting salvage in pumping machinery and planks purchased, the net cost was a trifle under $2.50 per lin. ft. Common labor was paid at the rate of 25 cts. per hour.

After the city assumed charge of the work, there were no accidents or delays of any kind. Previous to this, one man had been killed and four "bottom men" buried in a quicksand "cave-in" for 14 hours before they could be removed. The ditch besides having depth, quicksand and water, paralleled a railroad track but 25 ft. off center, and the jar from passing trains added new difficulties to those already present. The last 500 ft. of pipe was laid along the edge of the lake some 10 ft. from the water, and from 6 to 7 ft. below the water level, but due to the impervious character of the deposit in the lake bed, the difficulty of handling the water was less than was found in caring for the ground flow further removed from the lake.

Cost of Laying 10,693 Lin. Ft. of 8-in. Water Main at Tuscaloosa, Ala.—C. E. Abbott gives the following data in Engineering and Contracting, Nov. 16, 1910.

On July 22, 1910, work was started at Tuscaloosa, Ala., of laying an 8-in. main to the A. G. S. depot, a distance of 10,693 ft., inserting 10 valves and locating thereon 23 fire hydrants and 7 specials for future extensions, using 60 ft. of 6-in. pipe and 312 ft. of 4-in. pipe. Prior to starting this work all pipe, fittings, valves and hydrants had been distributed along the route. This main was laid to replace a 4-in. and 3-in. main along the main thoroughfare to the cemetery and the A. G. S. depot.

The streets had been graveled and rolled with a 5-ton roller, making the first 6 ins. of very hard picking. The trench was 3 ft. deep from the surface of the ground the entire distance, except 420 ft., which was 5 ft.

The main was tested to 125 lbs. hydrostatic pressure without a single leak.

The work was done by day labor under the personal supervision of the writer at the following cost.

Labor	$ 986.43
11,275 lbs. lead at $4.85	546.84
760 lbs. oakum at 3½ cts	26.60
1,000 lbs. coal at $2 per ton	1.00
Nails, etc	.60
Oil	2.55
8-in. plug wood	1.50
Total	$1,565.52

This gives a cost of 14.2 cts. per lin. ft.

In laying this pipe, 120 ft. were laid at a time, using tripod derricks, equalizers, tongs, etc.

The time required to complete this extension was 15 days, of 10 hours each; average number of men each day, 44 4–5; greatest number of feet of pipe laid in one day, 994; average number feet per day, 737 2–3; price paid labor, 12½ cts. per hour, yarners and calkers 15 and 20 cts. per hour.

Cost of Laying 1924-Ft. of 4-in. Water Pipe Extensions.—The following table is prepared from data given by Clark A. Bryan in Engineering and Contracting, July 2, 1913.

TABLE XXIX.—LABOR COST OF LAYING 1924-FT. OF 4-IN. PIPE

Item	Total hours	Hours per foot of pipe	Rate per hour	Cost per foot of pipe, etc.
Foreman	170.5	0.0886	$0.30	2.68
Plowing	11.5	0.0060	0.525	.31
Excavation	678.0	0.3530	0.175	6.18
Pipe laying	122.5	0.0635	0.175	1.11
Pouring and caulking joints	249.0	0.1295	0.22	2.85
Backfilling and tamping	254.5	0.1326	0.175	2.32
Cleaning up	36.0	0.0187	0.175	0.33
Hauling	45.0	0.0234	0.35	0.82
Total				16.60

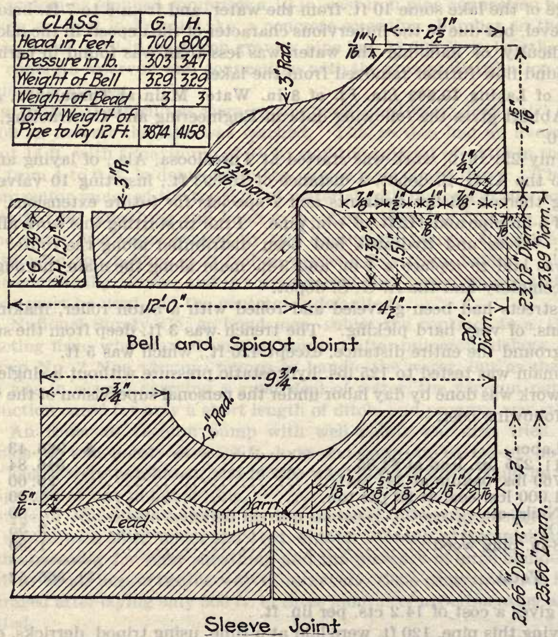


FIG. 26.—Types of pipe joint used in solid ground and soft ground.

The work consisted in laying five 4-in. extensions to the water system of Ridgely, Md. A 4-in. hydrant was installed at the end of each line by 4 × 4-in. tees and no valves were used. The pipe was laid at an average depth of 4-ft. 2-ins. in easily excavated, sand, loam and clay. To break up the first 2-ft. of the excavation a new ground plow attached to a traction engine was used with success on 1414-ft. of the trench. The work was done by force account Mr. Bryan being the Resident Engineer in Charge of Construction.

Of the five different connections, the maximum cost was 18.8 cts. per ft. for labor and the minimum cost was 14.4 cts. per ft.

Construction Cost of San Francisco's High-Pressure Fire Mains.—The following data are taken from an article in Engineering News, Feb. 18, 1915.

In the construction of the high-pressure system of San Francisco, after numerous tests, the types of pipe joints shown in Fig. 26 were finally approved. The bell and spigot joint was used in solid ground and the sleeve joint, which allows a greater displacement of the pipe without leakage, was used in soft ground and in places most susceptible to earthquake action.

The fire mains were constructed under contract, the following table gives the cost of labor, as estimated by the engineers in charge of construction.

TABLE XXX.—COST OF LABOR, AS ESTIMATED BY ENGINEERS IN CHARGE OF CONSTRUCTION

1. TRENCH WORK:

Removing pavements having concrete base, $0.06 per sq. ft.

Removing pavements without concrete base: not counted separately, as cost was found to be practically equal to that of an equal volume of ordinary digging.

Excavating and backfilling trenches and removing surplus excavated material.

Nature of ground	Labor cost per cu. yd. Congested district	Average conditions
Sand, about one-half lagged	$1.10	$0.95
Sandy clay	1.25	1.10
Hard clay	1.40	1.25
Soft rock (shale, red chert)	....	1.40
Hard rock (gadding, some blasting)	$4.00	$6.00

2. LAYING PIPE (Not including setting valves and hydrants):

Kind and size of pipe	Cost of labor, per foot: Hauling	Laying	Calking	Testing	Total
Congested district:					
Bell and spigot pipe: 8-in. (hydrant connection; all joints bolted)	$0.05	$0.17	$0.25	$0.02	$0.49
10-in.	0.06	0.16	0.11	0.02	0.35
12-in.	0.07	0.17	0.11	0.02	0.37
14-in.	0.09	0.26	0.12	0.02	0.49
16-in.	0.11	0.19	0.16	0.02	0.48
18-in.	0.12	0.25	0.14	0.02	0.53
Spigot pipe, sleeve joints:					
10-in.	0.07	0.13	0.14	0.02	0.36
12 in.	0.08	0.13	0.17	0.02	0.40
14-in.	0.10	0.13	0.20	0.02	0.45
16-in.	0.12	0.23	0.21	0.02	0.58
18-in.	0.14	0.15	0.24	0.02	0.55
Average conditions:					
Bell and spigot pipe: 8-in. (hydrant connections; all joints bolted)	$0.03	$0.29	$0.12	$0.01	$0.45
12-in.	0.05	0.06	0.07	0.01	0.19
14-in.	0.07	0.09	0.08	0.02	0.26
16-in.	0.08	0.10	0.12	0.02	0.32
18-in.	0.10	0.19	0.14	0.04	0.47
Spigot pipe, sleeve joints:					
12-in.	0.06	0.11	0.14	0.02	0.33
16-in.	0.09	0.06	0.15	0.03	0.33

Note: Cost of calking, per joint, was as follows:

	Congested district	Average conditions
8-in. joints	$0.90	$0.90
10-in. joints	0.85	....
12-in. joints	1.00	0.78
14-in. joints	1.10	0.90
16-in. joints	1.25	1.23
18-in. joints	1.40	1.44

3. Setting Gate Valves and Hydrants:

8-in. gate valves, each	$ 4.50
10-in. gate valves, each	4.50
12-in. gate valves, each	6.00
14-in. gate valves, each	7.50
16-in. gate valves, each	10.00
Hydrants, each	5.00

4. Miscellaneous Items:

Setting manhole castings	$ 7.00	per ton
Bolting joints of pipe lines	$24.00	per ton
Concrete valve vaults—labor only	$ 9.60	per cu. yd.
Setting reinforcing steel in valve vaults	$14.00	per ton
Laying creosoted wooden telephone duct	$ 0.036	per duct-foot

5. Wage Schedule, per day of eight hours:

Superintendent	$ 6.00 up
Foreman	$ 4.00 to $5.00
Straw boss	$ 3.50 to $4.00
Calker and yarner	$ 4.00
Leadman	$ 3.00 to $3.50
Laborer, watchman	$ 3.00
Team and driver, 4-horse	$10.00
Team and driver, 2-horse	$ 6.00
Team and driver, 1-horse	$ 4.50

Note: The above figures include only the wages of foremen, mechanics and laborers immediately engaged upon the work. Add 10% for general superintendent, timekeepers, watchmen, service wagon, and depreciation and repair of tools. The total cost of construction to the contractor will be obtained by adding the cost of all materials used, and the overhead expense, including office expense, liability insurance, etc.

The excellence of the workmanship on San Francisco's high-pressure pipe system is illustrated by a comparison with New York's fire system. The latter comprises 105 miles of mains, which are maintained under a pressure of 30 lb. per sq. in., and from which the leakage is approximately 850 gal. per minute or 1,200,00 per day. The San Francisco system contains 71.81 miles in which an average pressure of 200 lb. per sq. in. is maintained and the leakage is only 152,000 gal. per day, equivalent to a leakage of only 59,000 gal. per day under a pressure of 30 lb. per sq. in. Since the length of pipe in the San Francisco system is only 71.81 miles, and that in the New York system 105 miles, this 59,000 gal. per day in 71.81 miles of pipe is equivalent to 86,000 gal. per day in 105 miles of pipe, or the leakage per mile in San Francisco's system is only 7.2% of the leakage in the New York system.

Perhaps the principal reason for the tightness of the system were the tests which were made before the work was accepted, as follows:

Class of pipe	Use of head of	Test pressure, lb. per sq. in.
G & H	600 to 760 ft.	450
F	500 to 600 ft.	400
E	400 to 500 ft.	350
D	300 to 400 ft.	300
C	200 to 300 ft.	250
B	100 to 200 ft.	200
A	0 to 100 ft.	150

After several blocks of pipe were laid and calked, the trench between the joints was backfilled, and the bells left exposed. The pipe was then tested, the test pressure varying with the class of pipe.

Pipe to be tested was filled with water and the specified pressure applied by means of a double-cylinder force pump. This pressure was maintained for 20 minutes. If during that period the additional water introduced to keep the pressure constant exceeded 0.0055 gal. per lineal foot of pipe joint under test, the contractor was forced to recalk all joints that gave any evidence of leakage.

Cost of Making an 18-in. Tap on a 24-in. Water Main, Without Interrupting Service, at Columbia, South Carolina.—F. C. Wyse, gives the following matter in Engineering and Contracting, July 4, 1913.

The pipe on which the tap was made is 24 ins. in internal diameter and 25.80 ins. externally, and carries a pressure of about 20 lbs. per sq. in. The excavation was in earth bearing a large quantity of spring water and no record of cost of excavation was kept for the reason that the work was prosecuted intermittently and only at favorable times. A pump was necessary all the time, and the entire hole was close sheeted in order to preclude any accident to the machine by sliding mud. The excavation, however, was no larger than would have been necessary for the cutting in of a tee, and practicaliy the same amount of sheeting would have been used, therefore in making a comparison of costs it would be accurate to place the cost of excavation the same in both cases.

A 24-in. by 18-in. clamped sleeve, internal diameter 26¾ ins., and weighing 1,400 lbs., was adjusted on the pipe with lead wedges. Mud rolls were then placed at each end and in the neck of the sleeve and the lead was poured in the usual manner. This gave a sheet of lead approximately ½ in. thick between the sleeve and the pipe to be tapped. The ends were calked first then the lead in the neck, and the neck lead very carefully trimmed in order not to come in contact with the steel cutter. Onto the neck of the sleeve an 18-in. flanged valve weighing 1,600 lbs. was bolted, and to the valve the tapping machine, weighing 1,000 lbs., was bolted. A derrick supported the weight of the machine. The cutter was then started through the open valve and the cut was completed in 4½ hours, the cutter being turned by hand ratchets. After the cut was made the shaft was withdrawn, the valve closed, and machine removed.

The plug cut out remained tightly in the cutters, the center tapered drill helping in this. The plug was a clean cut, there being no break in the metal other than about 1/16 in. thickness of the inside shell. There were no leaks other than through the stuffing box of the machine which amounted to nothing.

The cost of the work was as follows:

Sleeve and valve	$210.00
Freight on sleeve, valve and machine coming, and machine returning	32.42
350 lbs. lead at 5 cts	17.50
Drayage on material with department truck	1.50
Labor placing sleeve, valve and machine (5 hours)	4.80
Labor operating and removing machine (4½ hours)	5.55
Total cost without excavation	$271.77

The work was done by the water department forces, the men being paid as follows:

Foreman, $2.75; calkers, $1.50; and helpers, $1.25 per day of 10 hours. More men were used in operating the machine than in placing the sleeve, hence the higher cost for a shorter time.

Relative Efficiency and Speed in Making Poured Joints and Lead Wool Joints also of Hand and Pneumatic Hammer Caulking.—The following data are taken from an abstract, of a paper before the Annual Convention of the American Society of Municipal Improvements by Andrew F. Macallum, City Engineer of Hamilton, Ontario, published in Engineering and Contracting, Oct. 20, 1915.

It was found that with the pneumatic hammers between four and five poured lead joints could be caulked to every one in which lead wool was used. This difference was due, generally, to the hammers becoming wedged in driving in the lead wool. It was also found that the compression in the caulking went deeper in the poured than in the wool joint, thus giving greater density.

Several alternate joints were caulked by the pneumatic hammers and by hand and this section was gradually put under pressure. It was found that every joint caulked by hand commenced to leak slightly at 110 lbs. pressure but that the pneumatic caulked joints remained tight.

To compare the relative speed of hand and pneumatic caulking, tests were made with the results shown in the following:

Size pipe, ins.	Class	Depth of lead joint, ins.	Weight of lead used, lbs.	Depth of yarn, ins.	No. of hand caulkers	No. of joints per day	No. of machine caulkers	No. of joints per day
36	C.	3½	121	1	2	4	2	12
30	C.	3	90	1	2	6	2	15

From the above it will be seen that on the 36-in. pipe the machine men caulked three times as many joints as the hand men and 2½ times as many on the 30-in. pipe.

Cost of Cement Joints for Cast Iron Mains.—In 1912 the city of Long Beach, Cal., began the use of cement joints with its cast iron water pipe. At the present time the city has 60 miles of mains, ranging from 4 in. to 24 in. in diameter, laid with joints of this type. All these pipes are under pressures ranging from 40 to 80 lb. per square inch and are giving perfect satisfaction. In a paper presented April 18, 1917 before the American Society of Civil Engineers Clark H. Shaw, Hydraulic Engineer Long Beach Water Department describes Long Beach's method of making these joints. The following, abstract from Mr. Shaw's paper, is taken from Engineering and Contracting, Dec. 12, 1917.

In making the cement joint the pipe is placed and spaced in the usual manner. A thin backing of the best dry jute is used instead of oakum, as the jute is free from oils and grease (which should be avoided). A Portland cement, conforming to the specifications advocated by the American Society for Testing Materials, is used. The dry cement is placed on a piece of canvas (usually a cement sack ripped open) and moistened just so that when thoroughly mixed by hand it will be of such a consistency that when gripped tight it will hold the form of the hand and when dropped 12 in. it will crumble.

The canvas containing the cement is placed under the bell and the cement is tamped into place by hand with a caulking iron until the bell is about half full. It is then caulked with heavy blows until the cement is thoroughly packed in the back of the socket. This process is continued until the bell is packed solid out to the face. A small bead of neat cement in a plastic condition is then put on, using the caulking iron as a trowel. As soon as the initial set of the cement in the bead has taken place the joint is covered with earth to protect it from the air and sun. In backfilling, the excavated material is always settled with water, which helps to cure the exposed portion of the joint.

In Mr. Shaw's opinion, the bead is essential, as the cement packed in the bell is so dry that without protection it would absorb moisture from the water used in settling the trench. It is believed that, should the joint develop seepage when the pressure is put on in the main, the cement, being dry, would expand and aid materially in keeping the joint tight.

Experiments on cement joints constructed without the bead showed that, 24 hours after completion, they absorbed water readily. In cases where seepage has developed and has subsequently closed, it is assumed that the dry cement absorbed the moisture from the inside, expanded, and filled the seepage pores.

About 20 per cent of the cement is wasted by falling off the canvas or being thrown out by the caulker. If any dust or earth from the trench falls on the canvas or in the cement, it is immediately taken out, together with enough cement to make sure that the remainder is clean. In mixing the cement with water, care is taken that there shall be no lumps in the material, no matter how small. If any cement is left on the canvas when a joint is completed, it is used on the next joint, provided the work is continuous, otherwise new batches are made. Special blunt caulking tools are used.

The joint is allowed to stand 48 hours before the pressure is turned on and the main is put into regular service. Cement joints have been used with satisfactory results, however, 12 hours after completion, but this is not considered safe practice.

At San Diego, Cal., a pressure test was made by caulking a 6-in. cast-iron tee, one side of the tee being filled with a plug and each of the two ends filled with short lengths of cast-iron pipe with plugs caulked in the ends. As the pieces of pipe caulked in the tee were scrap ends cut from other pipes, they had no bead on the joint end, and, notwithstanding the fact that the joint was made with smooth pipe, it took a pressure of more than 300 lb. per square inch to force the pipe out. The test was made about 48 hours after the joint was made.

In another test, made at Winnipeg, Man., three lengths of 6-in. pipe were laid with four cement joints, on Jan. 13, 1916. After 6 days, pressure was put on the pipe, in increments of 25 lb., and the joints were found to show no leakage or moisture, up to 125 lb. At 150 lb. one joint showed moisture on the surface of the cement.

On Jan. 24 another test was made, and at one joint moisture appeared at 175 lb. On Jan. 31 this joint showed moisture with 200 lb., and also on March 15, with a pressure of 225 lb. This joint was the weakest of the four. The pressure was kept on the pipe about one-half hour in each case.

The cement joint can be taken apart in a very simple and economical way The pipe is uncovered about one-half, or a little below the center. At the joint where the original bell-hole was dug, the trench is usually made wider on the sides (but not deeper under the pipe, in order to permit the caulker to work at the joint. The upper half of the joint is cleaned out with a cape-chisel; then, with tripod and blocks, the free end of the pipe is raised until the lower half of the joint breaks free from the bell. The pipe seldom has to be pulled out of the bell, as it nearly always works itself out as the free end is lowered. If portions of the cement stick to the spigot end of the pipe, or fail to be entirely crushed in the bell, it is a very simple matter to clean out the bell with a cape-chisel, or knock the cement from the spigot with a hammer.

On occasions, after a joint has been cemented tight in the line, it is necessary, to cut it out entirely (such as for laying a valve on its side; turning a tee or Y in another direction; adjusting a tee to conform to or meet a grade; avoiding a sewer connection or any other unforeseen obstacle). Table XXXI has been compiled from records of the actual time spent in doing such work.

At Long Beach unit costs have been kept on all construction, covering nearly the entire 60 miles of cast-iron water mains. Table XXXII has been carefully compiled from these unit costs, and presents data concerning cement joints.

TABLE XXXI.—TIME REQUIRED FOR ONE MAN TO DIG OUT A COMPLETE CEMENT JOINT, WITHOUT REMOVING FITTING OR GATES FROM THE LINE

Size	Time
4-in	18 min.
6-in	22 min.
8-in	26 min.
10-in	30 min.
12-in	38 min.
14-in	48 min.
16-in	60 min.

TABLE XXXII.—DATA RELATIVE TO CEMENT JOINTS

Size of pipe	Rings of jute per joint	Jute per joint in pounds (approximate)	Number of joints per 94-lb. sack of cement*	Number of joints per 8-hour day (one caulker)
4-in	2	0.14	24	50
6-in	2	0.19	18	42
8-in	2	0.24	14	34
10-in	3	0.43	11	28
12-in	3	0.51	8	24
14-in	3	0.58	7	20
16-in	3	0.66	6	17
18-in	3	0.73	5	14
20-in	3	0.80	4	11
24-in	3	0.95	3	7

*Including the 20 per cent of cement wasted or left over.

Cost of Repairing Fire Hydrants by Welding.—Engineering and Contracting, Aug. 13, 1919, gives the following:

In a discussion of damages to fire hydrants by motor vehicles at the (1919) convention of the American Water Works Association, Wm. W. Brush, Deputy Chief Engineer Department of Water Supply, Gas and Electricity of New York City, states that during the past two years an average of about 400 hydrants were damaged yearly by motor trucks, requiring an annual expenditure of about $12,000 for repairs. Repairs are made by welding by the oxyacetlene process. The hydrant is taken to the city shop and the broken section ground away to a bevel of about 45°, and then new metal is fused in at the break. If the portion of the hydrant thus treated is to be exposed above the ground it is finished off after the welding process is completed. If it is to be below the ground the rough surface is not finished off.

Mr. Brush gives the following costs on this work: The cost of replacing a broken hydrant when the old hydrant is salvaged and repaired, is as follows: welding standpipe of hydrant, $10; assembling hydrant, one mechanic $5 per day, ½ day, $2.50; total cost of repairing salvaged broken hydrant, $12.50. The cost of removing and resetting the hydrant where it has to be taken up about 3 ft. below the surface of the ground is as follows:

1 caulker, one day	$ 5.00
2 laborers at $3.25 per day each	6.50
1 Ford car, one day	3.00
Relaying 16 ft. of sidewalk at 30c per foot	4.80
Contingency	.70
Total	$20.00

The greater part of that $20 would be eliminated in the case of a hydrant that has a flange at the level of the sidewalk.

In the same discussion F. W. Cappeten, City Engineer of Minneapolis, Minn., stated that in his city 43 hydrants had been broken by motor vehicles in 16 months. The average expense per hydrant was as follows:

Excavation, removal and resetting	$14.40
Shop work and assembling	3.84
Welding (done by private concerns)	10.47
Cartage	2.50
Total	$31.21

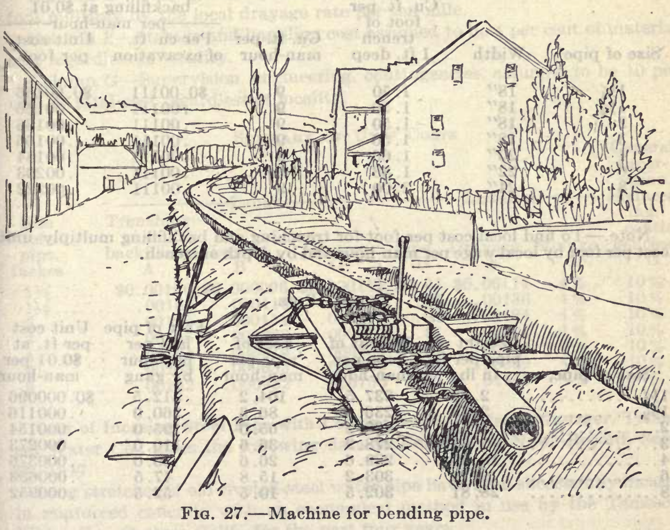


Fig. 27.—Machine for bending pipe.

Cost of Pipe-bending with a Machine (Engineering and Contracting, June 10, 1917).—A labor-saving device is used by the Philadelphia Suburban Gas & Electric Co., Chester, Pa., for the cold bending of 8-in. pipe. The machine is described by Charles Wilde, Engineer of Mains, in a paper presented to the October, 1916 meeting of the American Gas Institute. The arrangement consists of a 10-in. I-beam, 10 ft. long, braced with 1¼-in. tie rod; two ¾-in. chains 8 ft. long one at each end of the beam and an ordinary 20-ton screw jack and block. To operate, all that is necessary is to link the chains around the pipe and I-beam by means of a slip link, place the jack and pipe block in position between the pipe and the beam, and then by the force of the jack make the bend. If the bend required is only a slight one, it may be made without any shift of the machine. If it is a bend of any considerable extent, the machine should be shifted one way or the other, bending the pipe a few degrees until the required bend is made.

With this machine four men can make a bend in an 8-in. pipe, depending, of course, upon the radius and degree of the bend required, in from ½ to 2½ hours. To make the same bend—when possible to be made—in the old way would require about 25 men, who would never lose less than half an hour from their regular work, and would often require twice this time.

Unit Costs of Laying Standard Screwed Steel Pipe.—The following tabulations are taken from data compiled by George Wehrle, Supt. of the Gas Dept. of the Denver Gas and Electric Light Co. and were published in Engineering and Contracting, Jan. 8, 1919.

TRENCHING AND BACKFILLING

Size of pipe	Width	Cu. ft. per foot of trench 1 ft. deep	Cu. ft. per man-hour	Cost of excavating and backfilling at $0.01 per man-hour: Per cu. ft. of excavation	Unit cost per foot
1¼	18″	1.50	9	$0.00111	$0.00166
1½	18″	1.50	9	.00111	.00166
2	18″	1.50	9	.00111	.00166
3	18″	1.50	9	.00111	.00166
4	20″	1.66	9	.00111	.00184
6	22″	1.83	9	.00111	.00203
8	24″	2.00	9	.00111	.00222

Note.—To find local cost per foot for trenching and backfilling multiply unit cost per foot by local wage per man-hour and by depth of trench.

LAYING PIPE

Size of pipe,	Weight of pipe per ft. in lb.	Weight of pipe per man-hour	Feet of pipe per man-hour	Feet of pipe laid per per hour by gang	Unit cost per ft. at $0.01 per man-hour
1¼............	2.28	237.5	104.2	312.5	$0.000096
1½............	2.73	236.4	86.6	260.0	.000116
2..............	3.68	238.2	65.0	195.0	.000154
3..............	7.62	278.9	36.6	110.0	.000273
4..............	10.89	289.6	26.6	80.0	.000376
6..............	19.19	303.2	15.8	47.5	.000633
8..............	28.81	302.5	10.5	52.5	.000952

Note.—Laying pipe covers, reversing of couplings and handling of the pipe from the curb line to the trench and lowering into same. The weight of pipe per man-hour is not constant due to the reversing of a variable number of couplings per unit weight of different size pipes. To find the local cost per foot multiply unit cost by local pipemen hourly wage.

The number of men engaged in laying pipe is taken as 1 foreman and 2 pipemen for all sizes with the exception of the 8-in. pipe when 4 pipemen are used.

JOINTING

Size of pipe	Number of men	Joints per hour per gang	Ft. of pipe per hour per gang	Unit cost per ft. at $0.01 per man-hr.
1¼	2	9	180	$0.000111
1½	2	8	160	.000125
2	2	6	120	.000166
3	2	4	80	.000250
4	2	3	60	.000333
6	2	2	40	.000500
8	3	2	40	.000750

Note.—Jointing pipe covers the work of entering and screwing up pipe in the trench. The number of joints per man-hour varies as the diameter of the pipe. To find local cost per foot multiply unit cost per foot by local wage scale per hour.

Explanation of Summary Table for Standard Screwed Steel Pipe.—Column A—Cost per foot for trenching and backfilling a trench 1 ft. deep at a labor cost of 1 ct. per hour. For local costs per foot multiply by depth of trench in feet and by labor wage rate per hour.

Column B—Cost per foot for laying pipe at a 1 ct. per hour wage scale. For local costs per foot multiply by local wage rate in cents per hour.

Column C—Cost per foot for jointing pipe at a 1 ct. per hour wage scale. For local cost per foot multiply by local wage scale in cents per foot.

Column D—Cost per foot of pipe at 1 ct. Substitute local cost per foot.

Column E—Drayage cost per foot at $1 per ton-mile. For local cost per foot multiply by the local drayage rate per ton-mile.

Column F—Storage and handling cost assumed to be 4 per cent of material cost regardless of locality.

Column G—Supervision, engineering, contingencies, assumed to be 10 per cent of total cost regardless of locality.

SUMMARY OF UNIT COSTS

Size of pipe, inches	Labor			Material			General supervision, engineering, contingencies
	Trenching and backfilling A	Laying B	Jointing C	Pipe D	Drayage E	Storage F	G
1¼	$0.00166	$0.000096	$0.000111	$0.01	$0.00114	4%	10%
1½	.00166	.000116	.000125	.01	.00136	4%	10%
2	.00166	.000154	.000166	.01	.00184	4%	10%
3	.00166	.000273	.000250	.01	.00381	4%	10%
4	.00184	.000376	.000333	.01	.00544	4%	10%
6	.00203	.000633	.000500	.01	.00959	4%	10%
8	.00222	.000952	.000750	.01	.01440	4%	10%

Cost of Incasing Steel Pipe with Concrete.—H. R. Case, Manager, Temescal Water Co., gives the following data in Engineering News-Record, Sept. 20, 1917.

Long stretches of old riveted-steel water pipe have been successfully incased in reinforced concrete with an economical method in use by the Temescal Water Co., Corona, Calif., for the past four years.

The details were worked out for use in covering 10,000 ft. of 24-in. riveted-steel pipe line used as inverted siphons working up to 80 ft. head. This line was laid 30 years ago and is beginning to give way near the ends of the siphons, and where light weight steel was used on account of low heads. Possibly

95% of the iron is still in the pipe, but it has rusted badly and pitted particularly at the seams, so that it has been necessary to make repairs during the irrigation season. The system not only protects the outside of the pipe and prolongs its life by the jacket of reinforced concrete, but eventually utilizes all the iron in the old pipe, and when it has disappeared leaves a reinforced-concrete pipe without joints, sufficiently strong to carry the pressure.

Figure 28 shows the details of the wood form used in covering the 24-in. pipe. The forms are constructed of Oregon pine and lined with No. 26 black iron, which saves not only the forms but much material, making a smooth outside surface to the finished pipe. Forms for 24-in. and larger pipe are made in 8-ft. lengths, while the smaller sizes are made up in 12-ft. lengths.

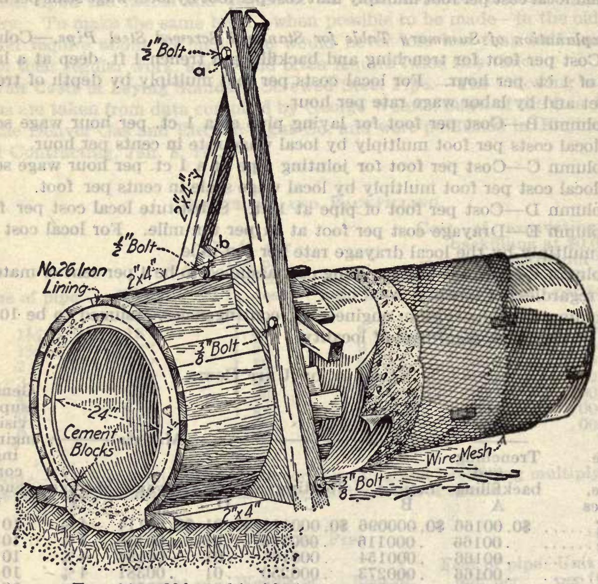


FIG. 28.—Old steel inside form for new concrete pipe.

After the steel pipe is uncovered it is thoroughly scraped and cleaned with steel brushes. The ground under the pipe is then shaped to the required depth, the pipe being supported on wood blocks until the forms are set. Bedplates of 2 × 4s are then spaced with a template, similar to the end section of the form, on each side of the pipe to support the forms when in place. The wire-mesh reinforcement cut to 50- or 75-ft. lengths is then wound spirally around the pipe and supported where the edges unite by small cement-mortar blocks made in the form of truncated pyramids, 1½ in. high, 2 in. square at the base and ¾ in. at the apex, which is placed next to the pipe. A man with a hand mold will make 2,500 or 3,000 of the small blocks in nine hours. The edges of the mesh rest on the base of the little pyramids, thus keeping the wire mesh spaced a uniform distance from the steel pipe or forms. As the blocks are placed, the edges of the wire mesh are tied together with No. 24 soft stovepipe wire.

The forms are then placed on the 2 × 4s and held rigid by the two ½-in. bolts as shown. The wood blocks supporting the pipe are removed, and the pipe is held in place by a strand of wire and a turnbuckle clamp until the form is filled to a point where the concrete will support the pipe. The concrete is a 1:2½:1 mixture of cement, sand and crushed rock or screened gravel of ¾-in. maximum size. It is mixed by hand and poured rather wet, being worked to place with a light rod and by tapping the forms with a hammer. In laying the pipe up hill the top openings, as the forms are filled, are closed with covers clamped to place until the concrete sets slightly, when the covers are removed and the surface is well trowled and smoothed. The next morning the forms are removed, and the pipe is painted with neat cement. The pipe is then covered with soil and kept wet for two weeks.

Progress and Cost.—Twelve men will easily build and backfill 140 ft. of 18-in. pipe, 100 ft. of 24-in. or 80 ft. of 30-in. pipe in a day of nine hours.

The company is replacing 30-in. steel pipe under 40-ft. head, placed on bridges, with concrete siphons of the same size, at a cost of $2.50 per ft., including the ditching. Covering 24-in. pipe including the digging costs $1.70 per ft., and 18-in. pipe $1.40 per ft. Cement is $2.30 per barrel and labor from $2.25 to $2.50 per day.

Cost of Wood Stave Pipe at Seattle, Wash.—The following data, taken from Engineering and Contracting, Feb. 13, 1918, show the cost of wood stave pipe in place at Seattle, Wash. The work was done in 1914 by the municipal water works of Seattle. The figures cover the cost of 42-in. and 54-in. pipe and are based on lumber at $31.25 per M ft. B. M. in place, steel bands at 4½ ct. per pound in place and common labor at $2 to $2.25 per day:

COST OF 42-IN. PRESSURE PIPE IN PLACE PER LINEAL FOOT WITH 3 ⅝-IN. BANDS PER FOOT

	Per lin. ft.
27 ft. B. M. of fir staves at $31.25 per M	$0.844
3 ⅝-in. bands 40½ lb. at 4½ ct	1.822
3 mal. iron shoes, 5.64 lb., at $0.0515	0.290
48 cu. ft. ex. back fill per lin. ft. at 31 ct. per yd	0.551
Total	$3.507

COST OF 54-IN. PRESSURE PIPE IN PLACE PER LIN. FT. WITH 3 ⅝-IN. BANDS PER FOOT

33 ft. B. M. fir staves at $31.25 per M	$1.03
3 ⅝-in. bands 52½ lbs	2.36
3 mal. iron shoes, 5.64 lb., at $0.0515	0.29
63 cu. ft. excavation at $0.31 cu. yd	0.72
Total	$4.40

42 in.	—25 ft. B. M. per ft	25 to 27 staves
44 in.	—26 ft. B. M. per ft	26 staves
54 in.	—33 ft. B. M. per ft	33 staves
*51½ in.	—40 ft. B. M. per ft	32 staves
60 in.	—46¼ ft. B. M. per ft	37 staves
48 in.	—30 ft. B. M. per ft	30 staves

The staves for this 51½ in. pipe are thicker than for the other sizes.

Forty eight-inch Wood Stave Pipe Line Across Marsh Land, Atlantic City, N. J.—George L. Watson, Engineer for the contractor describes in detail the methods employed and the difficulties encountered in carrying on the construction of the 48-in. wood stave pipe line supplying Atlantic City, in the Sept., 1912 number of the Journal of the American Society of Engineering Contractors. The following data are taken from an abstract of Mr. Watson's paper published in Engineering and Contracting, Oct. 30, 1912.

The work consisted of constructing 25,500 lin. ft. of 48-in. continuous wood stave pipe with three submarine "thorough-fare" crossings. The contract price for which was approximately $225,000.

The marsh, across which the pipe runs, is flooded at high tide and at times the work was completely stopped because of the water that covered the meadows. The surface of the marsh was so soft that it was necessary to float the pipe on a 2 × 12-in. plank cradle. This consisted of a 2 × 12-in. plank on each side of the bottom of the 2½-ft. ditch, in which the pipe was constructed, with the cross-pieces of the same size every 4 ft. Manholes were constructed at intervals of 1.000 ft. To protect the pipe line across the meadows from wave and ice action it was necessary to construct fenders on each side of the pipe embankment.

Construction of the Pipe.—The actual construction of the pipe was subdivided into sections. The excavation gang consisted of a Parsons Trenching machine and six men, and this outfit was about 1,000 ft. ahead of the finishing gang. This machine crept along and excavated a trench 5 ft. wide and 2 ft. deep, and at the rate of 500 ft. of ditch per day. However, there were so many delays not due to any defect in the machine, that it was not found expedient to continue to use this machine for more than 2½ miles of the work.

Following this machine was a gang of about 20 men and a foreman, who had to maintain the trench the proper width. This was necessary because the banks continually pushed toward each other into the trench, and, therefore, this gang was generally only about 500 ft. ahead of the men who were placing the cradles or foundation for the pipe. It was necessary to keep the ditch about 8 ft. wide to allow the men to do all the work properly and to cinch the bands.

The foundation gang consisted of six men and a foreman, and their duty was to build the timber foundation upon which the pipe was laid.

Then came the pumping gang, which consisted of six men, one engine man or pump man, and one foreman, and whose duty was to keep the ditch dry ahead of the pipe layers. Their outfit consisted of a larry upon which was mounted a 10 h.p. Olds gas engine, belt-connected to a 6-in. centrifugal pump, sod spades and other necessary tools. They divided the trench into sections by means of bulkheads, and kept dry only the sections in which the men were working, while other men threw up low dikes around the excavation to hold back tides as long as possible. It cost about 2 cts. per linear foot to build these dikes.

The pipe-laying gang consisted of 13 men and a foreman, and they were divided up so that in laying the pipe each man had only one portion of the work to perform. Two men were located on the bank as peddlers to handle the material of which the pipe was assembled, one man was located inside the pipe with mallet and chisel to set the staves and round them out, and two men placed at the end of the advanced pipe to assist in setting the staves. Along each side of the ditch three men would set the forms, and shape the section, while two men at the head of the section were employed to drive the staves home and band them up.

To assemble the pipe a form consisting of a piece of 3-in. pipe bent to a radius of 26½ ins. and reaching half-way up to the circumference was laid about 2 ft. back of the end of the advancing staves. This form was generally laid flat upon one of the foundation cross-pieces; then five or six staves were set at the bottom and tapped into position; and immediately thereafter the form was raised to an upright position, thus shaping the bottom of the pipe. The inside form, which consisted of a piece of 2-in. gas-pipe bent to a radius of 24-in., was next placed inside the lower portion of the pipe. It was set on the inside of the pipe directly over the outside form and the additional staves were then placed under the direction of the foreman at the head of the pipe who calls out whether he wants a long or a short stave. As soon as the circle was completed a band was slipped on at the head of the pipe and loosely cinched; one of the side staves was then marked with a pair of calipers and every sixth mark crossed as a guide to the "banders" who followed.

About ten bands were slipped on a section, which was then "rounded out," rolled and "driven home," after which the gang proceeded to lay the next section.

The pipe gangs averaged about 150 lin. ft. of pipe per day, while the best day's work of any one gang was 680 ft. Under ordinary conditions 400 ft. was a fair day's work, but the construction was much delayed because the men could not stand in the ditch without a platform or they would sink in the mud up to their waists, which, together with the large amount of water that had to be pumped was the cause of the slow progress made.

The tides also proved troublesome, especially when the wind was contrary, and at times the work was completely stopped because of the water that covered the meadows. Another thing that was a constant source of delay was the effect of the weather on the staves. The specifications called for 29 staves to complete the circle. During good and dry weather there was no difficulty in inserting the required number, but the slightest change in the weather affected the lumber, and if the air was damp or if it rained it was impossible to use all the staves. In that case, unless the work was to be stopped entirely, 28 staves and one strip cut out of a full stave had to be used.

Following the pipe layers came the band gang, which consisted of a foreman and 20 laborers, with four "band men." The latter were paired, one of each pair on opposite sides of the pipe. They slipped the bands on the pipe at the marks made by the pipe layers and tightened the nuts so as to merely hold the shoes in position.

The cinching gang, which came next, consisted of from 30 to 40 men and two foremen. This gang had to tighten the nuts on the bands to almost their final position by using a brace wrench. At the extreme end of this gang were four "spacers," who hammered the bands to their ultimate position and gave the nuts their final tightening. After them came the painters, who applied on the bands the remaining coat of rust preventive, as demanded by the specifications.

Finally, the gang which completed the embankment over the pipe varied from 10 to 40 men, depending upon the tides and conditions that influenced the building of the pipe.

Cost Data

The following are cost data for various operations of the pipe line work.

Pipe Line Materials

Staves, $47.17 f. o. b. cars job.
Bands, $2.20 per 100 lbs. f. o. b. cars job.
Saddles, $3.50 per 100 lbs. f. o. b. cars job.
Clips, $3.50 per 100 lbs. f. o. b. cars job.

Staves

Unloading from cars and hauling to job, 2 miles	$ 1.00
Sorting into sections and unloading	5.00
Loading on larries (teams $5.00 per day, 10 hrs.)	2.10
Delivering in sections along R. O. W	1.05
Per cent of cost of track and laying 30-lb. rails	0.15
Supervision	2.30
Total labor cost along ditch	$ 11.60
Cost lumber	47.17
Cost per M. ft. B. M	$ 58.77

Bands

Unloading from cars at Atlantic City, giving second coating of asphaltum as called for by Specs. reloading and shipping to Absecon, N. J., per 100 lbs	$ 0.10
Unloading from cars and haul to job	.035
Rehandling in yard	.015
Third coating in troughs. (Laborers at $2.00 per 10 hrs.)	.20
Loading on cars	.02
Delivering along R. O. W	.22
Per cent of cost of track laying	.005
Supervision	.015
Labor cost per 100 lbs	$ 0.610
Band cost per 100 lbs	2.20
Total cost per 100 lbs	$ 2.810

Saddles

Unloading from cars at Atlantic City, giving second coating of asphaltum, reloading and shipping to Absecon, N. J	$ 0.05
Unloading from cars and hauling to job	.035
Rehandling in yard	.015
Third coating in trough	.10
Delivery along R. O. W	.22
Loading on cars	.01
Per cent of cost of track laying	.005
Supervision	.015
Labor cost per 100 lbs	$ 0.45
Saddle cost per 100 lbs	3.50
Total cost per 100 lbs	$ 3.950

Clips

Cost per 100 lbs. in kegs delivered along the line of work	$ 3.68

Trenching

Cutting trench 2½ ft. deep, 6 ft. wide by Parsons trenching machine, trench filled with water, machine carried on heavy 4 × 12-in. planks 12 ft. long laid crosswise of trench, with 4 × 6-in. planks 24 ft. long laid on top for traction wheels to rest on, coal ($5.00 per ton) carried to machine by men in 50-lb. sacks across marsh, water rolled in barrels across marsh one-half mile to machine—cost per lineal foot	$ 0.20
Trenching by hand, cutting ditch to 8-ft. width, trimming bottom and sides, men in ditch standing on movable platform which was dragged along with them. All spoil thrown one side only	.09
Backfilling pipe, using material excavated from trench and placing same over pipe, per linear foot	.09

Cost of Building Pipe

Actual cost of building pipe in meadow exclusive of foundation or repainting or surplus enbankment, not called for by original specifications

29 ft. B. M. at .05877	$ 1.704
80 lbs. bands at .0281	2.248
10 lbs. saddles at .0395	.395
Total material per linear foot of pipe	$ 4.397
Machine trenching	.20
Hand trenching	.09
Pumping	.10
Laying pipe	.13
Banding	.11
Cinching	.42
Spacing	.103
Painting	.05
Backfilling	.09
General supervision	.14
Tools	.10
General expense	.22
Total cost per linear foot	$ 6.150

Actual cost of building pipe in Boulevard, trench 8 ft. wide, 7 ft. deep, running sand, water 18 ins. below surface, close sheeting, no allowance made for sheeting lumber, which was afterward used in fenders.

Total cost materials	$ 4.397
Excavation at .31	.63
Sheeting 16 sq. ft. at .023	.368
Pumping	.16
Laying pipe	.22
Banding	.13
Cinching	.48
Spacing	.12
Painting	.055
Backfilling	.15
Removing sheeting	.24
General supervision	.14
Tools	.10
General expense	.22
Total cost per linear foot	$ 7.410

Actual cost of building pipe along side of Meadow Boulevard Road, extra was paid for removal of sloping shoulder, trench 8 ft. wide, 3 ft. deep, in moist sand.

Total cost, materials	$ 4.397
Excavation	.07
Laying pipe	.09
Banding	.07
Cinching	.383
Spacing	.09
Painting	$ .04
Backfilling	.08
General supervision	.14
Tools	.10
General expense	.22
Total cost per linear foot	$ 5.680

Actual costs of building pipe on trestle over thoroughfare crossings 3 hrs. per tide.

Total cost, materials	$ 4.397
Temporary working platforms	.20
Additional cost, lighters and scows	.10
Laying pipe	.13
Banding	.10
Cinching	.40
Spacing	.10
Painting	.053
Blocking and temporary wedges	.12
General supervision	.14
Tools	.10
General expense	.22
Total cost per linear foot	$ 6.060

Embankment

Cost of constructing an embankment 18 ins. thick on top and 2 ft. thick on sides over pipe, to a width of 6 ft. at the top, 12 ft. at meadow level, all material taken from meadow, 16 ft. from center of pipe, trench to be cut even and graded, to act as drain for water in pipe trench.

1 foreman at $4.00	$ 4.00
1 sub-foreman at $2.50	2.50
15 laborers at $1.75	26.25
1 waterboy at $1.00	1.00
Per cent of cost of tools for sharpening	1.00
150 ft. per day	$ 34.75
Cost per linear foot	.231

Timber Foundation—Extra Work

Timber per 1,000 ft. f. o. b. Atlantic City	$ 26.50
Hauling to job, 6 miles, one trip per day	5.00
Unloading to cars and pushing along line	10.00
Unloading from cars, sawing and assembling along ditch	1.50
Placing in position and spiking	5.00
Supervision	2.00
Cost per M	$ 50.00
Cost per foot of pipe	.45

Erection of Laborers' Quarters, etc.

Cost based on 25,500 linear feet of pipe, for building and erecting one bunk house of 150 men capacity, one house of 100 capacity, one mess house, one store house, etc.

One storehouse and one foremen's quarters, no lumber taken into account, as the houses were torn down and the lumber used in the pipe foundation when a change of base was made.

Cost per foot of pipe	$ 0.18

Fender Construction

The operation costs per day of the pile driving crew were as follows: This crew was paid 12 hours for a day's work, but worked only 8 hours, 4 hours on each rising tide.

1 foreman at .80	$ 9.60
1 engineman at .30	3.60
1 topman at .225	2.70
2 deck hands at .20	4.80
2 set men at .20	4.80
1 boatman at .20	2.40
Labor per day	$ 27.90
Coal	2.00
Scow rental	8.00
Total cost per day	$ 37.90
8 piles for 2 tides, cost per pile	4.74
Cost per foot of pile driven	.157

This cost is high, but it must be borne in mind that the tide rose and fell so quickly that only 4 piles could be driven in one tide, while with deep water 25 piles could and have been placed under like conditions.

Fenders

One 30-foot pile every 5 feet.

Stringers, two 2-in. by 12-in. lower, two 2-in. by 12-in. upper notched in piles, and bolted with 1-in. by 8-in. bolts with O. G. washers. Uprights 2-in. by 12-in. —6 feet long, 2 bolts, one in upper and one in lower stringer, 4 O. G. ¾-in. washers. Fenders painted with bituminous paint.

Based on 10 linear feet of fender:

60 feet of creosoted piling at .28	$ 16.80
Hauling piling	2.00
Driving piling	9.42
120 feet B. M. uprights, $36.00 on job	4.32
80 feet B. M. stringers, $36.00 on job	2.88
Placing lumber and bolts, including boring holes	47.00
Painting	1.00
Bolts and nuts	4.80
Supervision	5.00
Cost per 10 linear feet of completed fender	$ 93.22
Cost per linear foot	9.32

Bottom stringers and bolts below low water 2 hours work per day, all timber floated out in position, bored and bolted and placed by men in small row boats; no scows or lighters to be had.

Scale of Wages

Pipe layers, $2.00 per 10-hour day.
Cinchers, $2.00 per 10-hour day.
Banders, $2.25 per 10-hour day.
Spacers, $2.25 per 10-hour day.
Painters, $1.75 per 10-hour day.
Laborers, $1.75 per 10-hour day.
Superintendent and engineer, $11.66 per day—$350.00 per month.
General foreman, $5.00 per day.
Gang foremen, $4.00 to $3.00 per day.
Excavation foremen, $3.50 per day.
Pump men, $3.50 per 10 hours.
Watchmen, $2.00 per 10 hours.

Wages paid were high, as all work was in water always at least 18 ins. deep, boots' average life 4 weeks with good care, cost $5.50 per pair wholesale. Hard to keep men at work, 600 to 700 on payroll—200 to 300 working.

Cost of Driving Piles for Manholes.

Four 30-foot piles for each manhole. Manholes 1,000 feet center to center. Cost includes building pile driver, assembly of plant, driving piles, moving driver, dismantling and returning to store yard and completion.

Lumber for machine, except skids	$ 90.00
Delivery at Absecon Camp	20.00
Hauling engine from Atlantic City to Absecon	15.00
Bolts, lines, bars, rollers, nippers, tools, etc.	80.00
Labor assembling driver—	
Foreman carpenter at $5.00; 3 laborers at $2.00, 4 days	44.00
Total cost plant	$249.00
Dismantling engine and haul to yard	10.00
Dismantling leads and skids and haul to yard	22.00
	$281.00
Less credit for skids, rope and tools charged to another branch on completion of driving	56.00
Total charge against the work for plant	$225.00

It must be remembered the machine started at Absecon end and worked toward Atlantic City; all piles were delivered at Absecon with exception of 12, which were delivered on "Old Turnpike Road;" therefore machine had to carry with it 40 piles. As each manhole required 4 piles, each move meant 4 piles less to drag forward, but you can see the handicap the work was done under having no base of supplies. This crew started out before track was laid or shanties built and water sometimes 2 feet deep on meadows, so that machine had to be blocked up or fire would be put out.

Pile Driving Crew

1 foreman at $4.00	$ 4.00
1 engineman at $3.50	3.50
1 top man at $2.25	2.25
4 laborers at $2.00	8.00
2 hours of superintendent's time at $1.16	2.32
2 hours of timekeeper's time at .30	.60
Coal, delivered within 2 miles of work and carried in 50-lb. sacks across marsh by men, per day—Coal cost delivered $5.00 per ton	4.10
Water rolled in barrels ½ mile across marsh	1.05
Oil, waste, etc	.09
Rental charge on engine and boiler	2.00
Total cost per day	$ 27.91
Number of days worked	16
Total cost of labor	$446.56
Total cost of plant	225.00
Entire cost of work	$671.56
52 30-ft. piles driven in place:	
4 piles, each 1,000 feet, cost per pile	$ 12.915
Cost per linear foot of pile	.43

Manhole Gang

1 foreman at $3.50	$ 3.50
6 skilled laborers at $2.00	12.00
1 hour timekeeper at $3.00	.30
1 hour superintendent at $11.66	1.16
Per cent of waterboy	.09
Cost per day	$ 17.05
Time required to set manhole complete, 2 days	2
Labor cost to set	$ 34.10
Per cent of plant cost	1.30
Unloading and hauling material	5.00
Cost each	$ 40.40

Cost of constructing manholes on meadow upon piles driven by pile driving crew. Weight of completed manhole, 4½ tons. Composed of 1 Tee (4,000 lbs.), 2 Bells and Flange Pins (4,200 lbs.), 88 1½-in. by 7¼-in. Tobin Bronze Bolts and Crex Nuts, 2½-in. Seamless Tubular Lead Gaskets, 1 Manhole Plate and Bolts. Base of supplies, average 1½ miles. Plant used to set manhole—1 tripod, 1 5-ton chain hoist, 1 2-ton chain hoist, six 10-in. × 10-in. × 30-ft. timbers, 8-in. × 8-in. blocking, chains, tackle, wrenches with 3-ft. handles, spades, cross-cut saws, diagraphm pump, 1 timber cart, wheels, 48-in. with 10-in. tread (iron), coup hooks, etc., rollers.

Manholes

Unloading from cars at Absecon and hauling to end of track at Absecon Camp, $1.00 per ton by contract	$ 5.00
Loading on cars and transporting to end of track	2.10
Unloading on cribs	.80
Excavating around piles 8 ft. by 8 ft. by 3 ft. 6 ins. water level at surface requiring constant pumping	3.30
Cutting off 4 piles and capping	.60
Skidding casting over hole and cribbing	6.20
Bolting on 2 bell pieces, including gaskets	12.00
Lowering into position and adjusting	3.10
Supervision	6.00
Percentage of plant cost less credit	1.30
Total labor cost each for setting	$ 40.40
Total labor cost each for piles	51.66
Total labor cost for foundation and setting	$ 92.06
Cost of 4 piles delivered	16.00
Cost of 2 caps delivered	2.04
Final cost, including piles, foundation and labor	$110.10

Cost of building intersection at Sta. 78 + 0 composed of two 48 × 42-in. reducers, two 42-in. gate valves, one 42 × 42 × 42-in. T., one 42-in. blank flange, 200 Tobin bronze bolts, five lead gaskets, etc. Nearest supply depot, 3 miles. Intersection located within 300 ft. of W. J. & S. R. R. main line; made arrangements with railroad to load all material on flat car at Atlantic City ; haul to job at night and railroad to unload all material on ground by railroad derrick.

Unloading from cars at Atlantic City at contractor's plant; by derrick of all material for intersection	$ 8.70
Loading on flat cars at contractor's plant at Atlantic City of all material and tools for intersection	12.30
Hauling to job by railroad and unloading on ground, railroad derrick used	25.00
Excavation 8 × 8 × 3 ft. 6 ins. water level at surface requiring constant pumping	18.23
Cutting off 12 piles and capping	1.97
Laying boards for track to skid castings	2.00
Skidding over in position over caps of all castings	62.10
Bolting up, including gaskets and blocking	42.00
Removing blocking and lowering into position	18.30
Supervision	18.00
Percentage of plant cost less credit	2.60
Total labor cost for setting	$211.20
Total labor cost for piles	154.98
Total labor cost for foundation and setting	$366.18
Cost 12 piles delivered	48.00
Cost caps—10-in. by 10-in.—delivered	19.82
Final cost, including piles, foundations and labor	$434.00

Curves for Estimating the Labor Cost of "Continuous Stave Pipe."— The following data are taken from an article in Engineering and Contracting, Feb. 17, 1915, by Andrew Swickard, Hydraulic Engineer.

The total cost of a "continuous stave pipe" is made up of numerous items and is about as follows:

Staves—
- Cost of rough lumber: (Factory price f. o. b. cars)
  - Yarding
  - Handling to mill
  - Milling
  - Interest and insurance
- Transportation:
  - Railway or boat.
  - Wagon or auto truck to convenient points.
  - Distribution along the line.
- Construction:
  - Assembling the staves, including tongues, with only enough bands on to hold them together.

Bands—
- Factory cost of rods:
  - Freight charges.
  - Wagon haul.
  - Distribution along pipe line.
  - Bending to proper form.
  - Painting.
- Factory cost of shoes:
  - Freight.
  - Haul.
  - Distribution
  - Painting.
  - Assembling on pipe, spacing and backclinching.

Tongues—
- Factory cost of band iron:
  - Freight.
  - Hauling.
  - Cutting into proper lengths.
  - Painting and distribution.

The cost of transportation is incidental to the distance and other physical conditions attending any given project. The same applies to the distribution of the material along the pipe line. If the topography is such that wagons can be drawn along in the immediate vicinity of the pipe line, the task is easy but if the line is along the side of a steep canyon and the material must be hoisted from below or let down from above by means of an aerial tramway, or other similar means, the cost becomes comparatively high.

After the staves have been distributed along the line at convenient points, in piles averaging about 300 ft. apart and each pile containing enough staves to fill in the intervening gaps, the material must be sorted and laid ahead of the construction party in piles containing the number of staves necessary to complete the ring of the pipe. This phase of the distribution is a part of the cost

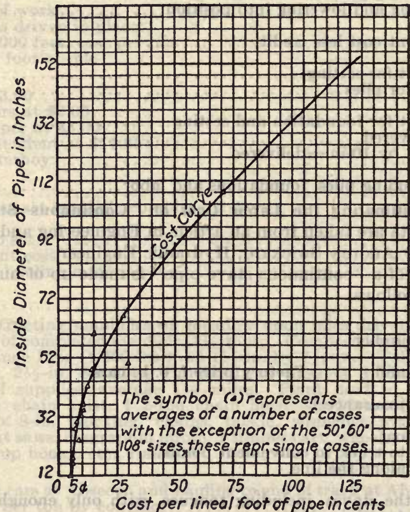


FIG. 29.—Labor cost curve for continuous wooden stave pipe.

Curve gives labor cost of assembling the staves, inserting the metal tongues, putting on 5 or 6 bands per 10 ft., driving the staves end-wise, and sorting and distributing the staves from piles about 100 ft. apart.

of assembling the staves in the pipe. The cost of assembling the staves with only enough bands put on to hold them together varies with local conditions. The cost curve shown in Fig. 29 is an average of actual costs for sizes of pipe below 9 ft. in diameter; above 9 ft. the curve is merely extended. This curve is based on 9 hours labor at $2.50 per day, one foreman at $3 per day, and part of a general foreman's time, say ¼ of $6 or $1.50 per day.

The cost of assembling the staves of a 66-in. pipe as represented in Fig. 29 is 28 cts. In an actual case where the average length of pile set up per day was 64 lin. ft. the detailed cost was as follows:

	Per day
Part of superintendent's time	$ 3.00
Foreman	3.00
Four assistant builders	10.00
One distributor of material	2.50
Water boy	.50
	64)$19.00
	29.7*

*Cts. per foot of pipe.

The crew putting on and placing the bands would follow the assembling gang, and following these would be the back-cinchers. When the spacing of

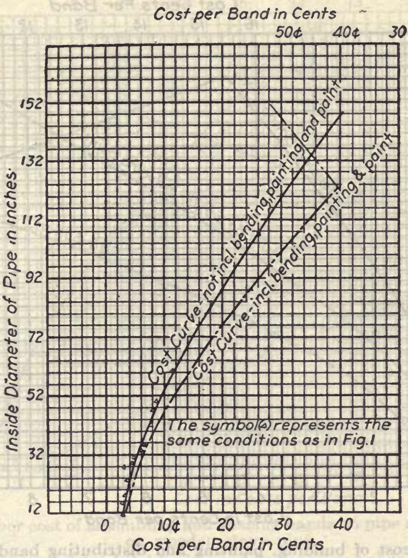


FIG. 30.—Labor cost curves for fitting on bands on continuous wooden stave pipe.

The solid line represents the cost of distributing, putting on, spacing and cinching. The dotted line includes bending, painting and paint in addition to the other items.

the bands averages about 3 ins., two men ordinarily can put on and space the bands as fast as the pipe can be assembled. The size of the pipe and whether the band is in one or two parts will influence the progress made. Because of the same influence the number of the back-cinching crew will vary from 4 to 8 men in order to keep up with the assembling of the pipe. Fig. 30 represents the cost per band in place on the pipe, painted and back-cinched or finally tightened.

A band passes through a number of stages of preparation before it is finally disposed of on the pipe; it must be bent to the proper form, dipped in paint, distributed, assembled and spaced on the pipe, hammered to a proper seating on the wood, and finally cinched. The dotted line in Fig. 30 represents the cost of putting a band through this process, and Figs. 31 and 32 represent the cost of each of the separate steps.

The bending and the painting of the rods is usually done immediately along the pipe line, it being more convenient to deliver the bands straight than bent. Also it is desirable to keep the handling of the bands, after they are painted, at a minimum.

The bending or shaping of the bands requires one man at a bending table. The table is a substantial structure as high as a man's waist, with a raised

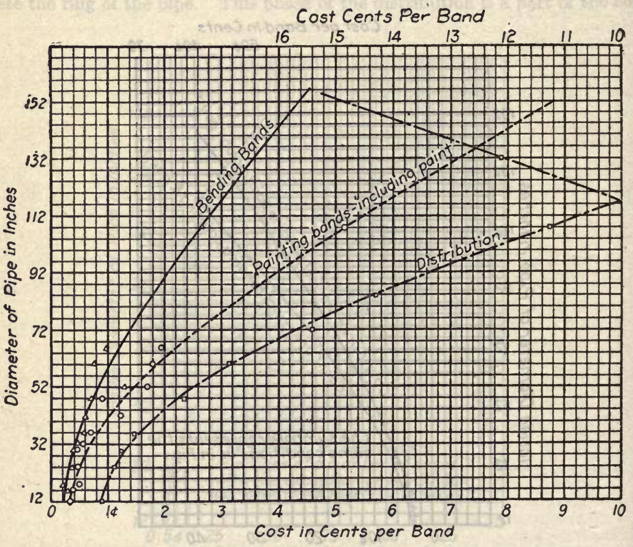


FIG. 31.—Labor cost of building, painting and distributing bands for wooden stave pipe.

Cost of painting includes paint. Distributing cost covers carrying band from dipping tank, located at about 300 ft. intervals along the pipe line. The symbols along the bending and painting curves are average cost, those along the distribution curve are the result of computations from relative information. The painting cost includes that of the rods, shoes and tongues.

circle or half circle on the top, around which the band is bent. A full circle is used when the rod is in one piece and the half circle when the rod is in two pieces.

The quantity and the character of the paint used will affect the cost of the painting; the quality only as far as the price is concerned, but the character will influence the thickness of the coat and waste. The use of a paint that dries rapidly and thickens quickly in the dipping vat, and therefore requires frequent additions of a thinner, will result in considerable waste, especially on the dripping board; the paint that drips from the bands will become too thick to run back into the vat.

The distribution of the bands after being painted should have considerable attention in order to keep the cost at a minimum. They are best placed when left in bundles alongside the line, out of the way of the stave assembling crew but so that the band assemblers have merely to reach for them. The number of bands distributed over, say, every 50 ft. should be determined by the band spacing over the given distance.

The cost of back-cinching, which consists of hammering the bands to a proper bearing on the staves and cinching them down tight, is the most varia-

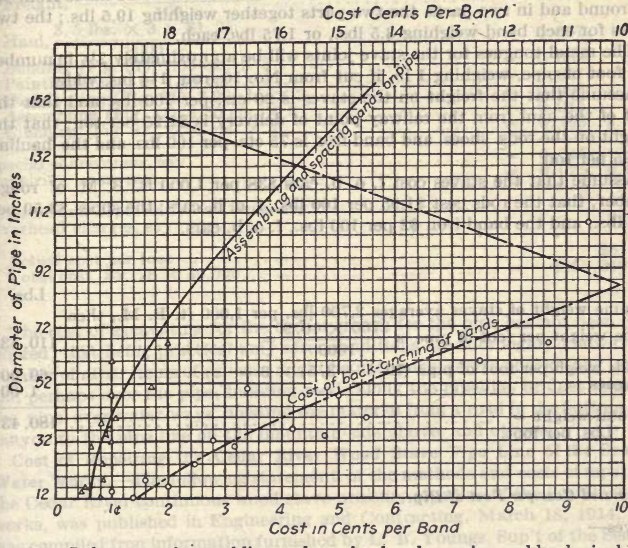


FIG. 32.—Labor cost of assembling and spacing bands on pipe and back-cinching on wooden stave pipe.

Black-cinching consists of tightening and hammering bands to a proper bearing in the wood. The symbols represent average costs; the variation in the cost of back-cinching is much greater than for any other item of cost because all classes of labor are employed on this part of the work.

ble of any item of cost connected with the actual construction of the pipe. It is a thoughtless sort of job and men, good, bad, and indifferent, are usually put at this task; the resulting cost in a way corresponds with the men.

The cost diagrams give average costs for building "continuous stave" pipe. The cost will be affected by: the quantity of pipe to be installed, the character of the season as affected by the locality, the physical character of the country over which the pipe is located, and the kind of labor that is available. A pipe built on a bench cut into a rugged mountain side, where nearly every section of pipe set up will have to be curved, would run up in cost. The assembling of the staves under such condition might exceed the cost given by the curve by 50 per cent. The cost of the items connected with the banding of the pipe would not vary nearly as much as the stave work under such conditions.

Example of Use of Unit Costs.—As an example of the use of the cost of the various items, we will apply them to an assumed case, as follows:

The pipe to be 60 ins. inside diameter; staves 2½ ins. thick, milled from 3 × 6-in. stock, 36 staves to complete the ring, requiring 54 ft. B. M. of rough lumber per foot of pipe, the actual material in the finished staves being 75.7 per cent of that in the rough material or 40.9 ft. B. M.

The total length of the pipe being, say, 30,000 lin. ft., requiring a total of 90,000 bands, or an average of 3 bands per foot; the rods to be made from ⅝-in. round and in two parts, the two parts together weighing 19.5 lbs.; the two shoes for each band weighing 3.5 lbs., or 1.75 lbs. each.

The metal tongues for the stave joints will be approximately 2½ in number per foot of pipe, weighing 1 lb. if cut from No. 10 iron, 1½ ins. wide.

Assume that the freight on the staves is 20 cts. per 100 lbs. and that the cost of the haul from the railway point of delivery is $1.25 per ton; that the freight on the rods, shoes, and band iron is 75 cts. per 100 lbs. and the hauling $1.25 per ton.

Assume that the staves cost f. o. b. cars $38 per 1,000 ft. B. M. of rough lumber; that the rods cost $1.95 per 100 lbs., f. o. b. cars; the shoes $3.50 per 100 lbs., and the band iron $2 per 100 lbs., f. o. b. cars.

	Lbs.
Assume weight of staves averages 2,700 lbs. per 1,000 ft. B. M., then the weight per foot of pipe is $\frac{2700 \times 40.9}{1000}$ =	110.43
Bands weigh per foot of pipe (19.5 + 3.5) × 3 =	69.00
Tongues	1.00
Total weight =	180.43*

*Lbs. per foot.

Estimated Cost per Foot of Pipe.

Staves—		
Material, $\frac{\$38.00 \times 54}{1000}$ =	$2.052	
Waste, ½ of 1% =	0.010	
Freight, $\frac{2700 \times 40.9 \times \$0.20}{1000 \times 100}$ =	0.221	
Hauling, $\frac{2700 \times 40.9 \times \$1.25}{1000 \times 2000}$ =	0.069	
Assembling (from Fig. 29) =	0.230	$2.582
Tongues—		
Material, 1 lb. × $0.02 =	0.020	
Waste, 1½% =	0.003	
Freight, $\frac{1 \text{ lb.} \times \$0.75}{100}$ =	0.008	
Haul, $\frac{1 \text{ lb.} \times \$1.25}{2000}$ =	0.001	
Cutting into clips =	0.002	0.034

Bands—		
Rods, $\frac{19.5 \text{ lbs.} \times 3 \times \$1.95}{100}$ =	1.141	
Waste, ½ of 1% =	0.006	
Freight, $\frac{19.5 \text{ lbs.} \times 3 \times \$0.75}{100}$ =	0.439	
Haul, $\frac{19.5 \text{ lbs.} \times 3 \times \$1.25}{2000}$ =	0.037	
Shoes, $\frac{3.5 \text{ lbs.} \times 3 \times \$3.50}{100}$ =	0.315	
Waste, 1% =	0.003	
Freight, $\frac{3.5 \text{ lbs.} \times 3 \times \$0.75}{100}$ =	0.079	
Haul, $\frac{3.5 \text{ lbs.} \times 3 \times \$1.25}{2000}$ =	0.007	
Bending (Fig. 31), 1.05 cts. × 3 =	0.032	
Painting (Fig. 31), 1.90 cts. × 3 =	0.057	
Distributing (Fig. 31), 3.20 cts. × 3 =	0.096	
Assembling (Fig. 32), 1.50 cts. × 3 =	0.045	
Cinching (Fig. 32), 6.50 cts. × 3 =	0.195	2.452
Special connections, say =	0.045	
Repairing leaks, say =	0.025	0.070
Interest and depreciation on tools, say		0.015
Overhead charges, say		0.025
Actual cost per foot		$5.178
Total cost, $5.178 × 30,000 =		$155,340.00

The cost of excavating for the bed or trench for the pipe has not been considered; that being practical only after conditions are thoroughly known. A number of other items of expense might be necessary, such as backfilling under and perhaps over the pipe, building roads along the pipeline, bridges to carry the pipe over water-ways, hoisting the material from a road in the bottom of a canyon to the pipe line on the mountain-side above, and others.

Cost of Repairing the Cedar River Wood Stave Pipe Line of the Seattle Water Works.—The following statement, of the methods and costs of repairing the Cedar River continuous wood stave pressure pipe line of the Seattle water works, was published in Engineering and Contracting, March 18, 1914, and was compiled fron information furnished by L. B. Youngs, Sup't of the Seattle Water Department.

Cedar River Water Supply Pipe Line No. 1 was put in commission in Jan., 1901. The pipe is mainly 42 ins. inside diameter, though some parts are 44 ins. It is built of 6-in. staves made from the native Douglas firs. These staves are cut from 2-in. × 6-in. scantling dressed outside and inside to true circumferential, and on the edges to radial lines.

After 13 years the steel bands do not seem to be seriously corroded. The staves, however, or more accurately speaking, individual staves here and there, began to show evidence of serious decay as early as seven years after installation. Other staves right alongside of them have remained practically sound. It has been necessary, therefore, to renew certain staves, rather than to renew the pipe as a whole. At some places, where the pressure is light and where the covering is of loose gravel which readily admits the air and changes of temperature, sections from a few hundred to a few thousand feet have been fully replaced, after a use of 12 years, with new pipe, using, of course, the old steel bands.

The method of repair is simple. It consists of uncovering the pipe, loosening the bands, taking out the decayed stave, inserting the new stave in its place, and cinching the pipe up again.

After the staves have been planed to form in the mill they are 1⅝ ins. thick. These staves will hold water very often until in some places they are decayed until there is only a shell ¼ in. thick. Of course this is where the pressure is comparatively light, and the backfilling compact. Sapwood naturally decays rapidly and the department specifies that not more than one-fourth of the thickness of the stave, and then only on the inside, shall be sap.

Following is a detailed statement of the actual cost of replacing 1,600 lin. ft. of 44-in. pipe in 1913. Common labor was $2.75 per day.

The work was done by day labor under departmental direction.

TABLE XXXIII.—COST OF REBUILDING 1,600 FT. OF 44-IN. WOOD STAVE PIPE AT SEATTLE, WASH., IN 1913

Item	Amt.	Cost	Cost per lin. ft.
Cost of Labor:			
Excavation—			
130 days labor	$ 357.50	....	....
28¼ days team	141.25	$ 498.75	$0.31
Wrecking pipe—			
30 days labor	82.50	82.50	0.05
Painting staves—			
17 days labor	46.75	46.75	0.03
Erecting pipe—			
72 days labor	198.00	198.00	0.12
Cinching pipe—			
58 days labor	159.50	159.50	0.10
Tamping pipe—			
78 days labor	214.50	....	.....
26 days team	130.00	344.50	0.22
Total cost of labor, 1,600 ft. pipe	$1,330.00		
Total cost of labor, 1 ft. pipe	$0.83		

Cost of Material:

Item	Amt.	Cost	Cost per lin. ft.
42,551 ft. stave lumber at $31.25 per M	$1,329.72	$1,329.72	$0.83
Hauling staves—			
6 days labor	16.50	....	.....
13¾ days team	68.75	85.25	0.05
155 gals. C. A. wood preserver at 65 cts.	100.75	100.75	0.06
Total cost of material, 1,600 ft. pipe (exclusive of iron bands and shoes)	$1,515.72		
Total cost of material perlin. ft. of pipe			$0.95
Total cost of labor per line ft. of pipe			.83
Total cost of pipe rebuilding per lin. ft.			$1.78

The painting mentioned under labor is an experiment. The department officials cannot say just what its effect will be.

Life of Service Pipes.—The following data, from the Preliminary Report of Committee on Service Pipes submitted at the Portland, Me. Convention of the New England Water Works Association, are given in Engineering and Contracting, Dec. 11, 1916. The figures given are the averages of replies received from a large number of questionnaires sent out by the committee.

	Years before trouble begins	Life of pipe (years)
Plain iron or steel	12	16
Galvanized	15	20
Lead	10	35
Lead lined	10	23
Cement lined	14	28

Methods and Costs of Thawing Water Mains and Services.—Data on the 1917–18 experiences of 96 cities with frozen water mains and services are included in the report of a special committee of the New England Water Works Association. The methods employed by these cities in thawing are summarized by Engineering and Contracting, Jan. 18, 1919, in the following table:

	Mains, No. cities	Services, No. cities
Electricity	36	31
Steam	8	8
Hot water	4	11
Electricity, hot water	5	24
Electricity, steam	5	6
Electricity, hot water, steam	2	10

One city reported that the blow torch was employed in thawing services; another city employed fire.

The cost of thawing with electricity per job varied from $20 to $1. A summary of the costs is as follows:

No. cities	Reported cost	No. cities	Reported cost
3	$20	10	$10
1	18	3	$8 to $10
3	$15 to $16	21	$5 to $8
3	12	6	$3 to $5
2	11	5	Less than $3

The cost of thawing with steam ranged from $4.50 to $75, the later figure being reported by Stamford, Conn. One city reported a cost of $5, one a cost of $17.70, one $20, one $9.41, one $7.63, one $4.50, one $7.50, one $6.50, one $16.50, and one $14.

The reported cost of thawing with hot water ranged from $2 to $20. Four cities reported the cost as being $2. One a cost of $2.67; three a cost of $3; five a cost of $4 to $5; three a cost of $5 to $6; one a cost of $11.20; one $14, one $17 and one $20. One city reported the cost as being 5 cts. per foot of pipe thawed.

Three cities reported on the cost of thawing by fire. In one case the cost was $11.16, in another $10.96 and in the third $10 to $30.

Cost of Water Main Cleaning in Kansas City, Mo.—The following data are taken from an article by Charles S. Foreman in Engineering News-Record, June 16, 1921.

Mr. Foreman believes that the following essential facts based upon his experiences will help to answer some of the questions which are usually asked:

(1) Cleaning can be so arranged that a main need not be out of service longer than twelve hours for cleaning. (2) The cleaning process is not injurious to the mains. (3) An increase in carrying capacity of from 60 to 85 per cent was obtained in large mains and the carrying capacity of such mains was restored to that of new pipe. (4) The saving in coal costs alone, derived from

cleaning, will pay the entire cost of cleaning within from one to three years. (5) Laying of additional mains to obtain increased capacity can be postponed until the consumption demands are equal to the maximum capacity of the old main on the basis of new pipe. (6) When taking as credits such items as coal saving and postponement of obligatory laying of new mains the entire cost of cleaning is saved within from six months to a year.

The contractor's price for cleaning ranged from 26c. per foot for 16-in. pipe to 45c. per foot for 36-in. pipe and the total cost, including all expenses for operating valves, cutting and repairing pipe and for all necessary sleeves and material was $22,046 for 43,837 lin. ft. of pipe cleaned, or 50.3c. per lineal foot for all sizes. The total cost of cleaning the various sizes including pavement repairs and operation of valves, etc., was as follows:

Length, ft.	Size, in.	Total cost	Cost per lineal foot, cents
7,202	16	$2,472.52	34.3
7,280	20	$3,056.80	41.9
3,371	24	$1,813.56	53.5
8,984	30	$5,604.93	62.3
17,000	36	$9,098.28	53.5

The table on the following page shows the length of time in service, the annual operating cost for coal before and after cleaning of the various sizes cleaned, the investment required and the annual interest thereon to obtain the increased capacity by laying new mains, and the total annual saving all being based on 5,000 ft. of each size and on the normal flow through the pipe at time tests were made.

Cost of Cleaning Water Mains of Louisville, Ky.—The following notes are taken from an article by F. Osborne Redford published in Engineering and Contracting, Sept. 6, 1911.

Cost of Cleaning Four-inch Mains in Louisville.—The cost of cleaning 4-in mains for the Louisville Water Company is given below. These costs are fo the work done from June 2 to June 12 inclusive, 1909. These dates are selected because at that time the most troublesome section of the city mains where being cleaned. During these eleven days 7,937 ft. of 4-in. mains were cleaned at a contract price for all labor and material of 7 cts. per ft. The total cost to the city was, therefore, $555.59.

Actual Cost.—The actual cost of labor and material used in this job was as follows:

42 4-in. sleeves	$ 55.88
63 ft. 4-in. pipe	18.26
Yarn	0.60
Lead	12.00
Cement	8.00
Sand	0.65
Labor	162.99
Teams	32.00
Overhead charges	44.69
Total actual cost	$335.07
Actual cost per ft., 4¼ cts.	

It should be noted that the mud and incrustation encountered on this section of 4-in. pipe nearly closed the main. The deposit in this section of the city was mostly a yellow mud from the Ohio, with just a very thin scale of incrustation at the bottom of the main. The capacity of this main was increased 550 per cent by cleaning.

Service years	41	42	28	33	33
Size, inches	16	20	24	30	36
M. G. D. normal flow	2.4	3.4	5.0	12.0	16.0
Loss of head per 5,000 ft.:					
Uncleaned	24.00	23.50	12.60	23.50	15.25
Cleaned	7.50	5.60	5.25	9.00	6.00
Annual coal cost to operate line:					
Uncleaned	$462.53	$641.60	$505.90	$2,264.46	$3,740.52
Cleaned	$144.53	$152.89	$210.79	$867.24	$1,471.68
Annual coal saving	$318.00	$488.71	$295.11	$1,397.22	$2,268.84
Size required to obtain increase in capacity if not cleaned, inches	12	16	16	24	30
Estimated cost	5,000 ft.	$27,200	$33,100	$70,000	$73,500*
Interest on expenditure 5 per cent	$1,360	$1,655	$1,655	$3,500	$3,675
Total annual saving	$1,778.00	$2,143.71	$1,950.11	$4,897.22	$9,618.84
Total cost of cleaning	$1,715	$2,095	$2,675	$3,115	$2,675

Annual cost for fuel to pump one million gallons 1 foot high at Quindaro = $0.042.
Annual cost for fuel to pump one million gallons 1 foot high at Turkey Creek = $0.022.
*No pavement or rock. Surface supply Missouri River water.

Cost of Cleaning Six-inch Water Mains in Louisville.—The contract price for cleaning the 6-in. main on 9,183 ft. of main, for labor and material, was 8 cts. per foot. The total contract price was $734.64.

Actual Cost.—The actual cost for labor and material was as follows:

33 6-in. sleeves	$ 55.77
9 ft. of 6-in. pipe	3.30
Lead	11.72
Yarn	0.39
Cement	4.60
Sand	0.60
Labor	131.69
Teaming	24.00
Overhead charges	28.00
Total actual cost	$260.07
Actual cost per ft., 2.83 cts.	

The writer also cleaned water mains in Middletown, Pa., for the Middletown Sawtara Consolidated Water Co., and found the cost of the work there about the same as in Louisville.

Cleaning Large Mains.—The machine used for cleaning larger size pipe such as 8-in. and over is of similar design, with a double plunger in the rear so as to propel the machine with water power, thereby doing away with the cable used with the smaller type of machine.

The writer knew of one case in the East where about five miles of 20-in. main was cleaned at a contract price of 60 cts. per ft. This price was exhorbitant. As a matter of fact the entire five miles of pipe were cleaned in about two weeks at a total cost not exceeding $1,500. It has been the writer's observation that such exorbitant prices have kept many water companies from cleaning their mains by contract. It is the judgment of the writer that water companies would save a great deal of money by cleaning their own mains.

Prices per Linear Foot for Cleaning Water Pipe.—The following data are taken from an abstract, of a paper by Caleb M. Saville, Chief Engineer of the Board of Water Commissioners of Hartford, Conn. before the New England Water Works Association, published in Engineering and Contracting, Feb. 18, 1914.

The city of Hartford, Conn. is supplied with water by gravity, there being three mains connecting Reservoir No. 1 with the city as follows: two 20-in. mains and one 30-in. main. The south 20-in. main originally laid in 1867 had been largely relaid. The north 20-in. main was laid in 1875 and was therefore 37 years old when cleaned. The 30-in. main was laid in 1896 and was 16 years old when cleaned.

The supply of water was inadequate through these pipes and there was considered the advisability of constructing a new connecting main or of cleaning the existing mains.

If a new supply pipe was laid it would be at least 36 ins. in diameter and about 33,000 ft. long. At a minimum price of $8.25 per linear foot, this line would cost about $270,000, the interests on which at 5 per cent simple interest would be $13,500 per year, and at compound interest the charge would be $74,500 in five years.

The preliminary estimate for cleaning three miles of 30-in. and six miles of 20-in. pipe was $15,300, a little more than the interest for one year on the amount necessary to lay a new 36-in. main. If, therefore, the construction of the 36-in. main could be put off for five years without detriment to the service, the saving to the city was estimated to be about $60,000.

The list prices quoted by the National Water Main Cleaning Co., of New York, for doing work in the distribution system were:

LIST PRICES PER LINEAR FOOT OF WATER PIPE FOR MECHANICAL CLEANING

Diam. of pipe	Cost per ft., cts.
6-in	16
8-in	17
10-in	18
12-in	22
16-in	26
20-in	30
24-in	40
30-in	65
36-in	80

These list prices were stated to be for average conditions for lengths of five miles or more only for purposes of preliminary estimate, and were submitted with the reservation that local conditions might cause considerable variation either way. In Hartford a price of 28 cts. per linear foot for 20-in. pipe was given for a 3-mile contract, with a further reduction if a greater length was cleaned. The conditions were exceedingly favorable for a large part of the way on account of few consumers on the line, advantageous location of gate valves and blow-offs for cutting out sections of proper length and also because of a parallel main with cross-connections which gave ample water for operating the machine without interference with the city supply.

A contract was entered into Sept. 4, 1912, with the National Water Main Cleaning Co. to clean, on trial, 3 miles of 20-in. pipe, and if satisfactory results were obtained the cleaning process might be continued through several miles additional of 20-in. and three miles of 30-in. pipe.

Work was begun Sept. 6 and suspended on Oct. 24 on account of scarcity of water in the reservoirs. The results were very satisfactory and during this period, 49 days, a total of 33,093 lin. ft. was cleaned. On this section there were 154 service pipes which were shut off during cleaning and only four were at all interfered with by the cleaning operations. Three of these were extension meters located at the street line with no curb cocks, and it was necessary to remove the meter and clean out the dirt. The other service affected was plugged, but was easily relieved by a force pump.

The usual force employed on this work was a superintendent, a foreman, a calker, 14 laborers and a double team for carting pipe, materials and supplies.

Under average conditions 3,000 lin. ft. was found to be the maximum effective length for cleaning. The contractor stated that 5,000 ft. had been successfully cleaned by him elsewhere, although in some places it had been possible to go only 1,500 ft. at a time, using water to drive the machine. If the machine is drawn through by a cable, the length of section is from 500 to 1,200 ft. It is stated that the machine can be operated by water under heads of as low as 10 or 12 lbs. The least available head on the Hartford lines was somewhat greater than this.

Relative Merits and Costs of Dug and Driven Wells.—The following data, given in Engineering and Contracting, July 14, 1915, are taken from a paper before the Boston Society of Civil Engineers by William S. Johnson, Consulting Engineer and published in the Journal of the Society for May, 1915.

As to the relative merits of driven wells, dug wells or filter galleries, there is no question but that dug well is the most satisfactory, provided the conditions are favorable and if the expense is not too large. Where water is obtained from some neighboring water source and the depth of porous material is small, a filter gallery parallel to the shore of the surface source may be desirable. Where the water-bearing soil is at some considerable depth it is almost invariably much cheaper to obtain water by means of tubular wells.

Table XXXIV.—Cost of Dug Wells

Place	Year built	Depth in ft.	Diameter in ft.	Cost
Bedford	1909	21.0	20.0	$ 3,981
Avon	1895	22.0	20.0	3,317
Canton	1889	29.0	40.0	8,555
Cohasset	1909	33.67	25.0	3,500
Greenfield	1913	31.0	40.0	7,850
Henniker, N. H.	1914	25.15	20.0	2,141
Manchester	1892	29.0	32.0	10,476
Marblehead	1912	31.0	25.0	6,100
Middleborough	....	22.0	26.0	4,964
Waltham	....	18.0	40.5	8,940
West Warren	1913	18.0	20.0	3,800
Winchendon	1911	35.0	40.0	7,815

Between these two extremes the best method to adopt must be determined by local considerations. One of the advantages of the dug well is that there is a large body of water in store from which to draw while the pumps are being run, and when this is exhausted the well has the time until the pumps are next operated to recover. This means that pumps of larger capacity can be used than with the driven well plant. Furthermore, under these conditions the average suction is likely to be less, as in the case of driven wells the ground water level at the wells goes down quickly when the pumps are started.

Perhaps the chief advantage, however, of the large well is the avoidance of troubles from sand and air which are likely to occur in any driven well plant.

Construction of Wells.—The construction of tubular wells and the method of making connections with the suction pipe are of the greatest importance, as the leakage of a small quantity of air will cause endless trouble; and it is also desirable that it should be possible to cut out any particular well from the system.

Table XXXV.—Cost of Tubular Wells

Place	No. and size	Depth, in ft.	Cost of wells	Cost per well	Cost, including suction to pump-station
Ashland	12–2½ in.	25–32	$1,267	$105.00	$1,460
East Brookfield	9–2½ in.	20.7 av.	604	67.20	......
East Douglas	9–2½ in.	....	......	....	629
Duxbury	22–2½ in.	27.8 av.	......	....	3,324
Littleton	10–2½ in.	22 av.	......	....	2,000
Merrimac	18–2½ in.	35 av.	......	....	3,100
North Chelmsford	20–2½ in.	30 av.	2,800	140.00	......
Oxford	15–2½ in.	24–28	......	....	800
Pepperell	34–2½ in.	19–28	2,704	79.50	3,200
Plainville	11–2½ in.	25–50	4,500	....	......
Uxbridge	16–2½ in.	26–35	1,800	112.50	......
Wrentham	9–2½ in.	29 av.	1,048	116.50	......
State School	6–2½ in.	....	680	113.20	......
Fairhaven	30–2½ in.	22½ av.	2,040	68.00	5,645
Wareham	12–2½ in.	39 av.	1,160	97.00	......

The usual size of driven wells in New England is 2½ ins. The adoption of this size is simply the result of experience, as it is found that this is about as large a pipe as can well be driven under ordinary conditions, and it is, of course desirable to have the pipe as large as is feasible. For the well, an extra heavy wrought-iron pipe should be used, as in the process of driving the pipe receives very hard treatment and it requires a heavy pipe to stand the strain. The pipes are driven with open ends except in the case of very fine sand, when strainers have to be resorted to. The bottom length of pipe is perforated with a large number of small holes about ¼ in. in diameter for a distance of perhaps 2 ft. from the end of the pipe.

The two methods of driving the pipes most commonly in vogue are the use of a tripod carrying a pulley block over which the rope carrying the driving weight passes to men standing on the ground, and the use of a platform, clamped to the well casing above the ground, upon which the men stand and lift the driving weight by hand. The use of the tripod is the simpler, but the platform has the advantage of carrying the weight of the men upon the pipe, which assists materially in sending the pipe down with each blow. It would seem that the raising weight by a rope would be much easier for the men than to stoop and lift the weight as is necessary with the platform. Men, however, incline toward the platform method.

After the pipe is driven and washed out, it is cut off at the level at which the suction is to be placed. A long-turn T is put on and then the pipe is continued up to somewhat above the surface of the ground, the object of the extension to the surface being to provide access to the well for cleaning out, as sand is likely to work into the pipe. The well is then connected to the suction with 2½-in. pipe and a lead gooseneck, each connection being provided with a gate so that it can be shut off in case it gives trouble. The object of the piece of lead is to give flexibility to the connection and prevent danger of leakage.

Cost of Water Supply Wells in Iowa.—The following table is arranged from data published in Engineering and Contracting, Jan. 27, 1915 given by Prof. John H. Dunlap in University Extension Bulletin No. 8 of the State University of Iowa.

TABLE XXXVI.—COST OF WATER SUPPLY WELLS IN IOWA

Place	Date of constr.	No. of wells	Depth, ft.	Diameter ins. Top	Diameter ins. Bottom	Total ft. cased	Water* stratum	Total cost with casing	Cost per foot
				Dug wells					
Clarinda......	1905	1	65	10 ft.–cement curb			Gvl.	$5,000	$77.00
Red Oak...........		1	59	18 ft.–conc. block curb			Gvl.	5,500	93.20
Ida Grove....	1914	1	30	225 ft.–brick curb			Gvl.	2,200	73.50
				Shallow wells					
Le Mars..............		1	60–65	36	36	60–65	Gvl.	500	8.00
Boone........	1911	28	30–45	12	12	30–45	R. S.	33,823	32.25
Shenandoah....	1892	6	46–48	6	6	46–48	Gvl.	1,200	4.25
Marshalltown.	1900–14	51	37.5	6	6	37.5	Gvl.	5,610	2.93
Muscatine....	1902	14	48–50	6	6	48–50	Gvl.	1,400	2.04
				Deep wells					
Waterloo.....	1910–11	1	1,365	20	12	860	Ss.	$10,855	$ 7.95
Mason City[1]...	1913	1	1,200	20	12	280	Ss.	5,975	4.98
Waterloo.....	1905–7	1	1,377	16	8	776	Ss.	8,054	5.85
Mason City...	1912	1	1,217	16	10	160	Ss.	6,295	5.17
Waterloo.....	1904–5	1	1,373	16	8	862	Ss.	5,956	4.35
Fort Dodge...	1907	1	1,828	15	5	.....	....	8,000	4.37
Algona[2]......	1914	1	998	12	10	374	Ss.	5,100	5.10
Rockwell City	1912	1	1,543	12	6	1,470	Ss.	7,340	4.75
Charles City...	1914	1	250	12	10	75	Ls.	1,000	4.00
Waverly......	1899	1	1,720	12	8	100	Ss.	3,300	1.92
Cherokee.....	1913	1	200	10	..	.....	Ss.	1,920	9.60
Rockwell City	1904	1	950	10	6	500	Ls.	4,750	5.00
Cedar Falls[3]..	1912	3	125	10	8	120	Ls.	1,800	4.80
Glenwood.....	1891	1	2,000	10	4	1,773	....	7,265	3.64
Charles City..	1905	1	1,589	10	8	851	Ss.	5,346	3.36
Mason City...	1911	1	865	10	8	175	Ss.	2,712	3.13
Fort Dodge ..	1913	1	200	8	..	...	....	1,500	7.50
Cherokee.....	1913	1	209	8	..	117	Ss.	700	3.35
Charles City..	1914	1	250	6	6	75	Ls.	426	1.70
Waterloo.....	1913–14	1	1,377	..	..	.....	Ss.	8,356	6.07

Note—

1. Drilled 24 ins. in diameter and filled with concrete outside 20-in. casing to cut off surface water.
2. The 10-in. casing is 374 ft. long, and extends to the surface inside the 12-in., which is 304-ft. long.
3. Double cased with 70 ft. of 12-in. casing and then 120 ft. of 10-in. inside.

*Gvl. = Gravel, R. S. = River Sand, Ss. = Sandstone, Ls. = Limestone.

CHAPTER VIII

WATER-TREATMENT PLANTS

The subject of water purification and treatment is a growing one and its importance becomes greater with increasing population and the consequent danger of contamination of public water supply. In this chapter are included not only, general data on the cost of constructing and operating water-treatment plants but also detailed costs of specific operations.

Further cost data on this subject will be found in Gillettes' "Handbook of Cost Data." For costs of pumps and pumping the reader is referred to Gillette and Dana's "Handbook of Mechanical and Electrical Cost Data."

Hypochlorite and Liquid-chlorine Costs.—The following data published in Engineering News-Record, May 3, 1917, are taken from a paper by Philip Burgess, before the Indiana Sanitary and Water-Supply Association in Feb. 1917.

Hypochlorite and liquid chlorine at Indiana water-treatment plants in 1916 averaged 8.5 lb. of hypochlorite and 1.8 lb. of liquid chlorine per 1,000,000 gal. of water treated. The average costs were 5.3 and 16c. per lb. respectively. Thus liquid chlorine cost only 60% as much for material as hypochlorite.

Cost of Liquid Chlorine Treatment of Water.—Engineering and Contracting, April 10, 1918, publishes the following cost data on the operation of liquid chlorine plants given in a recent technical paper of the New York State Department of Health prepared by C. M. Baker, assistant engineer, Division of Sanitary Engineering. The figures show the approximate cost of apparatus, maintenance and operation of the plants at Hudson Falls, N. Y., and Westfield, N. Y. The costs of chlorine treatment at these two plants was as follows:

HUDSON FALLS

Apparatus—		
Chlorinator	$400.00	
Apparatus for testing B. coli	25.00	
Incubator	10.00	
Total	$435.00	
Yearly cost, interest at 5 per cent		$ 21.75
Operation—		
Chlorine, 100 lb. at 9½ ct	$ 9.50	
Freight	1.05	
Trucking	.50	
Total	$ 11.05	
Yearly cost based on treating 600,000 gal. per day with .3 parts per million of chlorine		60.44
Maintenance per year		15.00
Total yearly cost		$ 97.19
Cost per 1,000,000 gal. water treated		0.44

WESTFIELD

Plant—		
Apparatus	$450.00	
Building	125.00	
Stove	10.00	
Total	$585.00	
Yearly cost, interest at 5 per cent		$ 29.25
Operation—		
Chlorine, 100 lb., at 17½ ct.	$ 17.50	
Freight	.65	
Cartage	1.25	
Total cost of chlorine per 100 lb	$ 19.40	
Yearly cost of chlorine based on treating 1,000,000 gal. per day with .3 parts per million of chlorine		177.00
Attendant per year		100.00
Oil for heater		20.00
Maintenance per year, estimated		20.00
Total yearly cost		$346.25
Cost per 1,000,000 gal. water treated		0.95

At Hudson Falls the plant is located in the pumping station and is attended by the engineer, thus eliminating the cost of the building, heating and attendance, while at Westfield the plant is 2 miles in the country and a new separate building had to be constructed to house the apparatus. The other item of difference in cost is chlorine. With the cost of chlorine the same at Hudson Falls as at Westfield, viz., 17½ ct. per pound, the total cost per 1,000,000 gal. of water treated would be $0.64 instead of $0.44.

Cost of Electrolytic Chlorine.—The following matter is taken from an abstract published in Engineering News—Record, May 24, 1917, of a paper before the American Water Works Association by F. H. Pitcher and James O. Meadows, respectively chief engineer and filter superintendent of the Montreal Water and Power Co.

The electrolytic-cell installation has been in service since only the first part of 1917, but during that time many interesting data have been secured.

The chlorine-cell installation includes a salt-storage bin having a capacity of 40 tons of salt, the brine saturating and purifying equipment, two 15-hp. motor generator sets, four chlorine cells, and the silver ejectors and distributing lines for applying the chlorine water to the water to be treated.

The brine saturating and purifying equipment consists of three vertical galvanized-iron saturators, 27 in. in diameter by 6½ ft. in height, provided with a spray system at the bottom and an outlet 6 in. from the top and two concrete reaction tanks having a capacity of 82 cu. ft. each. These tanks are built with sloping bottoms and have a pipe grid for air agitation. Two sand filters are provided for filtering the purified brine, which passes from the filters to the two concrete storage tanks, having a capacity of 276 cu. ft. each.

The distributing lines for applying the chlorine water to the water to be treated are 1-in. chemical hose lines. The chlorine gas is ejected into the water by means of a silver ejector, which maintains a 4-in. vacuum on the chlorine cells and takes the gas from the chlorine main through the ejector to distributing lines.

The electrolytic cell is of the Allen-Moore type. It is a standard 600-amp. cell and is 7 ft. long by 20⅜ in. wide. Each cell is provided with Acheson graphite anode plates and pure wrought-iron perforated cathode plates. The Allen-Moore cell is of the unsubmerged diaphragm type and uses asbestos paper for the diaphragm material. Unlike several other types of electrolytic chloroine, cells the cell box of the Allen-Moore cell is made of concrete, properly protected at the surface to withstand the chemicals.

The cells are connected in series and are provided with short-circuit switches or cutouts. The voltage carried on each cell is approximately 3.3 volts, and each cell is capable of producing 32 lb. of chlorine per 24 hours.

Cost of Chlorine Production

The annual cost of production is estimated as follows:

Salt at $8 per ton	$ 500
Power at $30 per horsepower	450
Interest at 6% on $5,000	300
Depreciation at 15%	750
Labor and superintendence	500
	$2,500

Three chlorine cells furnish the requisite amount of chlorine for sterilization. yielding 90 lb. of chlorine gas per 24 hours, or 32,850 lb. per year, making the cost of chlorine produced 7.6c. per pound.

Comparison with Present Hypochlorite Cost

The annual cost of sterilization previous to the installation of the chlorine cells was as follows:

Chloride of lime at 3.75c. per lb	$4,105
Interest at 6%	150
Depreciation at 5%	125
Labor and superintendence	500
Total	$4,880

As the amount of chloride of lime required was 300 lb. per day, or 100 lb. of available chlorine, the cost per pound was 13.4c. or 5.8c. per lb. more than chlorine produced by the electrolytic cells.

With normal market conditions the annual cost of the two forms of treatment would be approximately the same, if one did not consider the general depreciation that chloride of lime causes about a water-purification plant.

The three cells required to supply the chlorine consumed for sterilization are operated with a current load of 500 amp. and 13 volts. The electrolytic cells require very little attention and up to date have given excellent satisfaction.

Advantages of Metal and Rubber Tubing for Conveying Alum and Hypochlorite Solutions.—Charles W. Saxe, Chemist in Charge of the Newport, R. I. Water Filtration Plant, gives the following notes in Engineering and Contracting, March 19, 1913.

The conveying of "Alum" solution to the point of application in mechanical filter plants is attended with trouble from the pipes rapidly clogging up and thus hindering the flow.

At the Newport, Rhode Island, water works prior to August, 1912, the solution was fed through a 1¼-in. lead pipe by gravity a distance of 120 ft. It was very difficult to clean out the deposit and also to make the lead flange joints tight again. Inch and a quarter 2-ply chemical rubber hose was substituted in August and so far, 6 months, has needed no cleaning. When this is desired the two lengths are taken apart and are laid out on a flat surface. The hose is lightly rolled with a short piece of board and is then flushed out. The 3,000 grain per gallon "Alum" solution appears to have no effect on the rubber.

Hypochlorite of lime of ½ per cent strength is best carried in galvanized iron pipe. A thin crust forms inside at first but it does not increase rapidly. The 2 per cent "Soda" solution is being carried in galvanized iron pipe also.

Operating Costs of Ultra-Violet Sterilization Plants.—The following statement as to the operating costs of ultra-violet ray water sterilization plants is quoted, by Engineering and Contracting, Nov. 25, 1914, from a paper before the American Water Works Association by Dr. Max von Recklinghausen of New York City:

Operating costs will vary with the size and the running hours of the plant, and the coefficient of safety for the ultra-violet ray treatment. According to the quality of the water I expect in large plants which run 24 hours that the current consumption will vary between 30 and 125 kw. hours per 1,000,000 gals., allowing for a large safety coefficient. The labor charges are negligible as the apparatus only needs an occasional cleaning and starting of lamps. Apart from this the lamps have to be repumped and repaired from time to time. When the water is of variable physical quality, one will have so to establish the plant that all the lamps will be running during the period of least transparent water and only some of them during the period of best transparency.

Copper Sulphate Treatment for Algae.—The following matter is given in Whipple's "The Microscopy of Drinking Water" (1914).

In 1904 Dr. George T. Moore and Karl F. Kellerman, of the Bureau of Plant Industry, U. S. Department of Agriculture published a report stating the results of successful experiments made by them in the eradication of algæ and other microscopic organisms from reservoirs by the use of copper sulphate. This report immediately attracted wide attention and the method was tried in many places. Nearly ten years' experience has shown its advantageous use in many situations and has likewise developed some of its shortcomings.

Copper sulphate had been used as a fungicide long before Moore proved its worth for destroying algæ. Many experiments had been made by Miquel, Devaux, and many others, which showed that very minute doses of poisonous substances were able to destroy the unicellular microscopic organisms, but Moore deserves full credit for the use of copper sulphate in water-supplies. The first practical test on a working scale was made by him at the water-cress beds in Ben, Va., in 1901, where a troublesome growth of Spirogyra was eliminated.

Effect of Copper on the Human System.—The first question that was naturally raised when the copper treatment was mentioned was its possible effect on the human system. Moore had collected extensive data to show the extent to which copper salts were used in medicine and the wide distribution of copper in nature, its presence in vegetables and even in natural waters themselves. Clark showed that some natural waters in Massachusetts contained small amounts of copper. Experience with the use of copper in many water-supplies has fully demonstrated the innocuous character of this treatment if properly carried out. It is not a matter, however, that should be left to the ordinary laborer. It needs intelligent and continual supervision.

Method of Applying Copper Sulphate.—The method of application is extremely simple. Ordinary commercial crystals of blue-vitriol are used. The required quantity of these crystals is placed in a coarse, bag, gunny-sack, perforated bucket, or wire basket, attached to a rope and drawn back and forth in the water at the stern of a rowboat. Or an outrigger may be arranged so as to drag two or more bags at the same time. thus cutting a wider swath. By rowing slowly along about 100 lbs. can be thus dissolved in an hour. By using several boats quite a large reservoir can be covered in a working day. For a very large reservoir a motor launch may be used. In making the trips the parallel paths of the boats should be about 20 ft. apart. Care must be taken not to row too slowly, as too great a concentration may be obtained near the bags, and if fish should swim into this overdosed water they might be poisoned.

It is generally preferable to carry out the treatment on a day when the wind is blowing, so that the circulation of the water may more readily distribute the chemical. Advantage may be taken also of vertical convection currents. If the algæ to be killed are near the surface the application should be made early in the day when the surface-water is warming and tending to become stratified; but if the algæ are well scattered through the water it is better to make the application toward night. It will often be found best to row against the wind. It has been found difficult to treat a frozen reservoir with copper sulphate, as the chemical does not diffuse readily, but precipitates at the bottom near the point of application. The solution of copper sulphate is heavier than water.

Quantity of Copper Sulphate Required.—It is of great importance that just the right quantity of copper sulphate be used. If too little is applied the algæ will not be destroyed; if too much is used, there is danger that fish may be killed and there is also the money waste.

In deciding upon the quantity to be used several factors need to be considered, such as the kind of algæ present, the amount of organic matter in the water, the hardness, the presence or absence of carbonic acid, the temperature, the kind of fish present, and of course the quantity of water to be treated. It is hazardous for one not familiar with the various matters involved to attempt to treat a water-supply with copper, as the effect of overdosing may produce disastrous results in the destruction of fish and other animal organisms. Of particular necessity is it to know what organisms are present that need to be killed. For this a microscopical examination is essential. Fortunately this is an easy matter for a water-works superintendent to determine.

Quantity Required to Eradicate Different Organisms.—Organisms differ considerably in their susceptibility to copper sulphate. Some of the blue-green algæ are destroyed by the application of only one part of copper sulphate in ten million parts of water, while other organisms require more than ten times as much as this, and some twenty times as much. One of the organisms most easily killed is Uroglena which can be eradicated by using as little as one part of copper sulphate in twenty million parts of water.

It is probable that the stage of growth of the organisms is also a determining factor and that the presence or absence of carbonic acid is important. Different observers have brought in different figures for the quantities that have proved efficacious with the same organisms. It is impossible to state any very definite figures for the quantities required, but the following figures chiefly given by Kellerman, one of the originators of the method, are believed to be as reliable as any.

TABLE I.—QUANTITY OF COPPER SULPHATE REQUIRED FOR DIFFERENT ORGANISMS

Organisms	Parts per million	Pounds per million gallons of water
Diatomaceæ:		
Asterionella	0.10	0.8
Fragilaria	0.25	2.1
Melosira	0.30	2.5
Synedra	1.00	8.3
Navicula	0.07	0.6
Chlorophyceæ:		
Cladophora	1.00	8.3
Conferva	1.00	8.3
Hydrodictyon	0.10	0.8
Scenedesmus	0.30	2.5
Spirogyra	0.20	1.7
Ulothrix	0.20	1.7
Volvox	0.25	2.1
Zygnema	0.70	5.8
Microspora	0.40	3.3
Draparnaldia	0.30	2.5
Raphidium	0.30	2.5
Coelastrum	0.30	2.5
Cyanophyceæ:		
Anabæna	0.10	0.8
Clathrocystis	0.10	0.8
Coelosphærium	0.30	2.5
Oscillaria	0.20	1.7
Microcystis	0.20	1.7
Aphanizomenon	0.10	1.2
Protozoa:		
Euglena	0.50	4.2
Uroglena	0.05	0.4
Peidinium	2.00	16.6
Glenodinium	0.50	4.2
Chlamydomonas	0.50	4.2
Cryptomonas	0.50	4.2
Mallomonas	0.50	4.2
Dinobryon	0.30	2.5
Synubra	0.10	0.8
Schizomycetes:		
Beggiatoa	5.00	41.5
Cladothrix	0.20	1.7
Crenothrix	0.30	2.5
Leptomitus	0.40	3.3

The figures given may be assumed to apply at a temperature of 15° C. or 59° F. Moore and Kellerman state that these should be increased or decreased by about 2.5 per cent for each centigrade degree below or above 15° C.

They also state, though with less assurance, that an increase of 2 per cent should be made for each ten parts of organic matter per million and an increase of 0.5 to 5 per cent for each ten parts per million of alkalinity. A 5 per cent increase should be made if the amount of carbonic acid is small.

Calculating the Volume of Water to be Treated.—Usually the quantity of water to be treated is not known exactly, but has to be estimated. The following data will assist in making this estimate.

The problem is first to find the number of million gallons of water in the reservoir. When this has been found, the total quantity of copper sulphate required is ascertained by multiplying this by the figure in the last column of the preceding table corresponding to the organism that is to be killed. This must then be increased or decreased slightly to take account of the other factors above mentioned.

One million gallons of water represents a depth of about 3 ft. over one acre. Hence the number of acres of water surface, multiplied by the average depth of the water divided by 3 gives approximately the number of million gallons of water in the reservoir. In an ordinary reservoir the average depth may be taken as about one-third of the maximum depth.

If the reservoir to be treated is so deep that the lower strata are stagnant the calculation should be made to include only the water above and within the transition zone.

Safe Limit for Treating Water to Prevent Killing Fish.—Kellerman recommends that in order to prevent killing certain fish the following limits should be set to the amount of copper sulphate applied to water.

It will be seen that some of the amounts required for algæ destruction are critically near the amounts that will kill fish. This explains the need of cautious application of this remedy.

Fish	Parts per million	Pounds per million gallons (approximate)
Trout	0.14	1.2
Carp	0.30	2.5
Suckers	0.30	2.5
Catfish	0.40	3.5
Pickerel	0.40	3.5
Goldfish	0.50	4.0
Perch	0.75	6.0
Sunfish	1.20	10.0
Black bass	2.10	17.0

Copper Sulphate as a Disinfectant.—Copper sulphate will destroy bacteria if a sufficient quantity is used. The amount required is considerably greater than that needed to destroy algæ. For killing bacteria copper sulphate is less efficient than hypochlorites or liquid chlorine.

Hypochlorite Treatment for Algæ.—Algæ may be killed by the use of hypochlorite, but just as this substance is better than copper sulphate for bacterial disinfection so the copper treatment is generally better than hypochlorites for the destruction of algæ.

Comparative Costs of Coagulation.—The following matter is given in Stein's "Water Purification Plants" (1915).

Fig. 1 shows the costs of treatment of water by several methods with various amounts of coagulant, and also the cost of removing various amounts of acids. The cost of chemicals includes freight, unloading and cartage, deterioration, and the rehandling in charging the chemical tanks. The costs per hundred pounds used were: aluminum sulphate, \$1.10; ferrous sulphate, \$0.70; lime, \$0.35; soda ash, \$1.00. For large-sized plants these values could be reduced. From these curves it is evident that the iron and lime treatment is cheapest, followed by alum and natural alkalinity, alum and lime (sufficient to produce no CO_2), alum and soda ash, while alum and soda ash (no CO_2) is most expensive. It is also evident that by increasing the amount of lime used with the iron, the cost of this process may rise above that of alum and lime. The iron-lime treatment is slightly more effective for high turbidities, a fact not brought out by these curves. For acid removal, lime is by far the cheapest reagent.

Economic Size of Sand Filter Beds (Engineering and Contracting, Aug. 19, 1914).—The proper size of beds is a question of economical construction.

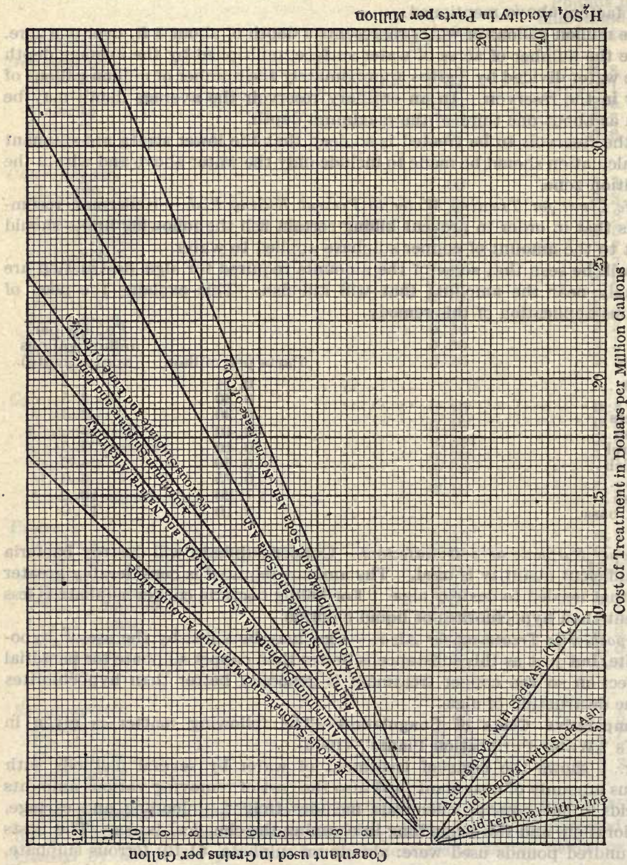


FIG. 1.—Cost of coagulation by various methods.

The larger the beds the less the cost per acre. Covered beds, which are generally used, vary in size from 0.4 to 0.8 acres.

The following calculation from an article on the purification of public water supplies, by C. H. R. Fuller, published in the Aug. 1914 issue of Applied Science, is of assistance in determining the economical number and size of beds. The cost of a filter may be estimated as made up of two items, (1) a portion proportional to the area, which would include cost of bottom, filling small drains, covers, and end walls, assuming basins rectangular and placed side by side, and (2) a portion nearly independent of the size, such as cost of piping, valves, valve chamber, division walls, etc.

Let c = Cost of first portion per acre,
and C = the cost of the latter portion per filter.
If q = area of one filter
n = number of filters
A = Total net area required.

Then, assuming one filter in reserve

$$n = \frac{A}{q} + 1 \tag{1}$$

The total cost is

$$K = Cn + c\,n\,q \tag{2}$$

$$= C\left(\frac{A}{q} + 1\right) + cq\left(\frac{A}{q} + 1\right)$$

$$= \frac{CA}{q} + C + cA + cq \tag{3}$$

We then have $\dfrac{dK}{dq} = -\dfrac{CA}{q^2} + c$

When for a minimum cost

$$q^2 = \frac{C}{c}A. \tag{4}$$

i. e. the economical area of one filter is proportional to $\sqrt{A}$ and to $\sqrt{\frac{C}{c}}$.

The larger the value of "c," the smaller is "q." The values of $\frac{\text{"}C\text{"}}{c}$ will hardly be larger than 1/9 or less than 1/16, giving a value of "q" = $\frac{1}{4}\sqrt{A}$ to $\frac{1}{3}\sqrt{A}$. Thus, when A = 9 acres, the capacity q = ¾ to 1 acre giving 9 to 12 beds. Where A = 1 acre, the capacity would be ¼ go ⅓ acre giving 3 to 4 beds. Larger beds than 1 acre are undesirable on account of increased difficulty of operation.

Filter beds are usually rectangular and arranged side by side. It is usual to place them in two rows with a space between for sand washing, regulating houses, etc The economical proportions of the beds is given by the following formula:

$$\frac{b}{a} = \frac{n+1}{2n}$$

where b = width, a = length, and n = number of beds in a row.

Cost per Million Gals. of Constructing and Operating Slow and Rapid Sand Water Filtration Plants.—Engineering and Contracting, June 17, 1914, publishes the following data given in a paper by George A. Johnson before the 1914 convention of the American Water Works Association.

Relative Cost of Slow Sand And Rapid Sand Filtration.—In discussing the cost of building water filtration works of the slow sand and rapid sand types, respectively, consideration will be given only to those items referring to the filter plant proper. Cost of land, pumping machinery outside connecting piping, intakes, etc., in fact everything outside the filtration plant proper, will not be considered.

For slow sand filter costs the items will include the necessary filter buildings and filters with all appurtenances, all inside piping, sand handling apparatus preliminary sedimentation basins, preliminary filters and appurtenances and clear water reservoirs.

For rapid sand filter costs the items will include the filter buildings and filters with all appurtenances, all inside piping, filter washing apparatus coagulating and clear water basins. Thus a fairly good idea may be had of the relative cost of building purification plants of the two types.

TABLE II.—COST OF CONSTRUCTION OF SLOW SAND AND RAPID SAND WATER FILTRATION PLANTS

City	Present daily filtering capacity, gals.	Approximate cost per 1,000,000 gals. daily capacity
Slow sand:		
Albany, N. Y	20,000,000	$20,000*
Pittsburgh, Pa	200,000,000	26,000*
Philadelphia, Pa.:		
Torresdale	250,000,000	37,700*
Upper Roxborough	28,000,000	29,800
Lower. Roxborough	17,000,000	26,300*
Belmont	60,000,000	45,200*
Washington, D. C	100,000,000	30,000†
Rapid sand:		
Cincinnati, Ohio	112,000,000	11,400‡
Columbus, Ohio	30,000,000	13,000§
Dallas, Texas	15,000,000	13,000
Harrisburg, Pa	16,000,000	10,300
Little Falls, N. J	32,000,000	15,000
Lorain, Ohio	6,000,000	14,000
New Milford, N. J	24,000,000	11,000
Watertown, N. Y	8,000,000	11,250
Weighted averages { Slow sand	....	$32,600
Weighted averages { Rapid sand	....	12,100

* Cost of preliminary filters included. † Cost of Dalecarlia Reservoir not included. Cost of McMillan Park Reservoir included, and also cost of remodeling Georgetown Reservoir, as well as cost of coagulating basin. ‡ Cost of large plain sedimentation basin not included. § Cost of softening works not included.

TABLE III.—COST OF OPERATION AND MAINTENANCE OF SLOW SAND AND RAPID SAND FILTRATION PLANTS

Year	City	Average volume of water filtered daily, gals.	Cost of operation and maintenance per 1,000,000 gals. of water filtered
Slow sand:			
1911	Albany, N. Y	20,000,000	$2.50
1912	Pittsburgh, Pa	100,000,000	3.41
1911	Philadelphia, Pa '	9,000,000	5.62
1911	Philadelphia, Pa.†	13,000,000	3.59
1911	Philadelphia, Pa.‡	38,000,000	3.88
1911	Philadelphia, Pa.§	202,000,000	1.91
1912	Washington, D. C	62,000,000	4.01
Rapid sand:			
1912	Cincinnati, Ohio	50,000,000	4.12
1911	Harrisburg, Pa	9,000,000	3.93
1912	Little Falls, N. J	30,000,000	3.20
1912	Louisville, Ky	25,000,000	3.48
1912	New Orleans, La	16,000,000	6.32
Weighted average { Slow sand		....	$2.86
Weighted average { Rapid sand		....	4.04

* Lower Roxborough; † Upper Roxborough; ‡ Belmont; § Torresdale.

John H. Gregory, who has been personally connected with 7 out of the 15 plants mentioned above, gives the following data in a discussion of the paper prepared by Mr. Johnson, which was delivered before the same convention.

Cost of Construction.—It is exceedingly difficult to compare satisfactorily the costs of construction of different plants, even where the fullest information regarding the same is available. Those who are not well posted as to the history of some of the plants cited in the table may possibly be misled as to the cost of building both slow and rapid sand filters if they accept the figures of the author without full knowledge of local conditions.

One of the features which very materially affects the cost of such works is the total reservoir capacity provided, that is, the combined capacity of the settling basins and of the clear water reservoirs. To illustrate: The rapid sand filter plant at Little Falls, N. J., which, in the author's table is the most expensive one cited, and which cost $15,000 per 1,000,000 gals. daily capacity, has a coagulating basin capacity of 1.3 hours and a filtered water reservoir capacity of 2.6 hours, or 3.9 hours total reservoir capacity. At Columbus, Ohio, the rapid sand filter plant there, which the author states cost $13,000 per 1,000,000 gals. daily capacity, the next to the highest in cost cited, has a settling basin capacity of 12 hours and a filtered water reservoir capacity of 8 hours, making a total reservoir capacity of 20 hours, or five times as much reservoir capacity as that of the Little Falls plant. If the reservoir capacity of the Little Falls plant had been approximately that of the Columbus plant the cost of construction of the Little Falls plant would have been materially increased over that given by the author. Again, the New Orleans rapid sand filter plant might be cited, which has 35.2 hours total reservoir capacity, or practically nine times as much reservoir capacity as that of the Little Falls plant. Other factors which affect the cost of construction are the character of the raw water, the rate of filtration, the character of the construction of the works, etc.

In his reference to the Albany slow sand filter plant the author gives its capacity as 20,000,000 gals. daily. The Albany plant as originally built before the pre-filters were added had a capacity of 15,000,000 gals. daily. The addition of the pre-filters increased the capacity of the plant very materially so that at the present time the capacity is probably in the neighborhood of 28,000,000 gals. daily. If the capacity is taken at 28,000,000 instead of 20,000,000 gals. daily the cost of the plant would be about $14,300 instead of $20,000 per 1,000,000 gals. daily capacity as given by the author.

The Philadelphia slow sand filter plants were expensive plants to build. They differ in one way from many of the other filters of the same type that have been built in that underneath the filter floors and carried up all around the sides of the filter is a layer of puddle. This item alone materially increased the cost of construction. The Lower Roxborough and Upper Roxborough plants were built on high ground in an isolated section several miles from the nearest railroad, and the cost of delivering materials to such plants was higher than would ordinarily be the case.

In the cost of the Lower Roxborough plant the author did not include the cost of the Lower Roxborough Reservoir which was built many years before, and which supplies settled water to the filter plant. Again, a similar condition exists at the Upper Roxborough filter plant with regard to the settling basin. The New Roxdorough Reservoir was built some ten years earlier than the filter plant, and the author has not included its cost in the cost of the filter plant. Strictly speaking, the costs of the reservoirs should be included in the costs of these two plants so that the figures would be comparable with the costs of the other slow sand filters cited.

The Philadelphia plants were built during a period of very high prices, and to use the costs of construction of these plants to indicate the reasonable cost of slow sand filters may be very misleading except to those who are familiar with the early history of these works and who are aware that the costs were high and that the plants could be duplicated at less cost.

The largest slow sand filter plant under construction in America at the present time is at Montreal, and, when completed next year, will have a capacity of 60,000,000 U. S. gals. daily capacity. The total cost of the plant, on the basis of the lump sum contract prices, including the low lift pumping station, will be about $22,600 per 1,000,000 gals. daily capacity. Deducting the low lift pumping station the cost will probably be about $21,000 per 1,000,000 gals. daily capacity.

It would have been interesting if the author had cited the cost of the slow sand filter plant which was completed at Toronto about two years ago. This plant has a capacity of 48,000,000 U. S. gals. daily, assuming one-sixth of the filter area to be held in reserve, and based on a rate of filtration of 6,000,000 U. S. gals. per acre daily, the rate for which the plant was designed. The cost of the plant, omitting the low lift pumping station, was only about $12,700 per 1,000,000 gals. daily capacity.

In considering the weighted average cost of slow sand filters given by the author, namely, $32,600 per 1,000,000 gals. daily capacity, it may be well to bear in mind that the Montreal plant will cost only about $21,000, that the Albany plant cost about $14,300 and the Toronto plant only $12,700 per 1,000,000 gals. daily capacity.

In referring to the cost of rapid sand filter plants the author cites the Columbus plant as costing $13,000 per 1,000,000 gals. daily capacity. This plant was designed and built under the speaker's direction and is a water-softening as well as a rapid sand filter plant. The speaker is not informed as to what items the author included in arriving at the cost of the Columbus plant, but in the speaker's judgment the Columbus plant, considered as a rapid sand filter plant alone, cost nearer $15,000 than $13,000 per 1,000,000 gals. daily capacity, the figure given by the author.

Another rapid sand filter plant which the author might have cited is that at Toledo, Ohio. Part of the plant was built for a capacity of 60,000,000 gals. daily, although the present capacity of the works is considerably less. Including only such items as are chargeable to the filter plant proper the works cost about $14,500 per 1,000,000 gals. daily capacity.

Another rapid sand filter plant which might have been cited is that at Grand Rapids, Mich. The plant was completed inside of the last two years and has a capacity of 20,000,000 gals. daily. The cost of the plant, as given to the speaker by the Grand Rapids officials last year, including such items as are chargeable to the filter plant proper, was $16,300 per 1,000,000 gals. daily capacity.

In December, 1912, the city of New York received bids for a rapid sand filter plant to be located at Jerome Park Reservoir and having a capacity of 320,000,000 gals. daily. Taking the lowest bid received and adding to it the cost of the buildings and other necessary work, the Jerome Park filter plant, which would have been the largest rapid sand filter plant in the world, would have cost $18,400 per 1,000,000 gals. daily capacity. When the plant is built, the actual cost will probably be in the neighborhood of $20,000 per 1,000,000 gals. daily capacity, as much of the excavation for the plant has already been completed.

The author gives the cost of the Cincinnati rapid sand filter plant, which has a daily capacity of 112,000,000 gals., as $11,400 per 1,000,000 gals. daily capacity, and states that the cost of the large, plain sedimentation basins is not included. At Cincinnati there are two large settling basins to which the raw water from the Ohio River is pumped. The water is first settled in these two basins, and is then delivered to the coagulating basins at the filter plant. There is no question in the speaker's mind but that the settling basins are part of the filter plant at Cincinnati, but just how much of the cost of the same should be chargeable to the filter plant may be a question. Mr. J. W. Ellms, the superintendent in charge of the filters at Cincinnati, in a paper printed in the Journal of the Association of Engineering Societies in January, 1912, states:

The settling reservoirs, which have a capacity of 330,000,000 gals. of available water, are in part a portion of the water purification plant, although they also serve the purpose of storage basins and were designed for such a use quite as much as they were for sedimentation purposes.

The two settling basins cost $1,521,000, or about $13,600 per 1,000,000 gals. daily capacity of filter plant. Adding this cost to that of the filter plant would give a total cost of $25,000 per 1,000,000 gals. daily capacity. As the settling basins serve as storage reservoirs also it may be reasonable to charge the filter plant with perhaps only half their cost. On this assumption the cost of the settling reservoirs chargeable to the filter plant would be $6,800 per 1,000,000 gals. daily capacity, thus making the total cost of the filter plant $18,200 per 1,000,000 gals. daily capacity.

Still another plant which the author might have cited, and among the best in the country, is that at New Orleans, which has a capacity of 40,000,000 gals. daily. Including only such items as are chargeable to the filter plant proper the cost of the New Orleans plant was about $30,200 per 1,000,000 gals. daily capacity.

The weighted average cost of the Columbus, Toledo, Grand Rapids, Cincinnati and New Orleans rapid sand filter plants is $18,600 per 1,000,000 gals. daily capacity, while the author gives a weighted average cost for rapid sand filters as $12,100. In other words, the weighted average cost of the five plants just cited, all of which are in operation and which are among the best in the country, is over 50 per cent higher than the weighted average cost given by the author.

The speaker has but little further to say on the subject of costs except that, in his judgment, the weighted average costs as given by the author are too high for slow sand filters and are too low for rapid sand filters. Similarly the fixed charges on the costs of construction would respectively be too high for slow sand and too low for rapid sand filters.

The speaker is not presenting any brief for slow sand filters. The rapid sand filter is more flexible than the slow sand filter and in the majority of cases in the United States is better adapted to the purification of water than is the slow sand filter. The slow sand filter has done and is still doing good work in this country, and the present status of water purification is, to a large extent, due to the introduction of the slow sand filter.

Relative Cost of Mechanical and Slow Sand Filtration.—The following data are arranged from a report to the Commissioner of Works of Toronto, Ont. by Allen Hazen, Consulting Engineer, as published in Engineering and Contracting, Jan. 15, 1913.

	Mechanical filters	Slow sand filters
Head required for filter operation	10 ft.	5 ft.
Settling and coagulating basin	Required	Not required
Average cost per mil. gals. storage	$12,000[1]	
Average cost per mil. gals. daily output	1,500	
Filters:		
Average cost American conditions	$25 per sq. ft.[2]	
Probable cost in Toronto	$30 per sq. ft.	$70,000 per acre[3]
Estimated cost per mil. gals. daily capacity	$11,500	$14,000
Pure water and reservoir piping	Assumed the same for both types of filters	
Cost of construction (exclusive of piping) per mil. imperial gals. daily capacity[4]	$15,000	$14,000
Cost of operation per mil. imperial gals.		
Additional cost of pumping account of greater lift	$.30	
Sulphate of alumina, 172 lbs. per mil. gals. @ $25 per ton	$2.15	
Other costs of operation, including superintendence, labor, laboratory expenses, repairs, renewals, heat, light, drainage, oil waste and pumping wash water	$2.35	
Total operating cost per mil. imp. gals	$4.80	$1.83[5]
Relative efficiency	No appreciable difference[6]	

Notes.—(1) The settling and coagulating basin should be of concrete and covered similiar in general design to the filters but with its flow line 5 ft. higher, and with the bottom sloped to drains to facilitate cleaning out the sludge produced by the action of the chemical on the water. The average depth of the basins would be about 15 ft.—Baffles and other appliances would be required.

2. The filter tanks would be of concrete and about 8 ft. deep similiar in design to those in use at Cincinnati, Columbus, New Orleans and many other places. Mr. Hazen usually allows 430 sq. ft. of net filter area for each million Imperial gals. daily capacity. In the case of Toronto the lake water is usually clear and of very constant composition, as compared with river waters. He assumes 385 sq. ft. of net filter area sufficient.

3. The actual cost of the existing sand filters was $57,000 per acre, including all contingencies. Including 10 per cent for engineering makes the total $62,700 a very low cost. Mr. Hazen assumes that the filters may cost 10 per cent more or $70,000 per acre.

Each acre of net filter surface has a nominal capacity of 5,000,000 Imperial gals. per day.

4. Adding the costs of coagulating basin and mechanical filters we have $13,000 per 1,000,000 gals. daily capacity. Add to this 15 per cent for engineering and contingencies; the total probable cost is $14,950, or say $15,000 per 1,000,000 Imperial gals. daily capacity.

5. *Cost of Operation of Sand Filters.*—The cost of operating sand filters, including superintendence, laboratory expenses, and the cost of pumping wash water, but excluding the cost of the main pumping, was estimated at $1.83 per 1,000,000 Imperial gals., in a communication to Mr. Rust, the former City Engineer, dated Nov. 20, 1908. The records of operation for the present year indicated a cost a third less than this, but it must be remembered

that in subsequent years it may be necessary to handle more sand than in the first period, when everything is clean, and Mr. Hazen therefore deems it wise to use the same figure that he used four years ago.

6. *Relative Cost of Operation.*—The estimated costs of operation, excluding pumping, per 1,000,000 Imperial gals., are as follows:

Mechanical filters	$4.80
Sand filters	1.83

Mechanical filters cost 2½ times as much to operate. This is mainly due to the cost of the chemicals required with them.

Relative Efficiency of Sand and Mechanical Filters.—Lake Ontario water lends itself admirably to the sand filter treatment and excluding the effect of hypochlorite, better and more reliable bacterial or hygienic results will be obtained by sand filters than can be obtained by mechanical filters.

From a physical standpoint there is no appreciable difference; either kind of filters will yield water free of color and turbidity and otherwise satisfactory.

With the systematic use of hypochlorite in the effluents, Mr. Hazen considers that any difference that there might otherwise be in favor of sand filters is eliminated. The hypochlorite treatment conscientiously used can be depended upon to correct any falling off in efficiency that there may be with filters of either system, and he considers that the results will be satisfactory from a hygienic standpoint in either case.

From the standpoint of certain mechanical uses to which the water may be put, and especially with reference to boiler feed water, the sand filters have a certain advantage. The hardness in Lake Ontario water is in the form of carbonate or temporary hardness. This is the least objectionable form of hardness. The use of chemicals in the water changes a certain part of the carbonate hardness to sulphate or permanent hardness, and this is more injurious than the carbonate hardness, especially in boilers. If there were other and sufficient reasons for using chemical treatment, it would be recommended, notwithstanding this condition. In the absence of such reasons, it must be recognized that whatever change grows out of the chemical treatment tends to make the water less desirable and is to be avoided as far as may be.

Cost of Water Purification Plants in Illinois.—The following data given in Engineering and Contracting, Feb. 11, 1914, are taken from a paper before the Western Society of Engineers by Edward Bartow and Paul Hansen, Director and Engineer, respectively of the Illinois State Water Survey and published in the journal of the society, December, 1913.

Table IV.—Data on Some Water Purification Plants in Illinois

City	Waukegan	Mt. Carmel	Rock Island	Quincy	Decatur
Population	18,000	8,000	26,000	37,000	35,000
Source of supply	L. Michigan	Wabash	Miss. R.	Miss. R	Sangamon R.
Ownership	M	P	M	P	M
Reaction chamber, minutes	..	..	..	16.5	16.0
Coag. basins, hours	..	2.7	12.0	4.6	4.0
Filters, M. G. P. D.	..	1.5	6.0	6.0	9.0
Clear well, hours	..	0.75	24.0	0.7	4.0
Type of plant	Sterilization	Rapid sand	Rapid sand	Rapid sand	Rapid sand
Chemicals used	H	A-H	A-H	A-L-I-H	A-H
Cost of plant per M. G. D.	$300	$6,700	$10,800	$11,100	$15,400

Legend: A—Alum. L—Lime. I—Iron. H—Hypo. M—Municipal. P—Private.

Cost of Water Purification and Pumping Plant at Bridgeton, N. J.—The following data are given by Henry Ryon in an article published in Engineering and Contracting, March 4, 1914.

The 3,000,000 gal. water filtration and pumping plant at Bridgeton, N. J., a city of approximately 15,000 inhabitants, was placed in regular operation on Nov. 1, 1913. As shown in Fig. 2, the purification plant consists of concrete coagulating basin, rapid sand filters, clear water basin, necessary chemical storage and mixing facilities and piping and the pumping plant consists of pumping station, coal bunker, pumps and boilers and chimney.

The 30-in. intake was built of vitrified tile pipe and cost $3.70 per lineal ft. complete. The maximum cut on the total length of 8,500 ft. was 14 ft.

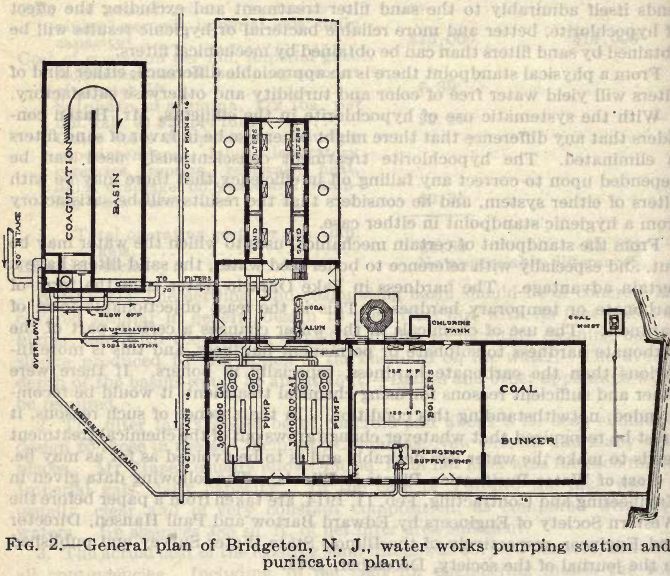


FIG. 2.—General plan of Bridgeton, N. J., water works pumping station and purification plant.

The coagulation basin has a capacity of 150,000 gals. or about an hour's flow. The filters, each 12 ft. by 14 ft. 6 ins., are arranged in two rows of three each on opposite sides of the operating floor and pipe gallery. They are operated at the rate of 500,000 gals. per day (120,000,000 gals. per acre per day). The clear water basin is located beneath the filters and has a capacity of 200,000 gals. This basin extends far enough beyond the end of the filter house to allow four additional filter units to be built on its roof at some future time.

The cost of the filter plant was as follows:

Coagulation basin	$ 5,820
Filters	17,960
Clear water basin	13,256

Making the cost of filter plant proper $37,000 or $12,300 per million gals. capacity.

The pumping plant consists of two cross compound pumping engines of the crank and fly wheel type with capacities of 5,000,000 and 3,000,000 gals. per day respectively. The larger pump had been in service at the old pumping station for several years. The steam for the pumps is supplied by two 125 h.p. water tube boilers and as with the pumps, only one boiler is used at a time, the other being held in reserve.

Under working conditions (average total head about 205 ft.) 430 gals. of water are pumped per pound of coal. This includes the coal burned to furnish steam for the blower and other small engines at the plant.

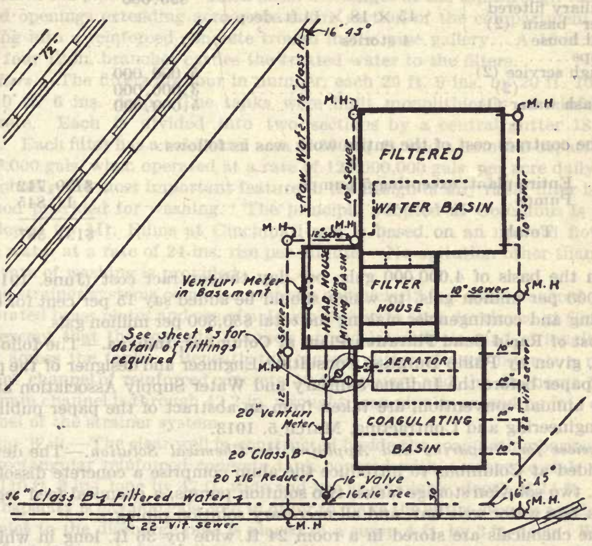


FIG. 3.—Layout of water filtration plant of Whiting, Ind.

The cost of the pumping station and equipment was as follows:

Pumping station	$30,003
Coal bunker	3,919
Pumps and boiler	21,934
Chimney	3,020

A total of $58,876 for the plant or about $19,600 per million gals. capacity including duplicate machinery.

During the period the complete plant has been in operation the cost per million gals. of water supplied has been $31.40. This figure includes interest and sinking fund and maintenance of the distribution mains.

Cost of Rapid Sand Filtration Plant of Whiting, Ind.—Renville S. Rankin describes the filter plant of Whiting, Ind., in Engineering and Contracting, Sept. 10, 1919, from which article the following is taken.

Fig. 3 shows the general layout of the plant, the capacity of which, based upon the filters is 4,000,000 gal. per 24 hours.

The dimensions, capacity and operating period on the basis of 4,000,000 gals. per day are as follows:

Item and number of units	Dimensions, ft.	Capacity, gals.	Capacity, hours
Aerator (1)	30 × 48 (in plan)	...	...
Mixing basin (1)	33 × 12 × 5 ft. deep	...	...
Coagulating basins (2)	40 × 81 × 16 ft. deep	700,000	4.2
Filters (6)	12 × 19.5	666,000 (each)	...
Filtered water storage basin (1)	94 × 91 × 14 ft. deep	890,000	5.3
Auxiliary filtered water basin (2)	45 × 18 × 11 ft. deep		...
Head house	4 stories	...	...
Pumps	...	...	...
High service (2)	...	5,000,000	...
(2)	...	3,000,000	...
Wash water (1)	...	5,000,000	...

The contract cost of the entire work was as follows:

Entire plant, excepting 5 pumps	$179,742
Pumps	11,845
Total	$191,587

On the basis of 4,000,000 gals. per day the contract cost (June, 1919) is $47,900 per million gals. to which should be added say 15 per cent for engineering and contingencies making the total $50,300 per million gals.

Cost of Rapid Sand Filtration Plant at Columbus, Indiana.—The following data, given by Philip Burgess, Consulting Engineer and designer of the plant in a paper before the Indiana Sanitary and Water Supply Association at the 1913 annual convention, are taken from an abstract of the paper published in Engineering and Contracting, March 5, 1913.

Devices for Preparing and Applying the Chemical Solution.—The devices provided at Columbus to introduce the alum comprise a concrete dissolving tank, two solution storage tanks, two solution pumps, a chemical feed regulator, a raw water weir box, and all necessary solution piping.

The chemicals are stored in a room 24 ft. wide by 36 ft. long in which is placed also the mixing tank. Beneath the latter are constructed two reinforced concrete solution storage tanks, each 5 ft. 6 ins. by 6 ft. 4 ins. by 8 ft. deep, containing 2,080 gals. The solution pumps have a capacity of 10 gals. per minute and lift the solution from the tanks into the chemical regulator, located in the pipe gallery near the raw water weir box. An overflow carries the excess of solution back to the storage tanks.

Coagulating Basins.—The coagulating basins are two in number, each 106 ft. 8 ins. long, 78 ft. 6 ins. wide, with an average available depth of 15 ft. 4 ins. The basins are built of reinforced concrete and are uncovered. The total capacity of the two basins is 955,000 gals., equivalent to 5.7 hours' treatment on the basis of 4,000,000 gals. daily capacity.

Each basin is divided longitudinally by a reinforced concrete baffle into two equal compartments so that the length of flow through each basin is 213 ft. Consequently, the maximum velocity of flow through the basin is 0.6 ft. per minute.

The basins are designed to operate semicontinuously and there is provided a sludge disposal system in each of the first compartments to provide for the removal of sludge without emptying the basins. Each sludge disposal system is divided into two sections and comprises 6 lines of 4-in. double strength soil pipe drilled with ⅝-in. holes 30 ins. apart. Each of the four sections discharges through an 8-in. pipe controlled by an 8-in. quick-opening valve, located in the pipe gallery of the filter house.

For the further removal of sludge and for the complete emptying of the basins, there are provided four 8-in. inlets into a 12-in. main drain.

The inlet to each basin is a 16-in. cast iron pipe leading from the raw water weir box to the center of the first compartment and controlled by a gate valve located in the pipe gallery. Each basin discharges at the top through 15 4-in. round openings extending across the entire section of the compartment and leading into a reinforced concrete trough in the pipe gallery. A 16-in. pipe with four 12-in. branches carries the treated water to the filters.

Filters.—The filters are four in number, each 29 ft. 9 ins. by 20 ft. 10 ins. by 10 ft. 6 ins. deep. The tanks were built monolithically of reinforced concrete. Each is divided into two sections by a central gutter 18 ins. wide. Each filter has a total sand area of 350 sq. ft. and a nominal capacity of 1,035,000 gals. when operated at a rate of 125,000,000 gals. per acre daily.

Probably the most important feature in the design of any rapid filter is the method provided for washing. The principal adopted at Columbus is that developed by Mr. Ellms at Cincinnati and is based on an upward flow of wash water at a rate of 24 ins. rise per minute. No agitation other than the high rate of washing is provided.

The strainer systems comprise concrete channels 12 ins. apart covered with perforated brass plates and are of a design similar to that developed at Cincinnati except that the concrete channels extend laterally insetad of longitudinally across the tanks. Beneath the central gutter of each filter is a main effluent channel of reinforced concrete 18 ins. square and the discharge from this main channel is through 42 2-in. wrought iron nipples extending into each channel of the strainer system.

Clear Well.—The clear well is constructed beside the coagulating basins and is a rectangular reinforced concrete tank covered with a concrete slab roof. It is 110 ft. 3 ins. long by 47 ft. wide and has an available depth of 14 ft. Its total capacity is 534,000 gals. and in order to make the entire storage available, the inlet to the discharge pipe is placed in a sump 4 ft. by 3 ft. deep. When the plant is operated at full capacity the period of storage available in the clear well is 3.5 hours, and the elevation of high water in the clear well is such that there is a minimum available head of 9 ft. on the filters.

Filtered water is conveyed from the clear well to the present pumping station through a 20-in. cast iron suction line, approximately 470 ft. long, constructed at large expense, because the trench is for a considerable distance over 20 ft. deep.

In order to furnish the required quantity of wash water, there is provided a 60,000-gal. steel tank and tower supplied by a 2-in. connection to a 4-in main of the distribution system. The bottom of the tank is 18.4 ft. above the gutters in the filters. The tank is of the so-called "railroad" type with an elliptical bottom and a 4-in. riser pipe. In order to maintain a constant depth of water in the tank and to prevent its overflow, an automatic altitude-controlling valve is provided in the 2-in. supply line.

Cost of Construction of Purification Plant.—The contract for the filter plant was awarded in July, 1912. In the following table are shown the costs of the several items comprising the work:

1. Coagulating basins, filters, pipe gallery, chemical laboratory, and office building, filter building together with all necessary inside pipes, valves, etc.	$38,454
2. Clear well, complete	6,600
3. All outside cast iron and tile pipe lines, including raw water force main, high service suction, main wash water line, and all drains.	7,700
4. 60,000 gal. steel tank and tower furnished and erected by the Chicago Bridge & Iron Works	2,150
5. Raw water pump house, including foundations and erection of the raw water pumps and changes in present suction lines	2,713
Total contract price	$57,617

The raw water pumps each of which has a capacity of 4,000,000 gals. daily against a maximum lift of 55 ft., are a centrifugal motor-driven pump with a

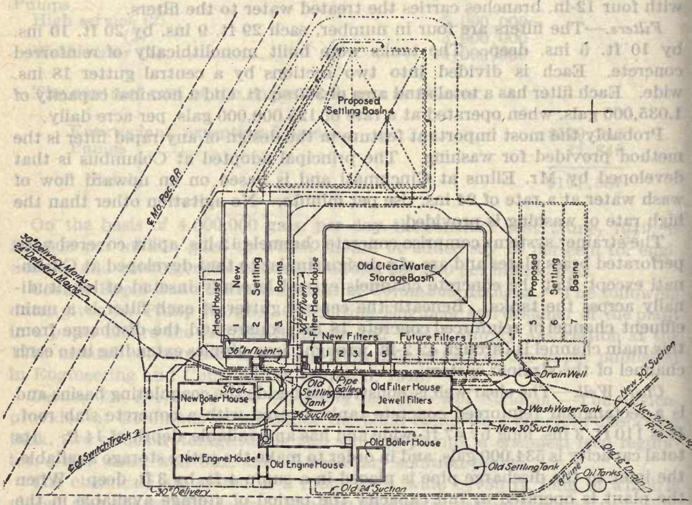


FIG. 4.—Quindaro station of Kansas City, Kan., Water Works.

guaranteed combined efficiency of 65.5 per cent and cost $940, and a centrifugal steam turbine-driven pump with a guaranteed duty of 36,500,000 ft.-lbs. when operated non-condensing, and of 64,600,000 ft.-lbs. when operating condensing, and cost $1,228.

Cost of New Plant for the Purification of the Water Supply Kansas City, Kansas.—Engineering Record, Jan. 27, 1912, gives the following cost of constructing the new 6,000,000 gal. rapid sand water purification plant of Kansas City. The work was done by contract in connection with the relhabilitating of the waterworks system purchased by the city from the Metropolitan Water Co.

Fig. 4 shows the general layout of the entire station and includes both the original plant and the additions, the costs of which follow.

Without going into the details the costs of the new pumping station and pumping station equipment were as follows:

Pumping Station

Pump house basement 60 × 120 ft. (21 ft. deep)	$ 25,922.83
Boiler house foundation, 50 × 108 ft.	6,035.00
Stack foundation	977.00
Pump house and boiler house	48,748.17
Chimney	5,089.00
Steel supports to floor	1,855.43
Tile floor	2,241.13
Grading about station	1,667.36
	$ 92,535.92

Pumping Station Equipment

Snow steam pump, 12,000,000 gals. daily	$ 38,595.00
Strait pumping engine, 15,000,000 gals. daily	18,600.00
Turbo generators, two at 70 kw. each	5,943.84
Turbo generator condensers	800.00
Boilers, two at 600 hp. each	27,007.00
Snow pump foundation	1,334.02
Strait pump and turbo generator foundations	1,923.60
Boiler foundations	719.40
Switchboard and electric wiring	3,937.79
Steam piping	4,793.19
Miscellaneous labor in and about the pump house and in installing steam pipes and small water pipes	3,355.40
Miscellaneous material, piping, fittings and similar materials	2,117.70
	$109,126.94

Inadequate settling facilities provided for the old filters (5,000,000 gals. rated capacity) by the two steel tanks 50-ft. in diameter and 25-ft. high necessitated building the new settling basins large enough to give preliminary treatment for both the old and new filters.

Settling Basins.—Each basin is 200 ft. long, 30 ft. wide and 25 ft. deep at the middle and 23 ft. deep at the ends, constructed of reinforced concrete. The basins have a combined storage capacity of 3,000,000 gals. and an estimated operating capacity of 12,000,000 gals. per twenty-four hours. They were designed to operate in series but may also be operated in parallel or separately if condition of raw water makes such operation desirable.

Filters.—The filters are of reinforced-concrete construction throughout, consisting of five tanks 32 ft. long, 12 ft. deep and 20 ft. 3 in. wide out to out measurements, each tank containing a sand area of 480 sq. ft. and possessing a moderate daily filtering capacity of 1,250,000 gals. or 6,250,000 gals. in the aggregate.

The cast-iron filter connections have been provided of such a size that additional units can be added to an ultimate capacity of 20,000,000 gals. per day.

No air is used, but the wash water is applied at the rate of 30 in. vertical rise per minute for an average of about 5 minutes until the water begins to run clear over the weir edges. With the Missouri River water and a high rate wash, the end point is very sharply defined.

Immediately under the filters is a clear-water basin 13 ft. in depth with a heavily reinforced-concrete 15-in. roof supported by reinforced-concrete columns which in turn rest upon an 18-in. floor slab extending entirely under the clear-water basin and pipe gallery. It is heavily reinforced with steel rods to distribute the pressures uniformly over the ground. The filters rest directly upon the roof of the clear-water basin and its supporting columns and beams. In addition to the 240,000-gal. storage under the filters there is about 70,000-gal. storage under the settling basin head house.

An elevated steel wash-water tank, holding 60,000 gals., built by the Chicago

Bridge & Iron Company, is supplied by an 8-in. motor-driven centrifugal pump. Running at 1700 r.p.m., this pump has a rated discharge of 1500 gal. per minute. The pump discharge pipe is connected into one end of the wash-water line in the pipe gallery. The other end discharges into the wash-water tank. The high water line is 43 ft. above the gutter weirs in the filters.

Cost of the settling basins per 1,000,000 gals. of storage capacity is about $24,000 or about $6,000 per 1,000,000 gal. of estimated operating capacity. In the item "Valves and sluice gates" are included many valves for the "Outside pipe lines" and other improvements, but "Outside pipe lines" include material for the settling basins so the two items tend to offset each other. On the basis of a 6,000,000-gal. plant, the filters, filter house, electrical equipment and drain well cost $14,620 per 1,000,000 gals.

Settling Basin

Concrete work	$51,500.00
Valves and sluice gates	10,000,00
Head house	5,760.00
Booster pumps and pipe connections	3,376.28
Miscellaneous work	1,211.52
	$71,847.80

Mechanical Filters and Drain Well

Material for filters	$21,981.51
Labor on filters	30,521.80
Filter house and drain well house	5,570.00
Floats and gages	222.45
Strainers and screens	2,588.00
Lead for pipe laying	459.58
Pipe and specials	9,080.30
Controllers	2,000.00
Wash-water tank	3,400.00
Valves	4,298.00
Labor on drain well and wash-water tank foundations	1,706.60
Booster pumps	2,784.25
Electric wiring, filter house and settling basin	3,115.00
	$87,727.49

Work was commenced in the fall of 1910 and the filter constructed complete in the latter part of July, 1911. The concrete work was continued throughout the winter months, provision having been made for the heating of all sand and water.

Cost of Water Purification Plant of Great Falls, Mont.—The plant, described, at length, in Engineering and Contracting, Jan. 9, 1918, from which the following is taken, consists of a mixing chamber, settling basins and mechanical filters. The capacity of the plant is 12,000,000 gals. per day and the cost was approximately $225,000, or $18,750 per million gals. per day of capacity, including the entire water purification and softening plant, the low service pumping station, real estate, engineering and supervision.

Operating at rate of 12,000,000 gals. per day the time of treatment is as follows:

Mixing chamber	1,660 ft. travel	36 minutes
Settling basins	465 ft. travel	8 hours

The thorough mixing and long period for settling result in an exceptionally clear water before it reaches the filters and allows of a saving in chemicals which within a short time will pay for the increased cost. Other savings due to the use of the large mixing chamber are, no lime is required for precipitation of the sediment in the water and since the water is exceptionally clean when it passes onto the sand beds less frequent washings are required to keep the filters in condition.

The filters are arranged in eight units of 1,500,000 gals. capacity each. The entire plant is housed in a reinforced concrete structure with brick walls above floor level. All of the chemicals are fed by dry feed machines which are regulated to feed the chemicals in proportion to the water pumped.

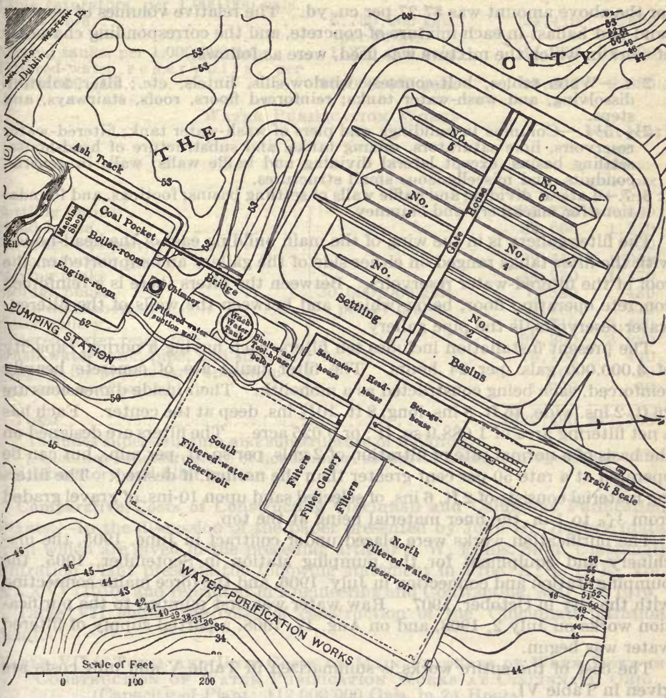


FIG. 5.—General plan of water purification works at Columbus, Ohio.

Some Costs of the Water Purification Works at Columbus, Ohio.—The following data are given in Engineering and Contracting, Feb. 9, 1910, and are from a paper by John H. Gregory in Proc. Am. Soc. of C. E., Vol. XXXVI, 1910.

The pumping station and purification works are designed for extension to an ultimate net normal capacity of 40,000,000 gals. per 24 hours. At present the pumping station has a net normal capacity of 20,000,000 gals. per 24 hours, but the building is of sufficient size for equipment having the ultimate net normal capacity. The purification works at present have a net normal capacity of 30,000,000 gals. per 24 hours, but have been arranged so that extensions may readily be made.

Fig. 5 is a general plan of the works. All building walls are of brick covered with red pressed brick; floors, stairways, etc., are of reinforced concrete. Roof trusses are steel, the covering being of slate laid on 3-in. hollow terra cotta block.

In the construction of the work, concrete, both plain and reinforced, was used extensively, the total quantity in the pumping station, purification works and adjacent structures amounting to 39,560 cu. yds. The average price paid for the above amount was $7.27 per cu. yd. The relative volumes of cement, sand and ballast in each mixture of concrete, and the corresponding character of work in which the mixture was used, were as follows:

1: 2: 4.—Water-tables, belt-courses, window-sills, lintels, etc.; filter, solution dissolving, and wash-water tanks; reinforced floors, roofs, stairways, and steps.

1: 2½: 5½.—Columns in buildings and piers of wash-water tank; filtered-water reservoirs, lime saturators, mixing tanks, and substructure of head-house; settling basins, except lateral dividing and baffle walls; walls in general, conduits, and miscellaneous small structures.

1: 3: 7.—Lateral dividing and baffle walls of settling basins; footings, and foundations for machinery and chimney.

The filter gallery is in the wing of the main building east of the head-house, with the filter tanks ranged on either side of the gallery and supported on the roof of the filtered-water reservoirs. Between the filters there is a reinforced concrete operating floor, below which, and between the walls of the filtered-water reservoirs, is the pipe gallery.

The present installation includes ten filters, each having a normal capacity of 3,000,000 gals. per 24 hours. The filter tanks are of concrete heavily reinforced, each being constructed as a monolith. Their inside dimensions are 26 ft. 2 ins. wide, 46 ft. 8 ins. long, 8 ft. 10½ ins. deep at the center. Each has a net filtering area of 1,088.9 sq. ft., or 0.025 acre. The filters are designed on the basis of a normal rate of filtration of 2 gals. per sq. ft. per min., but can be operated at a rate 50 per cent greater than the normal, if desired. The filtering material consists of 2 ft. 6 ins. of selected sand upon 10-ins. of gravel graded from 1/16 to 1-in. the finer material being at the top.

The purification works were placed under contract in June, 1905, the machinery and equipment for the pumping station in September, 1905, the pumping station and connection in July, 1906, and the force mains connecting with the city in October, 1907. Raw water was first pumped to the purification works on July 2, 1908, and on Aug. 17, 1908, a partial supply of filtered water was begun.

The cost of the entire works is summarized in Table V and unit costs are given in Table VI.

TABLE V.—SUMMARY OF COST

Land	$ 48,410
Work, exclusive of pumping station and water purification works	76,490
Pumping station	399,240
Water purification works	532,480
Total cost of works, exclusive of connections to city and exclusive of engineering	$1,056,620
Connections to city	181,000
Total cost exclusive of engineering	$1,237,620
Engineering*	95,950
Total cost	$1,333,570

* The cost of engineering work, was $95,950, divided as follows: Pay roll, $84,340; supplies, $6,120; expenses, $5,490, amounting to 7.75 per cent of the cost.

TABLE VI.—UNIT COST OF MAIN FEATURES OF WORK

Work	Capacity	Total cost	Unit cost
* Pumping station building, per cu. ft.	1,273,300 cu. ft.	$128,490	$ 0.101
† Main buildings, water purification works, per cu. ft.	534,000 cu. ft.	49,070	0.092
Settling basins, per 1,000,000 gals.	15,000,000 gals.	168,770	11,250
Lime saturators, per 1,000,000 gals. per 24 hrs.	6,750,000 gals. per 24 hrs.	24,410	3,620
Mixing tanks, per 1,000,000 gals.	1,270,000 gals.	44,230	34,800
Filtered-water reservoirs, per 1,000,000 gals.	10,000,000 gals.	98,300	9,830

WATER PURIFICATION WORKS

	Capacity	Total cost	Unit cost per million gals. per 24 hrs.
Settling basins	30,000,000 gals. per 24 hrs.	$168,770	$ 5,630
Head-house		39,660	1,320
Air-wash equipment		3,470	120
Lime-saturator house		32,550	1,080
Mixing tanks		44,230	1,470
Storage house		12,880	430
Office and laboratory		15,280	510
Filter gallery		102,710	3,420
Filtered-water reservoirs		98,300	3,280
Wash-water tank, pipe, and shelter		13,150	440
Supplies for preliminary operation		460	20
Expenses unclassified		1,020	30
Total		$532,480	$17,750

* Includes superstructure and substructure of building.
† Includes superstructure of head-house, saturator house, storage house, office and laboratory and filter gallery.

Comparative Costs of Constructing Cincinnati and Columbus Purification Plants.—In the discussion of the paper presented by John H. Gregory (data from which are given in the preceding article) J. W. Ellms, Supt. Cincinnati Filtration Plant presents the following statement in Proc. A. S. C. E., Vol. XXXVI (1910) and reprinted in Engineering and Contracting, Mar. 30, 1910.

Table VII shows the costs of construction of the Cincinnati filtration plant.

TABLE VII.—TOTAL AND UNIT COSTS OF MAIN FEATURES OF WORK DONE IN CONSTRUCTION OF WATER PURIFICATION WORKS AT CINCINNATI, OHIO (Capacity of Plant: 112,000,000 Gals. in 24 Hours)

Work	Total cost	Cost per million gallons of capacity for 24 hours
Preparation of grounds	$ 33,359.67	$ 297.85
Pipe lines between settling reservoirs and head-house	55,354.77	494.24
Head and chemical house	144,989,85	1,267.77
Coagulation basins, gate houses and pipe lines	304,913.05	2,722.44
Filters, filter house, piping, sand and gravel	592,112.30	5,286.71
Piping, valves and gate-house between filters and clear-water reservoir	29,701.91	265.20
Clear-water reservoir	121,362.39	1,083.59
Total	$1,278,793.94	$11,417.80

At Columbus, the unit costs per million gallons of capacity in 24 hours appear to be considerably greater for the settling basins and mixing tanks combined, than for the coagulation basins at Cincinnati. The figures for the Columbus tanks and basins are $7,100 per million gallons of capacity, as compared with $2,722 at Cincinnati. In a general way, these parts of the two plants correspond; but at Columbus more elaborate baffling of tanks and basins, more divisions of the flow of the raw and treated waters, and more places for the primary and secondary applications of chemical solutions were needed and provided for, than were required at Cincinnati. The greater combined unit costs of the headhouse, lime-saturator house, storage-house, wash-water tank, offices and laboratories at Columbus, than for the corresponding head-house, chemical-house, wash-water tank, offices, and laboratories at Cincinnati, are similarly explained by the necessity for designing a plant for softening, as well as for clarifying and purifying the water. The combined unit costs for the items noted above for the Columbus plant amount to $3,784, as compared with $1,268 for the Cincinnati plant.

The filters and piping in the Cincinnati plant cost more per million gallons of capacity than did those at Columbus. The figures for Columbus, which include the air-washing equipment, are $3,540, as compared with $5,287 for Cincinnati. However, the filtered-water reservoir at Columbus cost more than that at Cincinnati. The figures for the Columbus plant are $3,280 per million gallons, and for the Cincinnati plant, $1,084. At the latter plant, the clear-water reservoir is a separate uncovered reservoir, while at Columbus, it is directly under the filter tanks, which latter form a protecting roof. Virtually, no great difference in costs exists, if the cost of the filters, piping, and clear-water reservoir of each plant be combined and then compared.

The cost per million gallons of capacity for the whole purification plant at Columbus is stated to be $17,750, which amount does not include engineering; the corresponding figure for the Cincinnati plant, as shown above, is $11,418, and this also excludes the cost of engineering. The difference of more than $6,000 per million gallons capacity is doubtless due to the additional requirement demanded by the local conditions at Columbus, that is, for the softening of a very hard water, and one which is at times subject to rapid fluctuations in its physical characteristics.

Costs of Slow Sand Water Filtration Plant at Toronto, Ont.—The following data are taken from an abstract published in Engineering and Contracting, Nov. 19, 1913, of a paper by Francis F. Longley before the Canadian Society of Civil Engineers.

The filtration plant with a daily capacity of 40,000,000 Imp. gals., consists of the pumping station and equipment, 12 filters, each 117 ft. by 312 ft. arranged symmetrically on either side of the regulating equipment, sand bins, etc., and a pure water reservoir 312 ft. square with a capacity of 7,575,000 Imp. gals.

The filters are built of concrete with inverted groined arch floor and groined arch roof. The rate of filtration assumed in the design of the plant was 6,000,000 U. S. gals. per acre per day which with the relatively clear water of Lake Ontario is justified by experience as being fair, although much higher than that ordinarily used.

Most of the filter and reservoir excavation was made by means of slip scrapers and wheel scrapers and moved direct to the spoil banks. A considerable part, however, was dumped from the scrapers through a trap into cars, and these cars were hauled across the site and dumped for fill on top of the finished filter masonry. The fill on top of the filters was finished with 6 ins. of clay, the slopes sodded, and the tops and other unsodded portions grass seeded.

Sand and gravel were obtained in large part on or near the site, the work being on an island only a few hundred feet from Lake Ontario.

The equipment for cleaning the filters and recovering and replacing the sand consists in general of the following parts: A piping system to carry water under pressure into the filters and to the sand washers, and to carry the slush of sand and water in the ejecting and washing processes from the filters to the washers and from the washers to the sand bins; centrifugal pumps in duplicate in the pumping station for supplying water for this purpose; movable ejectors of suitable design for ejecting the dirty sand from the filters; the sand washers in the court; the sand bins for the storage of clean sand, and the appliances for replacing sand in the filters.

The sand storage bins are four circular tanks of reinforced concrete, the bottom of each being in the shape of an inverted cone. Each of these tanks has a diameter of 34 ft., a depth of 16½ ft. above the base of the cone and a capacity of about 600 cu. yds. The conical bottoms of the bins were placed first and included complete arrangements of piping and perforated brass plates and screens for the prompt draining of the water from the sand.

Cost of the Works.—Soon after July 1, 1912, an analysis of all expenditures on this work was made from the figures given in the accountant's books. For all work still to be done at that date, as accurate an estimate as possible was made of the cost, and the approximate total cost of the work made up on that basis.

ANALYSIS OF COST OF TORONTO FILTRATION PLANT

Filters and Appurtenances—		
Drainage during construction		$ 18,628.00
Excavation, 90,367 cu. yds. at 21 cts		18,977.07
Excavation, 2,897 cu. yds. at 63 cts		1,825.11
General fill, 75,517 cu. yds. at 22 cts		16,613.74
Clay fill, 10,185 cu. yds. at $1.50		15,277.50
Sodding, 4,920 sq. yds. at 25 cts		1,230.00
Concrete—		
Floors and walls, 17,641.4 cu. yds. at $6.35	$112,030.75	
Piers, vaulting, 13,209.4 cu. yds. at $8.80	116,247.12	
C. I. manholes and covers in place	9,865.00	
Steel reinforcing	2,722.24	
Filter roof drainage	836.00	
Filter masonry complete		241,701.11
Concrete pipe system		21,942.28
72-in. Venturi meter, main supply		2,133.84
Filter gravel, 11,436 cu. yds. at $1.50		17,154.00
Filter sand, 56,707 cu. yds. at $1.10		62,377.70
4 sand storage bins		9,363.36
7 sand washers		2,268.05
Sand washer pipe system		16,609.41
Sand ejectors, hose, etc		566.41
Cast iron pipe lines		19,600.18
Filter meters, gages, etc		6,750.63
Exterior drainage system, vitrified pipe		2,555.29
Surface drainage system		500.00
Electric duct system in court		1,398.96
Electric lighting, outside		300.00
Electric lighting, in filters		700.00
Tile underdrains in filters		6,090.00
Concrete sidewalks		1,250.00
2 regulator houses, complete		8,564.82
7 entrance houses, complete		7,670.39

Office and laboratory building		12,420.66
Office and laboratory equipment		3,063.85
Castings for additional 72-in. Venturi meter		385.00
Manhole extensions on 6 ft. steel pipe		563.25
Items properly chargeable to maintenance prior to Jan. 1, 1912		10,251.31
Miscellaneous		17,175.58
Total cost of 12 filters		$545,907.50
Pure Water Reservoir—		
Drainage during construction		4,000.00
Excavation, 21,500 cu. yds. at 21 cts		4,515.00
Fill, 17,000 cu. yds. at 22 cts		3,740.00
Fill, 8,323 cu. yds. at 30 cts		2,496.90
Clay fill, 2,346 cu. yds. at $1.50		3,519.00
Sodding, 1,062 cu. yds. at 25 cts		265.50
Entrance houses		1,261.90
Concrete—		
Floors and walls, 4,040.8 cu. yds. at $6.23	$ 25,650.00	
Piers and vaulting, 2,832.5 cu. yds. at $8.80	24,920.00	
Cast iron manholes, in place	617.60	
Steel reinforcing	46.36	
Outlet to 72-in. steel pipe	815.63	
Reservoir masonry complete		52,049.59
Miscellaneous		774.11
Total cost of pure water reservoir		$ 72.622.00
Pumping Station—		
Building, including structure		$ 24,625.12
Machinery—		
3 screw pumps (8 ft. lift)	$ 9,946.90	
48-in. steam pump (tandem compound Corliss)	9,290.32	
2 sand washer pumps (8-in. centrifugal)	5,234.00	
1 drainage pump (12-in. centrifugal)	1,675.00	
2 boilers (100 hp fire tube)	2,911.69	
Priming pump, complete	595.00	
Crane	1,110.00	
2 Venturi meter registers	894.00	
Total machinery		31,656.91
Coal bin (52 × 39 × 10 ft. deep)		3,402.93
Chimney		1,687.28
Gate valves and sluice gates		4,932.11
Cast iron pipes and specials		2,729.96
Steam piping, electric conduit work, Island supply and miscellaneous		17,148.57
Checker plates, in place		500.00
Coal during construction		4,237.82
		$ 90,920.70
Engineering and Inspection—		
General plans, specifications and supervision		$ 29,650.00
Construction, office force		26,810.00
Inspection		15,609.00
		$ 72,069.00
Summary—		
12 filters, complete		$545,907.50
Pure water reservoir, complete		72,622.00
Pumping station and equipment		90,920.70
Engineering and inspection		72,069.00
Total cost of work		$781,519.20

Approximately $14,500 of the above amount is fairly chargeable to improvements in the Island Supply, for which no special funds were provided.

Approximately $10,250 is fairly chargeable to maintenance, prior to Jan. 1, 1912, during which time there was no special fund for that purpose.

Percentage for engineering and inspection	10.2
Cost per acre for filters	$58,000
Cost per 1,000,000 gals. for reservoir	9,700

The total expenditures and outstanding accounts, as shown by the accountant's books about Dec. 1, 1912, amounted to approximately $783,400. Practically all construction work was at that time completed, and it is apparent, therefore, that the analysis given above was reasonably complete and accurate, and show satisfactorily the relative costs of the different parts of the work.

Construction and Operating Costs of Filters of the Pressure Type at New Canaan, Conn.—The following matter taken from an abstract, of a paper by Kenneth W. Leighton before the 1914 annual meeting of the Connecticut Society of Civil Engineers, was published in Engineering and Contracting, Aug. 5, 1914.

Excavation for the foundation of the building was started May 13, 1913, and water was turned through the filters on July 1, 1913. The filter plant was located so that the line of the old 12-in. supply main came about 2 ft. inside of the east wall of the building. About 80 ft. of this old supply main had to be taken up in order to insert the Venturi meter and branches for the filters. As this 12-in. main forms the only supply for the town, a temporary 6-in. pipe was tapped in below the filter plant and run to a notch cut in the concrete spillway of the dam.

The filter plant proper consists of four filters, each capable of filtering 250,000 gals. in 24 hours. This amount is based on 2 gals. per minute per square foot of horizontal filtering area. This arrangement provides sufficient filtered water for washing one filter while the other three are in use, and also allows for future growth in consumption. The consumption for short periods has run as high as 600,000 gals. per 24 hours.

The filters are of the Continental Jewell type and consist of steel tanks 10 ft. in diameter and about 7 ft. high with convex tops and bottoms. Just above the convex portion of the bottom are placed a series of bronze strainers, about 200 in number. The slits in these strainers are so small that the sand or gravel cannot get through them. The bottom of the tank is concreted in up to the strainers. Above the strainers is a 9-in. layer of gravel 1/8 to 3/4 in. in size. Above the gravel is a 30-in. layer of sand. From the top of the sand to the top of the tank there is just room for a man to get in and move around uncomfortably. A section of one unit is shown in Fig. 6.

Before the water reaches the filters some of it is forced by a back pressure valve through either one of two tanks, each containing about 100 lbs. of alum. A certain amount of the alum is dissolved and carried back into the supply main. The alum unites with a portion of the alkali in the water, forming a flaky precipitate of aluminum hydroxide which serves to entangle small particles and coloring matter and to make a coating on top of the sand. One grain of alum per gallon will use up about eight parts of alkalinity per million, so that if the water is deficient in alkalinity some alkali, such as sodium carbonate, would have to be added.

In seven months there has been used 4 1/3 tons of alum, and 47,596,000 gals. of water have been filtered, making 1 4/10 grains of alum per gallon of water. It is very likely that this can be reduced somewhat before long.

The water, on entering at the top of the filter unit, is deflected by a baffle plate, thus spreading it evenly over the top of the bed. In going through the filters, there is a loss in pressure of from 2 to 4 lbs. When it reaches the latter figure it is time to wash. The filters are washed at least once a day, even if the loss in pressure does not reach 4 lbs. The filters are of the sectional wash type and only one-third of a unit is washed at a time. This gives greater pressure and tends to keep the water from burrowing through the filtering material. The washing is done by reversing the flow of water. The washing of a unit takes about 15 minutes, unless the bed is exceptionally dirty.

When the reservoir is low the filters are washed by using the 10,000-gal. clear water tank and the pump. The pump is a 5-in. suction, 5-in. discharge, Kingsford centrifugal pump coupled to a 10-h.p Westinghouse induction motor. The clear water tank holds enough to wash approximately two filter units. The water used for washing is about 5 per cent of the total water consumed during 24 hours. After passing through the filters, the water is measured by a Venturi meter, which records the rate of flow every 10 minutes and the total amount in gallons.

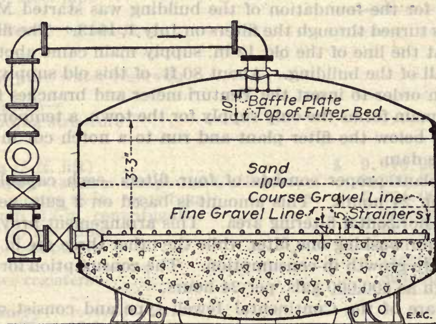


Fig. 6.—Section of filter unit, pressure filters, New Canaan, Conn.

The building is heated by an ordinary round station stove with about a 20-in. fire pot, and will burn about 5 tons of coal during the winter.

The efficiency of the plant is indicated by the comparative analyses of the raw water in past years and of the filtered water at the present. An examination of the raw water analyses made at monthly intervals from December, 1911, to June, 1913, shows that the color ranged from 28 to 96 parts per million, the turbidity from 1 p. p. m. to 60 p. p. m. and the alkalinity from 7 p. p. m. to 25 p. p. m. During the same period the odor has been characterized as grassy, faint, faint peaty, or distinct peaty, and the color of the sediment has been termed slight brown, slight gray or dark brown. The last analysis of the filtered water by the State Board of Health is as follows: Color, 0; turbidity, 0; nitrates, 0; free ammonia, 0; odor, 0; sediment, 0; chlorine, only 0.1 above normal; hardness, 32.68 (less than 60 is considered soft water); bacteria; 175 per c.c., no suspicious ones.

Construction and Operation Cost Data.—The following tabulation gives the approximate cost of the filter plant, the estimated cost of operating for a month, and the cost per 1,000,000 gals. of water:

Cost of filter plant:	
Building	$ 6,000.00
Filters	12,500.00
Venturi-meter	600.00
Miscellaneous	1,900.00
	$21,000.00
Cost of operating per month:	
Attendants' salary	$ 65.00
Power (minimum charge)	10.00
Light	.50
Telephone	4.50
Compensation insurance	1.00
Coal	3.30
Alum	27.00
Miscellaneous	2.00
Depreciation:	
Machinery, 10 per cent	125.00
Building, 2 per cent	10.00
Interest on investment at 6 per cent	105.00
	$ 353.30

Amount of water filtered per month equals 7,000,000 gals.
Cost per 1,000,000 gals. of water filtered, $50.43.

It should be noted that more water could be filtered, if the occasion demanded, without increasing the present cost materially.

Labor Costs of Constructing Filtration Plant at Minneapolis, Minn.—In Engineering and Contracting, June 11, 1913, June 25, 1913 and Nov. 5, 1913, W. N. Jones gives in great detail the design and methods and costs of constructing the 39,000,000 gal. mechanical water filtration plant at Minneapolis, from which the following matter is abstracted.

Hering and Fuller were commissioned to draw up the plans and specifications for the work in March, 1910 and after careful study of the old works, which consisted of a first-class pumping station, three miles of 50-in. steel force mains, and two settling or service reservoirs of a capacity of 47,000,000 gals. each, it was decided to use the old reservoirs as a part of the new plant.

The new plant contemplated the covering of one of the old reservoirs with a groined arch roof to be used as a clear water basin, the raising of the embankments of the other reservoir 10 ft., in order to maintain the elevation of the water in the clear water basin at the old level and provide a working head for the operation of the filters, also a mixing chamber, two coagulation basins, a headhouse, 12 mechanical filter units, with an auxiliary clear water basin underneath, and wash water tank of 135,000 gals. capacity.

The old reservoirs, which were built in 1896, were rectangular in shape, each 877 ft. 6 ins. long by 413 ft. 6 ins. wide, c. to c. of curbing, with a 1 on 2 slope inside.

Fig. 7 gives the general layout of the plant and shows the principal dimensions of the units.

The building of the filter plant was the largest single piece of work ever attempted by the City of Minneapolis under the "day labor system" and employed the greatest variety of labor, both skilled and unskilled of any job under the jurisdiction of the Engineering Department. All the labor had to be trained in filter work, as none had ever worked on a like job before. The conditions under which the work was done were far from being the best. More or less patronage was attempted by some of the aldermen, causing some friction between them and the constructing department. This patronage became less as the work progressed, as it was soon recognized that unless a man did his work well there was no place at the filter plant for him, no matter who his friends might be.

Rainy weather and the extreme cold of the winters delayed the work materially, as it was almost impossible to work to advantage in either. A large amount of work, however, was done at times when it would have meant a saving in the cost had one waited for more favorable weather. Especially was this true of the earth and concrete work, some of which was done under very trying conditions.

The amount of constructing machinery used on the job was very meager, amounting to almost a famine in this line. It caused many things to be

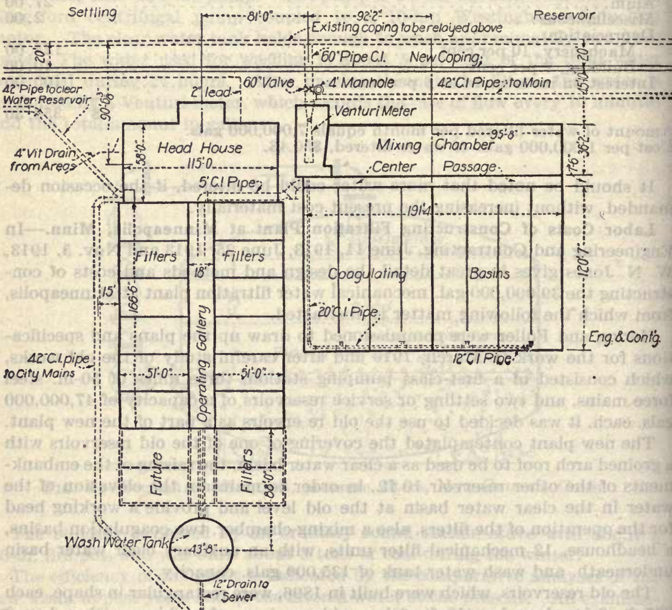


FIG. 7.—General layout plan of Minneapolis water filtration plant.

handled by hand that really required machinery for its economical handling, thus increasing the cost unnecessarily.

The quality of the work turned out by the force account system has been very good. Every man was warned not to place, knowingly, a defective piece of material of any kind in his work, and whenever he discovered anything that did not appear first class to report it to his superiors. Quality was always placed first, and quantity turned out next. It is safe to say that the quality of the work is much better than it would have been had the job been done by contract, and there is no reason to believe that the cost or the time of completion would have been any less.

WAGES PAID ON CONSTRUCTION WORK AT THE MINNEAPOLIS FILTER PLANT

Occupation	1911. Per mo.	1912. Per mo.
Assistant superintendent	$125.00	$125.00
Chauffeur	65.00	65.00
	Per day	Per day
Foreman	$ 5.00	$ 4.50
Assistant foreman	3.50	3.75
Sub-foreman	3.00	3.00
Timekeeper	4.50	4.50
Clerk	3.00	3.00
Rodman	2.75	....
Brick foreman	....	7.00
Bricklayers	5.20	5.20
Structural steel foreman	....	5.50
Structural steel workers	....	4.50
Steamfitters' foreman	5.00	5.00
Steamfitters	4.50	4.50
Plumbers	....	4.50
Roofers	....	4.00
Plasterers	....	5.60
Mortar mixers	....	3–3.25
Stonemason	4.40	4.40
Machinist	....	4.00
Blacksmith	3.00	3.00
Electrician	....	4.00
Steam engineer	4.00	4.00
Gasoline engineer	....	3.60
Concrete finishers	....	2.60
Sheet metal workers	....	4.80
Painters	....	3.60
Carpenters	4.00	4.00
Non-union carpenters	3.00	3.00
Erecting engineer, vacuum system	....	5.00
Bricklayer apprentice, 3rd year	....	3.60
Steamfitter helper	....	2.40
Water boy	1.25	1.40
Handy man	2.40	2.55
Calkers	....	3.15
Single horse	3.00	....
Teams	4.72	5.00
Laborers	2.25	2.40

The following are labor costs for work done on this filtration for 1911 and 1912.

LABOR COST DATA ON SETTLING BASIN IN 1912

Earthwork.—Excavation: 321 cu. yds. of earth were excavated from trenches by hand at an average cost of 78.4 cts. per cu. yd. This cost includes the sheeting and staging. Of the 321 cu. yds. excavated 236 cu. yds. was dry work, shoveled three times, 40 cu. yds. was wet clay handled four times, and 45 cu. yds. was wet clay handled twice, at average costs of 80 cts., $1, and 40 cts. per cu. yd., respectively. Backfill: 747 cu. yds. were backfilled by hand and scraper at an average cost of 34.7 cts. per cu. yd. The ground was wet and partly frozen. This figure includes the hauling of 93 cu. yds. 900 ft. Fill: The fill of 10,773 cu. yds. was well sprinkled and rolled in layers of 6 ins. with a 14-ton roller. Average cost, 49.8 cts. per cu. yd.

Puddle Wall.—The 1,529 cu. yds. of puddle were tamped by hand in 1½ to 2-in. layers at an average cost of 75.7 cts. per cu. yd. The water needed was pumped by hand.

Recovery of Crushed Stone and Screening Gravel.—All crushed stone was screened by hand to remove dirt. In all 77 cu. yds. of stone and gravel were screened at an average cost of $1.67 per cu. yd.

Hauling Crushed Stone and Gravel.—The crushed stone was handled by hand and hauled in common dump wagons. 172 cu. yds. were hauled an average of 330 ft. at an average cost of 39.9 cts.

Concrete.—Concrete was laid in slabs 13.5 ft. by 10 ft. by 6 ins. on 2 to 1 slope. 142 cu. yds. were laid at an average cost of $2.12 per cu. yd., including the 1:2 cement finish and the setting and removing of screeds.

Laying Crushed Stone.—Crushed stone shoveled down slopes and spread by hand. 1,134 cu. yds. were placed at an average cost of 35.2 cts. per cu. yd.

Laying Tracks.—745 ft. of 24-in. gage track in 16-ft. lengths at an average cost of 3.3 cts. per ft.

Laying Sandstone.—The sandstone blocks were 12 by 14 ins. in section and from 2 to 6 ft. long. They were laid on edge. In all 11,690 sq. ft. were laid at an average cost of 4.9 cts. per sq. ft.

Hauling Sandstone.—11,795 sq. ft. of sandstone was loaded by hand and hauled on a stone jigger at an average cost of 4.4 cts. per sq. ft.

Pouring Asphalt Joints.—805 lin. ft. of asphalt joints were heated and poured at an average cost of 7.1 cts. per ft.

Coping Stone.—Hoisting: The coping stone were hoisted 12 ft. by an old pipe laying derrick operated by hand power. 10,548 sq. ft. of this stone was hoisted at an average cost of 2.8 cts. per sq. ft. The coping stones are 4 × 12 ins. in section and from 4 to 8 ft. long. Hauling: The stone was loaded by hand and hauled a distance of 750 ft. on a stone jigger. The average cost for 2,750 sq. ft. so hauled was 4 cts. per sq. ft. Setting: the average cost for setting 11,792 ft. of coping stone was 5 cts. per sq. ft.

Fencing.—Hauling: 2,207 lin. ft. of fencing was hauled 650 ft. on common dump wagons, which were not suitable for the purpose, at an average cost of 3 cts. per lin. ft. Placing: 2,534 lin. ft. of fencing was placed at an average cost of 16.3 cts. per lin. ft. This includes drilling five ⅝-in. × 3-in. holes in the sandstone coping for every 12 ft. length of fence, placing all bolts, etc. Painting: 2,324 ft. of fencing was painted at an average cost of 5.5 cts. per lin. ft. This is for one coat and includes cleaning off all rust. Fence consists of 3-in. pipe rail and 4-in. by 4-in. ornamental posts 12 feet apart. Bolted lug midway of each section.

Crossover Pipe.—Setting: 14.85 tons of 42-in. cast iron water pipe was set at an average cost of $4.49 per ton. This includes some sheeting and the use of a pipe derrick. Cutting: The 42-in. cast iron pipe was cut in two at three sections outside the trench, by two men using cold chisels at an average cost of $1.50 per cut. The pipe was cut at two sections after the main was in place, in soft ground, at an average cost of $11.50 per cut. Calking: 12 joints in the 42-in. cast iron water pipe were calked by the calkers of the water department at an average cost, including yarning, melting lead, pouring, etc., of $2.41 per joint. This pipe inclines 22½ degrees from the vertical.

Making Bolts.—136 bolts ⅝ × 4½ ins. were made at an average cost of 5 cts. each. 660 bolts ½ × 5 ins. were made at an average cost of 4.3 cts. each. These figures include welding on heads or upsetting, and threading bolts and nuts.

LABOR COST DATA ON CLEAR WATER BASIN IN 1911

Ground and Segmental Arch Forms.—Building: 25,964 sq. ft. of these forms were built at an average cost of 5.2 cts. per sq. ft., including oiling. Transporting: 367,832 sq. ft. of these forms were transported a distance averaging between 200 and 300 ft. at an average cost of 0.6 cts. per sq. ft.

This cost includes hoisting 289,100 sq. ft. of the forms through a height of 22 ft. Setting: 346,731 sq. ft. of these forms were set at an average cost of 1.9 cts. per sq. ft. This includes all bracing, repairs and reoiling. Wrecking: 334,214 sq. ft. of these forms were wrecked an average cost of 1.7 cts. per sq. ft. This includes the wrecking of all braces. In all the foregoing square feet of formwork refers only to the portion exposed to concrete.

Supporting Posts.—Building: 108 supporting posts for the arch forms were built at an average cost of 18 cts. each. This includes the cost of transporting the posts. Setting: 3,524 posts were set at an average cost of 46.7 cts. each. This includes wrecking the posts and hauling them. The cost of wrecking only on 174 posts averaged 2.9 cts. each.

Column Forms.—Building: 3,330 sq. ft. of forms were built at an average cost of 1.3 cts. per sq. ft. Transporting: 17,200 ft. B. M. of these forms was transported about 800 ft. at an average cost of 95 cts. per 1,000 ft. B. M. Setting: 123,243 sq. ft. of these forms were set at an average cost of 3 cts. per sq. ft., including transporting to place and reoiling. Placing Clamps: 16,029 clamps were placed at an average cost of 5.7 cts. each. Wrecking: 112,478 ft. B. M. of these forms were wrecked at an average cost of $10.24 per 1,000 ft. B. M. This includes removal of clamps.

Making Clamps.—4,807 clamps were made at an average cost of 1.2 cts. each.

Tearing Up Forms.—101,930 ft. B. M. of forms were torn up at an average cost of $1.87 per 1,000 ft. B. M.

Sawing Wedges.—1,880 wedges were sawed at an average cost of 1 ct. each.

Recovery of Lumber.—128,200 ft. B. M. of lumber was recovered from the torn down forms at an average cost of $4.10 per 1,000 ft. B. M. This work was the pulling of old nails, removing concrete from the boards, etc.

42-in. Conduit Forms.—Making: 111 sq. ft. of collapsible forms were built at a cost of 17.8 cts. per sq. ft. Setting: 7,779 sq. ft. of 42-in. conduit forms were set at an average price of 2½ cts. per sq. ft. This included oiling and bracing.

Setting Forms for Pedestals.—726 pedestal forms were set at an average cost of 68½ cts. These forms were dropped onto the pedestals and squared up for holding up the column forms.

Concreting.—Conduit: 158 cu. yds. of concrete were placed in the 42-in. conduit at an average cost of $1.58 per cu. yd. This included placing the reinforcing bars. Columns and Groined Arches: 10,933 cu. yds. of concrete were placed at an average cost of 94 cts. per cu. yd. The average haul was 650 ft.

Holes for Pedestals.—Backfilling: 269 cu. yds. were backfilled at an average cost of 59 cts. per cu. yd. Sealing Up: 64 cu. yds. of concrete were used in sealing up holes for pedestals at an average cost of $3.22 per cu. yd. This concrete floor was 6 ins. thick and the cost given covers the 1:2 cement mortar finishing coat.

Tearing Up Old Revetment.—1,589 cu. yds. of the old revetment wall were torn up and hauled away at an average cost of 51 cts. per cu. yd.

Filling on Top of Basin.—36,949 cu. yds. were filled at an average cost of 48.5 cts. per cu. yd. The average haul was 1,200 ft. Common dump wagons were used. All earth was shoveled by hand.

Transporting Lumber.—170,590 ft. B. M. of old form lumber was transported 1,000 ft. at an average cost of $4 per 1,000 ft. B. M.

The total classified costs of this work on the clear water basin are given in Chap. VI. Dams, Reservoirs and Standpipes.

COST DATA ON FILTERS IN 1911

Excavation.—1,454 cu. yds. were excavated and hauled between 300 and 350 ft. with scrapers at an average cost of 26 cts. per cu. yd. 600 cu. yds. were shoveled into dump wagons and hauled 450 ft. at an average cost of 38.7 cts. per cu. yd. 265 cu. yds. were excavated by pick and shovel for the 36-in. drain at an average cost of 69 cts. per cu. yd.

Mixing and Placing Concrete.—This includes all track, trestle and runway building, moving, and wrecking same. Track 24-in. gage, 16-ft. sections. Runways 10 ft. × 16 ft. of 2-in. material. Inverted Arches: 855 cu. yds. of concrete mixed and placed at average cost of $1.21 per cu. yd. Foundation Walls: 445 cu. yds. concrete, average cost of $1.42 per cu. yd. Columns and Groined Arches: 1,423 cu. yds. of concrete, average cost of 47 cts. per cu. yd. Filter Boxes: 1,312 cu. yds. of concrete, average cost of $1.47 per cu. yd. Sewer and Lateral Gutters: 30 cu. yds. of concrete in the sewer cost on an average $1.39 per cu. yd. 55 cu. yds. of concrete in the lateral gutters cost an average of $2.39 per cu. yd.

Making and Setting Forms.—Areas given below are for contact with concrete. Costs given include all necessary supports, braces, scaffolds, etc. Inverted Groined Arches: 6,110 sq. ft. of forms at average cost of 3.7 cts. per sq. ft. Foundation Walls: 26,793 sq. ft. of forms at average cost of 4.2 cts. per sq. ft. Column Forms: 4,628 sq. ft. of column forms at average cost of 3⅓ cts. per sq. ft. 30 clamps were made and placed at an average cost of $1.19 each. and 458 column collars were made and set at an average cost of 12 cts. each, Groined and Barrel Arches: 40,355 sq. ft. of forms at an average cost of 3.6 cts. per sq. ft. Groined Arch Supports: The total cost of the groined arch supports was $151.94. Among other items 94 posts were set at 22 cts. each, 360 struts at 2 cts. each, and 118 intermediate posts at 13 cts. each. Filter Boxes: 75,174 sq. ft. of forms were set at an average cost of 5.9 cts. per sq. ft. Lateral Gutters: 3,328 sq. ft. of forms were oiled at 0.3 cts. per sq. ft. 2,113 sq. ft. of forms were built and set for 7.4 cts. per sq. ft., average. Sewer: 2,449 sq. ft. of sewer forms were built and set at an average cost of 8.8 cts. per sq. ft.

Backfill.—495 cu. yds. of backfill was hand-tamped at an average cost of 81 cts. per cu. yd. This was clay placed under all cast iron pipes.

Bending Steel.—7,063 lbs. of reinforcing steel were bent at an average cost of 0.63 cts. per lb.

Setting Steel.—129,295 lbs. of reinforcing steel was set at an average cost of 0.72 ct. per lb. This steel was tied at all intersections with No. 16 wire. The cost given includes transporting the steel 350 ft. at approximately 0.1 ct. per lb.

Transporting Pipe and Specials.—216.7 tons of cast iron pipe and specials were rolled about 200 ft. by hand at an average cost of 90.4 cts. per ton.

Setting Pipe and Specials.—130 tons of pipe and specials were set at an average cost of $8.25 per ton. This includes the erection of derricks, scaffolds, etc., necessary for setting the material.

Setting Pipe Hangers.—144 short pipe hangers were set at average cost of 8½ cts. each. 46 long pipe hangers were set at 98½ cts. each.

Wrecking Groined Arches and Conduit Forms.—21,586 sq. ft. of these forms were wrecked at an average cost of 1.4 cts. per sq. ft. This includes wrecking of scaffolds, braces, supports, etc., also hoisting out the groined arch form sections.

Wrecking Wall Forms.—63,905 sq. ft. of wall forms were wrecked at an average cost of 1½ cts. per sq. ft. This includes wrecking braces, supports, scaffolds, etc.

Transporting Form Lumber.—73,290 ft. B. M. were transported in common dump wagons, unsuited to purpose, at a cost of $4.14 per 1,000 ft. B. M.

Cutting Pipes.—Two men cut the pipe with cold chisels. 16 pieces of 18-in. pipe were cut at an average cost of 50 cts. per cut. 3 pieces of 20-in. pipe were cut at average cost of 60 cts. each. 3 pieces of 24-in. pipe were cut at average cost of 75 cts. each.

Setting I-Beams.—12.35 tons of I-beams were set at an average cost of $7 per ton. This includes the use of derricks, etc. 48 plates were set under the I-beams at an average cost of 82 cts. each.

Calking Joints.—This includes yarning, heating lead, pouring, etc.:

27 18-in. joints were calked at average cost of	$1.01
35 18-in. joints were calked at average cost of	90 cts.
90 20-in. joints were calked at average cost of	1.12
15 20-in. joints were calked at average cost of	1.00
10 24-in. joints were calked at average cost of	1.46
21 24-in. joints were calked at average cost of	1.19

Making Pipe Hangers.—120 1-in. × 18-in. pipe hangers were made at an average cost of 27 cts. each. One end of each hanger was upset to 1¼ in.

LABOR COST DATA ON FILTERS AND FILTER HOUSE IN 1912

Earthwork.—Excavation: 2,409 cu. yds. of clay was excavated with pick and shovel at average cost of 65.2 cts. per cu. yd. Some of this clay was handled three times. The cost includes a small amount of sheeting. Fill: 6,494 cu. yds. of fill was made at an average cost of 44½ cts. per cu. yd. Sandy soil was used and was tamped by hand under pipes. The average haul of material was 800 ft.

Making and Setting Forms.—Ridge Blocks and Lateral Gutters: 60,110 sq. ft. of these forms were made and set at average cost of 1.7 cts. per sq. ft. These were collapsible forms bolted together. Cost includes oiling and cleaning after collapsing. Beams and Columns: 23,893 sq. ft. of these forms were built and set at average cost of 9.7 cts. per sq. ft. This includes clamping column and beveling all beams. Cost includes all supports, etc. Roof and Floor Slabs: 24,539 sq. ft. of these forms were set at an average cost of 7.1 cts. per sq. ft. These areas indicate only surface of form in contact with concrete. This cost includes all bracing, supports and wiring.

Wrecking Forms.—102, 747 sq. ft. of forms were wrecked at an average cost of 1.2 cts. per sq. ft. This includes wrecking bracing and supports.

Reinforcing Steel.—Transporting: 86,481 lbs. of reinforcing steel was transported an average distance of 350 ft. at 0.2 ct. per lb. Bending: 23,481 lbs. of steel were bent at an average cost of 0.4 ct. per lb. Setting: 12,992 lbs. of reinforcing steel were set at an average cost of 0.4 ct. per lb. This includes wiring with No. 16 annealed wire at all intersections.

Electrical Work.—3,369 lin. ft. of ½ to 1-in. conduit was placed at a cost of 5.9 cts. per ft. 13,110 ft. of insullated wire was placed at 0.7 ct. per ft. 11 switch boxes were set at 25 cts. each. 10 arc lights were set at $1.50 each, and 8 arc lights were set at $1.00 each.

Concreting.—Lateral Gutters: 86 cu. yds. of concrete were placed at average cost of $6.10 per cu. yd. This includes firing of salamanders in each filter box for 72 hours continuously. Floors, Roof, etc.: 608 cu. yds. of concrete were placed at average cost of $1.50 per cu. yd. Ridge Blocks: 325 cu.

yds. of concrete were placed at average cost of $2.86 per cu. yd. This includes placing screen bolts and all reinforcing steel in each block.

Placing Lateral Gutter Weirs.—5,800 lin. ft. of concrete were placed at an average cost of 7.3 cts. per ft.

Ridge Blocks.—Transporting: 314.52 cu. yds. of ridge blocks were transported an average distance of 300 ft. and were hoisted from 20 to 23 ft. at an average cost of $1.39 per cu. yd. Setting: 305 cu. yds. of ridge blocks were set at an average cost of $6.97 per cu. yd. This includes all drilling for anchor rods, cutting and placing rods, grouting in rods, and chipping concrete.

Setting Strainer Plates.—3,736 strainer plates were set at an average cost of 32.8 cts. each. This includes cementing up, bolting, chipping concrete where necessary, etc., complete.

Laying Screen.—15,292 sq. ft. of screen was placed at an average cost of 6.2 cts. per sq. ft. This includes sewing with No. 20 wire, placing washers and bolting down.

Gravel.—Screening: 368.85 cu. yds. of gravel was screened at an average cost of $4.02 per cu. yd. Hauling: 265 cu. yds. of gravel was hauled at an average cost of $1.04 per cu. yd. Placing: 242 cu. yds. of gravel were placed at an average cost of $3.62 per cu. yd. This includes placing in wheelbarrows, hoisting 20 to 23 ft. and wheeling to place.

Filter Sand.—Hauling: 948 cu. yds. of filter sand was hauled 1½ miles at an average cost of 67 cts. per cu. yd. This includes loading from cars and wagons. Placing: 563 cu. yds. of sand was placed at an average cost of 54½ cts. per cu. yd.

Laying Brick.—221,700 brick were laid at an average cost of $12.50 per 1,000. This includes cost of mixing and coloring mortar, and all scaffold work.

Setting Terra Cotta.—14 terra cotta sills were set at an average cost of $2.14 each. Five were set at $1.20 each. 377 lin. ft. of terra cotta was set at an average cost of 14 cts. per ft.

Roofing.—82¾ squares of roofing were placed at an average cost of $3.54 per 100 ft. square. This includes placing tarred felt and shingles.

Setting Window Sashes and Frames.—171 frames and sashes were set at an average cost of 73 cts. each. This includes setting the necessary hardware.

Transporting Pipe, Valves, Specials and Machinery.—418 tons were transported through distances ranging from 150 ft. to 350 ft. at an average cost of $1.56 per ton. This includes loading, hauling, unloading, picking loose from frozen ground, etc.

Setting Pipe and Specials.—476 tons were set at an average cost of $2.00 per ton. This includes scaffolds, derricks, belting, etc.

Pipe Hangers and Supports—

Making:

No. of hangers	Size of hangers	Av. cost per hanger
31	¾ in. × 7 ft.	$1.24
7	⅞ in. × 29 ft.	2.26
12	⅞ in. × 23 ft. 3 ins.	2.15
31	⅞ in. × 18 ft. 6 ins.	1.38
17	¾ in. × 6 ft. 4 ins.	1.26
12	¾ in. × 6 ft.	0.37
18	1¼ ins. × 18 ins.	0.81
11	1¼ ins. × 7 ft. 9 ins.	0.85

Placing:

No. of hangers	Size of hangers	Av. cost per hanger
24	¾ in. × 7 ft.	$0.59
31	⅞ in. × 18 ft. 6 ins.	0.75
14	¾ in. × 21 ft. 6 ins.	1.17
3	¾ in. × 6 ft. 4 ins.	0.75
24	¾ in. × 6 ft.	1.20
18	1¼ ins. × 18 ins.	0.50
11	1¼ ins. × 7 ft. 9 ins.	0.14

Setting Hydraulic Gates:

Size, ins.	No. gates	Av. cost setting
12	14	$1.56
20	12	5.30
30	1	8.25
24	12	1.56

These costs include scaffolds, derricks, gaskets, etc.

Making Bolts:

Diam., ins.	No. bolts	Cost per bolt
½	147	1.7 cts.
⅞	553	8.3 cts.
1	688	9.6 cts.
¾	106	8.4 cts.
⅝	50	3.4 cts.

Ladder Rungs.—42 ¾-in. ladder rungs were made at an average cost of 33 cts. each. Sixty-four rungs were set at an average cost, including grouting, of 18 cts. each.

Transporting Lumber.—141,676 ft. B. M. of lumber was carried about 250 ft. at an average cost of $2.32 per 1,000 ft. B. M.

Cleaning Walls.—20,070 sq. ft. of brick wall was scraped free of cement and mortar and washed with a dilute solution of hydrochloric acid at an average cost of 2.1 cts. per sq. ft.

Drilling Holes in Concrete.—The following data shows the cost of drilling holes in concrete by hand:

Size of holes, ins.	No. of holes	Av. cost per hole
1⅜×9	3	$1.48
1¼×6	25	0.14
1⅛×8	8	0.63
1⅛×9	10	0.24
1⅜×9	18	0.15
1 ×4	30	0.09
⅝×2½	761	0.07

Painting.—27,500 sq. ft. of painting was done, one coat, at an average cost of 1 ct. per sq. ft.

Setting Small Pipe.—The following data relates to steam and vacuum pipe: 850 ft. of 1½-in. and 2-in. pipe was set at an average cost of 19 cts. per ft.

Setting Gate Stands.—Two stands for 36-in. × 48-in. sluice gates were set at an average cost of $2.87 each.

Placing Window Operating Device.—391 ft. of window operating rods were placed at an average cost of 28 cts. per ft. This includes setting all gears, brackets, chains, etc., complete.

Finish Coat on Roof.—A 1:2 cement coat from ¼ to ¾-in. thick was placed on the cinder concrete roof. 9,736 sq. ft. were placed at average cost of 3.7 cts. per sq. ft.

LABOR COST DATA ON HEAD HOUSE IN 1911

Excavation.—2,304 cu. yds. of material were excavated at an average unit cost of 50½ cts. Of this amount, 350 cu. yds. were hauled 750 ft. in dump wagons and 900 cu. yds. were of soft and sticky material excavated by hand tools.

Backfill.—125 cu. yds. of material were backfilled, at an average unit cost of 63 cts. per cu. yd. This material was tamped by hand.

Building Forms.—The following cost data on form building are stated in cents per sq. ft. The area considered is that portion which is exposed to the concrete only. The cost includes all bracing, supports, scaffolds, etc., complete.

Wall Forms.—41,620 sq. ft. of wall forms were built at an average unit cost of 6.9 cts. per sq. ft.

Beam and Column Forms.—29,039 sq. ft. of beam and column forms were built at an average cost of 3.9 cts. per sq. ft.

Stair Forms.—1,687 sq. ft. of stair forms were built at an average cost of 13.9 cts. per sq. ft.

Floor Forms.—7,629 sq. ft. of floor forms were built at an average cost of 5.9 cts. per sq. ft.

Wrecking Forms.—The area of forms wrecked is stated in terms of square feet, exposed to concrete only. The cost includes the removal of all bracing, supports, etc.

Wrecking Wall Forms.—34, 972 sq. ft. of wall forms were wrecked at an average unit cost of 0.86 ct. per sq. ft.

Wrecking Beam Column and Stringer Forms.—24,450 sq. ft. of these forms were wrecked at an average unit cost of 0.45 ct. per sq. ft.

Wrecking Floor Forms.—8,150 sq. ft. of floor forms were wrecked at an average unit cost of 0.81 ct. per sq. ft.

Transporting Lumber.—10,400 ft. B. M. of lumber was transported at an average unit cost of $3.72 per 1,000 ft. B. M. For this purpose ordinary dump wagons were used, and were not well suited to the purpose. The haul ranged from 300 to 500 ft.

Cleaning Lumber.—33,086 ft. B. M. of lumber was cleaned at an average unit cost of $6.38 per 1,000 ft. This includes cleaning off concrete and pulling out old nails.

Building Beam Supports.—663 sq. ft. of beam supports were built at an average unit cost of 14.6 cts. per sq. ft.

Bending Steel and Making Steel Column Reinforcement.—56,753 lbs. of steel were handled for this purpose at an average unit cost of $6.08 per 1,000 lbs. This includes the wiring together of the column reinforcement with No. 16 gage wire.

Setting Steel.—120,412 lbs. of steel were set at an average unit cost of $7.44 per 1,000 lbs. This includes wiring with No. 16 gage wire at all intersections of reinforcing material.

Concreting Floors, Columns and Bins.—1,575 cu. yds. of concrete were placed at an average unit cost of $1.43 per cu. yd. This includes the cost of raising elevator, etc.

Concreting Walls.—531 cu. yds. of concrete were placed at an average cost of $1.29 per cu. yd. This inicudes raising the elevator, etc.

Finishing Floors.—5,734 sq. ft. of floor were finished at an average unit cost of 1.45 cts. per sq. ft.

Preparatory Work for Concreting.—425 lin. ft. of track and trestle were erected at an average unit cost of 13.5 cts. per ft.

Setting Sluice Gates.—Four 36 × 48-in. sluice gates were set at an average cost of $21.45 per gate. One 42-in. sluice gate was set at a cost of $13.15.

Placing Cast Iron Pipe and Specials.—6.2 tons of 42-in. cast iron pipe and specials were placed at an average unit cost of $6.91 per ton. This includes a haul of 200 ft.

3.15 tons of 12 and 42-in. cast iron pipe and specials were placed at an average unit cost of $9.54 per ton. One ton of 12-in. pipe was placed at a cost of $2. The foregoing figures include the erection of derricks, scaffolds, etc.

Calking Joints.—Two joints in the 42-in. pipe lines were calked at an average cost of $2 per joint. This includes yarning, heating lead, etc.

Electrical Conduit.—500 ft. of 1-in. electrical conduit were placed at an average cost of 3.1 cts. per ft.; 100 ft. of 1¼-in. electrical conduit were placed at an average cost of 2½ cts. per ft.; 450 ft. of 1 to 2-in. electric conduit were placed at an average cost of 5 cts. per ft. These figures include transporting the conduit materials.

Manholes.—Three 24-in. manholes were placed on the hypo tanks at an average cost of $1.69 each.

Making Column Clamps, Blocks and Wedges.—75 column clamps were made at an average cost of 30 cts. each.

150 blocks and wedges were made at 1.6 cts. each.

Pipe Supports and Hangers, etc.—20 1-in. by 5-in. by 15-in. pipe supports and hangers were placed at an average cost of 42 cts. each.

60 trolley hangers were placed at an average cost of 20 cts. each. These figures include grouting in.

LABOR COST DATA ON HEAD HOUSE IN 1912

Making Fill.—2,020 cu. yds. of fill were made at an average unit cost of 48.7 cts. per cu. yd. This includes an average haul of 1,500 ft.

Building Forms.—Wall and Foundation Forms.—24, 965 sq. ft. of wall and foundation forms were built at an average unit cost of 5½ cts. per sq. ft. This includes only the surface in contact with concrete. Cost of erecting scaffolding and bracing is included.

Floor and Roof Forms.—20, 433 sq. ft. of floor and roof forms were built at an average unit cost of 8.7 cts. per sq. ft.

Building Tank Forms.—1,335 sq. ft. of tank forms were built at an average unit cost of 8.4 cts. per sq. ft.

Wrecking Forms.—46,294 sq. ft. of forms were wrecked at an average cost of 2.1 cts. per sq. ft. This includes wrecking scaffolds and bracing.

Transporting Lumber.—21,996 ft. B. M. of lumber was transported an average distance of 300 ft. at an average unit cost of $5.60 per 1,000 ft. B. M.

Cleaning Lumber.—6,000 ft. B. M. lumber was cleaned at an average unit cost of $8.80 per 1,000 ft. B. M. This included pulling out old nails and scraping off concrete which adhered to boards.

Reinforcing Steel—Bending.—5,369 lbs. of reinforcing steel were bent at an average cost of $3.26 per 1,000 lbs.; 34,540 were transported at $1.84 per 1,000 lbs.; 35,868 lbs. were set at $6.07 per 1,000 lbs. This includes the cost of wiring with No. 16 gauge wire at every intersection of reinforcing rods.

Structural Steel—Transporting.—21.09 tons of structural steel were transported a distance of 1,600 ft. at an average unit cost of $9.35 per ton.

Setting.—21.86 tons of structural steel were set at an average unit cost of $12 per ton. This includes all wall plates, bolts and rivets.

Concrete—Roof and Thin Walls.—431 cu. yds. of concrete were placed in the roof and thin walls at an average unit cost of $2.08 per cu. yd.

Foundation and Heavy Walls.—148.35 cu. yds. of concrete were placed in foundation and heavy walls at an average unit cost of $1.27 per cu. yd. The foregoing costs on concreting include the erection of runways, scaffolds, etc.

Finishing Floors, Roofs, etc.—17,158 sq. ft. were finished at an average unit cost of 4 cts. per sq. ft. This is for placing a 1:2 cement plaster from ½ in. to 1½ ins. thick.

Placing Expanded Metal Lath and Rib-Truss for Ceiling and Partitions.—7.568 sq. ft. of this material were placed at an average unit cost of 8.3 cts. per sq. ft. This includes all iron studs and part of the ceiling supports, etc.

Plastering.—31,711 sq. ft. of plastering were figured as a single coat and the average unit cost was 3.13 cts. per sq. ft.

Laying Brick.—158,800 brick were laid at an average unit cost of $14.60 per M. This includes all scaffolding. The brick was laid in Flemish bond. Three kinds of mortar were used.

Washing Walls.—8,800 sq. ft. of walls were washed at an average unit cost of 2.3 cts. per sq. ft. A dilute solution of hydrochloric acid was used for this purpose. The cost given includes the cost of erecting and removing the necessary scaffolding.

Windows and Doors.—18 window sills were set in the brick work after it was finished at an average unit cost of $3.26 each.

Copper Work.—Valley, Deck and Flashing.—4,044 sq. ft. of valley and deck copper work were placed at an average unit cost of 2.7 cts. per sq. ft.; 1,323 lin. ft. of flashing were laid at an average unit cost of 7.2 cts. per ft., 1,152 ft. of flashing were soldered only at a cost of 3.3 cts. per ft.

Ridge Roll, etc.—1,483 lin. ft. were placed at an average unit cost of 7 cts. per ft. In the copper work all the copper was cut and formed on the job.

Roofing.—80.75 squares of roofing were placed at an average cost of $4.24 per square. This roofing consisted of asbestos shingles each 16 × 16 ins., placed on a 1:2:4 cinder concrete roof with a layer of tarred felt between.

Electric Work—Conduit, ½-in. to 2-in.—2,435 lin. ft. of conduit were placed at an average unit cost of 5 cts. per ft. This includes the placing of all fittings.

Wiring.—13,190 lin. ft. of electric wiring were placed at an average unit cost of 1.1 cts. per ft. All the wires were well covered.

Cast Iron Pipe and Specials—Transporting.—102.57 tons of cast iron pipe and specials were transported at an average unit cost of $2.87 per ton.

Setting—61.94 tons of cast iron pipe and specials were set at an average unit cost of $3.50 per ton. The foregoing costs include the transporting and setting of scaffolds, derricks and all other necessary equipment.

Calking Joints.—Seven 42-in. joints were calked at an average cost of $1.91 each.

24 6-in. joints were calked at an average cost of 49 cts. each.

31 4-in. joints were calked at an average cost of 56 cts. each. Figures for calking include yarning, pouring, melting lead, erection of scaffolds, etc.

Setting Radiators.—6,942 sq. ft. of radiators were set at an average unit cost of 3.1 cts per sq. ft.

2-in. Lead Pipe.—233 wiped joints were made at an average cost of 60 cts. each. This includes heating, soldering, etc.

Setting.—1,019 lin. ft. of 2-in. lead pipe were set at an average unit cost of 0.5 ct. per ft. All this pipe weighed 7½ lbs. per ft. The cost given includes straightening pipe and placing all valves and fittings.

Small Pipe and Fittings.—The following costs relate to the small pipe and fittings which were installed in the heating, plumbing and vacuum cleaner systems. All valves and fittings, etc., were figured as straight pipe. The costs include all cutting, threading, transporting, etc. The cost of the necessary scaffolding is also included. All the work was done by hand, and some of it was very difficult.

Size of pipe, ins.	Amount placed, ft.	Aver. cost per ft., cts.
¼ to ⅜	127	9.2
½	1,147	6.7
¾	1,804	12.4
1	1,351	13.1
1¼	509	16.5
1½	1,657	24.4
2	1,251	25.7
2½	552	35.9
3	587	43.4
3½	209	37.7
4	422	50.4
4½	132	59.4
5	58	40.0
6	39	49.0

Soil Pipe.—The soil pipe was all placed by plumbers, working most of the time upon scaffolds. Everything connected with the installation of the soil pipe is included in the following costs: 122 ft. of 2-in. soil pipe were placed at an average unit cost of 16.9 cts. per ft.; 87 ft. of 3-in. pipe at 22.5 cts. per ft. and 307 ft. of 4-in. soil pipe at 53.0 cts. per ft.

Making Pipe Hangers.—A total of 532 pipe hangers were made at an average cost of 29 cts. each. These hangers were made of round iron, and the cost includes upsetting, threading, etc. The ¾ × 16-in. hangers were most expensive at 65 cts. each, and the ⅜ × 50-in. hangers cost for labor only 8 cts. each.

Setting Hangers.—445 hangers were set at an average cost of 44½ cts. each. This includes drilling, etc.

Transporting Castings, Machinery, etc.—52 tons of these materials were transported a distance ranging from 50 to 500 ft. at an average unit cost of $2.12 per ton. This includes all necessary loading and unloading.

Placing Miscellaneous Castings.—5,600 lbs. of miscellaneous castings were placed at an average cost of 1 ct. per pound. This includes necessary derricks, scaffolds, etc.

Painting.—42,176 sq. ft. of painting was done, figured as a single coat at 1.2 cts. per sq. ft.

Hand Rails.—360 lin. ft. of hand rails were placed at 29.1 cts. per ft. including all fittings.

Steel Ladders.—These ladders are about 6 ft. long and are of ⅜ × 3-in. iron and ¾-in. round rungs. Four of these were made at $3.71 each, and they were set at 44 cts. each.

Setting Laboratory Tables.—16 laboratory tables, each of oak 38 ins. high and 36 ins. wide; with tops 3 ins. thick, were set at an average cost of $3.65 each.

Excavation.—126 cu. yds. of red clay were excavated at an average cost of 53 cts. per cu. yd.

Calked Soil Pipe Joints.—Following are costs of calking joints in 2, 3 and 4-in. soil pipe, as made by plumbers:

Size, ins.	Av. cost per joint, cts.
2	42
3	48
4	48

Plumbing Fixtures.—A sum of $60 was spent for setting 23 plumbing fixtures, such as wash basins, urinals, showers, sinks, water closets and towel racks.

Setting Small Gates.—66 small gate valves, ranging in diameter from 3 ins. to 10 ins. were set at an average cost of 64 cts. per gate. This includes all gaskets, bolting up and fitting.

Making Bolts.—605 bolts were made at an average cost of 7 cts. each. These bolts were from ½ to 1½ ins. in diameter. The greatest length was 15 ins. The cost given includes cutting steel, welding on heads, threading of bolts and nuts, complete.

LABOR COST DATA ON COAGULATION BASIN IN 1911

Excavation.—605 cu. yds. of material were excavated in trench by pick and shovel at an average unit cost of 60.3 cts. per cu. yd.

Backfill.—350 cu. yds. were backfilled and hard tamped under 60-in. pipe at an average unit cost of 70 cts. per cu. yd.

375 cu. yds. were backfilled at 55 cts.

Setting Forms.—2,025 sq. ft. of forms were set at an average unit cost of 5.8 cts. per sq. ft. The area given is that exposed to concrete only. The cost given includes all bracing.

Setting Screeds.—7,433 lin. ft. of screeds were set at an average unit cost of 1.5 cts. per ft.

Making Forms.—610 sq. ft. of forms were made at an average unit cost of 5.8 cts. per sq. ft. The area given is that exposed to concrete only. All bracing is included. These forms were used about seven times.

Setting Steel.—38,333 lbs. of steel were set at an average unit cost of $4.25 per 1,000 lbs. This figure includes the hauling of the steel.

Placing Concrete.—1,087 cu. yds. of concrete were placed at an average unit cost of $1.16 per cu. yd. This includes the setting of expansion plates, and giving to the concrete a float finish.

Laying Cast Iron Pipe and Specials.—25.72 tons of cast iron pipe and specials were laid at an average cost of $9.65 per ton. Of this amount, 10.6 tons was 12-in. pipe and the balance 60-in. pipe. The cost of making one cut on 60-in. pipe is included.

Setting 60-in. Gate Valve.—A 60-in. gate valve weighing 6 tons was set at a lump sum of $188.50

Building Manholes.—2.6 M. of brick were placed in manholes at an average cost of $7.10 per M. The manholes were round, and the cost given includes the placing of 9 ladder rungs.

Driving Sheeting.—300 sq. ft. of sheeting were driven at an average unit cost of 2.7 cts. per sq. ft. This sheeting was 2 × 10-in. stuff.

LABOR COST DATA ON COAGULATION BASIN IN 1912

Excavation.—883½ cu. yds. of red clay were excavated by pick and shovel in trench at an average unit cost of 84 cts. per cu. yd.; this includes all necessary sheeting.

Fill.—14,580 cu. yds. of fill were made at an average unit cost of 48.8 cts. The fill was not rolled. A 24-in. puddle wall was hand-tamped in layers ranging in thickness from ½ to 2 ins., and the cost is averaged in the foregoing. The cost of puddling was 54 cts. per cu. yd.

Building Forms—Heavy Walls.—50,578 sq. ft. of forms were built at an average cost of 7.1 cts. per sq. ft. The area exposed to concrete only is figured on all form work. The cost includes all scaffolds, braces, supports, etc.

Thin Wall Forms.—28,566 sq. ft. of forms were built at an average cost of 12.8 cts. per sq. ft.

Floor Column and Beam Forms.—45,240 sq. ft. of beam forms were built at an average unit cost of 9.7 cts. per sq. ft.

Wrecking Forms.—121,702 sq. ft. of forms were wrecked at an average unit cost of 1½ cts. per sq. ft.

Transporting Lumber.—164,563 ft. B. M. of lumber was transported at an average unit cost of $3.52 per 1,000 ft. B. M. The average haul was 1,000 ft. A common dump wagon was used and was not well suited to the purpose.

Reinforcing Steel—Transporting.—192,029 lbs. of steel were transported an average distance of 1,500 ft. at an average unit cost of 80 cts. per 1,000 lbs.

Bending.—106,787 lbs. of steel were bent at an average unit cost of $1.15 per 1,000 lbs.

Setting.—234,295 lbs. of reinforcing steel were set at an average unit cost of $4.25 per 1,000 lbs. This includes wiring together of all steel at intersections with No. 16 gage wire.

Structural Steel—Transporting.—9.61 tons were transported an average distance of 1,500 ft. in common dump wagons at an average cost unit cost of 98 cts. per ton.

Setting.—9.61 tons were set at an average unit cost $12.13 per ton. This includes all hoisting, bolting up, riveting wall plates, etc.

Concreting—Heavy Walls.—1,198 cu. yds. of concrete were placed at an average unit cost of $1.11 per cu. yd. This does not include the necessary track trestle and runways.

Concrete Floors, Roof and Thin Walls.—1,413.5 cu. yds. of concrete were placed at an average unit cost of 97 cts. per cu. yd.

Track and Trestle.—1,711 lin. ft. of track and trestle were placed at an average unit cost of 7.6 cts. per ft. All this work was 24-in. gage in 16-ft. sections. The runways were 5 × 16 ft., of 7-in. material.

Finishing Roof and Floors.—5,818 sq. ft. of 1:2 cement finishing coat ranging in thickness from ½ to 1½ ins. were placed at an average cost of 6.1 cts. per sq. ft.

Transporting—Castings, etc.—141 tons of castings were transported a distance averaging 500 ft. at an average unit cost of $2.22 per ton. This includes loading and unloading by hand.

Setting Pipe and Specials.—103 tons of pipe and specials were set at an average cost of $3.54 per ton. This includes the erection of a derrick and all necessary scaffolds.

Setting Gate Stands.—21 gate stands were set at an average cost of $3.85 each. This includes bolting down on a bed of 1:2 cement mortar.

Setting Stems.—Stems for 48-in. gates were set at an average cost of $2.50 each.

Setting Sluice Gates.—25 sluice gates were set at an average cost of $6.80 each. These gates are from 42 × 42 ins. to 48 × 60 ins. The cost given includes cutting all necessary gaskets, bolting up, hoisting, derrick, scaffolds, etc.

Small Piping.—1,030 ft. of small piping ranging from ½ to 3 ins. in diameter were placed at an average cost of 7½ cts. per lin. ft. This includes all cutting, threading, fittings, valves, etc., complete.

2-in. Lead Pipe.—1,091 ft. of lead pipe were placed at an average cost of 18 cts. per ft. This includes straightening pipe, putting in fittings and valves, etc. The pipe weighs 7.5 lbs. per ft. 96 wiped joints were made at average cost of 60 cts. per joint.

Electric Wire.—900 ft. of No. 14 insulated electric wire were placed at an average cost of 0.9 ct. per ft.

Laying Brick.—84.5 M of brick were laid at an average cost of $17.90 per M. This includes the work done on electric conduit, window sills, all necessary scaffolds, etc. The brick was laid Flemish bond.

Setting Window Frames.—92 window frames were set at an average cost of $1.17 each.

Washing Walls.—5,030 sq. ft. of walls were washed at an average cost of 2. 6 cts. per sq. ft. A dilute solution of hydrochloric acid was used. The cost given includes all necessary scaffolding.

Painting.—22,925 sq. ft. was painted at an average cost of 1 ct. per sq. ft. The painting was figured as a single coat only, and the cost includes all necessary scaffolds.

Roofing.—85.5 squares of roofing were placed at an average cost of $3.30 per 100 sq. ft. The roofing consisted of asbestos shingles laid on 1:2:4 cinder concrete with a layer of tarred felt between the concrete and shingles. The cost includes all necessary staging.

Copper Work.—235 sq. ft. of copper work was placed at 10 cts. per sq. ft. 266 lin. ft. of copper was placed at 12 cts. per lin. ft.

Baffles.—19,852 ft. B. M. of baffles were placed at an average unit cost of $4.98 per 1,000 ft. The baffles were made of 1 × 6-in. D. & M. fencing.

Wooden Gates.—27 wooden gates were set at an average cost of $2.30 each. These gates were all of 1 × 6-in.M. & D. lumber. Each 24 × 36-in. with a 2 × 4-in. stem. The gates slide in guides. 53 wooden guides were made at an average unit cost of 0.33 cts. each.

Ladder Rungs—Making.—156 ladder rungs were made of ¾-in. round steel at an average unit cost of 11 cts. each.

Placing.—131 ladder rungs were placed at an average unit cost of 18.4 cts. each, which includes grouting in.

Placing Pipe Hangers.—124 pipe hangers were placed at an average unit cost of 27 cts. each. This includes grouting in when necessary.

220 pipe hangers of various sizes were made at an average cost of 23.5 cts.

Making Bolts.—1,173 bolts ranging in diameter from ½ in. to 1½ ins. and in length from 3½ ins. to 35 ins. were made at an average cost of 24 cts. each. This includes welding on heads, cutting steel and threading nuts and bolts. About one-third of the bolts were upset for 6 ins. of their length to 50 per cent excess diameter.

Drilling Concrete.—1,569 holes were drilled in 1:2:4 concrete from 30 to 90 days old at an average cost of 11 cts. per hole. These holes ranged in diameter from ⅜ ins. to 1 in. and in depth from 3 ins. to 8½ ins.

Wood Conduits.—840 lin. ft. of 6 × 6-in. wood conduit were placed at an average cost of 38 cts. per ft. This was . a conduit of 2-in. lumber around outside of 2-in. lead pipe, It was filled with sawdust.

LABOR COST DATA ON WASH WATER TANK IN 1912

Earth Work—Excavation.—694 cu. yds. of very hard clay were excavated with pick and shovel and wheeled in barrows at an average unit cost of 63.4 cts. per cu. yd.

Backfill.—187 cu. yds. of clay were backfilled at an average unit cost of 21.9 cts. per cu. yd. This clay was sprinkled and tamped by hand in 2-in. layers.

Fill.—6,399 cu. yds. of fill were made at an average cost of 44½ cts. per cu. yd. This includes a haul of 1,000 ft.

Puddle.—82 cu. yds. of puddle were placed at an average cost of $2.79 per cu. yd. This material was sprinkled and tamped by hand in layers ranging in thickness from 1½ to 2 ins.

Form Work—Transporting Lumber.—11,819 ft. B. M. was transported an average distance of 300 ft. at a cost of $3.54 per 1,000 ft. B. M.

Walls and Foundation.—14,271 sq. ft. of forms were placed at an average cost of 6.6 cts. per sq. ft. These forms were made of 2-in. lumber. The cost given includes all bracing. Only the area exposed to concrete is given.

Column, Beam and Floor Beams.—10,602 sq. ft. of these forms were built at an average cost of 9 cts. per sq. ft.; 2-in. lumber was used, and the cost includes braces and clamps.

Wrecking.—23,991 sq. ft. of forms were wrecked at an average cost of 1.7 cts. per sq. ft. This is for the area exposed to concrete, and includes the removal of all clamps, braces, etc.

Reinforcing Steel—Hauling.—57,093 lbs. were hauled an average distance of 500 ft. at an average cost of 85 cts. per 1,000 lbs.

Bending.—34,332 lbs. of reinforcing steel were bent at an average unit cost of $1.40 per 1,000 lbs.

Setting.—57,093 lbs of steel were set at an average cost of $4.55 per 1,000 lbs. This includes the wiring of all interesections of reinforcing rods with No. 16 gage wire.

Structural Steel—Hauling.—4.74 tons of structural steel were hauled a distance of 800 ft. at an average cost of 50 cts. per ton.

Setting.—4.74 tons of structural steel were set at an average cost of $9.32 per ton. This includes hoisting, riveting and bolting up.

Concreting.—636 cu. yds. of concrete were placed at an average unit cost of 95 cts. per cu. yd. This includes placing runways, hoisting, etc.

Finishing.—4,043 sq. ft. of 1:2 cement finish coat were placed at an average cost of 3½ cts. per sq. ft.

Brick.—71.2 M of brick were placed at an average cost of $19.40 per M. This includes the erection of scaffolds, hoisting, etc. Round tower bricks were used and were laid in Flemish bond.

Washing Walls.—21 sq. ft. of walls were washed at an average cost of 1.2 cts. per sq. ft. This includes the necessary scaffolding.

Roofing.—19 squares of roofing were placed at an average cost of $6.50 per square. This includes all scaffolding, Since this was a conical roof, the shingles at the last were very small. They were placed on a 1:2:4 cinder concrete.

Painting.—1,250 sq. ft. of painting figured as a single coat was done at an average cost of 1⅓ cts. per sq. ft.

Cast Iron Pipe and Specials—Cutting.—Cast iron pipe was cut with cold chisels, two men working on a cut. Three cuts were made of 12-in. pipe at 28 cts. each. Two cuts of 12-in. pipe were made under water at 93 cts. each. One 24-in. pipe was cut at 70 cts.

Calking.—15 joints in 12-in. pipe were calked at 57 cts. each. One 24-in. joint was calked at $1.90. These figures include yarning, pouring, heating lead, etc.

Laying.—8.81 tons of cast-iron pipe and specials were laid at an average cost of $2.92 per ton. This includes erection of necessary derricks and scaffolds, etc.

Ladder Rungs.—10 ladder rungs of ¾-in. round steel were made at 10 cts. each and set, including drilling holes, grouting, etc., at 26 cts. each.

Cutting Shingles.—3,140 shingles were cut to fit conical roof at $28.80 per 1,000.

COST DATA OF HAULING MISCELLANEOUS, ETC., IN 1914

Hauling—Cement.—24,590 barrels of cement were hauled a distance of 1½ miles at an average unit cost of 10¼ cts. per barrel. 70 bags to a load were hauled over roads which were very bad at times.

Sand.—7,538 cu. yds. of sand were hauled a distance ranging from 300 to 3,000 ft. at an average unit cost of 46½ cts. per cu. yd. 1¼ cu. yds. made a load. The cost given includes all snatch team work.

Steel.—438 tons of steel were hauled a distance of 1½ miles at an average unit cost of $1.35 per mile. This cost includes loading and handling by hand. Some of the steel was in very long sections, and all of it was badly mixed in the cars.

Cast Iron Pipe and Specials.—1,195 tons of cast iron pipe and specials were hauled a distance of 1½ miles at an average unit cost of $1.34 per ton. All pipe was unloaded by hand, no derrick being used.

Miscellaneous Castings and Machinery.—191 tons of miscellaneous castings and machinery were hauled a distance ranging from 1½ to 5 miles, the greater portion of it being 1½ miles, at an average unit cost of $1.67 per ton. All of this material was handled by hand.

Lumber for Forms.—239,500 ft. B. M. of lumber was hauled a distance ranging from 1,500 to 3,000 ft. at an average cost of $1.61 per 1,000 ft. B. M. This material was handled by hand and was hauled in wagons not well suited to the purpose.

Edgings and Waste Material.—93 loads of this class were hauled a distance ranging from 900 to 1,500 ft. at an average unit cost of 86½ cts. per load. All work was done by hand, and the material was all in small pieces.

Recovery of Lumber.—30,500 ft. B. M. of lumber was recovered at an average unit cost of $1 per 1,000 ft. B. M. This includes the pulling out of old nails.

LABOR COST OF HAULING AND MISCELLANEOUS WORK IN 1912

Hauling.—All hauling includes loading, unloading, handling, etc. Common dump board wagons were used in all cases.

Cement.—8,776 bbls. of cement were hauled a distance ranging from 1$\frac{1}{10}$ to 2½ miles at an average cost of 11.6 cts per barrel.

Sand.—3,137 cu. yds. of sand were hauled a distance of 1,200 ft. at an average unit cost of 31 cts. per cu. yd.; 49 cu. yds. of sand were hauled a distance of 20,000 ft. at an average unit cost of $2.15 per cu. yd. The latter sand was frozen to the ground and had to be picked loose.

Cast Iron Pipe and Specials.—552 tons of cast iron pipe and specials were hauled a distance of 3½ miles at an average cost of $1.16 per ton.

Miscellaneous Castings and Machinery.—142 tons of miscellaneous castings and machinery were hauled a distance ranging from 1½ to 4 miles at an average unit cost of $1.65 per ton.

Lumber.—82,000 ft. B. M. of lumber was hauled a distance ranging from 300 to 600 ft. at an average unit cost of 80 cts. per 1,000 ft. B. M.

Waste Material.—2,104 loads of waste material were hauled a distance of 1,200 ft. at an average cost of 60 cts. per load.

Recovery of Lumber.—158,900 ft. B. M. of lumber was recovered at an average unit cost of $3.73 per 1,000 ft. B. M. This included the pulling out of nails and the cleaning off of concrete.

Costs of Concrete Construction in the Water Filtration Plant at Niles, Ohio.—The following data are given by R. A. Boothe in an article published in Engineering and Contracting, Oct. 23, 1912.

Concrete Mixing.—The concrete plant consisted of a half-yard Ransome mixer with a batch hopper. The sand and gravel were shoveled off the cars onto stock piles at a cost of 8 cts. per ton and hauled from there to the mixer in barrows, the average haul being 50 ft. The cement was unloaded directly from the cars into the cement house at a cost of 2 cts. per bbl. and wheeled from there to the mixer.

The usual force employed on the mixer was 2 men wheeling sand, 4 wheeling gravel, 1 wheeling cement, 1 man on the mixer, and an engineer. The engineer and the man on the mixer received 25 cts. per hour and all others 20 cts. This made a total cost per hour of $1.20 and the usual capacity was 9 cu. yds. per hour, making a cost of 13½ cts. per cubic yard for mixing. The capacity has been as high as 12 cu. yds per hour, being controlled by the rate at which the concrete was taken away from the mixer, so the above costs cannot be taken as the capacity of the plant or the cheapest possible costs.

Concrete Floors.—All of the floors were in two layers, the bottom one being 8 ins. thick and the upper one 4 ins. thick, the upper one being laid after the walls were up.

The bottom floor was laid in alternate strips 8 ft. wide and 16 ft. and 30 ft. long, all joints being broken. The lower floor for the entire plant was laid before any of the walls were started, 2 × 6-in. keys being placed for all walls. This floor was made of a 1:2½:5 mix, using river sand and gravel. The pedestals for all of the columns were built with the floor.

For the floors the concrete was dropped from the mixer down a chute into barrows and wheeled into place.

Cost of labor on forms for screen boards and runs on lower layer of floor:

Item		Cost Per sq. yd.	Cost Per cu. yd.
3 carpenters, 67 hrs. at 25 cts.	$50.25	$0.038	$0.172
1 foreman, 53 hrs. at 50 cts	26.50	02	.09
Totals	$76.75	$0.058	$0.262

Cost of labor on concreting lower layer of floors:

Item	Cost	Per cu. yd.
14 men, 47 hrs. at 20 cts	$105.60	
4 men, 41 hrs. at 25 cts	41.00	$0.591
1 superintendent, 41 hrs. at 50 cts	20.50	.07
Water boy, 41 hrs. at 10 cts	4.10	.014
2 finishers, 50 hrs. at 20 cts	20.00	
1 finisher, 38 hrs. at 25 cts	9.50	.101
Totals	$226.70	$0.776

Or $0.173 per square yard.

Labor Cost of Forms, Placing Reinforcement and Concrete Coagulating Basins. —As soon as the floors were laid the walls of the basins were started. In building these one end and half of each side were built together, then the other end and the balance of the sides, and last the dividing wall and baffles. All were built in 5-ft. lifts. The outside walls are 16 ins. thick at the top and 20 ins. thick at the bottom, the latter being on the inside. On top they have an overhang of 26 ins., which with the wall gives a 42-in. walk, 6 ins. thick. The dividing wall is of the same construction while the baffles are 6 ins. thick with an 18-in. walk on top. The walls are all tied together by five 18 × 12-in. beams which extend across both basins.

For reinforcing, the outside walls have ⅞-in. rods 5 ins. on centers for outside verticals, and ½-in. rods 8 ins. on centers for the inside verticals, with ½-in. rods 9 ins. on centers for the horizontals on both sides. The dividing wall has ⅞-in. rods 5 ins. on centers for verticals on both sides and ½-in. rods 9 ins. on centers for the horizontals. The baffle walls are reinforced with expanded metal weighing 0.6 lb. per foot. The ⅞-in. rods in the walls are made long enough to be bent over to reinforce the walks. In addition the walks have three ⅞-in. rods along their edges. All rods are corrugated.

The average inside dimensions of each basin are 97 ft. × 34 ft. 8 ins. and 20 ft. 3 ins. deep with a high water mark 18 ins. below the top.

For the wall forms sheets 10 ft. wide and the full height of the wall were built of ⅞-in. tongue and grooved stuff on 2 × 6-in. studding spaced 18 ins. centers. These were used for the outside forms and were placed and braced in position, then the steel was placed. For this spikes were driven in the forms for every fifth vertical rod and the head allowed to extend out 2 ins. These rods were wired to the spikes, then a horizontal rod at the top and another at the bottom were wired to these, then the rest of the vertical rods were placed and wired to the horizontals, and then the rest of the horizontals were placed. For the inside reinforcing wooden spacers were used instead of spikes. These were fastened to the outside forms and were removed before the concrete was placed. On the inside the horizontal rods were carried up with each lift as they would have interfered with the dumping of the concrete if they had been placed any higher.

After the steel was placed the inside sheets were placed. These were 4 ft. high and 16 ft. long. Wooden spacers were used between the forms and two strings of 4 × 4-in. waling were placed on each side. No. 10 wire was carried through the forms around the waling and twisted on the inside. On top of the 4-ft. sheet a false sheet 1 ft. high was used. It was used so that the 4-ft. sheet could be removed and placed on top for the next lift, the wiring in the false sheet holding it solidly in place.

The runways were built with 4 × 4-in. uprights placed about 6 ft. from the forms. These were the full height of the wall and were X-braced together. Ledgers were spiked across from the forms to the uprights and the runway plank placed on these. These were raised for every new lift. The runway ran around the inside of the basins and back to the mixer; this gave a continuous circuit for the wheelers. The concrete was dropped from the mixer down a chute into the barrows until the height of the mixer was reached and then it was wheeled direct. In building the outside walls keyways and 2-ft. stubs of steel were placed for the dividing and baffle walls,. As each lift was built it was stepped back 2 ft. from the end of the preceding one so that there would not be a continuous vertical joint the height of the wall. When the concrete reached the height of the outlet box a section was left out and this was built with the boxes.

Cost of labor on forms for coagulating basins

Building sheets:

Item.	Cost
11 men, 6 hrs. at 20 cts	$13.20
5 men, 30 hrs. at 25 cts	37.50
2 men, 18 hrs. at 35 cts	12.60
Superintendent 27 hrs. at 50 cts	13.50
Water boy 20 hrs. at 10 cts	2.00
Total cost	$78.80

Or $0.014 per sq. ft. of form surface; or $0.195 per cu. yd. of concrete.

Cost of labor on erecting forms and runs and wrecking same:

Item.	Cost
5 men, 168 hrs. at 20 cts	$168.00
7 men, 190 hrs. at 25 cts	332.50
2 men, 190 hrs. at 35 cts	133.50
Foreman, 160 hrs. at 50 cts	80.00
Water boy, 100 hrs. at 10 cts	10.00
Total cost	$726.50

Cost, $1.802 per cu. yd.
Cost, $0.052 per sq. ft. of concrete surface.

Cost of placing 58,100 lbs. of steel for basins:

Item.	Cost
4 men, 54 hrs. at 20 cts	$ 43.20
7 men, 50 hrs. at 25 cts	87.50
2 men, 42 hrs. at 35 cts	28.40
Superintendent, 33 hrs. at 50 cts	16.50
Water boy, 33 hrs. at 10 cts	3.30
Total cost	$178.90

Cost, $0.0031 per lb., or $6.20 per ton.

Cost of labor on concreting walls of basins:

Item.	Cost	Cost per cu. yd.
19 men, 44 hrs. at 20 cts	$167.20	$0.490 (both rows)
4 men, 44 hrs. at 25 cts	44.00	
Superintendent, 44 hrs. at 50 cts	22.00	055
Water boy, 44 hrs. at 10 cts	4.40	.011
Totals	$237.60	$0.546

Cost of labor on forms for outlet boxes:

Item.	Cost
2 carpenters, 70 hrs. at 35 cts	$ 49.00
2 carpenters, 70 hrs. at 30 cts	42.00
4 carpenters, 70 hrs. at 25 cts	70.00
1 foreman, 70 hrs. at 50 cts	35.00
	$196.00
Less cost of walls included	34.00
Total	$162.00

Cost per cu. yd., $10.80.

Labor Cost of Forms and Concreting Clear Well.—The inside dimensions of the clear well are 26 ft. 4 ins. × 72 ft. 8 ins. and it is 11 ft. deep. The method of construction here was almost the same as that used on the basins except that the walls were built the full height instead of in 5-ft. lifts. For the forms the large sheets that had been used on the basins were cut down and used for both sides, all of the walls being poured at one operation.

Cost of labor on clear well forms:

Item.	Cost
3 men 22 hrs. at 20 cts	$13.20
8 men, 47 hrs. at 25 cts	94.00
2 men, 48 hrs. at 35 cts	33.60
Foreman, 46 hrs. at 50 cts	23.00
Water boy, 20 hrs. at 10 cts	2.00
Total	$165.80

Cost per cu. yd., $1.842.
Cost per sq. ft. of concrete surface, $0.05.

Cost of labor for concreting clear well:

Item.	Cost
20 men, 12 hrs. at 20 cts	$ 48.00
4 men, 12 hrs. at 25 cts	12.00
Superintendent, 12 hrs. at 50 cts	6.00
Water boy, 12 hrs. at 10 cts	1.20
Total	$ 67.20

Cost per cu. yd., $0.747.

Labor Cost of Column Forms.—Fourteen columns, 14 × 14-ins. and 11-ft. long support the roof of the clear well. The column side forms were built in one piece and were held together with 2 × 4-in. clamps and wedges.

Cost of labor on forms for 14 columns:

Item.	Cost
2 men, 22 hrs. at 25 cts	$11.00
2 men, 25 hrs. at 35 cts	17.50
Total	$28.50

Cost per column, $2.04.
Cost per cu. yd., $4.07.

Labor Cost of Forms and Concreting Filters.—Each filter was built complete including floors and walls and walks, and all poured at one pouring. The filter blocks and troughs were placed after the forms were removed. In building the forms all of the sides were built in sheets, the old sheets used on the pump room and clear well walls being used and cut down. The outside and sheets inside the channels were placed first. These rested on the concrete. Then the steel was placed and next the inside sheets were placed. The latter were set on 4-in. concrete blocks so as to form the floor. The walks were built on 2 × 4-in. brackets built out from the sheets and covered with ⅞-in. tongue and groove flooring. Rebate boxes were placed for the cross troughs. When the concrete was placed the floors were placed first with a mixture that was dry enough to tamp and show water on the surface. Then the walls were poured and as the inside forms were 4 ins. off of the bottom the concrete ran through and bonded with the floor. The walls were poured very wet and were well worked. It was found that in places the concrete would boil out under the inside forms but this was left until the next day and then chipped off before it was too hard; at this time the floors were also trimmed up to a level grade as they were always rough and uneven. The forms were braced across the filters and also had walings and wires in them.

Building 12 forms for filter blocks cost $42.50, or $3.54 each.

Labor cost of forms for four filters:

Item	Cost
Superintendent, 170 hrs. at 50 cts	$ 85.00
2 carpenters, 170 hrs. at 35 cts	119.00
3 carpenters, 170 hrs. at 30 cts	153.00
3 carpenters, 190 hrs. at 25 cts	143.50
2 men, 100 hrs. at 20 cts	40.00
Total	$540.50

Cost per filter, $135.12.
Cost per cu. yd., $5.00.

Cost of labor on concreting filters:

Item	Cost
Superintendent, 4½ hrs. at 50 cts	$ 2.25
3 men, 4½ hrs. at 25 cts	3.38
18 men, 4½ hrs. at 20 cts	16.20
Finisher, 5 hrs. at 30 cts	1.50
Water boy, 4½ hrs. at 10 cts	.45
Total cost	$ 23.78

Cost per cu. yd., $0.88.

The costs of forms given in this article include runways and wrecking. The work was done by contract started May 17, 1911 and the plant started operating Jan. 5, 1912.

Cost of Rebuilding Filter Beds at Cincinnati Filtration Plant.—The filter plant of the city of Cincinnati, O., as placed in operation in 1907, had a strainer system consisting of perforated plates covering concrete channels located at the bottom of trough-like depressions running lengthwise of the filter. The depressions were filled with gravel and to prevent its displacement during washing, wire cloth screens were bolted to the tops of the troughs. These retained the gravel effectively and prevented the passage of sand into the filters. It was found, however, that the screens corroded in the water at Cincinnati, and consequently they were removed, and the necessity for their use avoided by increasing the depth of gravel above the strainers to 14 in. The methods employed in reconstructing these filter beds are described by J. W. Ellms, Superintendent of Filtration, in the 1916 annual report of the Cincinnati Water Works Department, from which the matter following was abstracted by Engineering and Contracting in the issue of Oct. 10, 1917.

Following the experimental work that was undertaken to determine the best plan to pursue in rebuilding the beds after removing the brass wire cloth, one filter, No. 19, was rebuilt and put in service on Dec. 25, 1913. This filter was operated continuously in order to observe its action with the increased depth of the gravel bed (14 in.) that had been substituted for the 7½-in. gravel bed used with the wire cloth screen. The satisfactory results obtained with this filter after operating it for nearly a year, confirmed the conclusions derived from the experiments, and plans were made to rebuild the remaining beds of the plant.

As the handling of the sand by throwing it up to a platform made of plank laid over the top of an adjoining filter, had proven expensive, a centrifugal pump was installed in the middle gallery of the filter house on the motor gallery floor. The pump was capable of throwing 180 gal. of water a minute and would produce a pressure at the pump of 100 lb. per square inch. A sand ejector was purchased and was used to transfer the sand from one bed to another during the reconstruction work. This outfit proved satisfactory, and saved a great deal of the expense of manual labor that would have otherwise been necessary in handling the sand.

Late in the fall of 1914, Filter No. 2 was reconstructed before the sand handling apparatus was installed. The cost of rebuilding this filter, the same as in the case of Filter No. 19, which was rebuilt during the previous year, was much in excess of the cost of reconstructing the remaining 26 filters of the plant.

On Dec. 16, 1914, active work was commenced on the remaining 26 filters and they were completed on March 9, 1916. The laborers doing this work were the men from the reservoir force, and they carried on all the other work of the plant in conjunction with this work of rebuilding the filter beds. In consequence, they were not employed continuously on the reconstruction work, but gave it as much attention as they were able, in order to complete it as soon as possible.

Substantial screens were built to be used in grading the gravel. These screens were necessary, not only to separate the various sizes of new gravel needed for increasing the depth of the bed, but also to regrade the original gravel removed from the filter tanks. The grading and regrading of the gravel proved, if anything, more expensive than any other part of the work, since handling and rehandling the gravel was unavoidable.

The gravel layers placed in the bed were graded as follows:

Size of separation	Depth of layer, in.
Passed a 2-in. and retained on a 1-in. screen	2
Passed a 1-in. and retained on a ¾-in. screen	2
Passed a ¾-in. and retained on a ½-in. screen	3
Passed a ½-in. and retained on a ¼-in. screen	4
Passed a ¼-in. screen	3

Thirty inches of sand were placed directly on top of the finest gravel layer. No new sand was used, except about 6 or 7 cu. yd. in the last filter rebuilt. The sand now has an effective size of 0.38 m.m. and a uniformity coefficient of 1.35.

The sand received no cleaning other than what it may have obtained in being transferred from one bed to another. The handling of the sand was so arranged, that the removal of sand from one bed was the operation that transferred it to a reconstructed bed. Two handlings of the sand were thus avoided.

In order not to disturb the gravel, the sand shoveled into the ejector was discharged into a galvanized iron pocket swung between the wash troughs and above the newly laid gravel bed. The velocity of the escaping water was thus reduced, and no disturbance of the gravel resulted. A systematic method for cleaning the filtered water channels under the brass strainer plates was followed. Plates over the riser pipes were removed, and at the ends of the tank. Caps on the manifold headers under the filters were removed. Any sand that may have gotten down into the effluent piping was flushed back with the wash water out of the open ends of the manifolds. Hose streams were used to wash out the channels under the plates, and any sand in them was washed down the riser pipes and out of the ends of the headers.

Every hole in the strainer plates of each filter was opened up by pushing a sharp piece of steel into it. Any incrustation or lodged sand particles were thus removed. Many hook bolts were replaced that had been broken, either in the course of operation of the filter, or from having been originally strained too hard in placing them in the first place. Any plate that was improperly grouted was repaired, and the plates that had to be removed were carefully cemented back in place.

As the increased depth of the gravel has brought the sand surface nearer the edge of the wash troughs, the wash water valve has had to be reset, so as to give a velocity of wash water of less than 2 ft. per minute. The velocity of wash water is now about 18 in. per minute.

The estimated cost of reconstructing the filter beds was $8,500. Obviously there was not very much exact information on which to base an estimate. The handling of the gravel proved to be the most expensive part of the work. Gravel also cost an average of $1.62 per ton instead of the $1.39 per ton used in the estimate. The actual cost, as nearly as it is possible to get at it, appears to have been $9,502,76. This gives a total cost per filter of $339.38. which is equivalent to a cost of 24.2 ct. per square foot of filter area. There is a credit against the above cost for 150 tons of gravel left over and having a value of $1.62 per ton, or a total of $243. From the sale of old brass wire cloth, there was a saving of the scrap value of 38,125.5 lb., having an estimated value of $3,304.60. Adding these two items together makes a total credit of $3,547.60, which if deducted from $9,502.76, leaves a net cost to the city of $5,955.16 for this reconstruction work. This is equivalent to $205.54 per filter, or 15.2 ct. per square foot of filter area.

The cost of the various items was as follows:

Operation	Quantity	Hours	Costs
Removing old gravel		3,936	$ 996.75
Screening old gravel		3,890	985.25
Removing strainer plates over risers		645	163.12
Cleaning out holes in strainer plates		1,631	458.32
Flushing out filtered water channels		571	144.62
Replacing strainer plates		1,778	450.15
Replacing gravel		3,910	990.25
Transferring sand with ejector		1,218	308.22
Pump and sand ejector operated		304.3	48.77
Screening new gravel		2,885	724.85
Unloading new gravel from cars		192	48.77
Loading and unloading gravel from team		1,416	355.80
Hauling with team		307	153.50
Labor of machinst on header caps		69	34.50
Labor of machinst's helper		82	21.57
Common labor on header caps		665	169.30
Foreman's time (65 per cent)			650.00
Bags used up in hauling gravel	2,000		100.08
Reconstruction of Filters Nos. 2 and 19			819.37
Gravel purchased (tons)	1,159		1,879.57
Total cost of reconstructing 28 filters			$9,502.76

Common labor cost $2 per 8-hour day until Feb. 1, 1916, after which it was $2.25 per day. The machinist was paid 50 ct. per hour and the machinist's helper $2.25 per day. The team cost 50 ct. per hour. The water used was valued at $7 per 1,000,000 gal. The cost of power was placed at $0.086 per hour; or using 180 gal. per minute for sand ejecting, the cost for power and water was 16c per hour.

Cost of Treating Filter Water With Copper Sulphate.—The following matter is taken from an abstract, published in Engineering Record, July 26, 1913, of a paper presented before the American Waterworks Association at

Minneapolis by Frederick H. Stover, Bacteriologist and Chemist, Lousville Water Company.

The chief functions of water filters being the removal of bacteria and suspended matter the natural inference would be that the operation of the plant would be easiest at the times when these substances are present in least amount. Many filter superintendents, however, find that such is not always the case and that warm weather and clear water bring troubles peculiarly their own. The usual symptoms of these troubles are marked shortening in the length of the filter runs and the prevalence about the filter beds of a pronounced odor, varying from "grassy" to "fishy" in nature. Microscopical examination of the water at such times usually reveals the presence of numerous minute forms of the type generally classified by waterworks men as "micro-organisms," which, in the waters of the Ohio River, are principally diatoms, with a few algae and miscellaneous forms present.

The water of the Ohio River, when of a turbidity below 30 parts per million, almost invariably causes decreases in the length of the filter runs. If such turbidities are accompanied by micro-organism and much amorphous matter, still greater decreases follow. Filter runs may be greatly increased by the judicious use of copper sulphate, although after-growths of bacteria sometimes follow its application and must be guarded against.

With the copper sulphate ($CuSO_4$) applications markedly favorable results have been secured in all but one instance, and even in this case the results cannot be said to have been negative, as the runs were kept at 6 hours and above under conditions when much lower ones might have been expected, and probably would have occurred had not the copper been used. The minimum length of runs reached at this time was 5 hours, which occurred 9 days after this dosing.

Within 24 hours after the application of the copper there was in each instance a noticeable increase in the length of the filter runs and that these lengthened runs continued for periods varying from 8 to 19 days in length.

The copper was applied in the second sedimentation basin and in the coagulant basin by dragging bags of it from a boat.

The decreases in the length of the filter runs of course cause correspondingly large increases in the amounts of wash water used. During the year 1912 the average amount of wash water used at Louisville was 2.05 per cent—the lowest average for any one month being 1.44 per cent. During the periods of shortened filter runs, however, the amounts will vary from 6 to 10.7 per cent.

Small doses of hypochlorite of lime do not affect these micro-organisms in such a way as to increase the length of the filter runs. The determination of the time of filtration of samples of water through small laboratory filters will in some instances enable the operator to select the water from that point of his system which will give the longest filter runs.

AMOUNT AND COST OF COPPER SULPHATE TREATMENT

Date	—$CuSO_4$ Pounds	used— P.p.m.	Effects lasted (days)	Total cost	Cost per mil. gal. Dosed	Cost per mil. gal. Treated	*Value wash water saved
Aug. 20, 1910..	650	1.3	19	$31.20	$0.50	$0.065	......
May 27, 1911..	735	1.3	10	36.00	0.52	0.104	$149.76
June 15, 1911..	1000	1.7	9	49.00	0.70	0.217	228.50
June 10, 1912..	625	1.2	9	30.60	0.49	0.132	......

*At $30 per million gallons.

Operating Costs of Filtration Plants.—The following data are taken from Stein's "Water Purification Plants" (1915).

Perhaps the largest single factor affecting the cost of operation of filtration plants is the amount of coagulant used. This varies with the quality of the raw water, and increases greatly when the water is softened. The labor cost increases with the size of plant from the smallest to plants of perhaps 10,000,000 gallons capacity, after which the cost per million gallons decreases. Against the cost of filtering should be charged the cost of pumping the water against the head lost in filtration, which is generally from 10 to 15 feet. The following are typical examples of the cost of filtration in plants of various sizes:

Example No. 1. *Cost of Coagulation and Sedimentation at St. Louis, Mo.*—The treatment consists of coagulation with lime and iron sulphate, followed by sedimentation in large basins. The source of supply is the Mississippi River below the mouth of the Missouri, consequently a very high turbidity prevails much of the time. The average amounts of chemicals used in 1911 were 5.77 grains per gallon of lime and 2.70 grains per gallon of iron sulphate.

Cost of Purification per Million Gallons (1910–1911)

Lime	$1.967
Sulphate of iron	1.969
Unloading	0.094
Operating and maintenance (labor)	0.378
Repairs	0.030
Water, coal, oil, etc	0.047
Light and power	0.098
Water analyses (chemist's)	0.172
Total	$4.755

The average daily pumpage was about 86,000,000 gallons.

Example No. 2. *Cost of Filtration at Harrisburg, Penna.*—This is a standard type mechanical filtration plant. The pumpage for 1911 averaged 8,205,684 gallons per day. The average amount of coagulant used was 0.7 grain per gallon.

Cost of Purification per Million Gallons (1910–1911)

Coagulant	$1.22
Fuel (low service)	0.86
Supplies	0.28
Materials and repairs	0.36
Oil and waste	0.07
Laboratory	0.43
Labor	2.77
Total	$5.99

Example No. 3. *Cost of Filtration at a Typical Small Plant.*—Daily pumpage, 2,000,000 gallons. Water slightly acid at times, requiring the use of soda ash. Average amounts of coagulant used 0.7 grain per gallon of alum, 0.5 grain per gallon of soda ash.

Cost of Purification per Million Gallons

Alum	$1.25
Soda ash	.86
Fuel (low service)*	.73
Supplies, oil, and waste	.42
Repairs	.07
Labor	2.00
Total	$5.33

* Cost of pumping the additional head lost in the filtration plant.

Example No. 4. Cost of Purification in a Large Softening Plant.—Daily pumpage, 50,000,000 gallons; lime used, 8 grains per gallon; iron sulphate, 1 grain per gallon. Plant is equipped with conveyors, automatic scales, and other labor-saving devices.

Cost of Purification per Million Gallons

Lime	$2.71
Iron sulphate	0.72
Labor	0.69
Material, supplies, and repairs	0.56
Laboratory	0.12
Low-service pumpage*	0.40
	$5.20

*Cost of pumping the additional head lost in the filtration plant.

Cost of Water Purification at Cincinnati, O.—(Engineering and Contracting Jan. 14, 1920). The average cost of operating and maintaining the filter plant of Cincinnati, O., for the 10-year period 1908–17 has been $3.96 per 1,000,000 gal. of filtered water delivered for consumption. This total consists of $1.66 for coagulating chemicals, 36 ct. for maintenance and $1.94 for other operating costs, principally labor charges. The following table, from the 1917–18 report of the Water Department summarizes the cost since the plant was started:

Operating Costs per Million Gallons

Year	Operation: Coagulating chemicals	Operation: All other operating costs	Maintenance	Total
1908	$1.72	$2.47	$0.05	$4.24
1909	1.89	2.28	.09	4.26
1910	1.93	1.98	.28	4.19
1911	1.86	1.91	.35	4.12
1912	1.78	1.68	.38	3.84
1913	1.67	1.77	.48	3.92
1914	1.21	1.78	.39	3.38
1915	1.43	1.86	.76	4.05
1916	1.27	1.80	.38	3.45
1917	1.86	1.85	.40	4.11
1918	2.12	2.37	.67	5.16

The increase in maintenance in 1915 was largely due to cost of reconstructing the filter beds which item amounted to $0.34 per 1,000,000 gals. Another unusual item in that year was the cost of repairing roofs which amounted to $0.07 per 1,000,000 gals.

The average period of service has been between 22 to 23 hours. The time required for washing a filter has been from 3.75 to 4.50 minutes. The amount of wash water amounts to from 1 to 2.75 per cent and averages about 1.75 per cent of the total water filtered.

Cost of Operation and Comparative Cost of Chemicals for Columbus, O., Purification Works.—The total expense for operating and maintenance of the water softening and purification works of the city of Columbus, O., for 1916 was $199,299, of which $24,902 was for labor and supervision, $168,346 for chemicals and $6,051 for general supplies. The cost of purification per 1,000,000 gal. delivered to consumers was $27.75. The quantities and costs of chemicals used at the works during the 9 years, 1909 to 1917, inclusive, as given in Engineering and Contracting, June 12, 1918, have been as follows:

	Lime		Soda ash		Alum		Bleach	
Year	Tons	Cost per ton	Tons	Cost per ton	Tons	Cost per ton	Tons	Cost per ton
1909..........	2,467	$5.75	1,402	$17.50	624	$19.00	..	......
1910..........	3,081	5.80	2,164	17.50	423	18.00	..	......
1911..........	3,860	5.42	1,776	17.50	590	17.50	..	......
1912..........	3,296	5.27	1,583	15.20	895	17.15	22	$27.80
1913..........	3,629	5.17	2,895	12.88	711	17.10	17	27.80
1914..........	4,650	5.27	3,540	13.30	880	16.75	14	29.20
1915..........	3,970	5.17	2,383	15.14	69	*16.60	22	34.80
					805	†7.27		
1916..........	4,550	5.17	1,975	62.00	823	†20.18	19	85.00
1917..........	4,206	7.03	1,833	60.00	943	†10.69	24	70.00

* Crystal alum purchased in open market. † Cost of materials.

Cost of Operation of Filter Plant of Erie, Pa.—The following data are taken from Engineering and Contracting, July 11, 1917. The rapid sand filtration plant of Erie, Pa., filtered 6,881,170,000 gal. of water in 1916. Compared with 1915 this is an increase of 1,066,600,000 gal. or 18.34 per cent. At times, especially during the months of July and August, the plant was operated as high as 35 per cent above its normal capacity. While operating above normal capacity no decrease was noted in the high efficiency obtained while operating at normal rates. It required 304, 631 lb. of aluminum sulphate to treat all the water filtered; expressed in grains per gallon is equal to .31. This is an increase of 50 per cent over the amount required per gallon in 1915. The increased turbidity of the water treated made the increase in coagulant necessary. Total hypochlorite of calcium used 27,138 lb. or 3.9 lb. per 1,000,000 gal. treated. In washing the filters, 129,100,000 gal. of filtered water were used. This is 1.88 per centof the total filtered. The cost of operation and maintenance for 1916 was $13,868; cost per 1,000,000 gal. filtered $2.02. Cost of operation and maintenance is divided as follows:

		Per cent
Labor and supervision..............................	$ 6,539.20	47.1
Alum..	4,658.89	33.6
Hypo..	1,045.71	7.6
Wash water..	1,050.40	7.6
Maintenance of plant and laboratories..............	573.77	4.1
	$13,867.97*	100.0

* Does not include low duty pumping, light, heat or pressure water.

Cost of Filtering Water at Grand Rapids.—(Engineering and Contracting, Aug. 14, 1918).

The cost of filtering water at Grand Rapids, Mich., increased from $14.87 per 1,000,000 gal. for the year 1916–17 to $18.84 in 1917-18, according to the annual report of Walter A. Sperry, chief chemist of the filter plant. Comparative figures on the operating costs for the last four years are given in the report, as follows:

	1917–18	1916–17	1915–16	1914–15
Wages............................	$ 4.86	$ 4.26	$ 4.48	$ 3.57
Chemicals........................	10.06	7.37	5.10	4.76
Power............................	2.23	2.26	2.17	2.14
House water......................	.20	......	......	......
Supplies and repairs.............	1.49	.98	1.11	.86
Total............................	$18.84	$14.87	$12.86	$11.33

The Grand Rapids plant was put in operation November, 1912. The method of treatment is lime softening followed by mechanical filtration.

According to Engineering News-Record, Aug. 30, 1917, the amount of wash water for this plant has averaged about 2% of the total amount of water treated.

Eleven Years' Operating Results of Filter Plant.—The filtration plant of Harrisburg, Pa., has been in continuous operation since its completion in October, 1905. The following table, published in Engineering and Contracting, Sept. 12, 1917, shows the average turbidity, coagulants, length of runs and percentage of wash water during this period:

Year	Turbidity parts per million	Sulphate of alumina grs. per gal.	Calcium hypo-chlorite grs. per gal.	Length of runs hrs. min.	Wash water pct.
1906	101	.95	....	18–20	2.0
1907	76	1.05	....	12–20	2.6
1908	52	1.09	....	13–29	2.6
1909	42	.84	.025	14–22	2.4
1910	19	.61	.063	18–40	2.2
1911	32	.95	.070	23–07	2.3
1912	59	.77	.067	21–54	2.3
1913	56	.79	.069	17–26	2.9
1914	33	.53	.056	20–17	2.9
1915	85	.69	.064	17–41	3.2
1916	60	.66	.045	16–39	3.6
Average	56	.81	.057	16–11	2.6

The method of operating was as follows: The water is pumped to the settling basin, capacity 4,000,000 gal., flows by gravity to the secondary or coagulation basins, capacity 334,000 gal. and then flows by gravity to the 12 filters which are of the American gravity type. The filtered water is pumped to the storage reservoir, which has a capacity of 26,000,000 gal.

Cost of Water Purification at St. Louis, Mo.—(Engineering and Contracting, Sept. 8, 1920).

During the fiscal year ending April 1, 1920, 39,642 million gallons of water were pumped into the basins. To this amount of water were added 1,387 tons of sulphate of iron and 14,753 tons of lime, or an average of 0.49 grains per gallon of the former chemical and 5 21 grains per gallon of the latter. To the 39,092 millions of gallons filtered were added 2,388 tons of sulphate of alumina and 120,187 lb. of chlorine, or an average of 0.86 grains per gallon of the sulphate and 3.07 lb. per million gallons of the chlorine. The sulphate of alumina was added before, and the chlorine after, filtration. The average cost per million for lime was $3.89; for sulphate of iron, $0.67; for sulphate of alumina, $1.92 and for chlorine, $0.29. These costs are for chemicals alone and do not include the cost of handling or application. A comparison of the costs of the various parts of the purification work done during the past five years, based on the quantity of water delivered to consumers, is shown in the following table:

Table VIII.—Cost per Million Gallons, Based on Consumption

Old Plant	1915–1916	Nov., 1915 to April, 1916	1916–1917	1917–1918	1918–1919	1919–1920
Lime	$ 1.70	$1.61	$ 1.89	$ 2.94	$ 3.72	$ 3.89
Iron	1.42	.64	.61	.57	.82	.67
Unloading	.08	.07	.08	.09	.12	.12
Operating, maintenance and repairs	.47	.51	.38	.41	.60	.59
Water, coal, oil, etc	.03	.04	.03	.05	.08	.05
Light and power	.07	.07	.04	.10	.12	.11
Chemical work	.43	.49	.38	.34	.30	.31
Basin cleaning	.14	.08	.12[1]	.17	.22	.26
Basin repairs	.03	.03	.01	.02	.02	.02
[3] Switching and demurrage	......	.....	....	....	......	.22
Total old plant	$ 4.37	$3.54	$ 3.54	$ 4.69	$ 6.00	$ 6.24
Filters						
Aluminum sulphate	$ 0.76	$1.00	$ 0.79	$ 1.13	$ 1.37	$ 1.92
Chlorine	.18	.15	.14	.27	.31	.29
Operating, maintenance and repairs	.83	.98	.80	.77	.89	.94
Coal, miscellaneous supplies and expenses	.14	.26	.20[2]	.36	.39	.39
Light and power	.14	.15	.11	.21	.24	.31
[3] Switching and demurrage	......	....	....	....	......	.02
Total	$ 6.42	$6.08	$ 5.58	$ 7.43	$ 9.10	$10.11
Total consumption for year in million gals	32,583	13,138	35,633	38,090	36,840	38,004
Cost of Chemicals						
Lime, per ton, average 2 contracts	$ 3.65	.....	$ 4.49	$ 6.86	$ 8.75	$10.03
Sulphate of iron, per ton, average	10.00	.....	12.50	12.84	16.84	18.48
Sulphate of alumina, per ton, average	......	.....	21.00	22.25	27.60	30.49
Chlorine, per pound	.08	.....	.13⅜	.13⅜	.12⅝	.09¼

[1] Water used in basin cleaning—Omitted prior to 1916.
[2] Water used in filter plant operation—Omitted prior to 1916.
[3] Switching and demurrage in years 1915 to 1918, inclusive, are included in operating, maintenance, repairs, etc.

The complete purification system was not in use until October, 1915. The heading, November, 1915-April, 1916, is included to show the costs of purification after the system was completed. The figures are included for the year of 1915–1916. Under the head of lime, iron, sulphate of alumina and chlorine are included all charges connected with the switching of these materials from the interchange tracks at Bissell's Point and Humboldt avenue to the Chain of Rocks. The sulphate of iron, in the form of sugar sulphate, was furnished at $14.16 per ton after Aug. 1, 1919. The price of $23.50 was in effect prior to that date, but none was brought under that contract after April 1, 1919. Liquid chlorine cost 10.75 ct. per pound until Aug. 1 and at 5 ct. per pound after that date. The prices given are f. o. b. Niagara Falls, the prices delivered being 11.78 ct. and 6.40 ct. per pound. Sulphate of alumina was purchased under the same specifications as last year. Basic sulphate of alumina containing not less than 17 per cent of available water soluble alumina, Al_2O_3, was required. The sulphate was supplied from April 1st to Sept. 15th at a price of $34.50 per ton, from Dec. 15th to Jan. 1st at $30 per ton and after that date at $28.50 per ton. A few cars furnished during September cost $23 per ton. From Oct. 1st to Dec. 15th the sulphate of alumina was supplied at $30.90 a ton. Lime was purchased under a specification requiring a lime containing 85 per cent CaO with a bonus or penalty of 1½ per cent of the contract price for each per cent of CaO above or below the required 85 per cent. All lime was sampled as it came from the crusher after unloading and these samples, together with the samples obtained from the daily supply hopper, were analyzed in the laboratory. Lime was supplied at a price of $9.30 a ton from April 1st to Sept. 1st at $10.30 a ton, from Sept. 1st to Feb. 1st and at $11.30 a ton after that date. The above notes are taken from the report of August V. Graf, Chief Chemist, Filter Plant, as embodied in the 1920 annual report of Edward E. Wall, Water Commissioner, St. Louis.

Cost of Filtering Water at Providence, R. I.—The unit costs of filtering and pumping water at the Pettaconsett slow sand filters of Providence, R. I., are given by Engineering and Contracting, Oct. 10, 1917, as follows:

Year	Pumping on to filter beds	For cleaning beds	Total cost per mil. gals. to filter water	Pumping water to Sockanosset reservoir
1907	$3.28	$4.20	$7.48	$5.63
1908	3.48	2.03	5.51	5.03
1909	3.23	2.05	5.28	5.14
1910	3.20	1.78	4.98	4.74
1911	2.98	1.59	4.57	4.95
1912	2.72	1.56	4.28	5.05
1913	3.00	1.59	4.59	4.98
1914	3.15	1.71	4.86	4.78
1915	3.07	1.66	4.73	5.67
1916	2.79	2.13	4.92	5.40

With the exception of 1907, when open filter beds were used, the figures are for operating covered beds. In 1916 the plant consisted of 10 filters each of which was in service for from 7,969.5 to 8,216.0 hours; 8,101.9 being the average number of hours in service.

The beds required from 15 to 19 scrapings during year, the average being 17.3. The lengths of run in days varied from 2.3 minimum to 59.3 maximum, the average being 19.5. The average quantity of water filtered between scrapings varied from 35,890,000 to 47,080,000 gals., the average being 40,020,000 gals. The average quantity of water filtered per day varied from 2,010,000 to 2,070,000 gals., the average being 2,045,000.

Cost of Operating the Purification Plant of Wilmington, Del.—Engineering and Contracting, Oct. 11, 1916, gives the following:

The purification plant of Wilmington, Del., consists of preliminary filters, sedimentation basins and final filter. The water flows by gravity to the preliminary filters, of which there are 10, each 14½ × 100 ft., the medium being gravel, coke and sponge, through which the water passes upward. After the water has passed these filters, it is possible to treat it with liquid chlorine. The water then flows by gravity to the pumps, from whence it is delivered to the settling reservoir. The settling reservoir has a capacity of 35,000,000 gal., 91½ per cent of which is available. From the settling reservoir the water flows by gravity to the final filters. The final filters are regular English slow sand units. There are six of these units, each 364 × 40 ft. The water after passing these filters is treated with liquid chlorine before entering the mains. The water flows by gravity to the consumers.

The following figures on the operation of the plant are taken from the annual report of Edgar M. Hoopes, Jr., Chief Engineer of the Water Department, for the fiscal year ending June 30, 1915.

The total quantity of water delivered to the slow sand filters was 3,518,990,000 gal. (36-in. Venturi meter registration) of which 8,400,000 gal. or 0.24 per cent was consumed in washing the sand beds. The remainder of 3,510,590,000 gal. is the net amount delivered to consumers. The total quantity of water delivered from the preliminary filters was 3,551,373,390 gal., or about 40,000,000 gal. more than was actually distributed. This amount represents the difference in water stored at Porter Reservoir at the beginning and end of the year as well as leakage in the forcing main between the pumping station and reservoir.

At the slow sand, or final filters, the average rate of filtration was 4,900,000 gal. per acre per day, and the time of beds out of service for washing or raking 13.78 per cent. The average time out of service for each bed was 2.3 per cent.

The total number of gallons of water treated with liquid chlorine was 2,859,410,000 or about 84.2 per cent of the amount actually distributed to consumers. The actual time during which this treatment was applied was 308 days or 84.2 per cent of the year. For this purpose 3,842.5 lb. of chlorine were consumed—equivalent to 1.343 lb. of gas per million gallons of water treated. The total quantity of water used for absorbing this gas prior to treatment was 347,089 gal., or 1 lb. of chlorine to 750 lb. of water. A subdivision of operating expenses is given in the following table—interest on plant investment or depreciation not being included.

	Total	Per 1,000,000 gal.
Slow Sand Filtration (3,510,590,000 Gal.)		
Salaries	$1,578	$0.449
Labor	349	.099
Supplies	582	.163
Light and power	620	.176
Repairs and renewals to equipment	297	.084
Miscellaneous	535	.152
Total	$3,961	$1.123
Preliminary Filtration (3,551,373,390 gal.)		
Salaries	$1,293	$0.364
Labor	11	.003
Supplies	101	.028
Repairs and renewals to equipment	31	.008
Light and power	166	.046
Miscellaneous	60	.016
Total	$1,661	$0.465
Laboratory (3,551,373,390 gal.)		
Salaries	$1,516	$0.426
Labor	299	.084
Supplies	143	.040
Repairs and renewals to equipment	6	.002
Miscellaneous	313	.088
Total	$2,277	$0.640

Cost of Philadelphia Water-Filter Operations.—The following data are taken from Engineering News, March 25, 1915.

TABLE IX.—OPERATING DATA OF SLOW SAND FILTERS AT PHILADELPHIA, 1914

Item	Name of plant: Torresdale	Queen Lane	Belmont	Upper Roxborough	Lower Roxborough
Cost per mil. gals	$ 2.23	$ 2.65	$ 3.62	$ 3.02	$ 5.10
Rate per acre per day:					
Av. entire area	3.668	3.054	2.977	2.287	3.478
Max. area in service	4.761	4.224	4.159	3.615	5.531
Av. no. of cleanings per filter	4.60	1.86	7.12	6.00	10.6
Av. days in service between cleanings	73.04	201.33	48.43	58.36	33.44
Av. no. rakings between cleanings	2.00	1.68	0.37	0.19	0.09

Operating Costs of Water Softening and Purification Plant at McKeesport, Pa.—The following data are taken from an abstract published in Engineering and Contracting, May 11, 1910, of a paper by Alexander Potter read at the annual convention of the American Water Works Association, April, 1910.

The water treated is of a variable character which condition requires the greatest care and watchfulness on the part of the employees of the plant.

The variable character of the water is indicated by the fact that the water has jumped from a hardness of 110 at 4 o'clock in the morning to a hardness of 510 four or five hours later, and from an acidity of 30 up to an acidity of 210 during the same period.

The McKeesport plant was fully described by the author in a paper read before the Engineer's Society of Pennsylvania, and appears fully illustrated in their Journal for April, 1909. Novel features of the plant which might be mentioned, and which a year and a half of operation have given a sufficient test, are as follows:

The method of cleaning the settling tanks without emptying them or interfering in any way with the continuous operation of the plant. Carriers are built under the floor of the settling tanks. The carriers in each of the four tanks are divided into four zones. Small circular holes ⅞-in. in diameter, spaced 4 ft. apart, connect the bottom of the tanks with the carriers. The outlet end of each set of carriers is controlled by a valve. In cleaning the basins, the valve controlling each zone is kept open until the precipitated solids are removed, and the water runs free from sludge. The amount of water used in cleaning the settling tanks and baffling tank is approximately 1,700 gals. per day for each degree of hardness in the water.

Another novel feature in the plant is the economic use of wash water. The entire machinery is operated by a water motor on the top floor of the softening building. The waste water from the motor enters the wash water basin for the filters. This water, charged against the plant as power, should not be charged as wash water, thus effecting a substantial saving. The amount of wash water shown in the annexed table is, however, the actual amount of water used in washing the filters, and amounts to 0.72 per cent of the total amount pumped.

The character of the McKeesport water is so unusual that tables of cost of operation are apt to be misleading to other municipalities, because the persons seeking data of cost and practicability of water softening are apt to be swayed adversely in their opinions by applying to their own cases the costs of producing a softened water at other places, as for instance at McKeesport, without taking into consideration the possible differences in conditions between the water to be dealt with at different places.

The only fair way to analyze the cost of any particular plant is to weight cost thereof against the benefits to be derived therefrom. Bearing this in mind, we have on the one hand to consider, (*a*) first cost of plant; (*b*) cost of operation. As against this we must also consider, (*c*) the improvement in the water; (*d*) the decrease in operating expenses of the plant; (*e*) decrease in wear and tear upon the plant; (*f*) decrease in plumbing bills paid directly by private citizens; (*g*) the decrease in the cost of soap; (*h*) lengthening the wear of linens, flannels, and other fabrics; and (*i*) increase in the length of life or boilers.

Taking the case of McKeesport, the annual interest on the cost of construction is approximately $10,000.

The cost of operation for one year is $30,700.

The total cost of producing 4,000,000 gallons of softened filtered water a day is $40,700 per annum.

Against this we have the following saving.

Since the softening plant has been installed, the Water Department has dispensed with a number of its employes engaged on repaving curb connections whose wages, according to the president of the board of water commissioners, amounted to $15,000.

The private consumers expended annually in maintaining their plumbing fixtures over $35,000.

Since the softening plant has been installed, only 72 per cent of the water previously required is now pumped, thus making a reduction in the coal consumption of $6,090 per annum.

The reduction in repairs of plant amounts to $3,000 a year.

From the best evidence obtainable, the saving in soap and soap compounds alone amounts to over $10,000 a year, and the saving in the wear and tear in washing of fabrics of all kinds can be set down at $20,000 a year.

Summarizing these, we have, on the one hand, an added cost of treating the water of $40,700; and, on the other a saving, as enumerated above, of $89,090.

This balance sheet shows that the introduction of the water softening plant for the city of McKeesport, instead of being an added burden to the people, has proved to be a saving of $48,390 per annum.

As a side light upon the saving effected in the McKeesport plant, it may be stated that, before the water softening plant was put into commission, about 156 plumbers were at work in the city. Out of this number, only 46 were left, four months after the plant was put in operation.

The average amount of chemicals used and cost of treating the water from Feb., 1909 to March, 1910 was as follows:

Average time between washings of filters	152 hours
Per cent of total amount of water pumped, used as wash water.	0.72
Amount of chemicals per million gals.*	
Lime	750 lbs.
Soda ash	1,046 lbs.
Coagulant	76 lbs.†
Hypochlorite of lime	4 lbs.
Cost of treatment per million gals.	
Chemicals	$13.36
Labor	8.05
Average amount of filtered water pumped per day	3,928,000 gals.

*The average cost of chemicals (during the period) at the McKeesport plant was:

	Per ton of 2,000 lbs.
Lime	$ 8.30
Soda ash	18.00
Sulphate of iron	11.00
Alum	12.50
Hypochlorite of lime	42.00

†No coagulant has been used since the application of the hypochlorite of lime. A remarkable condition exists with the water at McKeesport, where with 450,000 bacteria and 1,500 turbidity in the raw water, no coagulant was used, and yet a clear water was secured from the filters.

Cleaning Sand in Filters of Wilmington, Delaware.—The cleanings required by the filters at Wilmington Delaware, are accomplished by a Blaisdell Washing Machine. A description of the machine and method of operation was given by Edgar M. Hoopes, Jr. and James M. Ciard in a paper before the 1914 annual meeting of the American Water Works Association.

The machine is operated by electric motors and covers a strip 20 ft. wide. It is mounted on a traveling crane which runs the length of the beds on rails supported on the party walls between the beds. The beds, being but 40 ft. wide, are cleaned in two runs.

It has been found that the time lost by beds being out of service on account of cleanings ranges from 7.5 to 10 per cent, while with the old method of hand scraping, ejecting and restoring from 15 to 25 per cent of time is lost.

Costs of Washing Filter Sand, Using a Nichols Separator.—The following costs, of washing all the sand in four of the slow sand filter beds of the Albany, N. Y., water purification plant, are published in Engineering and Contracting, Oct. 12, 1910, as given in the report for 1909 of H. J. Deutschbein, Supt. Bureau of Water. The beds had been in operation continuously for ten years, and the sand had become more or less segregated and had secured a gradual accumulation of pure clay and other particles which were not retained on the surface. More or less compacting of the sand had also occurred. The work of washing was begun with a box washer, but this, for various reasons, proved so slow and expensive that two Nichols separators were purchased for $1,550 and substituted for the earlier method. The filters cleaned were Nos. 1, 3, 6 and 7, and the Nichols washers were used for all but a portion of the washing on No. 7.

Filter No. 7.—Commenced cleaning June 1, 1909. Finished cleaning July 31, 1909. Cleaned and replaced by box sand washer, 2,808 cu. yds. Cost of labor, $1,147.28. Cost per cubic yard, 40.9 cts.

Cleaned and replaced by Nichols sand separators, 1,558 cubic yds. Cost of labor, $352.30. Cost per cubic yard, 22.6 cts.

Filter No. 3.—Commenced cleaning Aug. 5, 1909. Finished cleaning Aug. 19, 1909. Cleaned entirely by Nichols separators.

Worked 24 hours a day in three 8-hour shifts. Cleaned and replaced 3,213 cu. yds. Labor cost, $723.10. Cost per cubic yard, 22.5 cts.

Filter No. 6.—Commenced cleaning Aug. 14, 1909. Finished cleaning Sept. 8, 1909. Cleaned entirely by Nichols separators. Worked 24 hours a day in three 8-hour shifts. Cleaned and replaced 3,230 cu. yds. Labor cost, $696.74. Cost per cubic yard, 21.57 cts.

Filter No. 1.—Commenced cleanings Sept. 10, 1909. Finished cleaning Sept. 25, 1909. Cleaned entirely by Nichols separators. Worked 24 hours a day in three 8-hour shifts. Cleaned and replaced 3,325 cu. yds. Labor cost, $711.40. Cost per cubic yard, 21.39 cts.

The following is a record of 24 hours' work in Filter No. 3; water pressure 65 lbs. per sq. in.; water used, 47,080 cu. ft., or 1,744 cu. yds., which for a total of 225 cu. yds. of sand washed was a rate of say 7¾ cu. yds. of water per cubic yard of sand. The amount of sand lost was 3 cu. yds., or 1.33 per cent. The cost was as follows:

24 hrs. foreman at 31¼ cts.	$ 7.50
192 hrs. labor at 22½ cts.	43.20
Total	$50.70

This gives for 225 cu. yds. a cost of 22.53 cts. per cu. yd.

Time Studies in Connection With the Cleaning of Filter Sand at Philadelphia.—The following matter is taken from an abstract in Engineering and Contracting, Dec. 23, 1914, of a paper before the American Society of Mechanical Engineers by Sanford E. Thompson.

Philadelphia has five large filtration plants consisting of covered reservoirs operated by slow sand filtration. The water pumped into the reservoir from the Schuylkill and the Delaware Rivers, after passing through the pre-filters, percolates through about 4 ft. of sand and gravel and is thus purified. The impurities are caught largely in the upper few inches of sand, so that if this upper portion is washed the filtration area is practically renewed. Several methods of cleaning filter sands are in use, all of them involving considerable manual labor. Further details of the methods followed in the case under observation are referred to below.

Results.—The object of the plan has been to lay out the work of each gang of men so as to increase the effectiveness of the plant and provide a definite task to be accomplished in a day. The results of the plan which is being put into operation are as follows:

Rotation of cleaning the filters is planned in advance by well-defined rule.

A definite area of sand to clean is assigned to each gang, this area depending upon the depth of cleaning necessary.

This setting of tasks has increased output of each gang 15 per cent and this should be further increased to at least 25 per cent.

Accurate records are kept, showing the time consumed by each gang.

Cost accounts, as well as pay-roll, are made up from the time tickets furnished to the men.

Gang leaders are required to pay closer attention to their duties.

Improved apparatus and machinery are under consideration.

Methods of determining depths of sand to clean are being standardized.

Obstacles.—The greatest obstacle encountered has been the city ordinance fixing the rate of pay of unskilled laborers on a level wage per day regardless of the quality of the workman or the amount of work he is able to accomplish. While in city government strict regulation is necessary, a plan such as is followed in Chicago, where the employes in each department are definitely graded, with different wages for each grade, provides a means for rewarding a man according to his ability and giving a city good value for money expended. The Philadelphia ordinances prevent the payment of a bonus and thus make it difficult to encourage the men to accomplish the tasks assigned them.

Method of Cleaning.—In the filtration plant first handled by the new method there are 65 filters, employing about 128 men for cleaning. Each filter is about 140 ft. wide by 250 ft. long, and is built with groined arch bottom and roof, having columns about 16 ft. on centers.

The Nichols method of washing is used in this plant. In this method the dirty sand from the surface of the bed to a depth specified is shoveled to an ejector, furnishing water under about 85 to 100 lbs. pressure, which forces it through a large hose into the separator, which is a cylindrical iron tank provided with a concentric baffle about 6 or 8 ins. from the outside shell. The water and sand swirl around this, the clean sand settling in the conical bottom and passing out through a 2-in. hose below. The dirty water passes under the baffle and out of the top of the tank, whence it passes out of the bed through a hose and pipe to sewer.

From the separator the sand is returned by the hose to the bed, where it is properly distributed and leveled. Sometimes, according to conditions, the dirty sand is shoveled direct to the hopper of the ejector, and in other cases is scraped and piled from the first and one-half the third bay into the second line of bays; from the other half of the third and one-half the fifth line of bays into the fourth line of bays; and so on, to include the ninth bay. This scraping and piling is done usually as an independent operation by old men unfit for harder work.

Four washing gangs are required for each filter bed, the outside gangs having 2½ bays each and the inside gangs having 2 bays to clean. In each gang there are 3 shovelers to a hopper, 2 men shoveling at a time while one rests. Each man shovels 40 minutes and then rests 20 minutes. The fourth man takes care of the hose from the separator distributing the clean sand to the bed. A fifth man, recently introduced, working with 2 gangs,

Unit Times.—Time studies were made by the aid of the stop watch on the labor operations in the beds, such as shoveling dirty sand to hopper, cleaning up around hopper, moving hopper, moving separator, and moving track. These times for individual operations were then converted for direct use into the time per cubic yard for 1 in. of depth.

Studies were also made on the rate of delivery of sand from separator and the effect of opening and closing the separator on the rate of shoveling. Different methods of handling the ejectors were also included in the investigation.

The object of the time studies was to find the time of each individual operation, so that unnecessary operations could be eliminated and the unit times of the necessary operations could be combined to apply to all conditions. Over-all time records are of no use whatever, because, for example, with each change in depth of shoveling, the number of moves of the hopper and of the separator vary.

The unit times for the individual operations were determined by the taking of a large number of time studies in such a way as to eliminate all unnecessary delays, but with a sufficient allowance for resting and delays which were unavoidable. The unit times obtained are given in Table X.

TABLE X.—UNIT TIMES FOR VARIOUS OPERATIONS IN CLEANING FILTER SAND

Operation	Unit time per operation, min.	Time per cu. yd. per 1-in. depth, min.
Moving hopper	0.20	0.34
Moving separator	0.50	0.45
Moving hopper hose	0.25	0.11
Moving track	0.83	0.44
Waiting for hopper to empty	0.42	0.38
Moving pressure hose	1.80	0.36
Additional necessary rest	. . .	0.12
Shoveling to hopper	. . .	6.32

The time given in each case is that for the gang, since it was necessary on this work to set a task for the entire gang instead of starting the individual men, as it is always best to do when possible. The time of shoveling into the hopper is in each case based on the rate of output that the ejectors will take care of. It was found that one man, instead of two, could very nearly produce the required output, but this would have lengthened the time of cleaning so as to be inadvisable. For example, with one man shoveling, the shoveling time per cubic yard is 8.8 minutes with a 1-in. depth, and 6.75 minutes per cubic yard when the depth is 18 ins. These studies indicate therefore that further change is necessary in the method of operation so as to increase the output of the ejector and separator in order to obtain the full value of the labor of the gang.

In addition to the time studies on the work of the laborers in the filters, time studies were also made on the clerical work, such as making out tickets, operating bulletin board, extending time on tickets, entering time on various records, and checking up the payroll in order to distribute the work equally among the force employed to carry it on.

Setting Tasks.—Having determined the unit times and established the system of routing and giving out of tickets, the area of surface that should be shoveled by each gang was figured and the point to which they were supposed to go in a days' work was marked with a flag. In order to fix this, it is necessary to determine in advance by test holes the depth which should be cleaned, figuring the area from the volume at the required depth. Curves have been plotted, giving areas or rather distances to clean for the outside and inside gangs for various depths. These distances are converted into pier locations, so many feet in front or back of pier number so and so. The actual point reached each day is reported at the office and the mark for the following day calculated therefrom.

On the first two days, after everything was ready, no instructions were given the gang leader or the men as to how much they were expected to do. The total area shoveled by each gang, however, was noted, and compared with the area they should have accomplished. Every gang shoveled less than the figured area, the amount running from 10½ per cent less to 31½ per cent less. After this second day's work we concentrated on E-1 gang, since it is always necessary in order to avoid friction to work with a single man or a single gang, and laid out in advance the amount this gang should accomplish in a day by setting a flag at the point which marked the end of the day's work. As a result, they readily accomplished the task and reached the mark. The task setting was then extended to other gangs.

One rather interesting point came up in connection with the handling of the work at first. The men in the outside bays had to shovel about 7 per cent more sand than those in the inside bays because the areas were wider; never-the less, all gangs had been accustomed to keep abreast, the men who had the narrower width to handle slowing up to accommodate their speed to the outside men. When the men began working by the task, the operation was somewhat similar, except in the other direction, until the men realized the difference. The inside men, because of the narrower width, were given the longer area to cover and gaged their speed to accomplish their task. The outside men, although shoveling a greater width kept abreast with them without special trouble, thus exceeding their task.

Accomplishments.—The rates were set on the basis of a fair day's work which should be accomplished with a first-class foreman and with no incentive to the laborers. Because of this absence of incentive the work actually done averages considerably less than the actual tasks.

To compare the amount of work accomplished before and after setting tasks the records were averaged of 27 cleanings taken at random from a period of 1½ years previous to the introduction of the new methods. These showed an average rate of 6.3 cu. yds. shoveled per day per gang. An average of 55 cleanings after task work was started gave 7.2 cu. yds. per day, an increase of nearly 15 per cent. This increase, however, was less than half of what it should have been, the figured rate being 8.4 cu. yds. per day. Although the 15 per cent increase was well worth accomplishing, our tests showed positively that the larger increase of over 30 per cent should readily be accomplished with first-class supervision. One plan considered as a partial incentive is a record card for each man showing his output and thus indicating his relative rank as a workman. The rank of a man would influence the laying off if work is slack or, on the other hand, if a man is required for a higher position, this ranking would be taken into account. If it had been possible to pay an actual money bonus, the task would have been set still higher and the output would have been increased about 50 per cent.

As the work on the filter management was getting under way, circumstances called the men in charge to other locations in the city temporarily. Going back to the job and making further studies, it was found that time had been lost: (*a*) by not throttling down the separator so as to make it run continuously and thus deliver its full output; (*b*) by unnecessary throttling of the hopper and cleaning up ahead before moving hopper to next portion of pile; (*c*) by not keeping spray open to fullest capacity. It was noticed whenever the gang was watched closely that they accomplished their task without any difficulty.

Apparatus.—The studies, as is always the case where thorough investigations are made, indicated a number of changes advisable in the apparatus and methods of handling it. It was found that the line of piping for the water used under pressure were poorly arranged, so as to require in certain cases long lengths of hose and a consequent deduction in pressure which largely increased labor costs. In other cases certain pipe lines had to be moved from bed to bed during the operation of cleaning. The studies have shown that a mechanical washing device probably can be devised which will greatly reduce the cost of cleaning.

Even with the present apparatus the method of handling the separators, and ejectors can be considerably improved and the cost of this quickly made up by labor saved.

The design of the hoppers and separators, as already stated, could be improved so that they would handle just the right amount of material that a gang can readily shovel. The present output is limited by the design of the hopper and ejector.

Cost of Cleaning Settling Tanks by Perforated Underdrains.—The following matter is taken from an abstract of a paper by Alexander Potter presented at the 23rd Annual Convention of the American Society of Municipal Improvements and published in Engineering and Contracting, Oct. 11, 1916.

Muskogee Settling Basin.—The Muskogee settling basin is constructed of reinforced concrete. It is 212 ft. square and 19.5 ft. deep. When filled to a

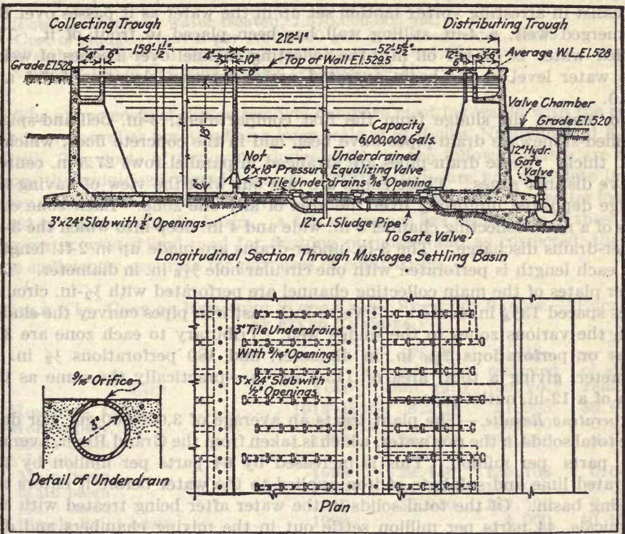


FIG. 8.—Longitudinal section through Muskogee settling basin. Detail of drain and plan.

depth of 18 ft. its capacity is 6,000,000 gal. A reinforced concrete curtain wall, 6 in. thick, supported by buttresses at intervals of 12 ft., divides the basin into two compartments. The first and smaller of these compartments, 52.5 ft. wide and 212 ft. long (about one-quarter of the basin), has its bottom perforated and underdrained for sludge removal. To underdrain the larger compartment was not considered advisable, first, because of the expense and, second, based upon the experience in other plants where the writer adopted this method, it was not considered necessary because of the relatively small quantity of suspended matter which experience indicated would settle out in this compartment. Three and a half years' continuous operation shows it to average about 1.3 per cent as opposed to 98.7 per cent removed over the area with the perforated bottom.

Fig. 8 is a section of the Muskogee settling basin taken parallel to the direction of flow. The raw water, treated with sulphate of iron and hydrated lime at the average rate of 1 and 2½ grains per gal., respectively, enters the settling basin at the left through the distributing trough. From the distributing trough the water is admitted to the first compartment of the basin through 32 8-in. circular openings. A vertical concrete baffle wall, 4 in. thick, constructed directly in front of these openings, tends to arrest all eddy and vortex motion and at the same time deflects the incoming water downward.

The partially settled water passes from the first to the second compartment over a submerged weir formed by the curtain wall. The crest of this submerged weir is about 6 in. below the average water level maintained in the tank. To assist in arresting vortex motion set up in the water as it passes over the submerged weir, a 4-in. stilling wall has been placed in front of it. The settled water is drawn off into the collecting channel over a series of weirs. The water level in the basin operated varies between elevation 527.5 and 528.0.

To remove the sludge from the first compartment, 3-in. bell-and-spigot vitrified-stoneware drain-pipes have been laid in the concrete floor, which is 9 in. thick. These drain-pipes are arranged in parallel rows 27.5-in. centers in five distinct zones. These zones are laid out with the view of having the sludge deposited uniformly over the area of any one zone. Each zone consists of a main collecting channel 8 in. wide and 4 in. deep into which the 3-in. under-drains discharge. The 3-in. under-drains are made up in 2-ft. lengths and each length is perforated with one circular hole 9/16 in. in diameter. The cover plates of the main collecting channel are perforated with ½-in. circular holes spaced 13¾ in. centers Twelve-inch cast iron pipes convey the sludge from the various zones to the sludge well. Tributary to each zone are 315 holes or perforations 9/16 in. in diameter, and 180 perforations ½ in. in diameter, giving a total area of 113.4 sq. in.—practically the same as the area of a 12-in. outlet pipe.

Operating Results.—The plant treats an average of 3,000,000 gal. per day. The total solids in the raw water, which is taken from the Grand River, average 451 parts per million. This is increased by 64 parts per million by the hydrated lime and sulphate of iron applied to the water before it enters the settling basin. Of the total solids in the water after being treated with the chemicals, 44 parts per million settle out in the mixing chambers and distributing troughs, 307 parts per million in the first compartment, i. e., the first quarter of the settling basin, and only about 4 parts per million in the second compartment.

The following table gives the most important facts relative to the operation of the sludge removal system at Muskogee.

Average total weight of dry solids removed daily by underdrains in the form of sludge, lbs	7,690
Average water content of sludge as discharged through blow-off valves, per cent	98.7
Total quantity of sludge water discharged at one operation, gal	70,000
Ratio of blow-off water to total water treated, per cent	2.33
Effective hydrostatic head for sludge removal, feet	20.5
Average velocity through underdrain perforations, feet per sec	20.4
Loss of hydrostatic head through perforations, 26.3% of total head, feet	5.4
Hydrostatic losses in underdrain system, 21% of total head, feet	4.3
Velocity head lost at discharge, 52.7% of total head, feet	10.8

Cost of Sludge Removal.—The total cost of constructing the sludge removal system for the Muskogee settling basin over and above the cost of constructing a plain tank of similar shape and size, and including all piping, valves, sludge chamber, etc., was \$3,570. This is at the rate of 32.5 ct. per square foot of bottom underdrained. The average annual cost of operating and maintaining the sludge removal system, including all fixed charges, amounts to \$523, and is made up as follows:

Interest and depreciation, 8% on \$3,570	\$286
Value of the blow-off water lost, 25,500,000 gallons raised 70 feet at \$6 per million (including fixed charges)	153
4,260 lb. ferrous sulphate lost with blow-off water at 1.15 ct. per lb.	53
9,370 lb. hydrated lime lost with blow-off water at 0.005 ct. per lb.	47
Attendance and supplies	34
Total annual cost	\$573

Total quantity of water treated, 1,970,000,000 gal.
Cost of sludge removal per 1,000,000 gal. of treated water, \$0.29.
Weight of dry solid matter removed in one year, 1,404 tons.
Cost per ton of dry solid matter removed, \$0.41.

The above costs of sludge removal compare most favorably with the cost of sludge removal as practiced on a large scale at St. Louis, Nashville and Kansas City. The costs of removing sludge given in the following table are taken from the municipal records, which, unfortunately, are not complete in that they only give the cost of labor, making no charge whatever for water lost and used in flushing out the basin. A fair allowance has been made in these costs for water wasted and used for flushing purposes, and as corrected, the data are sufficiently accurate for purposes of comparison.

Table XI.—Cost of Removing Sludge from Settling Basins.—(Exclusive of Fixed Charges.)

City	Year	Water treated (mil. gal.)	Sludge removed (cu. yd.)	Cost per cu. yd. of sludge removed
*Muskogee, Okla	1913–1916	3,210	21,903	\$0.0469
*McKeesport, Pa	1908–1913	8,890	96,000	0.0325
Main basin	1907	28,048	114,256	0.043
St. Louis, Mo.:				
Main basin	1908	29,156	135,108	0.048
Main basin	1909	34,201	129,035	0.051
Main basin	1910	33,910	182,500	0.045
Bissels Point basin	1908	......	4,000	†0.133
Baden storage reservoir	1908	......	700	†0.213
Nashville, Tenn	1908	......	4,500	†0.359

*Settling basins have underdrainage systems.
†Labor costs only.

At St. Louis it appeared to have been the practice of lengthening the period during which a settling basin may be kept in service by opening the mud gate 5 or 6 in. daily for a period of about an hour, or until the effluent is comparatively clear. None of this flushing water has been charged up against the cost of sludge removal. It is estimated that during the year 1910 approximately 193,000,000 gal. of water were used for this purpose in 175 days. Including the cost of pumping and treating this flushing water with chemicals, the cost of sludge removal becomes 29.3 ct., which is about the same as the cost of removing the sludge in Muskogee.

At Muskogee the percentage of sludge water to total water treated is 2.33 per cent, which, in the writer's opinion, can be considerably reduced by careful management. This ratio of sludge water to total water treated compares quite favorably with that of St. Louis, where in 1910, the only year for which accurate data are available, 523,000,000 gal. of water were chargeable against sludge removal. Of this amount, 300,000,000 gal. were lost in emptying the basin, 130,000,000 gal. were used for flushing purposes, and 193,000,000 gal. were wasted through the sludge gate, thus giving a ratio of 1.54 per cent.

The conditions at McKeesport are at times especially trying on the sludge removal apparatus, for there are periods, of short duration, when the precipitation reaches almost 10 per cent by volume of the water treated, and in the treatment 1,000,000 lb. of lime and 1,500,000 lb. of soda ash have been used annually. The cost of removing the precipitated material at the McKeesport plant has averaged about 35 cts.per 1,000,000 gal. of water treated.

The ratio of blow-off water to water treated ranges from 1.4 to 8.9 per cent when the water is bad, and averaged 2.3 per cent for the period that the plant has been in operation.

Costs of Cleaning Settling Basins by Sluicing.—The following data on cleaning one of the settling basins at Louisville, Ky., are taken from an article by G. D. Cain, Jr. in Engineering and Contracting, Dec. 3, 1913.

The two basins at the reservoir measure about 500 ft. square, and actual measurements showed that the amount of mud deposited in the basin which was cleaned was in the neighborhood of 18,000 cu. yds. The cost of removing this mass of material by the company's own forces was $2,700, or 15 cts. a cu. yd., which compares very favorably with the cost of the previous cleaning of the basins.

Of course the mud had not hardened sufficiently in the period of 20 months since the previous cleaning, to make literal excavation necessary, and this rendered it possible for the company to use the sluicing method. Lines of firehose were attached to the company's mains, and streams were directed upon the mud under a pumping pressure of 70 to 80 lbs. per sq. in.

The surface mud readily yielded to this treatment, but as the work went deeper the aid of a force of men armed with scrapers was necessary to expedite the removal of the mud. These scrapers were simple affairs made of 1 in. boards, and were constructed for use by three men at once, a fairly large surface thus being covered by each scraper.

The heavy mixture of mud and water was sluiced in this way into the central surface drain of the basin, which discharges into the sewer outlet provided for drainage purposes, and the entire 18,000 cu. yds. of silt were thus removed in about three weeks of actual working time. It was not possible to rush the work at a much greater speed on account of the danger of clogging the sewer. As it was, no trouble of this sort was experienced.

The following data computed from figures given in the report of Geo. H. Benzenberg, Chief Eng. water works, Cincinnati, O. are published in Engineering and Contracting, April 6, 1910.

The reservoir, known as Reservoir No. 1 of the Cincinnati, O., water works, had been in constant service for over two years. It was taken out of service on March 20, 1909, and allowed to stand for 4 days in order to allow complete sedimentation before drawing the water. The original turbidity of the water was 75 parts per million; after 4 days it was found to be 47 parts for a depth of 30 ft. and 50 parts at a depth of 40 ft. On March 30 the water was drawn off for a depth of 3 ft. during the night and allowed to stand during the day, when the mud was washed off the exposed slopes by hose streams under pressure of flushing pumps in the wier house. The following night the water level was again lowered to stand during the day, when the slopes were washed down. This procedure was repeated every 24 hours until April 9, when the water had become very turbid. The 30-in. drain was then opened, drawing off all the water and such mud as it carried. The deposit of mud remaining on the slopes and bottom was then disintegrated and slid to the drain opening by means of 1½-in. hose streams under heavy pressure. The depth of accumulated mud was found to be from 12 ins. to 36 ins. and the total amount removed was estimated as 30,000 cu. yds. Some 35,494,600 gals. of water were wasted in draining the reservoir and 16,902,600 gals. were used for removing the mud, or about 565 gals. per cubic yard of mud removed. The cost of cleaning was as follows:

16,902,600 gals. water, at $3.28 per mil. gals	$ 55.44
22,032 kw. electric power, at 1.1 ct	242.36
Labor operating pumps	57.94
Labor cleaning reservoir	427.27
Total	$783.01

The cost per cubic yard of mud removed was, for cleaning proper, 2.61 cts. Charging in the 35,494,600 gals. of water lost in draining the reservoir at $3.28 per million gallons we have an additional item of $116.42, or 0.39 ct. per cu. yd., making a total cost of 3 cts. per cu. yd. The cleaning was completed May 1, 1909, and water was turned back into the reservoir on May 8.

The cost of cleaning Reservoir No. 2 of the Cincinnati, O. water works is given in Engineering Record, June 21, 1913, as follows:

The time required to wash out the mud from this reservoir was twenty-eight working days. As nearly as could be estimated, 41,100 cu. yd. of mud were removed. This refers only to the sediment containing less than 50 per cent of water, which was left after draining off the liquid sludge. This volume of mud, together with the semi-liquid sludge, represents the deposit from over 34.5 billions of gallons of water. Besides 61,000,000 gal. of water being wasted in draining, about 21,000,000 gals. were used in cleaning out the reservoir.

The following table shows the costs for cleaning:

Cost of Cleaning Reservoir at Cincinnati, Ohio

	Total cost	Cost per cu. yd. of sediment removed
Labor	$1,100.45	$0.0267
Supplies	440.23	.0107
Power	154.44	.0037
Value of water used in cleaning	62.82	.0015
Value of water wasted in draining	183.13	.0044
Total	$1,941.07	$0.0470
Cost of cleaning per 1,000,000 gal. of water settled		$0.056+

The methods employed were similar to those used in cleaning reservoir No. 1. The increased cost noted is largely due to an increase of some 30 per cent in the rate paid for labor and the difficulty of opening the closed sump openings in this reservoir.

CHAPTER IX

IRRIGATION

In this chapter are included both general and specific cost data and articles dealing with many of the economic problems met with in irrigation.

For further data relating to this subject and included in the volume, see chapter on the following subjects: Excavation; Concrete; Dams, Reservoirs and Standpipes; Water Works; Small Tunnels and Land Drainage. Also refer to the index for other special information.

For costs of Pumping see "Handbook of Mechanical and Electrical Cost Data" by Gillette and Dana. For Methods and costs of excavation see "Earthwork and Its Cost" by Gillette also "Rock Excavation" by Gillette.

Cost of Irrigation Works Per Acre of Land Supplied with Water.—The cost of irrigation works per acre of land irrigated has been tabulated by the U. S. Reclamation Service for some 140 projects of which 87 are Carey act projects, 39 are private projects and 14 are projects of the Service. The data given in Tables I, II and III, are published in Engineering and Contracting, June 4, 1913.

TABLE I.—COST OF PRIVATE IRRIGATION PROJECTS

Name of project or company	Acreage in project	Cost or water right charge per acre
Colorado:		
Amity Canal	80,000	$100[2]
Beaver Land and Irrigation Co	20,000	175[2]
Catlin Canal	25,000	100
Colorado Co-operative Co	5,200	60
Denver Reservoir and Irrigation Co	200,000	45
East Palisade Irrigation District	645	63
Montana:		
Fort Lyon Canal	70,000	100[3]
Grand Valley Canal	40,000	60[4]
Greeley Poudre Irrigation Co	125,000	45
Mesa County Irrigation Project	2,568	73
Orchard Mesa Irrigation District	9,122	119
Otero Irrigation District	20,000	40
Palisade Irrigation District	6,000	41
Paradox Valley Irrigation Co	30,000	45
Pueblo-Rocky Ford Irrigation Co	100,000	150[5]
Redlands Irrigation and Power Co	5,000	100[6]
Routt County Development Co	39,000	45
South Palisade Heights Irrigation District	700	127
Conrad Land and Water Co		40
Great Falls Land and Irrigation Co	36,000	50

[1] Engineers' estimates where project is proposed or incomplete.
[2] Estimated at from $75 to $150 per acre. Includes land.
[3] Estimated at $75 to $150 per acre.
[4] Per miner's inch.
[5] Includes land.
[6] Estimated at from $65 to $150 per acre.

TABLE I.—(*Continued*)

Name of project or company	Acreage in project	Cost or water right charge per acre
Nebraska:		
Belmont Canal and Irrigation District	20,000	25[7]
Tri-state Canal	60,000	42
New Mexico:		
French Land and I. Co	40,000	50
Oregon:		
Bonanza Project	20,000	39
Eagle Valley	21,700	80
Turnish	6,000	60[8]
Paradise	100,000	60
Willamette Valley	20,000	50
South Dakota:		
Red Water Irrigation Association	4,000	40
Utah:		
Provo Reservoir	12,000	80
Utah Lake Pumping	8,000	40[9]
Washington:		
Cascade Canal Co	10,000	50
Congdon Canal Co	4,200	121
Kennewick Canal	14,000	163
Lower Yakima I. Co	12,500	129
Selah Moxie	7,000	86
Selah Valley Development Co	10,000	150
Union Gap Irrigation Co	5,000	135
Washington Irrigation Co	50,000	46

[7] For river rights only. Purchase of Pathfinder Reservoir water will increase this to $35.

[8] Estimated at from $50 to $70 per acre.

[9] Estimated at from $40 to $50 per acre.

TABLE II.—COST OF CAREY ACT PROJECTS

	Acreage	Cost per acre
Colorado Land and Water Supply Co	16,278	$45
Two-Butte Irrigation and Reservoir Co	22,000	35
Valley Investment Co	24,000	60
Colorado:		
Great Northern Irrigation & Power Co	2,121	55
Colorado Realty and Security Co	45,875	45
Toltec Canal Co	14,853	40
Idaho:		
American Falls Canal & Power Co	57,242	40
Big Lost River Irrigation Co	78,242	40
Birch Creek Irrigation Co	20,000	50
Blackfoot North Side Irrigation Co	22,280	
Black Canyon Irrigation District	98,492	72
Blaine County Irrigation Co	14,720	40
Boise City Carey Act Project	151,000	
Bruenau Irrigation Co	40,000	60
Emmett Irrigation District	5,800	50
Grandview Extension Irrigation Co	1,000	65
Grassmere Irrigation Co	47,500	65
Hansen, C. V., Mackay Project	3,456	40
Hegsted Victor, Project	3,410	40
High Line Pumping Co., Ltd	3,860	45
Houston Ditch Co., Ltd	1,884	35
Idagon Irrigation Co., Ltd	9,000	60
Idaho Irrigation Co., Ltd	130,000	50
Keating Carey Land Co	15,597	30
Kings Hill Extension Irrigation Co	9,655	65
Kings Hill Irrigation and Power Co	13,359	65
Lemhi Irrigation Co	3,500	50
Little Lost River Land & Irrigation Co	20,000	30

TABLE II.—(*Continued*)

	Acreage	Cost per acre
Marysville Canal & Improvement Co., Ltd	6,134	20
Owsley Carey Land and Irrigation Co	8,600	35
Owyhee Land and Irrigation Co	29,535	55
Owyhee Irrigation Co., Ltd	3,296	45
Pahsimeral Project	6,000	30
Portneuf-Marsh Valley Irrigation Co	11,914	35
Pratt Irrigation Co., Ltd	4,674	40
Snake River Irrigation Co., Ltd	6,500	50
Thousands Springs Land and Irrigation Co	6,300	30
Twin Falls Land and Water Co	244,000	25
Twin Falls North Side Land and Water Co	207,144	45
Twin Falls Oakley Land and Water Co	45,000	65
Twin Falls Raft River Irrigation Co	99,668	50
Twin Falls Salmon River Land & Water Co	127,707	40
West End Twin Falls Irrigation Co	46,000	50
Montana:		
Billings Land & Irrigation Co	27,000	40[10]
Big Timber Project	17,194	60
Valier Project	115,100	40
Oregon:		
Central Oregon Irrigation Co	139,204	40
Central Oregon Irrigation Co	74,198	60
Columbia Southern Co	27,000	50[11]
Deschutes Land Co	31,082	36
Deschutes Reclamation & Irrigation Co	1,280	40
Desert Land Board	27,000	
Portland Irrigation Co	12,000	46
Powder Land & Irrigation Co	65,000	100[12]
Utah:		
Mosida Pumping Plant	8,000	150[13]
Wyoming:		
Big Horn County Irrigation Co	20,411	50
Boulder Canal	6,120	30
Burch Canal	35,887	50
Carbon County Land & Irrigation Co	7,793	30
Cody and Salsbury Canal	77,199	
Cody Canal	26,429	50
East Fork Irrigation Co	4,901	30
Eden Land & Irrigation Co	95,658	30
Elk Canal	2,724	30
Fisher Ditch	320	10
Green River Land and Irrigation Co	75,257	35
Hammitt Canal	6,295	60
Hanover Canal	10,682	50
Hawk Springs Project	12,238	50
Hubbard Canal	38,604	40
James Lake Irrigation Co	14,554	35
La Prele Ditch and Reservoir Co	18,558	50
Lovell Irrigation Co	11,320	25
McDonald Canal	15,159	50
Medicine Wheel Canal Co	22,385	30
North Laramie Canal Co	4,133	50
North Platte Canal & Colonization Co	14,424	30
Big Horn Basin Development Co	204,650	50
Paint Rock Canal	53,162	50
Platte Valley Canal	18,171	30
Rock Creek Irrigation Co	11,696	45
Sahara Ditch Co	7,920	50
Sidon Canal & extensions	20,559	30
Tinsleep-Bonanza Canal	16,486	40
Uinta County Irrigation Co	26,000	35
Wheatland Industrial Co	33,115	45
Wyoming Land & Irrigation Co	4,526	50

[10] Estimated at from $20 to $60 per acre.
[11] Estimated at from $50 to $60 per acre.
[12] Estimated at from $75 to $200 per acre.
[13] Estimated at from $100 to $250 per acre.

The figures in Tables I and II obtained from printed reports of state engineers and public data, show that on over 90 modern irrigation systems being built by private or corporate capital, the cost per acre averages nearly $53. This cost does not include the annual cost for operation and maintenance.

TABLE III.—RECLAMATION SERVICE PROJECTS

State and project	Approx. acreage	Cost per acre from	to
Arizona-California			
Yuma	131,000	$55	$66
Idaho			
Minidoka	118,700	22	30
Montana			
Sun River	216,346	30	36
Montana-North Dakota			
Lower Yellowstone	60,116	45	
Nebraska			
North Platte	129,270	45	55
Nevada			
Truckee-Carson	206,000	22	30
New Mexico			
Carlsbad	20,277	32	45
Oregon			
Umatilla	25,000	60	70
Klamath	72,000	30	
South Dakota			
Belle Fourche	100,000	30	35
Washington			
Okanogan	9,900	65	
Sunnyside	102,824	52	
Tieton	34,613	93	
Wyoming			
Shoshone	164,122	45	50
Average		$41+	

Cost of Reporting on an Irrigation Project.—The following is given by Charles Kirby Fox in "Western Engineering," reprinted in Engineering any Contracting, Nov. 5, 1913.

During 1911–12 I was employed to make the surveys and estimates for an irrigation project. Careful records were kept of the time and cost of each item pertaining to the work. All told, the project covers 70,000 acres, of which a part is already irrigated and some of it does not require irrigation. We prepared preliminary plans for irrigating 80 per cent of the unirrigated arable land, or 40,000 acres. As a rule, the land was fairly smooth and for the greater part covered with sagebrush about waist high.

On account of the distances from trade centers, it was necessary in making the designs and estimates to provide for using as much local material as possible and minimize the quantity of materials shipped in from the outside. The approximate estimates follow: Excavation, 8,000,000 cu. yds.; tunneling, 5,800 lin. ft. lumber, 830,000 ft. B. M.; iron and steel, 500 tons; main and diversion canals, total 61 miles; laterals, 144 miles. There will be approximately 2⅔ miles of flume and a little over ½ mile of siphons in the system.

Outside of the engineering crew, local men were used. It was necessary with the greater part of the work to establish camps. These were, as a rule, 10 to 20 miles from the adjacent towns. Chainmen and rodmen were paid $40 to $50; cooks, $60 to $70; level-men, $75 to $85; instrument men, $90 to $110; draftsmen, $75 to $150, and assistant engineers, $100 to $150. All rates given are by the month and include board and expenses. About 10,000 meals were served in camp at a cost of 28 cts. each, segregated as follows:

	Cents
Food	21
Cook	6
Incidentals	1
Total	28

It was necessary to use canned goods almost exclusively. The cost of provisions was very high. The meals were excellent. Horses were hired at a cost usually of about $1 per day, including feed.

Water Shed and Irrigation Survey.—Eighteen stations were set by an assistant engineer and rodman with two horses. To place the stations, triangulate them and plot the work cost $35 per station. Eight and one-half days' time was put in on each station.

Sounding Lake and Contouring Reservoir Site.—In sounding a 3,000-acre lake it was necessary to cut over 1,000 holes through 13 ins. of ice. A party consisting of a transit man, two chainmen, two axmen and two horses were used. In contouring 4,000 acres around the lake the same party was used, except that a recorder and three stadia men were substituted for the chain and axmen. The sounding and contouring cost 6.4 cts. per acre.

The high-water line of the reservoir was run before I arrived. I understand that it cost about $50 per mile for 16 miles of exterior line. This includes ties to the section corners.

Section Lines.—Approximately 200 miles of section lines were re-run. Great difficulty was experienced in finding some of the corners. It is thought that between one-fourth and one-fifth of the time was spent in looking for old corners, and the work was greatly delayed by storms. The party consisted of an instrument man, two chainmen, two flagmen, a teamster, four horses and a cook. The work cost $10 per mile. It might be worth noting that on lines which were re-run, only one corner has been found that the original party did not locate. Some 60 corners were replaced at odd times at a cost of $2.50 per post.

Leveling.—(The section line party was followed by a level party (levelman and rodman), which set bench marks every half mile or mile. They ran 150 miles at a cost of $2.50 per mile.

Contouring.—The entire area under the ditch-line was contoured at a cost of 5 cts. per acre. Five-foot contour intervals were used on the flattest sections and 10 ft. on the steeper parts. It was platted on a scale of 1,000 ft. to the inch. The party consisted of an instrument man, recorder and two to four stadia men. Usually two parties were in the field under my supervision, with a draftsman, cook, one or two teamsters and six horses. After the field work was completed it took almost as much time to reduce and plat the transit stadia notes as it did to do the field work.

Cruising.—First the real estate department had a man cruise the land and plat it on a scale of 6 ins. to the mile. This cost 2 cts. per acre. It was later thought advisable to make a rough cultural and property map of the valley now under cultivation, so as to have an idea of the amount of hay and grain available. Two men on foot could cover about 10,000 acres per day. Office work took about the same time.

Canal Line.—With a view to determining the most economical location of the canal line, we ran a low line 39 miles long and a high line 20 miles long, and made a careful reconnaissance of the remainder. From these studies we determined that the high line would be cheapest. The lines were run by the following party: Chief, draftsman, transit man, stadia man, flagman, axman, level man, rodman, teamster, four horses and a cook. It cost $16 per mile to do this work.

We then started out with practically the same outfit except that two chainmen were added. The distance per shot on the preliminary line was about 400 ft. All the work was on the side hill. When contouring was commenced the party was divided.

On the transit line we set stakes every 100 ft. and took the elevation at each station. We then took, very careful topographic data, usually covering 30 to 40 ft. in vertical elevation by 5 ft. contours, which were platted in the field to a scale of 200 ft. to the inch. We were very careful to note all rock outcrops or other characteristics which would influence the final location of the line. We ran 61 miles of these lines at a cost of $30 per mile for the transit and level line, and $20 per mile for the topography. The cost of the ties to the section corners is included in the cost of the transit and level line.

Paper Location and Estimate.—The office work was done in the winter with a small force, consisting of myself, an assistant engineer, a draftsman or two and a blueprint boy. I had the assistant engineer and a draftsman spend a month to work up a special set of excavation tables especially adapted to side hill canal lines. They gave the balanced cut and fill, the yardage and the center cut for each different side slope. I estimate that by the use of these tables were saved several hundred dollars per mile on the excavation at a cost of less than 1 per cent of the amount saved. The estimate cost $16 per mile, or approximately ⅔ of 1 per cent of the cost of the excavation.

Field Notes and Maps for Filing.—The tracings included six sets (34 sq. ft.) of three maps each, and the field notes required 146 pages of legal size paper. All courses were balanced in connection with the section line survey. The office work cost $500, or about $6.50 per mile of canal and reservoir.

Designs and Estimates for Structures.—It is estimated that the structures, flumes, siphons, outlets, etc., will cost about $100,000. The designs and estimates cost 2 per cent of the estimated cost. Usually several types of structures were sketched out and estimates made for each type. These detailed drawings were made according to what appeared to be the best type, and included a complete estimate of the cost, including quantities, weights, etc. The difference in the cost of several types of structures, all of which appear suitable, is surprising.

It cost a little less than 1 per cent to make the surveys, designs and estimates of the rock fill dam and tunnels. Enough money will be saved on changing the dam site from the location selected by the promoters to pay the entire cost of the work. The laterals were laid out on the contour map and only a few of the larger ones were run out. The designs and estimates for the laterals cost about $2 per mile. The entire report with the specifications, etc., contained about 250 pages and 100 blueprints.

General Expenses.—The stenographic and clerical expenses amounted to approximately $400, the general expenses about $800 and approximately $1,000 was spent on hydrographic work. All told, this survey cost approximately $20,000, or 50 cts. per acre, or 3 to 4 per cent of the estimated cost of the work. About 4,000 man-days were worked at an approximate cost of $5 per man-day.

Cost of Constructing Irrigation Works.—The following matter is taken from Newell and Murphy's "Principles of Irrigation" (1913).

It has come to be an axiom that the cost of irrigation works is generally greater than the original estimate. This is due not so much to lack of care and thoroughness in preparing estimates as to the fact that the work is pioneer in its character, and improvements are suggested or new needs arise so rapidly that works which were planned in one year as adequate for the purpose in mind are found to be unsuited or undesirable by the time construction is well advanced. Many changes must be made, or additional details provided which were not known or not considered necessary in the original scheme. It is, of course, possible that an engineer may plan works and build them exactly as planned and within the original estimates, but this condition is one which with existing irrigation systems does not take place under ordinary circumstances.

The engineer may plan for certain works to meet the then prevailing conceptions, but the owners or financiers usually conclude that it is necessary to add certain extensions or modify details such, for example, as increasing the size of the reservoir, or of the main canal, or adding a pumping plant. Thus, as a result, the works cost more than anticipated, and, comparing the original statements of cost with the actual expenditures made, it is seen that the latter are far in excess of the estimates, but the reasons for this are rarely given.

Men's ideas with reference to limits of practicability or cost of the works have rapidly expanded. The small canals built before 1900 were cheaply executed, the structures were of wood and of temporary character. The location was made with reference to keeping the construction cost to the minimum and much of the work was done by the farmers themselves, no account being taken of what is generally termed the overhead cost including that of planning and organization of the work.

At the same time, the estimates of the area watered were very liberally made. If some water was provided for a farm, it was habitually stated that the entire area say of 160 acres was under irrigation, even though water had only been as a matter of fact applied to a portion of it. The capacity of the canal might not be enough to supply all of the lands which were claimed to be irrigated. For these reasons the cost per acre of irrigation was stated at an extremely low price, less than $15 per acre. Beginning about the year 1900, a cost of $20 per acre for irrigation was considered high, but when it began to be appreciated that the land with a sure water supply would yield a large return on a value of $50 or even $100 per acre, it was recognized that larger investments in construction would be justified. Year by year the limits of assumed feasibility have been increased, so that by 1905, it was assumed that $30 per acre was large, then $40 per acre, and finally by 1910, a cost of reclamation of $60 per acre was not considered prohibitory, for lands especially in the southern part of the country. In fact, when consideration is had of the great value of orchard lands an expenditure of $100 or more per acre to provide water is feasible. In semitropical lands, for example, in the Hawaiian Island, where pumping plants have been erected for raising water for irrigation to a height of 550 ft., an outlay of several hundred dollars per acre is not considered out of the ordinary.

In the northern temperate regions, for example, in Colorado and Montana, for the ordinary field crops an investment of $40 to $60 per acre may be now considered as large but not prohibitory. This may be increased notably for warmer regions with longer crop season, such as those of southern Idaho, and portions of Oregon and Washington. Going south from here to points as in

Arizona and California, where crops grow throughout the greater part of the year, an increase of 50 per cent. in the amount above named may be considered as moderate.

If estimates are based on the crop production of thoroughly irrigated lands it can readily be seen that these give a good income on an investment of from $200 to $500 per acre, so that theoretically, the figures above given could be increased several fold, but as a matter of fact, under existing conditions, it is hardly safe to figure on this basis, although it is possible to look forward to a time when far larger investments than now considered wise will be the rule rather than the exception.

Other Costs.—It must not be assumed that the cost of an irrigation system is simply that of the engineering or construction. There are other costs which may equal or exceed these and neglect of which in the preliminary estimates frequently leads to financial ruin. These are the somewhat vague and intangible expenses of the organization, the so-called overhead charges, especially of commission and interest upon bonds, or upon other securities issued for construction purposes. It is not infrequently the case that after the engineer has carefully estimated all of the construction cost and has allowed 15 per cent. or 20 per cent. for contingencies, the business man must double this to cover the items above noted.

Taking the ordinary conditions of private irrigation systems it may be said that assuming the engineer's estimate of construction at 100 per cent., the other items to be added will be about as follows:

Preliminary examinations, organization and promotion, 10 per cent.

General administrative, 10 per cent. This is after the funds have been raised, the general plans determined upon and construction carried to completion.

Interest on bond issue, 20 to 30 per cent. This is assumed to cover most of the construction cost, and is estimated at 6 per cent. per annum on the period required in the construction of large systems.

We thus have from 40 to 50 per cent. of the construction cost to be added at the time when the works are completed.

Beginning with the time of completion of the works and the beginning of active irrigation from then on is the period of greatest difficulty and stress. Settlement of the lands is usually slow, the farmers must experiment, the markets are to be established, and five, ten or more years may elapse before the land is completely irrigated and the farmers are able to make notable payments. During this time the cost of operation and maintenance has been large and this with the interest on bonds or other securities may amount to 75 per cent. or even 100 per cent of the actual construction cost.

Size and Cost of Organization for Operating Irrigation Systems.—The following data are given in Harding's "Operation and Maintenance of Irrigation Systems."

At the 1911 Operation and Maintenance Conference at Boise, a paper was presented by R. K. Tiffany, then manager of the Sunnyside project, in which a series of organizations for different sized systems were given as shown in Table IV. As stated by Mr. Tiffany the number of employees given would represent about the maximum which would be required. Under favorable conditions the number may be materially reduced and many systems are operated with smaller organizations.

As an instance of effect on the organization of the main canal system of the delivery of water to laterals only or to individuals, a case on the Boise project

TABLE IV.—SIZE OF ORGANIZATION

Position	Size of project—20,000 acres: Number of employees	Monthly salary	50,000 acres: Number of employees	Monthly salary	100,000 acres: Number of employees	Monthly salary
Manager	1	$ 200	1	$ 250	1	$ 300
Chief clerk	1	125	1	150	1	175
Bookkeeper	...	...	1	125	1	125
Stenographers	...	...	1	90	2 @ $90	180
Engineer	1	125	1	150	1	150
Hydrographer	...	...	...	...	1	100
Inspector	...	...	1	100	2 @ $90	180
Water masters	1	125	2	275	3 @ $150	450
Ditch riders	8 @ $90	720	20 @ $90	1,800	40 @ $90	3,600
Telephone lineman	1	75	1	90	1	90
Water-record clerks	...	...	...	...	2 @ $90	180
Total per month	...	$1,370	...	$3,030	...	$5,520
Cost per acre per month	...	6.8 cents	...	6 cents	...	5.5 cents

was cited. On 32,000 acres, of which 21,000 were irrigated, water was delivered to laterals only on about half of the area; one water master, one field clerk, 2 gate tenders and 8 ditch riders handled this area at a cost of 5 cents per acre per month. On another division containing about 33,000 acres of which 15,000 were irrigated, water was delivered to each individual farm at a cost of 12½ cents per month.

The average size of the clerical force for government projects was given as follows at the same conference: up to 15,000 acres, one clerk; 15,000 to 40,000 acres, two clerks; 40,000 to 75,000 acres, three clerks; 75,000 to 120,000 acres, four clerks; 120,000 to 175,000 acres, five clerks; 175,000 to 240,000 acres, six clerks. These do not include the keeping of the strictly operation or water-delivery records It was considered that one man should handle about 2,000 individual accounts in the books. For other forms of organization the clerical force is usually somewhat smaller.

Economic Water Conduit Location.—The following is given in Engineering and Contracting, Jan. 14, 1914.

Every conduit must change at certain points along its length from one type of construction to another, as from pipe line to lined canal, unless it traverses a country of uniform topography. Such changes arise from considerations of economy or safety. A conduit of any considerable length seldom consists wholly of canal section but changes from that type of construction to flumes, siphons, pipe lines, bridge flumes or tunnels, as the location conditions dictate. The points at which such changes are made are determined by economic considerations as well as by ground slope, by the nature of the material encountered in the excavation processes and by the other local conditions. Just as the comparative costs of deep cutting and tunneling are used to indicate when to pass from cut to tunnel in railroad location, so the transition from one type of conduit construction to another is based upon comparative costs.

In making various conduit locations C. E. Hickok, has evolved a diagram which gives the equivalent lengths, from an economic standpoint, of various types of conduits. The diagram and Mr. Hickok's discussion of it are here given as described by him in his paper entitled: A Study of Economic Conduit Location, as published in Vol. XXXIX Proc. Am. Soc. of C. E., pp. 2185–2190. When the locator comes to a point where he must decide whether

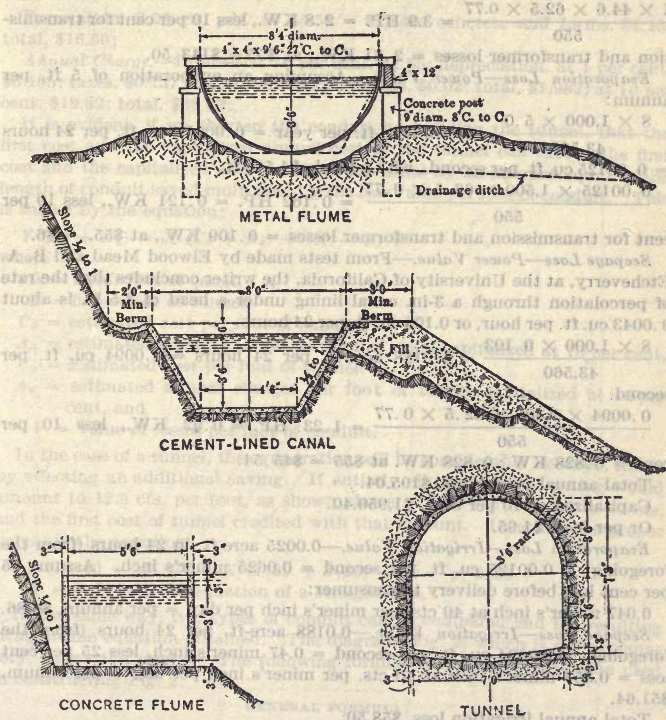


FIG. 1.—Cross-sections of four types of conduits.

to tunnel through a ridge or follow the grade around with a canal, he measures the length of the two possible routes, and, by an inspection of the diagram given herewith, reaches a decision as to the more economical of the two types of conduits. This not only saves time but, with a properly constructed diagram, assures a proper and complete comparison between the two alternatives as to first cost, depreciation, head-loss values, evaporation and seepage loss values, interest, taxes, inspection and repairs.

For purposes of illustration assume a case where the project under consideration is to be used for irrigation and hydro-electric purposes, and where the conduit has a capacity of 44.6 cu. ft. per second and a slope of one-tenth of 1 per cent. Four types of conduit are shown in Fig. 1.

It is obvious that for each foot saved in length of conduit there is a saving in head loss, as well as in evaporation and seepage losses. The value of this saving is ascertained in the following way, taking 1,000 ft. of conduit, for convenience in calculating:

Head Loss.—1,000 ft. of conduit dissipates 1 ft. head. With a discharge of 44.6 cu. ft. per second, and 77 per cent efficiency, the horsepower is:

$$\frac{1 \times 44.6 \times 62.5 \times 0.77}{550} = 3.9 \text{ HP.} = 2.8 \text{ KW.}$$, less 10 per cent for transmission and transformer losses = 2.61 KW., at $55 = $143.50.

Evaporation Loss—Power Value.—Assuming an evaporation of 5 ft. per annum:

$$\frac{8 \times 1{,}000 \times 5.0}{43{,}560} = 0.915 \text{ acre-ft. per year} = 0.0025 \text{ acre-ft. per 24 hours}$$

= 0.00125 cu. ft. per second., with a head of 1,500 ft.

$$\frac{0.00125 \times 1{,}500 \times 62.5 \times 0.77}{550} = 0.162 \text{ HP.} = 0.121 \text{ KW.}$$, less 10 per cent for transmission and transformer losses = 0.109 KW., at $55, = $6.

Seepage Loss—Power Value.—From tests made by Elwood Mead and B. A. Etcheverry, at the University of California, the writer concludes that the rate of percolation through a 3-in. canal lining under a head of 3.5 ft. is about 0.0043 cu. ft. per hour, or 0.103 cu. ft. per 24 hours.

$$\frac{8 \times 1{,}000 \times 0.103}{43{,}560} = 0.0188 \text{ acre-ft. per 24 hours} = 0.0094 \text{ cu. ft. per second.}$$

$$\frac{0.0094 \times 1{,}500 \times 62.5 \times 0.77}{550} = 1.23 \text{ HP.} = 0.92 \text{ KW.}$$, less 10 per cent = 0.828 KW.; 0.828 KW. at $55 = $45.54.

Total annual power loss, $195.04.

Capitalized at 10 per cent, $1,950.40.

Or per foot, $1.95.

Evaporation Loss—Irrigation Value.—0.0025 acre-ft. in 24 hours (from the foregoing) = 0.00125 cu. ft. per second = 0.0625 miner's inch. Assume 25 per cent loss before delivery to consumer:

0.047 miner's inch at 40 cts. per miner's inch per day = per annum, $6.86.

Seepage Loss—Irrigation Value.—0.0188 acre-ft. per 24 hours (from the foregoing) = 0.0094 cu. ft. per second = 0.47 miner's inch, less 25 per cent loss = 0.353 miner's inch at 40 cts. per miner's inch per day = per annum, $51.64.

Total annual irrigation loss, $58.50.

Capitalized at 10 per cent, $585.00.

Or per foot, $0.585.

Summary.—Power loss per foot, $1.95; irrigation loss per foot, 0.585; total loss per foot, $2.535.

The first cost and the annual charges of each type of conduit are next computed. The annual charges are taken as consisting of the following items: Interest, depreciation, taxes, inspection, and repairs. The annual charges of each conduit are capitalized at 10 per cent and added to its first cost, which gives a figure having a real comparative value. For instance, we obtain the comparison between a lined canal and a concrete-lined tunnel as follows:

CONCRETE-LINED CANAL

First Cost—Per Foot.—Excavation, 2 cu. yds. at 36 cts. = \$0.72; concrete, 4.25 cu. ft. at \$10.20 per cu. yd. = \$1.57. Total = \$2.29.

Annual Charge.—Interest at 10 per cent, \$0.23; depreciation, at 2 per cent, \$0.046; taxes, \$0.019; inspection, \$.01; repairs, \$0.02; total, \$0.325; at 10 per cent, \$3.25; total, \$5.54.

CONCRETE-LINED TUNNEL

Excavation, 2.25 cu. yds. at \$5.50 = \$12.40; concrete and forms, \$4.10; total, \$16.50;

Annual Charge.—Interest at 10 per cent, \$1.65; depreciation, at 1 per cent, \$0.165; taxes, \$0.137; inspection, \$0.01; repairs, \$0.02; total, \$1.982; at 10 per cent, \$19.82; total, \$36.32.

It is evident, if we shorten the conduit by building the tunnel, that the first cost and the capitalized annual cost of the tunnel can exceed the first cost and the capitalized annual cost of the canal by an amount equal to the length of conduit saved multiplied by the loss value per foot of conduit. This is shown by the equation:

$$Y\,(C_y + A_y) = X\,(C_x + A_x) + (X - Y)\,V$$

where

X = linear feet of canal,
Y = linear feet of tunnel,
C_x = estimated cost per foot of canal,
A_x = estimated annual charges per foot of canal capitalized at 10 per cent,
C_y = Estimated cost per foot of tunnel.
A_y = estimated annual charges per foot of tunnel capitalized at 10 per cent, and
V = value of losses per foot of conduit.

In the case of a tunnel, the evaporation will be considerably lessened, thereby effecting an additional saving. If entirely eliminated, this saving would amount to 12.8 cts. per foot, as shown above. This was reduced to 10 cts. and the first cost of tunnel credited with that amount. Inserting the proper values in the equation:

$$Y\,(16.40 + 19.82) = X\,(2.29 + 3.25) + (x - y)\,2.53$$

$Y = 0.208\,X$, the equation of a straight line.

In the same way, two types of conduit can be compared and the resulting straight-line equation obtained. The diagram, Fig. 2, which is self-explanatory, shows the results. The following formula and assumptions were used in constructing Fig. 2:

GENERAL FORMULA

$$y(C_y) = xC_x + (x - y)\,V + x\,(A)\,\mathrm{Y} - \mathrm{X}\,(A_y)$$

C_y = Estimated cost per foot of conduit above line.
A_y = Estimated annual expense per foot of conduit above line capitalized at 10 per cent.
C_x = Estimated cost per foot of conduit below line.
A_x = Estimated annual expense per foot of conduit below line capitalized at 10 per cent.
V = Estimated value of one foot of canal for power and irrigation purposes = \$2.53.

Tunnel is credited with 10 cts. per foot for saving in evaporation.

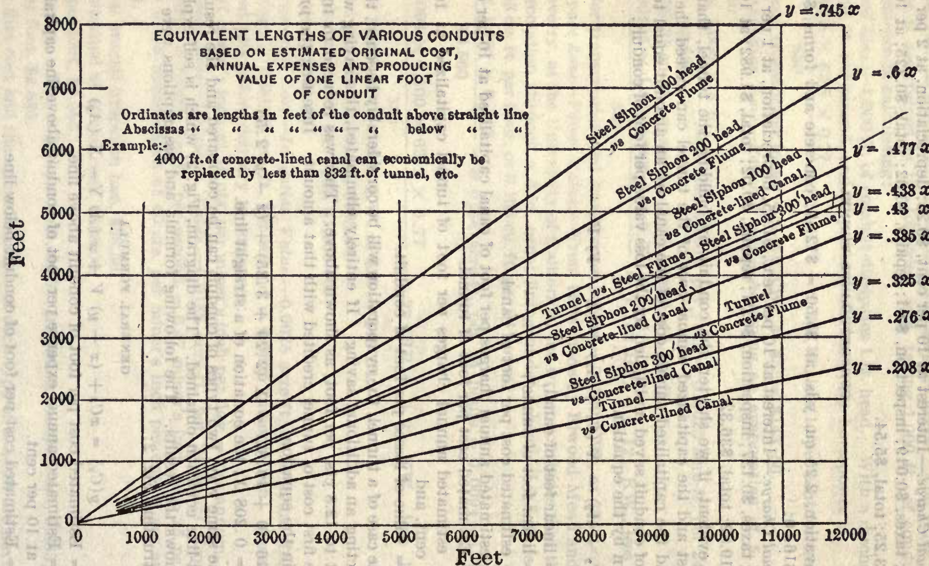


Fig. 2.—Equivalent lengths of various types of conduits all costs considered.

VALUES USED

	Original cost per ft.	Annual expenses per ft.
Tunnel	$16.50	$1.98
Concrete-lined canal	2.30	0.325
Concrete flume	4.28	0.579
48-in. steel siphon, 100-ft. head	5.88	0.961
48-in. steel siphon, 200-ft. head	7.46	1.211
48-in. steel siphon, 300-ft. head	10.64	1.714
Steel flume	5.58	0.887

Steel siphons are credited with $1.10 per ft. for saving in evaporation and seepage.

In the case where a siphon crossing a gulch is compared with a canal or flume passing around the head of the gulch, the cost of the siphon is credited with the saving in evaporation and seepage throughout its length, which in this case amounts to $1.10 per foot.

The writer realizes that such a diagram cannot be relied on entirely in the location of a conduit, for there are local conditions on every piece of work which must be taken into account.

Cost Curves Used for Location of Catskill Aqueduct.—The following notes are abstracted from matter given in White's "Catskill Water Supply of N. Y. City" by J. P. Hogan.

Types of Gravity Aqueducts.—The types of aqueduct construction in order of their relative cost, provided that in embankment or viaduct the elevation of invert above original surface is relatively small, are as follows:

Aqueducts on hydraulic grade	Following natural surface	1. Open channel 2. Cut-and-cover
	Above natural surface	3. Embankment 4. Viaduct
	Below natural surface	5. Grade tunnel
Aqueduct below hydraulic grade	Following or above natural surface	6. Wooden pipe 7. Reinforced concrete pipe (pressure aqueduct) 8. Steel pipe
	Below natural surface	9. Pressure tunnel

On the Catskill Aqueduct, to avoid contamination, open channel is not used. Embankment is used as sparingly as possible, as it is deemed rather unsafe for an aqueduct of this size. Viaduct is not used to any extent, but in a few places the aqueduct was placed on arches and the whole covered with embankment. Wooden pipe is not to be considered for an aqueduct of this size. Reinforced concrete pipe is used to some extent under heads considerably less than 100 ft.

Comparison between Croton and Catskill Aqueducts.—The new Croton Aqueduct was placed entirely in tunnel for the following reasons: greater permanency, decreased likelihood of accident, smaller cost of maintenance, smaller leakage, remote advantage of being less vulnerable in time of war, and decreased cost of real estate. These advantages are very real, but unless there is some special condition which increases the importance of one or more of them, they are outweighed by the smaller linear foot cost of cut-and-cover aqueduct.

The Catskill aqueduct, with twice the capacity of the New Croton aqueduct, cost less than 10 per cent more per linear foot due in great measure to substitution of cut-and-cover for grade tunnel.

Cost Curves.—In deciding upon the type of section to use, and the location for the Catskill Aqueduct, cost curves were prepared for the different sections and estimates of cost were made for alternate lines wherever possible. The combination of section and location that gave the lowest cost was used in determining the final location, depending upon field conditions and the advantages of the shorter line and of eliminating curves.

Fig. 3 shows cost curves used for location of cut-and-cover aqueduct. In preparing these curves unit costs were assumed for different classes of work and applied to quantities determined by planimetering typical sections. Costs were thus computed for every 2-ft. difference in center line elevation; for three different natural conditions, i.e., ground level, slope four on one, and slope three on one; and for five different subsurface conditions, i.e., all earth, all rock and with earth overlying rock, 4, 8 and 12 feet respectively.

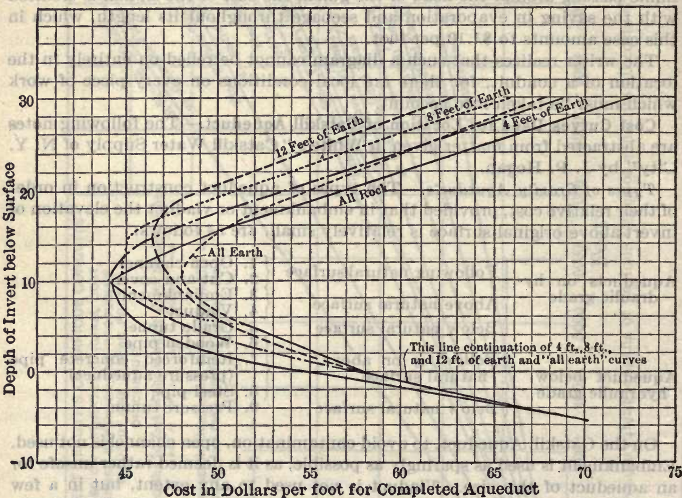


FIG. 3.—Cost curves used for location of cut-and-cover aqueduct.

Similar curves for grade tunnels, for three conditions, i.e. (1) in sound rock, (2) timbered tunnel in rock, and (3) in earth, were used in comparing alternate lines of cut-and-cover and grade tunnel and to indicate approximately the depth of cut at which it would be economical to start tunneling.

In the case of pressure tunnels, a tentative linear foot cost was estimated for each tunnel for comparison with alternate cut-and-cover, grade tunnel and steel-pipe locations.

In preparing curves of this kind the absolute unit prices are not of as much importance as the relative prices. If, for instance the relative price of excavation as compared to concrete is unduly low, the tendency would be to favor the shorter lines. Indeed, the curves in Fig. 3 show too low a cost for the type of aqueduct partly in rock, in some cases the cost being lower than aqueduct in all earth, due to the assumption that narrower cuts would be used through rock, the resulting saving of expensive concrete more than balancing the extra cost of rock excavation. However this assumption did not lead to any notable errors in location, as it was rarely possible to choose the kind of material the cut-and-cover aqueduct was to be constructed in.

The estimated costs for cut-and-cover aqueduct used in preparing the above curves were as follows:

Earth excavation	Cubic yard	$0.30
Rock excavation	Cubic yard	1.50
Refill direct from excavation	Cubic yard	0.30
Refill from borrow	Cubic yard	0.50
Concrete including forms and cement	Cubic yard	7.00
Surface stripping 1 foot deep	Cubic yard	0.60
* Surfacing, smoothing, sodding, and seeding	Cubic yard	Cost of refill plus 0.30
Rubble retaining wall	Cubic yard	2.00
Fencing one foot along aqueduct	Cubic yard	1.00

* Assumed for surface material 1 foot deep.

Unit and Linear Foot Costs of Aqueduct.—It is interesting to compare the original assumption of unit prices and linear costs with the prices for which the contracts were afterwards let. The original assumptions used on location of the Northern Aqueduct Department were as follows:

UNIT COSTS

Cut-and-cover

	Excavation per cu. yd.*	Refill per cu. yd.	Concrete per cu. yd.
Assumed price	$0.50	$0.30	$7.00
Contract price	0.58	0.30	7.30

Grade Tunnel

	Excavation	Refill	Concrete
Assumed price	$5.50	.....	$10.00
Contract price	5.17	.....	9.15

* For earth. A price of $1.50 per cubic yard was assumed for rock. Under the contract there was no classification.

LINEAR FOOT COSTS

Cut-and-cover

	Excav.	Refill.	Concrete	Culverts	Misc.	Total
Assumed price	$10.32	$5.00	$34.48	.....	$1.00	$50.80
Contract price	12.10	5.45	35.19	$1.70	2.90	57.34

All types

	Cut-and-cover	Grade tunnel	Press. tunnel
Assumed price	$50.80	$90.00	$120.00
Contract price	57.34	98.25	141.10

Fig. 4 shows the typical cross-section of cut-and-cover aqueduct in rock trench, showing construction of cover embankment. Rock was usually excavated to a 6 on 1 slope, minimum thickness of concrete along sides 20 ins., but usually thicker owing to disintegrated condition of surface rocks.

Fig. 5 shows the typical cross-section of cut-and-cover aqueduct in loose earth and on foundation embankment and hydraulic elements of aqueduct, side slopes usually 1 on 1, in firm earth 6 on 1, and 20 ins. minimum thickness of side concrete, above concrete slope of 3 on 1 used.

Scarifier Used to Loosen Dirt for Irrigation Ditches.—According to Engineering and Contracting, April 5, 1918, a scarifier has been used successfully in breaking the earth for irrigation ditches on the 70,000-acre properties of the Crocker-Hoffman Land & Water Co. in Colorado. The scarifier pulled by a

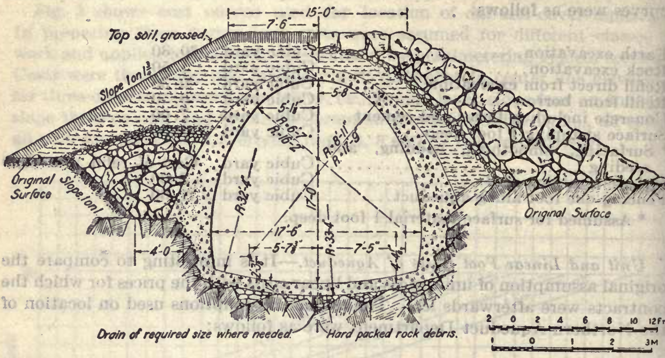
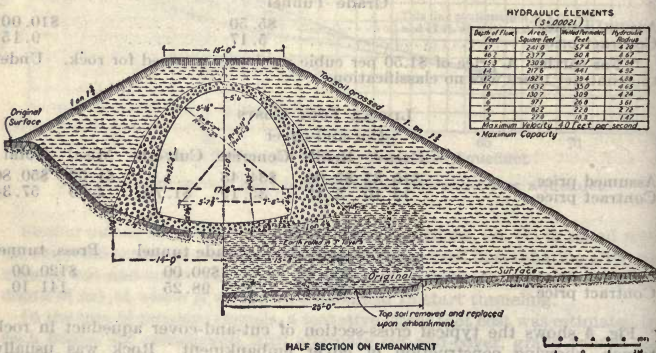


FIG. 4.

small size Caterpillar tractor loosened the earth and left it in shape to be scooped out by scrapers. Forty 4-mule teams were used to scoop out the dirt loosened by the tractor and scarifier. Prior to the use of this outfit, the dirt had been loosened by plows pulled by mule teams, five 10-mule teams



Depth of Flow, Feet	Area, Square Feet	Wetted Perimeter, Feet	Hydraulic Radius
17	241.0	57.4	4.20
16.2	237.7	50.8	4.67
15.3	230.9	47.1	4.84
14	217.6	44.1	4.92
12	192.6	39.4	4.88
10	163.2	35.0	4.65
8	130.7	30.9	4.24
6	97.1	26.8	3.61
4	62.2	22.8	2.72
2	27.0	18.8	1.47
Maximum Velocity 4.0 Feet per second			

FIG. 5.

being used. Each plow required three men to hold it, in addition to the driver of the teams. The cost of loosening the dirt by the plow method was $125 per day, with wages at $2.25 and mules at $1 per day. Under the new plan the cost was $18 per day—the cost for the tractor and operation.

Cost of Enlargement of the Main Canal Sunnyside Unit—Yakima Project, Washington.—E. A. Moritz and H. W. Elder, in Engineering and Contracting, Sept. 11, 1912, give the following data.

At the time the Reclamation Service purchased the system in 1906 the capacity at the intake of the main canal was about 650 c.f.s. and its designed cross-section was: Bottom width 30 ft., depth of water 6 ft. and side slopes 2:1. For the full supply flow at the intake the section had to be enlarged to a 46-ft. bottom width, 8 ft. depth and 1½:1 side slopes, giving a capacity of 1,076 c.f.s. A corresponding increase in section was required over the full length of 56 miles of the canal.

Methods and Costs of Enlarging the Main Canal.—The excavation of the canal demanded that certain requirements be met which controlled to a large extent the methods to be adopted. The principal controlling factors were the following: (1) A large portion of the work had to be done during the irrigation season which made necessary the use of a floating dredge or some type of excavator which could excavate under water from the banks. (2) The work on the upper half required a reach of about 70 ft. from the center of mass of excavation to the center of mass of waste bank. (3) The quantity to be excavated varied from about 1,200 cu. yds. per station at the upper end to 200 cu. yds. per station at the lower end, requiring, for economical work, that different methods be used for different reaches. (4) It was desirable to deposit most of the material on the lower bank, especially in the upper reaches, and furthermore it was generally impracticable to deposit on the upper side on account of the deep cuts.

After a careful study of available methods a combination was selected which involved the use of a floating dredge for the first 30 miles, a drag line excavator for mile 30 to 48 and team excavation for the remaining 8 miles. The final outcome of this program was that the floating dredge was run to mile 20.69 only as it was found that the drag line machine could do the work from mile 20.69 to 30 more economically. It was also discovered that, on account of the small quantities to be moved, team work was cheaper than drag line works below mile 43.4. Therefore, instead of the program as outlined the following resulted: Floating dredge mile 0 to mile 20.69; drag line excavator mile 20.69 to 43.4; and team work mile 43.4 to mile 56.

The concrete drop structures of which there are about 18 in the first 30 miles of canal had a clearance of only 32 ft. between the abutments, and as the dredge had to pass through these the hull could be only about 30 ft. wide out to out. The machine would nave been much easier to handle if it had had a wider hull. The machine used is a 3½ cu. ft. steam driven, continuous bucket elevator type with an 82 ft. × 30 ft. × 6 ft. 6 in. hull, drawing 5 ft. of water. Steam is furnished by two 80-hp. locomotive type boilers 44 ins. × 18 ft. Main drive and ladder hoist are driven by a 70-hp. 8 × 12-in. double horizontal engine. Winch machinery for spuds and for swinging the dredge are driven by a two cylinder, 20-hp. 6 × 6-in. double horizontal engine. Conveyors are driven by two 18-hp. 7 × 10-in. single cylinder horizontal engines. A No. 1 Hendy hydraulic giant supplied by a two-stage, 6-in. centrifugal pump, belted to an 80-hp. 10 × 12-in. single cylinder, upright engine, is mounted on the bow to remove banks above the water level and beyond the reach of the buckets. Conveyors are 72 ft. long and have seven-ply 32-in. rubber conveyor belting. The machine was furnished by the Bucyrus Co. of Milwaukee, Wis. It was operated from Dec. 1, 1909, to Oct. 1, 1911, and moved 921,000 cu. yds. of material.

The drag line excavator is a Lidgerwood-Crawford 1½ cu. yd. bucket machine with a 60-ft. boom. It is steam driven with a 48 in. × 114 in. vertical boiler and a 9 × 10-in. double cylinder engine. A 6 × 6-in. double cylinder engine is used to turn the machine. The machine was furnished by the Lidgerwood Manufacturing Co. of New York City. It was operated from April 20, 1909, to Sept. 27, 1911, and moved 804,200 cu. yds. of material. About three months of this time was consumed in moving the machine from mile 42.7 to mile 35.5.

Operations of Elevator Dredge.—The elevator dredge was built during the spring and summer of 1909 and began work in November of the same year, but owing to the fact that the machine was largely experimental and the material excavated was very hard, very little progress was made. A great deal of adjusting was necessary and many minor breaks occurred. No fair trial was made before the weather became so cold that little could be accomplished because of heavy ice. No water could be run in the canal because of team excavation which was under way at several points below. Water was held in bays by means of temporary dams built at several points above the team work. Attempts were made to break up the ice by blasting but it would form again so rapidly that almost no permanent good was accomplished. The machine closed down for two weeks during January, and by the time the ice had begun to break up the water had become very low in the bays and after a few days became so full of silt from constant agitation by the machine that it was almost useless as a steam supply.

Much excavation had to be done that, with running water of sufficient depth, would have been unnecessary, for the machine excavated in some cases 4 ft. below grade to keep clear of the bottom. No great amount of fresh water could be run in and the grade was such that sufficient depth to float the machine could not be maintained after the temporary dam at mile 1.30 was removed.

A great deal of difficulty was encountered in disposing of excavated material. So much water was carried over with the earth and gravel that a mud was formed which ran out into the adjoining fields and orchards, covering the original ground to a depth of several feet. Bulkheads were built along the right of way and an attempt made to hold the material. As the slope upon which the material was deposited was very steep, the material would fill to the top of the bulkhead in a short time and then run over into orchards. Higher and stronger bulkheads were built, but this was found to be very expensive. As the extremely wet material could not be held, the water jet which was played into the water buckets to aid in cleaning them, was removed. Then six ¾-in. holes were bored in each bucket to allow the water which picked up with the dirt to escape. This accomplished a great deal toward retaining the material on the right of way, but many bucketsful which in a saturated condition would have been dumped onto the conveyor, stuck in the buckets until they were loosened by the vibrations and released. This usually occurred after the hopper had been passed and the material was then dropped into the canal behind the digging line and had to be left to be excavated by other means later.

With the opening of the irrigation season the machine at once began doing better work. The material up to this time had been chiefly cement gravel, very compact chalky material, or compact wash gravel. Softer material was now encountered, and the weekly output increased from 2,000 to 14,300 cu. yds.

It was found desirable at this time to make some improvement in various parts of the machine. A larger pocket was put in the spud drive to insure greater power in sinking the spud foot. The position of the belt conveyor drive had been a great source of trouble as the drive sprocket was almost under the end of the conveyor drum and caught all the mud and water running off on that side. The sprocket was placed on the end of the shaft outside of the bearing, about 1 ft. from conveyor belt, thus affording a better opportunity for housing.

A great deal of trouble was caused when passing through deep cuts, by lack of dumping space. As built, the conveyor was fixed rigidly parallel to the spud arm. This necessitated depositing all the material excavated from one position into one heap. It was found necessary to have the conveyor swing over a greater arc. This was accomplished by removing the connection between the spud arm and the conveyor ladder and by fixing the conveyor rigidly to the deck forcing it to swing with the boat independently of the spud arm. Thus as the buckets made their swing across the canal, the conveyor covers an arc sufficient to distribute the spoil as desired.

As constructed, the spud sleeve was attached by rivets to the mast, but as this would not permit the raising of the spud arm a pinion hinge was put in with bolts replacing the rivets in the lower part of the plate allowing the spud to be loosened and raised readily.

After about nine months of operation the lower tumbler had become badly worn, and to reinforce it the hollow interior was filled wih cast iron. This added about 4,600 lbs. of weight to the exreme end of the bucket ladder and was probably to a considerable degree the cause of the breaking of the 12-in. I beams of the bucket ladder. After this accident 15-in. I-beams and a lighter tumbler reinforced with manganese steel wearing plates were substituted. The wearing plates had to be removed after six months use. It was found necessary to put similar plates on the upper tumbler but as the wear was not as great these plates did not have to be renewed.

About a week after the ladder was rebuilt with 15-in. I-beams these also broke. The cause of this was not definitely determined but it was probably due principally to a torsional moment. The great bulk of the material excavated was in the left bank and the buckets cut chiefly with the left side causing a twisting motion downward and to the left. This is undoubtedly a condition which should be provided for in the design of a machine for work of this kind.

The hull of the dredge was constructed only 30 ft. wide to permit it to pass numerous drops which had been built before the enlargement of the canal. This hull was too narrow for stability as practically all of the 200 tons of machinery was above the deck. The spuds, of course, served to maintain equilibrium except when raised as was the case when moving. On one occasion when the spuds were raised a man started out upon one of the conveyor ladders, causing the boat to tip. The crew lost control of the boat, which listed so far that water entered the hatches on the deck and caused it to sink. It took 12 days to get the dredge afloat and in working order. On another occasion the dredge was sunk, due to a hole being worn through the side of the bucket well by the returning buckets. This time ten days were lost in raising and repairing the dredge.

The typical sections shown in Fig. 6 show the relative positions of the masses moved by various methods. Much of the material was moved by teams during the last year of operation because it had been found that with the short haul the material not needed on the lower side could be disposed of more economically by team work on the upper side. The original plan had been to wash this material down with the giant and pick it up from the bottom with the buckets and deposit it on the lower side, but it was pulverized by this operation and spread out into the orchards as mud when carried across, which necessitated the abandonment of this process. The fills had to be built by teams ahead of the machine as otherwise much land would have been inundated when the old levee was cut out by the machine.

The statement of costs of the excavation done by the elevator dredge requires some explanation. The labor cost is low. The high cost charged to the item "spoil banks" is due to the fact that much of the material was deposited in the form of mud and ran over valuable farm lands and had to be hauled back when dry unless it had been retained by the expensive bulkheads built along the right of way. Another reason for the high cost of this item is that much of the material was deposited in high mounds which had to be graded down to permit ditch riders to travel over the levee.

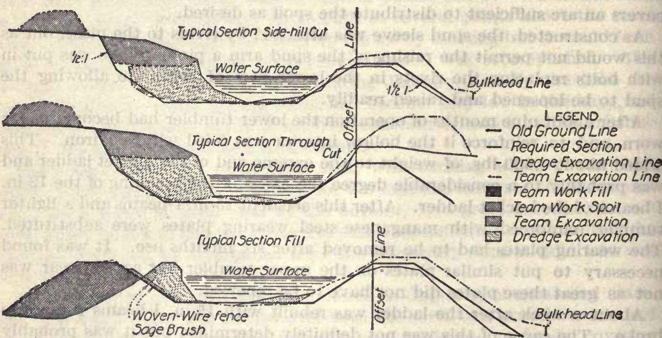


FIG. 6.—Typical sections excavated by elevator dredge.

The high cost of maintenance is due to the fact that much adjusting and many changes had to be made to adapt the machine to local conditions.

TABLE V.—COST DATA—ELEVATOR DREDGE WORK, 920,723 CUBIC YARDS

Item:	Cost	Unit cost
Excavation:		
Labor, dredge	$ 26,960.63	0.029
Labor, spoil banks	31,159.06	0.034
Fuel	33,043.07	0.036
Plant maintenance	52,327.40	0.057
Plant depreciation	41,432.53	0.045
Total	$184,922.69	0.201

Miscellaneous—Maximum excavation per 8-hour shift, 1,429 cu. yds.; maximum excavation for one week, 17,644 cu. yds. (three shifts); average excavation per 8 hour shift, 557.9 cu. yds.; average excavation actual working hour, 128.7 cu. yds.; per cent of lost time, 49; made up as follows: moving, 10 per cent; repairs and miscellaneous, 39 per cent.

Force and wages—An operating force consisted of 8 men and 4 horses.

Wages paid were—Operator, $5.00; engineer, $4.67; spudman, $3.83; fireman, $3.33; oiler, $3.00; deckman, $2.50; man and team, $4.50.

The depreciation item includes the entire cost of the machine charged against the total yardage. Everything except the hull should have considerable salvage value which will go toward reducing the cost.

Fuel had to be hauled about three miles across open country or over roads that were very rough.

One of the most gratifying results of this work is the solid lower bank produced by the saturated material discharged by the dredge and the substantial roadway over it. The trouble from breaks over this reach should be very small and maintenance charges will be correspondingly reduced.

Performance of the Drag Line Excavator.—The reach of the main canal between Miles 20.69 and 43.40 was excavated with a Lidgerwood-Crawford drag line machine. This machine was erected during January and February, 1909, and began operating at Mile 42.67 and worked down-stream to Mile 43.40. An attempt was; made at first to excavate from the lower side but was

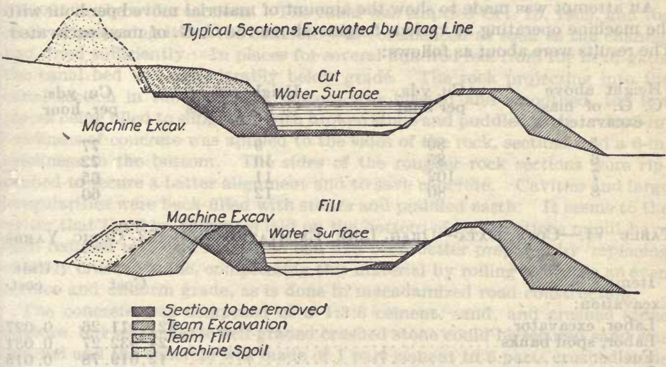


Fig. 7.—Typical sections excavated by drag line excavator.

unsuccessful because of the short boom and inability to sink the bucket into the narrow strip to be taken from the upper side. The machine was then dismantled and hauled to Mile 35.5 where operations were commenced from the upper side of the canal. A road had to be leveled ahead of the machine and all material not needed on the lower side was dumped on the upper side of the canal. The extra amount of road grading, not anticipated in the original schedule, and the additional work that had to be done to strengthen the levee caused the price per cubic yard to run higher than was anticipated.

A complete section, Fig. 7 was excavated from Mile 35.5 to Mile 38.3, but by the time the machine reached this point the demand for water over the lower parts of the project had become so great that it was decided to take out only about two-thirds of the material so as to allow the machine to move faster and increase the capacity over a greater reach of canal. It was found, however, that the machine moved very little faster when removing a two-thirds section, and that the cost per cubic yard was higher, so this plan was abandoned and a complete section was excavated throughout the remainder of the work. A great deal of team work had to be done in connection with the machine excavation. The profile of the upper bank was very irregular and in ravines the old levee had been almost, if not entirely destroyed. A roadway 18 ft. wide had to be built, and, as the grade could not exceed 5 per cent, the hills had to be cut down and the ravines filled up. Where the necessary cut on hills exceeded 5.0 ft., which is the distance from the base of track to bottom of engine car, the cut had to be 23 ft. wide to permit the car to swing and dump. In very deep cuts this placed the machine so far below the level of the natural ground that it was very difficult to dispose of the material because of the lack of dumping space. In some cases the road grading was 30 per cent of the entire excavation in cuts; and as the material was often hauled 200 ft. or more into the fill ahead the cost was high. The team cost was charged against the machine and the total cost distributed into the total yardage.

Much work was done on the spoil banks and in strengthening the levees and was all charged to the machine excavation. All repairs and maintenance costs are included in the item "Plant Maintenance." The item "Plant Depreciation" includes the entire cost of the machine.

An attempt was made to show the amount of material moved per hour with the machine operating at various heights above the C. G. of mass excavated. The results were about as follows:

Height above C. G. of mass excavated	Cu. yds. per hour	Height above C. G. of mass	Cu. yds. per. hour
5	80	9	77
6	85	10	72
7	102	11	65
8	80	12	60

TABLE VI.—COST DATA—DRAG LINE EXCAVATION, 204,183 CUBIC YARDS

Item:	Cost	Unit cost
Excavation:		
Labor, excavator	$21,411.26	0.027
Labor, spoil banks	24,932.27	0.031
Fuel	12,019.78	0.015
Plant maintenance	27,969.81	0.035
Plant depreciation	6,786.97	0.008
Total	$93,120.09	0.116

Force and wages—One crew consisted of 6 men and 2 horses.

Wages paid—Engineer, $4.00; fireman, $2.85; groundman, $2.00; man and team, $4.50.

Miscellaneous—Maximum excavation per 8-hr. shift, 1,170 cu. yds.; maximum excavation for week, 16,000 cu. yds.; average excavation per 8-hour shift, 545.5 cu. yds., average excavation per actual working hour, 93.7 cu. yds.

The excavation was done under water during seven months of the year and during the winter months when there was no water in the canal frost interfered with the work to a considerable extent. Due to the shape of the section the time consumed in lifting and swinging the bucket was probably considerably greater than on most excavation with an equal quantity of material to move.

Team Excavation.—From Mile 43.4 to the end of the canal and at other points where the material was too hard for the excavators to move the excavation was done by hand and teams. The total quantity moved of all classes was 583,400 cu. yds. at an average cost of 37.5 cts. per cubic yard. Most of this work was done by force account and under widely varying conditions.

Much of the material was of such a nature as to make its segregation into the different classes very difficult but approximate classification is as follows: Class 1—earth, 445,000 cu. yds.; Class 3—rock, 41,000 cu. yds.; Class 2—all other material, 97,400 cu. yds. All the work was done during the winter months and much frozen material which otherwise could readily have been plowed had to be blasted.

Cost of Concrete Lining for Irrigation Canals.—In a report by Samuel Fortier, U. S. Dep't of Agriculture, abstracted in Engineering and Contracting, Feb. 10, 1915, the following facts are given.

North Side Twin Falls Land & Water Co., Milner, Idaho.—This company lined 8,400 ft. of its main canal to increase its capacity. The canal is carried for several hundred feet along a rough lava rock cliff and is 60 ft. above low water in the river. The outer bank through this section is a concrete retaining wall. The remainder of the lined section is excavated almost wholly in solid lava. The grade varies from 0.001 in narrow places to 0.0002 and 0.00025 in the wider sections. The canal was emptied Oct. 10, 1909, and the work of preparing it for the concrete was commenced as soon as the channel had dried sufficiently. In places for several hundred feet from the head-gates the canal bed was considerably below grade. The rock projecting into the canal section in the sides and bottom was blasted and smoothed, the low places being filled to subgrade, with broken stone and puddled earth. An 8-in. thickness of concrete was applied to the sides of the rock, sections and a 6-in. thickness to the bottom. The sides of the rougher rock sections were riprapped to secure a better alignment and to save concrete. Cavities and large irregularities were back-filled with stones and puddled earth. It seems to the writer that the 6-in. thickness laid on the bottom of rock sections might have been reduced to 3 or 4 ins. if the bed had been better prepared by replacing of finely crushed stone, compressing this material by rolling to secure an even surface and uniform grade, as is done in macadamized road construction.

The concrete was composed of a 1:3:6 cement, sand, and crushed stone mixture, but whenever a well-graded crushed stone could be secured sand was omitted and the concrete was made of 1 part cement to 6 parts crushed stone from which all particles over 1½ ins. in diameter had geen excluded.

In earth sections the lining of the sides and bottom was 4 ins. thick and had side slopes of 1¾ to 1. Expansion joints of corrugated iron were inserted every 16 to 20 ft. along the sides and bottom except in the bottom of the rock sections. These joints consisted of pieces of corrugated iron cut into strips 4 ins. wide containing 1½ corrugations, these being designed to lock the edges of adjacent sections and to prevent slipping.

The side walls in the rock sections were supposed to have a slope of 1 to 4; but in many places where this would have necessitated the blasting of large amounts of rock, walls were made almost vertical. Heavy, collapsible forms of 2-in. lumber were used in placing concrete for the walls which approached the vertical. The concrete was wheeled directly from the mixers and spread in uniform layers 4 ins. thick over the bottom and on the sides of the easier slopes in earth sections. Concrete placed within forms made of 4 × 4-in. lumber was compacted by tamping and finished by working 24-ft. floats made of 2 × 6-in. timbers back and forth over the upper surface of the forms. Sixty cubic yards of concrete per day were sometimes laid in this way by one gang working under favorable conditions. The sides and slopes were finished with a coat of cement mortar whenever the surface was rough enough to warrant it.

The unusually high cost of this work was largely due to the difficulty of preparing the rock cut for the lining and to the absence of sand and gravel, which made it necessary to crush rock for the concrete. However, a greater factor than either of these was the added expense due to the necessity of prosecuting the work during severe winter weather. To do this the canal was roofed over for a distance of 2,000 ft. and the inclosed space warmed by specially constructed heaters, using sagebrush for fuel. The cost of labor and material was as follows:

Laborers, per day of 10 hrs.	$ 2.50
Drillers, per day of 10 hrs.	2.75–3.00
Engineers (steam), per day	3.00–4.00
Man and team, per day	5.00
Coal per ton, f. o. b. Milner	6.50
Cement per barrel, f. o. b. Milner	2.59–2.89
Cost of crushing rock, per cu. yd	1.10
Cost of labor for placing concrete, per cu. yd	2.75
Complete cost of material, mixing and placing concrete for form work only, per cu. yd	8.50
Same without forms	7.50
Cost of rock excavation (light cuts from 0.4 to 2 feet), per cu. yd.	5.00
Cost of placing riprap 1 foot thick, per cu. yd	2.00
Total cost of preparing 8,400 lin. ft. of canal for concrete	75,000.00
Gross cost of lining 8,400 lin. ft. of canal	200,000.00
Average cost of concrete, per cu. yd	8.00

Main South Side, or New York Canal, United States Reclamation Service, Boise, Idaho.—This canal is designed essentially to carry flood water from a point on the Boise River, nine miles above Boise, to the Deer Flat reservoir, a distance of 36 miles. Seventy thousand acres of land is also watered from the canal before the reservoir is reached. About 6½ miles of the canal was lined to prevent seepage, increase the carrying capacity, and for the safety of sidehill sections where breaks frequently occurred. The canal is an old one, originally built with side slopes of 1½ to 1, but the change and filling up of the section common to old canals necessitated considerable preliminary work in the removal of very gravelly earth and in shaping the sides before the concrete could be laid. The lined section has a grade of 0.00025 to 0.00032 and slopes of 1½ to 1. Forms of 4 × 4-in. lumber were placed upon the slopes and aligned, after which the surface between the forms was smoothed and thoroughly hand compacted. A uniform layer of concrete 4 ins. thick was then applied.

After heavy stripping, a good natural mixture of sand and gravel was secured adjacent to the canal. This was hauled by slip scrapers up a runway and dumped into the mixers, which were placed high enough to permit discharging the concrete directly into one-horse carts. The concrete was a 1:3:6 mixture of Portland cement, sand, and gravel. It was laid in sections measuring 8 × 16 ft. on the slopes and 8 × 16 or 16 × 16 ft. on the bottom. The lining was laid in alternate sections to make room for the workmen, and the upper sections were usually the first completed. As soon as the concrete of the first sections had set, the forms were removed and the intermediate sections filled in. Expansion joints of one thickness of tar paper were used between sections in part of the work.

After being dumped from the cars, the concrete was worked down and later smoothed by drawing long floats made of 2 × 6-in. timbers back and forth across the forms. In order to get a smooth face, the surface was painted with a 1 to 2 finishing coat of cement mortar as soon as the concrete was placed and set. The lining was kept wet by sprinkling for a period of seven days after being laid. It was protected from nightly freezes during the early part of the work by covering with a layer of straw, and during some freezing weather in the latter part of the work some concrete was laid under large tents heated by stoves. Some of the cost items are as follows:

Preparing canal section for lining, per lin. ft., approximately	$2.80
Hauling gravel to mixers, per cu. yd	1.14
Mixing and placing concrete, per cu. yd	2.20
Total cost of concrete, including cement, per cu. yd	7.70
Total cost of concrete in place, per lin. ft.	9.64
Cement per barrel, f. o. b. Boise	2.27–2.50
Common labor, per day	2.50
Man and team, per day	5.00

Northern Pacific Irrigation Co., Kennewick, Wash.—During the winter of 1910–11 this company lined 22,500 ft. of ditches on the "Highlands" at Kennewick to eliminate heavy seepage losses. The soil through which these ditches are built is principally a fine sandy loam overlying gravel at a depth of 18 ins. to 2 ft. One ditch 10,800 ft. long, 3 ft. wide on the bottom, with side slopes of ½ to 1 and a vertical depth of 26 ins., is designed to carry 18 sec.-ft. Another ditch having in part a bottom width of 3½ ft., side slopes of ½ to 1, and a vertical depth of 19½ ins. is designed to carry 14 sec.-ft. This ditch is reduced to a bottom width of 2½ ft., but with the same side slopes and depth as the upper part. The concrete used was a 1:3:4 mixture of cement, sand, and crushed rock.

In preparation for lining, center grade stakes were set and the bottom of the ditch brought to grade. Scantlings 2 × 4 ins. were then placed across the bottom of the ditch at 12-ft. intervals at right angles to the center line and flush with the subgrade. Three forms 12 ft. long were then set in the ditch on the cross strips and centered. Earth was shoveled and tamped behind the forms to secure the desired section. There were 14 men in a crew on this work.

After the earth sections were prepared in this way, 2 × 2-in. screeds were placed at intervals of 5 ft. 8 ins. and upon them forms 6 ft. long were set on every other space. The concrete was mixed with a one-third yard mixer, wheeled to place and dumped on planks laid on top of the forms. It was then shoveled behind the forms and lightly tamped. Strips of sheet iron were inserted behind the forms to protect the slope while the concrete was being put in and also to prevent a too rapid loss of water from the mixture by its contact with the drier earth. These strips were raised as the filling progressed. Two crews of 5 men each placed the concrete behind the forms, 2 men wheeled to each crew, and about 5 men were employed to move forms, etc. About 6 men were in the mixing crew and 2 others plastered rough places in the lining. Water kept in the finished ditch a few hundred feet in the rear of the work was pumped ahead to the mixer with a small gasoline engine.

The engineer stated that in one hour a crew could place about six sections, or 34 lin. ft., of the lining in the ditch having a 3-foot bottom.

Lower Yakima Irrigation Co., Richland, Wash.—The canal of this company parallels the Yakima River for several miles, where the earth sections run mainly through coarse gravel, boulders, or shattered basaltic rock. The remainder of the system is very largely built through sand. In the unlined channel the seepage losses were excessive, and through the sand it was also difficult to maintain the ditch owing to its tendency to fill up both by drifting and on account of the flat side slopes which the sand naturally assumed under the action of water. The lining was intended, therefore, not only to reduce the loss of water, but to increase the carrying capacity of the ditch and render it more stable and easy to maintain. About five miles of the ditch was lined in 1910. The company furnished all materials used and prepared the channel for lining, but the other work was done by contract.

In preparing the ditch, center stakes were set about 1½ ins. above grade, to which the excavating was roughly done with teams and scrapers. At intervals of about 25 ft. along the bottom of the side slopes stakes were set to grade, and from these the top slope stakes were set by the use of a slope triangle. Nails were driven into the grade stakes and chalk lines were stretched on them parallel to the ditch. Trimming to these lines was done then with square-pointed shovels and the slopes and bottom scraped to smooth surfaces with straight edges. The sides and bottom were tamped lightly with wooden tampers and sprinkled before the lining was applied. The section lined has a bottom width of 11½ ft., side slopes of 1½ to 1, and a wetted perimeter of 26½ ft.

The three mixers used were operated on planks in the bottom of the ditch in advance of the work. With each mixer there was a crew of about 25 men and in addition a finishing crew of 5 or 6 men to dress the earth surfaces immediately ahead of the mixer. One rock crusher was also operated, the crushed rock being hauled an average of 2 miles. Most of the sand was procured from pits along the line of the canal and was used without screening. The lining was laid in 8-ft. sections 1¾ ins. thick, with strips of building paper in the joints between the sections. Four hundred feet of lining was considered a good day's work for a crew. A 1:3:4 mixture of concrete was used for most of the lining, but on one section a 1:4 mortar applied 1 in. thick was considered just as good as the thicker lining of concrete, besides being much easier to apply.

The lining in gravel sections leaked considerably the first season, presumably because allowed to dry too rapidly on account of lack of water for keeping it moist after laying. In work that was done the following year this difficulty was obviated by allowing a small amount of water to flow in the ditch soon after lining, using check dams to prevent its interference with construction. Men wearing rubber boots then waded along and with shovels or buckets threw water upon the side slopes at frequent intervals to keep the concrete wet while setting. Where lining had been placed on moistened sand, the results were better than in the sections through gravel, there being no perceptible leakage. Conditions in the gravel portion improved with the first year's use of the lined sections, after which the seepage was considerably lessened. The various items of cost secured are as follows:

Laborers per day of 10 hours, without board	$ 2.50
Man and team per day, without board	4.50
Contract price per sq. ft. for mixing and laying concrete	.025
Cement per barrel*	3.10
Sand per cu. yd., approximately	.50
Total cost of lining, per sq. ft	.065
Total cost of lining	9,064.49

*This does not include an 8-mile haul over heavy roads.

During February and March, 1911, the company placed additional lining, using practically the same methods above described, except that all work was done by force account. The prices for labor and material indicate that the work was done considerably cheaper than in the previous year. Laborers were procured for $2 per day without board and men with teams for $4 per day each. Cement cost $2.95 per barrel delivered at the work.

Belgo-Canadian Fruit Lands, Kelowna, British Columbia.—About 3,000 ft. of this company's main canal, 11 miles long, and about 4 miles of its lateral ditches have been lined with concrete to prevent seepage losses in a porous soil. On the main canal a 3-in. thickness of lining has been used for a finished section having a bottom width of 3.5 ft., depth 3.75 ft., and side slopes of ½ to 1. Lateral linings are 2½ to 3 ins. thick on slopes, with a 3-in. thickness on bottoms which vary in width from 9 ins. to 2 ft.

After excavating the channel to be lined, a drain filled with loose rock or gravel was made beneath the bed. Cross drains from this through the lower bank were placed at 500-ft. intervals. The forms were then set and bolted together. Galvanized-iron plates placed outside the forms were spaced with pieces of lumber, and after the earth was back-filled and tamped behind the plates concrete was poured between them and the forms. The galvanized plates and spacing pieces were withdrawn as the space was filled with concrete, The bottom of the ditch was then floated in and the edges smoothed, using for this purpose the excess concrete which had passed over the forms. The forms were left in place 48 hours.

Curves were made by using special short forms having the outer edge superelevated ½ to 1 in. according to the degree of curvature. In placing the concrete around sharp curves, special galvanized plates were used to close the gap at the outer edge of the forms.

No cost data could be secured on the lining of the main canal. The cost of lining laterals per square foot and exclusive of excavation varied from $0.118 in the larger to $0.142 in the smaller ones. These costs include excavation, back-filling, rock drains and supervision. The work was done late in the fall when protection against frost increased the cost. Cement cost $3.75 per barrel delivered, common labor $2.75 per day, and skilled labor $4 per day.

Tucson Farms Co., Tucson, Ariz.—The water for this project is obtained by pumping from numerous wells. During the winter and spring of 1912–13 a reinforced concrete lining was placed in about 2½ miles of the new main canal for the prevention of seepage losses through a sandy and gravelly soil. The canal has a trapezodial cross section entirely in excavation and as lined is capable of carrying a 2.9-ft. depth of water. The bottom width ranges from 2 to 4¾ ft. and the side slopes are 1 to 1. The greater part of the concrete used in this construction is a 1:4:4 mixture and the lining is 3 ins. thick throughout.

In grading the channel for lining, a framed template was used to get a true section. The reinforcement is made of round steel bars intersecting at right angles and wired together. Four longitudinal bars, 5/16 in. diameter, were placed one on each side of the bottom for the lining floor and one on each side near the top of the side walls. Then at right angles to these, as stated, ¼-in. crossbars were spaced 12 ins. apart. Each crossbar was continuous and extended from the top of the lining on one side through the lining to the top of it on the opposite side of the canal. When it is not possible to obtain the ¼-in. bars, 5/16-in. bars were substituted and spaced 18 ins. apart.

Wooden-framed forms built in 12-ft. sections were then set in position over the steel reinforcement, blocked to place, and the adjoining ends bolted together. Then ⅛-in. steel backing plates, 2 ft. wide and long enough to reach to the bottom of the earth section, were slipped behind the forms and under the reinforcement. Before placing the concrete, wooden spreader-strips, 2 × 3 ins. were set between the wooden forms and the backing plates. Each spreader contained a staple driven almost full length into its side near the bottom, and in setting the spreader the staple loop was slipped over the end of the crossbar and the spreader was then slid into position. In this way the bar was carefully held in position while the concrete was being placed in the forms. A spreader was set beside each crossbar, and as the concrete for the side lining was tamped and puddled into place the spreaders were gradually removed, leaving the crossbars firmly embedded in the concrete. The steel plates likewise were withdrawn as the walls were built up. When the side forms were filled with concrete to within 3 ins. of the top, the longitudinal bars were placed and wired to the crossbars. The remaining concrete was then placed and smoothed with an edging trowel.

Expansion joints were provided by setting 1 × 3-in. wooden strips in the middle of each form in the same manner as the spreaders, except that no staples were used and the joint strips were not removed afterwards. To keep them in position while concrete was being deposited, each one was lightly nailed to the side of the form, aud before the latter was removed the nails were withdrawn. The forms were left intact for a period of 8 hours at least, and they usually remained undisturbed over night during a period of 14 to 20 hours. After their removal any defects in the wall surface were "picked" out and the cavities smoothly plastered with a 1:1½ or 2 cement mortar.

The canal bottom was then carefully cleared of litter, its surface smoothed, and solidly tamped. All reinforcement bars that may have become bent were straightened. The bottom piece of the expansion joint was fitted to the two side pieces and its top carefully laid to grade. The concrete for the floor lining was then tamped and puddled into place, and when it had reached the required thickness the surface was easily brought to grade and smoothed by the use of a straightedge resting on the bottom joint strips as guides. The entire lining was kept wet by continual sprinkling during a period of three to five days. After this was discontinued a wash coat of neat cement mortar was applied to the surface with a brush.

A 1 : 4 : 4 mixture of concrete was used on all the work except for about 1,000 ft. of bottom where there was excessive external water pressure. In this portion of the canal a 1 : 3.2 : 3.2 mixture was used. As a further protection in one very wet and miry place, additional reinforcement was used in the bottom. Extending over a length of about 5,000 ft. of the largest canal section near the Santa Cruz River bed, "weep holes" were formed in the bottom to relieve external water pressure. Two-inch tapering plugs extending entirely through the lining floor were set in the freshly laid concrete and these plugs were later removed as soon as the concrete had set sufficiently to retain its shape. Two rows of these holes were made 2½ ft. apart and spaced 4 ft. longitudinally. During construction a considerable portion of the canal was drained. A line of 8-in. tiling was laid in the bottom and pumps attached thereto were installed at intervals of about 1,000 ft. to withdraw the accumulated water.

The contractor received $12.50 per cubic yard for the finished concrete lining, using slab measurement. This included all costs except the original purchase price of the steel reinforcement. However, no excavation was included and the company paid extra for the wash coat. The contractor rented a rock crusher and delivered the rock. Sand was obtained from the river bed.

All concrete was mixed by hand and transported in wheelbarrows.

The work was performed with gangs of about 30 men, paid for a 9-hour day, as follows:

1 foreman	$4.00
Mixing boss and 2 plasterers	2.50
2 water boys	1.00
25 men	2.00

The gang was used in the following manner: Eight men on mixing board, 2 tampers, 2 men pulling plates and spreaders, 2 men setting forms and putting in expansion joints, 2 men laying steel reinforcement, 14 men transporting and depositing materials and concrete, finishing, screening sand, etc. The forms were usually all moved at one time and the whole force engaged on that work. It required this gang 21 days to place lining in 3,000 ft. of canal in dry excavation having a bottom width of 3 ft. The cost to the contractor was distributed as follows:

Labor, including the building of forms	$1,297.83
1,712 sacks ofment, at $0.81 each	1,386.72
232 cu. yds. of rock, at $1.75 per cu. yd	406.00
232 cu. yds. of sand, at $0.75 per cu. yd	174.00
Lumber in 15 sections of 12-ft. forms, 3,900 ft. B. M., at $30 per M.	117.00
Lumber for expansion joints, 750 ft. B. M., at $30 per M	22.50
Lumber for spreaders, runways, etc., 750 ft. B. M., at $30 per M	22.50
Water purchased from the city of Tucson, 21 days at $2	42.00
Hauling steel reinforcement	10.00
Depreciation of plant, breakage of tools, etc	20.00
Office expenses and expenses of contractor and superintendent, amounting to about $2 per day for this gang, 21 days	42.00
Total	$3,540.55

Computations made on the above basis for 298.9 cu. yds., the cost was $11.845 per cubic yard. However, there were in addition the following costs to the Tucson Farms Co.:

9,300 lbs. of steel, at $0.04	$372.00
One coat of cement wash, 34,500 sq. ft., at $0.0025	86.25
Engineering, about 5 per cent	195.00
Total	$653.50

On this basis the actual cost of the completed lining was $14.03 per cubic yard.

Cost of Lining an Irrigation Canal With Concrete.—In a paper by E. M. Chandler, before the Washington Irrigation Inst., and abstracted in Engineering and Contracting, June 2, 1915, the following data are given.

The canal lined was a used canal of the Burbank Power & Water Co., Burbank, Wash. Construction methods were carefully planned in advance and followed without variation. The canal bed was settled with water for two weeks, the canal being divided into short compartments, and water permitted to run from the upper compartments to the lower for filling.

After canal settlement, line and grade stakes were set every five feet, each stake being a hub with center marked and its top set to the final concrete grade. The pre-determined width of the strips was 5 ft. The pre-determined thickness of concrete of lining was 0.2 ft., the base 6 ft., depth of canal 3 ft. and side slopes 1½ to 1—the carrying capacity being 60 sec. ft.

With the line and grade set once and for all, templates were constructed having the exact thickness of the proposed lining and the exact shape of the finished canals. With the line and grade stakes and a carpenter's level, it was possible for the workmen to trim the sub-grade precisely as it should be. This work was carried on a few hundred feet in advance of the canal lining. Accurate work at this point was very essential to secure uniform thickness of lining.

Sand and gravel, after being run through a 1½-in. rotary screen, was found in natural proportions about one mile from the center of the work. This was hauled by contract at $1.75 per cubic yard measured in the finished lining and placed in piles above the canal 150 ft. apart and 15 ft. back from the slope of the canal, the slope of the ground above the canal not being very great. Experience subsequently proved that the piles of gravel might better have been 200 ft. apart.

Two steam driven concrete batch mixers mounted on trucks and equipped with side loaders were started at the center of the canal to be lined (8,250 ft.) each working away from the other and endeavoring to obtain its end of the lining first. The mixers were moved from pile to pile on plank runways and pushed by the men—the mixers being on the upper side of the canal at all times and passing between the canal and the line of piles of gravel. For each mixer outfit, a movable trough or chute was provided for taking the discharge of the mixer and depositing it in the concrete carts in the bottomof the canal. The lining was laid at two points for each mixer, starting 75 ft. on each side and working toward the mixer. Plank runways in the canal bed were provided and one concrete cart for each laying gang was employed.

The mixture was made on the basis of 1 bbl. of cement to 1 cu. yd. of finished concrete, or about 1 to 7, and made as wet as the side slopes would permit. Two men in each laying gang placed the concrete roughly with square pointed shovels, one man helped dump the concrete carts in the bottom of the five-foot-strip being lined, and between times made ready the next strip and dampened the subgrade, while a fourth man in each laying gang trowelled the rough concrete into the finished shape.

Three men were required for each mixer to supply the raw materials to the machine, one man for fireman and engineer, one man to dump the mixer, and one man to hoe the concrete down the chute. An additional man covered the finished lining with wet burlap strips and kept moving them forward.

The water was hauled 1½ miles on the average by three four-horse teams hauling 400-gal. tanks on wagon trucks. The exact amount of coal required at each setting was pre-determined and left there in advance in sacks. The laying of this 8,250 ft. of concrete lining was completed in 14 working days. As much as 900 ft. in one day were accomplished. The men became very skillful in moving the machines and were able to lose not over 15 minutes time at each moving. The cost of the actual concrete was as follows:

	Per cu. yd.
Sand and gravel	$1.75
Cement delivered	2.65
Water	.25
Coal	.10
Labor mixing concrete	.65
Labor laying concrete	.88
Superintendence	.31
Total per cubic yard	$6.59

In addition to the above, the cost of equipment less its salvage value, was 32 cts. per cubic yard, the cost of trimming the canal bed was 72 cts. per cubic yard and the engineering was 32 cts. per cubic yard. This made a grand total of $7.95 per cubic yard or $1.10 per linear foot of canal.

The cost of cement was $2.25 per barrel f. o. b. Burbank, common labor was paid 25 cts. per hour with a bonus of 2½ cts. for staying until the job was finished, and the finishers and firemen were paid 27½ cts. per hour with a bonus of 2½ cts. under the same conditions. With but few exceptions, we were required to pay the bonus, and it was a good investment, as it overcame the great demoralizer of day labor work of this kind—constant changing of personnel. The incentive to do fast work was created by the two mixer gangs racing for the finish.

Cost of Concrete Lining Irrigation Laterals, Orland Project, U. S. Reclamation Service.—The following is an extract, published in Engineering and Contracting, April 12, 1916, of an article by A. N. Burch, in the "Reclamation Record" for April, 1916.

To February, 1916, there had been lined about 22 miles of laterals on the Orland project, in sections ranging from a few feet in length and requiring less than a cubic yard of concrete to a maximum section of 8,800 ft. The cross sections of the laterals lined have ranged from a bottom width of 2 ft. and vertical depth of 1 ft. to a bottom width of 8 ft. and vertical depth of 4½ ft.

Laterals originally designed for lining were built with 1 : 1 bank slopes; other laterals with 1½ : 1 and 2 : 1 slopes. On the distribution system covering the 6,000 acres recently taken into the project all laterals were designed for lining, where a reduction of cross sections and the elimination of drops would justify this course, as compared with building a larger earth section and installing the necessary drops to reduce the grade.

On the project generally, lining has been placed in all fills; in the small laterals acquired from the old Stony Creek company and located within highway boundaries, for the purpose of increasing their carrying capacity and reducing maintenance; in sections where seepage was excessive; as a protection over storm culverts and on curves; also at forks of laterals where, because of the number of structures, it was difficult to clean with teams.

For the longer stretches of the work a 4-cu. ft. mixer, driven by a 3-hp. gas engine, all mounted on trucks, is used; for the short stretches small hand-mixing crews are employed. The aggregates used are run of bank material obtained from creeks in the vicinity of Orland. The proportions of mix are approximately 1: 3: 5, giving 1 cu. yd. of concrete in place of 1.1 bbl. of cement.

The mixer crew is made up of a foreman, with about 30 men and 2 teams. Nine men are employed at the mixer in wheeling and in placing and finishing, and from 18 to 20 men in trimming the slopes and preparing the bottom for receiving the lining. One team is employed in hauling cement and one in hauling water and miscellaneous work. When it is possible to do so, water is run in the laterals and kept close behind the lining crew, thus reducing the distance of haul to the mixer and simplifying the process of wetting the completed work. No special tools are used in preparing the slopes and bottom for lining, the work being done with mattocks, picks, and square-ended shovels.

The mixer is usually set up at the side of the lateral in the center of a 500-ft. section, making the maximum wheel for concrete 250 ft., which was found to be about the greatest economical distance to which the material could be wheeled. As most of the lining is placed in fills, trenches are cut through the ditch banks to admit of a wheeling plank, which, when placed, lands on a small turning platform, from which an incline leads to the bottom of the lateral, and to additional boards on which the material is wheeled to the placers.

End-dump barrows are used, and the material is dumped into a mud box, from which it is shoveled to the slopes.

The mixing crew is made up of one mixer operator, two shovelers for charging the mixer, three wheelers, and three placers and finishers. Of the latter, No. 1 places the concrete to the required thickness (being guided by a templet), No. 2 compacts the material and finishes it roughly with a square-ended shovel, and No. 3 gives the final finish with a 5 by 18-in. long-handled Arrowsmith trowel, finally cutting the expansion joints with a straight-edge and pointing trowel and smoothing them up with a grooving tool. Before placing the lining the slopes are thoroughly wet by means of a force pump attached to a water wagon, and the finished lining is kept wet from 3 to 5 days, depending on weather conditions. The average daily output of the mixer force is 25 cu. yd., and the maximum 30.3 cu. yd.

For short stretches of lining hand-mixing forces of about 12 men each are employed. From 5 to 7 men are employed in mixing and placing, and about an equal number in preparing the slopes and bottom for receiving the lining. The same equipment and about the same arrangement are used in the operation of these crews as is the case with the mixer, except that the mixing board is placed on timbers which span the lateral, the aggregates are wheeled on to the board, and the concrete shoveled into barrows in the bottom of the ditch, there being no incline over which to wheel the material. These gangs average about 12 cu. yd. per day, and when there has been a full day's run without any long moves have made 15 cu. yd.

There is little difference in the cost of lining whether the material be hand or machine mixed, although the machine turns out a better and more uniform grade of concrete.

From October to June climatic conditions on the Orland project are very favorable for this kind of work, as there are no temperatures low enough to affect the concrete adversely, and moisture conditions are usually such that the lining can be cured properly with little expense for wetting. During the summer months moisture conditions are reversed, and because of the thinness of the lining it is necessary to wet it from two to four times per day until it is properly set. Following are unit costs and related data:

Cost per Square Yard

Cement delivered on work	$0.0957
Gravel delivered on work	.0408
Mixing concrete	.0314
Placing concrete	.0294
Sprinkling and protecting	.0046
Preparing section for lining	.0697
Field superintendence and engineering	.0010
Maintenance of equipment	.0022
Plant arbitrary	.0043
Total labor and material	$0.2791
General expense	.0639
Total cost to United States	$0.3430

Thickness of lining, 1½ inches. Total placed in square yards, 191,400. Total in cubic yards, 7,900. Cost per cubic yard, $8.26. Average haul (round trip), gravel, 5 miles. Average haul (round trip), cement, 6 miles. Foreman, $3.20 per day to $95 per month. Finishers, $3 to $3.20 per day. Laborers, $2.40 to $2.60 per day. Teamsters, with teams, $4.50 to $5 per day. Cement, $2 per barrel. Gravel, $1 per cubic yard. Lumber, $14 to $22 per M. B. M.

Cost of Concrete Lining of Canals and Tunnels of the Natches-Selah Irrigation Works.—Public Works, April 3, 1920, gives the following:

The Natches-Selah Irrigation System in Yakima Valley, Wash., serves about 10,500 acres of orchard land by a conduit carried through a mountainous region in tunnels, flumes and canals. The work includes the reconstruction of about 3 miles of the original water-way and the building of nearly 4 miles of new structures and was executed on the cost-plus-fixed-sum basis.

The flumes and the canal linings were made with concrete mixed with aggregate from a bar in the stream, crushed when necessary, and delivered to the mixers at various plants located at convenient places for the different sections of the work.

Canal Lining.—The canal, some of which is a revision of the old canal, has a regular cross-section so as to conform as nearly as possible with average conditions and made with sloping sides and bottom covered with 3 inches of concrete reinforced by 12 × 12 inch Clinton wire mesh made with No. 12 wire embedded 1½ inches from the surface. Transverse construction joints 5 feet apart longitudinally were scored ½ inch deep to fix contraction cracks.

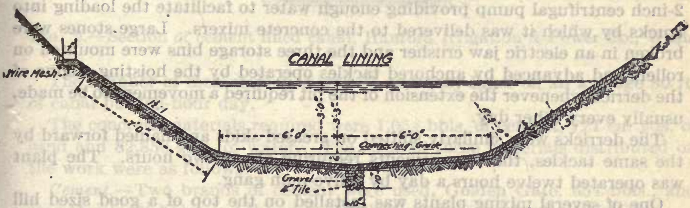


FIG. 8.—Standard cross-section of canal.

In general the canals are in adobe or other soil that retains the moisture and on previous work has caused much trouble with frost. In order to prevent as much as possible temperature cracks the 1:2:4 concrete was placed in cold weather so that any cracks will close by expansion in summer time.

The wire mesh in rolls a little more than 6 feet wide was laid in longitudinal strips, two on the bottom and one on each side, and tied together on the edges with wire projections from the sides of the strips. The concrete was placed in two courses, plastered on the bottom and sides of the canal like mortar with the reinforcement placed on top of the first course and covered by the second course.

Aggregate and cement bags delivered alongside the canal by motor trucks were stored in heaps adjacent to the portable mixers with elevating charging hoppers that were moved at frequent intervals as the work progressed. The mixers discharged through open chutes supported at the lower end on light wooden towers where the discharge was controlled and the concrete delivered to two-wheel carts, pushed by hand over plank runways, dumped as required and shoveled and raked to position.

The cost of preparing the subgrade and building the lining averaged $2.66 per linear foot, equivalent to $0.66 per square yard of surface. The cost of the concrete lining in place including the reinforcement was $5.79 per linear foot, allowing $23.16 per cubic yard for concrete. Laborers received from $4.50 to $6.00 per day and were of inferior quality.

Tunnels.—The tunnels have a horizontal floor, vertical side walls and segmental roofs with 2-foot rise. The uniform width of 7 feet was the most practicable minimum for construction operations and the height of the side walls varied from 4½ to 5 feet, according to grade. Except in timbered sections the concrete lining was generally 6 inches thick with a 4-inch floor over rock bottom.

With one exception, of a tunnel only 1,082 feet long which was through cemented gravel and large boulders, all of the eight tunnels aggregating 8,718 feet in length, were driven through soft dry sand-stone or shale in which the holes for blasting were made with coal augers. The tunnels were driven in full size headings. At one time the double shifts on the double headings of five tunnels required twenty gangs that made an aggregate advance of 140 feet per day. The muck was hauled by mules and the tunnel was lined as soon as possible, because, although the rock stood well when first blasted, a long exposure made it very treacherous.

Concrete Plant.—Concrete was made with sand, gravel and crushed stone all dredged from the river bed with a 1½-yard dragline bucket operated from a 60-foot derrick boom. The sand was washed through the screens by a 2-inch centrifugal pump providing enough water to facilitate the loading into trucks by which it was delivered to the concrete mixers. Large stones were broken in an electric jaw crusher and the three storage bins were mounted on rollers and advanced by anchored tackles operated by the hoisting engine of the derrick whenever the extension of the pit required a movement to be made, usually every other day.

The derricks were similarly shifted on greased skids and hauled forward by the same tackles, these movements requiring about two hours. The plant was operated twelve hours a day by a five-man gang.

One of several mixing plants was installed on the top of a good sized hill that enabled the trucks to dump aggregate directly into the storage bins which delivered by gravity to the two-bag machine that was operated by one man and discharged through an open chute 150 feet long terminating with a spout to the portal one hundred feet vertically below it.

Tunnel Lining.—Two 6 × 2-inch longitudinal strips of concrete were laid on the sides of the tunnel floor to support the wall forms and after the invert between the strips was concreted, the sectional wooden forms that were removed before the wooden arch forms were set, were wedged to position. The 4-foot sections of arch were concreted and rammed in about one-half hour by a four-man gang. The total cost of lining exclusive of engineering, including cost and contractors' compensation, was $103,834 averaging $23 per cubic yard. The total cost of the finished tunnels was $175,307, averaging $20.10 per linear foot. The inefficient labor received $4.50 per day.

Cost of Concrete Lining Irrigation Canal.—An article in Engineering and Contracting, Jan. 1, 1913, by A. T. Petheram, gives the following:

The general dimensions of the canal section are shown in Fig. 9.

The volumes of concrete in lining were 13,502 sq. yds., and 766 cu. yds., the mixture being a 1:6 cement and sand. All mixing was done by hand on 4½ × 10 ft. mixing boards set on the ditch bottom and moved by hand. Sand, water and cement were delivered on the upper side of the canal; the sand was measured in boxes containing 1 cu. ft. and dumped in trough to mixing board. Water was hauled in 650-gal. tanks an average distance of 2¾ miles, and was delivered in barrels to each mixing gang. Each batch was turned over twice dry, water was added and the wetted mixture was turned twice. A mixing gang consisted of 7 men as follows: 4 mixers, 1 top man to deliver sand and water, 1 assistant trowel man, and 1 trowel man, who also acted as foreman. The wages paid for labor were as follows, the rates per hour being for a ten-hour day:

Inspector, per day	$ 5.00
Foreman, per month	125.00
Timekeeper, per month	75.00
Cook, per month	98.00
Carpenter, per hour	35 cts.
Sub-foreman, per hour	27½ cts.
Trowel man, per hour	30 cts.
Team and driver, per hour	50 cts.
Common labor, per hour	22½ cts.

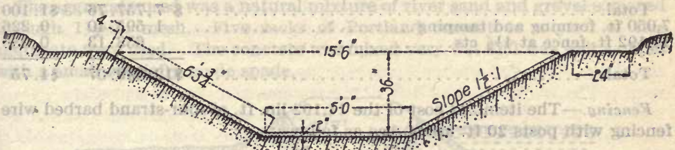


FIG. 9.—Section of cement lined canal, Hanford Irrigation & Power Co., Wash.

The number of men employed was 75 and they lined on an average 80 ft. of canal per ten-hour day.

The concrete materials required were 1,054 bbls. of cement, 771 cu. yds. of sand and 82,850 gals. of water. The costs of these materials distributed on the work were as follows:

Cement.—Two brands of cement were used, Golden Gate, 654 bbls., and Red Devil, 400 bbls., and the costs distributed on the work were as follows:

Item	Golden Gate	Red Devil
Cost, f. o. b. Kennewick	$2.75	$2.60
Drayage at 40 cts. per ton	0.076	0.076
Boat to Hanford at $3 per ton	0.57	0.570
Hauling to job, $1.50 per ton	0.285	0.285
Distribution	0.037	0.037
Total	$3.718	$3.568
Credit, 4 sacks at 10 cts	0.40	0.40
Net cost per barrel	$3.318	$3.168

The total cost for cement distributed on the job was therefore:

654 bbls. at $3.318	$2,170.20
400 bbls. at $3.168	1,267.44
Total	$3,437.64

Water.—The cost of water was the cost of handling 82,850 gals., which was $693.04, or slightly less than 0.85 cts. per gallon.

Sand.—Sand was secured on the company's property and its only cost was for hauling an average distance of 0.85 miles in loads of 1 cu. yd. This cost was $1,079.62. A total of 771 cu. yds. were hauled and 766 cu. yds. were actually used; the corresponding cubic yard costs were $1.40 and $1.41.

Lining.—The cost of lining, including materials as listed above and labor of all kinds, was as follows:

	Total	Per lin. ft.
Excavation		
2,230 cu. yds. earth at 33 cts	$ 735.34	$0.104
400 cu. yds. gravel and loose rock at $1.39	556.71	0.079
660 cu. yds. solid rock at $1.62	1,070.72	0.152
Total	$ 2,362.78	$0.335
Concrete		
1,054 bbls. cement at $3.262	$ 3,437.64	$0.488
771 cu. yds. sand at $1.40	1,079.62	0.153
62,850 gals. water	693.04	0.098
Mixing and placing 766 cu. yds. at $3.33	2,547.46	0.361
Total	$ 7,757.76	$1.100
7,050 ft. forming and tamping	1,595.40	0.226
14,192 ft. fence at 4½ cts	633.13	0.089
Totals	$12,349.07	$1.75

Fencing.—The itemized cost of the 14,192 lin. ft. of four-strand barbed wire fencing with posts 20 ft. apart was as follows:

Barbed wire, 3,168 lbs. at $2.85, f. o. b. Portland	$ 90.29
Freight, Portland to Hanford	21.72
Posts, 705 at 8 cts., f. o. b. Coyote (720 ft. B. M. at $22)	15.84
Timber for braces, 4 × 4 ins. (1,295 ft. B. M. at $23)	29.80
Staples, 210 lbs. at 10 cts	21.00
Miscellaneous material	3.58
Handling and hauling	85.67
Labor (common)	140.29
Surveying and proportionate camp charge	190.26
Total	$633.13
Cost per lin ft. of fence	$00.045
Cost per lin. ft. of canal	0.089

Concrete in Place.—The cost per cubic yard and per square yard of concrete lining in place was from the above costs as follows:

	Total cost	Cost per cu. yd.	Cost per sq. yd.
Cement	$3,437.64	$ 4.49	$0.249
Sand	1,079.62	1.41	0.078
Water	693.04	0.90	0.050
Mixing and placing	$2,547.46	3.33	0.185
Total cost	$7,757.76	$10.13	$0.562

Cost of Concrete Lined Ditch.—The following notes by C. D. Conway are taken from Engineering Record, Dec. 30, 1916.

The irrigation system of the Los Molinos Land Company, in Tehama County, California, comprises 120 miles of ditches with capacities ranging from 5 to 100 sec.-ft. In the main canals and primary laterals, where the water is running constantly during the irrigation season, the seepage losses average less than 1 per cent per mile. In the secondary laterals, in which the water is running only at intervals, the losses are as high as 50 per cent per mile. This excessive loss is owing to the character of the soil through which these laterals pass—a Sacramento silt loam underlain with gravel in which vegetation grows very rapidly and gophers thrive. As the cost of maintenance and the loss of water are very high the company is lining these ditches with concrete. During the spring of 1916, 4,000 ft. was lined.

Instead of reducing the size of the earth ditch, the writer decided to excavate a new ditch within the bank of the existing one, as shown in Fig. 10. Stakes were set at the outside edge of the base. That section was taken out vertically, after which two men with templates trimmed the bottom and sloped the sides. Grade stakes were set every 16 ft. Movable wooden forms in 16-ft. lengths were used.

The concrete was mixed by hand on a board large enough for 1-yd. batches. The platform was built on runners and moved along the ditch for each batch, the gravel being distributed far enough from the ditch to leave room for the board to pass. Water was hauled in a wagon, and the same team moved the mixing board. Six men were employed in mixing and placing the concrete with buckets.

The aggregate used was a natural mixture of river sand and gravel screened through 1½-in. mesh. Five sacks of Portland cement to a yard of this aggregate were used. The concrete was mixed very wet and was well worked with a small specially made spade.

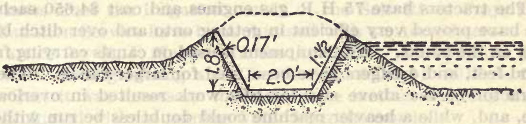


FIG. 10.—Section of new ditch excavated in bank of old one.

Expansion and contraction were provided for by placing ⅜-in. pine boards between forms. These were afterward broken off flush with the concrete. Though the temperature reached 110 deg. Fahr. in the shade at a time when the ditch was dry, no cracks have been noted.

Costs.—The cost per linear foot, including the cost of intake, outlet and a check and takeout every 660 ft., is given in Table VII. While the schedule of wages was low, the laborers were all inexperienced. The average progress was 170 ft. a day with a crew of six laborers and one carpenter, who acted as foreman. Toward the latter part of the job as much as 230 ft. per day was lined.

The itemized cost of concrete, exclusive of excavation, is given in Table VIII.

TABLE VII.—TOTAL COST PER FOOT OF 3050-FOOT DITCH

Excavation	$0.066
Forms (labor)	.021
Lumber	.014
Mixing and placing	.087
Cement	.171
Sand and gravel	.066
Engineering	.004
Superintendence	.010
Miscellaneous	.015
Total	$0.454

TABLE VIII.—COST OF CONCRETE PER YARD, EXCLUDING EXCAVATION

Sand and gravel	$1.45
Cement	3.75
Carpenters	.44
Lumber	.33
Labor	1.90
Equipment and team	.42
Total	$8.29

This ditch has been satisfactory in every respect. In the opinion of the writer this method is much cheaper, where the banks are of sufficient size, than reducing the cross-section of the original ditch. The capacity of the earth section was 10 sec.-ft.; that of the concrete is 9.6 sec.-ft., using 0.15 for the value of n in Kutter's formula and a depth of water of 1.5 ft. The grade of the ditches is 0.08 per cent. Laborers on excavation were paid $2 for a nine-hour day, those handling concrete, $2.25, and carpenters received $3 a day. Lumber cost $20 per thousand and cement $3 per barrel delivered at the job.

The Comparative Cost of Cleaning Irrigation Ditches with a V-machine and by Hand.—C. F. Harvey in the May, 1917 Reclamation Record, abstracted in Engineering and Contracting, May 9, 1917, gives the following:

A V-machine was at first rented for a short time for experimental purposes, and afterwards a similar machine was built on the project at a cost of about $700. The operation of such a machine has continued since May, 1916. At first one caterpillar tractor furnished the power, but now two tractors are used. The tractors have 75 H.P. gas engines and cost $4,650 each. These tractors have proved very efficient in getting onto and over ditch banks and traveling on the banks. This equipment is used on canals carrying from 12 to 50 second-feet, and dredgers have been used for larger canals. The use of a single tractor of the above size for this work resulted in overloading the machine, and, while a heavier machine could doubtless be run without overloading, the experience on the Yuma project has been that two machines of about this horsepower are probably more efficient than one larger machine would be, as the two machines can work to great advantage in getting the V in and out of the ditches and around structures. It is to be noted, by the way, that the number of structures in a ditch greatly affects the mileage cleaned. The life of the V-machines and of tractors on this work will be about five or six years.

The following figures are taken for the month of July, 1916, when the rented V-machine was in use:

Operating 114½ hours.
Repairs, 117½ hours.
Distance cleaned, 11.62 miles.
Distillate used, 715 gal. (one tractor).

Costs (July)

Labor	$552.25
Distillate	75.07
Hauling fuel	10.33
Shop orders	5.06
Oil and waste	8.35
Supplies	18.86
Rent of V machine	175.00
Depreciation	50.00
Total	$894.92
Cost per mile cleaned	77.01

By deducting the $175 rent for the machine the cost of cleaning would be reduced proportionately. The above is for one tractor. By putting on an extra tractor the cost of fuel would be doubled, but it is thought that the mileage of canals cleaned would also be nearly doubled, while the labor cost of repairs would remain about the same. With the benefit of experience and a perfected organization it is expected that the cost can be reduced to $40 per mile. With the old organization for cleaning by shovel and teams the costs would run from $200 to $300 per mile. This was with a foreman at $3 a day and labor at $2 a day, worked in such gangs as could be retained. The organization worked with the machine equipment at present is as follows:

1 foreman at $4.50 per day.	Crew of caterpillar:
Crew of V-machine:	
1 man at $3 per day.	1 operator at $5 per day.
1 man at $2.50 per day.	1 oiler at $2.50 per day.

There are on the Yuma project more than 200 miles of ditches to be cleaned of a size suitable for the economical use of the V-machine. This makes it possible to keep the equipment in operation for 12 months a year. The amount of work to be done is, of course, an important consideration in making the expenditure for the tractors.

Cost of Removing Vegetation from Irrigation Canals.—Excellent results in removing moss from the irrigation canals of the Salt River Project of the U. S. Reclamation Service have been obtained with an Acme harrow, according to an article by A. J. Haltom, in the April, 1917 Reclamation Record, and abstracted in Engineering and Contracting, April 11, 1917 as follows: On this project it was necessary to devise some method whereby the moss could be eliminated without turning water from the canals.

The Acme harrow, or, as called by some, the orchard cultivator, is a machine consisting of long parallel blades attached to an iron frame, with the blades turned to enter the ground and cut the roots horizontally an inch or two beneath the surface. It slices off the top surface of the silt, and after the moss roots are thus cut the moss floats to the top and is then caught by men stationed below on bridges or checks. This machine is drawn by means of a chain to a team on each bank of the canal, and by adjusting the length of the chains the harrow can be run on either slope or in the bottom of the canal. In this manner the moss can be removed without interrupting the flow of water. On part of the canals it was necessary to keep men and teams at work until the end of the season, and on others an occasional cleaning every two or three weeks answered all requirements. The Acme is also useful in stirring up the silt in the bottom of the canal, causing it to be again picked up in suspension, with the result that the silt deposits are considerably decreased. The stirring of the silt with the resultant muddy water tends to retard the growth of the moss farther down the canal, and it also helps to puddle leaky portions of the canal.

The methods employed on the Minidoka Project for the control of moss, weeds and willows in irrigation canals also were described in the above-mentioned issue of the Reclamation Record, from which we quote as follows:

It became necessary to begin the work of removing the moss as early as June 20. At this time the only method which was found successful in clearing the moss from the larger canals was by cutting with the Ziemsen submarine saw. This saw consists of a flexible band of steel with hooked teeth on both edges. It can be obtained in any length, and the weights to hold it to the bottom are adjusted to fit the canal. It is operated at an angle of about 30° with the cross-section of the canal, the crew always working upstream. The rate of progress is from 6 to 12 in. at each double stroke and from ¼ to 1 mile per day can be cut with each saw. The long streamers of moss when cut rise to the surface and float down to the next bridge or check, where they are thrown out by men with pitchforks. At times it has been necessary to have as many as three men to pitch out the moss cut by one crew.

Last season it was necessary to go over many of the canals three times. During the middle of the season the moss grew very rapidly. In one canal a length of 2½ ft. was measured 3 days after cutting. In another place a length of 8 ft. was observed 14 days after cutting. After the 20th of August the trouble began to decrease, partly due, no doubt, to the shorter days and less sunlight, partly to cooler weather, and partly to a slackening demand for water.

Removing the moss by dragging a ½ or ¾ in. chain by teams on each bank was not successful until after about the middle of August, when the moss had ripened enough to break away at the first joint. Prior to that time the chain would drag over the moss without breaking it. A V made out of railroad iron and weighing in all about 600 lb. was dragged up the canal but this method was not successful, as the rails slipped over the moss.

In laterals of about 1 ft. depth it was found that a spring-tooth harrow could be used quite well, but it had to be taken out and cleaned about every 50 ft. The harrow was not successful in the larger canals. In laterals the water was lowered at times so that there was only enough to support the moss and men were put in with brush scythes. This method was found very useful where the farmers on some lateral were having serious trouble in getting water and would get together to co-operate in cleaning it.

Where it can be done, the cheapest and most effective method of cleaning the canal is to shut the water out entirely and let the ditch dry in the sun. Five to seven days' exposure is necessary ordinarily to kill the moss. This method kills the growth, but does not destroy the bulb. On the Minidoka project it has not seemed practical to adopt this method, as it is felt that continuous water service was more important to the farmers than the money saving which would have resulted from a method such as this.

During the 1916 season, 260 miles of cleaning were done. The total cost of this work was $4,200, making the cost per mile a fraction over $16. The average cost per mile of the different methods is about as follows: Sawing, $22; chaining late in the season, $8; cutting with scythes in laterals, $11; spring-tooth harrow in laterals, $9.

Weeds and grass growing along the inner slopes of the canal and laterals decrease the discharge to a considerable extent by retarding the velocity. These are removed by men with brush scythes at a cost of about $12 per mile.

Willows are cut by men with grubbing hoes and brush scythes. Men equipped with grubbing hoes go ahead for cutting out larger willows, and men with scythes follow and cut the remainder. In the past little attention has been given to willows on the Minidoka project, but it is now believed to be advisable to cut them annually. The clearing during the last season was done with the idea of keeping stumps down so that a mowing machine can be used to cut the new growth. The cost on the removing of willows has been about $27 per mile. About 23 miles of banks were cut over.

Costs of Keeping Down Vegetation on Irrigation Canal Banks by Grazing.— The following data, abstracted in Engineering and Contracting, April 14, 1915. are given in a report in Reclamation Record, April, 1915, by A. J. Halton,

A considerable item of expense in irrigation canal maintenance is the cutting of Johnson grass and other vegetation which springs up on the banks. On the Salt River Project of the U. S. Reclamation Service, beginning in 1913, experiments have been conducted in sheep grazing as an aid to ordinary cutting for keeping down the bank vegetation. There follows a comparative statement showing decrease in cost of maintaining canals and laterals before and after introduction of sheep:

	Main canals	Laterals	Header ditches	Total cost
Clearing:				
Before	$1,356.88	$3,275.14	$2,226.53	$6,858.55
After	908.05	1,174.69	659.70	2,742.44
Repairing breaks:				
Before	166.43	211.64	121.87	499.94
After	50.48	....	94.00	144.48
Gopher poisoning:				
Before	39.42	....	96.93	136.35
After	....	....	10.00	10.00
Total:				
Before	$1,562.73	$3,486.78	$2,445.33	$7,494.84
After	958.53	1,174.69	763.70	2,896.92
Decrease, 1914 over 1912	$ 604.20	$2,312.09	$1,681.63	$4,597.92
Mileage	8	22	10	40
Average decrease per mile (after introduction of sheep)	$ 75.525	$ 105.095	$ 168.16	$ 114.95

Note.—Cost of repairing breaks and gopher poisoning are included because this expense has been greatly reduced by the grazing of sheep. The cost of cleaning in 1912 is based on a unit cost per mile.

Cost of Maintaining Ditches in the Imperial Valley, Cal. with a Traveling Clam-Shell Excavator.—J. C. Allison, in Engineering Record, Nov. 16, 1912, gives the following:

The irrigation season in Imperial Valley includes the full 12 months, so the canals are always carrying water. This prevents scraping out the deposits of silt with teams.

Up to 1911, about the only method of keeping the section of the canals large enough to carry the necessary water has been by continuously raising the banks to keep pace with the rising of the bottom, due to the deposition of silt. In the small ditches a V-shaped tool operated by a caterpillar engine has been used to drag the canal, thus crowding part of the silt out on the banks.

Experiments have been made with floating dredges of small capacity but these have been unsuccessful, since they are too cumbersome to transport from one point to another, and the time consumed in pulling the pontoons out around the checks is more than the time actually used in digging the silt between checks.

Design of a Special Dredge.—The time came finally when the limit of raising the canal banks was reached, most of the grade of the canals having been overcome, and it became necessary to obtain a new type of tool. A careful study was made of every available tool, but owing to the peculiar conditions of the work, each one was rejected. It was certain that if an appliance capable of operating a clamshell bucket could be so arranged as to permit moving from one point to another in a quick and easy manner, the silt problem in the main distributing canals could be solved.

With this idea in view, W. H. Holabird, receiver of the California Development Company, arranged with the Stockton Iron Works, of Stockton, Cal., to send an erecting engineer to the valley. With his aid, Mr. Holabird and the writer planned the assembling of an all-steel portable clamshell dredge, which would operate a ½-yd. bucket, and at the same time be light enough and narrow enough to transport over the average Imperial Valley road and over the county bridges spanning the canals.

The machine has a 14 × 22-ft. steel underframe, mounted on wide-tread wheels and carrying an A-frame and 40-ft. steel boom, operating machinery and operator's cabin. The wheels at the working end are 6 ft. in diameter, 24 in. wide and are 10 ft. apart between inside edges. The other wheels are only 3 ft. in diameter and are set close together under the frame, their axle being pivoted to provide for steering from that end. Traction is obtained on the large wheels by chain-drives and gears from the engine. Power for digging and traction is furnished by a 15-hp. Atlas two-cylinder vertical gas engine controlled from the operator's cabin, which is on a platform set in the A-frame. The end of the main boom has a normal elevation of 20 ft. above the wheel base, and has a swinging range of 180 deg. A ½-cu. yd. clamshell bucket is employed.

Owing to the small size of the bucket, the yardage per hour is not very great, and it becomes necessary to operate several machines to keep pace with the work. The unit price per yard, however, is satisfactory. Against this price, that paid in the past presents a marked contrast. In a great many cases the canals were entirely abandoned and a side ditch built to carry the water. The scraper work alone amounted to 15 to 20 cents per cubic yard, exclusive of right of way. Wherever the canals were cleaned with shovels the cost per yard ran as high as 50 and 60 cents.

The only other applicances which are satisfactory for use on the canals in Imperial Valley are the V-shaped drag and an endless-chain machine known as the Ruth dredge. Several of these are now operating. The scope of their work is limited to a very narrow, shallow ditch, since neither will cut more than 1 ft. in depth. The material is deposited only a few feet away from the channel, and in the future it will be necessary to remove this accumulation by some other means, since the banks will become too high for further operation of this nature. The new dredge is capable of discharging the material 35 ft. from the canal, if necessary, where the embankment may be leveled and used as a road.

Cost of Clearing Canals.—Table IX shows the cost of operation of the dredge in the Ash canal for the period between Sept. 18 and Dec. 1.

TABLE IX.—COST OF OPERATION OF DREDGE IN CLEARING CANALS

Item	Operation		Maintenance and betterment	
Material:				
Tools	$ 6.20		....	
Oil	31.51		....	
Fuel	132.56		....	
Commissary	2.25*		$ 1.14	
Misc. supplies	280.49		107.26	
Store expense	8.89		3.74	
		$ 457.40		$ 109.86
Labor		1,949.08	....	75.81
Totals		$2,406.48	....	$185.67
Per hour		2.26	....	0.17

* Note.—Commissary items a credit to cost.

PERFORMANCE OF DREDGE CLEARING CANALS

Total digging time, hours	1066
Cost of digging per hour	$2.43
Total yardage removed, approximate	21,321
Yardage removed per digging hour, approximate	20
Cost per cubic yard, approximate	$0.12

The plant consists of the dredge, a cook wagon, camp and commissary team, and the necessary stock and tools for leveling the road ahead of the machine along the ditch. The whole plant represents a cost of about $7,100 on the ground in this case.

No percentage for depreciation is included in the costs shown, but the actual maintenance work and the material necessary are given, the amount being added to the cost per yard. The maintenance and betterment for this run is considerably above normal, since several small weaknesses were discovered and remedied. Improvements were also made, such as building a pilot house, building moving planks, installing a Bristol lighting plant and providing in general for the comfort of the men in the way of heating applicances for the night shifts.

Two 10-hour shifts were run per day. The digging time shown in the table is the summary of the actual digging hours, and does not include the time spent in repairs, moving, etc. No commissary costs are shown, since each meal is deducted from the man's wages at 25 cents per meal. This amount provides for the cook's wages and the provisions, and accounts for the small credit shown. Of the running supplies necessary, the fuel represents the greatest expense. The engine consumed 0.9 gal. of distillate per hour. This fuel was subject to high customs duty in Mexico.

The labor necessary for operating the machine for the two shifts consists of two levermen at $125 per month each; two enginemen at $85 per month each, and two deck hands at $70 per month each. There was necessary at times an extra deck hand for each shift to aid in placing the moving planks while the machine was in soft material. Several four-horse fresno teams, at $6.50 per day, were sometimes required to level the road along the ditch ahead of the machine. All of this expense is shown under the item of labor.

Cost of Pipes for Farm Irrigation.—The following notes are given in Fortier's "Use of Water in Irrigation" (1915).

The materials composing the pipes most commonly used by irrigators are concrete, clay, wood, and metal. A brief description of each of these kinds follows:

Concrete Pipe.—This kind of pipe is used quite generally in southern California for conveying irrigation water underground without pressure or under low heads not exceeding 10 to 15 feet. C. E. Tait, Irrigation Engineer of the Department of Agriculture, states that "a good pipe for the smaller sizes is made from a 1 to 3 mixture consisting of 5 parts cement, 6 parts sand and 9 parts gravel. A larger proportion of gravel may be used in the larger sizes. A good pipe may also be made of cement, sand and crushed rock, no particle being larger than one-half the thickness of the pipe."

Failures in concrete pipe have been largely due to lean mixtures, the use of sand mixed with earth and improper moulding. A weak unreliable pipe is likely to result when the voids in the sand are not filled with cement, when earthy material is incorporated in the mixture or when the mixture is too dry when moulded. The porosity of concrete pipe is reduced and the carrying capacity is increased by the application to the inner surface of a cement brush coating.

The prices for materials in 1914 in southern California were for cement delivered $3 per barrel, sand and gravel $1 per cubic yard, tampers $3 and mixers $2.25 per day of 9 hours. The quantities of materials used, their respective costs and the cost of the various processes in making pipe, exclusive of overhead charges and profits are given in Table X.

TABLE X.—CONCRETE PIPE

Size of pipe	Lineal feet per barrel of cement	Lineal feet per cu. yd. of gravel	Cost data per lineal foot: Cement	Gravel	Moulding	Coating	Total
4 in.	126–130	174	$0.023	$0.006	$0.020	$0.003	$0.052
6 in.	82–100	112	0.036	0.009	0.020	0.003	0.068
8 in.	64–76	87	0.047	0.011	0.022	0.003	0.083
10 in.	48–56	64	0.062	0.015	0.025	0.003	0.105
12 in.	36– 44	50	0.083	0.020	0.028	0.004	0.135
14 in.	28– 30	40	0.108	0.025	0.032	0.005	0.170
16 in.	26– 28	34	0.115	0.029	0.038	0.006	0.188
18 in.	22– 26	28	0.136	0.036	0.042	0.007	0.266
20 in.	18– 20	23	0.166	0.043	0.100	0.008	0.317
24 in.	12– 14	18	0.250	0.055	0.110	0.009	0.424
30 in.	8–10	11	0.375	0.090	0.150	0.011	0.626
36 in.	6–8	8	0.500	0.125	0.200	0.012	0.837

Moulding the Pipe.—Concrete pipe as made in southern California for the farmer's use is moulded in 2-foot lengths with beveled lap joints. Since the price of moulds for pipe between 6 and 12 inches in diameter varies from $50 to $100 per set the tendency is to use the smallest possible number. This effort to economize frequently results in a brittle pipe caused by the use of too dry a mixture, such a mixture requiring less time in the moulds. To obviate this difficulty and increase the output from each set of moulds thin metal cylinders are sometimes introduced in the moulds and allowed to remain for some time around the freshly moulded pipe after its removal from the moulds. In this way a wetter mixture resulting in a stronger pipe can be made.

Vitrified Clay Pipe.—Pipe made of moulded clay, kiln-burned and glazed is extensively used to conduct sewage in the sewer systems of towns and cities. The requirements for this service are quite rigid and the pipe which is rejected by the sewer inspector can frequently be purchased at a low figure. In this way the irrigator who resides within hauling distance of a town or city can usually obtain from the municipality or the clay pipe company a serviceable water pipe for low heads at reasonable prices.

In southern California the rejected sewer pipe is classified into three grades known as Nos. 1, 2, and 3 water pipe. The defects in No. 1 grade are not serious and can be depended on to stand a head of 20 to 30 feet in the smaller sizes and 15 to 20 feet in the larger sizes. The No. 2 grade consists of pipe which is cracked in the main part of the joint or length and withstands less pressure than No. 1. No. 3 grade is used only for drainage, being usually cheaper than the tile. The prices of grades 1 and 2 in 3-foot lengths, f.o.b. cars Los Angeles, are at this writing (1914) as in Table XI.

TABLE XI.—VITRIFIED PIPE

Size	No. 1 grade. Cents per ft.	No. 2 grade. Cents per ft.
3 in.	4 7/8	4 1/8
4 in.	6 1/2	5 1/2
5 in.	8 1/8	6 7/8
6 in.	9 3/4	8 1/4
8 in.	12 3/8	10 1/8
10 in.	16 1/2	13 1/2
12 in.	20 5/8	16 7/8
14 in.	27 1/2	22 1/2
16 in.	34 3/8	28 1/8
18 in.	41 1/4	33 3/4
20 in.	56 7/8	48 1/8
22 in.	71 1/2	60 1/2
24 in.	81 1/4	68 3/4

Wood Pipe.—The various kinds of wood pipe used to convey water for irrigation purposes belong to one of two general types. One of these is the continuous stave pipe and the other the machine banded pipe. Since the former is only built in medium and large sizes in which the diameters run from 1 to 12 feet it is not well adapted to the farmer's needs and for that reason will not be considered here.

The factory for making machine-banded pipe in San Francisco, California, uses redwood; those located in Portland, Oregon, Tacoma and Seattle, Washinton, and Vancouver, B. C., use fir. In the States of New York and Pennsylvania the pipes are made of white pine and tamarack while in Louisiana cypress is considered the most suitable wood.

A quarter of a century and less ago, machine-banded pipe consisted wholly of logs turned in a lathe, machine-bored and wrapped with flat steel bands. Staves 8 to 12 feet in length in the eastern factories and up to 20 feet in length in the western factories have since been substituted for bored logs. The staves which vary in thickness from 1 to 1¾ inches are held together by galvanized steel wire spaced far apart or close according as the internal pressure of the water is low or high. In some factories flat bands of steel 14 to 16 gauge are used instead of the round wire. After the pipe is banded and the ends are milled for couplings each section is dipped in a bath of hot asphalt and when withdrawn is rolled in sawdust or shavings.

The joints are made in various ways. A common form for low pressures is that of the mortise and tenon joint. The joint is reinforced when the pressure requires it. Sometimes tenons are made on both ends of each section and the coupling is made by means of collars. In common with other kinds of pipes the joints in wood pipe are the chief source of trouble and expense.

Table XII.—Wooden Pipe

Diameter	Head, feet	Price	Weight, pounds	Diameter	Head	Price	Weight, pounds
2 in.	50	0.087	3.1	10 in.	50	0.268	13.1
	100	0.09	3.2		100	0.347	14.7
	150	0.092	3.2		150	0.392	15.7
	200	0.10	3.4		200	0.455	17.3
	250	0.105	3.5		250	0.479	18.4
	300	0.116	3.6		300	0.503	19.4
4 in.	50	0.129	5.8	12 in.	50	0.322	16.8
	100	0.131	5.9		100	0.413	18.9
	150	0.134	6.0		150	0.450	19.8
	200	0.166	6.3		200	0.532	21.7
	250	0.176	7.0		250	0.618	23.8
	300	0.189	7.3		300	0.660	25.3
6 in.	50	0.163	8.3	14 in.	50	0.445	21.3
	100	0.168	8.9		100	0.550	23.0
	150	0.184	9.1		150	0.629	25.3
	200	0.226	9.6		200	0.745	28.2
	250	0.242	10.0		250	0.834	29.9
	300	0.258	10.4		300	0.916	32.3
8 in.	50	0.203	10.3	16 in.	50	0.547	24.7
	100	0.224	10.5		100	0.639	26.9
	150	0.292	12.8		150	0.734	29.3
	200	0.332	13.7		200	0.871	33.4
	250	0.366	15.6		250	0.987	36.2
	300	0.387	16.2		300	1.132	40.2

According to S. O. Jayne, Irrigation Engineer, U. S. Department of Agriculture, the cost of laying wood pipe exclusive of earthwork, backfilling and haulage varies from 2 cents per lineal foot for pipes 4 to 6 inches in diameter up to 6 cents for pipes 24 inches in diameter.

The prices and weights per lineal foot of machine-banded pipe f.o.b. cars, Seattle, Washington, are given in Table XII.

Metal Pipes.—Space will not permit even a brief description of each kind of metal pipe used by irrigators. Notwithstanding the large variety in the market by far the most common is the steel-riveted pipe. This pipe may be purchased in a large number of sizes ranging from 4 to 30 inches and over in diameter and capable of withstanding heads of 50 to 300 feet. Each joint of pipe is made of a single sheet of steel which is sized, punched, rolled and riveted. A number of these joints are then riveted together making a shipping length about 30 feet. Each length is immersed in a bath of hot asphalt before being stacked up in the shipping yards. For all sizes up to 12 inches designed for ordinary pressures the lengths are simply driven together, the smaller joint of one end telescoping the larger joint of the adjacent length. For high pressures and large sizes the circular seams are single riveted and the seams may be split-calked. For low heads, lighter and less expensive pipe of galvanized iron from 20 to 24 gauge, both coated and uncoated, has during the past few years come into somewhat extensive use throughout certain sections of the Northwest.

The following table gives the list prices of steel-riveted pipe in Los Angeles, California, in 1914, these prices being subject to a discount of about 15 per cent.

TABLE XIII.—STEEL RIVETED PIPE

Size	16-Gauge	14-Gauge	12-Gauge
4 in.	$0.19	$0.22	....
5 in.	0.23	0.27	....
6 in.	0.28	0.32	$0.41
7 in.	0.31	0.37	0.48
8 in.	0.34	0.40	0.52
9 in.	0.38	0.42	0.57
10 in.	0.41	0.47	0.62
11 in.	0.43	0.49	0.65
12 in.	0.46	0.55	0.69

Cost of Plain Concrete Pipe for Irrigation Works.—Prof. B. A. Etcheverry gives the following in a report to the Dept. of Agriculture, Province of British Columbia, abstracted in Engineering and Contracting, Sept. 18, 1912.

TABLE XIV.—CEMENT PIPE DATA

Inside diameter of pipe in inches	Thickness of pipe in inches	Number of feet of pipe made with 1 barrel of Cement 1:4 mixture	Number of feet of pipe made with 1 barrel of Cement 1:3 mixture	Men composing one crew	No. of feet made per day
6	1 1/16	95	75	1 mixer, 1 or	400–500
8	1¼	63	50	2 moulders,	350–400
10	1⅜	47	37	1 finisher and	300–400
12	1½	36	28	helper	250–350
14	1⅝	28	22	1 or 2 mixers	225–325
16	1¾	23	18	2 moulders	200–275
18	1⅞	19	15	1 finisher	150–225
20	1⅞	17	14	and	125–175
22	2	15	11¾	helper	100–150
24	2¼	12¼	10½	3 or 4 mixers	100–150
26	2¼	11½	9	2 moulders	90–120
30	2½	9	7	1 finisher and	90–110
36	3	6¼	5	helper	80

Dimensions of Cement Pipes and Rate of Manufacturing.—Tables XIV give the thickness of the pipe, the number of feet made per barrel of cement, the number of men in one crew of pipe makers, and the number of feet of pipe made per day. The number of men stated is the number required for a large production. The number of feet per day is not the maximum which may be obtained but is an average rate for good experienced men. The 1 to 3 mixture requires about 2¼ bbls. of cement per cubic yard of concrete. For the 1 to 4 mixture 1¾ bbls. of cement per cubic yard are required.

TABLE XV.—COST OF MAKING CEMENT PIPES (IN CENTS), PER LINEAL FOOT

Diameter of pipe in inches	Cost for 1:2 mixture, cents	Cost for 1:3 mixture, cents	Cost for 1:4 mixture, cents
6	13	10	7
8	15	12	9
10	20	15	11
12	25	20	15
14	30	25	20
16	36	30	25
18	42	35	30
20	50	43	35
24	68	60	50
26	87	75	63
30	95	85	70
36	130	115	95

Cost of Making Pipe.—The cost given in Table XV is obtained from the above data and for the following prices of labor and material: Portland cement, $3.50 delivered on the ground. Gravel, $1.00 a cubic yard. Labor: Tampers $3.00 a day; mixers and sprinklers, $2.50 a day.

The figures given include all materials and labor and an allowance of about 10 per cent for interest and depreciation on plant, administration and supervision, and should not be exceeded with efficient workers.

CONSTRUCTION AND LAYING OF PIPE LINES

Excavation of Trench.—The pipe should be laid sufficiently deep below the surface to have an earth covering of at least 12 ins. and preferably 18 ins. or even more. The bottom of the trench should be graded on an even grade to avoid short siphons which may produce air chambers in the pipe. The width of the trench should be larger than the outside diameter of the pipe by about 12 ins. to allow the pipe layers sufficient space to work in. The trench width and depth with the cost of excavation are given in Table XVI, based on an 18 in. depth of earth covering. The cost of excavation and backfilling is assumed at 20 cts. a cubic yard.

Laying the Pipe.—The pipes are placed in the trench standing on end with the bell end or grooved end up. To lower the large pipes more easily they may be slid on a chute or skid made of timber. The pipe sections are joined with a mixture of 1 part of cement to 2 of fine sand. The taper end of the pipe which has already been laid, and the bell end of the pipe to which it is to be joined, are brushed clean and well wetted with a fiber brush. About an inch thick of the soil under the bottom of the joint to be made is removed and a trowel full of mortar is spread in its place to form a bed of mortar. The bell end of the pipe which is standing on end is filled with cement mortar and is jammed against the taper end of the previously laid pipe. The mortar which

TABLE XVI.—COST OF EXCAVATION FOR CEMENT PIPE LINES (IN CENTS), PER LINEAL FOOT

Size of pipe	Depth of trench	Width of trench	Excavation in cu. yds. per lineal foot	Cost of excavation in cents at 20 cts. per cu. yd.
6	26	20	.13	2.6
8	28	22	.16	3.2
10	31	25	.20	4.0
12	33	27	.23	4.6
14	35	29	.27	5.4
16	38	32	.32	6.4
18	40	34	.35	7.0
20	42	36	.38	7.6
24	47	41	.50	10.0
26	49	43	.55	11.0
30	54	48	.66	13.2
36	60	54	.83	16.6

is squeezed out on the inside of the joint is wiped with a wet brush to form a smooth joint. To complete the joint a band of mortar from 2 to 3 ins. wide and ¼ to ½ in. thick is formed on the outside of the pipe.

It is always preferable to lay the pipe uphill to avoid the shrinkage at the joints due to the pipe pulling away. It is well to protect the bands from the action of the sun for about 30 minutes before backfilling by using wet burlap or placing a board over them. To raise a pipe and hold it on grade do not use clods but shovel in the dirt and compact it by tamping. The bands should be wetted before backfilling; this must be done carefully by shoveling the earth, free from rocks, around the pipe and tamping it until the pipe is well covered. With loose sandy soil which packs easily, very little tamping is necessary. The pipe should not be used for at least two to three days, especially if under pressure, to give sufficient time for the bands to harden.

In Table XVII is given information regarding the laying and hauling of cement pipe, based on the wages and cost of material given above. Ten per cent has been allowed for supervision, organization, breaking of pipe and miscellaneous.

TABLE XVII.—COST OF LAYING AND HAULING CEMENT PIPE (IN CENTS) PER LINEAL FOOT

Diameter in inches	Weight of pipe in lbs. per ft.	Number of feet laid per bbl. of cement	Number of men in laying crew	Number of feet laid per day	Cost of laying exclusive of trenching and hauling, in cts. per ft.	Cost per ft. of hauling 2 miles
6	20	500	3	600	2.25	.9
8	32	400	3	600	2.50	1.4
10	42	350	3	500	3.00	1.9
12	56	300	3	450	3.50	2.5
14	69	225	3	400	4.00	3.1
16	85	200	3	300	5.00	3.8
18	100	175	4	300	6.25	4.5
20	110	150	4	300	6.60	5.0
24	160	100	6	300	10.0	7.2
26	175	85	6	250	12.0	7.9
30	220	75	6	200	14.0	9.9
36	320	60	7	200	17.0	14.4

The cost data given in the preceding tables are assembled and given in Table XVIII.

TABLE XVIII.—COST OF MAKING, LAYING, TRENCHING AND HAULING CEMENT PIPE (IN CENTS), PER LINEAL FOOT

Diameter of pipe in ins.	Cost of making 1:3 pipe	Cost of making 1:4 pipe	Cost of laying	Cost of trenching	Cost of hauling 2 miles	Total cost 1:3 pipe	Total cost 1:4 pipe
6	10	7	2.25	2.6	.9	15.75	12.75
8	12	9	2.50	3.2	1.4	19.10	16.10
10	15	11	3.00	4.0	1.9	23.90	19.90
12	20	15	3.50	4.6	2.5	30.60	25.60
14	25	20	4.00	5.4	3.1	37.50	32.50
16	30	25	5.00	6.4	3.8	45.20	40.20
18	35	30	6.25	7.0	4.5	52.75	47.75
20	43	35	6.60	7.6	5.0	62.20	54.20
24	60	50	10.0	10.0	7.2	87.20	77.20
26	75	63	12.0	11.0	7.9	105.90	93.90
30	85	70	14.0	13.2	9.9	122.10	107.10
36	115	95	17.0	16.6	14.4	163.00	143.00

These cost values agree quite closely with those given below which are those obtained for about 5 miles of pipe on the irrigation system of the Fruitlands Irrigation & Power Company, near Kamloops. The concrete mixture used was composed of 1 part of cement to 2½ sand and 1½ of stone, which corresponds to a 1 to 3 mixture of cement and pit gravel. Cement cost $3 a barrel, sand 75 cents a cubic yard, crushed rock $2.50 a cubic yard, common labor $2.50 per day, skilled labor $3 to $3.50 per day, and teams $6 per day. The cost given includes all materials, labor, supervision, and depreciation on plant.

TABLE XIX.—COST OF MAKING AND LAYING CONCRETE PIPE ON IRRIGATION SYSTEM OF FRUITLANDS IRRIGATION & POWER CO., NEAR KAMLOOPS

Diameter of pipe, inches	Cost of making, cents	Cost of laying, cents	Total cost, cents
8	11.1	....	....
10	15.7	....	....
12	20	11	31
16	29.5	15.5	45
20	39.5	20.3	59.8
24	54.7	23.3	78

Cost of Manufacturing Concrete Pipe.—The following data were published in Engineering and Contracting, Jan. 14, 1920.

During the past season the Modesto Irrigation District of Stanislaus county, California, constructed several thousand feet of standard concrete pipe. The pipe was hand tamped, reinforced, made in 2 ft. lengths with bell and spigot ends and walls varying in thickness from 1¼ in. for 8 in. to 3 in. for 36-in. pipe. The mix was 1 cement to 3½ sand.

The cost of the pipe was as follows:

Size, in.	Cost per lin. ft.
8	$0.12½
12	.21
16	.36
20	.51
24	.68
30	1.02
36	1.50

The above costs include an allowance of $1,000 for depreciation. Several thousand feet of each size up to and including 24 in. were made. Several hundred feet of the 30-in. and 36-in. pipe also were constructed.

The force consisted of 10 or 12 men at $4 per day each, and a foreman at $5 per day. The cost of materials was:

Cement	$3.25 per bbl.
Sand	1.50 per ton
Rock	1.50 per ton

An 8-hour shift was worked, and an average of 350 ft. of 8 in. or 180 ft. of 24 in. pipe was made per shift.

Costs of Continuous Wood Stave Pipe Lines.—In Engineering and Contracting, July 21, 1915, the following extract from Bulletin 155, U. S. Department of Agriculture, by S. O. Jayne, is given.

Eighteen-inch.—At Astoria, Ore., 7½ miles of 18-in. pipe built in 1895. Staves, fir, 1⅛ ins. thick, milled from 2 × 6-in. lumber. Bands, 7/16 in. diameter upset to ½ in. at threads. Clips No. 12, B. W. G., 1½ ins. wide, treated. Shoes, Allen patent, malleable iron, weight 10 ounces each. Contract prices of steel in bands, 4.8 cts. per pound. Lumber, gross measurement, $35.40 per 1,000 ft. b. m. Average spacing of bands, 5 9/16 ins. Cost of pipe to the city, 90.33 cts. per linear foot, including accessories or 76 cts. excluding them. These figures are not the actual cost of building the pipe, as Mr. Adams says: "It is presumable that the contract prices represent a profit of from 12½ to 15 per cent." The approximate cost of replacing this line with one of the same size and length in 1911 was $75,000, redwood staves 1½ ins. thick being used in the new pipe. The cost given includes engineering expense.

Thirty-inch.—At Denver, Colo., in 1889, a 30-in. pipe 16.4 miles long required 1,869,000 ft. b. m. of Texas pine, which cost $51,399.28, at $27.50 per M., and 271,900 half-inch bands, which cost $54,299.55; erection of pipe by contract, at 5.1 cts. per band, $13,866.03; total, $119,564.86, or $1.36½ per linear foot. Trenching cost 48.3 cts. per foot in addition to foregoing.

At Jerome, Idaho, 1912, 1,529 ft.; 30 ins. diameter; fir staves, 1⅝ ins. thick; bands, ½ in. diameter; pressure, 0 to 47 ft.; average haul, 10 miles; built in trench and buried 2 ft. deep. Cost, including everything except engineering and administration, $2,922, or $1.91 per linear foot.

At Idaho Falls, Idaho, 1905; 800 ft.; 30 ins. diameter; fir, ½ in. bands; maximum head, 34 ft.; supported on wood cradles. Cost, $1.55 per linear foot, including everything.

At Kennewick, Wash., 1908; 9,490 ft.; 30 ins. diameter; head, 0 to 180 ft.; built by contract on prepared foundation for $1.85 per foot. Includes delivery of material at railroad point, but no haul or earthwork.

Thirty-two Inch.—At North Yakima, Wash., 1894; Redwood siphon 940 ft. long; 32 ins. diameter; maximum head, 90 ft.; bands, ½ in. diameter; built by force account for $2,500, equals $2.66 per linear foot. Duplicated by contract, 1903, for same figure.

At Filer, Idaho, 1901; 1,300 ft.; 32 ins. diameter; fir staves, 1⅝ ins. thick, at $40 per thousand feet b. m. on basis of 2 × 6-in. lumber; bands, ½ in. diameter, 57 cts. each; malleable iron shoes, 4 cts. each; tongues, ⅛ × 1½ × 5 7/16 ins., 3 cts.; pressure head, 0 to 40 ft.; work done by force account; wages, $2.50 for 10 hours, and foreman $5; hauling material 8 miles, $75; erecting on top of ground, approximately $250. Cost of staves and steel laid down at

Filer, $1.35 per foot of pipe; haul and erecting, 25 cts.; total approximately, $1.60 per foot.

Thirty-six Inch.—At Jerome, Idaho, 1912; 650 ft.; 36 ins. diameter; head, 0 to 43 ft.; staves, fir, 1⅝ ins. thick; band, ½ in. diameter; built in trench and buried 2 ft. deep; average haul, 4 to 5 miles. Cost, including everything except engineering and administration, $1,596, or $2.46 per foot.

Forty Inch.—At Jerome, Idaho, 1912; 3,113 ft.; 40 ins. diameter; head, 0 to 100 ft.; fir staves, 1⅝ ins. thick; bands, ½ in. diameter; built in trench and buried 2 ft. deep; average haul, 10 miles; cost, $8,933, or $2.87 per foot, including everything except engineering and administration.

Forty-two Inch.—At Jerome, Idaho, 1912; 980 ft.; 42 ins. diameter; head, 0 to 51 ft.; staves, fir, 1⅝ ins. thick; bands, ½ in. diameter; built in trench and buried 2 ft. deep; average haul, 4 to 5 miles; cost, $2,556, or $2.61 per foot, including everything except engineering and administration.

Forty-four Inch.—At Wenatchee, Wash., 1902–3; 9,000 ft.; 44 ins. diameter; maximum head, 235 ft.; bands, ½ in. diameter; fir staves, 1⅝ ins. thick; laid in trench, and on bridge across Wenatchee River; contract price for pipe, $2.20 per linear foot. Excavating and backfilling not included.

At Palisades, Colo., 1909–10; three fir pipes, 44 ins. diameter; 2,850 ft.; 1,055 and 1,150 ft. in length; cost by contract, $3.15, $3.25, and $2.90 per linear foot, respectively. No earthwork included.

Forty-eight Inch.—At Palisades (orchard mesa), Colo., 1909–10; for six pipes 48 ins. in diameter and varying lengths and heads, the unit prices ranged from $2.40 per foot up to $4.75 per foot, the average of the six being $3.52; material, fir.

At Deer Park, Wash. (about 1909), 94,000 ft. of fir pipe; head, 0 to 70 ft., built in trench; contract price, $2.35 per foot, includes delivery of all material at railroad point and erection of pipe, but no haul or earthwork.

Forty-eight Inch.—At Clarkston, Wash., 1906; fir staves, 1⅝ ins. thick, ½-in. bands; built in trench by force account, for light head; cost, $2.25 per foot, no earthwork included. Foreman received $3.50 per day and other men $2.50 for 10 hours.

Fifty-eight Inch.—At Pueblo, Colo., 1907; 2,277.5 ft.; cost by contract, $6.14 per foot, no earthwork included.

Sixty Inch.—At Pueblo, Colo., 1907; on 17 fir pipes the unit price per foot ranged from $4.19 to $6.58, averaging $5.51. The combined length of 17 pipes equals 19,821.5 feet, making the average price per foot on this basis equal $6.27; earthwork not included.

Sixty Inch.—At Nissa, Ore., 1912; 6,700 ft.; average head about 65 ft.; bands, ⅝ in. diameter; staves, fir, 2 × 6 ins.; built on wooden cradles; contract price, $4.25 per foot, included material, erecting, and freight, but no haul or earthwork.

Comparative Annual Cost of Wooden Flumes and Pipes.—Prof. B. A. Etcheverry gives the following in a report to the Dept. of Agriculture, Province of British Columbia, abstracted in Engineering and Contracting, Sept. 4, 1912.

For ordinary conditions it is roughly estimated that a wooden flume system will cost one-half as much as a wooden pipe system. For very rough land requiring a great deal of fluming on high trestles, the comparison in cost would not be so favorable to wooden flume. As far as durability is concerned, the life of a well constructed wooden flume should be between 8 and 12 years. The life of a wooden pipe which is full only part of the time is problematical; it depends somewhat on the kind of wood and on the soil in which it is placed. In Idaho 4 × 4 in. wooden posts used for lot corners, made of the best fir and painted, have been almost completely destroyed in one year. There are a number of instances where wooden pipes have gone to pieces in 4 or 5 years or even less. However, if the pipe is made of good selected material, free from sap wood, the life should be from 10 to 15 years for a wooden pipe empty part of the year. The life of wooden pipe which is kept constantly full and buried to such depth as to prevent freezing would be considerably greater, probably 20 to 30 years, provided the soil in which it is buried does not contain injurious salts. Were it not necessary to prevent the water in the pipe from freezing, it is my opinion that the life of a wooden pipe kept constantly full and under sufficient head for the wood to be saturated would be increased if it was laid above ground not in contact with the soil.

As far as the cost of maintenance is concerned, a wooden flume system requires frequent repairs, tarring and calking, the cost of which would be greater than the maintenance of a pipe system.

It is impossible to represent numerically the above statements with any degree of accuracy because of the varying conditions. Roughly, they may be represented as follows:

Annual Cost of Wooden Flumes and Wooden Pipes Given in Per Cent of First Cost

	Per cent
For wooden flumes, life 8 to 12 years:	
Annual maintenance and repairs distributed over entire life	5
Sinking fund for renewals	9
Interested on capital invested	6
Total	20
For wooden pipes empty part of the time, life 10 to 15 years:	
Maintenance and repairs	2
Sinking fund for renewals	7
Interest on capital invested	6
Total	15
For wooden pipes always full, life 20 to 30 years:	
Maintenance and repairs	1
Sinking fund for renewal	4
Interest on capital invested	6
Total	11

These figures show that the annual cost which must be provided for to maintain and renew a system and pay interest on capital invested is 20 per cent for a wooden flume system, 15 per cent for a pipe system, in use part of the time and 11 per cent for a pipe system always full. These costs are in the ratio of 1.8, 1.3 and 1. Therefore a flume system is more economical than a wooden pipe system, which can be kept full of water only part of the time, when the cost of the wooden pipe system would be in excess of 1.3 times the cost of the flume system. Also the flume system is more economical when the cost of a wooden pipe system which can be kept full of water all the time is 1.8 times the cost of the flume system. As stated above, a wooden pipe system under average conditions will cost about twice as much as a wooden flume system; therefore, if the above cost alone is considered, a wooden flume system is more economical. But there are other relative advantages and disadvantages which should be considered.

The third type of system—that is, the wooden pipe system which can be kept full all the year around without freezing—has the advantage that it can be used for domestic supply. The other two types require a separate domestic system if domestic water is desired. But it is not always possible to combine the two, for often the source of supply from which the irrigation water is obtained may be frozen in the winter or it may be so polluted that it is not safe drinking water and if it must be filtered or treated to purify it, it would be very poor economy to have to purify the irrigation water as well as the domestic water which are carried in the same pipe. If these conditions exist a separate domestic system is preferable.

The Cost of a High Flume Trestle in Idaho.—A. M. Korsmo gives the following in Engineering Record, April 5, 1913.

The flume is a part of the Cottonwood Feeder Canal on the Twin Falls-Oakley irrigation project at Oakley, Idaho. The trestle forms the substruc-

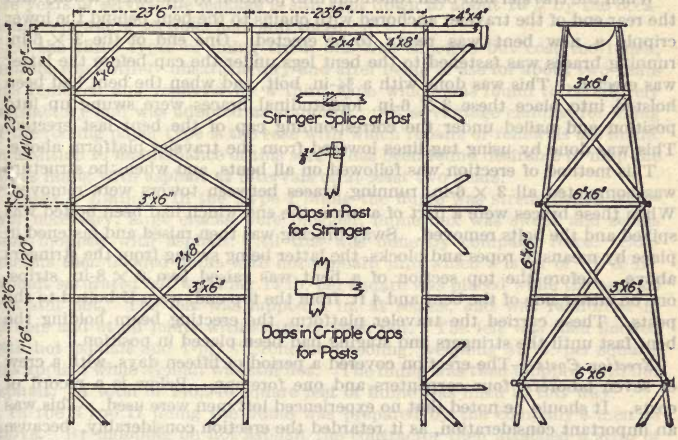


FIG. 11.—Framing details of timber trestle in Idaho.

ture for a corrugated-steel Lennon flume across a deep gulch. The material used in its construction was No. 1 common, rough Oregon fir lumber, which, considering its grade, was of good quality and fully dimensioned. In designing the trestle a batter of 3 in 24 was used on the bent posts, this being considered sufficient on account of the sheltered location of the structure. The gulch is a very winding one and high winds never occur.

Structural Details.—The structure consists of a series of timber bents 23 ft. 6 in. in centers, every pair of bents forming a tower. All posts rest on concrete piers 1 ft. square on top, 18 in. high and built with a batter of 1 to 2. Iron straps, anchored in the pedestals, are fastened to the posts to prevent sliding or overturning.

The trestle is 564 ft. long and has a maximum height of 96 ft. With the bents spaced 23 ft. 6 in. on centers it was considered impracticable to erect one deck at a time on account of the great amount of falsework and staging that would be required by this method. A cantilever erecting beam was then built with the idea of erecting the structure from one end and completing each bent as the work advanced. The framing of the trestle is shown in Fig. 11.

Erection Methods.—The north side of the gulch has a flat slope, the first four bents having no cripples; the erection was begun at that end. All cutting and framing was done below, in the bottom of the gulch, and "snaked up" to place by mule power, where it was assembled and erected.

All the falsework required was a platform 4 ft. below the stringers, running back two bents from the one last erected. It was used to set the traveler on and as a scaffold from which the stringers and kneebraces were placed in position. As the traveler advanced the falsework on the finished section was torn up, the 4 × 4-in. carriers of the flume were placed in position on the stringers and the running planks laid on the carriers.

When the traveler had been rolled out into position by the aid of a dolly and the rear end of the traveler anchored with chains to the bent behind the lower cripple a new bent was ready to be erected. One end of the 3 × 6-in. running braces was fastened to the bent legs under the cap before the latter was erected. This was done with a ⅝-in. bolt, and when the bent had been hoisted into place these 3 × 6-in. longitudinal braces were swung up into position and nailed under the corresponding cap of the bent last erected. This was done by using tag lines lowered from the traveler platform above.

This method of erection was followed on all bents, and when the structure was completed all 3 × 6-in. running braces between towers were removed. When these braces were a part of a tower the end which had been bolted was spiked and the bolts removed. Sway bracing was then raised and fastened in place by means of ropes and blocks, the latter being swung from the stringers above. Before the top section of a bent was raised two 2 × 8-in. strips, one on either side of the bent and 4 ft. from the top end, were U-bolted to the posts. These carried the traveler platform, the erecting beam holding the bent fast until the stringers and staging had been placed in position.

Erection Costs.—The erection covered a period of fifteen days, with a crew of seven laborers, four carpenters and one foreman. Below is a record of costs. It should be noted that no experienced loft men were used. This was an important consideration, as it retarded the erection considerably, because the men were unaccustomed to work high in the air. With an experienced crew the erection would have cost at least $1.75 less per 1000 ft. board measure, this estimate being based on the subsequent erection of another, somewhat smaller, trestle by the same crew that built the high one.

SUMMARY OF COSTS

Total Lumber Used Equals 27.9 *M. Ft. B.M.*

Laborers	775 hours at 25 cents	$193.75
Carpenters	649 hours at 35 cents	227.15
Foremen	148 hours at 45 cents	66.60
Mule	150 hours at 10 cents	15.00
Total		$502.50

Average, $18.00 per 1000 ft., board measure.

Cost of Repairing Leaky Wooden Flume with Roofing Paper Lining.—Engineering News-Record, Jan. 15, 1920, gives the following:

A wooden flume that has now supplied a Southern California irrigation district for over 30 years began to leak badly a few years ago. The leakage increased despite remedial measures, until about 50% of the flow was escaping. The water company was losing revenue and there was danger of crop loss through water shortage, so immediate relief was necessary. On account of the high cost of permanent flume construction and the improbability of earning a return on investment of that sort, effort was made to find some cheap and effective means of reducing leakage in the old flume. Various expedients had been tried before this time. Sections of the flume box had been caulked and battened, or coated with hot asphalt, a layer of burlap applied, and a second coat of asphalt put on over the burlap. None of these expedients, however, reduced the leakage materially.

It was finally decided to try lining the flume with prepared roofing paper. Three methods were worked out and careful records of each were kept. The more effective of these reduced the leakage from 50% to about 3%. After five years of service the leakage is still kept down to about 10% by the occasional renewal of sections here and there.

Of the three types of lining tried, one was effective but cost too much, another was entirely unsatisfactory and after being in use for about two years was removed and replaced by a third type which was found to be entirely satisfactory and was adopted as standard. An advantage claimed for lining of the roofing paper type is the ease with which repairs or renewals are made. In addition to maintenance of this sort it has been found desirable to mop the entire lining with asphalt at intervals of at least two years.

Types of Lining.—In the Type I lining the flume was strengthened wherever necessary, large cracks were plugged, flume box was swept and seams were mopped with asphalt. All this was done by company force. Contractors then flooded flume with hot asphalt, into which a layer of "P & B" asphalt saturated felt weighing 11 lb. per square was placed while the asphalt was still hot. The felt was lapped 3 in. at seams, and was reinforced in corners and at all joints with strips of Irish felt. The felt was then flooded with hot asphalt and 1-ply "Cronolite" roofing, weighing 37 lb. per square, was applied while asphalt was still hot. The lining was then mopped with hot asphalt. A total of 140,940 square feet of flume was lined in this way.

In the Type II lining the flume was prepared by the company's men as above. By mopping on hot asphalt the contractor then attached a strip of water proof felt to the flume box where the roofing paper joints would come. After mopping this felt strip one edge of the roofing sheet was nailed down to it and when the sheet had in turn been mopped the edge of the overlapping sheet was placed and nailed every two inches. Finally, the joint was mopped over the nail heads. The upper edge of the roofing on the sides of the flume was nailed without mopping. Two-ply Trino ready roofing was used in this type on 189,560 sq. ft. of flume. At least 35 lb. of asphalt per square was found to be desirable with this type.

In Type III the flume was prepared for lining by the company's men as already described. The contractor coated both flume and lining with hot asphalt and applied the lining while the asphalt was still hot, thus forming a tight bond between lining and flume box. Laps in the lining at joints were nailed with large flat-headed, roofing nails. A total of 1,051,402 sq. ft. of flume was lined in this way, using 2-ply Flaxine and Argonaut prepared roofing.

Costs.—The cost of preparing the flume for lining, hauling materials, supervision, etc., was $7,838.62, or $0.57 per square. This charge was made against all types of lining. California asphalt was used throughout. The costs were as follows:

TYPE I

Preparing flume, etc., 1,409.4 squares at $0.57	$ 799.67
Lining by contract, 1,409.4 squares at $3.43	4,831.30
1,409.4 squares at $4	$ 5,630.97

TYPE II

Preparing flume, etc., 1,895.6 squares at $0.57	$ 1,075.49
Lining by contract, 1,895.6 squares at $2.47	4,678.07
1,895.6 squares at $3.04	$ 5,763.56

TYPE III

Preparing flume, etc., 10,514 squares at $0.57	$ 5,963.46
Lining by contract, 10,514 squares at $2.43	25,541.44
10,514 squares at $3	$31,504.90
Total: 13,819 squares at $3.10	$42,889.43

Comparison of Wood and Concrete for Use in Irrigation Structures.—The following discussion is given by S. T. Harding, Assistant Professor of Irrigation, University of California, in Engineering and Contracting, April 12, 1916.

The relative economy of wood and concrete structures for use on irrigation systems is a question subject to much debate among irrigation engineers. The following comparisons were made to determine, first, the amount of wood in feet board measure which is the equivalent of one cubic yard of concrete in different types of structures and, secondly, to compare the relative cost for certain assumed conditions. The cost and conditions of use of these two materials will vary so widely in different portions of the West that the choice in any particular case will have to be based on a consideration of these local factors.

The comparisons which are made refer to the types of structures used on distribution systems. The choice of the material to be used in important single structures is often fixed by a consideration of other factors than the relative cost of the material used. The difficulties of replacement and damage from failure generally make the use of the more permanent forms of construction desirable for diversion dams and headgates.

The comparison of wood and concrete for the usual irrigation structures also involves more than considerations of first cost and the life of the structure. In new projects the location of parts of the distribution system, particularly sub-laterals, may need modification or change which involves less loss with the cheaper wooden structures. Also, a wooden structure has some salvage value; a concrete structure if removed is generally a total loss. Experience in operation or general advance in irrigation engineering may enable structures to be designed which may be more suitable than those first used. The methods of applying water to the lands may be modified. The present tendency is toward methods which permit of the handling of larger streams of water on the individual farm. This may require changes in the sub-lateral systems such as larger delivery turnouts and checks.

The financial conditions of the constructing company may be such that the initial expenses must be kept at a mimimum until the project is placed on an operation basis. The interest rate at which funds can be secured in the earlier stages of a project is often much higher than those obtainable later, so that the cheaper wooden structures may be more economical for first construction, to be replaced by concrete. It may be economical where the period of development expected is longer, than the life of the wood structures to construct the canals and structures of only sufficient capacity for this early period and to enlarge the canal at the time of replacement. Concrete structures in the original construction would need to be built to full capacity and thus increase the amount of non-productive investment. This applies to structures in main canals and laterals, such as checks and flumes, more than to individual division or turnout structures.

When originally constructed, the canals may be in undeveloped sections without adequate transportation facilities. Following settlement, this may be overcome so that the relative prices of the two materials may be much different at the time the original wood structures must be replaced. The prices of the two materials has tended to change, wood increasing and cement decreasing, so that concrete may be able to compete with wood in replacements where it would not have been able to do so for the original construction.

These various considerations will fix the choice between these two materials for original construction more often than a strict computation of ultimate economy. After a project has been in operation sufficiently long to establish itself as a going concern, the replacements as needed can be planned with greater attention to the relative cost and service of the two types. This tendency is evident in practice, as on many systems side hill bench flumes have been replaced with retaining wall lined sections, wooden drops with concrete, etc. The comparisons here given will have a larger application in such betterment work than in original construction.

Ratio of Cost of Concrete and Wood in Structures to Total Cost of Structure.—The unit of cost for wood structures generally used is the 1,000 ft. board measure or M.B.M.; that for concrete the cubic yard. These materials form only a part of the total structure, in both cases excavation, backfill, miscellaneous parts such as gates, footwalks, and footings for flumes are required. The proportion of the total cost, which consists either of the wood or concrete, was determined for many structures for which costs were available from various sources. The proportions vary rather widely with different conditions, but the following generalizations, Table XX, were made. The percentages given are for the cost of concrete and wood in place.

TABLE XX.—COST OF CONCRETE AND WOOD IN IRRIGATION STRUCTURES EXPRESSED AS A PERCENTAGE OF THE TOTAL COST OF THE STRUCTURE

Type of structure	Conc. structures: Usual max.	Conc. structures: Usual min.	Conc. structures: Mean	Wood structures: Usual max.	Wood structures: Usual min.	Wood structures: Mean
Turnouts	75	50	65	65	40	50
Checks	85	60	75	75	50	60
Drops	90	60	80	75	50	65
Box culverts	95	60	80	70	50	60
Wood flumes	..	..	..	95	75	85
Buried concrete pipe siphons	85	65	75	..	..	..

Number of Cubic Yards of Concrete Which are Equivalent to 1,000 *Ft. Board Measure.*—Comparisons of the amount of concrete or wood required were made for individual structures. Drawings of either wood or concrete structures were used and the amount of material for an equivalent structure of the other type computed. From these comparisons the number of cubic yards of concrete which were equivalent to one M.B.M. of wood were obtained. The resulting general figures are given in Table XXI.

TABLE XXI.—NUMBER OF CUBIC YARDS OF CONCRETE WHICH ARE EQUIVALENT TO 1,000 FT. B.M., OF WOOD

Kind of structure	Number of comparisons.	Usual min.	Usual max.	Mean
Turnouts	29	9.0	4.5	6.6
Checks	12	8.0	5.5	6.4
Drops	13	7.5	4.5	6.0
Box culverts	23	10.0	5.0	7.6
Flumes	13	5.5	3.5	4.2
Bridge floors up to 20-ft. span	20	7.0	4.0	5.2

As shown in the table, the ratio varies widely. This is largely due to differences in design on different systems. Wood structures are better standardized than concrete, the commercial thicknesses of lumber are used, such as 2-in. plank for the smaller structures and 3-in. plank for the larger ones or those difficult to replace, such as culvert barrels. With concrete, the required thickness of such parts as headwalls for small structures cannot be definitely computed and practice varies with the policy of different forms of organization and climatic conditions. Examples were found of similar structures having over 100 per cent variation in the thickness of similar parts; the inlet floors to turnouts of similar size varied from 4 in. of plain concrete to 8 in. cross reinforced. In the comparisons it was attempted to use wood structures of equivalent heaviness of design to the concrete structure for which the comparison was being made.

If comparisons are made for straight wall construction, such as would be used in small head walls, the ratios in Table XXII will be obtained.

TABLE XXII

Thickness of concrete wall inches	Number of cubic yards of concrete which are equivalent to 1,000 ft. B.M. of wood in straight walls: For 2-in. plank with 4 × 4-in. posts spaced 4 ft.	For 3-in. lumber with 6 × 6-in. posts spaced 3 ft.
3	4.0	2.3
4	5.3	3.1
6	8.0	4.6
8	10.6	6.2
10	13.2	7.7

Three-inch concrete walls have been used in some small structures with separately cast slabs. Four-inch walls have been used in favorable climates, particularly for those parts where forms were not required. A thickness of 6 in. represents the usual minimum where forms are used, especially when reinforcing is needed. Eight and ten-inch walls are used in lalrger structures where more than average strength is required or where generaly heavy types of structures are adopted.

The structures included under turnouts include both lateral headgates and farm turnouts. The ratios for these, as well as for checks and drops, are less variable than for such structures as culverts. In these structures the thickness of the concrete is more often fixed by construction conditions than by any determinate stresses, and the design is as largely the result of experience as of theory. With culverts a wide variation in practice was found; the average ratio was higher than for any other type of structure. This is due most largely to the use of realtive heavy barrels in concrete culverts. Such barrels require forms and the use of thin walls under favorable conditions is prevented where box culverts are used by construction conditions. Separate comparison of the inlets and outlets gave ratios for these similar to those for turnouts, checks and drops; for the barrels of box culverts the ratio averaged about 8.5. Pipe culverts in which the barrel is made of various types of pipe were not included in these comparisons.

The ratios are smallest in those types of structures where the concrete can be designed to withstand definite stresses of compression or as beams. This occurs in bridge floors and in flumes. Concrete flumes have been actually used to only a small extent as yet, due mainly to the difficulties in constructing the trestle members. Standard designs have been prepared for various sizes of flumes of both concrete and wood by the U. S. Reclamation Service, and equivalent sizes of these were compared for both the flume box and for bents 10 ft. high. The average ratio for the flume box was about 4.5 and for the bents 4.0. The cost per cubic yard of concrete in concrete flumes is greater than for other types of structures, and this excess cost may more than balance the smaller amount required.

The standard designs of slab and T-beam highway bridges of the U. S. Bureau of Public Roads were compared with standard designs of wood stringer bridges for the floors only for spans of from 8 to 20 ft. The average ratio for the slab bridges was 6.7, varying from about 5.0 for 8-ft. spans to 7.5 for 16-ft. spans. For T-beam forms of concrete bridges, the ratio varied from 4.3 for 10-ft. spans. to 3. 7 for 20-ft. spans.

The more usual comparison between wood and concrete which will be made in irrigation practice is for the more numerous turnouts, checks, drops and culverts. For flumes the comparison is more often between the wooden flume and other forms of construction, such as siphons or steel flumes. With bridges the choice is often determined by the fact that in many western States the county maintains the bridges after their original construction by the canal company. For the more typical irrigation structures, a ratio of about 6.5 cu. yd. of concrete to 1,000 ft. B. M. can be taken as an average with variations of from about 4.5 to 9.0 under different conditions, methods and policies.

Relative Cost of Wood and Concrete.—The choice between wood and concrete construction depends on the relative total cost. The ratio of the amount of concrete equivalent to 1,000 ft. board measure has been discussed. The relative unit cost also needs to be known, in order to make complete comparisons.

The unit cost of both concrete and wood in irrigation construction varies very widely. This applies both to the material cost and the cost of construction. The price of cement on the work is usually much higher than in the East. Aggregate may be expensive to secure and the haul to scattered structures is usually a considerable item. Also, even water for mixing, particularly on first construction, may have to be hauled considerable distances. Under such conditions the cost per cubic yard of concrete is naturally very variable. Under favorable conditions costs of $10 per cubic yard may be secured. This represents about the minimum for the usual small scattered structures; for larger single structures or linings the cost may be less. Under unfavorable conditions of material, or for thin walls requiring forms, the cost may be as high as $20 or $25 per cubic yard. About $12 to $16 per cubic yard may be taken for such structures, although where the costs vary so widely average costs should be used with caution.

The unit cost of wood in place also varies widely. The material price depends on the nearness to the source of supply and the wagon haul required.

The labor cost of construction varies with the type of structure. For small scattered special structures or for high flumes, it may be as high as $20 per 1,000 ft. B. M.; for standard structures of which large numbers are used, such as individual turnouts where the framing can be done at central points, the cost may be as low as $6 per M. B. M. For usual conditions for structures except high flumes, the labor cost will generally be about $10 or $12 per M. B. M. The material cost varies equally widely. In localities near the sources of supply suitable lumber may be obtained for as low as $15 per M. B. M.; in others it may be as high as $30, averaging perhaps about $20. This gives a cost in place of from as low as about $20 to as high as $50 with an average of $30 to $40. These averages, as in the case of average costs of concrete, have a limited application. They give a ratio of average cost of 1,000 ft. B. M. to that of 1 cu. yd. of concrete of about 2½ to 1. If the average ratio of the quantities required is taken as 6.5 to 1 and cost as 1 to 2½, the ratio of the total cost of the lumber or concrete part of the structure will be 2.6 to 1. The cost of the other parts of structures as previously given is for concrete structures about 25 per cent of the total cost, or one-third of the cost of the concrete, and for wood structures 40 per cent of the total cost, or two-thirds of the cost of the wood in the structure. On this basis the average total cost of concrete structures will be about 100 per cent greater than that of similar wood structures. Where the price of lumber is high and the conditions for concrete are favorable, a condition more often found in parts of California the cost of concrete structures may not be more than 50 per cent greater, and in some particular cases no greater, than equivalent wood structures. In the higher altitudes where lumber is often relatively low in price and the cost of concrete often relatively high, the concrete structures may cost 200 per cent or more in excess of the cost of wood structures.

Maintenance and Depreciation.—Few definite data on the actual cost of manitenance of structures is available. Such costs would be difficult to obtain for smaller structures. In some systems operation and maintenance costs are not kept separate; in others all maintenance is carried in a single account. The life of wood structures has been observed under different conditions. The cost of maintenance is small for the first portion of the life of wood structures and increases in amount until replacement is warranted. The total cost of maintenance during the life of such structures may approach the first cost of the structure. With concrete structures the cost of maintenance should be small. Such maintenance is more often required for the auxiliary parts of structures, such as protection to the adjacent canal and repairs, due to accidents rather than to gradual depreciation. It should be fairly uniform from year to year.

The total life of structures varies with the type and the conditions of use. Concrete has not been in use sufficiently long to give data on its life. There is always a certain probability of failure through injury, such as undercutting, removal due to enlargement of the systems, or replacement with a different type of design.

The life of wood structures depends on the character of their construction and conditions of use. Generally structures set in earth, such as drops and checks, have a shorter life than the boxes of flumes set on well built trestles. Where the operation season is long, so that structures are kept wet practically throughout the year, there may be little difference. Records of wood structures under various conditions indicate that ordinary turnouts, drops and checks can be expected to have a useful life of 6 to 10 years for pine, 8 to 12 years for fir, and 10 to 20 years for redwood. Under favorable conditions redwood structures have considerably exceeded the figures given. For well built trestle flumes, the useful life can be expected to be 8 to 14 years for pine, 10 to 16 years for fir, and 12 to 20 years for redwood. Wood pipe under conditions to which it is suited should have a useful life exceeding these figures.

The cost of replacing structures is usually greater than their first cost. This is due to the fact that the excavation will be more largely hand work and to the cost of tearing out the old structure.

The salvage value of concrete structures is usually negligible; the lumber removed from old structures may have some value for use in forms, etc., being usually greater for flumes than for structures set in the ground.

Comparison of Cost of Wood and Concrete Structures on Investment Basis.— On the basis of the average figures previously developed, comparisons of the cost of wood and concrete structures can be made. This has been limited to drops, checks, turnouts and culverts, as these are the structures occurring in greatest number on irrigation systems and whose design and construction can be most closely organized. A comparison of such structures as high flumes will involve so many local and special considerations that a general comparison would be of little value.

The capitalized cost can be taken as the basis of comparison. Table XXIII has been worked out to show the ratio of first cost at which the capitalized cost will be equal for different conditions.

Interest rates of 6 and 8 per cent were used. Irrigation district bonds generally bear 6 per cent; the terms of sale, however, more often make the rate on the price received 8 per cent or higher. Western mortgage rates vary from 6 to 8 or even 10 per cent; this represents the value of money to stockholders in mutual companies or on systems where improvements are paid for by stock assessments.

Different lengths of life for the structures were assumed. The annual maintenance cost is estimated as a percentage of the first cost, a higher rate being used where the life of the wood structure was relatively short. Maintenance on the concrete was taken as zero. Salvage value was neglected; its amount would probably be less than the error involved in some of the other assumptions.

TABLE XXIII. — RATIO OF TOTAL FIRST COST OF CONCRETE AND WOOD STRUCTURES AT WHICH THE CAPITALIZED COST OF SERVICE BECOMES EQUAL.

Interest rate per cent	Assumed life of concrete structures in years	Assumed life of wood structures in years	Assumed annual cost maintenance in per cent of first cost: Conc.	Wood	Ratio of total first cost of concrete structures to total first cost of wood structures at which capitalized cost becomes equal
6	30	10	0	5	2.6 to 1
6	45	15	0	4	2.2 to 1
6	20	10	0	5	2.1 to 1
6	40	20	0	3	1.8 to 1
6	15	15	0	4	1.4 to 1
8	30	10	0	5	2.25 to 1
8	45	15	0	4	1.9 to 1
8	20	10	0	5	1.95 to 1
8	40	20	0	3	1.6 to 1
8	15	15	0	4	1.3 to 1

Table XXIII shows the ratios of first cost at which the capitalized cost of service becomes equal for these assumed conditions. For useful lives of 30 and 10 years for concrete and wood and interest at 6 per cent and annual maintenance on the wood structure of 5 per cent, a concrete structure costing 2.6 times as much as the wooden one would be equal in capitalized cost. The ratios are higher for the lower rates of interest.

Ratio of Cost of Structures to Total Cost of Canal System.—In comparing the relative economy of different types of structures, the proportion of the total cost of the canal systems which consists of structures must be known, in order that the proportion in which the total construction cost will be increased by different types of structures may be estimated. In some of the Annual Reports of the U. S. Reclamation Service, the total cost of structures and excavation is stated separately for some of the projects. From these and other records Table XXIV was derived.

TABLE XXIV.—USUAL COST OF STRUCTURES ON CANAL SYSTEMS EXPRESSED AS PER CENT OF THE TOTAL COST

	Main canals	Laterals	Whole project
Regular topography:			
Concrete structures	10–20	25–40	20–35
Wood structures	8–15	15–35	10–25
Irregular or steep topography:			
Concrete structures	20–35	40–50	35–45
Wood structures	15–25	25–40	20–35

The use of concrete structures costing twice as much as wood will increase the total cost of the canal system by from 15 to 30 per cent under usual conditions. This applies to the canal system structures only and not to diversion dams or to such conditions as side hill locations requiring bench flumes or lined canals.

Conclusions.—The preceding discussion of the factors involved in a choice between concrete and wood for irrigation structures, both for the factors for numerical limits have been given and also for those not capable of numerical expression but which are of equal or greater importance, makes it evident that no general conclusions can be drawn as to the most economical type of construction. For any particular project where the construction costs can be estimated and the other factors, such as financial conditions of the constructing organization, rate of interest, certainty as to type of structure desired and permanence of its location can be given proper weight, a decision can be made. Under usual conditions concrete will be the preferable material if the capitalized cost of service alone is considered. The other factors are, however, more usually such as to incline the choice toward wood for first construction, except for the larger and more important structures. That the capitalized cost is being given more consideration and that many systems are reaching a condition where replacements and betterments can be made on a more permanent basis is evidenced by the increasing use of concrete in irrigation structures.

Life of Irrigation Structures.—The following notes are taken from Harding's "Operation and Maintenance of Irrigation Systems."

Life of Wood Flumes.—The life of wood flumes depends on the kind of material used, conditions of use and character of construction. As these conditions vary on different systems, the life of wood flumes as reported by different users varies widely. A rigidly built flume having little leakage will outlast one less strongly built. Poor footings which settle and cause leakage will shorten the life of a flume. The thickness of the flume lining also affects length of service. Various protective coatings or even relining the flume box are used to increase the life.

The period of serviceable life which can be expected from flumes for usual conditions will not exceed 20 years for redwood or cedar, 12 to 15 years for fir, and 8 to 10 years for pine. These figures apply to the portions of the flume not in contact with the ground and are as long a life as can be expected under general favorable conditions. Some flumes have been used for periods longer than those given, but the annual cost of repairs in the later years of use or the uncertainty of service will generally make such use undesirable. The life of small flumes is generally less than that of large ones due to the less continuous use of many flumes on sublaterals. Flumes used intermittently on farms will have a shorter life than on laterals operated continuously. Bench flumes or flumes set in contact with or near the ground usually have a shorter life than well-built higher flumes. For unfavorable conditions the life of flumes may not be over one-half that given. Some redwood flumes have been in use for 25 years in California, the relatively long operation season and rains during the remainder of the year keeping them continuously moist. Others have been replaced after fifteen years, the chief difficulty being with the rotting of the butt joints at the end of the lining plank and of the yokes behind them. Well-constructed fir flumes on the Hedge canal in Montana having 3-inch T & G siding were replaced in 12 to 14 years. Small pine flumes have not lasted over 4 or 5 years in some cases.

Life of Wood-stave Pipe.—The life of wood-stave pipe varies more widely than that of wood flumes as it is more dependent upon the conditions of service. Under favorable conditions, the life of wood pipe should exceed that of

Table XXV.—Life of Wood-stave Pipe

Kind of wood	Condition of use	Average life in years
Fir	Uncoated, buried in tight soil	20
Fir	Uncoated, buried in loose soil	4 to 7
Fir	Uncoated in air	12 to 20
Redwood	Uncoated, buried in tight soil, loam or sand and gravel	over 25
Fir	Well-coated, buried in tight soil	25
Fir	Well-coated, buried in loose soil	15 to 20

flumes; under unfavorable conditions, it may be quite short. Wood used in pipes comes into more direct comparison with other materials than does wood used in flumes and the results with its use have been more closely observed. Table XXV prepared by Mr. D. C. Henny and printed in the Reclamation Record of August, 1915, summarizes the data collected from a large number of installations.

The following general conclusions were also given:

"(*a*) Under favorable conditions of complete saturation, fir well-coated may have the same life as redwood uncoated.

"(*b*) Either kind of pipe will have a longer life if well-buried in tight soil than if exposed to the atmosphere. Such life may be very long, 30 years or over, if a high steady pressure is maintained.

"(*c*) Either kind of pipe will have a longer life if exposed to the atmosphere than if buried in open soil, such as sand and gravel and volcanic ash, provided in a hot and dry climate it be shaded from the sun.

"(*d*) Under questionable conditions, such as light pressure or partially filled pipe, fir even if well-coated may have only one-third to one-half the life of redwood.

"(*e*) Under light pressure the use of bastard staves should be avoided.

"(*f*) The use of wooden sleeves in connection with wire-wound pipe is objectionable and has caused endless trouble and expense.

"(*g*) If wooden sleeves are employed they should be provided, at least for sizes from 10 inches up, with individual bands to permit taking up leaks."

These results indicate the importance of the character of the backfill. If porous soils into which air penetrates easily are used, the benefits of covering are lost, with the added disadvantage that inspection cannot be readily made. A covering of heavy soil, 3 to 4 feet in depth, which maintains more constant moisture conditions and excludes air, gives the best results. The pipe should be kept full of water if a long life is to be secured. The upper portions of siphons, which may be only partly filled, have been found to have a shorter life than the parts under greater pressure. The water, when under pressure, maintains a more uniform condition in the staves, a condition also more easily secured if the thickness of the staves is no greater than required for strength. Cuts from the butts of trees, being denser, are considered to have longer life than top cuts. The life of the pipe is usually determined by the life of the staves. Certain chemical conditions in the soil, such as the presence of some alkalis or of acids from decaying vegetation may result in a shorter life for the bands than for the staves. For such locations it is preferable to place the pipe above ground and free from such action.

Wood pipe is often coated, particularly the smaller machine-banded pipe. The coating on these is applied by running the pipe through a bath of warm asphaltum pitch. The pipe is then rolled in sawdust to preserve the outside coating and make handling easier. On large pipes an application of gas tar followed by one or more coats of refined coal tar, is often used. A mixture of asphaltum and tar has also been used. These are applied to the finished pipe before it is put under pressure. It is difficult to secure adherence to wet wood, particularly with oil paints. In general it appears that the use of a coating is preferable for buried pipe in dry porous soil and possibly on all buried pipes, although the added benefit may be small for pipe buried in heavy moist soils free from vegetable matter. Above ground the value of the coating is more uncertain. For the protection of the bands on exposed pipes paints similar to those used on structural steel may be used.

Life of Wood Structures.—The conditions of use for the usual wood structures are not as favorable as for wood flumes or pipes. Parts of the structure may be continuously wet, parts alternately wet and dry and parts continuously dry. The cutoff walls and other substructure may outlast one or more renewals of the superstructure. Heavy well-built structures will have longer life than light ones due to the longer time required to cause the complete decay of the thicker material as well as to the greater resistance to injury offered by the stronger structures.

Under favorable conditions irrigation structures built of redwood or cedar may have a useful life of as high as 20 years; for aveage conditions the average life is about 12 years and in some cases as low as 8 years. It is longest in the larger and heavier structures such as have been used on some of the earlier systems in California. Some of these have actually been in use for over 25 years. It is shortest in regions of high temperature where the wood is both damp and heated at depths of from 1 to 2½ feet below the surface. At lower depths the heat is not sufficient to make decay as rapid; nearer the surface the structure is dryer. Small redwood structures have required replacement after 5 years in such locations. Structures built of fir have a life varying from a usual maximum of 15 years to a usual minimum of 6 years with an expected life under usual conditions of 8 to 10 years. Where pine is used, structures will not generally last over 10 years and may not last over 5 years; under usual conditions a life of 6 to 8 years is to be expected. Structures will usually have a longer life in heavy soils than in those in which the air has greater access such as sands or gravels.

Life of Concrete Structures.—Considered as a material, concrete is practically permanent. There has been some injury from the action of certain forms of alkali but the injuries to concrete structures are much more generally those due to undercutting or other accidents in use rather than to any disintegration of failure of the material similar to the failure of wood structures due to decay. Concrete has not been in use in irrigation sufficiently long to secure data on its rate of depreciation. Depreciation estimates which have been used in valuations have been based on estimated obsolescence or mechanical injury rather than on actual deterioration of the structure. In a few instances resurfacing has been required; such cases have generally been due to lack of care in the original construction rather than to actual abrasion. Structures, such as linings or retaining walls, may fail due to excess pressure behind them; such failures are not due to the material of the structure itself but to faults in drainage or design. Winter operation may cause injury in the opening of frozen gates or in the breaking of side walls.

The examples of injury from the action of alkali while scattered have in some cases been important. There is still need for further knowledge as to the details of such action and the methods of its prevention. Injury is caused by the seepage into the concrete of alkali water, the sulphates, particularly magnesium and sodium sulphate, being the most harmful. With some salts no harmful action may occur. The best remedy is prevention which can be secured most practically by using a dense well-mixed and faced concrete which reduces the absorption of the alkali water to a minimum. The conclusions of the U. S. Bureau of Standards based on the observations of the first year's tests with concrete drain tile exposed to alkali in a number of localities are that tile not leaner than a 1 to 3 mixture are apparently unaffected structurally when exposed for 1 year in operating drains in very concentrated alkali soils. Leaner mixtures are not generally recommended although in some cases tile of 1 to 4 mixture were not affected at the end of 1 year.

To overcome or reduce the effect of low temperatures on concrete, the surfaces have been treated with waterproofing solutions on the Strawberry valley project. This was applied to structures on which surface disintegration had already begun. Vertical surfaces were treated with alum and soap solution and horizontal surfaces with paraffine. The surfaces were thoroughly dried and cleaned before treatment. The alum solution consisted of 2 ounces of alum to 1 gallon of hot water. The soap solution consisted of ¾ pound of castile soap dissolved in 1 gallon of hot water. The alum solution was applied at a temperature of 100°F. and worked in with brushes, the soap solution being similarly applied while the surface was still moist. In some cases additional coats were given. One gallon of alum solution and ½ gallon of soap solution were sufficient to give two coats to 50 square feet. The cost of treating 24,000 square feet varied from $0.41 to $1.28 per 100 square feet and averaged $0.76. Alum costs 18 cents and soap 12½ cents per pound.

For horizontal surfaces, the paraffine was boiled to drive off water, heated and applied with a paint brush. A blow torch was used to force the paraffine into the pores by its heat. The concrete would absorb only one coat of such treatment. On 4,000 square feet treated, 1 pound of paraffine was used for 11¾ square feet of surface. The cost varied from $1.70 to $3.78 per 100 square feet, averaging $2.11. Paraffine cost $4.80 per 100 pounds. The surfaces treated have shown no further disintegration after going through four winters.

Concrete pipe has been used very extensively on a number of systems during the past 10 years. With the present knowledge of its construction and use there should be little difficulty in securing well-made pipe. Such pipe should have a relatively long or indefinite life. In 1907 the Irrigation Co. of Pomona relaid a line of 8-inch concrete pipe of 1 to 4 mixture which had been laid in 1888. Only 7 per cent. of the joints were found to be perfectly sound, the remainder had disintegrated. General maintenance of such pipe lines consists of draining in winter and the sluicing of deposits which may form. It is usual for such pipe lines to operate at higher velocities than the canals so that deposits of silt or sand are not to be expected. Such deposits may occur, however, at the lower rates of discharge which may be used at the beginning and end of the season. Cracks at the joints due to the expansion and contraction of the pipes have caused trouble in some cases where the range of temperature is large or the covering of the pipes porous or thin. A length of life of 30 to 40 years has been used in valuations of concrete pipe lines. These figures are largely arbitrary, however, as direct experience has not extended over the full life of larger concrete pipe. In common with other forms of permanent materials, replacements may be more often needed due to changes in the requirements of use such as changes in location or capacity needed, rather than due to actual deterioration of the material itself.

Life of Steel.—Steel is used in irrigation practice in flumes, in pipes and in gates. The development of steel flumes has occurred within the past 15 years. A steel flume with wood supports is a combination type of structure. The trestles and stringers are similar to those used with wood flumes and should have a useful life similar to that of the same kind of material when used with wood flumes. Such trestles with steel flumes may have a longer life than with wood flumes, if the leakage with the steel flume is less. The useful life of steel flumes has not been determined, as their adoption is guite recent. Many have been built on the systems of the U. S. Reclamation Service. From observations on the Boise project it was reported at the Conference of Operating Engineers in 1914, that "Of the flumes built in 1909 practically all were more or less corroded. Of about 13 flumes built in 1910, the majority were in good condition but one was considerably corroded. Of about 21 flumes built in 1911, two were considerably corroded. Of about 14 flumes built in 1912, two were seriously corroded." It was stated that there was no decided difference between different makes of flumes. The greatest amount of corrosion and rust appeared to be along the joints, on the downstream side. It was recommended that the bands, channels or other parts forming the joints should be galvanized as well as the sheet metal of the flume. In case deterioration appears, painting was recommended. In an article in the Reclamation Record for November, 1916, Mr. F. D. Pyle states that of several kinds of paint tried on the Uncompahgre project only coal tar and coal-tar compound paints had stood one season's use and gave indications of permanence. It was also stated that the indications on that system were that unprotected galvanized-steel flumes will have a life of 10 or or 12 years except under the most trying conditions, *i.e.*, high velocity of water carrying sand and fine gravel, where the life in one particular instance was only four season's use.

The use of steel and iron pipe in irrigation has generally been limited to those conditions of pressure for which other types of pipes were not suited. Their use in irrigation has not been sufficient in length of time or in amount to indicate their probable useful life for such purposes. Data, however, are available from use in mining and power service. Thin steel pipes, such as ⅛ inch in thickness, are used in the smaller sizes for the lighter pressures in some distribution systems, particularly with pumping plants. These should have a useful life of 15 to 25 years. Heavier pipe, ¼ inch thick, should last 25 to 50 years. For pipe of the larger sizes, which can be recoated during the portion of the year when they are not in use, even longer life may be secured.

Due to the thinness of the pipe, protective coatings are relatively more important on steel pipes than on those of other material. The more generally used coatings consist of some of the forms of tar or Asphalt mixtures applied hot, the smaller pipe being dipped and the larger ones treated in the field. The San Fernando siphon of the Los Angeles aqueduct was painted inside and outside with one coat of water-gas tar and two coats of coal tar. One gallon of tar covered about 200 square feet of pipe. The Spring Valley Water Co. has used a mixture of coal tar and natural crude asphaltum, using 1,400 pounds of asphaltum to 50 gallons of coal tar. Some of this coating has been in use nearly 50 years. The Pacific Gas & Electric Co. uses one coat of Dixon's Graphite Paint, inside and outside on unburied pipe, repainting every 2 or 3 years. In some cases steel pipe may be encased in concrete. Where steel pipes are laid in alkali soils special protection may be needed. Pipe 5/16 inch thick has in some cases been corroded entirely through in 3 years where laid in alkali soil in the California oil fields. On the Uncompahgre project in Colorado a 26-inch siphon was built in 1910 in alkali ground for which ingot iron pipe was used. This was in good condition after 4 years use although some rusting had occurred.

Cost of Reinforced Concrete Drops, Canadian Pacific Ry., Irrigation Projects.—Robert S. Stockton gives the following data in Engineering and Contracting, April 14, 1915.

On the Western Section of the Irrigation Block being developed by the Department of Natural Resources of the Canadian Pacific Railway Co., some of the timber structures were built as early as 1905 and have had eight years in the ground. Most of these structures, especially the highway bridges and division gates, are good for a number of years yet, but some of the drops, of which there are a large number, are beginning to develop signs of weakness, and as they must be replaced without stopping the flow of water during the irrigation season, May 1 to Oct. 1, the reconstruction must take place before or after the water season, or during that time by diverting the water around the structure by temporary works.

The policy of the company has been to replace the large timber structures as they approached the end of their life with permanent concrete structures of approved design. The program of betterments for 1913 included the replacement of the large timber holdup drop known as drop No. 2A in the Secondary "A" Canal, Langdon District, S. E. ¼ section 19-23-27. The new 10-ft. drop was designed to be built of reinforced concrete with a central pier and two openings that can be closed with stop plank 5 ft. 9 ins. long. The holdup feature of this drop is required to insure the delivery of water to "B" Distributary in Langdon district, which takes out 3 ft. above canal grade. The drop is designed to discharge 1,000 sec. ft. of water over the crest when the canal carries 8 ft. depth of water. Previous experience indicated the economy of diverting the water and building the drop during favorable weather. The construction crew was moved to the site July 17 to 19 and began the work of excavating the by-pass and building a diverting dam in the canal. The by-pass was completed July 29 and the work of tearing out the old timber drop commenced. The old structure was heavily built, having 2,200 lin. ft. of piling and 54,243 ft. B. M. of lumber incorporated in it. Certain timbers in the old drop proved to be pretty well decayed, particularly above the water line. The piling behind the breast wall was rotted and constituted the weakest spot in the structure.

The excavation disclosed 4 ft. of soil underlaid by a compact boulder clay which proved to be quite impervious, and after the footings and lower concrete floor was in place, there was no pumping required.

The nearest gravel pit was about 15 miles distant and 42 cu. yds, of unscreened material was hauled and used. The pit contains good sand but poor gravel, and when the cost of screening was added and quality considered, it was thought best to ship the larger part of the sand and gravel to Bennett Siding, about two miles from the work. The gravel received from the Calgary Sand & Gravel Co., however, had some oversize that was picked out by hand. The steel shipped to Bennett Siding was mixed up with steel for Strathmore, which necessitated a team haul to straighten out.

A carload of lumber was delivered at Bennett Siding for building the forms, chute, and cement shed, and 1,421 F.B.M. was hauled from Dalroy Watermaster's Headquarters. The carpenters started building forms on August 6 and the cut-off walls were poured on Aug. 27. The last concrete was put in on Sept. 20.

The general mixture was intended to be 1 sack of cement to 2½ cu. ft. of sand and 5 cu. ft. of gravel. For thin walls and copings a mixture of 1-2½-4 was used, and for the lip of the drop 2-2½-5. Since 948 sacks of cement were used, the average was 4.74 sacks per cubic yard of concrete. The concrete was mixed wet enough to spade and was spaded so as to require little patching when the forms were removed. The concrete appears to be of excellent quality. The concrete was mixed with a No. 1 Smith Mixer with steam engine, boiler and side loader mounted on steel trucks.

All labor was paid at prevailing rates, stated at so much per day of 10 hours. Every rate is stated in full and so carried in the time books with board deduction of $5.50 per week. The cost of team feed is taken at 90 cts. per day per team and pro-rated to all work on which team time is charged.

The wages of foreman, barn boss, and for Sunday time of teamsters are pro-rated to all labor items. Two rates of wages were paid, as it has been necessary to make a raise at harvest time to hold the men; even at the increased rate, considerable trouble was experienced, as farmers were then paying about $2.50 per day and board. The wages paid were as follows: Laborers at $2.50 to $2.75 per day of 10 hours; teamsters at $2.10 to $2.35 per day of 10 hours, and including Sundays; carpenters at $3.50, $4 and $5 per day, and foreman at $120 per month.

The detailed cost records follow:

LABOR COST—DROP NO. 2A—LANGDON DISTRICT

Feature	Labor cost	Unit cost	Quantity and unit
Moving camp (16 miles)	$ 68.00	....	
Setting up camp (for 24 men)	19.55	....	
Camp expenses	7.00	....	
Hauling supplies	159.30	....	
Excav. of by-pass (Clayloom)	210.00	$ 0.139	1,507 cu. yds.
Excav. of old drop	1,250.00	0.636	1,967 cu. yds.
Removal of old drop	126.80	2.338	54.243 M. ft. B. M.
Building cement shed	8.96	8.070	1.112 M. ft. B. M.
Building chute in by-pass	34.00	33.660	1.010 M. ft. B. M.
Hauling lumber (2 miles)	46.60	1.987	23.438 M. ft. B. M.
Steel (2 miles)	4.10	0.031	129.96 cwt.
Cement (2 miles)	40.00	0.042	948.00 cwt.
Gravel (2 miles)	162.90	0.975	167 cu. yds.
Sand (2 miles)	72.00	1.060	68 cu. yds.
Sand and gravel (15 mi.)	88.60	2.685	33 cu. yds.
Mixer and pump (21 mi.)	29.30	....	
Pumping water	13.10	....	
Building forms	591.00	0.100	5,929 sq. ft.
Bending and placing steel and wire fabric	110.65	0.851	129.96 cwt.
Mix. and placing concrete	336.10	1.680	200.00 cu. yds.
Removal of forms	51.25	0.009	5,929 sq. ft.
Backfilling by-pass	143.40	0.090	1,600 cu. yds.
Backfilling drop	375.70	0.237	1,588 cu. yds.
Removal of chute	6.88	6.812	1,010 M. ft. B. M.
Repairs to bank	106.88	0.822	130 cu. yds.
Riprap to bank	30.10	1.027	29.3 cu. yds.
Cleaning up, etc	13.72	....	
Total labor cost	$4,105.89	....	Includes team feed.

MATERIAL COST—DROP 2A—LANGDON DISTRICT

Feature	Quantity	Cost	Freight	Total cost	Unit cost
Reinforcing steel	11,921 lbs.	$ 229.72	$ 60.55	$ 290.27	$ 0.024
Wire fabric	1,075 s. f.	22.84	6.73	29.57	0.027
Cement	237 bbls.	482.86	45.75	528.61	2.230
Gravel	167 yds.	183.70	61.30	245.00	1.467
Sand	68 yds.	74.80	25.10	99.90	1.469
Lumber	23,438 ft. B. M.	323.94	54.80	290.13*	12.380
Rope repairs, etc		44.35	......	44.35	....
Total material cost		$1,362.21	$254.23	$1,527.83	......

Total labor cost, including team feed		$4,105.89
Total material cost		1,527.83
Depreciation on concrete mixer, pump, wagons, harness, horses, etc	$302.44	
Depreciation on camp equipment	42.45	
		344.89
Overhead expense of superintendence, engineering, office work, accounting, etc		938.00
		$6,916.61

* Less $88.61 salvage value.

Summary of Feature Costs—Drop No. 2A—Langdon District, 1913

	Cost	Cost per yd. of concrete
Camp and supplies	$ 311.92	$ 1.560
Excavation and backfilling	2,085.98	10.430
Preparatory work	219.04	1.095
Hauling materials	414.20	2.071
Building forms	591.00	2.955
Bending and placing steel	110.65	0.554
Mixing and placing concrete	336.10	1.681
Removal of forms	51.25	0.257
Steel and wire fabric	319.84	1.595
Cement	528.61	2.643
Gravel and sand	344.90	1.725
Lumber	290.13	1.451
Riprap below drop	30.10	0.151
Depreciation	344.89	1.725
Overhead expense	938.00	4.690
	$6,916.61	$34.583
Camp and supplies and preparatory work	$ 530.96	$ 2.655
Excavation and backfilling	2,085.98	10.430
Concrete work	2,986.68	14.932
Riprap below drop	30.10	0.151
Depreciation	344.89	1.725
Overhead expense	938.00	4.690
	$6,916.61	$34.583

Cost of a Reinforced Concrete and Check Delivery Structure for an Irrigation Canal.—H. M. Rouse, in Engineering and Contracting, Sept. 6, 1911, gives the following:

Five small reinforced concrete check and delivery structures were constructed in 1910 by the California Development Co., for one of its new irrigation canals in the Imperial Valley, California. Three of the five gates were under construction at the same time, the common camp being a half mile from the Banyan check and delivery.

All materials were purchased through the company Store Department which made a charge of 10 per cent of cost of materials in store. This charge includes unloading from cars at Calexico, Store Department bookkeeping and miscellaneous labor, and depreciation on tools. The labor rates were as follows:

Foreman, per month	$135.00
Sub-foremen and first carpenters, per day	3.50
Second carpenters, per day	3.00
Carpenter helpers, per day	$2.75 & 2.50
Laborers (white), per day	2.50
Laborers (Mexican), per day	1.50
2-horse team, wagon and driver, per day	4.50
4-horse team, wagon and driver, per day	7.00

The structure contains 66.5 cu. yds. of concrete, and the total cost was $2,124.27, divided as follows:

Development Work.—The development work was little; it comprised building a protection levee, placing a water storage tank and building a mixing board at an aggregate cost of $6.61 or 9.94 cts. per cubic yard of concrete.

Excavation.—The excavation for the concrete work amounted to 180 cu. yds, and was done with shovels. About one-half of the excavation was from trenches 10 ft. deep and 3 ft. wide, maximum dimensions, and the material had to be handled twice. The material was adobe and its excavation cost $160 or 88.8 cts per cubic yard. The charge per cubic yard of concrete in the structure was $2.41. There were 2.71 cu. yds. of excavation per cubic yard of concrete.

Form Construction.—A total of 3,200 ft. B. M., second-hand Oregon pine lumber was used for the forms; 2,400 ft. B. M. 1 × 6-in. boards and 800 ft. B. M. 2 × 4-in. studding. This lumber was valued at $25 per M. ft B. M. by the Store Department. The labor required comprised erecting forms on both sides of 6 and 8-in. walls. The cost of forms for materials and labor was as follows:

Materials:	Cost
3,200 ft. B. M. lumber at $25 per M	$ 80.00
Store department charge of 10%	8.00
Loading	3.00
Hauling	20.00
Total lumber	$111.00
80 lbs. nails at 4 cts	$ 3.20
Store department charge of 10%	0.32
Total nails	$ 3 52
Grand total materials	$114.52
Labor:	
Building and renewing forms	$197.65
Grand total materials and labor	$312.17

Summarizing we have the following cost per cubic yard of concrete for forms:

Item	Per cu. yd.
Materials	$1.72
Labor	2.97
Total	$4.69

The cost of forms per thousand feet, board measure, was as follows:

Item	Per M ft.
Materials	$35.79
Labor	61.80
Total	$97.59

Reinforcement.—The reinforcement used consisted of ⅝-in. round bars and wire. The bars used were of nickel steel and were cut with hacksaw and bent with gas pipe. The cost for materials and labor was as follows:

Materials:	Cost
3,500 ft. ⅝-in. bar at 3.28 cts	$114.80
Store department charge	11.48
Loading	1.50
Hauling	5.25
Total bars	$133.03
Wire at $4.07 per 100 lbs	$ 2.23
Total materials	$135.26
Labor:	
Cutting, bending and placing	$ 27.22
Total reinforcing in place	$162.48

Summarizing we get the following costs per cubic yard of concrete:

Item	Per cu. yd.
Materials	$2.03
Labor	0.41
Total	$2.44

Concrete.—The concrete was a cement, sand and gravel mixture of 1.24 bbls. cement and 1.28 cu. yds. of sand and gravel per cubic yard of concrete in place. The cost of 82½ bbls. of cement on the ground was as follows:

Item	Cost
65 bbls. Calton at $3.80 on cars Calexico	$247.00
17½ bbls. Alsen at $4.98 on cars Calexico	87.15
Store department charge	33.42
Loading	1.50
Hauling	47.00
Total cost on ground	$416.07

This is a cost for cement of $5.04 per barrel on the ground and of $6.26 per cubic yard of concrete in the structure.

There were used 79.07 cu. yds. of gravel and 6 cu. yds of sand at the following cost:

Item	Cost
44.85 cu. yds. Andrade gravel at $2.95	$132.31
30.46 cu. yds. Frink gravel at $3.11	94.80
3.76 cu. yds. Mammoth gravel at $2.91	10.94
6 cu. yds. Whitewater sand at $2.17	13.02
Total on cars at Calexico	$251.07
Store department charge	$ 25.10
Loading	8.00
Hauling	140.00
Total sand and gravel on ground	$424.17

The average cost of sand and gravel on cars at Calexico was $2.95 per cubic yard. Hauling cost $1.65 per cubic yard and the other charges noted brought the cost per cubic yard on the ground up to $4.98. The cost per cubic yard of concrete in the structure was $6.37. The concrete was mixed by hand in ½ cu. yd. batches, wheeled in barrows and rammed in place. The labor cost for mixing and placing was $171.09 or $2.57 per cubic yard of concrete. Summarizing we have the following costs for concrete in place:

Item	Total	Per cu. yd.
Cement	$ 416.07	$ 6.26
Sand and gravel	424.17	6.37
Labor mixing and placing	171.09	2.57
Totals	$1,011.33	$15.20

Backfilling and Puddling.—The cost of backfilling and puddling trench as described above was as follows:

Item	Total
Men	$32.97
Fresno team	2.25
Total	$35.22

This is a charge of 53 cts. per cubic yard of concrete.

Gates and Gate Lifters.—The cost of materials and labor for six gates and lifting apparatus was as follows:

Item	Total	Per gate
410 ft. B. M. redwood at $40	$ 16.40	$ 2.73
82 ft. 2½ × 3-in. angle at 4 cts. lb	20.80	
Bolts	3.43	4.04
6 lifter sets at $20.31	121.86	......
6 c. i. pedestals at $4.34	26.04	......
11 30-in. sections c. i. rack at $1.35	14.85	......
Total	$162.75	$27.12
Grand total material	$203.38	$33.89
Store department charge	20.33	......
Hauling	10.00	......
Total material on ground	$233.71	$38.95
Labor 6 gates at $2.11	12.70	......
Total gates in place	$246.41	$41.07

General Labor.—The charges for general labor was one-third of foreman's time at $135 per month; one-third of time keeper's time at $2.50 per day. The amounts were:

Foreman	$57.35
Timekeeper	16.60
Total	$73.95

Engineering.—Engineering included office work, drafting and paper and field work inspection and staking our structure. The charges were:

Office work	$ 47.30
Field work	68.80
Total	$116.60

This is a cost of $1.74 per cubic yard of concrete.

Recapitulation.—From the above figures we get the following summaries of costs:

Item	Total	Per cu. yd. concrete
Development work	$ 6.61	$ 0.9094
Excavation	160.00	2.4100
Concrete work	1,485.98	22.3400
Backfilling	35.22	0.5300
Gates, etc	246.41	3.7000
General labor	73.95	1.1120
Engineering	116.10	1.7400
Total	$2,124.27	$31.94

Summarized by the items, labor, materials and engineering the cost per cubic yard was as follows:

Item	Per cu. yd.	Pct.
Labor	$10.29	32.22
Materials	19.91	62.32
Engineering	1.74	5.46
Total	$31.94	100.00

Costs of Irrigation Construction on the Rock Creek Conservation Co.'s Project at Rock River, Wyoming.—W. D'Rohan, in Engineering and Contracting, Dec. 27, 1911, gives the following:

All the canals and laterals were taken out by contract to a uniform section of 8 ft. bottom and 1 to 1 slopes, at an average price of 17 cts. per yard, they are all in cut, with an average depth of 4½ ft.

Owing to the wide extent of the project, the long moves over rough roads would soon wreck any machinery, so the management decided that it would be more economical to mix all the concrete by hand, and over 3,000 cu. yds. were mixed and placed in this manner. Gravel was obtained from the creek. and was hauled to the various points by contract at $6.70 per yard. The contractor had to screen it as well. For this, he built a trap 18 ft. high, with a 10-ft. chute, in the bottom of which was placed the screen; the gravel was taken out of the creek bed with wheelers, carried up the inclined run and dumped into the trap from which it ran down the screen into the wagons. Sand was shipped from Laramie at 40 cts. per ton, freight $1, and hauling on the job $1.80 per ton. Ideal cement cost $2.20 per bbl. laid down and was hauled by company teams on the work. Lumber for forms cost $22 per 1,000 ft. and was used four times.

Headgate.—The top slab of the gate over which is a wagon road was reinforced with ½-in. rods spaced 8 ins. apart, while plums were used in the heavier parts of the walls. The mix used throughout was 1:2½:5 for plain concrete, and 1:2:4 for reinforced. The cost of the headgate was distributed as follows, for 111.7 cu. yds. of concrete:

Excavation:	Total	Per cu. yd.
Item		
276 hrs. laborers at 25 cts	$ 69.00	......
15 hrs. teams at 50 cts	7.50	......
50 hrs. foreman at 35 cts	17.50	......
Total excavation	$ 94.00	$ 0.84
Materials:		
133 bbls. cement at $2.20	$ 279.30	......
5,000 ft. lumber at $22 per M	27.50*	......
46 cu. yds. sand at $4.80	220.80	......
60 cu. yds. gravel at $6.70	402.00	......
48 cu. yds. "plums" at $1	48.00	......
160 lbs. steel rods at 2 cts	3.20	......
Water and hauling cement	25.00	......
Total materials	$1,005.80	$ 9.00
Labor:		
540 hrs. mixing and placing at 25 cts	$ 135.00	......
160 hrs. carpenters at 40 cts	64.00	......
90 hrs. helpers at 27.5 cts	24.75	......
80 hrs. foreman at 40 cts	32.00	......
Total labor	$ 255.75	$ 2.29
Grand total	$1,355.55	$12.13

* Lumber used four times.

Dimensions	Ft.	ins.	Ft.	ins.	Ft.	ins.	Ft.	ins.	Ft.	ins.
	Depth of water in feet.									
h........	2	..	2.5	...	3	...	3.5	....	4	
m........	4	0	4	6	5	0	5	6	6	0
n........	6	0	6	6	7	0	7	6	8	0
o........	1	0	1	1½	1	3	1	4½	1	6
e........	8	0	8	7½	9	3	9	10½	10	6
b........	1	10	2	0¾	2	3½	2	3½	2	9
t........	7	2	7	7½	8	6½	8	6½	9	0
h........	..	..	4.5	....	5	..	5.5	....	6	..
m........	..	..	6	6	7	0	7	6	8	0
n........	..	..	8	6	9	0	9	6	10	0
o........	..	..	1	7½	1	9	1	10½	2	0
e........	..	..	11	1½	11	9	12	4½	13	0
b........	..	..	2	11¾	3	2½	3	5¼	3	8
t........	..	..	9	5½	9	11	10	4½	10	10

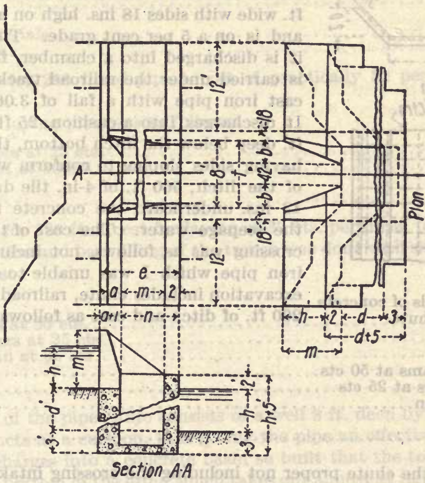


FIG. 12.—Standard concrete drop.

Drops.—All of the drops were of the standard design, shown by Fig. 12. The cost of this drop was as follows for 65.5 cu. yds. of concrete:

	Total	Per cu. yd.
Excavation:		
270 hrs. laborers at 25 cts.	$ 67.50	.....
30 hrs. foreman at 30 cts.	9.00	.....
Total excavation	$ 76.50	$ 1.15
Materials:		
2,500 ft. B.M. lumber at $22 per M.	$ 13.75*	.....
32 cu. yds. sand at $4.80	153.60	.....
317 sacks cement at $2.10 per bbl.	166.42	.....
35 cu. yds. gravel at $6	210.00	.....
25 cu. yds. "plums" at $1	25.00	.....
Total materials	$568.77	$ 8.55

	Total	Per cu. yd.
Labor:		
315 hrs. mixing and placing at 25 cts	$ 78.75	......
58 hrs. carpenters at 40 cts	23.20	......
95 hrs. helpers at 27.5 cts	26.12	......
20 hrs. wiring forms at 25 cts	5.00	......
Hauling cement, water, etc	6.60	......
Total labor	$146.47	$ 2.20
Grand total	$791.74	$11.90

*Lumber used four times.

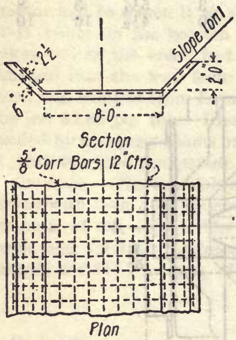


Fig. 13.—Details of concrete lined chute.

Open Chute.—The open chute, shown by Fig. 13, is 297 ft. long. It is built of reinforced concrete 6 ins. thick, the bottom being 8 ft. wide with sides 18 ins. high on a 1 to 1 slope, and is on a 5 per cent grade. The water from it is discharged into a chamber, from which it is carried under the railroad tracks by a 54-in. cast iron pipe with a fall of 3.06 ft. in 60 ft. It discharges into a cushion, 25 ft. long, and 5 ft. deep below the ditch bottom, the upper part having sides sloping to conform with the shape of the ditch; 560 ft. of 4-in. tile drain pipe laid 12 ins. underneath the concrete takes care of the seepage water. The cost of the chute and crossing was as follows, not including the cast iron pipe which I was unable to obtain. The excavation includes chute, railroad crossing and 200 ft. of ditch and cost as follows:

Item:	Total
632 hrs. slip teams at 50 cts	$316.00
735 hrs. laborers at 25 cts	181.25
129 hrs. foreman	38.79
Total	$535.95

The cost of the chute proper not including the crossing intake and outlet, was as follows for 146.6 cu. yds.:

	Total	Per cu. yd.
Materials:		
513 cu. yds. sand at $4.80	$ 246.24	......
77.7 cu. yds. gravel at $6	466.19	......
24.9 cu. yds. "plums" at $1	24.90	......
698 sacks cement at $2.10 per bbl	366.45	......
4,000 ft. B.M. lumber at $22 per M	22.00	......
¾-in. steel rods, 12 ins. on centers, at 2½ cts	279.19	......
Total materials	$1,422.97	$ 9.71
Labor mixing and placing concrete	$ 317.10	$ 2.16
Grand total	$1,740.07	$11.87

The intake and outlet structures, contained 139.3 cu. yds. of concrete which was placed for $10.42 per cubic yard. The chute and railroad crossing were put in according to plans made by the Union Pacific R. R. Co.

Concrete Pipe.—About one mile from the railroad on another hillside, it was decided to put in concrete pipe instead of the open chute; 288 ft. of bell pipe was made. The mix used was 1:2:3 and was reinforced with ordinary barbed wire, 6 rings being used to each pipe. The concrete was placed very wet and allowed to stay overnight in the forms which were painted with crude oil before every setting. The cost of the pipe making and laying was:

Pipe making:	Cost
810 hrs. mixing and placing in forms at 25 cts	$202.50
50 hrs. team hauling water at 50 cts	25.00
158 hrs. foreman oiling and setting forms at 30 cts	47.40
Total	$274.90
Materials:	
220 sacks cement at $2.20 per bbl	$121.00
33 cu. yds. sand at $4.80	158.40
Oil	10.00
Barbed wire	10.50
Total materials	$299.90
Total pipe	$574.80

(This gives for 288 ft. of pipe a cost of practically $2 per lineal foot.—Editors.)

The cost of laying pipe was as follows:

292 hrs. laborers at 25 cts	$73.00
45 hrs. foreman at 30 cts	13.50
Total	$86.50

(This gives for 288 ft. a cost for laying of 30 cts. per lineal foot.—Editors.)

The excavation and backfilling of the trench was done with slip scrapers at a cost as follows:

Item:	Cost
220 hrs. teams at 50 cts	$110.00
160 hrs. laborers at 25 cts	40.00
87 hrs. foreman at 35 cts	26.10
Total	$176.10

The intake of the pipe chute consists of a well 8 ft. deep by 7 ft. wide, the bottom 2 ft. acts as a cushion, thus giving the pipe an effective head of 6 ft. The pipe discharges into a concrete basin so built that the top of the pipe is level with the bottom of the ditch which takes out almost at right angles to the chute. The two structures contain 118.5 yards of concrete and cost $14.10 per yard.

Wooden Drops.—Owing to the difficulty of obtaining sand, it was impossible to complete the concrete structures in time for the irrigation season, so, temporary wooden drops had to be put in. The drops are very effective. The cost of an 8-ft. drop was:

Materials:	Cost
4,000 ft. B.M. lumber at $22 per M	$ 88.00
35 lbs. nails at 5 cts	1.75
Total materials	$ 89.75
Labor:	
42 hrs. carpenters at 40 cts	$ 16.80
90 hrs. labor excavating at 25 cts	22.50
20 hrs. teams at 50 cts	10.00
Total labor	$ 49.30
Grand total	$139.05

Flashboards.—All of the ditches being in cut makes it necessary to place diversion gates in the channel in order to divert a sufficient head into the laterals. For this purpose, large steel overflow gates are provided. Owing to the want of sand however thay could not be placed in time, and temporary flashboards which contain 250 ft. B. M. of lumber and cost $7.75 to build were used.

Siphon Construction.—The intake and the outlet of the siphon ditch which takes out of the Bosler Canal are two massive reinforced concrete structures. The floor of the intake, is 7 ft. thick reinforced top and bottom, with 1 in. corrugated bars spaced 12 ins. apart. The walls are 15 ins. thick reinforced with ½-in. and ¾-in. rods front and back, spaced 12 ins. and are strongly buttressed. The structure contains 394 cu. yds. of concrete, and 26,627 lbs. of steel. The concrete cost $15.88, and forms and placing steel 73½ cts. per cubic yard. The gates are of the Western type, and cost $500, and the whole structure cost $7,249.97.

The outlet of the siphon is a triangular shaped chamber with 200 sq. ft. of floor space; the east and west outlets taking out at the lower corners. The floor is 3 ft. thick, reinforced with ½ in. and ¾ in. rods spaced 10 ins. The outlets are controlled by overflow diversion gates with three openings each 4 × 5 ft. The structure contains 367 cu. yds. of concrete, and 17,727 lbs. of steel and without the gates cost $5,879.07. Forms and steel placing cost 86 cts. per cu. yd. and the concrete $16.01 per cu. yd.

The 54-in. wood pipe inverted siphon is 4,939 ft. long, and is built of Oregon fir. The staves are 1⅝ ins. thick and kiln dried. The shoes are of the Allen patent of cast iron, and the bolts ½ in. thick are of mild steel, and 50,000 lbs. tensile strength. At the intake and the outlet, and also under the track, the wood pipe laps over a 60-in. cast iron pipe, the joint being made by lapping the iron pipe with tarred oakum rope.

All of the pipe forms, and the welding of the bands for the swelled joints were made on the works, the slotting of the staves which is usually done at the factory was also done here. The bands were painted with asphaltum on the pipe. The tarred rope did not make a successful joint as the tar prevented the rope from absorbing water and swelling; so a concrete collar was put around the joint, an open space 2 × 12 ins. being left on the top of the pipe, this was afterwards plugged with oakum. The costs of the pipe were distributed as follows:

Slotting staves:	
970 hrs. laborers at 27½ cts	$ 266.75
260 hrs. foreman at 30 cts	78.00
Total	$ 344.75
Making Pipe Forms, Bells and Sills:	
140 hrs. carpenter at 40 cts	$ 56.00
20 hrs. blacksmith at 25 cts	5.00
Total	$ 61.00
Welding bands:	
50 hrs. blacksmith at 30 cts	$ 15.00
Laying pipe, cinching bands, painting bands:	
7,932 hrs. laborers at 25 cts	$1,983.00
207 hrs. foremen at 30 cts	62.10
541 hrs. foreman at 35 cts	189.35
Total	$2,234.45

Materials used:	
163,000 ft. B.M. lumber at $31	$5,053.00
Bands	3,188.06
Shoes	605.20
Asphaltum	10.00
Splines	196.00
Oakum for iron pipe joints	20.00
Manhole	56.30
Total	$9,128.56
Hauling cost (distance 2 miles):	
Lumber	$ 489.00
Bands	162.75
Shoes	60.00
Splines	4.50
Total	$ 716.25
Back filling of pipe line:	
1,101 hrs. teams at 50 cts	$ 550.50
790 hrs. laborers at 25 cts	197.50
217 hrs. foreman at 35 cts	75.95
Estimated to complete backfilling	150.00
Total	$ 973.95

That is 4,939 ft. of pipe cost $13,473.96, or $2.70 per foot, without the excavation. The pipe was laid under a maximum head of 75 ft., the bands cost roughly about 42 cts. each, the shoes 8 cts. each.

Cost of Spray Irrigation.—The following is an abstract in Engineering and Contracting, March 14, 1917, of a bulletin on Spray Irrigation issued by the U. S. Dept. of Agriculture:

Economic Conditions Justifying Spray Irrigation.—The cost of spray-irrigation systems depends upon the type installed as well as upon conditions peculiar to each form. A portable outfit may cost as little as $50 per acre for the field equipment, while a stationary distribution system may cost as much as $150 per acre. To these figures must be added the cost of a main pipe line leading from the water supply to the fields and usually the cost of developing a water supply and installing a pumping plant. These additional items may being the total outlay per acre up to two or three times the cost of the distribution system, especially on small acreage. Assuming a cost of $250 per acre on a stationary plant for a small acreage, the farmer should be able to increase his annual returns from each acre to cover approximately the following charges:

6 per cent interest on $250	$15.00
5 per cent depreciation on equipment	12.50
2 per cent maintenance and repairs	5.00
Cost of fuel and oil at 4 cts. per 1,000 gal. of water pumped for 6 acre-inches	*6.50
Labor in irrigating, 1 man 6 days at $2	12.00
Total overhead and operating expenses	$51.00

* Cost of pumping estimated for a plant operating at 50 per cent efficiency against a total head of 150 ft., using gasoline as fuel. The amount of water pumped annually is assumed at 6 acre-inches as a typical duty of water in the Atlantic Coast States where spray irrigation is most extensively used. More arid sections require larger amounts.

It will be noted that $51 per acre per year is necessary in returns to cover overhead and operating expense incidental to the spray system. To realize a fair profit from the irrigation plant, the crops must increase in value something more than $51 per acre. In the case of berry, tobacco, and orchard crops the increase must be derived from one main crop and a possible intercrop. On the other hand, the irrigator of truck who follows intensive culture has a chance of dividing the annual increase among three to six crops. The high cost of spray irrigation eliminates its use on many crops which respond readily to irrigation. It is possible, however, to use cheaper methods of distribution on many of these crops which are grown on land having an even surface. A combination of spray irrigation and surface methods on the same farm often can be placed under one pumping plant, as illustrated in Fig. 14, thereby utilizing to the fullest extent the water supply, pumping equipment, and main pipe lines. The typical farm illustrated in Fig. 14 indicates the use of spray irrigation on the more uneven parts where the topography is not adapted to cheaper methods, but where the soil and southern slope are desirable for the growing of early and intensive truck and berry crops that will justify spray irrigation. The main feed pipe is extended to the upper and more even parts of the farm, where cheaper methods of irrigation can be applied to alfalfa, orchard, bush berries, potatoes, and other crops grown in wide rows for horse cultivation.

Truckers in the arid sections seem to favor a combination of spray irrigation and surface irrigation on the same field. The spray is used in the preparation of the seed beds, germinating seeds, and starting newly set plants. Later the crops are irrigated during the maturing and fruiting periods by the surface furrow or check methods. A portable spray equipment often meets these conditions most economically, because it can also be used for the irrigation of hot-bed and cold-frame crops.

Farm Conditions Adapted to Spray Irrigation.—Spray irrigation can be practiced to advantage on both light and heavy soils. By this method it is possible to apply evenly to sandy soils the small quantities of water which such soils will retain, without the loss of water by percolation which might occur with other methods. It is possible also to apply to heavy clay soils the small quantities of water required to soften such soils when they have baked after rains, and to apply water no faster than the soil can absorb it, thus preventing loss by surface run-off.

Lands to be irrigated should be drained as completely as possible of excess moisture. Many tile-drained fields are the most responsive to crops under spray irrigation.

Spray irrigation is practically independent of the topography of the field and can be applied to land too rolling or rough for surface methods. It is, therefore, adaptable to the irrigation of side hills on which soils tend to wash or erode.

Amount of Water Required for Spray Irrigation.—As yet, the available knowledge on the amount of water required for spray irrigation is limited, because of the comparative newness of the methods and the lack of actual records on plants under a time test. In the humid regions amounts not exceeding ¼ in. in depth often are considered a sufficient application to seed beds and young vegetables, while in the case of maturing garden crops and strawberries ½ to 1 in. may be applied. It is probable that truckers in the humid region do not use more than 6 in. in a growing season and in many seasons 4 in. or less will supplement the rainfall sufficiently. More water is required for sandy soils than for clay. A crop like the spray-irrigated citrus groves of

Florida may require as much as 3 in. per irrigation. Truck and citrus growers in the arid regions apply more water than those in the humid region, probably because of a large evaporation loss. In the arid region the truck farmer is inclined to make frequent applications—every 3 or 4 days—rather than to apply the extra amount of water required in large applications which will wet below the reach of the vegetable roots, while the citrus grower applies from 4 to 8 in. each time.

For spray irrigation sufficient water to cover the land to a depth of 1 in. per week for humid regions and 1½ in. per week for arid regions is believed to be a safe estimate for designing purposes. A spray plant should be large enough to supply these amounts of water in a reasonable length of time. This is accomplished generally by installing the system of spray from one-fifth to one-half of the total acreage at one time, depending somewhat upon the type of distribution used and the available water supply.

All spray irrigation plants require power pumping equipment unless pressure can be supplied from an elevated source or municipal waterworks. To generate a spray requires a high-pressure pump producing 25 to 40 lb. pressure on the nozzles in addition to elevating the water to the field.

The Designing of Spray Irrigation Systems.—Every spray irrigation system can be divided into three parts, which must be considered in their proper relation to each other in the design of a plant. First, the distribution-pipe system, which applies the water directly to the crops through some type of nozzle; second, the main feed pipe, which conveys the water from the source to the distributaries; third, the pumping equipment, which lifts the water and develops the pressure, unless the water and pressure are obtained from a gravity or municipal supply.

The distribution system should be laid out to use the minimum amount of large pipe for both distributaries and main feed pipe. The laterals or nozzle lines should run in a direction which will give the least amount of obstruction to the cultivation of the field in the most efficient manner. The field should be laid off in irrigation blocks or units, a unit representing the area to be irrigated at one item. The unit should be of a desirable length for the kind of crops to be irrigated. Where possible, it is advisable to divide the field by the irrigation system into blocks which will make the estimating of acreages easy when arriving at the amount of seed and fertilizer required or determining yields. This is done usually by having a convenient fraction of an acre under each spray line or by having the crop rows a length which will make each rod or yard in width a known fraction of an acre.

To keep the cost of a spray distribution system as low as possible, yet obtain a good uniform pressure and distribution of water, the sizes of pipes must be proportioned properly. Each lateral or nozzle line must be proportioned in size according to the number and capacity of the nozzles used. The main feed pipe must be proportioned to carry the total amount of water to the most distant irrigation unit and then be reduced in size as the water is decreased by each nozzle line within the irrigation unit. The water required to run an irrigation unit determines the capacity of the pumping equipment.

Table XXVI is a bill of materials for the typical farm shown in Fig. 14. Pipe less than 2 in. in diameter can be cut in the field, hence the actual number of feet required is stated for such pipe. "Location" refers to the location in the field. Nozzle lines are assumed to be 630 ft. long on each side of the farm road. Pipe posts are assumed to be set 18 ft. apart, and 9 ft. long, to support nozzle lines 6½ ft. above the surface.

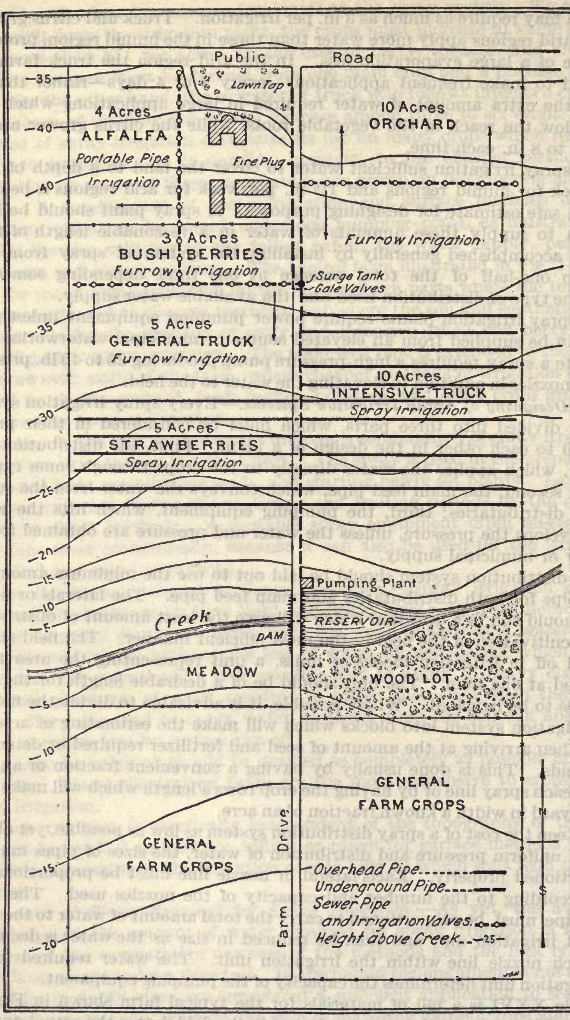


FIG. 14.—Typical 80-acre farm in humid regions, showing development of water supply by reservoir and a combination of spray and surface methods of irrigation operated from one pumping plant.

TABLE XXVI.—BILL OF MATERIALS

Amount	Size, inches	Item	Location
1 run, 410 ft	6	Black guaranteed wrought-iron pipe, cut to exact length, with allowance for 1 tee in each run	Main feed pipe.
12 runs, 50 ft. each	6	do	Do.
1 run, 25 ft	6	do	Do.
20 runs, 30 ft. each	2	Galvanized wrought-steel pipe	Feed end east-and-west nozzle lines.
20 pieces, 7 ft. each	2	do	Nozzle-line risers.
7 pieces, 15 ft. each	2	do	Pipe under road, east-and-west lines.
3,500 ft	1½	do	Do.
3,500 ft	1¼	do	Do.
3,200 ft	1	do	Do.
1,800 ft	¾	do	Far end all nozzle lines.
700 pieces, 9 ft. each	1¼	Galvanized wrought-steel pipe, plain ends	Pipe posts.
7	6 by 2 by 2	Black side outlet cast-iron tees	Main feed pipe.
6	6 by 2	Black cast-iron tees	Do.
7	2	Black malleable 90 ells	Bottom west risers.
20	2	Galvanized malleable 90 ells	Top east-and-west risers.
20	2	Galvanized long nipples	Feed end nozzle lines.
20	2 by 1½	Galvanized reducing sockets	Nozzle lines.
20	1½ by 1¼	do	Do.
20	1¼ by 1	do	Do.
20	1 by ¾	do	Do.
20	2	Standard brass gate valves	Feed end nozzle lines.
20	⅔	do	Far end nozzle lines.
1	6	Standard iron-body gate valve	End of main.
20	2	Trade name, etc., turning unions	Nozzle lines.
3,160	No. —.	Trade name, etc., nozzles	Do.
700	No. —.	Trade name, etc., galvanized hangers	Top of posts.

Note.—Main feed pipe is made 6-in. size full length, as full head of water to be pumped to farther fields for surface irrigation.

Cost of Spray System of Irrigation for Lawn Sprinkling.—According Burt A. Heinly, Engineering News, April 11, 1912, the cost of lawn sprinkling which was practically eating up the annual appropriation for parks, was cut 80 per cent by automatic sprinkling apparatus.

The system is simple in the extreme. It is composed (Fig. 15) of pipes laid in radiator circuits from 12 to 15 in. beneath the ground, which supply stand-pipes to which sprinkler heads placed flush with the ground are attached at intervals of 20 ft. Experiments showed that a circle whose diameter is the diagonal of a 20-ft. square is about the maximum over which water can be distributed from a single sprinkler top. It is obvious that to irrigate any large area simultaneously, the supply main and radiating pipes would have to be of large size, else the resultant release of water from many escapes would so reduce the pressure as to destroy the purpose of the apparatus. The radiator system is therefore separated into circuits or series, each of which is

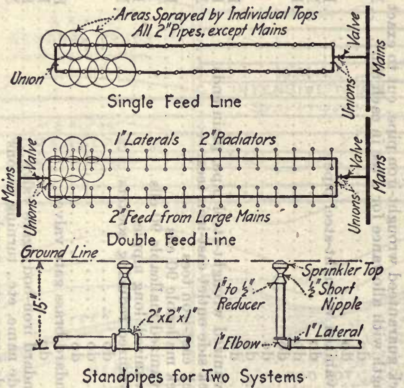


Fig. 15.—Spray irrigation system, Los Angeles, Cal.

controlled by one or two valves, according to whether the circuit is fed from one or two ends. With the application of a volume of water equal to the discharge, the series is set in operation, the sprinkler then providing the necessary distribution in the form of a spray.

The system was devised by Frank Shearer, superintendent of parks, and the installation was made in Central Square, a five acre tract near the heart of the retail shopping district. The park was being entirely remodeled, which included the stripping of the lawn, so that unusual opportunity was offered for the work. Here a single-feed system, controlled by one valve (Fig. 15) was used. The supply main is 4 in. in diameter and the circuit pipes 2 in. in diameter. The water pressure in the city mains is approximately 60 lbs. per sq. in. at this point. Three dozen sprinkler heads were attached to each series, which irrigates approximately 17,000 sq. ft. Eleven series are thus required for sprinkling the 4.3 acres of lawn area. The system cost about $400 per acre, installed, which is nearly double the cost of piping for hose irrigation which includes the purchase of hose.

With this system in use, it requires the time of one man for only two hours to do the day's sprinkling over the entire park. With irrigation by hose sprinkling it took two men the entire day to perform the task. At the rate of $2 per day for eight hours' work this is a net daily saving of $3.50 per day, or $1277.50 per year on this small park, where within 20 months the device will pay for itself.

Selection, Installation and Cost of Small Pumping Plants for Irrigation.—The following discussion is given by B. A. Etchverry, Department of Irrigation, University of California, in Engineering and Contracting Nov. 5, 1913.

The proper selection of a pumping plant depends upon many factors which should be carefully considered by the intending purchaser. These factors are: (1) source of water supply, (2) capacity of plant and period of operation, (3) the kind of pump, (4) the class of engine or driving power. (5) the first cost, (6) the fuel cost, (7) the cost of fixed charges and attendance. These factors are interdependent and should be considered together. Their relative importance will vary with local conditions and for that reason it is not possible to state definite rules which will apply in all cases. A study of the conditions affecting each factor is therefore necessary in each case.

1. *Source of Water Supply.*—The source of water supply may be surface water supply, such as water occurring in rivers, lakes, canals, etc., or may be ground water supply. Where surface water is available, the water will be developed by means of a proper intake, which for the simplest cases will consist simply of the suction pipe of the pump extending into the body of water. Where ground water is available the most common means of development is by wells.

Wells.—The well may be a dug, bored or drilled well. The most common form of well for individual pumping plants in California is a drilled or bored well 10 to 16 ins. in diameter or larger, lined with a casing, which may be one of the three following types:

(1) Standard steel screw casing;

(2) Single galvanized iron casing, No. 12 to No. 16 gauge, with joints riveted together;

(3) Double black steel casing, No. 12 to No. 16 gauge, known as California stovepipe casing, and very generally used in southern California. This casing is made of riveted steel sections 2 ft. long placed with broken joints. The bottom of the casing consists of a starting section 15 to 20 ft. long, made of triple thickness, riveted together, with a steel shoe at the lower end.

The well and casing should extend into the water-bearing gravel sufficiently far to give a perforated area equal to at least five times the cross section area of the well. The perforations are made with an improved cutting tool, and consist of 6 to 8 slits made in each ring or circle; each slit 12 to 18 ins. long and ⅜ to ¼ in. wide. A space of 4 ins. is skipped and another ring of slits staggered with the adjacent ones is made. Slits should not be over 18 ins. long with stovepipe casing.

In southern California, near Chino, the price of drilling deep wells is as follows:

For 10, 12 and 14-in. wells in fine material, $1.25 per foot for first 500 feet.

For 16-in. wells in fine material, $1.50 per foot for first 500 feet.

For depths greater than 500 ft. the price is 50 cts. extra for each additional foot.

The cost per foot of steel stovepipe casing is about as follows:

Diameter, ins.	12 gage	14 gage
10	$1.12	$0.92
12	1.27	0.99
14	1.51	1.12
16	1.80	1.24

2. *Capacity of Plant and Period of Operation.*—The required capacity of the plant will depend on the area irrigated, the duty of water or depth of water required on the land and the period of operation. For ordinary orchard soil a total depth of 12 ins. of water during the irrigation season will be sufficient for young orchards. For a full-bearing deciduous orchard 18 ins., and for a citrous orchard 24 ins. should be ample, while for alfalfa and other forage crops 24 to 36 ins. is plenty. Where the cost of pumping is high, such as for small plants and high lifts, it will usually not be feasible to grow at a profit anything but orchards. To reduce the cost of pumping, no excess water should be used, all losses should be prevented by careful irrigation and thorough cultivation, in which case a young orchard on fairly deep retentive soil may not require more than 6 to 9 ins. of irrigation water and a full-bearing orchard not more than 12 or 15 ins. for deciduous trees and 18 ins. for citrus trees during the irrigation season. To put a depth of 2 ft. of water on one acre, it takes a flow of very nearly 1 cu. ft. per second for 24 hours; this is equivalent to 450 gals. per minute for 24 hours. This relation can be applied to any case to obtain the size of the pump. For example, if it is desired to irrigate a 40-acre orchard 1½ ft. deep, in an irrigation seasons of 120 days, this requires 60 acre feet in 120 days or ½ acre foot per day. This will be obtained by a pump giving ¼ cu. ft. per second, or 110 gals. per minute, when the pump is operated continuously 24 hours a day every day during the irrigation season of four months. For a 10-acre orchard the required capacity based on the same conditions would be one-quarter of the above, or 28 gals. per minute, or 1/10 cu. ft. per second.

The above two examples are based on a pump operating continuously at the rates given above. While continuous operation decreases the required size of plant, it is usually preferable to select a plant of larger capacity and operate it only a part of the time. This is especially desirable for very small orchards, in which case continuous operation gives a stream too small too irrigate with. The other disadvantages of continuous operation are:

(1) Continuous operation requires continuous irrigation and constant attention to operate the pumping plant. For very small tracts a regulating reservoir may be used, but it must be of considerable capacity to be of any service, and it must be lined with concrete to prevent seepage losses of the water, which when pumped is too valuable to lose. Usually it is preferable to purchase a larger plant and do without a reservoir.

(2) Continuous operation gives a small stream which cannot be applied economically.

(3) Continuous operation means that the water cannot be applied to the different parts of the orchard within a short time, so that only a small part of the orchard or farm receives the water when most needed, and the remainder must be either too early or too late.

(4) A small plant is less efficient and requires a proportionately larger fuel consumption than a larger plant, to pump the same quantity of water.

On the other hand, a very short period of operation requires a comparatively large pumping plant, which will greatly increase the first cost of installation the interest on the capital invested, the depreciation and fund necessary to provide for renewal. It also requires a larger source of supply, which may not always be available. For instance, the required flow may exceed the capacity of the well or may so lower the water plane that the cost of pumping will be increased. Also in some localities the power company may offer a low flat rate for continuous use.

Usually it is desirable to operate the pump not over one-half or one-third of the time during the irrigation season and often a shorter period is desirable. This requires a pumping plant two or three times or more the size required for continuous irrigation. The capacity of the pump must be sufficient in all cases to give a large enough stream to irrigate economically; even for the smallest orchards a stream of at least 5 to 10 miner's inches or about 50 to 100 gals. per minute is desirable.

For a full-bearing orchard 18 ins. of irrigation water for deciduous trees and 24 ins. for citrus trees, applied in three to four irrigations of 6 ins. each, at intervals of 30 to 40 days, should be ample in most cases. As stated above where the water has to be pumped to high elevation, the higher cost of the water demands greater care in its use and 12 to 18 ins. total depth of irrigation water would be sufficient.

Table XXVII gives the required pump capacity for various sizes of orchards or farms and for different periods of operation. It is based on a depth of irrigation water of 6 ins. each month, or 18 ins. in three months, which is taken as the irrigation season. The period of operation is given in number of 24-hour days that the pumping plant is operated each month. These days need not be consecutive; for instance, if the operation period is 10 days, instead of applying 6 ins. of water in one irrigation lasting 10 days, the soil may be so porous and gravelly that it will not retain the moisture, in which case it may be preferable to apply 3 ins. at a time in two irrigations during the months, of five days each. The required pump capacity is given in U. S. gallons per minute.

The capacity of pumps for smaller or greater depths of water applied per month can be easily computed by proportion from the values given. For different areas and different periods of operation the capacity may be obtained by interpolation.

TABLE XXVII.—NECESSARY CAPACITY OF PUMPS IN U. S. GALLONS PER MINUTE TO GIVE A 6-INCH DEPTH OF WATER ON THE LAND EACH MONTH WHEN OPERATED THE FOLLOWING NUMBER OF 24-HOUR DAYS EACH MONTH

Area, acres	30 days	20 days	15 days	10 days	5 days	1 day
5	19	28	38	56	113	563
10	37.5	56.25	75	112.5	225	1,125
15	57	85	113	170	340	1,690
20	75	113	150	225	450	2,250
30	113	169	225	338	675	3,375
40	150	225	300	450	900	4,500
60	226	338	450	675	1,350	6,750
80	300	450	600	900	1,800	9,000
120	450	675	900	1,350	2,700	13,500

3. *Kind of Pump.*—The kinds of pump commonly used to raise water for irrigation are: (1) centrifugal pumps, (2) power plunger pumps, (3) deep well pumps, (4) air lift pumps, (5) hydraulic rams. Where the source of water supply is a surface body of water, either a centrifugal pump, a power plunger pump or a hydraulic ram will be used; where the source of water supply is ground water developed by wells, usually either a centrifugal pump, a deep well pump, or an air lift pump will be used and in some cases a power plunger pump. For deep wells usualy the vertical centrifugal pump placed in a pit or an air lift pump is used. Hydraulic rams are used for small quantities of water such as for domestic purposes or for irrigation of small pieces of land. They are economical in operation, but require special conditions such as a nearby stream or canal with sufficient fall in a short distance.

Centrifugal Pumps.—A centrifugal pump consists of a circular casing with the inlet or suction end connected to the center and the outlet or discharge end formed tangent to the perimeter. Inside the casing is the runner or impeller keyed on the shaft and revolving with it. It is formed of curved vanes closely fitting the casing. There are two general types: First the horizontal centrifugal pump, which has a horizontal shaft; second, the vertical centrifugal pump with a vertical shaft. When in operation the impeller by revolving imparts a velocity to the water between the vanes and forces it away from the center of the casing towards the perimeter of rim of the casing through the outlet and up the discharge pipe. This produces a partial vacuum at the center of the impeller, which induces a flow through the suction pipe into the casing. The number of revolutions of the runner or speed of the pump has an exact relation to the head or lift against which the pump is working and for every head there is a speed for which the pump works most efficiently. This speed can be obtained from the pump manufacturers. It is important that the pump be connected to an engine or motor which will give it the proper speed. Over-speeding is preferable to underspeeding, but either reduces the pump efficiency.

Simple centrifugal pumps specially designed and driven at a sufficiently high rate of speed may be used for lifts considerably over 100 ft., but usually the stock pump obtainable from the manufacturers is not suitable for lifts over 75 ft., and for the smaller sizes the total lift should not exceed 50 ft. For higher lifts compound or multi-stage centrifugal pumps are used. These consist of two or more pumps connected in series, the discharge of the first pump or stage is delivered into the suction of the next pump and the operation is repeated, according to the number of stages. Usually 75 ft. to 125 ft. is allowed to each stage. When the required capacity of the pumps is over 100 or 150 gals. per minute and the total lift less than 75 ft. the centrifugal pump is no doubt the best adapted.

Centrifugal pumps are usually denoted by a number which represents the diameter of the discharge in inches. The efficient capacity of each size will vary to some extent with the speed of the pump, which depends on the total lift pumped against. The pumps can, therefore, not be rated accurately. The capacities given in Table XXVIII are worked out from the ratings given by a reliable pump manufacturer and are subject to considerable variations either above or below the values given.

TABLE XXVIII.—CAPACITIES OF CENTRIFUGAL PUMPS

No. of pump or diameter of discharge in ins.	Capacity in U. S. gallons per min.	Capacity in second-feet, or acre-inch per hr.	Number of acres irrigated 6 in. deep each month for operation period during the month of 30 days	20 days	15 days	10 days	5 days	1 day
2	100	0.22	27	18	13	9	4½	0 9/10
2½	150	0.33	40	27	20	13	6½	1 3/10
3	225	0.50	60	40	30	20	10	2
3½	300	0.66	80	53	40	27	13	2⅔
4	400	0.90	110	71	55	36	18	3⅔
5	700	1.60	190	127	95	63	32	6⅓
6	900	2.00	240	160	120	80	40	8
7	1,200	2.70	320	213	160	107	54	10⅔
8	1,600	3.50	430	287	215	143	72	14⅓

To start a centrifugal pump the suction pipe and the pump must be filled with water or primed. This may be done by closing the discharge pipe with a check valve and connecting the suction end of a hand pump to the top of the casing. Where a steam engine is used, a steam ejector may take the place of the hand pump. For small pumps and low lifts a foot valve on the end of the suction pipe may be used and the pump primed by pouring water in the casing or suction pipe. The disadvantage of a foot valve is that if the water is not clear a small stone or twig may lodge itself in the foot valve and prevent priming. This will necessitate that the suction pipe be uncoupled and the obstruction removed.

The pump must be placed as near as possible to the water level to keep the suction lift down. While theoretically the suction lift may be as great as 33 ft. at sea level and about 30 ft. at an elevation of 3000 ft., it is desirable not to exceed 20 ft., and less is preferable. The horizontal centrifugal pump is preferable where the depth from the ground surface to the water plane is not large. But where the depth is large, it is necessary to place the pump in a deep pit, in which case either the vertical centrifugal pump or a deep well pump is generally used. A horizontal shaft centrifugal pump is usually more efficient than a vertical centrifugal, and it eliminates the end thrust of the shaft obtained with the vertical shaft which is difficult to balance properly. During the past few years a new type of vertical centrifugal, commonly named turbine centrifugal pump, has been developed for pumping from deep wells without the necessity of a pit. These pumps are installed inside the casing of bored wells 12 to 30 ins. in diameter.

The plant efficiency can be increased by reducing the friction in the suction and discharge. As few bends as possible should be used and those should be made by using long turn elbows. The suction and discharge pipes should be larger than the intake and outlet openings of the pumps and joined to the pump with an increaser. The diameter of the suction pipe and especially of the discharge pipe should be 1½ times the diameter of the intake, and if the discharge pipe is long it may be economy to make the diameter even larger. Where the source of water supply is a surface body of water, enlarging the lower end of the suction pipe will further decrease the friction. This may be done by a funnel-shaped section whose length is about three times the diameter of the suction pipe and whose large end is about 1½ times the diameter of the pipe. The larger opening at the entrance to the suction pipe will decrease the tendency to suck up sand or gravel. When the water carries weeds, gravel or other material a strainer should be used and the total area of the strainer should be at least twice the area of the suction pipe. The discharge pipe should not carry the water any higher than necessary.

Power Piston or Plunger Pumps.—This type of pump is used where the water is obtained from a surface source or where the water plane is near the surface of the ground and the lift to the point of delivery is large. It consists of one or more cylinders, in each one of which a piston or plunger moving backwards and forwards sucks the water into the cylinder and forces it up the discharge pipe. When the cylinder has only one suction valve and one discharge valve, the motion of the piston in one direction causes suction and the displacement in the opposite direction forces the water through the discharge pipe. With two sets of valves so arranged that there is a discharge for each displacement of the piston, the pump is known as a double acting pump. When the pump has two cylinders, it is known as a duplex pump, with three cylinders it is a triplex pump, and in either case may be either double acting or single acting. The cylinders with the driving gears or pulleys are assembled together and built at a height above the water plane, which must not exceed the suction lift.

The capacity of the pump will depend on the diameter of the cylinder, the length of the stroke of the piston, and the number of strokes or revolutions per minute. The capacities of a few sizes of double acting, single piston pumps, single acting triplex pumps and of double acting duplex pumps are as follows:

CAPACITY OF DOUBLE ACTING, SINGLE PISTON PUMP

Diameter of water cylinder ins.	Length of stroke, ins.	Revolutions or strokes per min.	U. S. gals. per min.
3	5	40	12.4
4	5	40	21.6
5	5	40	34
6	6	40	58
7	6	40	80
8	6	40	104
CAPACITY OF SINGLE ACTING, TRIPLEX PISTON PUMP			
3	4	50	18
4	4	50	32
4	6	50	50
5	6	50	76
5	8	45	91
6	8	45	131
7	8	45	180
7	10	42	210
8	10	40	270
8	12	40	310
9	10	40	340
CAPACITY OF DOUBLE ACTING, DUPLEX PUMPS			
2¼	4	75	20
3	4	75	36
3½	6	60	58
4	6	60	78
5	6	60	120
6	6	60	174
5	10	50	170
6	10	50	245
7	10	50	334
8	12	50	522
9	12	50	660

The sizes of pumps and the capacities vary with the different manufacturers. The values stated above show the approximate range of the different sizes. For small capacities the double acting single piston pump may be used.

Deep Well Pumps.—These pumps are used where the water plane it at large depths below the ground surface. A deep well pump consists of a brass cylinder in which operate two plungers with valves. The lower plunger is connected to a solid rod which fits into a hollow rod to which the upper piston is connected. The plungers are so operated by the driving power that the pump is double acting, one plunger moving up while the other moves downwards, so that there is a continuous discharge. Above the cylinder and connected to it is the vertical discharge or column pipe into which discharges the water passing through the valves in the plunger. The cylinder is about 2 ins. smaller in diameter than the well casing and the delivery pipe about 1 in. less; the cylinder and delivery pipe are both lowered into the well until the plungers are under water. At the surface the driving power and circular motion of the belt of the engine is transmitted to the driving rods by means of gears and levers combined into a power head designed to produce overlapping strokes, so as to eliminate to some extent the pulsations which are further decreased by an air chamber. The sizes range from 6-in. cylinders and

28-in. stroke to 16-in. cylinders and 36-in. stroke. The number of strokes ranges from 16 to 24 per minute, depending on the lift and the size. The maximum lift is 350 ft. The capacity ranges from about 115 gals. per minute to a maximum of 1000 gals. for the largest pump with extra long cylinder.

Air Lift Pumping Plants.—Air lift or compressed air pumping plants consist of one or more air lift pumps. The air compressor with receiver and motive power and the necessary piping to deliver the compressed air from the receiver to the pumps. Each pump consists of: (1) the discharge pipe, which is smaller than the well casing and is placed inside of it, extending below the water surface to a depth equal to 1½ to 2 times the lift measured from the water surface; (2) the air pipe, which is usually inside the discharge pipe, but may, if the well is enough larger than the discharge pipe to so permit, be placed outside and connected at the lower end of the discharge pipe by means standard fittings or special castings; (3) the foot piece, which is a special casting connected to the lower end of the air pipe and so designed to admit the air evenly in small bubbles. There are various designs of patented foot pieces, but there is little difference in their efficiency; (4) the tail piece which forms a slightly enlarged extension of the lower end of the discharge pipe below the foot piece. The air is delivered through the foot piece at pressures varying according to the lift and the ratio of diameters between air pipe and water pipe, and its expansion and displacement produces the lifting power. The relation between the volume of air supplied and the volume of water pumped for different lifts has been found by experiment to be as follows:

Head in feet..........................	10	20	30	50	100
Ratio $\dfrac{\text{Cubic feet of air}}{\text{Cubic feet of water}}$	1.0	1.5	2.0	2.5	3.0

The velocity of water in the discharge pipe, based on the volume of water pumped should not exceed 5 ft. per second in order to keep down friction losses.

The compressor may be direct connected to a steam engine or gasoline engine or may be connected by means of belts, gears, etc., to the driving power which may be a steam engine, a gasoline engine or electric motor. The compressed air passes from the air cylinder to the receiver, which is used to store the air and equalize the pressure. From the receiver the air is conducted through pipes to each well.

The efficiency of the plant when properly installed as calculated from the ratio of actual water horse-power to the indicated horsepower in the cylinder of the engine is generally between 20 and 30 per cent. Air lifts are best adapted for pumping from several wells not farther apart than one-half mile and where the wells are sufficiently deep to allow proper submergence.

Hydraulic Rams.—The hydraulic ram works on the principle that a large volume of water falling through a low head will pump a smaller volume of water through a higher head. The ram consists of the valve box and air vessel, the supply or drive pipe which connects the valve box with the source of supply and the delivery or discharge pipe which connects the air vessel with the point of delivery. The efficiency of the plant is $E = qh/QH$ where q = volume of discharge water, h = discharge head in feet above ram, Q = volume of drive water, H = drive head in feet. For best results the ratio of the length of drive pipe to the length of drive head should not exceed 2.5; but it is practicable to increase this ratio to 25 and use a drive pipe 1000 ft. long. The delivery head may be anything up to about 250 ft. and the drive head anything above 18 ins. The efficiency diminishes as the ratio of delivery to drive head increases. With this ratio as great as 30 to 1 the efficiency will not be over 20 per cent; with a ratio not greater than 4 to 1 the efficiency may be as high as 75 per cent. Rankine gives the following equation to determine the efficiency for varying ratios of drive head to discharge head: $E = 1.12 - .2\sqrt{\frac{h}{H}}$.

Hydraulic rams are usually limited to small quantities of water. A notable example of a large plant for irrigation purposes is one installed at Sunnyside, Wash., for the irrigation of 240 acres of land. The plant was installed by the Columbia Steel Works of Portland, Ore., and consists of eleven 6-in. rams, with a common discharge cylinder emptying into a 10-in. wood stave discharge pipe. The plant is used to irrigate 150 acres under 105 ft. lift and 90 acres under 144 ft. lift. The lifts are measured from rams. The drive head is 38 ft. and the drive water 5 sec. ft. The plant was furnished under guarantee to deliver .75 sec. ft. at higher outlet. The cost of plant is as follows:

Eleven 6-in. rams and 3,212 ft. of wrought iron drive pipe	$3,200
1,900 ft. of 10-in. wood discharge pipe	608
Installation, complete	2,000
Total cost	$5,808

No maintenance except two visits per day to clear weeds out.

An efficiency test gave the following results: $H = 37.6$; $h = 144.1$; $Q = 6.25$; $q = 1.15$

$$E = \frac{1.15 \times 144.1}{6.26 \times 37.6} = .70$$

Adaptability of the Several Types of Pumps for Small Pumping Plants.— Where the source of water supply is a stream or surface body of water, the choice is usually between a power pump and a centrifugal pump and will depend largely on the lift and capacity. Power pumps are best adapted to high heads above 75 ft. and to small or moderate volumes of water, usually under 200 gals. per minute. For these conditions the efficiency of a power pump is usually greater than that of a centrifugal pump. For greater volumes the plunger pumps are comparatively expensive and centrifugal pumps are usually preferable unless the lift is excessive. The centrifugal pump has the advantage that it is simple in construction with no parts to get out of order, and that it is cheaper than a power pump.

Where the source of water supply is ground water with the water table in the well at a depth below the surface not much greater or less than the limit of suction lift, so that a deep pit is not necessary, then the choice is between a centrifugal pump, a power pump and an air lift pump. The selection between the centrifugal and power pump will depend on a consideration of lift and capacity as explained above. Air lift plants have low efficiency, require a depth of well below the water table equal to about twice the lift measured from the water table and are hardly to be considered in connection with separate small pumping plants. They are best adapted to a large number of wells (at least six or preferably more) placed close together.

Where the source of water is ground water developed by deep wells with the water table at a large depth below the surface (50 to 200 ft. or more) the choice is between a vertical centrifugal pump in a pit and a deep well pump which eliminates the pit. Deep well pumps are best adapted where the lift is in excess of 100 or 150 ft. and for wells that do not yield more than about 400 gals. per minute. Their efficiency is greater than that of centrifugal pumps, but the cost of repairs and depreciation is greater.

The selection should be made only after careful consideration of the first cost of the pump and the annual cost of fuel, operation and maintenance. Where the lift is high, the fuel cost will be considerable and it is good economy not to select the cheapest pump obtainable, but one that is guaranteed for its efficiency. On the other hand, if the pump is to be operated only during a very small portion of the season, it would be poor economy to invest a large capital in a high-grade pumping plant to save in fuel cost.

4. *Classes of Engines or Driving Power. Methods of Connection of Pump with Engine.*—The driving power is generally either gasoline engine, steam engine, or electric motor.

Centrifugal pumps are usually either direct connected (except for varying low heads) or connected by means of belt, gears, or chains. Power pumps are connected by belts or gears. Direct connection is preferable when possible; it is more efficient and eliminates the adjustment of belt or chain necessary with belt or chain driven pumps. The connection of these pumps and driving power must be such that the pumps will be given the speed or number of revolutions per minute for which they are designed and for which the highest efficiency is obtained. For this reason direct connection can only be used where the driving power and the pump have the same speed. The speed of centrifugal pumps is usually high; so is that of electric motors; and for this reason they can, if properly designed, be direct connected. This is done usually by means of a flexible coupling. Gasoline and steam engines are generally operated at a much lower speed than centrifugal pumps, and for that reason are not direct connected unless the engine and pump are specially designed. This is done by some manufacturers. Power plunger pumps are operated at a low speed, and for that reason are not direct connected to the driving power. When connected by gears, belts or chains, the driving gear and driven gear, or the driving pulley and driven pulley must be so proportioned that the pump will be given its correct speed. When a plunger pump is built with steam engine in a single machine, with the piston or plunger of the water cylinder on the same driving rod as the piston of the steam cylinder, it is called a direct acting steam pump. The fuel consumption of a steam pump is greater than that of a steam driven power pump and for that reason steam pumps are not considered.

Deep well pumps are usually equipped with gears and levers combined and connected with the driving rods of the pump, forming what is called the pump head, the object of which is to convert and transmit the circular motion of the driving power to the driving rods of the pump. The engine or motor is usually connected to the pump head by belts, but may be connected by means of gears. In some cases steam heads are provided in the place of the pump head.

Capacity of Engine.—The power necessary to life water is indicated in horsepowers. A horse power represents the energy required to lift 33,000 lbs. 1 ft. high in one minute; this is equivalent to 3960 gals. of water per minute raised 1 ft. high. This relation enables one to find the net horsepower required in any case by multiplying the discharge of the pump in gallons per minute by the total lift in feet and dividing by 3960. The result obtained represents the useful water horsepower necessary to lift the water. The horsepower delivered by the engine to the belt or gears when the pump is belted or geared to the engine, or to the pump itself when direct connected is the brake horsepower, and must be greater than the useful water horse power to allow for the loss of energy in the pump and transmisson. The horsepower developed within the engine itself is the indicated horsepower, and must be greater than the brake horsepower to allow for the energy loss in the engine itself. Gasoline engines and motors are rated on brake horsepower, but gasoline engines are frequently over-rated. Steam engines are rated on indicated horsepower.

The combined efficiency of a pumping plant represents the ratio of the useful water horsepower, to the rated horsepower of the engine, and will vary considerably with the type of pump, method of connection of engine with pump and the care taken in operating both pump and engine at the proper speed. In ordinary field practice a good pumping plant, properly installed, should easily reach the efficiency given in Table XXIX:

TABLE XXIX.—EFFICIENCY OF CENTRIFUGAL PUMPING PLANTS AND BRAKE HORSEPOWER PER FOOT OF LIFT

No. centrifugal pump	Discharge, U. S. gals. per min.	Water h.p. per ft. of lift	Efficiency, pct.	Brake h.p. per ft. lift
2	100	.025	30	.081
2½..................	150	.038	35	.11
3..................	225	.057	40	.14
3½	300	.08	45	.18
4..................	400	.10	45	.22
5..................	700	.17	50	.34
6..................	900	.23	50	.46
7..................	1,200	.31	50	.62
8..................	1,600	.41	55	.75

The efficiency of power plunger pumps varies with the size of the pump and with the lift. A greater efficiency is obtained with the higher lifts and with the larger sizes. The efficiencies of properly installed plunger pumps and the horsepower for various lifts are given in Table XXX.

TABLE XXX.—BRAKE HORSEPOWER REQUIRED TO OPERATE PLUNGER PUMPS

Diameter of cylinder ins.	Length of stroke ins.	Capacity in U. S. gals. per min.		—Efficiency and brake hp. for lifts of— 50 ft.	100 ft.	150 ft.	200 ft.	250 ft.
3	4	18	E.	0.30	0.40	0.42	0.45	0.45
			Hp.	0.75	1.1	1.6	2.0	2.5
4	4	32	E.	0.35	0.50	0.60	0.65	0.65
			Hp.	1.2	1.5	2.0	2.5	3.1
4	6	50	E.	0.35	0.50	0.60	0.65	0.65
			Hp.	1.9	2.5	3.1	4.0	4.8
5	6	76	E.	0.40	0.55	0.65	0.70	0.70
			Hp.	2.4	3.5	4.4	5.5	6.7
5	8	90	E.	0.40	0.55	0.65	0.70	0.72
			Hp.	2.8	4.1	5.2	6.5	7.8
6	8	131	E.	0.45	0.60	0.65	0.70	0.72
			Hp.	3.6	5.5	7.5	9.3	11.4
7	8	180	E.	0.45	0.60	0.65	0.70	0.72
			Hp.	5.0	7.5	10.5	13.0	15.5
7	10	210	E.	0.50	0.65	0.70	0.75	0.78
			Hp.	5.25	8.0	11.0	14.0	17.0
8	10	270	E.	0.50	0.65	0.70	0.75	0.78
			Hp.	6.75	10.25	14.50	18.25	22.1
9	10	340	E.	0.50	0.65	0.70	0.75	0.78
			Hp.	8.5	13.0	18.0	23.0	28.0

The plant efficiency of deep well pumping plants as ordinarily installed and operated was found from measurements made in a number of pumping plants in southern California to be from 35 to 55 per cent. With proper installation and operation the plant efficiency or ratio between useful water horsepower and brake horsepower should be from 50 to 65 per cent.

The plant efficiency of air lift pumps expressed as the ratio between the useful water horsepower and the indicated horsepower in the engine cylinder was found from test on a number of such plants in southern California to average a little less than 20 per cent.

Type of Engine.—Tables XXIX and XXX will give the size of the engine. The driving power must be either a gasoline engine, steam engine, or electric motor. The methods of connecting the engine with the pump have been already considered. Other factors being equal direct connection is preferable when possible.

For small plants irrigating a few acres, the steam engine, although very reliable, is not so commonly used as the gasoline engine except where coal or oil is very cheap as compared to gasoline. However, for larger areas and where coal or oil is cheap, it may be cheaper than either a gasoline engine or electric motor. For large plants operated continuously it may be economy to install an efficient boiler and a high grade compound condensing, triple expansion, or quadruple expansion, steam engine, in order to decrease the fuel cost. For small plants operated only for short periods during the irrigation season it is much more important to decrease the cost of installation. The interest on the capital invested and the depreciation of the plant are very important items of cost as compared to the fuel cost. For these reasons, unless the acreage is large and the lift very high, the steam plant will consist of a semi-portable locomotive type boiler and an ordinary slide valve steam engine.

5. *First Cost of Plant.*—The first cost of a pumping plant depends on the grade of machinery, the cost of transportation, the expense of installation. Because of these factors accurate estimates of cost cannot be given. However, the approximate cost values given below in Tables XXXI, XXXII and XXXIII will be of value to the land owner who is considering the feasibility of a pumping plant. The values given represent the prices at the factory and do not include transportation and installation.

TABLE XXXI.—APPROXIMATE COST OF SINGLE STAGE CENTRIFUGAL PUMP

No. of pump	Capacity in gals. per min.	Cost
2	100	$ 42
2½	150	51
3	225	57
3½	300	65
4	400	75
5	700	85
6	900	115
7	1,200	145
8	1,600	170

The cost of two step centrifugal pumps of the same sizes will be about four times the values given above.

TABLE XXXII.—APPROXIMATE COST OF TRIPLEX SINGLE ACTING POWER PUMP

Diameter of water cylinder	Length of stroke in ins.	Capacity in gals. per min.	Height of lift, ft.	Cost
4	8	65	75 to 100	$17
5	10	130	100	250
5	12	220	100	340
4	6	48	175	225
5	8	91	175	325
7	8	180	175	450
8	10	270	175	700
8	12	310	175	750

TABLE XXXIII.—APPROXIMATE COST OF ELECTRIC MOTORS GASOLINE ENGINES AND SIMPLE SLIDE VALVE, NON-CONDENSING STEAM ENGINES, WITH LOCOMOTIVE BOILER AND AUXILIARIES

Horsepower	Cost of electric motors, 1,200 rev. per minute	Cost of gasoline engines	Cost of steam engines
2	$ 70	......	......
3	85	......	......
5	110	$ 375	$ 500
10	200	550	625
15	230	700	800
20	320	850	925
25	360	1,000	1,000
30	....	1,200	1,200
40	450	1,600	1,350

Cost of Accessories and Installation.—The costs given in Tables XXXI, XXXII and XXXIII are for the pumps and engines, and do not include the accessories, the foundation, the labor of installation, and the housing. For an electric plant the cost of transformers should be added unless these are supplied by the electric company. The accessories will include the suction and discharge pipes, the valves and fittings, the priming pump, the connection between pump and engine. The suction pipe is usually made of steel; the discharge pipe may be steel or wood banded pipe and should cost delivered as given in table XXXIV.

TABLE XXXIV.—COST OF PIPES SAFE FOR 150 FEET HEAD

Diameter of pipe, inches	Cost per foot of wood banded pipe	Cost per foot of steel pipe
4	$ .20	$ .30
6	.30	.50
8	.40	.80
10	.55	1.10
12	.65	1.35
14	.75	1.60
16	.95	2.00
18	1.10	2.50
20	1.44	3.00

For a rough estimate the total cost of valves, priming pump, all fittings and suction pipe, but not discharge pipe, may be taken as about 10 per cent of the cost of pump and engine for a gasoline or steam plant and 20 per cent for an electric plant. The cost of installation should not exceed 5 per cent. The cost of a building to house the plant will range from about $25 for a small plant to $100 or more for a larger plant. The cost of transportation and hauling will depend on the railway charge and on the distance from the station to point of installation.

6. *Fuel Consumption and Fuel Cost.*—The selection between a steam engine, gasoline engine and an electric motor will depend to some extent on the comparative cost of coal, gasoline and eletrical energy.

A gasoline engine is usually guaranteed for a fuel consumption of ⅛ gal. per rated or brake horsepower per hour. A new engine well adjusted will come up to this efficiency, but an engine that has been operated some time will consume about ⅙ gal. of engine gasoline or distillate per brake horsepower per hour.

The fuel consumption of a steam engine will vary greatly on the type of boiler and engine. A small slide valve non-condensing engine under 25 hp.

will use probably 50 to 60 lbs. of steam per brake horsepower per hour. A locomotive type of boiler should give 5 or 6 lbs. of steam for 1 lb. of coal or about 0.6 lb. of oil. Therefore, a small steam engine under 25 hp. should consume 10 lbs. of coal per brake horsepower per hour or about 6 lbs. of oil. Steam engines of the same type from 30 to 50 hp. will consume from 8 to 5 lbs. of coal per brake horsepower per hour or from 5 to 3 lbs. of oil.

Electrical energy is measured in kilowatts. A killowatt is equal to 1⅓ hp., but because of the loss of energy in the motor, 1 kilowatt will usually give about 1.1 brake horsepower. Based on this figure 1 brake horsepower hour is equal to 9/10 of a kilowatt hour.

The above values show that to produce 1 brake horsepower per hour requires either ⅙ gal. of distillate, about 10 lbs. of coal, or 6 lbs. of oil, or 9/10 of a kilowatt hour. Based on these figures Table XXXV shows the cost of fuel per brake horsepower per hour for several equivalent cost values of fuel. In the table is also given the fuel cost of pumping one acre foot of water through one foot of lift, assuming plant efficiency of 50 per cent and 75 per cent.

TABLE XXXV

Equivalent unit costs of fuel				Fuel cost (in cents)		
Gasoline, cents per gal.	Crude oil per bbl. (335 lbs.)	Coal per ton	Cost of electric, cents per K.W. hour	Per brake hp. per hour	Per acre foot of water lifted 1 foot high 50 per cent efficiency	75 per cent efficiency
6	$ .55	$2.00	....	1.00	2.75	1.83
8	.75	2.66	....	1.33	3.70	2.45
10	.93	3.33	1.85	1.66	4.60	3.05
12	1.12	4.00	2.22	2.00	5.50	3.65
14	1.30	4.66	2.60	2.33	6.40	4.25
16	1.50	5.33	3.00	2.66	7.30	4.90
18	1.67	6.00	3.33	3.00	8.25	5.50
20	1.85	6.66	3.70	3.33	9.15	6.10
22	2.05	7.33	4.10	3.66	10.10	6.70
24	2.25	8.00	4.35	4.00	11.00	7.35
26	2.42	8.66	4.80	4.33	11.80	7.95

7. *Fixed Charges and Attendance. A. Fixed Charges.*—The cost of installation represents a capital which if invested would bring in an income represented by the interest. It is therefore necessary to consider this interest as part of the cost of operation. To this should be added the annual cost of repairs maintenance and renewal. These items of cost represent the fixed charges. After six or eight years a gasoline engine may need to have its cylinder rebored and a new piston provided, the cost of which is about one-fourth the cost of a new engine. With ordinary care the life of a gasoline engine may be taken as 10 years; the life of an electric motor about 15 to 20 years. The fixed charges on the entire plant may be taken as follows:

	Gasoline engine plant	Electric plant	Steam engine plant (small)
Depreciation and renewal	8%	5%	8%
Repairs and maintenance	3	1	2
Interest	6	6	6
	17%	12%	16%

B. Attendance.—An electric motor requires a minimum of attendance, small gasoline plants require frequent inspection, and steam engines require considerable attention and usually cannot be economically used for small plants operated during short periods. The cost of attendance for an electric motor pumping plant should not exceed 5 cts. per hour, for a gasoline engine plant 10 cts. per hour, and for a steam engine plant 30 cts. per hour. While electric motors and gasoline engines are usually operated by the orchardist or irrigator, his time is valuable and a charge should be made for it.

8. *Final Selection of Type of Plant.*—The final selection of a pumping plant should be based on a careful consideration of the factors stated above. The best size of plant, the period of operation, the kind of engine or driving power, can only be correctly determined by a final consideration of a cost of installation and cost of operation. Where electric power is available, the choice is between a steam engine, a gasoline engine and an electric motor. The electric motor requires minimum attendance. It is reliable and its first cost is much less than that of a gasoline or steam engine. For these reasons if electric power is available, an electric motor is preferable and will prove far more economical even should the cost of electrical energy be higher than the fuel cost for a gasoline or steam engine.

The application of the above information and cost data to any particular case is illustrated by the following examples:

A 20-acre orchard is to be irrigated by pumping from a surface body of water requiring no wells. The quantity to be applied is 6 ins. per month, and the total depth in one season 18 ins. The lift is 50 ft. and the discharge pipe 200 ft. long. Engine gasoline or distillate costs 12 cts. per gallon. Assuming the pump is operated one-third of the time or ten 24-hour days each month, this will require a pump capacity of 225 gals. per minute, which is obtained with a No. 3 centrifugal pump and 7 hp. engine. The discharge pipe will be 4 ins. in diameter. The first cost and total cost of operation will be about as follows:

First Cost of Plant

No. 3 centrifugal pump	$ 57
7 hp. gasoline engine	450
Priming pump, suction pipe, fittings, etc	50
Freight charges and hauling	30
Wood banded discharge pipe, 200 ft. of 4-in	40
Installation, 5 per cent of cost	35
Building to house plant	40
Total cost	$702

Total Annual Cost of Operation

Fuel cost of 7 brake hp. engine for 3 periods of 10 days each or 720 hours = 720 × 7 × 0.02	$100
Fixed charges at 17 per cent of first cost	120
Attendance, 720 hours at 10 cts	72
Total cost for 20 acres	$292
Cost per acre, $15.	

Where electric power is obtainable, the first cost of plant and annual cost of operation for same conditions, assuming the unit cost of electric power to be 3 cts. per kilowatt hour, would be:

First cost of plant	$375
Total cost of operation (annual)	215
Cost of operation per acre	11

Tables XXXV and XXXVI show the first costs of gasoline engine pumping plants and the costs of operation for orchards of 20, 40 and 80 acres for lifts of 50 ft. and 150 ft., and for different periods of operation. For the higher lifts single acting triplex pumps are used. The costs given are based on gasoline at 12 cts. a gallon, for a depth of irrigation of 18 ins. for the lower lift and depths of 18 ins. and 12 ins. for the higher lift, it being assumed that by careful use of water, if the soil is retentive, 12 ins. may be sufficient. The discharge pipe is assumed to be 200 ft. long.

TABLE XXXVI.—COST OF PUMPING WITH GASOLINE ENGINES AND CENTRIFUGAL PUMPS FOR 50-FOOT LIFT, GASOLINE 12 CENTS A GALLON

Area in acres	No. of 24-hour days pump is operated monthly	Capacity of pump Gals. per min.	Number of pump	Horsepower of engine	First cost of installation	Annual cost of operating per acre; –18 ins., depth of water applied– Fuel	Fixed charges	Attendance	Total
20	5½	400	4	12	$ 970	$4.80	$8.25	$1.90	$14.95
	10	225	3	7	700	5.10	6.00	3.60	14.70
	20	113	2	5	590	7.00	5.00	7.20	19.20
40	5	900	6	25	1,575	4.50	6.70	.90	12.10
	11	400	4	12	970	4.80	4.10	2.00	10.90
	20	225	3	7	700	5.10	3.00	2.60	11.70
80	10	900	6	25	1,575	4.50	3.35	.90	8.85
	22	400	4	12	970	4.80	2.05	2.00	8.85

TABLE XXXVII.—COST OF PUMPING WITH GASOLINE ENGINES AND SINGLE ACTING TRIPLEX PUMPS FOR 150-FOOT LIFT

Area in acres	No. of 24-hour days pump is operated monthly	Capacity of pump Gallons per minute	Horsepower of engine	First cost of installation	Annual cost of operation per acre for a depth or irrigation, water of: ——18 inches—— Fuel	Fixed charges	Attendance	Total	12 ins. Total
20	8⅓	270	15	$1,850	$ 9.90	$15.75	$3.00	$28.65	$24.35
	12½	180	10	1,375	9.90	11.70	4.50	26.10	21.30
	25	90	6	1,025	10.90	8.70	9.00	28.60	22.00
40	13¼	340	18	2,200	8.70	9.35	2.40	20.45	16.75
	16⅔	270	15	1,850	9.90	7.90	3.00	20.80	16.50
	25	180	10	1,375	9.90	5.85	4.50	20.25	15.45
80	26½	340	18	2,200	8.70	4.70	2.40	15.80	12.10

The capacities of pumps, especially plunger pumps, and the sizes of engines vary with the different makes, and for that reason the sizes given are not always obtainable, but sizes approximating these can be used in place.

The above cost estimates are only approximate. They are based on the conditions stated above and are not applicable to all cases because of the varying conditions which make the installation of nearly every pumping plant a special problem. The estimates are made for gasoline engines and are considerably higher than for electric motors. The first example showed that with an electric plant the cost of pumping was only 73 per cent of the cost with a gasoline plant. The tabulated values show the following interesting results:

(1) The cost per acre of pumping is much larger for a small area than for a large area.

(2) The cost per acre does not vary considerably with the period of operation, and in some cases a plant moderately large operating for a shorter period will cost less per acre than a smaller plant operating a longer period. This is due to the lower fuel cost with the larger and more efficient plant and the decreased cost of attendance for the shorter period of operation which overbalance the larger fixed charges. Even should the resulting cost be smaller for the smaller plant, the inconvenience due to pumping for a long period and the extra labor in irrigation may overbalance the saving in cost.

(3) For the lifts assumed a period of operation equal to about ten 24-hour days during the month of one-third of the time during the irrigation season seems to be preferable with the centrifugal pump. With the higher price triplex plunger pumps a period of operation of one-third to two-thirds of the time is preferable.

Co-operative Pumping.—The lower cost per acre for larger areas shows the advantage to be gained by co-operation between small owners. By uniting and installing a large plant instead of several smaller plants, the cost of installation and operation is very much reduced, and the plant can be given more competent attention, which relieves the orchardist and increases the life of the plant. Where by such co-operation several hundred acres can be brought together, a central steam plant to generate electric power, which is transmitted to the several electric motor pumping plants, is the most economical and best solution.

For separate plants above 20 or 40 hp., gas producer plants connected to gas engines will furnish the cheapest power. These plants are reliable and easily operated. They consist of the producer in which hard coal is placed and through a process of partial combustion, in the presence of air and steam, forms the gas which operates the engine. Gas producers operated on hard or anthracite coal have been in successful operation for a number of years, and those operated on soft or bituminous coal and on oil are coming into use, but are still in the experimental stage. The fuel consumption is very low, usually from 1 to ½ lbs. of coal or ⅙ to 1¼ gals. of crude oil per horsepower for one hour; or ½ to ¾ ct. per horsepower for one hour with hard coal at $10 per ton and about ⅛ ct. with oil at 2 cts. a gallon. This is from 2½ to 6 times less than the fuel cost with gasoline at 12 cts. a gallon. Producer gas plants are much expensive than gasoline engines and for small plants the fuel economy will be overbalanced by the larger interest and depreciation charges. For very large single plants, high duty steam engines will be the most economical form of installation.

Limits of Economical Pumping.—The cases previously worked out for gasoline engine pumping plants show that for small tracts of 20 to 80 acres the cost of lifting sufficient water to give a depth of irrigation water of 18 ins. will range for a lift of 50 ft. from about $8.85 per acre for the larger area to about $15 per acre for the smaller area, and for lifts of 150 ft. the respective costs are about $15 and $25 per acre. These costs may seem high as compared with gravity water, but to obtain an idea of the economy and feasibility of developing water by pumping, comparisons must be made with the value of gravity irrigation water in the same conditions. Except in southern California, up to a few years ago gravity water without pumping has been obtainable. For that reason pumping has not been necessary, and comparatively few pumping plants have been constructed. However, water is becoming more valuable and the steps which many irrigation companies are taking to conserve water and prevent losses of transportation by carrying the water in concrete-lined canals and in pipes constructed at considerable expenses, show that in some localities at least, water has become sufficiently valuable to justify pumping. If a comparison is made with water thus obtained, we find that the cost of construction of a well constructed system may go up to $50 or $60 an acre and even higher. This cost is charged up to the land which is sold to the orchardist and in addition reasonable profit is made on the value of the land. It is probably conservative to assume that land under an irrigation system in localities well developed and where irrigation is necessary, will cost at least $100 an acre more than similar land for which there is no gravity supply. The chief advantage of gravity systems is the low annual cost of operation, usually less than $2 or $3 per acre, although in some cases it may be as much as $5 per acre or more, but if to this be added the interest on the difference in cost between land under the irrigation system and land which is to be supplied by pumping, assumed at $100, the total annual cost may be $10 to $15 an acre. This is about equal to the cost of pumping with gasoline engines to a height of 50 feet and about half as large as for lifts of 150 feet. Where electric power is available or for large pumping plants the cost of pumping would compare very favorably with gravity water, even for higher lifts than those stated above.

Some of the advantages of underground pumped water as compared to water obtained from a gravity irrigation system are:

(1) An underground supply is more reliable and is not likely to be deficient before the end of the irrigation season.

(2) The irrigator is independent and controls his own water supply, and is prepared to irrigate his crops at the best time.

(3) The underground water is free from the seeds of weeds.

A consideration of pumping in some of the well developed irrigated districts is of interest to show its feasibility. In eastern Washington water is being pumped in one case to an elevation of 250 ft. above the source of supply. In the citrus district of southern California lifts above 200 ft. are not unusual, and it is considered profitable to pump 460 ft. In the Pomona district of southern California the cost of pumped water averages $15 per acre for one acre foot when purchased from irrigation companies, while for smaller private plants the cost is often greater. In 1905 the Irrigation Investigations Office of the United States Department of Agriculture made tests on various pumping plants and these show that the cost of pumping at private plants of 10 to 100 hp. with lifts of 100 to 300 ft., varied from $10 to $90 per acre for one acre foot of water.

There is a limit beyond which it is not economically feasible to pump. In the California citrus districts lifts above 400 ft. have been considered profitable. For the orchard lands of the Northwest equally high lifts should be profitable, for the net return per acre from a good apple orchard is usually more than that from a citrus orchard. A citrus orchard 10 years old should average a net profit of $100 to $150 per acre. The net profits from apple orchards 10 to 12 years old in the Yakima Valley are given in bulletins of the United States

Department of Agriculture as $200 to $600 per acre. With profits larger than those obtained from citrus orchards in southern California, what has been considered feasible in pumping there, is at least equally so for apple orchards or other valuable crops when no other more economical source of water supply is available. However, for small pumping plants and small areas it is well not to exceed 200 ft., while the larger plants lifts of 400 ft. may be economically feasible.

First Cost and Cost of Operation of Irrigation Pumping Plants.—The following data, published in Engineering and Contracting, June 2, 1915, are condensed from a paper by H. D. Hanford in the proceedings of the Washington Irrigation Inst.

Plant Costs.—As a basis for the figures, the representative of a well-known manufacturer was asked to give prices, efficiency and other data on both centrifugal and triplex power pumps, ranging in capacity by the hundred gallons, from 100 to 500, inclusive, a minute, and for heads of 25, 50, 100 and 200 ft. Taking these prices as a basis, and adding the cost of motor, fittings, erection and building, we have the following schedule of plant costs:

DIRECT CONNECTED CENTRIFUGAL PUMPS

Capacity, G. P. M.	Head	Size	Cost of plant
100	25	2½-in.	$ 407.00
100	50	2-in.	369.00
100	100	2-in.	479.00
100	200	2-in. 2 S	715.00
200	25	3-in.	550.00
200	50	3-in.	550.00
200	100	2½-in.	600.00
200	200	2½-in. 2 S	875.00
300	25	4-in.	644.00
300	50	3-in.	644.00
300	100	3-in.	715.00
300	200	3-in. 2 S	1,034.00
400	25	5-in.	732.00
400	50	4-in.	698.00
400	100	3-in.	748.00
400	200	4-in. 2 S	1,249.00
500	25	5-in.	787.00
500	50	4-in.	765.00
500	100	4-in.	831.00
500	200	5-in. 2 S	1,524.00

BELT DRIVEN TRIPLEX PUMPS

Capacity G. P. M.	Head	Size	Cost of plant
100	50	5½ × 8-in.	$ 741.00
100	100	5½ × 8-in.	764.00
100	200	5½ × 8-in.	821.00
200	50	7½ × 8-in.	1,216.00
200	100	7½ × 8-in.	1,261.00
200	200	7½ × 8-in.	1,319.00
300	50	8½ × 10-in.	1,437.00
300	100	8½ × 10-in.	1,517.00
300	200	8½ × 10-in.	1,600.00
400	50	10 × 10-in.	1,877.00
400	100	10 × 10-in.	1,979.00
400	200	10 × 10-in.	2,065.00
500	50	10 × 12-in.	2,463.00
500	100	10 × 12-in.	2,510.00
500	200	10 × 12-in.	2,792.00

In comparing the schedule note that in a number of instances the cost of plant for a given head is less than that of the preceding lower head, and that smaller sizes are used,—these are not errors. In centrifugal pumps, the capacity within a certain range is governed by the design of the impeller and the speed, and not by the diameter of the discharge nozzle. Also in the triplex pumps, exactly the same pump is offered for more than one head. The total plant costs are also affected by the cost of motor used, which varies according to the speed, the slow speed motors costing considerably more than those of high speed. The sizes and types of pumps and motor speeds are those selected by a man of large experience in irrigation work; and while better selections might be made in some cases, the list represents probably average practice, and as used here, is a fair basis.

Operating Costs.—In arriving at a basis of operating costs for each year, the following assumptions were made:

(1) That the irrigation season covers the period from May 1st to September 30th, inclusive.

(2) That the pumps would operate 24 hours a day for 26 days each month, or a total of 130 days.

(3) That the pump would operate 624 hours each month.

(4) That the capacity of the several sizes of pumps operating on the above schedule would be as follows for the season:

Size	Acre ft.
100 gallons per minute	57.5
200 gallons per minute	115.0
300 gallons per minute	172.0
400 gallons per minute	230.0
500 gallons per minute	287.5

(5) That power would be paid for on the meter basis, and on the schedule in use in the Yakima Valley.

(6) That interest on investment in plant be figured at 7 per cent.

(7) That depreciation and renewals be figured at 7 per cent.

(8) That cost of supplies be taken at 1 per cent of cost of plant

(9) That insurance be figured at 1 per cent.

The total for the last four items is 16 per cent.

In determining final costs for any particular location, it will be necessary to add the charges upon whatever pipe line is required to deliver the water to the desired point, also the yearly cost of water right, if water is purchased from a ditch. Estimated costs of pumping follow:

Direct Connected Centrifugal Pumps

Capacity, in gals. per min.	Head, in ft.	Cost per acre-foot pumped
100	25	$2.24
100	50	3.00
100	100	4.93
100	200	8.17
200	25	1.68
200	50	2.24
200	100	3.68
200	200	6.59
300	25	1.37
300	50	1.93
300	100	3.16
300	200	5.57
400	25	1.25
400	50	1.74
400	100	2.90
400	200	4.99
500	25	1.11
500	50	1.59
500	100	2.65
500	200	4.82

BELT-DRIVEN TRIPLEX PUMPS

Capacity, in gals. per min.	Head, in ft.	Cost per acre-foot pumped
100	50	$4.08
100	100	4.80
100	200	6.65
200	50	3.47
200	100	4.25
200	200	5.89
300	50	2.83
300	100	3.64
300	200	5.23
400	50	2.76
400	100	3.54
400	200	5.02
500	50	2.77
500	100	3.46
500	200	5.00

By platting these figures on paper, we have, Fig. 16, a diagram from which it is possible to ascertain the approximate cost per acre foot for pumping to any

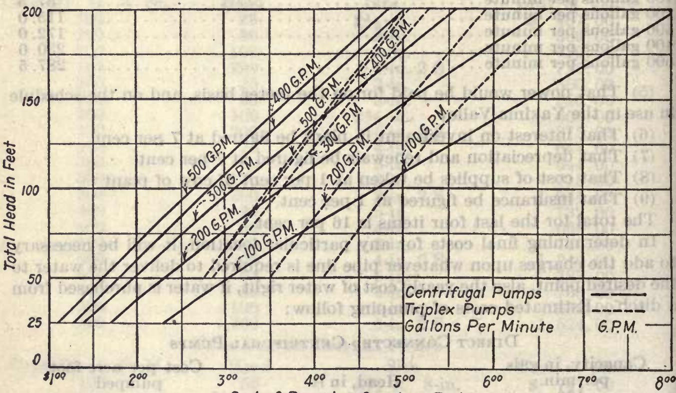


FIG. 16.—Cost per acre-foot of pumping for irrigation.

head between 25 ft. and 200 ft. for the centrifugal pumps of the respective capacities, and for heads between 50 ft. and 200 ft. for the triplex pumps. On the diagram, the centrifugal pumps are represented by full lines, and the triplex pumps by dotted lines. The point at which the full and dotted lines of the same capacity cross, indicates the approximate head at which the types will operate with equal economy. This is 110 ft. for the pumps of 100 G. P. M. capacity, 150 ft. for the 200 G. P. M., and 165 ft. for the 300 G. P. M. Above these heads, the diagram indicates that the triplex pumps will be the more economical. It also shows that for the 400 G. P. M. capacity the types balance at 200 ft. head; and that for the 500 G. P. M., the centrifugal is the more economical pump within the range of head considered.

The figures and diagram clearly show the lower cost per acre foot as the size and capacity are increased. This leads to the suggestion that where conditions are favorable for serving two or more tracts from one point, that it will be economy for the owners to join in building one plant that will give the best results, rather than to construct two or more plants of lower efficiency and higher cost and maintenance.

Over Head Charges for Pumping Plants Used for Irrigation.—In Engineering and Contracting, Aug. 30, 1911, the following is given.

The rate of depreciation of pumping plants varies through an enormous range, being determined largely by the skill and care of the attendant. Many plants are not insured at all. Averaging all conditions, the following appears to be a fair estimate of the rates suitable for use in computing the fixed charges of the various types of plants.

	Per cent
Gasoline engine plants	
Depreciation	12 to 15
Interest	6
Taxes and insurance	1
Average total	20
Motor-driven plants	
Depreciation	7 to 9
Interest	6
Taxes and insurance	1
Average total	15
Steam plants of ordinary type	
Depreciation	9 to 11
Interest	6
Taxes and insurance	1
Average total	17
Highest quality steam plants—average	12

These percentages, determined by the Office of Experiment Stations, Department of Agriculture, are applied to the first cost of the entire pumping station, including the cost of wells.

Cost of Small Earth Reservoirs as an Adjunct to Electrically Operated Irrigation Pumping Plants.—Engineering and Contracting, June 13, 1917, gives the following data:

Earth reservoirs as an adjunct to electrically operated pumping plants are now being used to a considerable extent on small individual irrigation developments in southern California. In the territory served by the Southern Sierras Power Co. some 45 of these storage basins have been constructed within the past two years. The pumping installations in general operate about 700 hours per month and deliver a quantity of water to the storage basins approximately equal to ½ in. of water per acre under cultivation. The reservoir is located upon the highest point of the acreage and the water drawn out through the pipe line as needed.

Three general types of reservoirs have been constructed during the past two years. The least expensive of these is a basin with earthen embankments. This is constructed with a four-horse team and fresno and the bottom is sealed by puddling with clay, adobe or manure. One of these basins, 120 × 120 × 5 ft. inside dimensions, clay sealed and holding 450,000 gal., cost \$125. Another, 150 × 150 × 5 ft., holding 750,000 gal., cost \$147. In each of these the embankments were 14 ft. thick at the base and 3½ ft. at the top.

The cement basins commonly have walls 6 in. thick at the base and 4 in. at the top. They are banked around the exterior with earth. One of these basins, 4 ft. deep and 75 ft. in diameter, with a capacity of 125,000 gal., was constructed at a cost of $380. This basin holds water for the irrigation of 23 acres of alfalfa and 4 acres of garden truck. The pumping installation consists of a 5-hp. motor and a 2-in. horizontal pump. This outfit delivers water at the rate of 140 gal. per minute. The total expense of irrigation in this case is $250 per year.

The third type of earth reservoir is a basin rendered watertight by spraying the bottom and sides with oil or by applying a coat of cement or lime plaster. This plaster lining is from ½ to 1 in. thick and is applied after the soil has been thoroughly tamped. Two-inch mesh chicken wire is spread over the bottom and sides of the basin prior to the application of the plaster. The plastering costs about 6 ct. per square foot.

In sealing the earth reservoir by spraying with oil the best results have been obtained by using heavy crude oil with not less than 90 per cent asphaltum, heating this from 400 to 450° and pumping it on the ground under pressure in the form of a spray, then following this up with sand, which is spread over the oil. This latter feature is very essential, especially on the banks. Best results are obtained with two coatings of oil, in all about ¾ gal. per square yard. The oil costs from $2 to $3 per barrel put on, depending upon the distance to be hauled. It is delivered to the job in motor truck loads, each of about 25 bbl.

The success of construction work of this kind depends upon the thoroughness with which the work is done. The soil should be worked over very carefully and raked with a fine rake, eliminating any large lumps, etc., that might be either in the bottom or on the banks. A second coat of oil has proven very efficient in making the reservoir tight. It must be borne in mind, however, that the oil used should be asphaltum residue of very heavy specific gravity, about the consistency of heavy coal tar. The sifting of the soil and sand on the hot asphaltum keeps it from running until it has an opportunity to cool and thus gives it a better body to keep it in place.

One of these oil-sealed basins, holding 500,000 gal. of water, was constructed in 1916 at a total cost of $350. The sealing required 75 bbl. of oil and cost $160; construction cost $147, and the gates, inlet and discharge pipes cost $33. This basin is operated in conjunction with a direct connected plant consisting of a 25-hp., 400-volt, 3-phase Westinghouse motor and a special 4-in. Bryon Jackson pump. The basin furnished water for 90 acres of alfalfa and 20 acres of grain.

Cost Wells and Well Drilling Equipment.—The following is given in Fortier's "Use of Water in Irrigation" (1915).

According to C. E. Tait, the most common sizes of drilled wells for new plants in southern California at this writing (1914) are 12, 14, 16, and 20 inches in diameter. A few 24- and 26-inch wells are also in use. The increase in size in recent years has been largely due to two causes. The larger circumference of the casing permits more openings to be made and more water to enter from the adjacent gravel. They are also better suited to the use of deep well pumps of the plunger and turbine types in that they permit a long stroke at low speed.

The casing consists of a double thickness of riveted steel sheets 2 feet long. The cost of casing per foot for various diameters and thickness of metal subject to a discount of 30 per cent is as follows:

Diameter, inches	Well casing 16-gauge	14-gauge	12-gauge	10-gauge
7	$0.59	$0.68	....	....
10	0.83	0.99	$1.20	....
12	0.90	1.06	1.37	$1.78
14	1.08	1.20	1.62	1.97
16	1.21	1.33	1.94	2.17
20	....	1.57	2.23	2.64
24	....	....	2.69	3.20

What is known as a starter is a tube about 20 feet long riveted to the bottom of the casing. This consists of a triple thickness of metal for large wells and for wells in bowlders or rock. A steel shoe or ring is in turn riveted to the bottom of the starter. A 3-ply, 12-gauge starter for a 12-inch well costs $1.80 per foot, while a 12 × ¾ inch ring costs $16.

Wells in southern California are drilled by contract. The equipment consists of a California portable rig costing $500 to $600 without the tools. In starting a well a hole is first bored and the starter inserted. A sand bucket is then used to make the excavation unless rock is encountered. The rig is provided with hydraulic jacks which apply a pressure of 100 tons or less to an iron ring which rests on the top of the casing. The cost of drilling in sand or clay exclusive of casing is $1.50 per foot for a 12-inch well. Contractors are usually protected by a provision inserted in the contract to the effect that if bowlders or rock are encountered requiring more than 2 hours to bore through an extra charge will be made.

Strainers, which form so essential a feature of many wells in the rice belt, are not necessary in southern California as there is no quicksand or very fine sand unmixed with coarser material. Water is admitted through long vertical slots in the casing which are cut by a special tool after the casing is in place. The cross sections of the openings thus made are trapezoidal in form, the narrowest side being at the outside to prevent clogging. Four vertical slots about 20 inches long are made in the circumference of each joint of a 12-inch casing opposite and slightly below each water-bearing stratum.

In the rice belt, according to C. G. Haskell, Irrigation Engineer, Department of Agriculture, the hydraulic rotary method for drilling wells is the most common.

CHAPTER X

LAND DRAINAGE

This chapter contains data on the methods and costs of constructing both open and tile drains. Further matter of use in relation to this subject may be found by referring to the index.

The reader is also referred to Gillette's "Handbook of Cost Data" pages 1796–1802 for costs of laying tile drains and for the weights of drain tile which are given on page 1798.

The Elements of Costs of Drainage Systems are given by J. L. Parsons in "Land Drainage" as follows: Cost of materials, cost of labor, cost of delivery of materials, cost of administrating drainage contracts, cost (interest and depreciation) of necessary plant, cost of financing the contract, and probable damage claims and legal expenses. In addition to the probable contract price as thus estimated, the element of engineering and other overhead expenses and right of way or damage claims must be considered by the engineer in arriving at the total estimated cost to the owner.

Probable Damage Claims and Legal Expenses.—During the prosecution of drainage contracts there is considerable danger of stock falling into ditches, with resulting claims for damages by the owners, and some allowance must be made in the contractors estimate for such damages. Also a contractor should avail himself of enough legal advice to insure business methods.

Overhead Expenses.—The overhead expenses incidental to legal drainage organizations, as engineering, legal expenses, publication of notices, etc., if wisely administered, need not exceed 8 to 12 per cent of the total cost for drains costing $5,000 and upward. These expenses equal a larger percentage for the smaller districts, as many of the legal procedures required are as expensive for small drains as for larger ones.

The item of engineering alone, including the preliminary survey, construction superintendence, and assistance in the assessment of benefits and fixing of damages, should not be less than 5 to 10 per cent of the total cost, ranging from approximately 10 per cent for $2,000 districts to 5 per cent for $25,000 districts and upwards.

Types of Equipment Best Adapted to Land Drainage.—Power machinery is now available which will construct outlet drainage ditches of all sizes, and under all conditions of soil and water, more cheaply than can be accomplished by any other method, according to D. L. Yarnell, drainage engineer of the Office of Public Roads and Rural Engineering. In a special bulletin issued recently by the Department of Agriculture, the uses and limitations of the different machines that have been employed in such work are summarized by by Mr. Yarnell, whose conclusions as abstracted in Engineering Record, Feb. 25, 1916, follow.

The floating dipper dredge is more widely used in drainage work than is any other type of excavating machine. For work through wet land no other excavator will equal it in cheapness of construction of ditches having a cross-section of from 100 sq. ft. to 1200 sq. ft. It is by far the most efficient machine to use where many stumps will be encountered. Owing to its limited reach it is not generally applicable to levee construction. Dipper dredges as constructed for drainage work range in capacity from ½ cu. yd. to 4 or 5 cu. yd. The sizes most commonly used vary from 1 to 2 cu. yd. The smallest dredge costs about $5,000; the cost increases rapidly with the capacity of the dipper. The floating dipper dredge should be operated downstream, where practicable, to insure sufficient water at all times.

In general, the clamshell or orange-peel dredge is not well adapted to ditch construction, especially if there be stumps to handle. Certain types of soil, such as the muck of southern Louisiana, can, however, be handled to advantage with this machine. It is also suited to levee building when a long boom is used.

The dragline scraper excavator is constantly increasing in favor for drainage work. It is especially suited to the construction of ditches and levees of large cross-section, where the ground is sufficiently stable to support the machine. The scraper excavator is also suitable for ditch cleaning.

The various forms of so-called dry-land machines find quite extensive use in drainage. The dipper and orange-peel dredges of the dry-land type are suitable for use where sufficient water cannot be had to float a dredge. The templet and the wheel types of excavators are applicable to open land, where the soil is neither too hard nor too wet. The ditches cut by these latter machines are superior in hydraulic efficiency to those of similar section cut by any other type of excavator. The dry-land machines should be operated upstream.

The hydraulic dredge is not suited to ordinary drainage ditch construction. It has been used to some extent in cleaning ditches, and, with the use of slope boards, has in at least one instance made a satisfactory record in levee construction.

Costs of Dredge Excavation of Drainage Ditches.—D. L. Yarnell gives the following in Bulletin No. 300, Office of Public Roads and Rural Engineering, abstracted in Engineering and Contracting, Feb. 2, 1916.

Method of Operating.—With a floating dredge the construction should, where practicable, begin at the upper end of the ditch and proceed downstream. Sometimes it is not feasible to transport the machinery and material to the upper end of the ditch and the dredge must then work upstream. This is undesirable, unless the fall be slight, since in working upstream dams must be built behind the boat to maintain the necessary water level. In working downstream the ditch remains full and the dredge, floating high, can dig a much narrower bottom than if working upstream in shallow water. Moreover, when floating low, the dipper may not properly clear the spoil bank. Again, in working downstream, any material dropping from the dipper into the ditch will be taken out in the next shovelful; whereas if working upstream any material dropped or any silt washed behind the dredge is left to settle in the bottom of the ditch. If work is begun on the natural ground surface a pit must be dug to launch the boat; or if in a stream, it may be necessary to build a temporary dam in the channel to raise the water high enough to float the boat. The depth of water required varies from 2 ft. upward, depending on the size of machine.

The floating dipper dredge moves itself ahead by means of the dipper. The spuds are first loosened from their bearings and the dipper is run ahead of the machine and rested on the natural ground surface in front of the ditch. The spuds are then raised and the engines operating the backing drum are started; the dredge being free, is thus pulled ahead. The spuds are then lowered and excavation continued.

In timbered country the right of way must be cleared. In many cases the timber cut will supply sufficient fuel for the dredge. It is poor policy to fell the trees and leave them on the ground to be removed by the dredge. The stumps should always be shattered with dynamite, as the strain on the machinery is thus rendered much less and the life of the dredge increased.

An engineer, a craneman, a fireman, and a deckhand are required to operate a dipper dredge. The output, loss of time due to breakdowns, and the cost of repairs, depend almost wholly upon their skill and efficiency. The engineer should be an all-around mechanic as well as experienced in dredging.

The amount of fuel consumed depends upon the size and type of boiler used, and upon the burning and heating qualities of the fuel. A very great saving can be effected by covering the boiler with an asbestos coat. Ordinarily, about 25 lb. of coal per horsepower-hour are consumed on dredges. The cost of repairs depends largely upon the operator; a careless operator will cause many unnecessary breakdowns. It is not only the high cost of repairs for machinery but also the time lost which aids in increasing the actual cost of the output. It is a well-established fact that it is not the initial cost of a dredge or of any machine, but the operating and overhead expenses, that reduce the profits.

Cost of Operation.—The cost of dredge work depends upon a number of factors. The locality of the work, the kind of soil, repairs, delays, labor, etc., greatly influence the actual cost of any work. If the water level can naturally be maintained within a foot or so of the surface of the ground, the cost of excavation can be reduced very low with this type of machine. The data given in the following pages were obtained from the actual cost records of the various projects. Unfortunately, the figures are not always strictly comparable, one project with another, owing to variations in the items of cost included. Unless otherwise stated, interest is taken at 6 per cent and depreciation at 35 per cent per annum on the cost of the dredging outfit. Interest and depreciation are, however, charged only for the interval of time upon which the unit cost is based. This is not strictly correct, as a certain amount of time consumed in getting the machine on and off the work should be charged to each project. In most cases it was impossible to ascertain the time that should be charged to moving, building, etc., and therefore the item has been ignored in all cases, for the sake of uniformity. On some projects figures for operation over an extended period were not obtainable. In such cases the unit cost is based upon the daily cost of operation and the average amount of ditch dug per day, no allowance being made for interest and depreciation.

In the construction of a ditch in North Carolina a new 1¼-yard dipper dredge was employed. This dredge had a 5 × 20 × 70-ft. hull and was equipped with 8⅜ × 10-in. double-cylinder hoisting engines; 7 × 7-in. double cylinder, reversible swinging engines; a 50-hp. Scotch marine return-flue boiler; a 1¼-yard dipper, 31-ft. dipper handle, and 45-ft. boom. The spuds were convertible to bank or vertical and were operated by the hoisting engines. The cost of this dredge, erected, was $10,342.19. The dredge was operated continuously, each shift working 11 hours per day. The men were paid at the following rates per month: Superintendent in charge, $110; engineers, $100; cranemen, $60; firemen, $48; deck hands, $36. The men furnished their own subsistence. The ditch was 9½ miles long and ranged from 22 to 30 ft. wide on top and from 8 to 10 ft. deep; it had side slopes of ½ to 1 and a berm 8 ft. wide. The water level was easily maintained near the ground surface. Very little right-of-way clearing was required. In the construction of this ditch the dredge excavated 350,720 cu. yd. of earth. One year was required for the dredge to complete this work. The following cost data were taken from the records of the drainage district which owned and operated the dredge:

Cost of operation, including labor and fuel	$15,889.01
Repairs	1,948.24
Interest and depreciation	4,240.22
Total	$22,077.47
Cost per cubic yard, $0.0629.	

A new dredge of the same size and type as the one just described was used in the excavation of a drainage ditch in the same locality as the foregoing project. The ditch followed an old creek channel for the greater part of its length. The cost of the dredge, erected, was $9,365.34. It was operated in one shift of 11 hours; the actual time of operation was not recorded. The crew and the rates of pay were the same as in the foregoing example. The ditch was 3¾ miles long and ranged in top width from 22 to 26 ft. and in depth from 6 to 10 ft. The side slopes were ½ to 1; the berm was 8 ft. wide. The dredge worked downstream and the water level was easily held near the ground surface. Practically no right-of-way clearing was done. The material excavated was a loam top soil underlain by stiff clay; very little rock was encountered. The cost of the work was considerably affected by the expense ($1,459) of passing three bridges. The total amount excavated in a period of about 10 months was 121,200 cu. yd. The dredge was owned and operated by the drainage district. The following costs were recorded:

Cost of operation, including labor and fuel	$ 5,921.05
Repairs	1,028.73
Incidentals	117.95
Interest and depreciation	3,199.80
Total	$10,267.53
Cost per cubic yard, $0.0847.	

A dipper dredge with a 5½ × 16 × 60-ft. hull, 7 × 8-in. double-cylinder hoisting engines, friction swing, 1-yard dipper, 35-ft. boom, and telescopic bank spuds was used in the construction of about 5 miles of ditch in western North Carolina. No reliable information was available as to the amount of material moved; but the following figures as to the cost of installing the dredge are of interest:

Hull: Labor and material	$1,803.23
Machinery:	
Material	4,800.00
Freight	379.10
Drayage	72.60
Installing	310.60
Extra equipment (forge tools, etc.)	80.00
Lighting equipment (engine and dynamo and wiring)	207.00
Total	$7,652.53

In Colorado, a dipper dredge having a 24 × 75-ft. hull, 1½-yd. dipper, and 50-ft. boom, was used in cleaning out and enlarging about 20 miles of canal. The equipment, complete, including cook and bunk boats, cost $16,500. Two shifts of 11 hours each were run. During the year for which the data are given the dredge was actually in operation but 187 days, or 58 per cent of the total working days. The following crew were paid the given rates per month, including board: Head runner, $120; 1 runner, $110; 2 cranemen at $55; 2 firemen at $45; 2 deckhands at $40; 1 teamster, $40; 1 cook, $50. No right-of-way clearing was required. The water for the boiler was taken from the canal, and as a result considerable trouble was experienced from mud and scale. The cost data below are based on the amount of material moved from inside the grade stakes during the year, amounting to 394,387 cu. yd. It was estimated that an excess of 25 per cent was actually moved. The following was the cost of the work for one year:

Operation:	
Labor operating dredge	$ 6,243.70
Coal, including freight, 1,276.65 tons, at $2.35	3,000.13
Hauling coal, 1,276.65 tons, at 82½ cents	1,053.24
Oil, waste, and miscellaneous supplies	692.80
Cost of controlling water to float dredge	369.24
Repairs, labor, and material	3,894.67
Removing and replacing bridges	837.78
Interest and depreciation	6,765.00
Total	$22,856.56
Cost per cubic yard, $0.058.	
Miscellaneous expenses:	
Engineering and supervision	$ 1,856.10
Building up ditch bank and making road on top	4,721.75
Right of way and legal expenses	190.42
Total	$ 6,768.27

The cost of the dredging outfit was as follows:

Hull:	
Material	$ 1,960.83
Labor, including hauling	1,959.99
Machinery:	
Cost, including freight	9,997.72
Hauling and installing	817.55
Cook and bunk boats:	
Material	663.90
Labor	453.66
Equipment	646.35
Total	$16,500.00

In connection with a drainage project in southwest Louisiana a steam-operated, floating dipper dredge, equipped with a 1-yd. dipper, 40-ft. boom, and convertible power spuds was employed in the excavation of about 10 miles of ditch which varied in width from 18 to 50 ft. and in depth from 4 to 6 ft.; 15-ft. berms were specified. The cost of the dredge on the work is said to have been $10,000. Two shifts of 10 hours each were run, but the actual number of days of operation was not recorded. The crew and monthly rates of pay, including subsistence, were as follows: Two runners, at $100; 2 cranemen, at $60; 2 firemen, at $60; 1 deckhand, $40; 1 cook, $30. The material excavated was a hard, stiff clay. The total amount excavated in about 8 months was 147,000 cu. yd. The average cost, per month, of operation was as follows:

Labor	$ 510
Board	100
Coal	262
Repairs	200
Oil and supplies	50
Interest and depreciation	342
Total	$1,464
Cost per cubic yard, $0.0796.	

On another project in southern Louisiana there was employed a floating dipper dredge with a 5 × 22 × 73-ft. hull; 8 × 10-in. double-cylinder hoisting engine; 6 × 8-in., double-cylinder reversible swinging engines; 1¼-yd. dipper, and 40-ft. boom. The machine was equipped with bank spuds. The cost of the dredge, ready to operate, was $13,000. The ditches averaged about 30 ft. wide and were from 5 to 6 ft. deep. The land was nearly level and the water surface was easily kept within a foot of the ground surface. The material was a top muck underlain by an alluvial mud which was hardly solid enough to hold its shape when dropped from the dipper. There were few submerged logs or stumps. The dredge was operated the year around for two years. No record was kept of the actual time of operation. The average output per shift (12 hours) on a 30-ft. ditch 5 ft. deep was 1,200 cu. yd., at a cost as follows:

Labor (4 men)	$10.50
Fuel, 6 barrels oil, at $1.75	10.50
Repairs, oil, and grease	5.50
Total	$26.50

Cost per cubic yard, exclusive of interest and depreciation, $0.0221.

In the same general locality as the foregoing case, and under the same soil conditions, a 1-yd. dredge which was, except in respect to capacity, equipped similarly to the above-described machine, was operated in the construction of ditches which averaged 30 ft. wide and 5 ft. deep. The cost of the dredge, erected, was $11,000. The average output per 12-hour shift during a 2-years' run was 1,000 cu. yd. The cost per shift was as follows:

Labor (4 men)	$10.00
Fuel, 5 barrels oil, at $1.75	8.75
Repairs, oil, and grease	5.50
Total	$24.25

Cost per cubic yard, exclusive of interest and depreciation, $0.024 2.

In another drainage project in southern Louisiana several ditches, each three miles long, were constructed by a dipper dredge installed on a 5½ × 18 × 70-ft. hull. The power was obtained from a 60-hp. internal-combustion engine. The dredge had a 1¼-yd. dipper, 40-ft. boom, and convertible power spuds. The total cost of the outfit, including house-boats and small towboats, was $12,000. Two shifts of 10 hours each were run for 26 days in each month. The crew were furnished subsistence, and each shift consisted of: One runner, at $125; 1 craneman, at $65; and 1 engine tender, at $40 per month. One cook, at $35, and one general utility man, at $60, were also employed, making a total labor cost of $555 per month. The average dimensions of the ditch were: Top width, 25 ft.; bottom width, 18 ft.; and depth, 8 ft. The ground was nearly level and the water stood about 3 ft. below the ground surface. The excavated material was a stiff, sandy clay. About 3.4 miles of the work consisted in cleaning old channel, which required frequent moving and gave small yardage. The total excavation in five months was about 216,000 cu. yd. The cost was as follows:

Labor and board	$3,555
Fuel and oil	2,300
Repairs	980
Interest and depreciation	2,050
Total	$8,885

Cost per cubic yard, $0.0411.

A steam-operated floating dipper dredge, mounted on a 5 × 15 × 60-ft. hull and equipped with a 1-yd. dipper, 38-ft. boom, and inclined telescopic bank spuds, was used in the excavation of about 10¾ miles of ditch in North Carolina. The cost of the dredge is stated to have been $6,613.82. One shift of 10 hours per day was run. The actual number of days of operation was not recorded. The crew and rates of pay were as follows: One engineer, $125 per month; 1 craneman, $2 per day; 1 fireman, $1.25 per day; 1 watchman, $1.50 per day. The crew furnished their own subsistence. The ditch was about 18 ft. in top width, 12 ft. deep, and had ½ to 1 slopes. It followed an old creek bed for a large part of the distance. The material excavated was a clay, though some rock was also encountered. Based upon the given dimensions of the ditch, the total excavation amounted to 295,000 cu. yd. Eighteen months were required to complete the work. The cost was as follows:

Operation:	
Labor	$ 6,310.94
Fuel	2,210.30
Repairs:	
Labor	1,380.12
Material	1,136.71
Interest and depreciation	4,067.00
Total	$15,105.07
Cost per cubic yard, $0.0512.	
Miscellaneous expenses:	
Engineering	$ 164.83
Clearing right of way	282.70
Rebuilding bridges	104.96
Incidentals	48.77
Administration	618.00
Total	$ 1,219.26

Costs of Dredging Main Canals on a Drainage Project in Louisiana.—Engineering and Contracting, Oct. 25, 1911, gives the following:

The excavation was begun in the latter part of 1909 and was prosecuted almost continuously until the completion in August, 1911. This work was carried on by means of two Marion dipper dredges, one with a ¾ cu. yd. and the other with a 1½ cu. yd. bucket. The large dredge was on the ground when the work was begun and the small one was built afterward at a cost of about $8,500. Two oil barges of about 400 bbls. capacity each were built to carry fuel oil for the dredges from New Orleans. All supplies had to be brought in on barges. One 25-h.p. gasoline tug was used for all towing.

The cost figures for the work which follow were taken from the company's books, with the exception of the charge for plant. This is an arbitrary figure based on an estimate of 25 per cent depreciation of the plant for the two years' work. The plant is taken as worth $20,500 at the beginning of work. The labor charge is taken from the payroll account and includes all labor charged to the contract, such as dredgemen, camp labor, clearing, towing, superintendence, etc. The supplies include all supplies except camp supplies. The repair account includes all repair parts and freight on same, but does not include the labor for making repairs. The general expense account includes all expense not included in other accounts, such as taxes on plant, traveling expenses, railway fares of men, office expenses, etc. No interest is included. The fuel account includes only the oil used for the operation of the dredges.

The rates of wages paid were for common labor $2 per day, engineer $125 per month, craneman $65, fireman $50.

The rates of the monthly men include board in addition. The costs follow:

Total yardage 674,921	Per cu. yd.
Plant (arbitrary)	$0.0076
General	0.0059
Repairs	0.0020
Supplies	0.0138
Fuel	0.0094
Labor	0.0219
Camp	0.0081
Total cost per cu. yd	$0.0687

Costs of Ditch Excavation with Templet Excavators.—Engineering and Contracting, Feb. 9, 1916, gives the following extract from Bulletin No. 300 (Office of Public Roads and Rural Engineering) by D. L. Yarnell.

A single-bucket templet excavator was used in southern Louisiana on the construction of 7,825 ft. of ditch having a 24-ft. bottom width and ranging in depth from 3.5 to 7 ft. The side slopes were 1 to 1, and the width of berm was 15 ft. The total excavation was 43,128 cu. yd. The total cost of this machine on the work was $8,506.22. The soil was a yellow clay with a few spots of gravelly clay, and the top soil was baked very hard. No special difficulties were encountered except that considerable cribbing was necessary to level up the track supporting the excavator when crossing natural water courses; except for these streams the ground was level. Some trouble was also experienced with the traction device, due to the fact that the ditch was larger than that for which the machine was designed. The actual number of working days was 128, 73 days of which were spent in actual digging; 43,128 cu. yds. were dug. The cost of operation per day was as follows: One operator, $3.85; one fireman, $2.28; three deck hands, $6.27; one team and teamster, $5.40. The total cost per day was $17.80. The average daily excavation for the 128 days worked was 337 cu. yds. or 107 lin. ft. of ditch. The total cost of operation for 5 months was $3,500 divided as follows:

Operating, labor	$1,885
Operating, materials	496
Fuel	602
Repairs, labor	294
Repairs, materials	223
Total	$3,500

Interest and depreciation in that time, at 41 per cent per annum, would amount to $1,453, making the total cost $4,953 and the cost per cubic yard $0.1149.

Cost of Operating Wheel Type Excavators in Drainage Ditching.—Engineering and Contracting, Jan. 26, 1916, publishes the following extract from Bulletin No. 300, by D. L. Yarnell, office of Public Roads and Rural Engineering.

Two machines of the wheel type designed to cut a ditch 4 ft. deep, 4 ft. wide at the top, and 2 ft. wide at the bottom, were used on the excavation of some ditches in one of the Gulf States. Each machine was driven by a 28-hp. gasoline engine. The digging wheel was 15 ft. in diameter and the two apron tractors each 5 ft. by 12 ft. The weight of each excavator was about 30 tons. The first cost of the machine was $5,500 and freight to the point of use was $338.36, making the total cost of each machine $5,838.36. The soil was a hard, yellow, sandy clay overlain by a turfy muck, varying in depth up to 2½ ft. The turf was easily cut, but the hard clay caused excessive wearing on the bearings. A large part of the work was done when water was from 2 to 3 ft. deep on the land. The total length of the ditches dug was 165 miles, the average length of ditch being 2,475 ft. The average depth of digging was about 4 ft., with a 4-ft. top and 2-ft. bottom. The average distance dug per shift of 10 hours of actual running time was 2,250 ft.; the maximum distance dug in 10 hours was 6,600 ft. The average yardages per month for the two machines were 13,245 and 13,180 cu. yds., respectively. The average daily outputs on the basis of the actual running time were 1,000 and 1,126 cu. yd., respectively. A part of the time the first machine ran a double shift, which accounts for the higher monthly and less daily average It required 13 months to complete the work, the actual time of operation being about half this. On account of the excessive wearing on the bearings, caused by the heavy sandy clay, it was necessary to make frequent stops for rebuilding the machines, which operation occupied an average of nearly two weeks. The total excavation was 317,162 cu. yd.

The daily operating expense per 10-hour shift for each machine was about as follows:

	Per day
One operator, at $100 per month	$ 4.00
One assistant	2.00
50 gallons gasoline, at 16 cents	8 00
Repairs	6.00
Other charges	12.00
Total	$32.00

The itemized cost for operation for the entire work was as follows:

Labor	$ 5,172.11
Interest, discount, and exchange	202.05
Maintenance and repairs	2,860.08
General expense	273.10
Management expense	1,600.00
Provisions and cooking (cook's wages)	2,245.91
Freight and express	75.74
Towing	458.19
Gasoline	1,792.22
Other oil	281.49
Teams and livery	932.11
Telephone and telegraph	25.29
Motor boat operation	540.96
Interest and depreciation on machinery	5,185.00
Total	$21,644.25

Cost per cubic yard, $0.0682.

	Machine No. 1	Machine No. 2
Machine running	$ 917.97	$1,509.66
Machine repairing	1,431.37	771.96
Machine moving	105.20	88.51
Machine bogged	156.90	190.54
Total	$2,611.44	$2,560.67

The excessive cost of labor given for the machines when bogged was due to the frequent crossings of a wide, muck-filled bayou which ran the entire length of the district. This bayou was about 1,500 ft. wide; the muck ranged from 5 to 15 ft. deep and was very soft. No tree roots, submerged timber, or stumps were encountered. The work covered an area of about 7,000 acres, approximately square, which was traversed by parallel canals every half mile. The ditches cut by the excavators were at right angles to these canals and were spaced 330 ft. apart. It was thus necessary to turn the machine around and run it light 330 ft. for each half mile of ditch cut. The item "moving" is for taking the machine across the canals and for moving from one part of the district to another; it does not refer to the moving between adjacent ditches.

On a project in southern Louisiana a wheel excavator, cutting a ditch 4½ ft. deep with a top width of 4½ ft. and a bottom width of about 20 in., was used. The machine worked on comparatively solid ground. Power was supplied by a 28-hp. gasoline engine. The first cost was $4,000, and freight charges from factory to works were $350. After the machine had been operated for a short time it became apparent that the excavating wheel was far too light and a new wheel was substituted. The soil was a silt loam, firm and uniform but not tenacious. No special difficulties due to soil conditions were encountered in this work. The chief obstacles to rapid progress were at first the weakness of the light excavating wheel, and afterwards the extra-heavy excavating wheel which unbalanced the machine. The tractors were larger than necessary and often broke down when turning on the hard ground. At the time the following cost records terminated, the work had been carried on intermittently for about 18 months; about one-half this time was occupied in repairs. During this time the machines dug 117,000 ft. of ditch 4½ ft. deep, 45,500 ft. 3½ ft. deep, and 9,250 ft. twice over, the machine making two 4½-ft. cuts side by side. The average length of ditch cut per day was 800 ft., while the maximum was 1,950 ft. The daily cost of operation was as follows:

Labor	$ 5.50
Fuel	4.20
Incidentals	.50
Repairs	2.40
Total	$12.60

The average excavation per day was 410 cu. yd., based on the average of 800 ft. of ditch, 4½ ft. deep, 4½ ft. wide at the top, and 20 in. wide at the bottom. The machine excavated 82,330 cu. yd. in 18 months at the following itemized cost:

Gasoline based on 215 actual days' operation (estimated)	$ 903.00
Repairs, actual cost	860.00
Incidentals at 50 cents per day	120.25
Labor of foreman, 18 months, at $75 per month	1,350.00
Other labor, two men, $2.50 per day for 250 days	625.00
Interest and depreciation	2,675.25
Total	$6,533.50
Cost per cubic yard, $0.0793.	

Cost of Straddle Ditch Excavators Work.—D. L. Yarnell gives the following in Bulletin No. 300, office of Public Roads and Rural Engineering, abstracted in Engineering and Contracting, Jan. 19, 1916.

A machine of this type often used has a 30-ft. boom and a 1-yard dipper. The steam power used is obtained through a 2-cylinder, 35-hp. engine and a vertical boiler. The machine rests on a platform which is mounted on two steel beams, each 29 ft. long, that straddle the ditch. It can be mounted on either caterpillar tractors or wheeled trucks. In the latter case, each end of the two beams is supported on a two-wheeled oscillating truck, the wheels being 2 ft. high and 18 in. wide. They run on a wooden track 6 in. thick and 3 ft. wide, which is built in six sections each 20 ft. long. One section of the track on each side is always unoccupied and these are lifted ahead by means of cranes operated by power derived from the engines. This track will support the machine in the softest ground. The excavator will dig 12 ft. deep and 22 ft. wide on firm ground; with an extension to the dipper handle it can dig 18 ft. deep. It will deposit the dirt on either side at a distance of 32 ft. from the center of the ditch. The dipper will swing over a bank 14 ft. high. Where track is used the machine is pulled ahead by a cable from the engine which hooks to the track on both sides; this is done without interrupting the work of excavating. If desired, caterpillar tractors are furnished instead of the wheeled trucks. The front tractors are 4 ft. wide by 11 ft. long, and the rear tractors are 4 ft. wide by 7½ ft. long. This excavator has been known to dig as high as 1,500 cu. yd. in 10 hours in especially favorable material. It has dug through 12 in. of frost. From seven to eight men can set up and take down the machine in from five to eight days.

Another machine of this type has a 38-ft. boom and a 1-yard dipper. Power is supplied by an internal-combustion engine of 25 or 40 hp. which burns kerosene, gasoline, or distillate oil. The machine rests on a platform which is mounted on two steel beams, whose standard span is 32 ft. Extension axles are provided which permit of a maximum increase of 3 ft. in the span. The front axle is mounted on a two-wheeled swiveling truck with cast-steel doubleflange wheels. The rear end is carried by two heavy, wide-faced, doubleflange steel wheels set loosely on the axle. The shipping weight of this size of dredge, including engine, dipper, and machinery, is approximately 38,000 lb.

Perhaps the cheapest straddle-ditch excavator of the dipper type that is in use is a home-made one which has been used to some extent on small ditches in Iowa. The machine is of the revolving type. It is equipped with a ¾-yard dipper and a 28-ft. boom. The power is derived from a 6-hp. gasoline hoisting engine geared to three hoisting drums, one of which hoists the end of the dipper, one hoists the boom, and one pulls the machine ahead. The machinery is mounted on a platform which revolves upon a turntable supported on two wooden beams which straddle the ditch. The beams rest on wooden wheels, the entire span being 22 ft. The dipper handle, instead of moving forward and backward at the boom, is pivoted. The entire machine weighs only about 17,000 lb. and costs about $1,200.

This excavator has dug as high as 400 cu. yd. a day, but averages about 200 cu. yd. It can excavate a ditch with a 20-ft. top and can dig 13 ft. deep, but 6 or 7 ft. is the best working depth. Two men can erect the machine in 2½ days and dismantle it in ½ day; it makes about seven wagon loads. The hoisting apparatus, which is the heaviest part of the machine, weighs 4,100 lb. The excavator is moved ahead by means of a "dead man" and cable, and can be moved across country at a speed of about 1 mile per day. The machine can take out five shovel-loads in two minutes, and has dug through 6 in. of frost. Only two men are required to operate it—one operator and one trackman.

A ditch constructed by this machine in Iowa had an 18-ft. top, 4-ft. bottom and 6½-ft. depth. From 8 to 10 gal. of gasoline, costing 16½ ct. at the works, were used per day. The material, which was a loam underlain by a stiff gravelly subsoil, was excavated at the rate of about 200 cu. yd. in 10 hours. The cost of operation per shift was as follows:

One operator	$4.00
One trackman	2.00
Ten gallons gasoline, at $0.16½	1.65
Total	$7.65

The cost per cubic yard, exclusive of interest and depreciation, was about 3.8 ct. The contract price on 5,000 cu. yd. was 12 ct.

Such a machine as this would be well adapted to digging the small ditches in the South that are almost universally put in by hand at a cost of about 25 ct. per cubic yard. Even in ground covered with stumps, by using plenty of dynamite this type of excavator could be used to advantage in reducing the cost of small ditches.

In general, it may be said that the dry-land dipper dredge, though applicable to certain conditions, has no extensive use in drainage work, as excavation that is suitable to this machine can usually be handled to better advantage by the drag-line scraper excavator.

Drag Line Excavators on Ditch Work.—The following extract, from Bulletin No. 300, office of Public Roads and Rural Engineering on "Excavating Machinery Used in Land Drainage" by D. L. Yarnell, is given Engineering in and Contracting, Feb. 2, 1916.

A drag-line excavator of the rotary type, having a 2-yard scraper bucket and a 60-ft. boom, was used in the construction of drainage ditches in southern Texas. It was built mostly of wood and moved on rollers. Power was derived from an 80-hp. internal-combustion engine, burning oil. The cost of the excavator, ready to operate, was $12,000. It was operated about 10 months in two daily shifts of 10 hours each, a shift consisting of 10 men. The actual working time was not recorded. The ditch ranged from 4 to 22 ft. in bottom width, from 3 to 12 ft. in depth, and had 1 to 1 side slopes. The soil varied from a stiff, heavy clay to a fine sand. The excavation amounted to 230,000 cubic yards; the cost was as follows:

Operating expenses	$22,313.36
Miscellaneous expenses	374.70
Interest and depreciation	4,100.00
Total	$26,788.06
Cost per cubic yard, $0.1164.	

On another drainage project in southern Texas, a 2-yard rotary excavator was used. The machine was of steel throughout, had a 60-ft. boom, and was mounted on caterpillar traction. The crew consisted of a foreman, operator, engineman, oiler, and two laborers. The machine was operated by a 110-hp. internal-combustion engine, with oil as fuel. The total cost of the machine was about $17,500. The cost of erection was $509. During the four months of operation two 10-hour shifts were run. The ditches ranged from 4 to 22 ft. in bottom width and from 3 to 12 ft. in depth, with 1 to 1 side slopes and 8-ft. berms. The material excavated was a stiff, heavy clay. The excavation amounted to 91,400 cu. yd.; the cost was as follows:

Operating expenses	$ 8,873.82
Miscellaneous	371.00
Interest and depreciation	2,391.00
Total	$11,635.82
Cost per cubic yard, $0.1273.	

In the same general locality as the last example a 1½-yard rotary drag-line excavator, operated by a 50-hp. internal-combustion engine and mounted on caterpillar traction, was used in the construction of some ditches in soil ranging from stiff, heavy clay to fine sand. The ditches were of the same dimensions as in the foregoing example. The machine was rebuilt from an old dipper dredge at a cost of about $1,200. It was operated in two daily shifts of 10 hours each. The crew for each shift consisted of from five to six men. During the five months of operation the machine moved 59,014 cu. yd. at an expense, exclusive of interest and depreciation, of $8,921, or $0.1512 per cubic yard.

A rotary drag-line excavator with a 2¼-yard bucket and 65-ft. boom, mounted on skids and rollers, was used in the excavation of 222,500 cu. yd. in South Dakota. The power was obtained from a 50-hp. internal-combustion engine, using gasoline. The cost of the machine, complete, was $10,500. The total time of construction was 148 working days, or approximately six months, of which 23 days were occupied in making repairs. Two shifts of 11 hours each were run. The soil was a loam underlain by clay. The crew and rates per month were as follows: One superintendent, $125; 2 cranemen, at $100; 4 trackmen, at $50; 1 teamster, $45; 1 cook, $40. The operating expenses were as follows:

Gasoline, 15,444 gallons, at $0.124	$ 1,915.05
Labor	3,060.00
Subsistence	561.81
Cables	978.87
Repairs and renewals	845.93
Miscellaneous	2,078.72
Interest and depreciation	2,152.50
Total	$11,592.88

Cost per cubic yard, $0.0521.

The following costs were secured on the operation of a rotary drag-line excavator with an 85-ft. boom, 2-yard bucket, and a 50-hp. engine. The work was done on the New York State Barge Canal. The machine weighed 147 tons and cost $10,000. It excavated earth 90 ft. from center on one side and deposited it 100-ft. from center on the other. It dug a channel 25 ft deep. and deposited the material on waste bank 15 to 25 ft. high. The material was a stiff clay, with few stumps or bowlders. The following is a condensed cost record for five months' work:

Month	Total expense for month	Yards excavated during month	Average cost per yard
April	$1,088.21	5,205	$0.209
May	1,041.53	18,365	.0568
June	1,152.04	25,333	.0455
July	1,317.61	33,055	.0399
August	1,535.36	47,363	.0324

Average cost per yard for 5 months, including all charges, $0.0474.

In May, items of cost were as follows:

Engineer, at $90 per month	$ 90.00
Engineer, at $95 per month	84.04
Fireman, pumpmen, watchmen, etc., at $1.75 per day	363.00
Coal, at $3 per ton	147.00
Repairs, including labor and material	15.82
Interest and depreciation	341.67
Total	$1,041.53

Cost of Drag Line Excavator Operation.—Engineering and Contracting, Feb. 20, 1918, gives the following.

In connection with drainage construction on U. S. Reclamation Projects over 2,000,000 cu. yd. of earth were excavated during 1916 with four Class 9½ Bucyrus electric dragline excavators. The machines were operated by Government employes. Electric power was furnished at a cost of about 0.35 ct. per kilowatt hour from the Reclamation Service power plant.

The drains constructed were all open-channel cuts varying from 7 to 12 ft. in depth, with side slopes of 1½ to 1 and 2 to 1, and with usual base width of from 5 to 10 ft.

The drag-line excavators were operated three 8-hour shifts per day with crews of one operator and one oiler. The material excavated consisted principally of clay, loam, soil, and boulder gravel laid in clay and sand. This latter material constituted about 40 per cent of the total excavation and wore out bucket parts very rapidly. Temporary 3-phase electric transmission lines for operating the excavators were erected at a labor cost of about $85 per mile and torn down at a cost of $20 per mile, the line materials being used repeatedly along successive drains. The following table from the last annual report of the U. S. Reclamation Service shows the cost of excavating with the four drag lines for the 12 months, Jan. 1 to Dec. 31, 1916:

Classification	Total cost	Cost per cu. yd.
Operation	$ 20,529.88	$0.0077
Power	15,661.15	.0059
Repairs	33,650.11	.0126
Moving up	3,943.89	.0015
Cutting side drains	4,984.68	.0019
Finishing (hand labor)	629.37	.0002
Drilling and blasting*	217.34	.0001
Moving to new work	1,923.00	.0007
Sub-total	$ 81,539.42	$0.0306
Project general expense	4,468.96	.0017
Depreciation excavation equipment	31,943.96	.0120
Depreciation temporary power system	29,351.11	.0110
Total cost	$147,302.99	$0.0554
Total yardage	2,660.465	
Total mileage	54.17	
Cost per mile	$ 2,719.27	

*For excavation of 2,385 cu. yd. of rock.

The average digging rate of the four machines was 150 cu. yd. per-hour, or at the rate of two cycles per minute, with 1½ cu. yd. capacity buckets. The following table shows the machine efficiency:

	Total hours	Per cent
Digging	17,732.50	76.9
Repairs	2,729.75	11.8
Moving	1,486.00	6.5
Blasting	64.75	0.3
Side drains and runways	591.75	2.6
Power off	430.25	1.9
Total	23,035.00	100.00

In excavating 2,660,465 cu. yd. the machines worked 2,824 shifts, the average yardage per shifting being 940. The highest run per shift was 1,967 cu. yd.

Cost of Digging Drainage Ditch with Gasoline-driven Dragline.—P. F. Jones gives the following information in Engineering and Contracting, Dec. 17, 1919. A ½ cu. yd. dragline during the past season excavated a drainage ditch for the Modesto Irrigation District of Stanislaus County, California, at cost of 13 ct. per cubic yard. This figure comprises actual running expenses, including labor and material, but not interest or depreciation. The material excavated was 50 per cent sandy loam and 50 per cent clay hard pan. The ditch had a 6-ft. bottom, was 8 ft. deep, with slopes of 1½ to 1. It was approximately 2 miles in length. The crew included one operator at $200 per

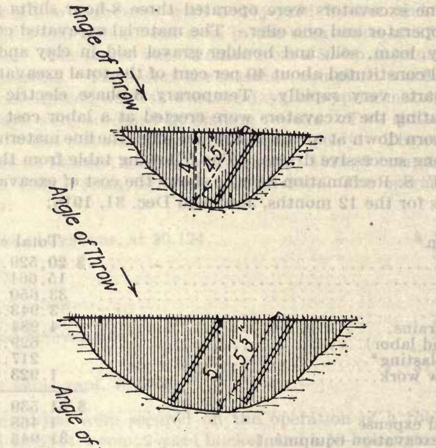


Fig. 1.—Sketches showing arrangement of holes for excavating ditches with dynamite.

month; one oiler at $5 per day and one 2-horse team and driver at $7 per day. The quantity of earth moved per 12-hour shift amounted to approximately 400 cu. yd.

Cost of Excavating Drainage Ditches with Dynamite.—A very considerable amount of farm ditching is being done with dynamite. Instead of digging these ditches by hand or machine, one or more rows of holes are made along the line of the ditch and a small dynamite cartridge is placed in each hole and the cartridges are exploded simultaneously. The result of the explosion is a channel which with very little labor makes a satisfactory drainage ditch.

Dynamiting is confined to the smaller sizes of ditches, say up to 5 ft. deep, but for channels of these sizes in suitable soils some very excellent results are reported.

Fig. 1 shows the arrangement of holes for ditches of several widths. A steel bar driven with a sledge is employed to make the holes. The cartidges are placed at the bottom of the holes and connected up with fuse or wire and then fired in the usual manner. The arrangement and spacing of the holes differ with the soil and had best be determined for each condition by a series of trials. As examples, the following reports of work done at Chadbourne, N. C., for the Brett Engineering Co. are of interest:

"Where the ground was comparatively free from stumps and roots we put down holes 18 ins. apart, 3½ ft. deep, and 100 holes in all. Each hole was pointed 45° and loaded with one stick of Hercules 60 per cent N. G. dynamite 1¼ × 8 ins., the center hole being primed with an extra stick and a double strength exploder. The result was a good ditch 7 ft. wide on top, 3 ft. on the bottom and 3 ft. deep and 150 ft. long. Costs of finishing and trimming according to specifications per running foot were:

Total cost of explosives used	$11.35
Total cost of putting down holes	.50
Total cost of finishing and trimming	4.50
Total cost of 150-ft. ditch	$16.35
Total cost per running foot	.109

"The next ditch was shot at Sollo Swamp, where the ground was heavily matted with roots and stumps. The specifications here called for a ditch 14 ft. wide, 2½ ft. deep. We put a double row of holes, 100 in each row, 18 ins. apart laterally, 4½ ft. apart longitudinally, and 4 ft. deep. Both rows pointed 45° in the same direction. The middle holes primed with an extra stick and a double strength exploder. Along the path of this ditch we counted 35 stumps from 6 ins. to 3 ft. in diameter. The result was a clean ditch 12 to 14 ft. wide, 4 ft. deep and 150 ft. long.

Cost of explosives per running ft	$0.10
Cost of holes per running ft	.0066
Cost of labor per running ft	.03
Total cost per running ft	$0.1366

"The next ditch was shot at Dunn Swamp, where we decided to put down 150 ft. in the muddiest and stickiest kind of ground. We put down a double row of holes 18 ins. apart, 4½ ft. laterally, 4 ft. deep, both rows pointed 45° in the same direction. Each hole loaded with one stick of 60 per cent and the middle hole of each row primed with a double strength exploder. All the holes well tamped. Result was a very clean ditch 14 ft. wide, 3½ to 4 ft. deep and 150 ft. long. The total cost of this ditch was the same as the ditch shot at Sollo Swamp."

According to Engineering and Contracting, March 21, 1917, dynamite was used in blasting open drainage ditches at the experiment station farm of the Montana Agricultural College at Bozeman, Mont. The soil where the ditching was done is very gravelly and contains many large rocks, making digging difficult and expensive.

Two sticks of 60 per cent Hercules dynamite were placed in holes 22 in. apart, this distance being determined by experimenting to be the most desirable for the soil conditions. About 25 holes were usually fired at one shot, the middle hole being used for the primer. A length of 647 ft. was blasted at a cost for labor of $51.25, or $1.31 per rod. The expense of cleaning out the ditch after blasting was 27 cts. per rod, which is included in the above cost. Dynamite, caps and fuse for the job cost $1.05 per rod (dynamite at 22 ct. per pound). The following is a comparison of three lengths of ditch constructed in 1915:

Kind of work	Length of ditch, rods	Total cost per rod
Hand-dug ditch	14.0	$3.35
First length of blasted ditch	17.0	3.10
Second length of blasted ditch	39.2	2.36

Cost of Maintaining Drainage Ditches in the South.—According to Engineering News-Record, Aug. 8, 1918, keeping a land drainage channel clear of growth and debris, cost $15 to $35 per mile on a ditch 8-ft. deep, 14-ft. wide at base and with side slopes of 1½: 1. These costs per mile include: labor, moving camp, food and cook's salary, depreciation on camp equipment and tools, together with all incidental expenses with the exception of Engineering supervision.

The rates of wages were as follows: foreman $3 per day, laborers boarding in camp $1 per day and laborers boarding themselves $1.25 to $1.50 per day.

Costs of Cleaning Drainage Ditches.—Methods employed in cleaning drainage ditches are described by Seth Dean, in the Proceedings of the Iowa State Drainage Association; from which Engineering and Contracting, Oct. 28, 1914, abstracts the following:

In the spring of 1910 the writer cleaned a bed of silt ranging from 6 ins. to 3 ft. in thickness and three-fourths of a mile in length from a channel originally cut 16 ft. wide on the bottom, but at the time in question the stream of water flowing over the silt was about 10 ft. wide and 1 ft. deep, the rate of fall being about 2 ft. per mile. There was considerable sand and some drift in the silt but no growth of weeds or brush. The plant used consisted of a flat-bottomed boat or scow, 7 × 18 ft. in size and 16 ins. deep, made of 1-in. plank. In the bottom of the scow a platform of 2-in. plank was laid to support the machinery, which consisted of a 4-hp. gasoline engine belted to a Myers pump with 3-in. suction and 2½-in. discharge. The pump was equipped with 10 ft. of 3-in. suction hose with strainer on the inlet end, and for discharge had about 15 ft. of 2½-in. fire hose with 1-in. nozzle. The scow when loaded required about 6 ins. depth of water to float. Commencing at the lower end of the silt bed the boat was poled forward or held in place, as required, and a jet of water turned through the nozzle into the silt that readily broke and stirred it up, permitting the water to float it away. The work was done in March and April, when the flowing water was clear and capable of carrying silt in suspension, the distance from the center of the silt bed to the outlet of the ditch was about 10,000 ft., and the current sufficiently strong that little settling of silt occurred. Three highway and one railroad bridge spanned the ditch in the distance cleaned, but the boat readily passed under them. Two men operated the machine and the total amount of silt removed was 2,346 cu. yds. in 33 working days. The cost of the equipment was as follows, viz.:

Cost of scow	$ 45.00
Engine and pump	200.00
15-ft. condemned hose and nozzle	3.00
Belting and fixings	8.60
Freight hauling and setting up	32.00
Two men 33 days at $4	132.00
Gasoline and oil	26.40
Repairs on machinery	1.05
Total	$448.05

After the work was completed the plant was dismantled and the engine and pump shipped to other work which was charged with their cost, thus making the net cost of the plant $248.05 and the cost of cleaning 10.53 cts. per cubic yard.

On one occasion a bed of silt interspersed with logs, brush, cornstalks, etc., was removed, using drags made from the beams and shovels of wornout corn cultivators by bolting the parts together in such manner that they presented the appearance of two anchors placed at right angles. The point of the beam was fitted with a swivel so the implement could revolve. By attaching ropes to the drag, placing a team on each bank and dragging the plow in the channel, the mass was broken up. After pulling out the logs and wire (dynamite being used sometimes to dislodge them) the water floated out the silt. A close measurement of the silt and drift removed from the channel was not made, as the work was done under the day system, but approximately 2,800 cu. yds. were taken out, the cost being the following items:

Four teams with drivers, at $3.50 each for 24 days	$336.00
Two drags with ropes and fixtures	10.00
Dynamite used	5.00
Foreman, 24 days at $2.50	60.00
Total	$411.00

Or about 15 cts. per cubic yard.

In the fall of 1912 we cleaned and deepened what is known as Seaton's ditch, near Missouri Valley. This is a drainage ditch 7,600 ft. long with 6 ft. bottom width, and side slopes 1 to 1. During the rainy season and for a time afterward the ditch carries water but is usually dry during the fall months. The work of cleaning was done by contract at 19 cts. per cu. yd. The contractor bid to do the work with teams, but the ground proved too soft for this method, and a small drag line dredge was purchased and the work successfully carried out with this, which proved to be an excellent machine for the work. The machine was made at Cherokee, Ia., of light timber construction. The framework, 16 ft. wide, is mounted on rollers and designed to work astride the ditch in clean-out work. The power is generated by an 8-hp. gasoline engine, which also serves to move the machine forward or transport it from one job to another along the country roads if the distance is not great. It uses a one-third yard scoop; two men operate it, using about 10 gals. of gasoline per day. About 250 cu. yds. of earth in ten hours was the capacity of the machine on the job in question. The machine is of wood construction and is not very durable, but as most of it is of sizes kept in all lumber yards, defective parts can be easily replaced.

Cost of and Profits from Tile Underdrains.—The following discussion by R. D. Marsden, published in Engineering and Contracting, July 7, 1914, is taken from the Year Book of the Department of Agriculture.

Costs.—The cost of drainage will vary considerably with the location of the work, owing to differences in the cost of tile and of labor: it will vary more with the nature of the soil and the consequent depth and spacing of the drains. Tile of 4-in. inside diameter will cost $16 to $20 per thousand feet at the factory and often $25 per thousand delivered at the railway station. If 4-in. tile cost $25 per thousand, 5-in. will cost about $35, 6-in. about $45, and 8-in. about $80 per thousand feet. Labor will vary from 75 cts. to $1.50 or more per day, but as the cheaper labor is considerably less efficient the cost per rod of drain will be more uniform. As an average cost for trenching, laying, and backfilling over the tile, about 50 cts. per rod for a depth of 3 ft. may be assumed; lower prices may be secured on large contracts that make it economical to use a trenching machine or a large force of experienced workmen. Deeper digging and larger tile require more excavation and involve higher prices. There also will be expense for hauling the tile from the railroad, and for engineering work in planning and laying out the drains. Silt wells, surface inlets, and masonry protection for tile outlets must be provided where needed. The total cost of drainage will ordinarily range from $15 to $45 per acre, the lower price mentioned being reached when the spacing of drains is perhaps 150 ft. and the higher figure when the spacing is about 4 rods or a little less. A very common cost for tile drainage is $25 per acre. The farmer can often do a considerable part of the hauling and other labor with his own teams and regularly employed help, especially where the amount of work is not large, saving no small cash outlay. Of course the foregoing prices do not anticipate the excavation of rock, large stones, or other very hard formation in any considerable quantities, for this will quickly multiply the labor cost.

Open ditches cost from 12 to 20 cts. per cubic yard of dirt removed, the price increasing with the size of the ditch because the material must be moved farther. A ditch 3 ft. deep, 2 ft. in top width, and 1 ft. in bottom width would cost 33 cts. per rod at 12 cts. per cubic yard; a ditch 4 ft. deep, with 3-ft. bottom and 6-ft. top, would cost $1.65 per rod at 15 cts. per cubic yard; and a ditch 4 ft. deep, with 4-ft. bottom and 8-ft. top, would cost $2.95 per rod at 20 cts. per yard. If open ditches of the smallest size were used 150 ft. apart, with a collecting ditch of the medium size, the cost of drainage would hardly be less than $7 per acre. The difference between tile and open drains would then be $8 per acre; the interest on such an investment would be 80 cts. per acre at 10 per cent, or 50 cts. per acre at 6 per cent. This amount would not nearly pay for the labor of keeping the ditches clear of weeds, dirt, and other obstructions, not to mention the increase in labor occasioned by having the field cut into small parts. The advantage of using tile becomes greater as the distance between drains is reduced, not only because of the labor of cultivation, but also because of the ground area used for ditches instead of for cropping.

Profits.—The actual value of farm drainage is indicated by the testimony of owners who have done this kind of work. Many of them state enthusiastically that drainage has doubled and trebled their crops and has increased the value of the land 50 to 300 per cent. The examples cited herein have been selected as typical of the results from properly draining farm lands in the humid region of the United States. Because the reclamation of large swamp tracts frequently involves considerable expense for clearing and sometimes for soil treatment after drainage, the profits shown below are in no way indicative of those to be obtained from large swamp reclamations. Neither should these results be used in considering the drainage of irrigated land in the arid region.

In the coastal plain of North Carolina about 25 acres that were producing nothing were tile drained for perhaps $250, probably not including costs of teaming and of supervision, and since then have produced a bale of cotton per acre. A field of six acres was drained for about $160, and the owner makes good crops on soil worthless without drainage. In the black prairie belt of Alabama, a field that had not been cultivated in years because too wet was drained with tile; then it produced one bale of cotton per acre and repaid the entire cost of drainage the first year. The following year the field yielded 50 bushels of corn per acre, twice the rate from the other parts of the farm. Another drained field produced one bale of cotton per acre, while the undrained land produced only half a bale. A 10-acre field that yielded practically nothing in 1912 was tile drained, and in 1913 produced 60 bushels of oats per acre; in 1914 the rate was again 60 bushels of oats, in contrast to 10 bushels per acre from the adjoining 15-acre field planted to the same grain. The cost of most of the tile drainage in Alabama has been about $25 per acre, some of it as high as $30 to $35, but increases of 50 to 200 per cent in yields and the assurance of good crops every year instead of only in very favorable seasons are very satisfactory returns. The cost of drainage there has usually been repaid in two to three years by the improved crops. In Iowa, a field of 40 acres too wet for planting was tile drained at a cost of $24 per acre, after which it produced 60 bushels of corn per acre. Another field was drained for $23 per acre, thereby increasing the yield from 15 bushels to 40 and 50 bushels of corn per acre. In Arkansas, on one of the State farms, 1 bale of cotton per acre was secured in favorable years, and nothing at all when the early part of the season was wet; the year following the installation of tile the yield was 1½ bales per acre. In Nebraska a tract of more than 700 acres was tile drained at $24.25 per acre, a pumping plant cost $2 per acre, and as part of a larger district the cost of levees to protect from overflow was $9 per acre. The improvement, for a total cost of $35 per acre, immediately increased the crop on about 80 acres of corn 22 bushels per acre, and on another part the increase in two years was from nothing to more than 30 bushels of wheat per acre.

Owners have found that tile drainage has reduced the cost of farming operations 20 to 50 per cent, so the increased production on land cultivated previous to drainage is clear profit. To find the profit upon draining land that has been abandoned, of course the cost of planting, cultivating, and harvesting must be deducted from the gross receipts for the crops raised. Investigations of the cost of producing cotton and of producing wheat indicate that where expensive fertilizers are not used the cost per acre for growing and marketing varies little if at all with the rate of yield.

To compute the actual money value of drainage requires that certain assumptions be made. If the average production of a field is increased about one-half bale of cotton per acre, worth 10 cents per pound, the income is increased about $25 per acre, equivalent to a 10 per cent dividend on $250, or a return of 71 per cent on a drainage cost of $35 per acre. If drainage increases the yield of corn 25 bushels per acre, worth 50 cents per bushel, the returns of $12.50 per acre would be equivalent to a 10 per cent dividend on $125, or 50 per cent annually on a cost of $25 per acre. However, to capitalize the net increase in value of the crops at the regular rate of interest might be a fair measure of the increase in producing value of the land, but this is the result of drainage added to what may be called the unused fertility of the soil. It will be better to consider the increase brought about by drainage in the market value of the property. In the Piedmont section of North Carolina a 55-acre farm was bought about six years ago for $1.900; ditching was started the first year and tile drainage two years later; in 1913 the crops were worth $2,000, and in 1914 the owner refused $5,000 for the farm. In the mountain section of the same state about 22 acres that grew only saw grass and bulrushes were tiled for $35 to $40 per acre, and the owner now values the land at $150 per acre. Another farmer spent about $200 cash, and probably some of his own time, in tile drainage, and thereby increased the market value of his farm $500 to $800. Another man reports the results as 300 per cent increase in the selling price of the land and 40 per cent in the assessed value; still another, who drained 10 acres for about $140, gives the results as one-third increase in assessed value, two-thirds increase in selling price, and more than 100 per cent increase in production. In eastern Maryland tile work costing $500 increased the farm value $1,000, and work costing about $240 increased the value of another farm $500.

In considering the economy of farm drainage it is proper to compare the anticipated results with the probable returns from otherwise investing the money that the drainage work will cost. When a farmer considers investing some of his savings to increase his business a question often to be met is: Shall he buy more land or improve some of what he already owns? If corn land producing 50 bushels per acre sells for $80 per acre, and he has marsh land which cost $10 per acre that produces nothing, drainage at $30 per acre will be profitable if it will make the marsh produce 25 bushels of corn, provided there are no other costs for preparing the land for cultivation. If the whole cost of drainage and other reclamation work is $50 per acre, and the result 50 bushels, the land has been made worth $80 for a total cost of $60 per acre. If land yielding 40 bushels per acre can be made to produce 50 bushels by drainage at $25 per acre, perhaps it would be true economy to buy more good land at the price stated rather than to drain; for $1,000 spent improving 40 acres would yield 400 bushels, while the same money buying 12½ acres new would yield 625 bushels. The difference in value at 50 cents per bushel would be $112.50. However, the increase in cost of farming the larger acreage might be considerable; if it would amount to as much as $3 per acre it would more than offset the difference in total yield, for there would be no increase in cost of farming on the drained land. Actual comparisons of the profits to be obtained from farm improvement and from purchasing improved land will many times show the farmer to be true economy, in spite of seemingly small gross returns. As larger markets raise the prices of agricultural products, land values must increase and larger expenditures per acre for drainage will be profitable.

Cost 35 Miles of Tile Drains.—The following data are given by L. H. Goddard and H. O. Tiffany in Circular No. 147 of the Ohio Agricultural Experiment Station.

*Description of Soil on the Farm Drained.**—Practically all of the soil on this farm is of glacial origin, and has been derived from the drift, which is here composed very largely of pulverized shale. The principal type, called Papakating clay, is a clay loam containing quite a large percentage of silt. The surface soil consists of a pale yellowish or grayish brown clay or heavy silt loam about 9 inches deep, which gradually becomes heavier with depth until at 18 to 24 inches it is mottled yellow and gray or blue clay, which becomes decidedly plastic at a depth of 3 feet. The higher elevations, or knobs, which were occasionally encountered, are somewhat lighter in texture, sometimes approaching a sandy loam, and usually contain some large stones or gravel in both soil and subsoil.

The lower lying soil, called Volusia silty clay loam, consists mainly of a dark colored clay loam or clay, varying greatly in depth and underlain by very

* Prepared by Dr. George N. Coffey of the Ohio Agricultural Experiment Station.

stiff mottled or bluish clay. This subsoil clay was considered by an expert to be of the right quality for tile making.

Near the centers of the main swamp areas there occur small areas of muck and washed-in material. The deposit of muck is shallow and the soil is very porous, allowing the water to disappear readily after rains and storms.

Methods of Procedure.—The work of installing the tile was conducted in the field by the Junior author, and all records were kept and compiled by him. The compilation and the manuscript have been checked by O. E. Brown, who was an assistant on the farm under Mr. Tiffany's management. This work of installation was done in cooperation with the Ohio Experiment Station and the U. S. Department of Agriculture, the regular time blanks of the Department of Cooperation of the Ohio Experiment Station being used. The records given herein are quite accurate so far as they go, and for the conditions under which the work was done.

The planning and laying out of the tiling systems in any given field was done by the Farm Manager, usually just previous to starting tiling operations. In a few instances surveys of the main ditches were made by an engineer to determine the necessary depth of cuts at intervals along the line. Surveys of this kind are especially valuable when a deep cut is to be made. In many instances levels were run on ditches where the amount of fall was doubtful. An ordinary carpenter's spirit level with sights attached was used for this purpose. This method is hardly accurate enough, but on most laterals up to 80 rods in length very good results were obtained. When a main ditch is over 80 rods long and has but little fall the Y level should be used. At the close of the season's operations an engineer was employed to make a plot of the fields tiled, showing the exact locations of all the drains.

All ordinary labor, such as hauling of tile, filling of trenches, etc., was done by men and teams taken from the regular force on the farm.

Tiling Work Done in 1909.—In the season of 1909 the drainage operations were confined to a single field (hereafter designated as No. 2), with the exception of about one-half mile of tiling for which figures are not included in this circular. The outlet for this field, which was an open ditch, had been provided the previous fall.

The surface conditions of this field were somewhat varied. The larger portion of it, or about 30 acres, was upland and quite rolling for this section of the state. The other 10 acres was mostly a clay and muck swamp. On the upland it was comparatively easy to secure a sufficient fall in all ditches, the fall per 100 ft. averaging about 8 inches, but the swamp area the fall would not average over one inch per 100 feet. One main ditch, which was in 12-inch tile, was carried practically on a level for about 800 feet, the grade being determined by the use of water. The condition of the upland portionl of this field would be an average for land in that section that had never been working It was covered with a heavy bluegrass sod which had been pastured for many years. The ten acres of lowland or of swamp area were covered with bulrushes, cat-tails, swamp brush, trees, etc., and in many instances a clearing had to be made before starting a ditch. The cost of this clearing for a ditch was comparatively trivial, however, and is included in the cost of tiling the field.

With the exception of about 160 rods the trenching was all done by hand this year; this 160 rods was dug by a machine rented at an average price of 25c per rod for the trenching alone. This cost of trenching was not deducted and figured separately, but included with the hand dug ditches by using exact figures of cost. Regular workmen employed for spading or trenching were paid from 20c to 22½c per hour for actual time put in. One man of long experience who did the bottoming, grading and laying of the tile received 25c per hour. The distance actually covered by each workman would not average over 8 rods per day under very favorable conditions.

Operations in 1909 were begun in the month of May, and for two months an average of 6 men were employed to dig the trenches. Little work was done, however, during the month of July and early August because some of the workmen were needed for harvesting and because the ground became so hard and dry. No tiling was done later than Oct. 1st. that year. Table I shows a summary of the 1909 tiling operations.

TABLE I.—SUMMARY OF TILING OPERATIONS IN 1909

Total rods, 2,560; total area, 40 acres. Man rate, 15c per hour; horse rate, 10c per hour.

	Total labor			Labor per rod		
	Hours			Hours		
	Man	Horse	Cost	Man	Horse	Cost
Hauling tile	135.5	271	$ 47.42	.053	.106	$0.0186
[1]Trenching & laying tile	3855.0	...	963.74	1.500	....	.3760
Filling ditches	305.0	305	76.23	.119	.119	.0300
[2]Other equipment charges	.....	...	10.00	.....	....	.0040
Cost of tile	.....	...	555.39	.....	....	.2170
Overhead charges	.....	...	58.88	.....	....	.0230
Plotting drains	.....	...	40.45	.....	....	.0158
Totals	.....	...	1,752.11	.....	....	.6844

[1] Man rate varied from 20 to 25 cents per hour. The cost is exact, but hours approximate.

[2] Approximate.

Explanation of Cost Classifications Found in Tables I, II and III.—Of these classifications, figures for machine operator, hauling tile, trenching and laying, laying tile, filling ditches, undivided operations and plotting drains are given in dollars based on the number of hours worked, the cost being obtained by multiplying hours of labor by the rate per hour. Machine charges and other equipment charges include, in addition to labor, cash repairs, interest on investment and depreciation on equipment. The gasoline, oil and cost of tile are straight cash charges and are put in at the actual price paid.

Overhead charges in this work included only the cost of the actual time of the farm manager to lay out and plan the drainage system and to direct the work in the field. The time required to execute this duty varied considerably from day to day. After the system was once outlined and everything working well it did not ordinarily require more than one or two hours a day.

Tiling Operations in 1910.—In 1910 tiling operations were conducted on ten separate fields, covering twelve water sheds. Table II shows that seven of these fields were small, and as several operations were carried on simultaneously in them, it was not practical to keep the cost of each one separately. These contained 21 acres and included 216 rods of water pipe line, sewers and lines for hog barn disposal. The total area drained during the year was 65½ acres and a total of 4080 rods or 12½ miles was installed in that area.

For the work this year a new power tile ditching machine, equipped with a gasoline engine, was purchased early in the spring and nearly all the trenching done during this season was with this machine. One man was required to operate the ditching machine and another man to lay tile, although the tile layer occasionally assisted the machine operator in setting grade stakes,

TABLE II.—SUMMARY OF TILING OPERATIONS IN 1910

Man rate, 15c per hour; horse rate, 10c per hour; machine operator, 20c per hour.

	Field cost				
Operations	Field 24	Field 29	Field 30	Seven misc. areas	Total
Areas in acres	29	10½	5	21	65½
Rods	1,591	755	300	1,434	4,080*
Machine charges	$172.46	$ 81.84	$ 32.52	$155.41	$ 442.23
Machine operator	66.92	28.04	12.64	20.86	128.46
Gasoline	35.50	14.34	5.17	34.51	89.52
Oil	1.74	1.43	.64	2.06	5.87
Hauling tile	59.34	41.80	12.03	18.83	132.00
Contract laying tile	115.95	41.25	22.95	78.60	258.75
Filling ditches	52.08	28.40	5.16	17.12	102.76
Other equipment charges	6.17	3.05	1.20	4.58	15.00
Undivided operations	25.51	3.00	3.60	144.53	176.64
Cost of tile	325.95	132.16	79.47	297.42	835.00
Overhead charges	36.59	17.37	6.90	32.99	93.85
Plotting drains	25.13	11.93	4.74	18.88	60.68
Grand totals	$923.34	$404.61	$187.02	$825.79	$2,340.76

* 12¾ miles.

repairing the machine, etc. The main ditch was first installed and then the laterals were connected to it in a systematic manner. In connecting laterals to the main it was necessary to do some hand digging, because the machine could not be put to the proper grade nearer to the main ditch than 6 or 8 feet, depending, of course, upon the depth of the main. The cost of this necessary hand digging in connecting the laterals with the main ditches has been assembled with other costs in a column called "Undivided operations."

The largest field tiled during the year 1910 contained 29 acres. In it 1591 rods of drains were installed, or an average of 55 rods per acre. During July, August and September the work was much interrupted because of using the men for harvesting and farm work.

This field, which was a heavy blue grass sod, with the exception of about 3 acres of muck swamp which usually was covered with water about half the year, had been used as a pasture for many years. The drains of this field had two outlets; the principle one being a twelve-inch tile leading to an open ditch. The fall of this main for the last 500 feet did not exceed one inch per one hundred feet. In general, however, the topography of the field was quite broken, affording plenty of fall. Indeed there were slopes in which the fall was as much as 8 feet to the hundred.

The second field of importance, which was drained in 1910, was a young orchard which had been set that same spring. There were 10½ acres in this orchard and in it a total of 755 rods of drain were installed, or 72 rods per acre. This greater amount of tile per acre was due to the fact that the trees were set 32 feet apart and that a line of tile was installed between each two rows of trees, whereas in other fields 40 feet apart for laterals was the distance more frequently used. The topography of this orchard field was rolling, but without abrupt breaks. The fall per hundred feet would run about 6 inches, although in a few instances there was a fall of three or four feet to the hundred.

It should be noted in passing that wet weather in April, September and October, interfered quite a little in the operation of the tile ditching machine, due to mud sticking to it.

Tiling Operations in 1911.—During the season of 1911 tiling operations were confined to two fields, Nos. 5 and 31 with the exception of 198 rods in two other fields. In all 4,755 rods of tile were installed in 122½ acres. Table III gives a summary of the work executed this year.

Operations were begun late in March and continued throughout the season until October 31st. The first work was done under very unfavorable conditions. It was the digging of a main ditch which followed the channel of an old open ditch, in which the cut in places was from 4 to 6 feet. The ground was so wet at this time of the year that slipping of the propeller was not infrequent and caving in of the ditch greatly hampered the progress and necessarily increased the cost. In some places the soil where wet was such a waxy clay that it caused considerable trouble by sticking to the machine.

TABLE III.—SUMMARY OF TILING OPERATIONS IN 1911

	Field 5	Field 31	Misc. areas	Total
Area in acres	54	65	3½	122½
Rods	2,666	1,891	198	4,755
Machine charges	$ 407.88	$ 289.32	$30.28	$ 727.48
Machine operator	95.10	72.00	19.16	186.26
Gasoline	66.00	69.48	9.72	145.20
Oil	7.84	4.34	.96	13.14
Hauling tile	63.10	94.94	12.50	170.54
Contract laying tile	184.98	121.33	20.11	326.42
Filling ditches	78.08	82.22	12.31	172.61
Other equipment charges	11.17	7.98	.89	20.04
Undivided operations	107.62	35.78	24.90	168.30
Cost of tile	567.00	765.85	61.34	1355.19
Overhead charges	61.32	43.49	4.56	109.37
Plotting drains	42.12	24.58	*	66.70
Grand totals	1,692.21	1,572.31	196.73	3,461.25

Overhead charge is 2.3c per rod. Plotting drain charge is 1.58c per rod.

* Not plotted.

Ditching in field No. 5 began in April and continued throughout the summer until August 25th. As shown by the table, the area covered in this field is 54 acres, in which were installed 2,666 rods of tile, making an average of 49 rods per acre. The general topography of this field is rolling. There were two swamps in it; one a cat-tail swamp full of brush and trees and another which covered about 2½ acres. A former owner had attempted to drain this latter swamp a number of years previously, but the attempt was unsuccessful. The soil in these swamps varied from a muck in their center to a heavy, black waxy clay around the outside. In a few places in this field stones were sufficiently numerous to retard the progress considerably but no serious breakage was occasioned.

One of the main ditches in this field is worthy of note. It is 830 feet long with an average depth of cut of about 6.5 feet. The maximum cut was 9.7 feet, which was maintained for a distance of about 300 feet. The machine was operated in this ditch to its maximum depth, which is 4½ feet, and the remainder was dug by hand, using contract labor. The total cost of extra labor on this ditch, after the machine had done its part, was $103.62, or an average of $2.06 per rod. If we add the cost of gasoline, oil and other machine charges, which amount to $10.44, to the other labor charges of $103.62 we have a total cost of $114.06, or $2.27 per rod, which is the installing cost of his main ditch. Approximately 266 cubic yards of earth were excavated in digging this ditch. This would make the cost of excavating 42.9 cents per cubic yard. From the foregoing it will be manifest that outlets are expensive when no natural outlet is available.

Tiling in field No. 31 began at the conclusion of work in field No. 5 and continued until the close of operations on October 31st. The area covered in this field was 65 acres. The field joined field No. 24, which was tiled in 1910. 1,891 rods were installed in it, or about 29 rods per acre. The distance between laterals was greater in this field than in many of the others; varying from 50 to 110 feet, with an average distance of about 90 feet. Fully 35 acres of this field was a swamp, a portion of which had been farmed and nearly all of which had been previously drained. The drains, however, which had been installed from 30 to 35 years previously, had become useless.

Before anything could be done toward draining this field it was necessary to secure a satisfactory outlet. The excavation of this open ditch outlet, which was done by the farm teams and laborers, using slip scrapers, was started in the summer of 1910 and finished in October 1911, the work being prosecuted upon this ditch only at such times as men and teams were not required for farm work. The total length of outlet streams was 1.2 mile, which included about 500 feet of new cuts. When this ditch was finished the bottom of the outlet had been lowered fully 2½ feet. The cost of making this outlet was $558.18 and is not included in summary Table III.

In the ditching of this field a few round stones were encountered in the upland but no trouble or serious delay was experienced. Continued heavy rains during the late fall caused considerable delay, especially in the muck portions. The muck became so full of water that it rushed in from the sides of the ditch so fast that the tile layer had to let the excess run away before he could lay the tile. A few rotted logs, buried beneath the surface in the muck portion of the field, interfered somewhat with the work.

Character and Cost of Tile Used.—The tiles used in all this work were ordinary, medium burned tiles, made from a good quality of clay. All tiles up to a diameter of 10 inches were in foot lengths, but 10-inch and larger sizes were in 2-feet lengths. The breakage of tiles through handling was not large, the maximum amounting to five or six feet per load of 1,000 3-inch tiles. Even with this breakage the over-run amounted to from 3 to 6 per cent, in other words 100 feet of tile paid for at the factory would lay from 103 to 106 feet in the ditch. The larger tiles seemed to have a greater over-run than the smaller ones. The cost of tile per acre for tile drains varies of course in accordance with the size of tile and the number of rods per acre. The average cost of tile per rod in the main fields in Table IV is 24.45 cents, and the cost per acre, with an average of 48 rods, is $11.72.

Cost of Hauling Tile.—Table V furnishes a very good basis for estimating the time required for, and the cost of, hauling tile, especially when taken in conjunction with Table IV. Naturally, the cost of hauling tile would vary with the size of the tile, the length of the haul, and the condition of the roads. Favorable or adverse conditions in connection with any one of these factors may affect the cost materially.

For example, in the case of fields Nos. 29 and 30, in which the haul and weight of tile were practically the same, the roads were so bad when the tile was hauled for field No. 29 that it cost 38 per cent more per rod than it did for field No. 30. Again, in case of field No. 31, for which the haul was much shorter than for No. 29, and for which the roads were in good condition, the expense was much increased by the haul within the field, because it was

TABLE IV.—SHOWING SIZES AND TOTAL COST OF TILE USED

Field	Area	No. feet and size of tile: 3-inch	4-inch	5-inch	6-inch	8-inch	10-inch	12-inch	Totals: Rods	Totals: Cost	Per acre: Rods	Per acre: Cost	Cost per rod
No. 24...	29	20,721	2,772	487	775	548	267	687	1,591	$ 325.95	54.9	$11.24	$0.2049
No. 29...	10½	10,912	541	729	...	275	...	...	755	132.16	71.9	12.59	.1750
No. 30...	5	3,102	802	...	273	773	...	...	300	79.47	60.0	15.89	.2649
No. 5....	54	37,757	1,010	2,146	894	751	623	830	2,666	567.00	49.4	10.50	.2127
No. 31*..	65	13,843	9,241	2,626	957	450	1,825	2,265	1,891	726.85	29.1	11.18	.3843
No. 2....	40	Various sizes not tabulated							2,560	555.39	64.0	13.88	.2169
Totals....	203½	....	....	....	....	....	....	....	9,763	2386.82	....	......	.....
Averages.	.....	....	....	....	....	....	....	....	....	....	47.97	11.72	.2445
Small fields													
Misc. areas...	24½	....	....	....	....	....	....	....	1,632	$358.76	66.62	14.64	.2198
Cost of tile per 1,000 feet													
	....	$9.90	$14.85	$21.78	$29.70	$49.50	$74.25	$99.00	....	....	....	....	....

*405 feet of 13-inch tile were added to the 12 inch.

TABLE V.—HOURS REQUIRED FOR AND COST OF HAULING TILE

Man rate 15c per hour. Horse rate, 10c per hour

Fields	Rods	Area	Distance of haul in miles	Conditions of roads	Totals: Hours: Man	Totals: Hours: Horse	Totals: Cost	Per rod of tile: Hours: Man	Per rod of tile: Hours: Horse	Per rod of tile: Cost
No. 24......	1,591	29	2½	Good	184.0	317.5	$59.34	.116	.200	$0.0373
No. 29......	755	10½	3½	Bad	124.0	232.0	41.80	.164	.307	.0554
No. 30......	300	5	3½	Good	35.5	67.0	12.03	.118	.223	.0401
No. 5......	2,666	54	1½	Fair	194.7	339.0	63.10	.073	.127	.0237
No. 31......	1,891	65	3	Good	275.0	537.0	94.94	.145	.284	.0502
Totals.....	7,203	163½	..	.....	813.2	1492.5	271.21	....	....	......
Av. per rod....	....	....	..	......	......	......	......	.113	.207	.0377

necessary to haul much smaller loads, especially through the muck portions of the field. Ordinarily about the same sized loads were hauled on the road and in the field but in the case of field 31 it was necessary to unload a part of the tile and make a second trip through the field.

Had it been possible in all cases to haul tile at no other time than when the roads were good the cost of hauling could have been materially reduced, but in this work it seemed necessary to use the regular farm teams and to try to do the hauling when it was not possible to use the teams at other farm work. This hauling was done with heavy teams, weighing not less than 2,700 pounds, and with wagons having 4-inch tires, thus enabling the handling of heavy loads regardless of the condition of the roads. 100 feet of 12-inch tile or 1,000 feet of 3-inch tile were considered a load on good roads.

The Power Tile Ditching Machine.—The power tile ditching machine, in connection with which these data were obtained was equipped with caterpillar tractor the weight of the machine thus being distributed over a surface of about 24 square feet. This feature enabled the machine to be operated over very wet ground and in many instances to be run through swamps covered with water without having serious trouble from miring.

TABLE VI.—SUMMARY OF HOURS AND COST FOR MACHINE OPERATOR

20c per hour for operator

Fields	Area	Rods	Totals Hours	Totals Cost	Per acre Hours	Per acre Cost	Per rod Hours	Per rod Cost
No. 24	29	1,591	334.6	$66.92	11.54	$2.31	.2103	$0.0421
No. 29	10½	755	140.2	28.04	13.35	2.67	.1857	.0371
No. 30	5	300	63.2	12.64	12.64	2.53	.2106	.0421
No. 5	54	2,666	475.5	95.10	8.81	1.76	.1784	.0357
No. 31	65	1,891	360.0	72.00	5.54	1.11	.1904	.0381
Total	163½	7,203	1,373.5	274.70	.....	.....	.....	.....
Average	.....	.....	.....	.....	8.40	1.68	.1907	.0381

Uneveness of the ground surface made but little difference in controlling the grade, as the operator had complete control over the machine at all times. In a few instances the depth of cut was changed from 4 feet through a knoll to half that depth within a distance on the surface of about the length of the machine, and in doing this a perfect grade was easily maintained.

The machine was equipped to do work at four different rates of speed, which were used according to depth of digging and stickiness of dirt. A higher speed would dig to a depth of two feet and with very favorable conditions even deeper at practically the same cost. The second speed was used in digging to a depth of 3 feet under ordinary conditions, and in some cases as deep as 3½ feet. The third speed would dig to 4½ feet in depth, which was the limit of the machine. The fourth or slowest speed was not used in connection with this work. Dry ground had no effect upon the machine except to cause the knives to need sharpening more frequently. Soil frozen to a depth of four inches caused but little trouble. Freezing of wet earth to the machine occasionally caused trouble but this was of little consequence. While in some cases, in the early spring or late fall when the ground was soaked full of water and was of a spongy nature, good progress could not be made because of the slipping of the propellers in the soft mud, yet during the greater part of the season the machine could be operated satisfactorily immediately after heavy showers. In most cases the machine was run only one way—from the main up the slope. However, at times when but little water came into the ditch the machine could be operated down the slope just as successfully. Round stones or boulders in the ditch line caused more or less trouble, depending upon the location in the ditch, the size of the stones, etc. Usually boulder the size of a man's head could be removed by the machine with comparative ease, but when larger than this it was necessary to raise the digger wheel and remove them by hand.

TABLE VII.—SUMMARY OF GASOLINE AND OIL COSTS

Field	Area	Rods	—Total cost— Gas	Oil	—Per acre— Gas	Oil	—Per rod— Gas	Oil
No. 24......	29	1,591	$35.50	$ 1.74	$1.224	$0.0600	$0.0233	$0.0011
No. 29......	10½	755	14.34	1.43	1.365	.1360	.0190	.0019
No. 30......	5	300	5.17	.64	1.034	.1280	.0172	.0021
No. 5.......	54	2,666	66.00	7.84	1.222	.1450	.0248	.0029
No. 31......	65	1,891	69.48	4.34	1.069	.0670	.0368	.0023
Totals......	163.5	7,203	190.49	15.99	......	......	......	......
Averages....	.....	....	......	......	1.165	.0977	.0264	.00221
Misc. area..	24½	1,632	44.23	3.02	1.805	.1235	.0271	.00185

Hours and Costs for Machinery Operator.—In Table VI, in which are summarized data regarding the machine operator, it will be noted that the cost per rod varies from 3.57 to 4.21 cents, with an average cost of 3.81 cents.

It should be noted, however, that these prices are figured at 20 cents per hour for operator. This was the price actually paid, but it was lower than that for which an operator could ordinarily be secured, because of the fact that the man used for this purpose was one of the regular farm workmen, who had a natural bent in that direction. Ordinarily the wage of the operator would run from 30 to 40 cents per hour, thus making the cost greater. In order to be able to operate a machine successfully a man should understand the principles of tile drainage, the running of grade lines, etc., and at the same time he should be handy with machinery.

Gasoline, Oil and Grease Costs.—In Table VII is shown a summary of gasoline, oil and grease costs for the entire area trenched with the machine. The average price of gasoline per gallon was 13.3 cents in 1910 and 12 cents in 1911. Cup grease cost 6¾ cents per lb., and oil from 16 cents to 35 cents per gallon. The best grade of gas engine oil was used on the engine but a cheaper oil was used on chains, sprockets, etc. While this factor of the costs may seem somewhat small, yet 3 cents per rod cannot be ignored nor can we ignore the fact that the price of gasoline is advancing constantly.

Tiling Machine Charges.—In Table VIII are summarized the overhead machine charges for the two years within which the machine trenching was done. These charges are classified under four headings, as follows:

1. "Labor repairs" which included cost of labor, usually rendered by the machine operator, in connection with actual repair work on the machine. While of course there are many cases in which a half-hour's time or less was spent by the operator repairing the machine, these have not been separated from the operating charge. All periods of a longer time than one-half hour are charged to "Repairs" and are itemized in this summary.

2. "Cash repairs" includes all repairs for machine, such as bolts, sharpening of knives, batteries for engine, for which cash is paid.

3. "Depreciation" is a variable item, depending upon several influencing factors. In this table it has been figured at 5.1 cents per rod, although at best this charge must be an arbitrary one unless a machine is actually worn out. The number of miles of ditch a machine will dig during its lifetime depends

TABLE VIII.—TILING MACHINE CHARGES. DEPRECIATION, REPAIRS AND INTEREST ON INVESTMENT

			Total costs					
Year	Acres	Rods	Miles tile	Depreciation	Repairs—Labor	Repairs—Cash	Int. on investment	Total
1910........	65.5	4,080	12.75	$208.08	$50.74	$100.00	$81.60	$441.23
1911........	122.5	4,755	14.86	242.50	88.05	365.47	71.15	767.18

	Per rod				
Year	Labor	Cash	Interest	Depreciation	Total av. cost
1910....................	$0.01240	$0.02450	$0.02000	$0.0511	$0.1079
1911....................	.01852	.07677	.01495	.0510	.1613
Av. for two yrs.........					$0.1368

upon the depth of digging; condition of soil as regards texture and freedom from stones; care given machine by operator, etc. In determining the arbitrary figure of 5.1 cents per rod it was assumed that the machine would be capable of digging 100 miles of trench within its lifetime. Some machines have dug over 200 miles of ditch. It will be noted, however, that even on the 200-mile basis the cost of depreciation per rod would be 2.55 cents and that the total machine charge would only be lowered from 13.68 cents to 11.13 cents, thus making this, comparatively speaking, a minor point. Depreciation is figured on an initial cost of the machine amounting to $1,632. This price, of course, may vary from time to time. If no larger tile than 8-inch were to be installed it would probably be cheaper to buy a smaller machine unless the ground to be trenched is somewhat stony. In this connection it is interesting to note that the repair charge, especially cash repairs, for the second year was almost three times as much per rod as it was the first year.

4. "Interest on investment," which was figured at 5 per cent, decreases from year to year, as the initial price is cut down by the amount which is charged off annually for depreciation.

Machine Trenching Compared with Hand Trenching.—In Table IX is shown a comparison between the costs of hand and machine trenching, so far as it is able to make such a comparison from the work done on this farm. It will be noted that the cost per rod of machine trenching varies from 30.5 cents to 39.8 cents, whereas the hand trenching cost is 44.9 cents. It should be noted, however, that in these averages, there are more than four times as many rods of machine trenching as of hand trenching. While the cost of machine trenching would, in most cases, be increased somewhat by a higher rate per hour for the machine operator, and probably would be increased by the cash repair charges, yet even with these increases it probably never would overcome the difference between machine and hand trenching, which, as shown by Table IX, is 7.4 cents.

While there may be conditions in the very early spring when the ground is thoroughly water-soaked which make the ditching machine not very satisfactory because of its slipping and of mud sticking to it, yet this is fully offset by the fact that it digs readily in dry weather even though the ground may be so hard that it is almost impossible to trench with a spade. It is very much easier to maintain a uniform grade when ditching with a machine than doing the work by hand. In the trenching which was done by hand in 1909 almost all of the ditches were tested with water before tile was laid. This is, of course, somewhat expensive, especially if the water is not near at hand. A

TABLE IX.—COMPARISON BETWEEN HAND AND MACHINE TRENCHING

Field	Acres	Rods	Total cost except tile and hauling	Per rod machine	Per rod hand
No. 2	40	2,560	$1,149.30	......	$0.449
No. 24	29	1,591	538.05	$0.338	.....
No. 29	10½	755	230.65	.305	.....
No. 30	5	300	95.52	.318	.....
No. 5	54	2,666	1,062.11	.398	.....
No. 31	65	1,891	750.52	.397	.....
Misc. areas	24½	1,632	632.43	.388	.....
Totals	228	11,395	4,458.58	......	.....
Averages	.....	.....	....	0.375	0.449

fall of from four to six inches per hundred feet in the ditch line would, however, remove the necessity of testing with water.

One other point in favor of the ditching machine is the speed that can be made with it. By a comparison of Tables I, VI and X, it will be noted that the machine operators use less than one-sixth as much labor per rod in trenching and laying tile as is spent when the work is done by hand. Considering the scarcity of labor and the advancing wages that farmers are being forced to pay, it is evident that even though machine trenching were to cost more than hand trenching they probably would be forced to make use of the machine.

Cost and Time Required to Lay Tile.—In Table X is summarized the cost of laying or installing 7,203 rods of tile upon 163½ acres. This includes placing the tile in the ditch and putting on just enough earth to hold it in place. For various reasons the tile layer is required to excavate by hand occasional short ditches, as for example, in finishing a ditch where the machine could not approach a fence as close as was necessary. In field No. 30 the larger "Tile laying cost" of 7.65 cents per rod is due to hand work of this character, which was not separated from the laying of the tile. From this summary table it will be noted that the cost varied from a minimum of 5.46 cents to a maximum of 7.65, and that the average is 6.75 cents per rod. It will also be observed that one man installed on the average almost 45 rods of tile per day.

TABLE X.—SHOWING HOURS AND COSTS FOR LAYING TILE

Wages, 30c per hour

Field	Acres	Rods	Totals Hours	Totals Cost	Per rod Hours	Per rod Cost
No. 24	29	1,591	386.5	$115.95	.243	$0.0729
No. 29	10½	755	137.5	41.25	.182	.0546
No. 30	5	300	76.5	22.95	.255	.0765
No. 5	54	2,666	616.6	184.98	.231	.0693
No. 31	65	1,891	404.4	121.32	.214	.0642
Totals	163½	7,203	1,621.5	486.46	....	....
Averages	.....	....	....	......	.225	0.0675

Owing to the very great importance of having the tile laid properly it is usually deemed advisable to secure for this purpose the services of an efficient man who makes tiling his business. The services of such a man are always in demand and consequently a higher price per hour must be paid to secure him.

In Table XI is summarized the cost of filling the ditches for 7,203 rods of tile installed in 163½ acres. From this table it will be noted that the cost per rod of filling ditches varies from 1.72 cent to 4.4 cents and that the average is

3.43 cents. It will also be noted that two men with a team can on the average fill 140 rods of ditch per day.

TABLE XI.—HOURS AND COSTS FOR FILLING DITCHES

Man rate, 15c per hour; horse rate, 10c per hour

	Totals					Per rod		
	Fields		Hours			Hours		
Field	Area	Rods	Man	Horse	Cost	Man	Horse	Cost
No. 24	29	1,591	208.70	207.8	$ 52.08	.1312	.1307	$0.0327
No. 29	10½	755	131.40	87.0	28.41	.1740	.1152	.0376
No. 30	5	300	21.07	20.0	5.16	.0702	.0666	.0172
No. 5	54	2,666	319.50	302.0	78.13	.1198	.1132	.0293
No. 31	65	1,891	333.50	332.0	83.23	.1764	.1756	.0440
Totals	163½	7,203	1,014.17	948.8	247.01	....	....	....
Averages						.1408	.1317	.0343

The cost of filling ditches varies with the condition of the soil and the depth of the cut. It was found advisable to fill the ditches soon after trenching, because they could then be filled about one-fourth faster than if allowed to remain open during a heavy rain storm. The rain packed the soil and made filling much more difficult for both men and team.

A heavy team was used with a specially prepared scraper about 4 feet long, which consisted of a straight board with a steel cutting edge and had a hitch so constructed that when the team pulled taut at right angles to the ditch and the operator bore down on the handles the scraper would move into the ditch all the dirt thrown out on one side of it. It was, of course, necessary to back up the team and move the scraper longitudinally along the ditch for each scraper full. This method was found to be more satisfactory than the use of a plow or a large township road scraper.

Plotting Drains.—The maps or plots of the several drainage systems were made by county surveyors after the system was installed. The charge for this operation includes the engineer's time, expenses in the field and in plotting and blue printing. It was not deemed necessary or advisable to make a plot of a system before installing, but after installing it was thought wise to have such a map for the purpose of affording a ready reference for the location of drains in case of trouble with the system.

TABLE XII.—RECAPITULATION OF INSTALLING COSTS PER ROD

	Hand work 1909	Machine 1910	Machine 1911	Average machine
Area in acres	40	65½	122½	....
Number rods	2,560	4,080	4,755	....
Machine charges	......	$0.1084	$0.1529	$0.1324
Machine operator	......	.0315	.0392	.0356
Gasoline	......	.0219	.0305	.0266
Oil	......	.0014	.0028	.0022
Contract laying	*$0.376	.0634	.0686	.0663
Filling ditches	.030	.0252	.0363	.0312
Other equipment charges	.004	.0037	.0043	.0040
Undivided operations	......	.0433	.0354	.0390
Overhead charges	.023	.0230	.0340	.0230
Plotting drains	.0158	.0149	.0140	.0144
Averages	0.4489	0.3367	0.4071	0.3746

* Includes trenching.

In Table XII is given a summary of the preceding tables as regards all tiling operations except hauling, which, in accordance with Table IV, may be figured at about 4c per rod. The cost of tile will vary with size of tile used and other factors, but Table IV will assist in making an estimate of such cost in the absence of figures from the factory. From the foregoing pages it will be manifest that had the trenching for all the 11,395 rods of tile been done by machine the total cost of tile and installation would have been about two-thirds of a dollar per rod, and that with the fifty rods per acre used on this farm, three acres would have cost about one hundred dollars.

Costs of Laying 20 Miles of Tile Drains.—S. C. Hartman gives the following in "The Monthly Bulletin" of the Ohio Agricultural Experiment Station for May–June, 1921.

Twenty miles of tile have been laid on the Washington County experiment farm. Because different systems are used in the work the 20 miles or 6,400.7 rods were divided into five sections. Section I was installed in 1915 and consisted of 955.6 rods; the trenches were dug by hand. The cost of the work is taken from the records of E. J. Riggs, who was then superintendent of the farm. Other sections were dug with the Station traction ditcher during the spring and summer of 1919.

Section II was started on May 17 and consisted of 1,984.8 rods. Section III consisted of 1,202.5 rods and was begun on July 15. Section IV was dug on the farm of H. J. Tresch and consisted of 1,399.6 rods. This work was done under the direction of Mr. Tresch and serves as a check for the work done on the Washington County experiment farm. Section V was installed on the experiment farm after August 8; it consisted of 858.2 rods.

Character of Soil Trenched.—The soil is underlaid with shale and sandstone from which it was largely formed. The soil varies from a comparatively light clay, commonly known as a mixed soil to a heavy red or Upshur clay. There are no boulders but the underlying rock interfered with the work in several places. While the soil has a slight tendency to run together it does not dry out as some of the other soils of the State. The ditcher, therefore, made good progress even in a dry season.

Because of good fall and convenient outlets but a few large tile were required. Two-thirds of the tile were 4-inch. Those laid on the experiment farm in 1919 held out to the number purchased with 15½ feet of tile laid to a rod. A few Y-tile were used for making connections at branches. Sewer pipes were used for the outlets because they are longer than drain tile, are burned harder and are more easily held in place.

Cost of Labor.—The labor available varied with the different sections. The work of digging the trench in Section I was in charge of an experienced ditcher. Practically one-third of the hours of labor were performed by him at 30 cents an hour. The remainder of labor performed for Section I was paid 20 cents per hour. The labor of 1919 was figured at 32 cents per hour. For comparison, the unskilled labor of 1915 is figured at 32 cents also, and the skilled ditcher at 48 cents per hour. The labor employed in 1919 in addition to the farm force was such as one was able to employ, for the second and third sections, at one of the busiest seasons of the year. Because of the scarcity of help it was necessary at times to employ more help than could be used at an advantage that sufficient help might be available when needed. For the fourth and fifth sections which were completed after harvest more help was available.

The trench for practically all the tile was dug 30 inches deep. The large main tile were laid in a deeper trench. Over most of the area drained the tile lines were laid 2 rods apart. Some lines were laid 3 rods apart. Those laid in 1915 were 36 feet apart. About 70 acres were drained by the 5,000 rods on the experiment farm and 20 acres by the 1,400 rods on the Tresch farm.

Various Operations in Drainage.—The various operations in connection with installing the drainage system are conveniently considered as four operations; namely, digging the trench, hauling the tile, laying the tile and back filling.

Digging the trench includes setting the stakes, and a small amount of time at laying off the tile lines. Only where the fall was doubtful or on a deep cut was a level used.

Hauling the tile includes the actual operation of hauling and also laying the tile carefully along the trench so that they could be easily reached by the person in the trench.

Laying the tile followed the ditcher as closely as possible and includes the various operations between the digging and the filling of the trench after the tile are laid; helping the operator of the ditcher by setting stakes, cleaning out the crumbs in the trench, digging for connections where the branches unite with the main tile lines and other places where digging is necessary; the actual operation of laying the tile and binding them or covering them with enough dirt to hold them in place until the trench can be filled. There is always some filling to be done by hand. With hand trench-digging, trenching and laying the tile could not be conveniently separated. In filling the trench the dirt was backed into the trench when possible. The dirt was also rigged over the trench. In some places it was necessary to finish the work by hand. Some time was also spent in refilling the trenches before the work was completed. Such work was included in "filling the trenches." With a considerable amount of fall in some of the tile lines and because of the nature of the soil some of the trenches washed deeply after being filled. In other places it was necessary to again refill before the cropping work could be continued in the field. Such work was not included in "filling the trenches" but charged to drainage maintenance. Other operations in some sections were considered as miscellaneous, such as hauling water and gasoline for the ditcher, measuring and laying off the lines, repair work and other work not closely connected with other operations. These items form a very small part of the work totaling less than 1 cent per rod at the most. In two sections these items were included as most convenient with other operations.

Trenching.—Section I, where the trenching which was done by hand required an average of 1.6 hours for each rod of tile. It was not possible to separate the time spent at digging from that of laying his section. The time and cost therefore of laying the tile in Section I is not easily comparable to laying the tile after the machine trenching in the other sections. In both the second and third sections considerable hand digging was necessary because of the interference of the underlying rock and because of a gas line which crossed many of the tile lines. The distance dug is estimated and the required time determined as accurately as possible. It is a significant fact that the hand digging in Section II required more than twice as much time per rod as that of Section I. Ditching with the power ditcher is often done when conditions are not favorable for hand ditching which therefore must be done at a greater cost than would ordinarily be necessary. The cost of laying the tile after the machine trenching varied but averaged 4.6 cents per rod. The highest cost, that of 5.5 cents in Section IV, was due to the fact that it incluces some miscellaneous work.

Allowing 30 cents per rod for the ditching machine, hand trenching and laying cost from 170 to 180 per cent of the cost of machine trenching and laying, or one and three-fourths times as much, a considerable saving for machine trenching. With hand trenching, an average of 1.6 hours of labor were spent on each rod, with machine trenching .14 of an hour, exclusive of the machine operator. Hand trenching and laying, therefore, required eleven times as many hours of labor per rod as machine trenching.

TABLE XIII.—LABOR AND COST OF DISTRIBUTING TILE

Section number	Tile, rods	Man labor, hours	Horse labor, hours	Man labor per rod, hours	Horse labor per rod, hours	Cost per rod cents
I	955.6	90	60	.094	.062	.04
II	1,984.8	225¼	381¼	.113	.192	.065
III	1,202.5	130	194	.108	.161	.059
IV	1,399.6	140	180	.100	.129	.053
V	858.2	67¾	86	.079	.10	.04
Average	....	.....	.....	.102	.141	.054

Man hours at 32 cents per hour; horse hours, 15 cents.

Hauling the Tile.—A variable factor in the cost of a drainage system is the cost of hauling the tile. The cost varies with the distance and the condition of the roads. Since in this case the tile were delivered to the corner of the experiment farm the cost of hauling to the farm is not considered. Table XIII shows the labor required and cost of distributing the tile from the pile on the farm to the various tile lines as required. The larger factor in the cost of distributing the tile, exclusive of the efficiency of the labor, is the distance necessary to haul the tile. Part of the tile in Section II were hauled directly from the car to the field. The distance was greater and the cost more. The greatest distance necessary to haul the tile in distributing them was less than three-fourths of a mile and the average nearly one-fourth of a mile. The cost varied from 4 cents per rod in Sections I and V to 6.5 cents in Section II. The economy of delivering the tile to as near the place where they will be used as possible is apparent. It is evident from the number of man and horse hours that two men usually worked at hauling with each team. This proved to be the most economical, especially where the hauling distance was not great.

TABLE XIV.—TIME AND LABOR COST OF LAYING TILE

Section number	Rods	Digging and laying by hand Time, hours	Digging and laying by hand Cost, dollars	Laying only Time, hours	Laying only Cost, dollars	Per rod Time, hours	Per rod Cost, dollars
I	955.6	1,522	574.88	....	.....	1.6	.601
II	1,946.8	......	......	292	93.43	.15	.048
	*38.0	–†24½	39.84	....	.....	3.28	1.05
III	1,195.0	......	......	168	53.76	.14	.045
	*7.5	10½	3.36	....	.....	1.40	.45
IV	1,399.6	......	......	243	77.76	.174	.056
V	858.2	......	......	78½	25.12	.091	.029
Average for machine dug trenches						.123	.039

* Estimated distance dug by hand, other than that usually required.
† The time required does not include laying the tile but merely the digging.

Laying the Tile.—The most particular work of installing the drainage system is that of actually laying the tile in the trench. Anyone with a little experience can do a good job if they will take care with the work. Unless such a one is available an experienced tiler should be employed. If the tile are not properly laid the expense of tiling is a poor investment. The actual operation of laying the tile in the trench required but little time. The various operations which were for convenience considered with laying the tile required considerable time. Table XIV gives the time and labor cost of laying the tile for each section.

Costs of Laying Tile Drain on Two Jobs.—H. R. Ferris, in Engineering and Contracting, Sept. 13, 1916, gives the following costs of laying 300 ft. of drains of the design and cross-section shown by Fig. 2 (1), all excavation in sandy loam surcharged with water (not quicksand). The ditch required close timbering in certain places. The actual excavation was about 3½ ft. only, as a slight fill covered the top. The work was designed to be permanent, and has been in continual and satisfactory use for over three years. The costs follow:

		Per lin. ft.
Labor:		
Foreman, 5 days @ $ 3.00	$ 15.00	$0.050
Labor, 174 hrs. @ $0.30	52.20	.174
Materials:		
Lumber (2 × 12 cedar), 600 ft. B. M. @ $18.00	10.80	.036
Gravel 25 cu. yd. @ $ 1.50	37.50	.125
Timber (bracing), 800 ft. B. M. @ $12.00	9.60	.032
Tile (4-in. farm), 900 lin. ft. @ $0.03	27.00	.090
	$152.10	$0.507

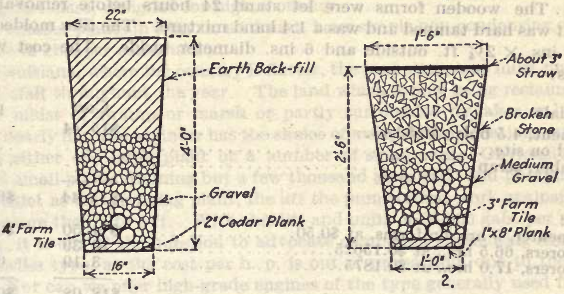


FIG. 2.—Sections of tile drains.

It was not practicable to separate the cost of laying planks, tile, etc. The labor (174 hr.) represents the total time on this work, with the exception of earth backfill, which was done several days later with team and scraper. The prices for materials include delivery along the work. Fig. 2 (2) shows the type of drain construction for the second job, covering 1,900 ft. of drain The costs were as follows:

		Cost. per ft.
Labor:		
Foreman, 98 hrs. @ 40c	$ 36.80	$0.019
Labor, 700 hrs. @ 30c	210.00	.115
Team, 12 hrs. @ 65c	7.80	.004
	$254.60	0.138

Materials:		Cost per ft.
Rough planks (1 × 8), 1,900 lin. ft. @ $8.00	$ 15.20	.008
Gravel, 160 cu. yd. @ $1.00	160.00	.084
Straw, 11 bales	6.60	.003
Tile (3-in. form), 3,800 lin. ft. @ 0.03	114.00	.060
	$295.80	0.155

The prices for materials cover cost delivered along the line of the work. Cost of removing surplus earth is not included. Excavation was in stiff clay, and the work was performed in wet weather. Good foreman and average crew. The costs of excavation, backfilling with gravel, etc., were not separated.

Broken stone (30 cu. yd.) used in the drain was taken from a nearby sewer trench, which had been excavated in rock. This was delivered conveniently along the line of the trench, and the cost of delivery is not included in the above, but the cost, however, of the handling in the trench is included In all about 190 cu. yd. of gravel and rock were used over the tiles.

Making Cement Drain Tile by Hand on an Isolated Job.—R. C. Hardman, in Engineering and Contracting, May 29, 1912, gives the following costs for making 297 lin. ft. of cement drain tile by hand using unskilled Mexican labor.

Two sets of wooden forms were built, each having molds for six sections of tile; these formed the outside. For the core mold, or inside form, a galvanized iron cylinder was used. This cylinder was centered inside the wooden mold and pulled as soon as the cement was placed, to be inserted in another wooden mold. The wooden forms were let stand 24 hours before removal. All cement was hard tamped and was a 1:4 hand mixture. The tiles molded were 8 × 8 ins. × 2¼ ft. outside and 6 ins. diameter inside. The cost was as follows:

Materials:	Cost	Cost per ft.
Cement, 4.5 bbls., at $3.43	$15.44	....
Sand on site	......	....
Lumber, scrap	......	....
	$15.44	$0.0519
Labor:		
Carpenter, 9 hrs. on forms, at $0.50	$ 4.50	$0.0152
Laborers, 66.5 hrs., at $0.15625	10.39	....
Laborers, 17.0 hrs., at $0.1875	3.19	0.0457
	$18.08	$0.0609
Total	$33.52	$0.1128

Centrifugal Pumping Plants for Drainage with Diagram of Plant Costs.—In a paper before the Louisiana Engineering Society, and published in the Journal of the Association of Engineering Societies, H. L. Hutson discusses a type of drainage pumping plant which his experience leads him to believe is preferable to others for conditions as found in Louisiana. The following abstract of Mr. Hutson's paper, is given in Engineering and Contracting, July 3, 1912.

The plant which I should like to see become standard for drainage work in Louisiana would be one of large capacity consisting of two or more large centrifugal pumps, each direct connected to compound condensing engines of the Corliss or 4-valve type; the steam being furnished by water tube boilers using oil fuel. Such a plant, if the units were of 50,000 to 100,000 gals. per minute capacity, would be ideal from the mechanical engineer's standpoint, as the units would be sufficiently large to get good economy, the engines would run at such speed and be of such horse-power that the very lowest prices could be obtained, and the plant would be large enough to employ skilled labor to operate. I realize that this means the use of one plant for a large acreage, say 10,000 to 100,000 acres, and that this in turn means long canals and a high lift, but I will try to show that the cost of operation, even the cost of fuel, will be less per 1,000,000 gals. gotten rid of by the large plant than the small. I am giving only the point of view of the mechanical engineer. There may be conditions known to the civil engineer or to the farmer which would make the use of large plants out of the question in this territory.

The drainage work which I am familiar with is that in Illinois and Iowa and that in Louisiana. The conditions are somewhat different, and these differences are partly responsible for the variations in engineering practice. In Illinois and Iowa the drainage districts lie along the river bottoms and consist of land which have limited natural drainage when the rivers are low but which are subject to overflow. In the formation of levee and drainage districts, the natural boundaries are usually followed so that each district will have a single outlet with a pumping plant to take care of the rainfall during such time as the river is high enough to prevent gravity drainage. The Bay Island Drainage and Levee District No. 1, a district in Mercer County, Illinois, is typical of the larger plants. It has an area of 20,000 acres and takes the run-off of a smaller district of 4,000 acres additional. This plant was designed for a capacity of 200,000 gals. per minute against a lift varying from 0 to 12½ ft., and consisted of two 60-in. units, all the equipment being of the highest class, designed for high economy.

The smaller plants in Illinois, no doubt, have simple non-condensing engines and are of cheaper construction.

In Louisiana, where the country is flatter, the pumping plant must pump off the rainfall throughout the year. The land which is now being reclaimed lies in the midst of swamp or marsh or partly surrounded by lakes or bayous. Being nearly flat, the engineer has the choice of many outfall locations and may install either one large plant or a number of small ones. Obviously, with several small plants draining but a few thousand acres each and pumping to a free outlet at the pumping plant, the lift the pumps must work against is low —not more than 3 to 6 ft. With this lift and units of 36,000 gals. per minute or less, it is out of the question to advocate compound condensing engines of the Corliss type, as the cost per h. p. is out of proportion, due to the small size. Nor can we offer high-grade engines of the type generally used for this horse-power in electric work because the rotative speed of these large pumps is much below that of a generator requiring equal horsepower. No doubt the majority of engineers would consider that a low lift is very desirable and that it means getting rid of the water at a low cost of fuel. As a matter of fact, the fuel for pumping off a million gallons will be less with an economical plant pumping against a 9-ft. lift than with a simple non-condensing plant such as is usually installed pumping against 3-ft. lift. The extra 6 ft. of fall would undoubtedly be sufficient to increase the area which could be drained by from three to nine times the size of that served by the small pump.

The saving in the matter of labor of a large plant over a number of small ones is obvious. The larger plant would require a higher class of help, but this is an advantage as the higher class man is more reliable than the cheaper help. The cost of the machinery for such a plant would be greater than that of several small plants with cheap equipment, but the cost of the complete plant erected would undoubtedly be less for the large than for a number of small plants. There would be many advantages with the large plant and better machinery. If compound engines were used, they would be made to carry great overload if necessary by using live steam in the receiver. If they were cross compound and an accident put one side out of commission, it would still be possible to run; and as the pump is little subject to accident, this feature would practically give a reserve unit.

I have advocated water tube boilers and oil fuel as these features would permit steam to be raised quickly and one fireman could operate a boiler plant of any size required. If the boilers are of the sectional water tube type similar to those used in naval work, steam may be raised in 30 minutes without danger to the boiler. With automatic oil-fuel pumps, one man could, if necessary, operate a plant in an emergency. In fact, there is one irrigation plant of which I know which is operated by one man who attends the boiler and engine. It is a compound condensing engine of 225 h. p.

Cost of Plants.—The question as to the approximate cost of a plant of a certain capacity and lift is often asked by engineers and others who are making preliminary estimates. In fact, this is the first question which the prospective customer is likely to ask. Although we have several rough rules for figuring these costs, none of them is satisfactory as applying to both drainage and irrigation plants. It has been the custom in making rough estimates of pumping plants designed for lifts of from 25 to 40 ft. to figure them at $80 to $100 per water horse-power, but one will readily see that the same figure will not apply to a drainage plant of like capacity pumping against a head of 3 ft., as the cost of the pumps, suction and discharge pipes, etc., would be very nearly the same for the low-lift plant as for the high-lift, whereas the horse-power would be so small as to put the plant in a different class altogether from the one with the higher lift. In order to be able to give approximate figures I endeavored to tabulate the various bids which the concern I am connected with has made on pumping plants within the last ten years, and found that a tabulation, or even a curve, of these bidding prices would be of little value, as in some cases we bid including the building, foundations and even intake work, whereas in others our price was merely for machinery f. o. b. cars, or again for machinery erected on foundations built by the purchaser. To make a comparison, therefore, I decided to take the cost of all the mechanical equipment necessary for the plant, and using our costs sheets as a guide make up curves which would represent these plants erected ready for operation at some point in Louisiana or Texas; in other words, I have assumed, what is very far from the fact, that the cost of freight, barging, foundations, erecting, etc., is a constant percentage. This is done because it is not the intention that this diagram of costs shall be used for obtaining actual costs of plants but that it shall be relative only and be used for the purpose of deciding the most economical size of units to use in a large plant and also for making approximate estimates on the assumption that a plant of two or more units will be a multiple of the cost of a single unit plant. In this diagram, I have not included the building, as the cost of this would depend upon the style of architecture, nor have I included any dredging, intake work, flume or canal work. I did include the building foundation, as it is usually necessary to place a pumping plant in a pit, in which case the pit walls form the building foundation, and the pump foundation, engine-room floor and walls are made monolithic.

For the reasons above given, it will be impossible to make smooth curves using either the water horse-power or the gallons per minute as one of the coordinates. It seems more logical, therefore, and gives data which are much more useful, to divide the plant into two parts, and consider it merely

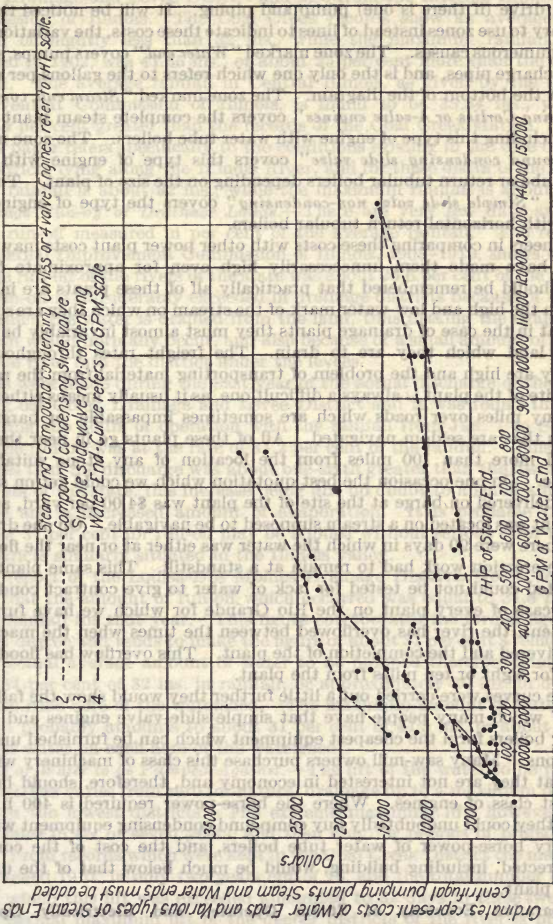


FIG. 3.—Diagram of relative costs of drainage pumping plants.

as a steam-power plant, which drives a pumping plant. I have, therefore, divided the cost into two parts: cost of the "steam end" and cost of the "water end," but showed these on the same sheet. In using this diagram it is very important that this fact should be borne in mind and that the cost of the "water end" should be added to that of the "steam end." The cost of the "water end" is given in terms of gallons per minute at the rated capacity. The cost of the "steam end" is given in terms of indicated horse-power and it is, therefore, necessary to figure this horse-power by assuming the combined efficiency of the engine, drive (if there is one) pump and piping. It will be noticed that it is necessary to use zones instead of lines to indicate these costs, the variation being due to numerous causes. The zone marked "*Water end*" covers pumps, suction and discharge pipes, and is the only one which refers to the gallons per minute scale at the bottom of the diagram. The zone marked "*Steam end, compound condensing Corliss or 4-valve engines*" covers the complete steam plant equipment including this type of engine with water tube boilers. The zone marked "*Compound condensing slide valve*" covers this type of engine with either water tube or return tubular boilers depending on the size of plant. The zone marked "*Simple slide valve non-condensing*" covers the type of engine indicated with horizontal return tubular boilers.

Engineers in comparing these costs with other power plant costs may decide that I have made them unnecessarily high even for approximate figures, but it should be remembered that practically all of these plants are installed between the high and low-water mark of the stream on which they are situated and that in the case of drainage plants they must almost invariably be put in on the land which they are to drain. The freight rates throughout this territory are high and the problem of transporting material from the railroad to the site of the plant is always a difficult one, as it usually means either hauling many miles over roads which are sometimes impassable, or barging on streams that are seldom navigated. All of these plants go in near the coast on land more than 100 miles from the location of any stone suitable for concrete. On one occasion the best quotation which we could get on sand or gravel delivered on barge at the site of the plant was $4.00 per yard, and yet this plant was located on a stream supposed to be navigable. On one drainage plant there were 90 days in which the water was either at or near the floor line and the erection work had to remain at a standstill. This same plant when completed could not be tested for lack of water to give contract conditions. In the case of every plant on the Rio Grande for which we have furnished equipment, the river has overflowed between the times when the machinery was delivered and the completion of the plant. This overflow has flooded the valley for eight or ten miles from the plant.

If the curves were carried out a little further they would show the fallacy of a belief which many people have that simple slide-valve engines and return tubular boilers form the cheapest equipment which can be furnished under all conditions. Many saw-mill owners purchase this class of machinery with the idea that they are not interested in economy and, therefore, should buy the cheapest class of engines. Where the horse-power required is 400 h. p. or above, they could undoubtedly buy compound condensing equipment with the necessary horse-power of water tube boilers, and the cost of the complete plant erected, including building, would be much below that of the uneconomical plant.

Comparative Economy of Steam Operated and Electrically Operated Pumping Plants for Drainage.—An argument for the use of electric power for operating drainage pumping plants is contained in a paper read before the fourth meeting in Jan., 1912, of the Association of Drainage and Levee Districts of Illinois. The following matter is from an abstract of the paper as published in Engineering and Contracting, Oct. 1, 1913.

Amount of Water to be Pumped.—The average rainfall for the lands comprising the districts in the Illinois River may be closely estimated from the records which have been kept since 1899 by the Commissioners of the Coal Creek Drainage and Levee District and also from the Internal Improvement Commission of Illinois. The Coal Creek records show an average yearly rainfall of slightly less than 32 ins., while the maximum rainfall, which occurred in 1902, was 41.55 ins., or about 25 per cent more than the average rainfall. The average rainfall in Central Illinois, as given by the Internal Improvement Commission of Illinois, is found to be 35.34 ins., which is about 9 per cent greater than the records of the Coal Creek station.

This paper refers specifically to the conditions existing in the case of drainage districts lying along the Illinois River, and for these districts the average yearly rainfall is about 32 ins., while the maximum rainfall is about 40 ins.

Average Run-off of Drainage Lands.—There are very few data as to the actual run-off measured in per cent of the average rainfall. The report of the Internal Improvement Commission of Illinois, 1908–1910, shows that the average run-off of the rivers of the state was about 26.6 per cent of the rainfall. This run-off is considerably exceeded in drainage districts because of the ease with which the water is drained from the land, thus making the evaporation less than would normally occur, and also because of a small amount of seepage from the river into the district under the levees.

Tests were made during the past year of the actual discharge of the pumps in the Coal Creek Drainage and Levee District and it was found that after comparing the hours of operation with the rainfall from Jan. 1 to Sept. 25, 1911, the run-off was at the rate of 31.2 per cent of the rainfall. This run-off indicates that the discharge was about one-sixth greater than the discharge of the rivers of the state, this increase being due no doubt to a small amount of seepage and a decreased amount of evaporation. It is probable that the figure of 31 per cent for run-off may be applied without serious error to all of the districts similarly situated in the Illinois valley.

The report of the Louisa-Des Moines Drainage District, No. 4, for 1911, shows that the amount of run-off which occurred was equal to 31.8 per cent of the rainfall for that year. This figure corroborates the former figure to a marked degree and tends to make the figure of about 31 per cent a reliable one.

The actual average amount of water to be pumped therefore amounts to about 31 per cent of 32 ins. in rainfall, or approximately 10 ins. in depth of water on each acre of the watershed. The maximum amount of water to be pumped probably amounts to about 31 per cent of 41.5 ins. or about 13 ins. depth of water on each acre of the watershed.

Head of Water to be Pumped Against.—The lift of the water to be pumped from districts varies from zero for natural drainage up to a maximum of about 21 ft. in the lowest districts. The extreme maximum lift, however, only occurs once in six or seven years, and then only for periods of probably ten days. From records which were kept in the Coal Creek District the maximum lift exceeded 19 ft. in only two years out of 13, and the total number of days during which this lift was exceeded amounted to 31 days in these two years.

The normal maximum lift of the deeper districts of the river is probably about 18 ft. for those districts which never have natural drainage. Many districts are able to drain their land during time of low water simply by opening sluiceways. In these districts the normal maximum lift is about 13 to 14 ft. The average lift through which water has to be pumped varies from 6 to 11 ft.

Maximum Pumping Capacity Required.—S. W. Woodward, in the United States Department of Agriculture bulletin, "Land Drainage by Means of Pumps," concludes after a very thorough examination of this question, that the maximum capacity should be sufficient to remove ¼ in. of rainfall in 24 hours of continuous operation. Pumping plants which have had this capacity have been able to drain successfully their districts in the worst storm conditions, and it would seem therefore that a larger capacity than this only entails useless investment.

Since the maximum lift occurring in any district only occurs once in about six years, and then only for a short period it is not necessary to provide this capacity of ¼-in. per day at the maximum lift. In general, the maximum power required should be that necessary to remove ¼-in. of water in 24 hours against a lift of about 3 ft. less than the highest recorded lift. In other words, if the highest recorded lift be 21 ft. a pumping capacity of ¼-in. per 24 hours against a lift of 18 ft. will be sufficient.

To the lift mentioned above must be added the loss of head due to friction of the water in the suction and discharge pipes and the velocity head.

Types of Steam Pumping Stations.—Most of the pumping stations now used to drain districts are steam driven and the majority of these stations comprise an installation of fire tube boilers, Corliss or four-valve engines either belt-driven or direct connected to centrifugal pumps. The usual arrangement is to have two pumps to a station, the relative capacities of which may usually be one-third and two-thirds, respectively, of the total capacity. The object of having a dissimilarity of sizes is due to operating conditions which require heavy pumping for only about three months of the year. During the other nine months the amount of water to be pumped is far below the capacity necessary for the maximum requirements, and the smaller unit is generally intended to handle the minimum flow of water as economically as possible.

From 60 to 75 per cent of the total work done in pumping the water is ordinarily done from March 15 to June 15, while the remaining 25 or 40 per cent is about evenly distributed over the other nine months of the year. This condition is detrimental to the economy of a steam plant because during a period of about nine months the amount of pumping to be done is far below the capacity of the plant.

Fixed charges are a very appreciable part of the total cost of pumping. For the conditions existing on the Illinois River the item of interest should be taken at 6 per cent, taxes and insurance at 1 per cent and depreciation at 10 per cent, giving a total of 17 per cent fixed charges per year on the original investment. The fixed charges provide for the financing of the pumping plant as a permanent institution so that a sinking fund may be established which will provide money for renewals and rebuilding from time to time so as to maintain the plant continuously in working order. When the fixed charges have been properly taken into account after an adequate pumping station has been built it is never necessary to levy additional assessments from time to time to provide for rebuilding the plant.

The operating expenses, of which the principal items are coal, labor, supplies and repairs, provide merely for the daily operation of the plant, and these operating expenses are in no sense the total cost of operation, as has often been assumed when the cost of pumping is discussed. The actual cost of operating the steam pumping stations of several drainage districts, based on the acreage in the district, is given in Table XV.

TABLE XV.—COST OF STEAM PUMPING

Name of district	H. P. in engines installed	Initial cost of pumping plant	Annual fixed charges	Annual operating expenses	No. of acres in watershed	No. of acres in district	Operating expenses per acre per year	Total cost per acre per year	Operating ratio, per cent
A..........	100	$ 7,000	$1,190	$2,200	2,160	2,160	$1.02	$1.57	65
B..........	275	30,000	5,100	8,412	11,000	11,000	.765	1.23	62
C..........	500	50,000	8,500	5,966	16,000	13,000	.459	1.11	41
D..........	250	25,000	4,250	5,400	7,420	6,800	.795	1.42	56
E..........	325	35,000	5,950	4,700	7,420	6,800	.690	1.57	44
Totals..........							$3.74	$6.90	268
Average..........							$0.748	$1.38	53.6

The average cost of drainage by well designed steam stations draining districts of about 10,000 acres is about $1.25 per acre per year, of which the operating expenses will be about 60 cts. at the present prices of coal and labor.

Types of Electric Pumping Stations.—The types of electric pumping stations now in use in the Illinois River include standard centrifugal pumps belt-driven by constant speed induction motors and the transformers and other electrical equipment necessary for the operation of the motors. The pumping capacity of these plants should preferably be divided into three units instead of two, as is the usual design in a steam plant.

One of the great advantages of the electric pumping station over a steam station is that the pumping units may be properly sized for the work that they have to perform. One of these pumps should be small enough so that it may run for long periods and merely take care of the minimum flow of water. This small unit permits the level of the water in the ditches to be kept practically constant and this water may be pumped out each day without additional expense over letting the water accumulate and pumping it down at a high rate, as is done in steam plants.

The average initial cost of the steam stations given in Table XV is $3.71 per acre. The cost of electric stations for this same work would vary from $2.22 to $2.41 per acre.

The fixed charges of an electric plant are less than the fixed charges of a steam plant and they have been taken as follows: Interest at 6 per cent; taxes and insurance at 1 per cent, depreciation at 6 per cent, giving a total of 13 per cent fixed charges per year on the investment in an electric station. Taking the higher figure of $2.41 per acre as the cost of electric stations, the fixed charges per acre per year amount to 13 per cent of $2.41, or 31 cts. per acre per year.

The total average cost of drainage by steam pumps in Table XV is $1.38 per acre per year, based on the acreage in the district. Subtracting from this figure the 31 cts. fixed charges on an electric station shows that $1.07 per acre per year can be paid for operating expenses including electrical energy, without incurring a higher total cost than the average cost of steam pumping.

Taking the total cost of pumping by well-designed steam stations as $1.25 per acre per year, we find by the same method that the sum of 94 cts. per acre per year may be expended for operating expenses in an electric station before the total cost exceeds the cost of steam pumping.

Following the same process with the minimum attainable cost of $1.10 per acre per year, it is found that 79 cts. per acre per year may be expended on operating expenses without these expenses exceeding the cost of steam pumping.

The items of labor and supplies in an electric plant will not exceed 16 per cent of the total operating expenses. Reducing this figure to terms of the energy required, it is seen that if we combine the energy required with the labor and supplies on this basis an equivalent amount of energy equal to 24 kilowatt hours per acre per year would be required.

On this basis the average steam station given in Table XV could be substituted by an electric station and a rate of $1.07 divided by 24 kilowatt hours, or 4.97 cts. per K W. H., could be paid without the total cost of pumping exceeding the cost given in Table XV.

In the case of the total average cost for well-designed steam stations or $1.25 per acre per year, a district could afford to pay 3.92 cts. per K. W. H. without the total expense exceeding $1.25 per acre per year.

In the case of the minimum attainable cost of $1.10 per acre per year a district can afford to pay 3.29 cts. per K. W. H. before the total cost of operation exceeds $1.10 per acre per year.

All the evidence shows that if a supply of electrical energy can be bought for 4 cents per K. W. H., that the total cost of pumping by electricity does not exceed the total cost of pumping by steam in well-designed steam stations. If a district is able to obtain a lower rate than 4 cts. per K. W. H. for energy they are able to save money over the cost of operating steam stations.

If energy cannot be bought for less than 4 cts. per K. W. H., the question as to how high a rate it is permissible to pay depends on the relative value of electric pumping compared with steam, as measured by the results obtained instead of the money expended. When considering this question from the broadest view, a drainage district is formed for the purpose of raising agricultural products and not for pumping. It therefore follows that the method of pumping should be that which secures the best results, provided the expenses be not too great.

The districts having electric pumping stations are known and recognized as the best drained districts in this locality. The failure of one crop would often pay for the building of three or four power stations, and such failures are less likely to occur with electric drive than from any other type of prime mover.

For this reason electric drive, while it may cost less than steam drive, and it generally does, is worth considerably more money than is steam pumping.

Explanation of Advantages of Electric Drive.—(1) The investment necessary to build well-designed electric pumping stations complete will vary from about $55 to $70 per horse power of the nominal capacity of motors installed. In general an electric station will cost from 55 to 65 per cent of an equally well-designed steam pumping station.

(2) The size of the buildings required to house the pumping apparatus and the auxiliary electric equipment necessary is, roughly, about one-half of the size of a building required for a steam station on account of the elimination of boilers.

(3) It often happens that the pumping capacity of a plant is found insufficient at a time when there is greatest need for power. Should this occur,

additional power may be secured on shorter notice by electric drive than by any other means. This ability to enlarge the power at short notice gives the district added safety against failure of crops due to unusual flood conditions.

(4) An electric station will have a far longer life than a steam station because the rate of depreciation is much less. The pumps will last longer driven by motors than will the same pumps driven by steam engines, because the torque of the motor is perfectly uniform.

In a well-designed induction motor there are no other important materials than iron, copper and insulation. The only reason why a well-designed motor goes out of use is when the motor has been overloaded so as to heat the insulation to the limit of endurance, beyond which the fabric of insulating material deteriorates, and this fabric is always treated by a preserving material, after which it is baked so as to form a solid substance, and is thus protected against moisture, mildew or decay. Theoretically, if the insulation has not been overheated due to overloading, a motor will last indefinitely, when the bearings are renewed from time to time, at small expense. Practically, owing to the fact that in spite of all precautions materials do deteriorate, the life of a motor under these conditions is at least 20 years, and the rate of depreciation is generally from 4 to 5 per cent, and the motor has considerable scrap value for the copper contained at the end of its life.

In a motor there are no cylinders to be bored, valve seats to be refaced, or the usual maintenance that has to be put on engines and also on boilers to insure their continuous operation. The efficiency of motors is retained indefinitely, while the efficiency of every other type of prime mover grows less with increasing wear.

One of the largest items in the cost of operating a steam station is the continual maintenance and repairs to boilers, in fact many boilers in this service have lasted for only five or six years. As the boiler nears the end of its life the pressure on it must be reduced and this therefore lowers the power which can be developed by the engine, and hence reduces the pumping capacity. Boilers are apt to fail at the time of greatest need and when this occurs the loss of one boiler from the service is likely to result in serious damage to crops. The life of boilers in this service is also shortened by the fact that they are idle for such long periods, and as a result the brick work cracks, the boiler setting becomes leaky, and the flues and shell are attacked by corrosion. The electric pumping station enables all boilers to be eliminated and thus the weakest element of a steam plant is not necessary in an electric station.

(5) There is no objection, as stated above, to installing small pumping units which may operate continuously at high efficiencies, as is not the case in a steam plant, because small steam-driven units are not as efficient as large ones.

(6) It is practicable in electric stations to install protective devices which will protect the motors in case there is a temporary interruption of the service, or in case the motors are overloaded.

A no-voltage release effectually protects the motors against temporary interruption of service, and an over-load release or circuit breaker protects the motors against any load greater than that which it is safe to use continuously. It is good practice in electric stations to install in the pumping stations loud-sounding alarms which would operate if the power supply were interrupted temporarily, and in the residence of the attendant, so that in case the motors are stopped from either of these causes then the attendant may restore the service.

(7) An electric pumping station of almost any size now required may be operated by one man, whereas as many as seven men are sometimes required to operate steam plants running 24 hours per day. It is not necessary for an attendant to be on hand when the pumps are operating. In fact, during a large part of the year electric plants can be made entirely automatic by means of float controls when submerged centrifugal pumps are used with a foot valve in the discharge pipe.

(8) Only a few minutes are consumed in getting the station into operation after the attendant has arrived at the pumping station. The only preparation which has to be made before actual pumping is started is to exhaust the air from the pumps by means of a small motor-driven vacuum pump, which operation requires from 5 to 15 minutes.

(9) The motors themselves have only two bearings and these run in a constant stream of oil fed by the oil rings on the shaft. The oil in these bearings need not be replenished except at intervals of several weeks, and the grade of oil necessary to use costs far less than cylinder oil.

The only repairs or renewals necessary to make in the motors are infrequent renewals of bearings and the brushes on the slip rings. The cost of supplies such as oil, waste and packing is greatly reduced in an electric plant.

(10) A volume could be written on the difficulties which have been experienced by drainage districts on having coal and supplies delivered at the pumping station. Many crop failures may be traced to the supply of coal running out at a time when the river was closed to navigation or to other causes beyond the control of the district. The necessity of storing practically a year's supply of coal in the fall results in the loss of interest on a large amount of money, and the heating value of the coal thus stored seriously falls off because of air slacking.

(11) There is less risk from fire with an electric station than with any other type of prime mover, as no fire need be kept around the building except a small heating stove in the winter, if this is desired. The station is adequately protected from lightning entering on the transmission lines by the installation of efficient lightning arresters.

(12) High-speed pumps may be used with electric drive and higher efficiencies may be obtained from the higher speeds. High-speed pumps cost less to install than the slow-speed pumps which are necessary with steam engines. The even torgue given by electric motors insures a longer life to the pump and pump bearings, which with steam engines would, with the constantly changing direction of the forces applied, tend to throw the whole structure out of line.

The steam engine is inherently a low-speed machine, especially when an effort is made to obtain economy by use of four valves in the cylinder. On account of this low speed the pump, if it is to be direct connected, must be made to suit the needs of the engine and thus sacrifice the efficiency which is attainable when higher speed pumps are used. The speed of the pumps in electric stations is not limited by any such consideration and hence the pumps may be designed for high efficiency without a compromise on account of the inherent characteristics of the prime mover.

(13) Electric power companies are generally willing to contract for a supply of power over a long period of years, thus guaranteeing the districts that the cost of power will not increase during that period. The operating expenses of a steam station are almost wholly composed of coal, labor and supplies, and it is certain that the cost of these items will continually increase during the next few years. Electric power is the only kind of power for which a definite

contract can be obtained as to its cost. This feature alone makes electric power supply a very safe one as an insurance against continually increasing operating expenses.

(14) It is impracticable to operate more than one steam pumping plant in a district because of increasing operating expenses, and this fact has controlled the design of the layout of the districts so that the engineers were compelled to bring all of the water to one point.

This feature of a steam station is very unfortunate, because many districts are so situated that if more than one pumping station could be built the cost of canals and ditches would be considerably less. In addition to this advantage, the long and elaborate canal system when all of the water is brought to one point means that the water generally has to be lifted through a greater height to the river than would be the case if two stations could be built.

In other words, electric drive makes possible a revision of the accepted design for drainage systems, because more than one station can be operated without seriously increasing the cost of pumping. One attendant may operate both stations in a satisfactory manner. The added cost due to having more than one station is simply the larger cost of investment because of the separation.

Amount of Energy Required.—The amount of electrical energy required to drain the water from a district depends on the lift, the efficiency of pumps and the amount of water to be removed. As has been previously shown, the average amount of water to be removed is about ten inches. The maximum average attainable efficiency would probably be 70 per cent for the pumps and 90 per cent for the motors, or 63 per cent combined efficiency from the in-put to the motors to the work done by the pumps. An example has been worked out along these lines for a district comprising 7,518.5 acres of watershed, as follows:

Average rainfall, 32 ins.
Average run-off, 31.2 per cent $\times$ 32 = 10.00 ins.
Average static head pumped against, 10.8 ft.
Add 3 feet for frictions.
Total head, 10.8 plus 3 = 13.8 ft.
Water to be pumped per year:

$$\frac{10}{12} \times 43{,}560 \times 7{,}518.5 = 273{,}000{,}000 \text{ cu. ft.}$$

Work done in raising water at 100 per cent efficiency:

$$\frac{273{,}000{,}000 \times 62.5 \times 13.8}{60 \times 33{,}000} = 119{,}000 \text{ H. P. hours.}$$

$119{,}000 \times .746 = 88{,}800$ K. W. H. of electrical energy.

70 per cent $\times$ 90 per cent = 63 per cent maximum combined efficiency motor and pump.

$$\frac{88{,}800}{.63} = 141{,}000 \text{ K. W. H. per year, or } 18.7 \text{ K. W. H. per acre per year.}$$

Energy Required for Various Combined Efficiencies

Combined efficiency	K. W. H. required per acre per year
63 per cent	18.7
60 per cent	19.6
55 per cent	21.4
50 per cent	23.6

The minimum energy requirements for average rainfall conditions are seen to be 18.7 K. W. H. per acre per year. If the average combined efficiency of 63 per cent could not be secured the table shows that the energy requirements would go up to 23.6 K. W. H. per acre per year if the combined efficiency were as low as 50 per cent. The combined efficiency of 50 per cent in this case would mean an average pump efficiency of 56 per cent, which is considerably less than can be attained by good pumps operated with care. The actual energy requirements for average conditions would probably be 20 K. W. H. per acre per year. This figure would correspond to a combined efficiency of about 59 per cent or an average pumping efficiency of about 65 per cent, which can probably be realized.

Cost of Electric Drive.—The average cost of building an electric station is from 55 to 65 per cent of the cost of an equally well-designed steam station.

Conclusions.—It is fair to draw the following conclusions from the evidence presented:

First—The total cost of steam pumping in well-designed plants is $1.25 per acre per year.

Second—If electrical energy can be purchased for 4 cts. per K. W. H. the total cost of electric pumping does not exceed the cost of steam pumping.

Third—Electric pumping has so many advantages over any other kind of power that it is worth more money to drainage districts because of these advantages.

Reference to Cost Data on Pumping and Pumping Plants.—For greater detail and more data on the cost of pumping refer to the chapter on Pumps and Pumping in the "Handbook of Mechanical and Electrical Cost Data" by Halbert P. Gillette and Richard T. Dana, McGraw-Hill Book Company Inc. 1918.

CHAPTER XI

SEWERS

This chapter consists of cost data relating to the construction of vitrified and concrete pipe sewers and larger sewers of reinforced concrete and brick. Further data on sewers may be found in this volume by referring to the index.

There is an extensive section on cost of sewers in Gillettes' "Handbook of Cost Data" and detailed Methods and costs of trenching are given in Gillettes' "Earthwork and Its Cost" and the "Handbook of Rock Excavation."

Cost of Shallow Sewer Trenching with Sewer Excavator.—A. W. Peters gives the following data in Engineering and Contracting, Feb. 28, 1912.

Work was begun on the Moundsville, W. Va., sewer system in May, 1911. Labor troubles developed a few weeks later. The contract time was one year. The cuts called for were as follows: 3½ miles of trench from 0 to 6 ft.; 16½ miles, from 6 to 8 ft. deep; 3 miles, from 8 to 10 ft. deep; and 3 miles of trench in which the cut was greater than 10 ft.

The contractor, finding the soil suitable for machine work, purchased a No. 00 Chicago Sewer Excavator, steam driven. The excavator was fitted with buckets 22 ins. wide, and a separate set of buckets 27 ins. wide was secured. The length of arm was 8 ft., with an extra 2 ft. extension for use in cutting trenches 10 ft. deep. The contractor was then in shape to handle 23 out of 26 miles of his trench work, regardless of labor conditions.

The topography of Moundsville was favorable to machine work; the grades, within the corporate limits, being, very light, The soil was excellent for machine work, being mostly fine sand mixed with loam and unstratified yellow clay, moist enough to stand well with only occasional vertical braces. Where the sand and loam predominated in the mixture, the machine made big daily runs; when the clay predominated, the going was much harder and slower. At places soil was encountered which was as stiff as a glacial drift hardpan, but which contained no boulders, or even small stones.

As the light cuttings handled by this machine were situated between the two trunk sewers, and therefore pretty well bunched, not much time was lost in shifting the machine from one street to another. When an occasional long shift was necessary the machine traveled under its own power at the rate of 1½ miles per hour. Table I gives the operating cost of the excavator. A little explanation is due some of the items:

Superintendence.—Four gangs working, therefore one-quarter of superintendent's time is charged to the excavator.

Sheeting.—Although this item has been figured into the daily cost, yet there were times when no bracing was necessary, the banks standing up well during the backfilling and flushing. For those cases where vertical bracing is not necessary our excavation cost is slightly high, or on the safe side.

Coal.—A steam driven machine was selected by the contractor, because there are three bituminous coal mines within a mile of the city which supply coal, run of mine, at 5 cts. a bushel, 7 cts. delivered.

TABLE I.—DAILY OPERATING COST OF CHICAGO SEWER EXCAVATION AT MOUNDSVILLE, W. VA.

Operation:	
Superintendence	$ 1.50
Engineer and helper	4.75
Watchman	1.75
Coal, 15 bu. at 7 cts.	1.05
Water, 1 single team	2.50
Plumber, service pipes, average	1.00
Total	$ 12.55
Sheeting: Uprights and jacks; no rangers.	
2 men at $1.75	$ 3.50
Lumber, used repeatedly, neglected.	
Maintenance:	
Replacing dull spuds on buckets	$ 0.50
Engineer's time Sunday cleaning up, $3.00/6	0.50
Miscellaneous	0.50
Total	$ 1.50
Depreciation:	
Life of machine figured at 5 years, 9 months to the year, 25 days to the month	$ 4.00
Daily total	$21.55
Hourly total	$ 2.15

TABLE II.—QUANTITIES AND COSTS OF MACHINE EXCAVATION ON SEWER WORK

Run no.	Lin. ft. trench excavated	Aver. depth, ft.	Hours actual run. time	Cu. yds. per hr. actual run. time	Cu. yds. per day	Cost per yd. on day basis
1	590	6.6	10	26.4	264	$0.082
2	565	7.5	10	28.6	286	0.075
3	638	6.5	10	28.1	281	0.076
4	530	8.6	9	34.2	308	0.070
5	547	6.7	7.5	33.0	.....	......
5	180	6.0	2.5	29.2	321	0.067
6	426	5.2	7	21.4	.....	......
6	100	6.0	2	15.0	180	0.119
7	180	5.2	4	16.0	.....	......
7	272	6.9	4	31.8	191	0.113
8	340	6.9	7.5	21.2	.....	......
8	130	4.3	2	19.0	197	0.109
9	106	4.3	2	15.0	.....	......
9	162	6.8	3.5	21.4	105	0.204
10	100	6.8	3	15.3	46	0.468[a]
11	565	7.8	10	29.8	298	0.072
12	200	6.4	10	8.7	87	0.248[b]
13	283	6.4	5	24.6	.....	......
13	200	6.9	5	18.6	216	0.100
14	100	5.5	4	9.2	37	0.582[c]
15	400	5.0	10	13.5	135	0.159
16	109	5.0	5	7.4	.....	......
16	348	5.5	5	26.0	167	0.129[d]
17	450	5.5	10	16.8	168	0.128
18	248	6.0	8.5	13.4	114	0.189
19	447	6.3	10	19.1	191	0.112
20	200	6.0	10	8.2	82	0.262[e]
21	316	5.8	10	12.4	124	0.173
22	400	7.0	9.5	20.0	190	0.113
23	400	4.0	6.5	16.6	108	0.200[f]
Totals			203		4,096	

$$\frac{23 \times \$21.55}{4096} = \text{aver. cost per cu. yd.} = \$0.121 \text{ on 10-hour day basis.}$$

$$\frac{203 \times 2.155}{4096} = \text{aver. cost per cu. yd.} = \$0.107 \text{ on actual running time basis.}$$

[a] Broken chain. [b] Bad banks. [c] Long shift. [d] Wet. [e] Bad banks. [f] Long shift.

Depreciation.—In this particular case, no serious breakages have occurred to date, most of the smaller delays being due to the breakage of links in the bucket chain, the defective links being easily replaced. Still a time must come when the breakages, figured not in dollars and cents necessary to replace defective parts, but in delays to the general progress of the work, must convince the contractor that the efficiency of his machine is low enough to allow of its being discarded. It may be that five years is a conservative estimate; if so, then the costs deduced from this depreciation are on the safe side—a good place for them to be.

Table II shows this excavator during a run of 23 consecutive working days, with time lost in making shifts from street to street and delays due to waiting for the pipe layers in wet ditches, handled an average 178 cu. yds. per day, at an average cost of 12 cts. per cubic yard. The maximum yardage per day was 308. It is well to note this figure of 0.063 was made in a run of 530 ft. in 9 hours with an average trench depth of 8.6 ft. This is significantly the maximum depth quoted in this record. In explanation it may be stated that in shallow trench work the upper 6 or 8 ins. of road metal or even solid compacted surface, which in comparison to the rest of the is ditch hard to excavate, forms a considerable percentage of the total material excavated.

Cost of Backfilling the Trench.—The backfill is divided into two parts: first, the foot of earth covering, which is thrown in and tamped by hand, which serves as a protection for the pipe and the cement joints during the 24 hours in which the ditch is left open for the joints to set up before flushing can commence; and. second, the remainder of the backfill which is put in with team and scraper and flushed and settled with water.

Part 1.—Part 1 may be estimated at 16 cts. per cubic yard, although the variation from this average cost was great in some instances. It is readily seen that in estimating the cost of backfill per lineal foot on ditches of various depths, the proportion of this expensive form of backfill varies inversely as the depth. It has also been noted that in shallow trenches the cost per cubic yard of excavation runs higher than the same unit cost in ditches whose depth approximates the maximum reach of the digging arm.

Part 2.—The trench above the 1 ft. covering was filled with a Sydney scraper and team. Water was run into the ditches during this fill, from the hydrants, with a meter on the line. Two men followed behind the scraper, cleaning out the gutter and rounding off the top of backfilled trench.

The daily cost of this part of the backfill is shown in Table III.

Table III.—Cost Per Cubic Yard of Scraper Backfill

Length trench ft.	Depth trench ft.	Backfill, cu. yds.	Actual time, hours	Cu. yds. per hr.	Cost per cu. yd. actual time	Cu. yds. per day	Cost per cu. yd. day basis
150	6.5	65	3	22	$0.055	.....	....
550	4.0	147	7	21	.057	212	$0.057
800	4.0	213	6.5	33	.036	......	....
280	5.0	93	3.5	27	.045	306	.039
600	3.0	120	5	24	.050	(240)	.050
565	5.0	188	5	38	.032	(376)	.032
445	5.0	148	5	29	.041	(296)	.041
							(.044)*
Totals...........		974	35				

$\frac{974}{35} = 28$ = average backfill in cubic yards per hour.

* $0.044 = average cost per cubic yard.

Remarks. Depths taken to top of pipe covering.

The operating cost per day for the scraper outfit was as follows:

Team and driver	$ 4.50
Helper on scraper	1.75
Helper on hose, etc.	1.75
Cleaning up gutter, 2 men at $1.75	3.50
Water. 5,000 gals., at 10 cts. per M	.50
Per day of ten hours	$12.00
Per hour	$ 1.20

Cost of Deep Sewer Trenching with a Carson Machine.—A. W. Peters engineer in charge of sewer construction of Moundsville, W. Va., gives the cost of deep trench work with a Carson machine in Engineering and Contracting, April 2, 1913. The Carson machine is not an excavating machine but is used to convey in buckets on a cable material which is excavated by hand tools.

On the two sections for which costs are quoted, the soil consisted of fine sand mixed with loam and unstratified yellow clay. In the shallow trenches this material could be excavated for a depth of 8 ft., and the ditch left open for several days in ordinary weather without endangering the banks, although in general verticals and trench braces were used. When the contractor opened up his deep ditches in this material he decided to use 8-ft. lengths of sheeting, placed without driving, in the excavated 8-ft. depth. In this way a section of trench 8 ft. deep would be excavated and the sheeting placed; then the next lower 8 ft. of material would be removed, and the second set of sheeting placed with its top butting up against the bottom of the upper section, the banks being carried down approximately plumb. In backfilling, 8 ft. of sheeting would be knocked out and the trench filled, the material being tamped against the trench side wall and not against the sheeting, as is ordinarily necessary.

TABLE IV.—QUANTITIES ON SECTIONS 1 AND 2, MOUNDSVILLE SEWER TRENCHES

	Length, ft.	Depth, ft.	Total excavation, cu. yds.	Excavation per lin. ft., cu. yds.	Actual mach. days	Excav. per actual mach. day, cu. yds.	Cu. yds. per man-day
* Section 1	296.0	31	1,529	5.2	28	55	4.6
† Section 2	135.0	14–16	.....	...	..	..	...
Section 2	65.0	16–18	.....	...	..	..	...
Section 2	40.0	18–20	.....	...	..	..	...
Section 2	50.0	20–22	.....	...	..	..	..
Section 2	42.0	22–24	.....	...	..	..	...
Section 2	53.8	24–26	.....	...	...	..	...
Section 2	137.0	26–28	.....	...	..	..	...
Section 2	92.8	28–30	.....	...	..	..	...
Section 2	615.6		2,526	4.1	31	82	6.8

* Uniform depth of 31.0 ft.
† Average depth of 22.1 ft.

Of course, these Moundsville conditions are particularly favorable to low sheeting costs, and all that that means in deep trench work, so that the results as derived in Table V should be considered in that light.

The material in these two sections was usually picked before shoveling into the buckets, as it could be handled more rapidly in that way. The general progress of the truck work seemed to be fairly good. The buckets were loaded rapidly, the best men being placed at this work. The machine was handled efficiently and the buckets were run back and forth at a fairly high speed.

Regarding the items of which the total cost is comprised a few explanations will be given:

Excavation.—The first 3 or 4 ft. were thrown upon the bank and not loaded into buckets. For the remaining depth two men shoveled into each bucket, usually loosening the material before shoveling.

Machine.—The sub-heading "moving" is made up principally of the cost of moving the machine along the ditch, which required tracklaying, anchorages and hitches ahead.

TABLE V.—TRENCH COSTS ON SECTION NO. 1, UNIFORM DEPTH, MOUNDSVILLE SEWERS

Item	Cost	Per cent total	Cost per lin. ft.	Cost per cu. yd.
Cost bucket loading	559.80	35.2	$1.88	$0.36
Machine moving	$ 13.96	0.9	$0.05	$0.01
Machine engineer	80.40	5.0	0.27	0.05
Machine signal	52.60	3.3	0.18	0.03
Machine coal	18.00	1.1	0.06	0.01
Machine rental	300.00	18.9	1.01	0.20
Cost, conveying	$ 464.96	29.2	$1.57	$0.30
Sheeting	$ 231.42	14.6	$0.78	$0.15
Tamping	97.06	6.1	0.33	0.06
Teams	40.50	2.6	0.14	0.03
Pavem't removal	15.12	1.0	0.05	0.01
Pavem't replacement	41.20	2.6	0.14	0.03
Superintendent	138.45	8.7	0.47	0.09
Cost, misc	$ 563.75	35.6	$1.91	$0.37
Grand tota	$1,588.51	100.0	$5.36	$1.03

TABLE VI.—TRENCH COSTS ON SECTION NO. 2, VARIABLE DEPTH, MOUNDSVILLE (W. VA.) SEWERS

Item	Cost	Per cent total	Cost per lin. ft.	Cost per cu. yd.
Cost bucket loading	$ 639.89	31.7	$1.04	$0.26
Machine moving	$ 62.56	3.1	$0.10	$0.03
Machine engineer	100.33	5.0	0.16	0.04
Machine signal	58.25	2.9	0.09	0.02
Machine coal	10.20	0.5	0.02	.....
Machine rental	416.00	20.6	0.68	0.17
Cost, conveying	$ 647.34	32.1	$1.05	$0.26
Sheeting	$ 117.06	5.8	$0.19	$0.05
Tamping	145.12	7.2	0.24	0.06
Teams	155.25	7.7	0.25	0.06
Pavem't removal	52.42	2.6	0.08	0.02
Pavem't replacement	85.00	4.2	0.14	0.03
Superintendent	175.19	8.7	0.28	0.07
Cost, misc	$ 730.04	36.2	$1.18	$0.29
Grand total	$2,017.27	100.0	$3.27	$0.81

Coal.—Due to the nearness of the bituminous mines, three within the city limits, coal could be bought for 5 cts. a bushel at the mine or 7 cts. a bushel delivered. This fact makes the coal item very low.

Sheeting.—Method of placement described under general soil conditions above. Thickness of sheeting 2 ins.; stringers 4 ins. × 6 ins. The cost as given includes placement, removal and depreciation.

Tamping.—This gang consisted of six men, one shoveller and five tampers. The men did not use the heavy iron tampers, but were provided with pieces of 4 ins. × 6 ins., about 2 ft. long, with an old shovel handle set into one end. Better results were secured with these wooden tampers than with the iron ones.

Teams.—This item is made up principally of the cost of removal of surplus dirt, and cost of evening up inequalities in trench depth. On Section 2 the cost of this item is greater than on Section 1, because the trench depths were increasing as the machine moved ahead, so that when the backfill was made under these conditions, a surplus resulted which necessitated the team expense.

Pavement.—Brick on both sections laid on 1-in. sand cushion with 6 ins. of gravel foundation. Very little of the base was saved, so that in the replacement of paving new gravel was necessary. A great many brick were broken on removal or afterwards lost.

Labor.—The wages on these ditches varied from $1.85 to $2.00, about 70 per cent of the men getting $1.85 per day, and the remainder $2.00.

Cost Analysis.—Referring to the tables it will be seen that Table IV is a general table of quantities with unit quantities reduced. Table V gives the trench costs for uniform depth, and Table VI presents the cost on a ditch of variable depth.

For a trench ranging in depth from 14 to 30 ft. in Moundsville, the "Digging Cost," equal to cost of bucket loading and conveying, was found to be 52 cts. per cu. yd., as shown by the sum of "Bucket Loading" and "Conveying" costs in Table VI.

For the trench with uniform depth of 31 ft., the "Digging Cost" at Moundsville equals 66 cts. per cu. yd. See Table V.

Referring to Table IV we see that the yardage per man-day for the variable ditch was 6.8, while for the uniform ditch it was 4.6.

These results, without any further study of the tables, show that we cannot quote a uniform price for all depths of excavation, as is done by the machine people and some authors.

A moment's thought will show that the difference between the lengths of haul in a 10-ft. ditch and a 35-ft. ditch may vary by as much as 15 per cent.

It will also be noticed that the three main divisions of the total cost are approximately equal in each table, both in the case of the ditch of uniform depth as shown in Table V, and in the ditch of variable depth as shown in Table VI. This fact would seem to offer an approximate method of estimating trench costs, by using the "Cost of Bucket Loading" as a starting point. It would seem that this ratio ought to hold in soil conditions different from those encountered at Moundsville, because the three main divisions contain items that are more or less dependent upon each other, so that a change in one would cause a corresponding variation in the others. For example, suppose that a wet ditch is being excavated. It will then take longer to load the buckets and the cost will therefore, be greater; the Conveying Costs will be similarly increased because the Machine Rental, which is a large item, will be greater. It can readily be seen that the Miscellaneous Costs will be increased and the item of Pumping will be added.

In the two Moundsville ditches quoted, the cost of bucket loading varies with the depth, and is almost numerically equal to it. The expression (D + 4) where (D) is the depth of trench in feet, would give the cost per cu. yd. of Bucket Loading for both trenches.

For a trench in "ordinary earth," such as the Moundsville trenches, with either a uniform or average depth, D, the total cost per cubic yard of trench work would then be given by the expression 3 (D + 4).

It is usually the case that excavation in hardpan costs approximately double the excavation of the ordinary earth. With a hardpan trench, therefore, the expression for total cost per cubic yard would become 6 (D + 4).

Of course, it is not expected that this expression will serve as other than an approximate check on estimated costs of deep trench work; neither is it expected that it will meet the demands of a quicksand ditch; but for the ordinary run of ditches it is believed that it will check up in fairly good shape providing the Bucket Loading cost is selected with some care and judgment.

Cost of Deep Trenching by Machine at Glencoe, Ill.—The following is taken from an article in Engineering and Contracting, April 5, 1911, by Don E. Marsh.

The length and depth of the various sizes of pipe for the sewerage system at Glencoe, Ill. are as follows:

15,500 lin. ft. of 8-in. pipe from 8 to 12. ft. cut.
5,600 lin. ft. of 10-in. pipe from 7 to 13 ft. cut.
250 lin. ft. of 12-in. pipe about 13 ft. cut.
1,000 lin. ft. of 15-in. pipe about 16 ft. cut.

4,700 lin. ft. 18-in. pipe from a very shallow cut up to a cut of 30 ft.

Reference to the above tabulation will show that a good percentage of the larger size pipe was placed in very deep cuts. The soil, especially in the deep cuts, was a hard clay. The top fifteen feet was a brownish clay with slight traces of sand. Below this was a hard blue clay. During the fall and winter months this soil becomes extremely hard and difficult to handle, too hard in fact to be dug by hand without the aid of a pick. In some respects the character of the soil was an advantage, since no sheathing was required.

It was determined to utilize the largest size Municipal Excavator. The excavator was constructed to dig a trench up to 25 ft. in depth. Where the depth of excavation exceeded this amount, as it was for a considerable distance as deep as 30 ft., the street was graded down 3 or 4 ft. and the remaining foot or two was excavated by hand in the bottom of the trench and the dirt thrown either into the boom or back upon the completed pipe.

The trench dug by this machine was about 33 ins. in width, giving ample room for the proper laying of the 18 ins. sewer pipe and for securing proper joints and also for the reception of junctions. All joints were calked with oakum and then cemented, to exclude seepage as far as possible, making a wide trench quite necessary, for room in which to operate.

The sides of the trench were smooth and vertical. Vertical plank and pack screws were used for bracing. These were placed about 3 ft. apart in the deep trenches and farther apart in shallow cuts.

Cost.—A record of a few average days, which does not take into consideration the long or short delays caused by break-downs, storm, or otherwise, the cost of labor alone for excavating at a depth of about 25 ft., laying 18-in. pipe and back filling appears about as follows:

	Per day
1 foreman	$ 8.00
Excavating machine, including operator	40.00
1 engineer	4.00
1 fireman	3.00
5 trenchmen at $3.00	15.00
20 laborers, backfilling, at $2.50	50.00
2 teams at $6.00	12.00
Coal	5.00
Repairs and sundry expenses	10.00
Total	$147.00

One hundred and forty-seven dollars for 80 ft. or approximately $1.85 per lin. ft. While working in the deep cuts progress of 60 to 100 ft. per day was made.

It will be noticed that a large amount of the cost is for backfilling. This item can be reduced where it is possible to use teams with slips. If the backfilling can follow close behind the excavating while the dirt is still fresh, one team with driver and one scraper holder will backfill about as much as ten laborers with shovels.

Comparative Cost of Hand and Machine Trench Excavation and Some Miscellaneous Sewer Costs.—The following is taken from Engineering and Contracting, July 9, 1919.

Machine trenching in the construction of the Stanley St. sewer at San Francisco cost about one-fifth as much as by hand trenching.

During construction, where the contour of the ground permitted, a ditching machine was used, which not only produced cheaply a uniform trench in which to lay the heavy cast-iron pipe but speeded the completion and earlier use of the entire system.

The following costs to the contractor of some of the items—office overhead and the necessary insurance and bond not included are taken from the report of M. M. O'Shaughnessy, City Engineer, for the fiscal year ending June 30, 1918:

15-in. iron stone-pipe, per foot	$ 1.65
21-in. iron-stone pipe, per foot	1.79
2 × 3 reinforced concrete sewer, per foot	3.31
2 ft. 6 in. × 3 ft. 9 in. reinforced concrete sewer, per foot	3.51
Brick manholes, each	40.50
Overflow structure	465 65

Trench excavation for the cast-iron pipe was in stiff sandy clay. The cost of that portion of the work done by hand was $0.91 per cu. yd.; the cost by machine was $0.18 per cu. yd., including a fixed charge of $32 per day for the use of the machine.

The 18-in. cast-iron pipe cost $0.228 per foot to lay, yarn, pour and calk the joints.

The prevailing rate of labor during construction was $3.00 per day.

Average Daily Progress in Excavating 37,800 Ft. of Sewer Trenches with Trenching Machines.—Engineering and Contracting, Feb. 10, 1915, publishes the following data given by J. E. Schwaab in a paper before the 30th annual meeting of the Illinois Society of Engineers and Surveyors.

In the construction of the sewer system of Alton, Ill. there were used one small 00 Austin gasoline ditching machine which excavated a ditch 24 ins.

wide. The following out-put data were furnished by G. M. Johnson, of the Lillie Construction Co., sub-contractors, and owner of this machine:

Total amount of work done, lin. ft.	19,800
No. of working days	90
Average cut per day, lin. ft.	220
Maximum cut per day, lin. ft.	800
Average cost per day for operation	$30

Depth of trench averaged 11 ft., with a maximum of 22 ft. and a minimum of 4 ft.

There was also used a Parson's steam ditching machine with backfiller, which excavated a ditch 28 ins. wide. The following figures as to the work done by this machine were computed by the writer and are only approximate:

Total amount of work done, lin. ft.	18,000
Number of working days	90
Average cut per day, lin. ft.	200
Average cost per day for operation, laying pipe, and backfilling	$45.00
Average depth of trench excavated, ft.	11½

The material excavated was clay and sandy clay. The work was done during the summer of 1914.

Progress and Distribution of Time of Force on Sewer Trenching by Machine. W. G. Kirchoffer gives the following information in Engineering and Contracting, April 10, 1912. In excavating for 5,270 ft. of 8-in. Sewer at West Salem, Wis., in a sandy gravelly clay, the contractor used a Parson's trenching machine.

The trench averaged about 8 ft. deep. The total number of days' work put in on the job was 325¾, or an average of 61.8 days per 1,000 ft. of sewer. The trenching machine was operated 20 days out of the total 26 put in upon the work, or an average of 263½ ft. per day. The least distance made in a day was 20 ft. and the maximum distance was 550 ft. of completed sewer. There were five days in which the rate exceeded 400 ft. of sewer per day.

The labor put in upon the work was divided as follows in days per 1,000 ft. of sewer:

Contractor	1.092
Inspector	4.935
Pipe layer	4.315
Foreman	4.270
Engineer	4.79
Fireman	4.412
Team	3.417
Mason	3.75
Water boy	1.993
Common labor	26.04
Tamper	4.13

The greatest number of men employed in any one day was 16 and the smallest number was two.

Cost of Excavating for Large Trunk Sewer with Locomotive Cranes and Automatic Buckets.—Engineering and Contracting, June 29, 1910, gives the following data relative to the excavation of a section of the Louisville, Ky. sewerage system.

The contract under consideration was for 2,723 ft. of sewer through unimproved land. The sewer is of concrete, 12 ft. × 9 ft. for 1,126 ft. in length, and of three centered arch section. For the balance of the length it is horseshoe shaped, and about 9 ft. 3 ins. × 9 ft. in section.

The average depth of excavation was 22.4 ft. and the average number of cubic yards of excavation per lineal foot of trench was 12¼. The material excavated consisted of 6 ft. of blue and yellow clay below which was 6 to 12 ft. of yellow clay and loam and the balance, fine and coarse sand.

In opening the trench horse scrapers were used, and enough of the trench was excavated in this way and used for filling in low land nearby, to take up the amount which would necessarily have to be spoiled. An average of half a dozen teams were used on this work with one team acting as a snap team. The longest haul was about 100 yards.

The main excavating plant for this contract consisted of three ten-ton Browning locomotive cranes, two of which were equipped with automatic buckets, one orange-peel of 1 cu. yd. capacity and one clamshell of ½ cu. yd. capacity. The cranes ran on standard gage track, of 60 and 65-lb. rails, laid along the trench for 600 ft.

Progress and Costs.—The working day is 10 hours. Crane No. 1 operates a ½-cu. yd. Owens clamshell bucket and averages 400 buckets in 10 hours or 200 cu. yds. This bucket handles a full half yard at each operation. The labor cost on this machine is as follows:

1 engineer at	$ 3.50
1 fireman	2.00
1 tagman	1.75
1 signalman	1.75
Cost of labor for 200 cu. yds. (clay)	$9.00

Cost of labor per cu. yd., $0.045.

The second crane handles sand in a ¾-cu. yd. dump bucket filled by hand. It handles 300 buckets or 225 cu. yds. a day. The labor cost on this is as follows:

1 engineer	$ 3.50
1 fireman	2.00
1 foreman	2.00
8 men in bottom at $1.75	14.00
Cost of labor for 225 yds	$21.50

This gives a cost of labor for 1 cu. yd. of $0.095.

The third or backfill crane operates a 1-cu. yd. orange-peel bucket and handles 500 cu. yds. of material in 10 hours. The cost of labor backfilling is as follows:

1 engineer	$3.50
1 fireman	2.00
1 signalman	1.75
Labor cost backfilling, 500 cu. yds	$7.25

Labor cost per cu. yd. of backfilling, $0.0145.

This crane when not backfilling, pulls timbers and sheeting. The average amount of coal used by one crane in a day is 1,200 lbs. Run-of-mine coal is used at $4 per ton. About 160 gals. of water are used per crane per day. The cranes each cost $5,000 new and their annual interest and depreciation is figured by the contractor at 30 per cent.

Cost of Excavating Trench in Granite.—The following data, published in Engineering and Contracting, April 20, 1910, was arranged from a paper by E. A. James in Applied Science for March, 1910.

The excavation was for an 18-in. sewer built at Muskaka, Ont. This sewer had a total length of some 1,300 ft., but only the 550 ft. in rock trench is referred to here. The rock was Laurentian granite and the trench was 9 ft. deep. The excavation was by drilling and blasting, the rock being hoisted by horse derricks and skips and deposited in horse drawn cars operating on track. The haul was some 1,500 ft. for about two-thirds of the spoil and less than 300 ft. for the remainder. The total amount of rock excavation was 1,850 cu. yds., and the itemized cost of excavation was as follows:

	Total	Per cu. yd.
Superintending:		
Walking boss, at 60c per hour	$ 222.45	$0.12
Clerk and timekeeper, at 37½c per hour	158.60	0.085
Foreman, at 45c per hour	608.15	0.328
Total for superintending	$ 989.20	......
Labor—Mucking, loading, hauling and dumping:		
Laborers, at 20c per hour	$2,877.00	$1.555
Teamsters, at 21c per hour	499.70	.270
Teams, at 40c per hour	1,010.60	.545
Cars, at 5c per hour	117.00	.063
Carts, at 5c per hour	65.50	.035
Derricks and power, at 15c per hour	175.50	.095
Handy men, at 27½c per hour	125.15	.067
Total labor	$4,870.45	$2.630
Drilling rock:		
Foot drilling, at 30c per ft	$1,245.00	$0.673
Sharpening drills, at 27½c per hour	250.80	.135
Nippers, at 17½c per hour	382.20	.206
Coal, at $10 per ton	29.00	.157
Total	$1,907.00	$1.171
Explosives:		
Electric fuses	$ 95.95	......
Caps and fuses	23.20	......
Batteries, rent	38.00	......
60% dynamite, at $10 per box	1,020.00	......
Total	$1,117.15	$0.636
Grand total		4.97

To the above total must be added $930. for depreciation of plant or 50 cts. per cu. yd., making a total cost per cubic yard of $5.47. In studying this cost it must be noted that the trench was narrow, and small shots had to be used, making the amount of drilling large; 1 ft. of hole was drilled per 4.5 cu. yds. excavated.

Cost of Hand Drilling Bastard Granite in Trench Work.—Edward B. Roberts gives the following data in Engineering and Contracting, June 15, 1910.

The trench was 2½ ft. wide and 5¾ ft. deep and the rock, a bastard granite, was found in the bottom of an average depth of 2¾ ft. The drilling was done by hand using 1¼-in. drills, 1 man holding and 2 men striking with 8-lb. hammers. A total of 96 ft. of hole was drilled or 3.2 ft. per cu. yd. of work.

The time required was 3.1 hours per lin. ft. of hole. The time work of excavating 35 cu. yds. was:

Item	Per cu. yd.
347 hrs. drilling	9.92
120 hrs. mucking	3.43
Total	13.35

The materials used were as follows:

Item	Per cu. yd.
53 lbs. 60 % dynamite, lbs	1.5
Explosives	2.

A batch of 120 drills were sharpened or 4 per cu. yd., or 1 per 0.75 ft. of hole drilled. The amount of explosive used per foot of hole was ½ lb. Labor estimating does not include backfills.

Progress of Sheeting a Sewer Trench with Light Steel Sheet Piling.—Engineering and Contracting, Nov. 15, 1918, gives the following.

The work was the laying of a terra cotta sewer pipe in the City of Watertown, N. Y. The course of the sewer was in a sandy soil which obtained quite uniformly throughout its length to a depth of about ten feet, underneath which was a wet sand mixed with gravel. The average depth of the sewer pipe below the surface was 15 ft. The nature of the soil necessitated the use of sheeting to prevent caving in of earth and thus permit of a narrow excavation with the minimum of material to be removed. Accordingly, 400 sheets of ⅛-in. Wemlinger corrugated steel sheet piling in 10-ft. lengths were obtained and for driving them a steam-driven pile hammer, weighing approximately 650 pounds, was used. The trench was first excavated for its width to a depth of about 5 ft., which was left unsheeted. The sheet-piling was then carried by hand and set in position on each side of the trench and driven its entire length before any further excavating was done.

An A-frame built of timber straddled the excavation, and from it was suspended a 2-ton triplex differential chain block. It was intended to use the chain block for raising and lowering the pile hammer during the driving and, subsequently, to withdraw the sheet-piling. Throughout the entire operation the work of placing the sheeting, driving it with the pile hammer and pulling and resetting, was done by 3 men for each separate operation. As before stated the sheeting was all handled by manual labor, and it required 1 hr. and 30 min. to set up 32 sheets in position for driving, including the time required to carry these sheets an average distance of about 175 ft. The time required to drive each sheet 5 ft. into sand was from 33 to 37 seconds. The driving was done so fast that the triplex block could not be worked quickly enough to follow the pile hammer, and so it was steadied by hand. No difficulty was experienced in doing the work in this way and the chain block was needed only to hoist the hammer from one pile to another. That this method of handling the hammer proved to be a success is largely due to the fact that it stood only about 4 ft. high on top of the sheet-piling. Including the time required for moving both the hammer and A-frame, an average of 7 ft. of trench was sheeted on both sides per hour.

Average Costs of Sewers, Washington, D. C. 1902 to 1917.—Tables VII and VIII, are given in Engineering and Contracting, April 11, 1917, from the report of A. E. Phillips for the year ended June 30, 1916.

TABLE VII.—AVERAGE COST OF CONSTRUCTING PIPE SEWERS FOR 15 YEARS

Year	8-in. diam. *L	8-in. diam. *M	10-in. diam. L	10-in. diam. M	12-in. diam. L	12-in. diam. M	15-in. diam. L	15-in. diam. M	18-in. diam. L	18-in. diam. M	21-in. diam. L	21-in. diam. M	24-in. diam. L	24-in. diam. M
1902	$0.83	$0.32	$0.97	$0.41	$1.04	$0.46	$1.46	$0.62	$1.74	$0.78	$1.91	$0.96	$2.43	$1.23
1903	.80	.36	1.03	.53	1.09	.54	1.32	.73	1.52	.81	1.57	1.06	1.74	1.32
1904	.97	.36	.92	.55	1.17	.65	1.45	.81	1.61	.91	1.94	1.24	2.24	1.47
1905	.98	.38	.96	.55	1.19	.60	1.41	.77	1.45	.89	1.92	1.01	1.87	1.43
1906	.87	.33	1.19	.47	1.26	.54	1.41	.67	1.53	.78	1.88	.93	2.45	1.24
1907	1.42	.43	1.43	.48	1.30	.56	1.46	.70	1.82	.85	2.09	.98	2.78	1.26
1908	1.34	.42	1.26	.50	1.44	.61	1.69	.75	1.91	.90	1.74	1.14	2.65	1.50
1909	1.34	.36	1.16	.36	1.46	.46	1.59	.56	1.58	.62	1.67	1.07	1.91	1.18
1910	1.00	.29	.99	.35	1.12	.43	1.19	.52	1.49	.66	1.52	.85	1.72	1.14
1911	1.01	.27	1.02	.32	1.17	.40	1.36	.52	1.64	.67	1.50	.75	1.82	1.08
1912	1.06	.25	1.08	.33	1.20	.39	1.46	.56	1.63	.67	1.70	.88	1.76	.98
1913	1.02	.26	1.07	.29	1.35	.38	1.53	.58	1.74	.75	1.93	1.08	2.20	1.28
1914	.78	.28	1.08	.45	1.32	.51	1.44	.69	1.56	.89	1.69	1.34	2.11	1.41
1915	.58	.19	1.12	.42	1.25	.51	1.56	.67	1.63	.89	1.89	1.18	1.78	1.45
1916	.76	.25	1.00	.36	1.05	.43	1.31	.62	1.49	.72	1.87	1.13	2.11	1.16

*Note: L = Labor, M = Material.

TABLE VIII.—CONTRACT PRICES FOR CONSTRUCTION MATERIALS FOR 15 YEARS

Year	Cement, per bbl.	Sand, per cu. yd.	Gravel, per cu. yd.	Terra-cotta pipe, linear foot 8-in.	10-in.	12-in.	15-in.	18-in.	21-in.	24-in.
1902	$ 1.82	$ 0.65	$ 0.88	$ 0.115	$ 0.17	$ 0.205	$ 0.275	$ 0.39	$ 0.59	$ 0.77
1903	1.96	.55	.87	.12	.185	.235	.33	.42	.62	.80
1904	1.75	.85	.85	.12	.228	.297	.401	.5049	.7425	.965
1905	1.13	.81	.85	.14	.20	.29	.40	.50	.74	.96
1906	1.35	.85	1.05	.122	.1647	.2236	.2997	.3672	.5454	.7263
1907	1.55	.74	.97	.155	.195	.261	.353	.443	.5454	.848
1908	1.52	.84	1.04	.155	.225	.30	.405	.51	.75	.975
1909	1.20	.55	.75	.155	.1707	.239	.3233	.4066	.5975	.7775
1910	.975	.54	.65	.125	.15	.20	.27	.3825	.5625	.73125
1911	.99	.395	.485	.115	.175	.22	.30	.42	.55	.715
1912	.98	.345	.435	.121	.176	.22	.31	.40	.59	.715
1913	.94	.345	.435	.105	.15	.18	.351	.494	.78	.845
1914	1.11	.54	.69	.11	.256	.25	.432	.608	.96	1.04
1915	1.04	.54	.69	.11	.23	.245	.43	.60	.96	1.04
1916	1.00	.54	.69	.11	.16	.21	.284	.40	.63	.6825

Cost of Sewer Construction, Webb City, Mo.—E. W. Robinson gives the following data in Engineering and Contracting, Aug. 14, 1912.

The nature of the excavation encountered in this locality is too rocky to permit the use of a trenching machine. This necessitates that the work all be done by hand except the top two or three feet which can be loosened with a plow or rooter. While there have been a few instances of finding treacherous ground in the nature of joint clay, generally it is very stable and requires very little or no timbering for depths not exceeding 10 ft., except during wet weather. A fair sample of the log for the excavation for a trench 10 ft. deep would be, 0 to 1 ft. black dirt with few small boulders; 1 ft. to 3 ft. boulders varying from the size of a man's fist to the size of a water bucket cemented together with a sort of dried clay; 3 ft. to 5 ft. large flint boulders and ledges with seams of clay between; 5 ft. to 7 ft. red or yellow clay with occasional boulders; 7 ft. to 10 ft. alternate clay and boulders and ledges, with occasional out-cropping of lime rock. As everything except lime rock in masses of 9 cu. ft. or over is classed as earth, one need not be surprised at the cost of excavating in this city compared with that of other localities.

Construction Costs of 8" Sewer.—The following data give the actual cost of constructing one district sewer, and is a fair average for like sewers in this city. Total length of sewer, 2,135 ft.; 1,430 cu. yds. of excavation; 2 flush-tanks, 3 manholes. The items follow for the sewer proper:

Item	Unit cost cts. per ft.
Labor:	
Foreman, 310 hrs. at 35 cts	5.08
Pipe layer, 82 hrs. at 25 cts } Helper, 106 hrs. at 20 cts	1.95
Team hauling, 17 hrs. at 35 cts	0.28
Excavation, 153.5 hrs. at 25 cts., 3,909 hrs. at 20 cts. ($0.5736 per cu. yd)	38.41
Backfilling, 567.5 hrs. at 20 cts. ($0.0792 per cu. yd.)	5.31
Cleaning up, teams, 177.9 hrs. at 35 cts	2.92
Flushing and tamping, men, hose rent, drayage, etc	1.61
Per lineal foot	55.56

Item	Cost	
Materials:		
1,845 ft. straight 8-in. clay pipe at 13.05 cts	$240.77	
156 ft. 6-in on 8-in. Y branches at 71 cts	110.76	
Cement for joints, 30½ sacks at 40 cts	12.20	
Jute for joints, 88 lbs. at 14 cts	12.32	
Picks sharpened, 352 at 10 cts	35.20	
Caps for Ys, 156 at 3 cts	4.68	
Drills sharpened, 3 at 20 cts	.60	
Fuse, caps and dynamite	1.20	
Total materials on sewer pipe	$417.73	19.57
Total labor and materials on sewer proper		75.3

Cost of Manholes.—The walls of the manholes are 8 ins. thick and are made of brick. The bottom is concrete. The manholes are circular in section with an inside diameter of 4 ft. The walls are carried up vertically and are drawn in in the upper 2 ft. 6 ins. to a clear opening of 28 ins. in diameter to admit the cast iron frame and cover. The inside of manhole is finished with three coats of Portland cement grout, and the outside of the wall is plastered with a ½-in. coat of mortar, mixed 1 part Portland cement to 2 parts sand. Wrought iron manhole steps are spaced 15 ins. apart vertically. The itemized average cost of labor and material are here given. The average is based on three manholes of an average depth of 8½ ft. The cost data follow:

Item Labor:	Cost
Excavation, 24 hrs. at 20 cts	$ 4.80
Mixing concrete for base, 2 hrs. at 20 cts	0.40
Bricklayer, 7 hrs. at 40 cts	2.80
Helper, 7 hrs. at 20 cts	1.40
Team hauling, 2 hrs. at 35 cts	0.70
Painting inside with cement wash, 2 hrs. at 25 cts	0.50
Total labor on manholes, average	$10.60
Per vertical foot	$ 1.25

Item Material:	Cost
Brick, 1,066 at $8 per 1,000	$ 8.53
Cement in concrete, 3 sacks at 40 cts	1.20
Cement in mortar, 8 sacks at 40 cts	3.20
Sand in mortar, 16 cu. ft. at 8 cts	1.28
Gravel in concrete, 0.4 cu. yds. at 50 cts	0.20
Water, 2 bbls. at 10 cts	0.20
Cast iron cap and cover	9.50
Wrought iron steps, 3 at 40 cts	1.20
Total material on manholes, average	$25.31
Per vertical foot	$ 2.98
Total labor and materials on manholes average of three	$35.91
Per vertical foot	$ 4.22

Cost of Flush-tanks.—Flush-tank walls are 8 ins. thick and are constructed of brick. The bottom is concrete and the siphon also is set in concrete. The top of the walls are drawn in as in the manholes previously described. The inside surface of the wall is finished with three coats of neat Portland cement mortar, and the outside surface with a ½-in. coat of 1:2 mortar. The inside diameter of the flush-tank is 4½ ft. A 6-in. clay pipe overflow is provided. The overflow discharges into the vertical stack of the 6-in. clay pipe lamp hole placed adjacent to the flush-tank. The lamp hole stack at the base joins the outlet pipe forming the siphon discharge. The flush-tank has wrought iron steps of the type and spacing described for manholes. The following cost data on flush tanks give the average cost of two tanks of an average depth of 8 ft.:

Item Labor:	Cost
Excavation, 19 hrs. at 20 cts	$ 3.80
Team hauling, 4 hrs. at 35 cts	1.40
Mixing concrete for base, 2 hrs. at 20 cts	.40
Bricklayer, 9.5 hrs. at 40 cts	3.80
Helper, 10 hrs. at 20 cts	2.00
Digging ditch for water connection, 64 hrs. at 20 cts	12.80
Tapping water main	3.00
Total labor on flush tanks, average	$27.20

Item Material:	Cost
Brick, 1,232 at $8 per 1,000	$ 9.86
Cement for concrete, 3½ sacks at 40 cts	1.40
Gravel for concrete, 0.6 cu. yds. at 50 cts	.30
Cement for mortar, 12 sacks at 40 cts	4.80
Sand for mortar, 24 cu. ft. at 8 cts	1.92
Water, 2 bbls. at 10 cts	.20
Cast iron cap and cover	9.50
Wrought iron steps, 4 at 40 cts	1.60
Siphon, 6-in. Miller standard	23.50
Corporation cock and lead connection	5.08
Regulator, IXL	4.00
6-in. clay pipe and specials for lamp hole	2.08
Cast iron lamp hole cover	4.25
306 ft. ¾-in. galvanized water pipe at 6.37 cts	19.49
Curb box and cock	2.50
Total materials on flush tanks, average	$90.48
Total cost of sewer, including manholes and flush tanks	$ 1,947.02
Per lineal foot	91.19 cts.

It will be noticed that the above cost of the flush-tanks is rather high. This was partially due to the fact that it was necessary to go so far to make connection with the water main for both tanks.

On the construction of four small (10-in. pipe) public sewers, aggregating 8,551 ft. in length and 4,540 cu. yds. of excavation, two years previous to the construction of the sewer of which data are given above, the total cost complete of sewer proper was 59.8 cts. per lineal foot. For the construction of 28 manholes averaging 8.5 ft. in depth the average cost was $4.01 per vertical foot. However at that time common labor was getting $1.50 and $1.75 per day of ten hours instead of $2.00 as in the later case. An average of three sewers constructed about the same time and under the same labor conditions as given in the foregoing data gave the following unit costs: Total labor and materials on sewer proper, 76.92 cts. per lin. ft.; total labor and materials on manholes, avg. depth 9 ft., $4.14 per vertical foot; labor and materials on flush-tanks, avg. depth 7.5 ft., each, $100.58; grand total, sewer complete, including manholes and flush-tanks, was 95.45 cts. per lineal foot.

Cost of Sewer at Davenport, Ia.—W. S. Anderson, in Engineering and Contracting, Sept. 3, 1913, gives the following:

The sewer construction here described was executed by contract under the Davenport specifications. All work was done by hand.

The method used on most of the work here described was the "step up" system of excavation. Particular attention was paid, on this work, to keeping the pipe close up to the point of excavation, and in keeping a man on the same step, hence the method is referred to as the step up method. By the use of this method the probability of caving was lessened considerably; the foreman was better able to judge the output of each man; each man apparently did a like share of work; the pipe was always up to the point of excavation, which was a helpful factor after a cave in; the pipelayer had more confidence in his safety and was therefore able to do more work. Each man removed only a definite portion, one spade in depth. The excavated material was thrown back far enough to allow walking space between the trench and the material bank.

The first three feet were excavated considerably in advance of the steps, which allowed a greater number of men to be used. One man lowered the pipes, provided the jute and the 1:1 mortar for the joints. The pipe layer in addition to laying and jointing the pipes carried a cut averaging from 15 to 22 ins. in depth, the material from which was thrown directly onto the laid pipe, where it was firmly tamped to prevent any lateral displacement of the pipe. A sand bag was used to remove all projecting material at joints and other loose material.

No staging or platforms were used for a depth less than 9 ft. When used they consisted of planks 8 ft. long supported at the right elevation by trench braces. The pipe was laid on an up-grade as usual so as to make use of the laid pipes for drainage. The trenches were water tamped in nearly every instance.

Contract 1, 1911, Section 1.—Work was started at Section 1. This section lies entirely in pasture land. The length of the 15-in. pipe line laid was 330 ft. The average depth of trench was 6.5 ft. The maximum depth was 8 ft. 9 ins. The minimum depth was 4 ft. The average width of trench was 30 ins. The total yards excavated and back filled were 190. The pipe layer excavated a trench 15 ins. × 23 ins. and averaged 18 ft. of laid pipe per hour. No cave-ins resulted. A Doan scraper was used for back filling. The soil was all yellow clay except the upper foot which was black loam and sod.

The weather was warm and dry. Wages per hour on job A were 40 cts. for foreman, 20 cts. for laborers, 25 cts. for pipe layers and timbermen, and 50 cts. for teams. The following items do not include foremanship, water boy, or incidental expenses which amounted to 3 cts. per ft. of pipe on all sections of this contract.

With these exceptions the costs for Section 1 follow:

Item	Cost per lin. ft., cts.	Cost per cu. yd., cts
29 cu. yds. excavation by pipe layer	0.8	7.6
Laying pipe	2.4	....
161 cu. yds. excavation	10.5	21.4
161 cu. yds. backfill	5.1	10.5
Totals	18.8	49.5

Section 2.—On Section 2 a 327 ft. stretch of 12-in. pipe was laid. This section also lies entirely in pasture land. This section also lies entirely in pasture land. The average cut on this section was 9.3 ft.; maximum 15 ft.; minimum 5½ ft. The weather was very wet. The average width of trench was 26 ins. for 180 ft. and 30 ins. for 147 ft. (This extra width was necessary only where the depth exceeded 12 ft.) The pipe layer excavated a trench 15 ins. × 18 in. for 180 ft. and a trench 23 ins. × 18 ins. for 147 ft., averaging 15 feet, of laid pipe per hour through the shallow cut and 10 ft. through the deep cut. There were no cave-ins to speak of. For the deep cut one platform was required. The cu. yds. of material excavated and back filled were 219.

The costs on this section follow:

Item	Cost per ft., cts.	Cost per cu. yd., cts.
28 cu. yds. excavation by pipe layer	1.2	14.0
191 cu. yds. excavation	21.1	36.1
Laying pipe	3.1	....
191 cu. yds. backfill	6.7	11.5
Totals	32.1	61.6

Section 3.—Section 3 consisted of 390 ft. of 12 in. pipe. The cut on this section varied from 10 feet to 24 ft. Tunnelling was resorted to through the

deep sections. The longest tunnel was 54 ft. while several tunnels 15 ft. in length were put through. The total distance tunnelled was 95 ft., while the open cut distance was 295 ft. The average width of trench was 36 ins. The material was firm clay which stood up remarkably well when tunnelled. Near the bottom a material, which tended toward bog iron, was encountered. The weather was very favorable.

Each tunnel was worked from both ends simultaneously, the excavated material being relayed back into each shaft. In one of the shafts part of the material was deposited onto the pipe, which had previously been laid, while in the other shaft some material for back filling the tunnel was allowed to remain. The excess material was removed to the surface.

The tunnellers were paid 35 cts. per lin. foot tunnelled. The average height of the tunnel was 3½ ft. and the width 3 ft. The tools used were a miner's pick with a "duck bill" on one end, and an 18 in. tile spade, a sharp adz, and a shovel, the handles on these tools being not over 20 ins. long. No timbering of the tunnel was required. The pipes were laid after the entire tunnel section was complete. Grade was teed in from stakes driven at the correct elevation, at each end of the section. The pipe was lowered into the shaft by means of a rope, and slid to the desired point on planks placed on the tunnel bottom. The back filling was carried on by relaying the material in from the tunnel opening and tamping it solidly. The unit costs on the tunnels in Section 3 follow:

Item	Cost per ft., cts.	Cost per cu. yd., cts.
Tunneling, 95 lin. ft. (37 cu. yds.) at 35 cts. per ft..	35.	92.4
Removing 22 cu. yds. material from tunnel........	5.5	28.2
Removing 25 cu. yds. material from shaft..........	17.4	66.
Backfilling tunnel..................................	8.2	21.7
Pipe laying, 95 ft. of 12-in. pipe..................	4.1	....
Totals..	70.2	$ 2.083

The item "removing material from tunnel" includes only 22 cu. yds. The remaining 15 cu. yds, were excavated from the short tunnels, where an additional man was not required for removing the material from the tunnel since the tunnellers were able to throw the material back far enough for the shaft men to reach.

The open cut on this section consisted of a 295 ft. stretch which includes the shafts. This entire length had to be sheeted with skeleton sheeting. The number of ft. B. M. used was 5,920. The average depth of this 295 ft. stretch was 17 ft., minimum 6 ft., maximum 23 ft. The average width excavated was 30 ins. The weather was favorable. The trench bottom consisted of a mixture of clay and sand and water, which made pipe laying as well as excavating very difficult. The back filling was done mostly by hand. The material was so wet, sticky, and heavy that a scraper and team could not move the material satisfactorily. The pipe layer excavated a bench 12 ins. deep and 18 ins. wide, or 16 cu. yds. of material and threw it back on the laid pipe.

The cost of the open cut portion follows:

Item	Cost per ft., cts.	Cost per cu. yd., cts.
Excavation by pipe layer, 16 cu. yds..............	1.3	24.
Excavation, 437 cu. yds............................	99.5	63.1
Sheeting...	10.4	....
Laying 12-in. pipe.................................	3.5	....
Backfill...	15.6	9.9
Totals...	130.3	97.0

The labor of sheeting cost $5.20 per 1,000 ft. B. M.

In comparing the cost of tunnelling with the cost of open cut, one must remember that excavating shafts is more difficult and therefore more costly than straight open work, since the ends of a shaft must be cut square; and the "step-up" method of excavation cannot be used to advantage. Still the costs show that tunnelling for this particular sewer cost less per foot than the open cut. This is evidently true for any sewer excavation below a certain depth.

Section 4.—Section 4 consisted of a 403-ft. stretch of 10 in. pipe. The average cut was 8.5 ft., minimum 6 ft., maximum 9.5 ft. The average width of trench was 24 ins. The bottom was very wet, but no sheeting was required. The pipe layer excavated a bench 15 ins. × 18 ins. The trench was back filled by hand. The unit costs follow:

Item	Cost per ft., cts.	Cost per cu. yd., cts.
Excavation by pipe layer, 28 cu. yds.	0.9	12.4
Excavation, 216 cu. yds.	13.6	25.4
Laying 10-in. pipe	2.2	.....
Backfill	4.5	8.4
Totals	21.2	46.2

Section 5.—On Section 5 a 550 ft. length of 8 in. pipe was laid. The average depth was 11.5 ft., minimum 9 ft., maximum 16 ft. Width of trench 24 ins. The trench bottom was wet for 200 ft. Two caveins resulted, due to insufficient bracing. Skeleton sheeting was provided every 5 ft. The pipe layer excavated a bench 12 ins. deep by 15 ins. wide and averaged 20 ft. of laid pipe per hour. The trench was back filled by hand. The costs follow:

Item	Cost per ft., cts.	Cost per cu. yd. cts.
Excavation by pipe layer, 26 cu. yds.	0.7	16.5
Excavation, 428 cu. yds.	23.4	30.1
Laying 8-in. pipe	2.0	.....
Sheeting	2.3	.....
Backfill	7.9	10.2
Totals	36.3	56.8

2,560 ft. B. M. of sheeting cost $4.97 per 1,000 ft. for labor in placing and pulling.

Section 6.—Section 6 consisted of a 563 ft. length of 6 in. pipe. The average cut was 11 ft., minimum 9 ft., maximum 12 ft. The average width of trench was 22 ins. The pipe layer averaged 30 ft. of laid pipe per hour, and excavated a 12 in. × 12 in. bench. The trench was back filled by hand. The costs follow:

Item	Cost per ft., cts.	Cost per cu. yd., cts.
Excavation by pipe layer, 22 yds.	0.4	10.5
Excavation, 380 cu. yds.	15.2	22.2
Laying 6-in. pipe	1.1	.....
Backfill	6.5	9.7
Totals	23.2	42.4

Section 7.—On Section 7 a 550 ft. length of 8 in. pipe was laid. The average cut was 10½ ft., minimum 9 ft., maximum 11 ft. The average width of trench was 24 ins. The material was a hard and dry clay, which had to be picked for the first 4 ft. The pipe layer averaged 28 ft. of laid pipe per hour and removed a 6 in. × 12 in. bench. The trench was back filled by hand. No sheeting was required. The costs follow:

Item	Cost per ft., cts.	Cost per cu. yd., cts.
Excavation by pipe layer, 20 cu. yds	0.3	16.5
Excavation, 407 cu. yds	22.2	30.0
Laying 8-in. pipe	1.4	.....
Backfill	6.0	8.1
Totals	29.9	54.6

The material which had to be picked cost approximately 35 cts. per cu yd.

Section 8.—Section 8 is 559 ft. stretch of 6 in. pipe. The average cut was 10 ft., minimum 9 ft., maximum 10½ ft. The average width of trench was 22 ins. The pipe layer averaged 36 ft. of laid pipe per hour, and removed a 12 in. × 12 in. bench. The trench was back filled by hand. The costs follow:

Item	Cost per ft., cts.	Cost per cu. yd., cts.
Excavation by pipe layer, 20 cu. yds	0.4	11.5
Excavation, 340 cu. yds	14.3	23.5
Laying 6-in. pipe	1.0	.....
Backfill	6.4	10.5
Totals	22.1	55.5

A 6 in. house connection 56 ft. long was laid at the following costs:

Item	Cost per ft., cts.
Excavation	12.9
Laying pipe	2.0
Backfill	6.4
Total	21.3

The average cut was 8 ft. The average width of trench was 24 ins., the material was yellow clay.

The general expense for all work on this contract, which includes foremanship, water boy and incidentals, was 3 cts. per ft. of pipe. This cost is not included in the foregoing unit costs.

Contract 2, 1912.—Labor was very scarce and wages were high on this job. Laborers were paid 25 cts. per hour, while the pipe layer was paid 27½ cts. per hour. The foreman received 45 cts. per hour.

Section A.—On Section A a 272 ft. length of 10 in. line was laid. The average cut was 9½ ft., minimum 7 ft., maximum 10 ft. The average width of trench was 24 ins. For a stretch of 50 ft. the bottom material was all "muck" and necessitated the use of buckets for its removal. Considerable rain fell before the completion of this section, resulting in two cave-ins. The pipe layer excavated a trench 12 ins. deep and 15 ins. wide. The material encountered was black loam and a mixture of clay and sand. The unit costs follow:

Item	Cost per ft., cts.	Cost per cu. yd., cts.
Excavation by pipe layer, 13 cu. yds	1.6	33.0
Excavation, 170 cu. yds	23.9	38.2
Laying 10-in. pipe	2.8	......
Backfill	6.7	10.7
Water boy	0.8	......
Foreman	4.1	......
Totals	39.9	81.9

Section B.—On Section B a 420 ft. stretch of 8 in. pipe was laid. The average width of trench was 22 ins. The average cut was 9½ ft., minimum 9 ft., maximum 10 ft. The material was so hard that picks had to be used. The pipe layer excavated a 12 in. × 12 in. trench at the bottom. Most of the material was solid clay, making spading difficult. About 250 ft. had to be picked to a depth of 4 ft. The costs follow:

Item.	Cost per ft. cts.	Cost per cu. yd., cts.
Excavation by pipe layer, 15 cu. yds.	1.4	36.2
Excavation, 240 cu. yds.	25.0	43.7
Laying 8-in. pipe	3.2	......
Back fill	7.3	12.8
Foreman	4.0	......
Totals	40.9	92.7

Section C.—Section C consisted of a 292 ft. length of 6 in. pipe. The average cut was 9½ ft., minimum 9 ft., maximum 10 ft. The average width of trench was 20 ins. The weather was very wet. The pipe layer removed a 10 in. × 12 in. bench. The material was sand and clay and was good spading. The costs follow:

Item.	Cost per ft. cts.	Cost per cu. yd., cts.
Excavation by pipe layer, 20 cu. yds.	0.8	11.7
Excavation, 150 cu. yds.	15.4	30.0
Laying 6-in. pipe	1.7	......
Back fill	5.5	10.7
Foreman	4.0	......
Totals	27.4	52.4

Contract 3, 1912.—The rate of wages on Contract 2 was the same as on Contract 1.

Section A.—On Section A a 374 ft. length of 12 in. pipe was laid. The average cut was 9.7 ft., minimum 8½ ft., maximum 14 ft. The average width of trench was 26 ins. The material encountered was a mixture of sand and clay and was good spading. No bracing was required. The weather was ideal. In back filing the back-fill was tamped in layers of 10 ins., one tamper to every two shovelers. The pipe layer excavated a trench 8 ins. deep by 18 ins. wide. The costs follow:

Item	Cost per ft. cts.	Cost per cu. yd., cts.
Excavation by pipe layer, 14 cu. yds.	0.5	13.3
Excavation, 270 cu. yds.	25.4	35.2
Pipe laying, 12-in.	2.3	.....
Back fill	10.8	14.9
Foreman	2.4	.....
Totals	41.4	63.4

Section B.—Section B is 265 ft. long. A 10 in. pipe line was laid. The average width of trench was 26 ins. The average depth was 9½ ft., minimum 8 ft., maximum 11½ ft. No bracing was required. A considerable number of small boulders made excavation difficult. The material traversed was made land and clay. The weather was ideal. The trench back filling was tamped by hand as in Section A. The pipe layer excavated a trench 12 ins. deep by 15 ins. wide. The costs follow:

Item	Cost per ft., cts.	Cost per cu. yd., cts.
Excavation by pipe layer, 12 cu. yds.	0.9	20.0
Excavation, 180 cu. yds.	30.1	44.3
Laying pipe, 10-in.	3.0	.....
Back fill	11.1	16.3
Foreman	4.0	.....
Totals	49.1	80.6

Section C.—Section C is a 10 in. line 330 ft. long. The average width of trench was 24 ins. The average depth was 9½ ft., minimum 8 ft. 6 ins., maximum 11 ft. 3 ins. The weather was ideal. The material was mostly clay with some loam. The back filling was not tamped. The pipe layer excavated a 6 in. × 15 in. trench. The costs follow:

Item	Cost per ft., cts.	Cost per cu. yd., cts.
Excavation by pipe layer	0.3	16.5
Excavation, 175 cu. yds.	22.4	42.2
Pipe laying, 10-in.	2.6	.....
Back fill	3.9	7.3
Foreman	3.2	.....
Totals	32.4	66.0

CONCLUSION

The labor costs of building manholes on Contract 1 show an average cost of 85 cts. per ft. depth, while on Contracts 2 and 3 with higher rate of wages prevailing, the cost averages $1.25 per ft. of depth.

The labor costs of excavating trenches of various depths and widths, supplemented by observation, show that the cost per cubic yard of excavating a trench 22 ins. wide is no greater than is the cost for excavating a trench 24 ins. or 26 ins. wide. From this it appears that a saving can be effected by giving particular attention to the width of the trench to be excavated. Small contractors are, as a rule, prone to choose a constant width for pipe up to 12 ins. in diameter; whereas, a saving would result, in shallow excavations, by following a rule such as: add 14 ins. to the pipe diameter to secure the trench width. In a shallow trench up to about 8 ft. a man can work efficiently if the width is only 20 ins.

The cost of back filling averages 8½ cts. per cu. yd. on contract 1 and 10 cts. per cu. yd. on contracts 2 and 3.

For the purpose of estimating the cost of excavation from trenches up to 10 ft. in depth with labor at 20 cts. per hour, material which requires no picks, and an absence of water may be taken at 25 cts. per cu. yd. When water is encountered the cost may be several times that figure. For the pipe layer 12 cts. per cu. yd. can be used.

The cost per lineal foot for the actual laying of the pipe, which includes the lowering, the bedding of and the joining of the pipe may be arrived at approximately by multiplying the diameter of the pipe in inches by 0.0025 when the pipe layer receives 25 cts. per hour and his helper 20 cts. per hour.

A saving is effected by having the pipe layer carry a cut in addition to laying the pipe. The figures show a reduction of 50 per cent in cost per cu. yd. for this excavation when compared to the cost per cu. yd. of the trench men.

On any sewer construction the most important individuals are the men who lay the pipe and the men on the two benches preceding. Those men set the pace or speed of excavation for the entire gang and should, therefore, be paid accordingly.

The author of this article was foreman on the jobs described, and, also, recorded all the costs given.

Cost of Pipe Sewers and Appurtenances in Water Bearing Sand.—The following data, published in Engineering and Contracting, May 10, 1911, are given by A. P. Melton, who was city Engineer in charge of the work.

During the years 1909–10 three district sewers were laid in Gary, which will be here referred to as Local Sewers Nos. 8, 9 and 10. These sewers were laid, for the most part, in water bearing sand. In some cases water stood in the ground within a foot of the surface. In all cases where water was encountered it was drawn down by pumping. In some cases small hand pumps were sufficient, but in the majority of cases steam power pumps were used.

Suction lines were laid horizontally along the braces and two-way valves were placed in this main every four feet; 1¾-in. well points were driven into the sand with their tops near the water line and their bottoms from 1 ft. to 6 ins. below the grade of the sewer. The points were connected to the suction main at the valves by means of a short piece of flexible hose.

The excavating was done by teams and slip scrapers until the level of the ground water was reached. Below that point, after the water had been pumped out, the excavating was done by hand. The backfilling was done by teams and slip scrapers. The trenches were about 4½ ft. wide and were sheeted in all cases except on about two-thirds of the 12-in. lines in Sewer No. 10, where the cut was small. The cost of backfilling is included in all cases. The labor of sheeting is included unless otherwise stated. The sheeting was all pulled as the backfilling progressed.

European laborers were employed on the common labor and all work was done under labor union conditions.

The standard brick manholes and concrete gutter inlets, are shown by Figs. 1 and 2, respectively.

Local Sewer No. 8

747 ft. of 18-in. Sewer.

	Total	Cost per lin. ft. cts.
Teams and drivers, 49 days at $5.50	$ 269.50	36.08
Foreman, 19 days at $3.00	57.00	7.63
Laborers, 208 days at $2.00	416.00	55.70
Tenders, 30 days at $2.00	60.00	8.03
Pipe layers, 12 days at $2.75	33.00	4.42
Mixers, 14 days at $2.00	28.00	3.75
Sta. engr., 21 days at $3.00	63.00	8.43
Firemen, 21 days at $2.25	47 25	6.33
Pipeline men, 26 days at $2.00	52.00	6.96
Water boy, 6 days at $1.00	6.00	0.80
747 ft. of 18-in. pipe at 37½ cts	280.12	37.47
Hauling pipe at 6 cts. per ft	44.82	6.00
Total	$1,356.69	181.60

Cost of sheeting trench and coal for boiler are not included in the above. This sewer was laid in water bearing sand. Well points were used for pumping. The average depth of cut was 14.5 ft.; maximum cut 18.0 ft.

	Total	Cost per lin. ft., cts.
1,125 ft. of 15-in. Sewer.		
Teams and drivers, 14½ days at $5.50.....	$79.75	7.08
Foreman, 16½ days at $3.00..............	49.50	4.40
Laborers, 235½ days at $2.00.............	471.00	41.85
Tenders, 20 days at $2.00................	40.00	3.55
Pipe layers, 14 days at $2.75............	38.50	3.42
Tenders, 14 days at $2.00................	28.00	2.48
Mixers, 16 days at $2.00.................	32.00	2.84
Sta. engr., 25 days at $3.00.............	75.00	6.67
Firemen, 18 days at $2.25................	40.50	3.60
Pipeline men, 44½ days at $2.00..........	89.00	7.91
1,125 ft. of 15-in. pipe at 29.7 cts.....	334.13	29.70
Hauling pipe at 5 cts. per ft............	56.25	5.00
Totals.................................	$1,333.63	118.50

The cost of sheeting trench and coal for boiler are not included in the above. This sewer was laid in water bearing sand. Well points were used for pumping. The average cut was 11.3 ft. and the maximum cut was 13 ft.

897 ft. of 12-in. Sewer, So. of 13th Ave.

	Total	Cost per lin. ft. cts.
Teams and drivers, 26½ days at $5.50......	$143.00	15.93
Foremen, 14½ days at $3.00...............	43.50	4.85
Laborers, 166½ days at $2.00.............	333.00	37.13
Tenders, 25 days at $2.00................	50.00	5.57
Pipe layers, 9¾ days at $2.75............	26.81	2.99
Mixers, 11¼ days at $2.00................	22.50	2.51
Sta. engr., 21 days at $3.00.............	63.00	7.02
Firemen, 19 days at $2.25................	42.75	4.77
Pipeline men, 29 days at $2.00...........	58.00	6.47
Helpers, 2 days at $2.00.................	4.00	0.45
897 ft. of 12-in. pipe at 22 cts.........	197.34	21.98
Hauling pipe at 2½ cts. per ft...........	22.42	2.50
Totals.................................	$1.006.32	112.17

The cost of sheeting trench and coal for boiler are not included in the above. This sewer was laid in water bearing sand. Well points were used for pumping. The average cut was 13.8 ft., and the maximum cut was 26 ft.

1,023 ft. of 12-in. Sewer, N. of 13th Ave.

	Total	Per ft., cts.
Teams and drivers, 26 days at $5.50........	$143.00	13.97
Foremen, 15½ days at $3.00...............	46.50	4.55
Laborers, 186 days at $2.00..............	372.00	36.35
Tenders, 10 days at $2.00................	20.00	1.95
Pipe layers, 10 days at $2.75............	27.50	2.69
Mixers, 9¼ days at $2.00.................	18.50	1.81
Sta. engr., 14 days at $3.00.............	42.00	4.11
Firemen, 13 days at $2.25................	29.25	2.86
Pipeline men, 43 days at $2.00...........	86.00	8.43
Helpers, 2 days at $2.00.................	4.00	0.39
1,023 ft. of 12-in. pipe at 22 cts.......	225.06	22.00
Hauling pipe at 2½ cts. per ft...........	25.57	2.49
Totals.................................	$1,039.38	101.60

The cost of sheeting trench and coal for boiler are not included in the above. Well points were used for pumping. The average cut was 13.8 ft., and the maximum cut was 19.8 ft.

10-in. catch basin connections. Total length of connections 710 ft.

	Total	Cost per lin. ft., cts.
Teams and drivers, 2 days at $5.50	$11.00	1.54
Foremen, 1½ days at $3.00	4.50	0.63
Laborers, 48 days at $2.00	96.00	13.52
Pipe layers, 6¼ days at $2.75	17.19	2.42
Tenders, 1 day at $2.00	2.00	0.28
Mixers, 5½ days at $2.00	11.00	1.54
710 ft. of 10-in. tile at 16½ cts	117.15	16.47
Hauling tile at 2 cts. per ft	14.20	2.00
Totals	$273.04	38.40

No sheeting was required and no pumping was necessary. The average cuts were as follows:

	Ft.
Average cut for 110 ft	16
Average cut for 110 ft	12.6
Average cut for 140 ft	16.2
Average cut for 220 ft	7.0
Average cut for 130 ft	16.2

11 Brick Manholes. Average depths 11.7 ft.

	Total	Per manhole
Bricklayers, 102 hrs. at $1.25	$127.50	$11.58
Tenders, 37 days at $2.00	74.00	6.73
Mixers, 10¾ days at $2.00	21.50	1.96
Laborers, one day at $2.00	2.00	0.18
Sta. engr., 1 day at $3.00	3.00	0.27
Pipemen, 1 day at $2.00	2.00	0.18
22 M. brick at $7.00	154.00	14.00
11 manhole covers at $5.00	55.00	5.00
Totals	$439.00	$39.90

10 Standard Brick Catch Basins.

	Total	Per basin
Bricklayers, 62 hrs. at $1.25	$77.50	$7.75
Tenders, 18¾ days at $2.00	37.50	3.75
Mixer, 8 days at $2.00	16.00	1.60
Laborers, 1 day at $2.00	2.00	0.20
10 M. brick at $7.00	70.00	7.00
10 C. B. covers at $5.00	50.00	5.00
250 ft. 10-in. pipe at $0.16½	41.25	4.12
10 double Ls and traps at $1.15	12.50	1.25
Totals	$306.75	$30.67

4 Standard Gutter Inlets and Connections.

	Total	Per inlet
Laborers, 10 days at $2.00	$20.00	$5.00
Concrete	10.00	2.50
4 gratings at $2.00	8.00	2.00
100 ft. 8-in. tile at 11 cts	11.00	2.75
4 8-in. L's at 50 cts	2.00	0.50
Total	$51.00	$12.75

2,136 ft. of 6-in. House Connections.

	Total	Per ft., cts.
Pipe layer, 37¾ days at $2.25	$84.93	3.98
2,136 ft. of 6-in. pipe at $0.07½	160.20	7.50
Hauling pipe at $0.01	21.36	1.00
137 12-in. Y's at $0.46	63.02	2.95
78 15-in. Y's at $0.60	46.80	2.19
52 18-in. Y's at $0.75	39.00	1.82
267 6-in. stoppers at $0.01	2.67	0.13
Total	$417.98	19.57

All house connections were tunneled from the connection to the lot line. The sewers are in the center of the 12 ft. alleys.

Local Sewer No. 9

852 ft. of 12-in. Sewer, on Alley No. 4 West, North of 13th Ave.

	Total	Per lin. ft., cts.
Foreman, 15 days at $3.00	$45.00	5.28
Pipe layer, 15½ days at $2.75	42.62	5.00
Mixer, 13 days at $2.00	26.00	3.05
Sta. engr., 28 days at $2.50	70.00	8.22
Firemen, 28 days at $2.25	63.00	7.39
Pipeline men, 42 days at $2.25	94.50	11.08
Laborers, 139½ days at $2.00	279.00	32.72
Tender, 8 days at $2.00	16.00	1.87
852 ft. of 12-in. pipe at 22 cts	187.44	21.95
Hauling pipe at 3 cts. per ft	25.56	3.00
28 tons coal at $4.00	112.00	13.14
Total	$961.12	112.70

This sewer was laid in water bearing sand. Well points were used for pumping; 20 hp. steam boiler and No. 4 Nye Pumps were used. The average cut was 10.9 ft., the maximum was 11.2 ft.

747 ft. of 18-in. Sewer, on Alley No. 4, South of 13th Ave.

	Total	Per lin. ft. cts.
Foreman, 24 days at $3.00	$ 72.00	9.64
Pipe layer, 13½ days at $2.75	37.12	4.97
Mixer, 13½ days at $2.00	27.00	3.61
Sta. engr., 14 days at $2.50	35.00	4.68
Fireman, 21 days at $2.25	47.25	6.32
Teams and drivers, 5 days at $6.00	30.00	4.02
Pipeline men, 41 days at $2.25	92.25	12.34
Bricklayer, 1 day at $10.00	10.00	1.34
Laborers, 143 days at $2.00	286.00	38.28
Sheeting men, 37 days at $2.00	74.00	9.92
Tender, 15½ days at $2.00	31.00	4.15
747 ft. 18-in. pipe at 37½ cts	280.12	37.50
Hauling pipe at 6 cts. per ft	44.82	6.00
14 tons coal at $4.00	56.00	7.49
Total	$1,122.56	150.26

This sewer was laid in water bearing sand. Well points were used for pumping; 20 hp. steam boiler and No. 4 Nye Pumps were used. Average cut, 12.3 ft.; maximum cut 16.1 ft. The labor union rules required the presence of a bricklayer on the job.

750 ft. of 15-in. Sewer, on Alley No. 4 West, South of 15th Ave.

	Total	Per lin. ft., cts.
Foreman, 27 days at $3.00	$81.00	10.80
Pipe layer, 13 days at $2.75	35.75	4.76
Mixer, 11½ days at $2.00	23.00	3.06
Sta. engr., 16½ days at $2.50	41.25	5.50
Fireman, 19 days at $2.25	42.75	5.70
Teams and drivers, 1½ days at $6.00	9.00	1.20
Pipeline men, 31 days at $2.25	69.75	9.30
Laborers, 152 days at $2.00	304.00	40.50
Tender, 14 days at $2.00	28.00	3.73
Steam roller, 1 day at $10.00	10.00	1.33
750 ft. of 15-in. pipe at 29.7 cts. per ft	222.75	29.68
Hauling pipe at 5 cts. per ft	37.50	5.00
Total	$904.75	120.56

This sewer was laid in water bearing sand. Well points were used for pumping. A 20 hp. steam boiler and No. 4 Nye Pumps were used. Average cut, 9.7 ft.; maximum cut 13.2 ft.

693 ft. of 12-in. Sewer, on Alley No. 4 West, South of 17th Ave.

	Total	Cost per lin. ft., cts.
Foreman, 8 days at $3.00	$24.00	3.46
Pipe layer, 13½ days at $2.75	37.12	5.36
Mixers, 12½ days at $2.00	25.00	3.61
Sta. engr., 15½ days at $2.50	38.75	5.59
Fireman, 20 days at $2.25	45.00	6.49
Teams and drivers, 2 days at $6.00	12.00	1.73
Pipeline men, 33 days at $2.25	74.25	10.72
Laborers, 219 days at $2.00	438.00	63.20
Tenders, 14 days at $2.00	28.00	4.04
15½ tons coal at $4.00	62.00	8.95
693 ft. 12-in. pipe at 22 cts	152.46	21.92
Hauling pipe at 3 cts. per ft	20.79	3.00
Total	$957.37	138.07

This sewer was laid in water bearing sand. Well points were used for pumping. A 20 hp. steam boiler and No. 4 Nye Pumps were used. Average cut, 10.9 ft.; maximum cut, 14.5 ft.

220 ft. of 10-in. Pipe Connections for Catch Basins.

	Total	Cost per lin. ft., cts.
Pipe layer, 3 days at $2.75	$8.25	3.75
Laborers, 16 days at $2.00	32.00	14.54
Mixers, 3 days at $2.00	6.00	2.73
220 ft. 10-in. pipe at 16½ cts	36.30	16.50
Hauling pipe at 2 cts. per ft	4.40	2.00
	$86.95	39.52

These connections were all laid in dry sand and pumping was not required. Average cut, 4 ft.; maximum cut, 6 ft.

1,632 ft. of 6-in. House Connections.

	Total	Cost per lin. ft., cts.
Pipe layer, 40 days at $2.25	$90.00	5.52
1,632 ft. 6-in. pipe at 7½ cts. per ft	122.40	7.50
Hauling pipe at 1 ct. per ft	16.32	1.00
204 6-in. stoppers at 7 cts	14.28	0.87
12 10-in. stoppers at 12 cts	1.44	0.08
1 12-in. stopper at 12 cts	.12	0.10
Total	$244.56	14.98

All house connection were tunneled to the lot line from the sewer in the center of the 12 ft. alleys.

9 Standard Brick Manholes. Average Depth 12.106 ft.

	Total	Cost per manhole
Bricklayer, 10 days at $10.00	$100.00	$11.11
Laborers, 33 days at $2.00	66.00	7.33
Mixers, 9 days at $2.00	18.00	2.00
9 manhole covers at $5.00	45.00	5.00
18 M. brick at $7.00	126.00	14.00
81 manhole steps at 20 cts	16.20	1.80
Total	$371.20	$41.24

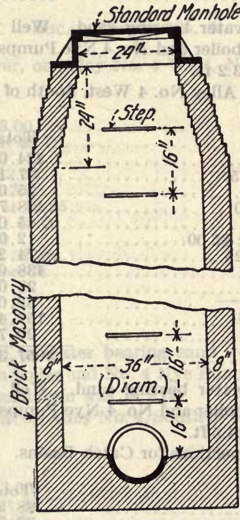


Fig. 1.—Standard brick manhole for Gary, Indiana.

7 Standard Catch Basins and Connections.

	Total	Cost per basin
Bricklayer, 5 days at $10.00	$50.00	$7.13
Laborers, 17 days at $2.00	34.00	4.88
Mixers, 5 days at $2.00	10.00	1.42
7 M. brick at $7.00	49.00	7.00
7 cast iron covers at $5.00	35.00	5.00
7 double L traps at $1.25	8.75	1.25
Total	$186.75	$26.68

Well points and a small hand pump were used. There was about 6 ins. of water to remove.

Local Sewer No. 10

1,046 ft. of 12-in. Sewer in Alley No. 3 West, N. of 13th Ave.

	Total	Cost per lin. ft, cts.
Foreman, 4 days at $3.00	$12.00	1.14
Laborers, 258 days at $2.00	516.00	49.35
Pipeline men, 35 days at $2.25	78.75	7.53
Bricklayer, 5½ days at $10.00	55.00	5.26
Pipe layer, 11 days at $3.00	33.00	3.15
Tender, 11 days at $3.00	33.00	3.15
Firemen, 27 days at $2.00	54.00	5.16
Mixers, 8½ days at $2.00	17.00	1.62
Water boy, 10 days at $0.50	5.00	0.48
1,046 ft. of 12-in. pipe at 22 cts. per ft	230.12	22.00
Hauling pipe at 2½ cts. per ft	26.15	2.49
14 days' rental of boiler and outfit at $10.00	140.00	13.38
14 tons of coal at $4.00	56.00	5.35
Total	$1,256.02	120.06

This sewer was laid in water bearing sand. Well points were used for pumping. Boiler and pumps as before. Average cut, 6.6 ft.; maximum cut, 8.4 ft. The labor union rules required the presence of the bricklayer on Sewer No. 10 wherever shown, to take charge of and assist in the pipe laying.

746 ft. of 18-in. Sewer in Alley No. 3 West, South of 13th Ave.

	Total	Cost per lin. ft., cts.
Teams and drivers, 17 days at $6.50	$110.50	14.82
Foreman, 14 days at $3.00	42.00	5.63
Laborers, 150 days at $2.00	300.00	40.19
Pipeline men, 31½ days at $2.25	70.88	9.52
Bricklayer, 12 days at $10.00	120.00	16.07
Pipe layer, 11 days at $3.00	33.00	4.42
Tender, 11 days at $3.00	33.00	4.42
Firemen, 35½ days at $2.00	71.00	9.52
Mixer, 9½ days at $2.00	19.00	2.55
Water boy, 12 days at $0.50	6.00	0.80
746 ft. of 18-in. pipe at 37½ cts	279.75	37.47
Hauling pipe at 6 cts. per ft	44.76	6.00
Rental of boiler and outfit 18 days at $10.00	180.00	24.13
18 tons of coal at $4.00	72.00	9.66
Total	$1,381.89	185.20

Water in sand, well points, boiler and pumps as before. Average cut, 10.1 ft.; maximum cut, 12.9 ft.

750 ft. of 15-in. Sewer in Alley No. 3 West, South of 15th Ave.

	Total	Cost per lin. ft., cts.
Teams and drivers, 8 days at $6.50	$52.00	6.93
Foreman, 16 days at $3.00	48.00	6.40
Laborers, 162 days at $2.00	324.00	43.20
Pipeline men, 36 days at $2.25	81.00	10.80
Bricklayer, 9½ days at $10.00	95.00	12.67
Pipe layer, 14½ days at $3.00	43.50	5.80
Tender, 13½ days at $3.00	40.50	5.53
Firemen, 13½ days at $2.00	27.00	3.60
Mixer, 11 days at $2.00	22.00	2.93
Water boy, 7 days at $0.50	3.50	0.47
750 ft. of 15-in. pipe at 29.7 cts	222.75	29.68
Hauling pipe at 5 cts	37.50	5.00
Rent of boiler and outfit 13½ days at $10.00	135.00	18.00
13½ tons of coal at $4.00	54.00	7.19
Total	$1,187.75	158.20

Water removed as before. Average cut, 11.5 ft.; maximum cut, 15.1 ft.

719.5 ft. of 12-in. Sewer in Alley No. 3 West, South of 17th Ave.

	Total	Per lin. ft., cts.
Teams and drivers, 37 days at $6.50........	$240.50	33.
Foreman, 24½ days at $3.00................	73.50	10.22
Laborers, 207 days at $2.00................	414.00	57.55
Pipeline men, 27 days at $2.25..............	60.75	8.45
Helpers, 20 days at $2.00..................	40.00	5.55
Bricklayer, 16½ days at $10.00.............	165.00	22.93
Pipe layer, 4 days at $3.00.................	12.00	1.67
Tender, 17½ days at $3.00.................	52.50	7.29
Fireman, 20 days at $2.00..................	40.00	5.56
Mixers, 16½ days at $2.00..................	33.00	4.58
719.5 ft. of 12-in. pipe at 22 cts............	158.29	21.98
Hauling at 2½ cts. per ft...................	17.99	2.50
Rent of boiler and outfit 20 days at $10.00....	200.00	27.80
10 tons of coal at $4.00....................	40.00	5.56
Total..................................	$1,547.53	215.06

Water removed as before. Average cut, 12.8 ft.; maximum cut, 14.5 ft.

18 Standard Brick Manhole, Average Depth 12.106 ft.

	Total	Per manhole
Bricklayer, 14 days at $10.00...............	$140.00	$7.78
Mixer, 14 days at $2.00....................	28.00	1.56
Laborers, 55 days at $2.00.................	110.00	6.11
36 M. brick at $7.00......................	252.00	14.00
18 cast iron covers at $5.00................	90.00	5.00
164 manholes steps at 20 cts...............	32.80	1.82
Total..................................	$652.80	$36.27

3 Standard Brick Catch Basins and Connections.

	Total	Per basin
Bricklayer, 2½ days at $10.00..............	$25.00	$8.33
Foreman, 2 days at $3.00...................	6.00	2.00
Mixers, 2½ days at $2.00..................	5.00	1.67
Laborers, 21 days at $2.00.................	42.00	14.00
3 M. brick at $7.00.......................	21.00	7.00
3 cast iron covers at $5.00.................	15.00	5.00
309 ft. of 8-in. pipe at 11 cts..............	33.99	11.33
3 double L traps at $1.25..................	3.75	1.25
Total..................................	$151.74	$50.58

Well points and small pump used to remove about 6 ins. of water.

Cost of Constructing a Small Submerged Sewer Outfall Into a Stream.—J. C. Schneidwind in Engineering and Contracting, June 14, 1911 gives the cost of constructing the Leland Ave. outfall into the North Shore Channel Chicago as follows:

Briefly the design requires the end of the sewer to be built as close as possible to the water edge where a concrete bulkhead is placed and the sewer carried through it to the face. At a sufficient distance back from the face, an ordinary junction pipe is placed with the connection on the flow line of the sewer. This in turn is joined by means of straight and curved tile pipes to a cast iron water pipe which extends into the water about 2 ft. below the surface. To deflect the sewage into the drain pipes, a brick weir is placed at the joint on the down stream side of the junction, and of sufficient size to care for a quantity equal to two times the dry weather flow plus 10 per cent.

The construction of the Leland Avenue outfall was carried on as follows: after the sewer was built to the site of the bulkhead, the excavation for the latter was completed and filled with concrete to a depth of 6 ins. The junction pipe was then placed in its proper position and held by a block and tackle, while the connection with the cast iron pipe was made. Concrete was

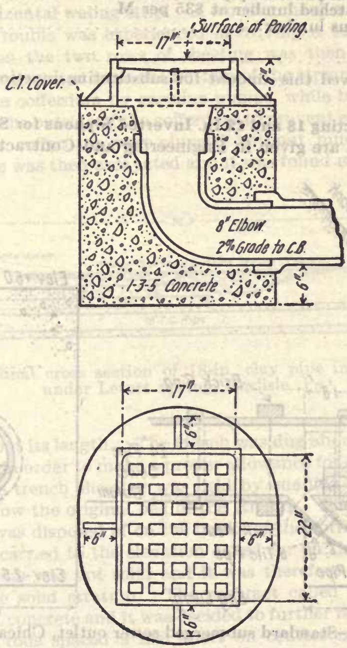


FIG. 2.—Standard concrete gutter inlets, Gary, Indiana.

then placed and securely tamped around the pipes to protect them from disturbance, after which the work was merely a matter of constructing a cradle for the sewer proper and junction pipe. Elevations were taken on the latter to discover a settlement, if any, but none of material importance was observed. The next pipe was then set and in the joint was placed the brick weir. To fit the last pipe flush with the form the exact measurement was taken and a pipe cut to fit. The balance of the work consisted only of filling the form with concrete.

The work was carried on by direction of a foreman, who did the necessary mason work, and a gang of six laborers. The concrete was composed of 1 part Portland cement, 2 parts torpedo sand and 4 parts crushed stone. The temized cost was as follows:

1 foreman 5/8 day at $10	$ 6.25
3 laborers (excavating), 1/2 day at $3.75	5.62
5 laborers (concreting), 1 day at $3.50	17.50
7 cu. yds. crushed stone at $1.65	11.55
4 cu. yds. torpedo sand at $1.50	6.00
11 bbls. Portland cement at $1.50	16.50
5 lin. ft. cast iron pipe at $1.00	5.00
6 lin. ft. 6-in. tile pipe at 10 cts	.60
2 lin ft. 24-in. junction pipe at $1.50	*3.00
100 lin. ft. matched lumber at $35 per M	3.50
Miscellaneous lumber	2.00
Total	$77.52

*Contractor allowed this amount for substituting junction pipe for straight pipe.

Costs of Constructing 18 and 12 In. Inverted Siphons for Sewer Crossings.—The following data are given in Engineering and Contracting, April 29, and

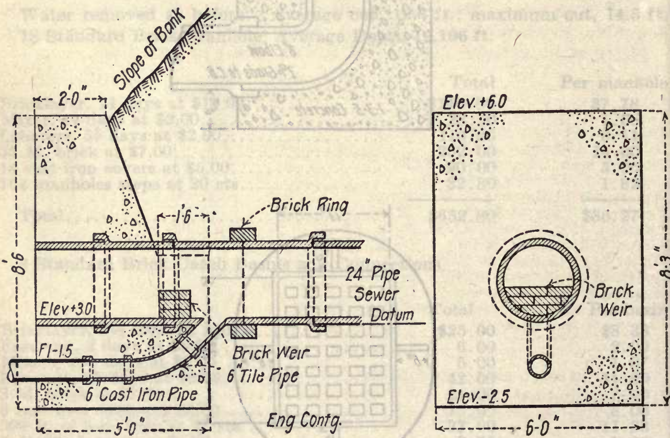


FIG. 3.—Standard submerged sewer outlet, Chicago, Ill.

Aug. 12, 1914, by C. A. Bryan who was resident engineer for the work.

Cost of 18-in. Crossing.—The construction of the outfall sewer serving the northern and the western section of the Borough of Carlisle, Pa., necessitated making a crossing of the Letort Spring, a stream flowing through the eastern section of the borough, in order to connect this sewer with the main outfall sewer.

The width of the spring at the point where the crossing was made was 33 ft. at the water surface. The channel itself was, however, about 15 ft. wide, the remainder of the cross-section being more or less choked with mud and silt, and through this part of the section the velocity of flow was low. The average depth of water in the cross-section was 1.05 ft.

Soundings taken at the crossing showed that the bed of the spring was composed of a stratum of soft mud and clay about 4 ft. deep and underlaying this a stratum of stiff clay through which the soundings were not carried. It was therefore decided to construct this crossing in two sections, and to completely finish and fill in the first section before beginning work on the other.

Work was commenced on the eastern half of the crossing, and a cofferdam built extending from the eastern bank of the spring to a point a little beyond its center. The cofferdam was made about 20 ft. long and 5 ft. wide inside dimensions, and was built by driving two rows of 2-in. plank around the three sides exposed to the water. The plank used were 8 ft. long and were braced by one horizontal waling strip. A wooden maul was used to drive this sheeting and no trouble was experienced in driving it to a sufficient depth. The space between the two rows of sheeting was then filled with a well-puddled stiff clay excavated from the bottom of the stream. Water was then pumped out of the cofferdam by gasoline pumps, while bags filled with sand were piled around the outside of the cofferdam to prevent excessive infiltration. The leaks in this cofferdam were plugged without much difficulty. The trench for the pipe was then excavated and it was found necessary to use tight

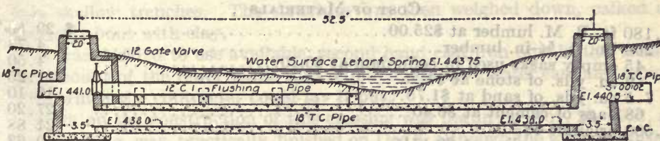


FIG. 4.—Longitudinal cross section of 18-in. clay pipe inverted sewer siphon under Letort Spring, Carlisle, Pa.

sheeting throughout its length. The trench was dug about 3 ft. wide inside to inside of sheeting in order to make a proper allowance for clearance of the bells of the pipe. The trench sheeting was held by one line of horizontal waling strips set just below the original bed of the stream. The material excavated from the trench was disposed of on the banks of the spring. When the excavation had been carried to the elevation called for on the plan, it was found that the foundation was not solid and it was therefore carried about 8 ins. deeper to a more solid stratum. The contract called for surrounding the pipe with 6 ins. of concrete and it was decided to further reinforce this by using 1-in. round iron rods spaced 9 ins. apart on centers underneath the pipe.

Work on the western half of the crossing was started a few days after the completion of the work just described. This work was handled in the same manner. The brick manholes at both ends of the crossing were then built. The water leaking into the cofferdam was handled by two gasoline diaphragm pumps.

In order to provide a method of flushing out this syphon it was decided to connect the manhole on the west bank of the spring with the spring by a 12-in. cast iron pipe resting on the bed of the latter. This pipe was provided with a 12-in. gate valve which was set in a valve chamber built into the manhole.

Work on the construction of this crossing was started on Sept. 12, 1913, and completed on October 1. The itemized cost of this work to the contractor was as follows:

COST OF LABOR

Item	Amount
18 hrs. supervision at $0.80	$ 14.40
188 hrs. foreman at $0.30	56.40
40 hrs. carpenters building cofferdam at $0.35	14.00
40 hrs. carpenter helper on above at $0.17½	7.00
280 hrs. excavation at $0.17½	49.00
80 hrs. stopping leaks at $0.17½	14.00
20 hrs. stopping leaks at $0.20	4.50
153 hrs. driving sheeting at $0.17½	26.78
35 hrs. pipe laying at $0.17½	6.13
11 hrs. pipe laying at $0.27½	3.03
80 hrs. mixing and placing concrete at $0.17½	14.00
5 hrs. mixing and placing concrete at $0.20	1.00
40 hrs. backfilling at $0.17½	7.00
37 hrs. moving pumps at $0.17½	6.48
36 hrs. engineer at $0.40	14.40
44 hrs. mason at $0.30	13.20
44 hrs. mason helper at $0.17½	7.70
25 hrs. cleaning up at $0.17½	4.38
1 hr. cart at $0.27½	0.28
8 hrs. team at $0.45	3.60
3 hrs. hauling 12-in. pipe at $0.45	1.35
Total cost of labor	$268.63

COST OF MATERIALS

1,180 ft. B. M. lumber at $25.00	$ 29.50
200 lin. ft. ⅝-in. lumber	4.73
45 empty sacks used in cofferdam at $0.10	4.50
9 cu. yds. of stone at $1.25	11.25
7.5 cu. yds. of sand at $1.75	13.10
68 bags of cement at $0.40	27.20
2,500 brick at $8.75	21.88
55 gals of gasoline at $0.17½	9.63
52 lin. ft. 18-in. terra cotta pipe at $0.60	31.20
0.448 tons 12-in. c. i. pipe at $24.90	12.28
2 manhole frames and covers at $6.70	13.40
10 manhole steps at $0.35	3.50
1 cut stone at $2.25	2.25
1 12-in. valve at $39.50	39.50
Leading pipe into valve	2.50
Steel reinforcement	3.40
4 diaphragms for pumps at $3.25	13.00
Oil for pumps	1.50
25 days of pumping for gas pumps at $1.00	25.00
Total cost of materials	$269.32
Total cost of labor	268.63
Total cost of crossing	$537.95

The itemized cost of constructing the 12-in. flushing main and valve in the manhole on the western bank of the spring was as follows:

61 hrs. of laborers building cofferdam at $0.17½	$ 10.68
17 hrs. of mason at $0.30	5.10
3 hrs. of teams hauling supplies at $0.27½	0.83
1 12-in. gate valve at $39.50	39.50
450 brick at $8.75 (M)	3.94
1 cut stone	2.25
2 cu. yds. of stone (crushed) at $1.25	2.50
2 cu. yds. of sand at $1.75	3.50
10 bags of cement at $0.40	4.00
300 ft. B. M. lumber at $26.00	7.80
10 gallons of gasoline at $0.15	1.50
Leading pipe into valve	2.50
Total cost of 12-in. flushing device	$ 84.10

Deducting the cost of constructing the 12-in. flushing device from the total cost of the crossing gives $453.85 as the cost of the contractor of constructing this inverted siphon together with the two manholes and other appurtenances.

The length of this crossing was 52.5 lin. ft., or the cost of construction amounted to $8.65 per lineal feet.

Cost of 12-in. Crossing.—The 10-in. branch sewer serving the northeastern section of the borough, joins the main outfall sewer, constructed along the east bank of the Letort Spring, at the corner of North St. and Porter Ave. In order to effect this junction it was also necessary to carry this branch sewer across the spring.

In making this crossing a complete cofferdam was made so that the work could be finished without interruption.

The spring at the point where the crossing was made was about 33 ft. wide and about 1.9 ft. deep in the deepest portion. A timber frame work was first built from 2-in. by 10-in. plank. This frame work, built on the bank, was 32 ft. long and 6.5 ft. wide and 3.5 ft. deep. At the center of the long sides of the frame a flume was built across it. This flume was 5.65 ft. wide and its bottom was 1 ft. 3 ins. below the top of the frame at upper side and with a pitch of 3 ins. in the width of the frame work. When completed the frame work, sheathed on the sides, was placed across the stream, the sides resting in two shallow trenches. The structure was then weighed down, calked and banked about with clay.

It was decided to use available, second hand cast iron pipe in this crossing on account of the fewer joints thus required and the greater ease and rapidity with which the contracter could lay it out.

Work on the construction of this crossing was begun on Nov. 20, 1913, and the crossing was practically finished on Dec 3, although the work of finishing the construction of the various manholes, cleaning up, etc., was not completed until Dec. 19.

The itemized cost of all work at this crossing was as follows:

Cost of labor	Amount
Superintendent, 16 hours at 80 cts	$ 12.80
Foremen, 106 hours at 40 cts	42.40
Foremen, 6 hours at 30 cts	1.80
Excavation, 651 hours at 17½ cts	113 93
Sheeting and bracing, 100 hours at 20 cts	20.00
Engineer, gas pumps, 82 hours at 40 cts	32.80
Mason, 83 hours at 30 cts	24.90
Mason helper, 83 hours at 17½ cts	14.53
Carpenter, 57 hours at 35 cts	19 95
Carpenter helper, 111 hours at 17½ cts	19.43
Sheeting and bracing, 100 hours at 17½ cts	17.50
Laying pipe, 61 hours at 20 cts	12.20
Laying pipe, 50 hours at 17½ cts	8.75
Concreting, 147 hours at 17½ cts	25.73
Backfilling, 80 hours at 17½ cts	14.00
Miscellaneous, 60 hours at 17½ cts	10.50
Cleaning up, 38 hours at 17½ cts	6.65
Hauling material, 4 hours at 45 cts	1.80
Total cost of labor to complete all work at this crossing	$399.67

Cost of materials:	Amount
Bags of cement, 87 at 40 cts	$ 34.80
Cu. yds. of stone, 25 at $1.25	31.25
Cu. yds. of sand, 13 at $1.75	22.75
Lumber for sheeting and piles, 2.0 M. ft. B. M. at $26	52.00
Flanged cast iron pipe, 48 lin. ft. 12-in.	61.44
Gaskets separating pipe, 6 at 5 cts	.30
Gallons of gasoline, 80 at 15 cts	12.00
Manhole frames and covers, 2 at $6.70	13.40
Lamphole frame and cover, 1 at $4.20	4.20
Cast iron pipe, 12 lin. ft. 10-in	6.40
Valve, 1 10-in. at $18	18.00
Brick, 2,000 at $8.75	17.50
Diaphragms for gasoline pumps, 5 at $3.20	16.00
Gasoline torches, 3 at $1.25	3.75
Pumping with gasoline pumps, 25 days at $1.00	25.00
Total cost of materials and plant	$318.79
Total cost of labor	399.67
Total cost of crossing to contractor	718.46

The itemized cost of constructing the 10-in. flushing device to the contractor was as follows:

Labor building cofferdam, etc., 50 hours at 17½ cts	$ 8.75
Mason labor, 30 hours at 30 cts	9.00
Mason helper, 30 hours at 17½ cts	5.25
Gasoline, 10 gals. at 15 cts	1.50
Valve, 1 10-in. at $18.00	18.00
Cast iron pipe, 12 lin. ft. 10-in	6.40
Lamphole frame and cover, 1 at $4.20	4.20
Brick, 300, $8.75 per M	2.64
Stone, 1.5 cu. yds. at $1.25	1.88
Sand, ¾ cu. yds. at $1.75	1.31
Cement, 7 bags at 40 cts	2.80
Lumber, 300 ft. B. M. at $26.00	7.80
Total cost of flushing device	$ 69.53

Deducting the cost of constructing the flushing device from the total cost of the work leaves $648.93 as the cost to the contractor of making this crossing. The length of this crossing from the center of the manhole on the east bank of the spring to the corresponding point on the west bank was 51.5 ft., or the coat of this crossing per linear foot amounted to $12.60.

Cost of Concrete Sewer Pipe at Bellingham, Wash.—H. A. Whitney gives the following in Engineering and Contracting, Feb. 8, 1911.

The city of Bellingham, Wash., is using cement and concrete pipe for storm water sewers. This pipe is made under a guarantee by the manufacturers. While the city does not stipulate any process of manufacture as long as the finished product conforms to the specifications, all the cement pipe used is made by one local concern and gives satisfactory results, as compared to the vitrified clay sewer pipe. All sizes of pipe from 4 ins. to 24 ins. are machine made. The process is as follows:

A flask made in halves is placed around a cast iron core, in a vertical position. The cement is placed in the annular space thus formed in batches, dry mixed, having 8 per cent to 10 per cent water. As the cement is deposited in the mold it is automatically tamped with a wood tamper running at the rate of five blows per second. The core in the meantime is kept stationary while the pipe is revolved around it, thus giving a smooth glazed effect to the inside. The actual cost to the manufacturer is as follows:

4-in. pipe	4 cts. per ft.
6-in pipe	7 cts. per ft.
8-in. pipe	14 cts. per ft.
10-in. pipe	19 cts. per ft.
12-in. pipe	25 cts. per ft.
15-in. pipe	35 cts. per ft.
18-in. pipe	50 cts. per ft.
20-in. pipe	65 cts. per ft.

The above costs are based upon: Cement at $2.30 per bbl.; sand at $1.10 per cu. yd.; gravel at $1.20 per cu. yd.; labor at $2.25 per day, 8 hrs.; foreman at $4 per day, 8 hrs.

The pipe as sold, delivered upon the line of work at the following rates:

4-in. pipe	11 cts.
6-in. pipe	16½ cts.
8-in. pipe	22½ cts.
10-in. pipe	32½ cts.
12-in. pipe	40 cts.
15-in. pipe	60 cts.
18-in. pipe	75 cts.
20-in. pipe	90 cts.

The difference in manufactured and delivered price, represents hauling, breakage and profits.

Cost of 8-Ft. Circular Reinforced-concrete Sewer.—The following labor-cost summary taken from Engineering News, Feb. 18, 1915, is for an 8-ft. circular reinforced-concrete sewer built between electric-car tracks in a street within the commercial district of San Francisco (Howard St. from Second St. to Fourth St., a distance of 1650 ft.):

UNIT COSTS OF 8-FT. SEWER

Excavation	$ 7.86 per lin. ft.	$0.618 per cu. yd.
Lagging	6.450 per lin. ft.	0.106 per sq. ft.
Forms	1.765 per lin. ft.	0.070 per sq. ft.
Steel	1.480 per lin. ft.	0.028 per lb.
Concrete	6.915 per lin. ft.	5.310 per cu. yd.
Brick lining	0.691 per lin. ft.	0.046 per brick
Finishing	0.348 per lin. ft.	0.014 per sq. ft.
Backfill	2.020 per lin. ft.	0.202 per cu. yd.
Miscellaneous	0.567 per lin. ft.	
Total	$28,096 per lin. ft.	

The pavement consisted of basalt blocks on sand. During construction the street was left open to vehicular traffic. Ordinary labor was at the rate of $0.37½ per hr. and superintendence at $0.50 and $0.625 per hr.

Labor Costs on Concrete Sewers.—D. B. Davis, gives the following in Engineering and Contracting, April 14, 1920.

The data show the labor required and the procedure followed in constructing a 48-in. diameter monolithic concrete sewer in Richmond, Ind., on which semi-circular forms were used. The contractor had 100 lin. ft. of the half circle forms, of which he used 50 ft. for invert and 50 ft. for the arch. The concrete was machine mixed; the wheel being about 100 ft. from the mixer to the forms. The men were good workers.

The order of the day's work was as follows:

6:30 a. m. to 9:30 a. m.—Sliding invert forms ahead and setting.
9:30 a. m. to 11:15 a.m.—Pouring concrete invert.
11:15 a. m. to 2:30 p. m. (1 hour for dinner)—Moving and setting arch forms.
2:30 p. m. to 4:00 p. m.—Pouring concrete arch.
4:00 p. m. to 5:30 p. m.—Pouring flow-line strip 2 ft. wide.

The labor required for a day's run of 50 ft. of sewer was:

	Total labor, hours
Invert forms—8 men in gang	24
Pouring invert—12 men in gang	21
Arch forms—6 men in gang	13
Pouring arch—10 men in gang	15
Pouring base strip—10 men in gang	18
Total labor, hours	91

Or 1.82 labor hours per lineal foot.

The organization of concreting gang was:

2 men spreading and tamping concrete about forms.
3 men shoveling gravel in mixer.
4 men wheeling concrete a distance of 100 feet.
1 man running concrete mixer.
2 men setting metal, etc.

The extra men used for pouring concrete were taken from the gangs doing excavation.

The following data shows the labor required to build a 48-in. diameter monolithic sewer, using complete circular forms. The contractor had six sections of form, each section was 6 ft. long. When these were assembled it made a length of 35 ft. The concrete was machine mixed and the wheel for concrete was about 90 ft. The workmen were exceptional and the conditions good.

The labor required for a day's run of 35 ft. of sewer was:

4 men working 2½ hours each removing and resetting six sections of complete circular forms, or total of	10 hours
4 men working 6 hours each and 7 men working 2 hours each pouring concrete for complete circle and for flowline strip, changing runs, etc., or total of	38 hours
Total labor required for 35 ft.	48 hours

Or 1.37 labor hours required for each lineal foot.

The labor required to build 175 ft. of 42-in. monolithic sewer, using the complete circular forms with the same gang as above, was:

	Hours
First day's work, poured flow-line	16
Second day's work, built 35 feet complete sewer	30
Third day's work, moving forms (rain)	10
Fourth day's work, built 35 feet complete sewer	35½
Fifth day's work, built 35 feet complete sewer	30¼
Sixth day's work, built 35 feet complete sewer	31½
Seventh day's work, built 35 feet complete sewer	30
Total labor for 175 ft. of sewer	183¼

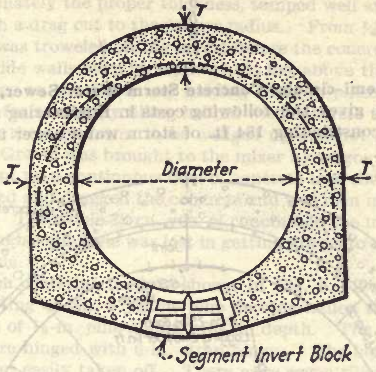
Or 1.05 labor hours required per lin. ft.

In building 245 ft. of 36-in. monolithic sewer using complete circular forms, the gang built 35 ft. of sewer each day.

It required 31½ hours each day for 7 days or total of 220 hours. Or 0.90 labor hours required per lineal foot.

It will be observed that it requires approximately the same number of labor hours on the form labor for the 36-in., the 42-in. and the 48-in. diameter sewers.

Fig. 5 shows the standard type of monolithic concrete sewer construction in Richmond, Ind. and the cost per lineal foot of labor to construct a 36-in., 42-in. and 48-in. sewer.



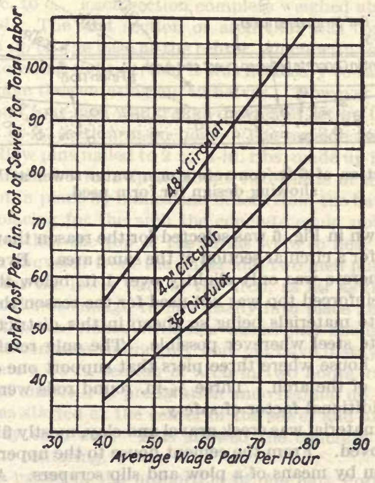


FIG. 5.—**Labor cost of building monolithic concrete sewers of standard section shown.**

In Fig. 5 the costs are plotted on the following basis:

36 in. diam. requires 0.90 hours per lin. ft.
42 in. diam. requires 1.05 hours per lin. ft.
48 in. diam. requires 1.37 hours per lin. ft.

The principal dimensions of the pipe are as follows:

Inside diameter, in.	Thickness "T," ins.	Volume concrete, cu. ft.
36	4	3.5
42	4	5.0
48	5	7.3
54	5	8.5
60	6	11.2
66	7	14.3

Cost of 6-Ft. Semi-circular Concrete Storm Water Sewer, Webb City, Mo. E. W. Robinson gives the following costs in Engineering and Contracting, July 9, 1913, of constructing 184 ft. of storm water sewer through a lumber yard.

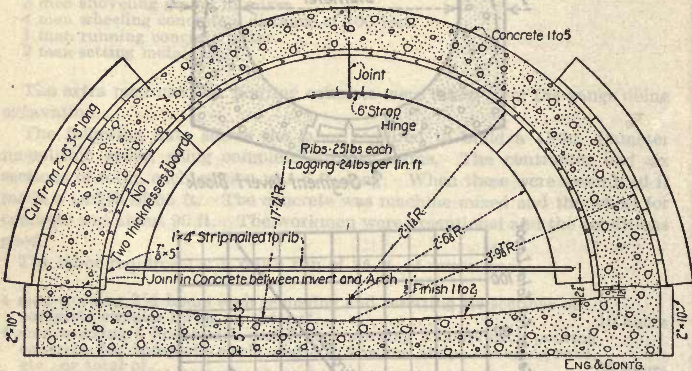


FIG. 6.—Cross section of 6-ft. concrete storm water sewer at Webb City, Mo., showing design for form used.

The section shown in Fig. 6 was selected for the reason that sufficient depth was not available for a circular section of the same area. Even as constructed the top of the concrete was only slightly over 1 ft. below the surface of the ground. A flat reinforced top was not used for the reason that it would have cost more, concrete materials being so cheap in this district that it pays to reduce or eliminate steel wherever possible. The only reinforcing used was under the cement house where three piers that support one end of the house rest on the crown of the arch. Three ½-in. round rods were inserted under each pier as an additional factor of safety.

The excavated material was creek gravel and clay, mostly fill, and was easily loosened and removed. From the cement house to the upper end the excavation was carried on by means of a plow and slip scrapers. All other excavation was taken out with pick and shovel and reshoveled into wagons which were dumped about 100 yds. from the site. No supports were needed under the projecting end of the cement shed for the reason that it was nearly empty all the time and was well supported by numerous other piers. The total cost for excavating 259 cu. yds. was $95.72, or a unit cost of about 37 cts. per cubic yard.

The base or invert was first concreted and allowed to set before the arch was started. Two-by-six pieces were used for the side forms, and were set accurately to line and grade from a line of center stakes. A Coltrin continuous mixer, No. 9, was mounted upon the bank of the trench and the concrete was chuted into the ditch and wheeled some 50 ft. each way. The concrete was placed to approximately the proper thickness, tamped well and shaped to the exact contour with a drag cut to the proper radius. From ¼ to ½ in. of 1 to 2 cement mortar was troweled on the invert before the concrete had taken its initial set. The side walls were brought up 1¾ ins. above the base by laying 2 × 4-in. scantlings on the finish and holding them in place by short pieces nailed to the side forms and by filling behind with concrete to the top. This was done to allow the arch forms to be wedged up and not let concrete flow under the sides. Gravel was brought to the mixer by wagons, and three men at the machine kept up a continuous flow of concrete into the trench. Three men placed, tamped and dragged the concrete and two men mixed and placed the mortar finish. The whole 33 cu. yds. of concrete in the invert was placed in nine hours, though some time was lost in getting gravel to the feeder and in moving the machine.

The form of arch centering used is shown in Fig. 6. Two 16-ft. sections were made, consisting of No. 2 yellow pine flooring nailed to ribs consisting of two thicknesses of ⅞-in. pine about 5 ins. in depth. The ribs were cut at the crown and were hinged with 6-in. strap hinges. The bottoms were held so as to be rigid yet easily taken off. There were seven ribs to each section, spaced 2 ft. 6 ins. c. to c. Each section complete weighed about 750 lbs. and was easily handled. The first section or arch that was concreted was not wedged far enough up off the base at the center, which with the swelling of the wood caused an exceeding tight fit, and it was necessary to take off the hinges at the crown and take the centering out in halves. However no other trouble was experienced, and four men would take down and set up both outside and inside forms for a 15-ft. section in an hour. The outside forms consisted of No. 2 1 × 4-in. yellow pine nailed to 2 × 4-in. ribs, made up in 16-ft. sections. They reached from the bottom up to about two-thirds of the heighth of the arch, and were held in place by stakes and braces from the bank of the trench.

In mixing and placing for the arch the concrete could not be chuted into place for the reason that the top of the forms were so near the level of the ground. One man shoveled from the mixer and two men placed and tamped it. The concrete for the lower part of the arch, as far as the outside forms extended, was mixed wet enough to flow easily into place ahd required little tamping, but the top was mixed with less water, just enough being used to permit tamping the concrete thoroughly and yet have it stay in place. Five men would complete a 15-ft. section of arch in two hours, consisting of one hour actual run and one hour of preparation and cleaning up. The construction of the arch was started at the center of the sewer and alternate sections were built each way each day. This allowed the concrete 48 hours to set before removing the centering.

All concrete was mixed in the proportion of one part Portland cement to five parts of "chats" or "mill tailings." The latter is the by-product of the zinc and lead mines of this district and can be had for the hauling. In this case the nearest suitable pile was at such a distance that 1 cu. yd. an hour was the best the teamsters could do. It consists of crushed white and blue flint ranging in size from 1/16 to ¾ in. in size, with sufficient of the finer material to practically fill the voids in the larger. When mixed wet in the proportion of 1 to 5 a very dense concrete was produced.

The following data give the actual cost, except overhead charges and back filling, reduced to lineal foot of sewer:

	Lineal ft. of sewer	Total lineal ft. of sewer
Excavation:		
259 cu. yds. at 37 cts.	$0.5202	$0.5202
Lumber (two 2 × 6) 2 ft. B. M. at 2¼ cts.	0.0450	
Labor, two men 0.153 hrs. at 22⅜ cts.	0.0338	
		0.0788
Base—concrete in place (1.18 cu. yds. per lin. ft.):		
Foreman, at 30⅝ cts. per hr.	0.0299	
Laborers, 8, at 22⅜ cts. per hr.	0.1304	
Mixing machine, at $1 per hr.	0.0489	
Cement, $1.60 per bbl. on job	0.3152	
Gravel, at 38⅝ cts. per cu. yd. on job	0.0655	
Sand, at 8 cts. per cwt. on job	0.0156	
		0.6055
Arch—forms (two 15-ft. sections):		
Mill work on circles, labor and material	0.1033	
Hinges, nails, wedges, etc.	0.0258	
Lumber, at $2.75 and $2.25 per 100,100 ft. B. M.	0.0680	
Labor, 2 men, at 25 cts. per hr.	0.0245	
		0.2216
Arch—concrete in place (0.237 cu. yds. per lin. ft.):		
Foreman, at 30⅝ cts. per hr.	0.0598	
Laborers, 5, at 22⅜ cts. per hr.	0.2265	
Mixing machine, at $1 per hr.	0.0745	
Gravel, at 38⅝ cts. per cu. yd. on job	0.0923	
Cement at$1.60 per bbl. on job	0.6043	
		1.0574
Total per lin ft. sewer		$2.4835
Total per cu. yd. of concrete		5.956

Nine hours was a day's work and common labor was paid $2 per day for concreting and $1.75 for excavation. The above price for excavation included a foreman at $2.75 per day and teams at $3.50 per day. The mixing machine belonged to a local contractor and was rented for $1 per hour. The work was stopped twice on account of rain, but most of the time the weather was ideal for concreting.

Cost of a Large Concrete Sewer.—E. T. Thurston gives the following in Engineering and Contracting, Sept. 12, 1917.

The work consisted of the complete construction of 450 ft. of 8-ft. 6-in. × 9-ft. standard horseshoe section, reinforced concrete sewer, 100 ft. 8-ft. 6-in. × 9-ft. extra-heavy, horseshoe section, reinforced concrete sewer under a 4-track main line railroad crossing, 908 ft. 7-ft. 6-in. diameter, circular-section, reinforced concrete sewer with vitrified brick invert, and 2,695 ft. 5-ft. 2-in. × 7-ft. 9-in. egg-shape, reinforced concrete sewer with brick invert (including a 90° curve of 21 ft. radius and two 10-ft. taper sections connecting the respective standard sections), representing a total length of 4,173 ft. of sewer. Auxiliary structures comprising 18 standard brick manholes, 26 concrete catch basins and catch-basin connections consisting of 79 ft. of 18-in. vitrified pipe and 1,724 ft. of 12-in. vitrified pipe are not included. The sewer for most of its length runs in a 100-ft. street, its center line being located 22 ft. from the center line of the street, and from 8 to 10 ft. from the center line of a single-track electric street railway, the operation of which was suspended during construction. The required excavation was from 9 ft. to 20 ft. 6 in. deep, averaging 15 ft. 3 in.

For the first 1,000 ft. the excavation averaged 12 ft. in depth through a layer of heavy, black gumbo about 6 ft. thick, overlying black, muddy silt carrying considerable water and in places approximating quicksand. The conditions required close sheeting and heavy timbering and much trouble was had with sloughing sides and seeping water. This changed gradually to stiff yellow clay mixed with black gumbo overlying water-bearing gravel and finally to very stiff yellow clay, difficult for the steam shovel to handle without the assistance of its crowding engine. For two-thirds the length of the trench the ground required constant attention and careful shoring to ensure against cave-ins Ten street intersections were crossed, six of which carried live sewers and water mains and one carried a 4-track, main-line railroad, one a 2-track interurban railroad and one a 3-track electric street railway, a concrete sewer culvert and a network of heavy water mains. The work was commenced in the middle of March, 1914, and was completed with the end of October, 1914.

Organization and Equipment.—The original working equipment consisted of a steam shovel, two concrete mixers supported on trucks, charging barrows, concrete hoppers and chutes, 2-yd. dump wagons, slip scrapers, 2 diaphragm pumps, 1 gas-driven centrifugal pump and miscellaneous small tools such as shovels, picks, mattocks, German hoes, etc. A locomotive crane with equipment of dump buckets was added later.

The working force consisted of a superintendent, a time-keeper, an engineer, 6 foremen (overseeing respectively the finishing of the excavation, the shoring and lagging of the trench, the concrete work, the steel reinforcement, the handling of forms and the extra gang constructing catch-basins and outlying manholes and connections with same, gutters, curbs, etc.), the steam shovel crew, a general mechanic, carpenters and laborers; to which was subsequently added an engineer and a signal-man for the locomotive crane.

The superintendent had active general charge of the work, assisted by the engineer, who in addition attended to overseeing the manufacture and handling of the forms and the bending of steel reinforcement, the forms being designed at the main office, the ribs sawed out to order in a planing mill and the forms made up on the job. Had it not been impossible at the commencement of the work to secure a general superintendent that was competent to read and interpret plans and specifications, the engineer would not been necessary, and during the latter half of the work his services were dispensed with.

The timekeeper kept a carefully segregated record of time, employing a mnemonic system of record and making four round trips per day over the entire work to secure a classified record. He also assisted in keeping track of materials and supplies and made out and forwarded the superintendent's daily report to the head office.

The excavation foreman had charge of a gang of about 30 laborers which followed the steam shovel, shored or lagged the trench, finished the trench to size, line and grade by templet, excavated street crossings and installed the underdrains. The excavated material was handled out of the ditch by stages.

The concrete foreman supervised the work of a gang of 10 men mixing and placing concrete and assisting the foreman carpenter in handling the forms.

The steel foreman had one or two assistants and when not engaged in placing reinforcement the gang was kept fairly busy bending it into the shape required.

The foreman in charge of the extra gang had a dozen or more men, depending on the demands of the more important part of the general work.

General Plan of Operation.—This required that the finishing gang keep close behind the steam shovel, but owing to the fact that the latter was limited in depth of cut to about 16 ft. and as the ground was of an extremely unstable nature and the excavated material very wet and difficult to handle, it was found impossible even approximately to follow this plan. The fact that the street crossings had to be excavated entirely by hand also delayed the progress of the finishing gang. For this reason the numerous delays in the steam-shovel work really retarded the general progress very little. At one time the shovel was 850 ft. ahead of the finishing gang.

After the trench had been finished to exact size and underdrain installed, the invert reinforcement was placed, then the invert forms, after which the first of the two mixers was moved into place and the invert poured. At the expiration of two days the forms were removed and brick invert, if any was required, laid, after which the arch reinforcement was placed; then the arch forms set in place and braced, and the balance of the concrete poured with the second mixer. The sides were poured first and after the concrete had set the wing forms were adjusted and braced and the top poured, the sides and arch generally, but not necessarily, being poured on different days.

After sufficient time, in the opinion of the inspectors, had elapsed, generally about a week, backfilling was proceeded with by means of a team with slip scraper, driver and holder, scraping into the trench that portion of the excavated material that had been dumped alongside for that purpose. The loose fill being thus completed up to within about a foot of the surface of the ground the whole ditch was flooded. Additional fill to bring the trench up to subgrade was brought by team direct from the steam-shovel excavation. The trench being thus filled practically to the level of the pavement it was left until near the end of the job when the entire work of repaving was done as one job.

Excavation.—The main excavation was done with a steam shovel mounted on trussed cross-timbers supported on hardwood rollers running on boards laid on either side of the proposed trench, spanning about 20 ft. on centers, the outfit pulling itself along as required by means of a cable attached to a deadman ahead. The shovel was especially equipped with a 1-cu. yd. dipper on a long dipper stick enabling it as mounted to dig about 16 ft. below grade.

The outfit, assembled as described, just as it had been returned from a similar job some 3 years before was rented for $250 per month on the assurance that the boiler and engine, though dirty and rusty, were in good working order, the boiler having received new tubes just before it was laid up in the yard. Two days overhauling and inspection by a complete crew and the contractor's supervision engineer resulted in a favorable report on the shovel, but, within the rental period, the boiler tubes were rerolled until they had to be reinforced, the boiler required sheathing and a new idler pulley, new bronze gear pinion, new friction strap and shoes, and ultimately an entire renewal of the crowding engine were necessary. Minor troubles, such as chain breakage, were of about daily occurrence and probably doubled the reasonable cost of operation.

Rental was paid for 161 calendar days. Of these, 22 days were required in moving from storage to job and return; 20 days were holidays or rainy days and 15 days were lost on account of jurisdictional disputes between labor unions, leaving 104 days available for actual work. Of these 104 working days 37 were devoted wholly to repairs and renewals, leaving only 67 days or 64 per cent of the working time or 41½ per cent of total time on which actual excavation, together with incidental repairing, was done.

Sufficient material for backfilling was piled on one side of the trench and the balance of the excavated material was dumped direct into wagons moving on the other side. In addition to the shovel crew, three attendants were in general required for miscellaneous work, principally keeping street clean around wagons, watching trench banks for signs of failure, planting and shifting deadmen and attending rollers while moving ahead. Owing to the structural limitations of the machine and the weakness or entire uselessness of the crowding engine, which limited the control and power of the dipper, the cut was not carried as close as desirable to the finish lines on the sides and bottom, and an average of about 6 in. on either side and from 6 in. to 5 ft. in the bottom was left for the finishing gang to remove.

The trench as dug by the shovel varied from 12 ft. to 7 ft. wide and from 7 ft. to 15½ ft. deep, and the material was mostly black gumbo and sandy clay, easy digging except in the last quarter of the work, where stiff, sandy clay, merging into hardpan, was encountered, and with a crippled crowding engine the digging was found difficult.

The shovel crew, working 8 hours per day, 6 days per week, with time-and-half allowance for overtime and double time for working Sundays and holidays, comprised the following:

	Per day and board
1 steam shovel engineer	$6.00
1 cranesman	4.25
1 fireman	3.00
3 laborer attendants	2.50

Coal was $9.00 per ton delivered.

Following the statement of the performance of the steam shovel:

STEAM SHOVEL PERFORMANCE

	Days	Mat'l.	Labor	Total	Per cu. yd.
Investigating outfit	4½	$.....	$ 70	$ 70	$.....
Moving on and off job—					
Moving ¼ mile and loading on car	5	42	318	350	......
Unloading and setting up on job	5½	7	110	117	......
Freight both ways	5	60	......	60	......
Moving off job ¼ mile and loading on car	3½	7	130	137	......
Unloading and returning ¼ mile to owner	3	......	100	100	......
Compensation insurance on labor	.....	40	....	40	......
Totals for moving	22	$ 156	$ 658	$ 814	$0.063
Operation—					
Rental and labor	161	$1,356	$1,494	$2,850	$0.228
Fuel and oil (coal at $9 per ton)	.....	1,063	......	1,063	0.082
Compensation insurance	.....	113	......	113	0.008
Repairs and renewals	37	256	474	728	0.056
Total operation cost	67	$2,788	$1,968	$4,754	$0.366

Note.—Quantity of material handled (13,000 cu. yd.) is given as originally estimated necessary to be done and takes no account of extra material handled because of slides and failure of banks.

The best day's performance of the shovel was 109 lin. ft. of trench or about 345 cu. yd. excavating to a depth of about 12 ft. 6 in. Toward the end of the job, while excavating to its maximum depth of 16 ft., its best day's work was 60 ft. of trench or 220 cu. yd. The shovel averaged 194 cu. yd. for each day in which digging was done and 125 cu. yd. for each available working day. In considering the performance record it should be borne in mind that the necessity for storing a portion of the excavated material along the trench for subsequent backfill enabled the shovel to keep at work regardless of whether the dump wagons were spotted promptly for loading, thus materially reducing what is usually the controlling factor in steam-shovel output.

Hand Excavation and Trimming.—The finishing gang with picks, shovels, German hoes and mattocks, did all the excavation left by the steam shovel, and finished the trench carefully to size, shape, line and grade and laid an underdrain of 4-in. tile covered with gravel which carried the seepage water to sumps constructed at intervals of about 600 ft., which in turn were relieved by an electrically operated, 2-in. centrifugal pump, tended chiefly by the general mechanic. During the first two months the gang comprised about 30 laborers at $2.50 per day (8 hours), a straw boss and interpreter (Italian) at $3.75, and a foreman at $5. The excavated material was shoveled by stages to the surface of the ground and thence into wagons. This portion of the work in particular was in very wet ground, necessitating the construction of dams of sacks of sand and the use of a 2-in. centrifugal pump and a 3-in. diaphragm pump. Latterly, a 5-ton locomotive crane with outfit of dump buckets was secured and mounted on the street car track alongside the trench, greatly facilitating the work. There was less mud to contend with in the portion of the trench served by the crane.

Preceding the finishing gang and immediately behind the steam shovel, a lagging gang of from 2 to 5 men at $2.50 and $2.75 per day, under a foreman at $4 per day, placed necessary shoring and lagging. The bracing, where sheeting, was required, comprised 2 lines of 6 × 8 rangers on either side with 6 × 8 spreaders on 6 to 8-ft. centers and 2-in. × 12-in. sheeting was driven behind these rangers, a total of 29,000 ft. B. M.; 2-in. plank was used for this lagging, very little of which was recovered intact. In addition 16,00 ft. B. M. Oregon pine lumber were used for rangers, spreaders, etc.

The total cost of deepening and finishing trenches to templet after rough work had been done by the steam shovel (except at street crossings which the shovel had to skip and which, therefore, was all hand work) and depositing material either in spoil bank or in wagons (except the section through unimproved street, which was all hand work under superior working conditions and from which all material was spoiled along the trench) was as follows, laborers receiving $2.50 and $2.75 per day and foreman $3 per day:

	Quantity, cu. yd.	Mat'l.	Labor	Total	Per cu. yd.
Hand work, by stages......	1,800	$.....	$4,382	$ 4,382	$2.43
Hand work, crane and bucket..................	3,100	766	3,059	3,825	1.23
Hand work, by stages, through unimproved street..................	1,700	......	1,553	1,553	.92
Tools, etc...............	.....	422	58	480	.....
Total................	6,600	$1,188	$9,052	$10,240	$1.55

The performance of the crane alone is summarized as follows, engineer on crane receiving $6 per day and signalman $5 per day:

	Mat'l.	Labor	Total	Per cu. yd.
Rent, crane (96 days)	$624	....	$ 624	$0.201
Rent, buckets	63	....	63	.020
Freight and cartage	15	....	15	.005
Renewals and repairs	9	$ 37	36	.012
Fuel, oil, etc	55	....	55	.018
Crew (engineer and signalman)	....	854	854	.276
Compensation insurance	69	....	69	.022
Total (3,100 cu. yd. handled.)	$835	$891	$1,726	$0.556

Forms.—The forms for invert, sides and arch of each standard section were constructed of 1½-in. solid and 1¾-in. and 2¾-in. built-up ribs, and 1 × 3 and 1 × 6 tongue and groove sheathing. The ribs were sawn to detail, delivered from mill to job in the knockdown and there, with sheathing, assembled into units. The invert units were made in one piece, but those of the arch in three pieces designed to collapse on removal of separator at bottom and be moved forward in sections. The arch and invert forms for the two 10-ft. taper sections, joining sewers of different shape and size, were built in place on ribs delivered sawn to detail. The forms for a 90° bend of 21-ft. radius were assembled and built in three sections comprising arch and sides intact, and three invert sections, on ribs taken from discarded straight units, and lowered into place bodily.

The forms for the 8-ft. 6-in. × 9-ft. horseshoe-shape and the 7-ft. 6-in. circular sewers were made in units 10 ft. long, but these were found too bulky and the forms for the arch and sides of the 5-ft. 9-in. × 7-ft. 6-in. egg-shape sewer were therefore made in 8-ft. units; 200 ft. of arch and 100 ft. of invert forms were made for the horseshoe-shape sewer, 200 ft. of arch and invert forms for the circular sewer, and 320 ft. arch and 100-ft. invert forms for the egg-shape sewer. The quantity was about right for the last-named, but turned out to be excessive by about 50 per cent for the others, due to erroneous anticipation of working conditions. The mill work on these built-up ribs cost about $23 per M ft. and on the solid ribs $10 per M ft.

The labor cost per foot of sewer built was as follows, carpenter's wages averaging $3.50 per day: Making forms, exclusive of millwork, 10.2 ct.; placing and removing forms 51.6 ct.; making, placing and stripping forms for curve, $8.52 per foot. The forms were greased with crude oil to facilitate stripping and the abutting ribs of adjoining sections were connected by special bolts with loose threads and thumb nuts, thus largely obviating the use of wrenches and accelerating the work of stripping and erecting.

The wing or outer arch forms for the horseshoe and circular sewers were made up in 10-ft. lengths of sheet steel reinforced with flat bars, sufficient to form 50 ft. of sewer. It was considered that these forms, which were so made as to be adjustable, by rebending over a form, to suit the varying extradosal curvature, would serve the entire job, but they proved somewhat awkward to handle and were not used for the egg-shape sewer, wooden forms being substituted.

Reinforcement.—The bars were bent to templet in the material yard close by and brought to the job ready to place. To avoid treading the invert reinforcement into the mud at the bottom of the trench, it was necessary to lay boards in the bottom and to tie the bars to position after the invert forms were in place, after which the boards were removed. The arch reinforcement was placed before the forms were set and rigidly tied and braced to position. The arch bars were required to be bent slightly but sharply 18 in. from each end so that when wired at the angle points to the invert bars they were in exact position. This expedient was noticeably effective in speeding up the work. In all 174,300 lb. of reinforcing steel was used, averaging 56.4 lb. per cubic yard concrete, and cost to handle 68 ct. per 100 lb., with labor averaging \$2.87½ per day.

Concrete.—The specifications provided: "All concrete used in the work shall be composed of Portland cement, sand and broken rock or cement and gravel in the proportion of 1 cu. ft. of cement to 2 cu. ft. of sand and 4 cu. ft. of stone."

The contractor's choice of a concrete plant was governed by the experience of another contractor on a similar job in a nearby locality and by the fact that a complete outfit of two mixers mounted on cross-timbers, with gas-engine power, trucks and rails complete, was ready to hand at a fair rental. The rails were laid on heavy longitudinal timbers on either side of the trench and the mixers mounted directly over the center of the sewer. One mixer was placed ahead to pour invert and the other followed to pour the arch. This plan was adopted to avoid delay involved in moving the heavy machinery back and forth, for the invert progressed at times 200 ft. ahead of the arch.

The outfit was expensive to install (this item amounting to about \$300), difficult and expensive to move (requiring the entire concrete gang, a team of horses and the undivided attention of the superintendent) gave frequent trouble and often flatly refused to perform at critical moments; and the splashing and dripping of the concrete out of the mixer on the workmen beneath rendered the working conditions decidedly unsatisfactory. After three months of trying experience, a new 12-cu. ft. mixer on trucks and equipped with side loader and electric motor was substituted. The new outfit worked alongside the trench and delivered the concrete to the forms by means of open metal chutes. It was specially fitted to be operated, fore and aft, by one man, was easily moved and the labor cost of mixing and placing the concrete was thereby reduced 40 per cent. The progress of the concreting was not chiefly dependent on the capacity of the plant, but on the advancement of other portions of the work, mainly the preparation of the trench.

The forecasting of the work was assisted by the following table (Table I) of roughly approximate unit quantities, from which delivery and placement of material was determined and performance of the gang judged during the progress of the work.

TABLE I.—APPROXIMATE UNIT QUANTITIES

Type.	8′ 6″ × 9′ 0″ —Standard—		8′ 6″ × 9′ 0″ —Heavy—		7′ 6″ cir.		5′ 2″ × 7′ 9″	
Total length, including taper sections	450 ft.		105 ft.		918 ft.		2,700 ft.	
	Invert	Arch	Invert	Arch	Invert	Arch	Invert	Arch
Concrete per ft., cu. yd.	.315	.685	.430	1.000	.185	.630	.148	.500
Rock, per ft., cu. yd.	.27	.58	.37	.85	.16	.53	.13	.43
Sand, per ft., cu. yd.	.14	.29	.19	.43	.08	.27	.07	.22
Cement, per ft. bbl.	.45	.98	.62	1.44	.27	.91	.21	.72
Rock, per 25 ft., cu. yd.	7	15	9	21	4	13	3	11
Sand, per 25 ft., cu. yd.	3	7	5	11	2	7	2	6
Cement, per 25 ft., bbl.	12	25	16	36	7	23	5	18

The cost of the concrete work done by each outfit is shown in the following statement:

Old Mixers:	Material	Labor	Total
Rent	$ 502.00	$........	$ 502.00
Freight and cartage	60.00	157.00	217.00
Repairs and equipment	102.00	36.00	138.00
Gasoline	53.00	....	53.00
Small tools (½ total)	37.00	....	37.00
Plant expense	$ 754.00	$ 193.00	$ 947.00
Concrete (1,405 cu. yd.)	6,930.00	2,241.00	9,171.00
Totals	$7,684.00	$2,434.00	$10,118.00
Totals per cu. yd	5.47	1.73	7.20
New Mixer:			
Depreciation	$ 400.00	....	$ 400.00
Equipment	81.00	$ 33.00	114.00
Small tools (½ total)	38.00	....	38.00
Freight and cartage	13.00	28.00	41.00
Motor rent and installation	57.00	....	57.00
Power	35.00	....	35.00
Plant expense	$ 624.00	$ 61.00	$ 685.00
Concrete (1,686 cu. yd.)	8,317.00	1,598.00	9,915.00
Totals	$8,941.00	$1,659.00	$10,600.00
Totals per cu. yd	5.31	0.98	6.29

The average concrete gang on the original outfit numbered 10 laborers at $2.75 per day, 1 mixerman at $3 and 1 foreman at $5; on the new outfit, 6 laborers at $2.75, 2 men at $3 each and 1 foreman at $5, the latter being displaced ultimately by one of the $3 men raised to $3.50. It may be noted that the labor cost of mixing and placing concrete was 95 ct. under the new arrangement, against $1.59 under the old.

The largest day's concrete work with the old mixers included about 60 ft. of invert and 50 ft. of arch, the invert being 350 ft. in advance of the arch at this stage; 64½ bbls. of cement were used, indicating 43 cu. yd. concrete and the labor was as follows:

1 foreman at $5	$ 5.00
2 laborers at $3	6.00
10 laborers at $2.75	27.50
Total labor	$38.50*

* Or $0.90 per cu. yd.

The largest day's concrete work with the new mixer comprised about 79 ft. of complete arch and 97 ft. of sides only, the work extending over a distance of 176 ft. of sewer; 98¾ bbls. of cement was used, indicating 66 cu. yd. concrete and the labor was as follows:

1 foreman at $5	$ 5.00
2 laborers at $3	$ 6.00
6 laborers at $2.75	$16.50
2 laborers at $2.50	$ 5.00
Total labor	$32.50*

* Or 0.50 per cu. yd.

In each of the foregoing instances, conditions were favorable for rapid work, which consumed an entire day of 8 hours with the men working for a record. Concrete was poured on 62 days by the former plant and 71 days by the latter plant, the average outputs being 22.6 cu. yd. and 23.8 cu. yd., respectively, per day worked.

Cement cost $2.375 per barrel delivered in sacks, with an allowance of 10 ct. each for empty sacks returned in acceptable condition (about 70 per cent of total); sand and gravel $1.40 per cubic yard delivered; water at 7 ct. per cubic yard of concrete—all included in cost of concrete materials as it appears in the statement. The statement covers cost of patching, applying the cement wash specified for the interior and final cleaning out of the sewer in preparation for minute and official inspection.

Brick Lining of Invert.—The invert of the circular and egg-shape sewers was lined with vitrified paving brick, laid flat in mortar composed of 1 part Portland cement to 2 parts quartz sand. This work, necessarily intermittent, had an important influence on the progress of the job, rendering speed, reliability and expertness on the part of the men especially desirable. Slowness or unavailability on call meant direct delay, and an uneven lining would greatly increase the difficulty of making a tight joint between the side arch forms and the invert. The brick mason on this work was paid $8 per day, his hodcarrier $5, and a laborer helper $2.75 for 8 hours, work. The bricks were first piled along either side on the haunch of the invert against the reinforcing bars, and then the surface of the concrete swept and flushed clean and dusted with cement. The hodcarrier mixed the mortar as required and generally assisted the mason, while the laborer kept them supplied with material from above. The labor cost of laying the invert was 4 ct. per square foot, or about $10 per 1,000 brick. Although the wages paid the mason and hodcarrier involved an advance of $1.00 each per day over the standard wages for high-grade workmen, the results are deemed amply to have warranted the extra expense.

Backfilling.—The backfilling was accomplished in part by wagon dump direct from the steam-shovel or other excavation, and in part by shoveling and scraping from the spoil bank left on one side of the trench, using a slip scraper, team and driver at $6.00 per day with generally two men at $2.50 and $2.75 per day to handle the scraper. The trench was filled to a crown as soon as convenient after completion of concrete, puddled by introducing water at the bottom through a pipe attached to the end of a hose and inserted in the ground and allowing to run until water appeared on the surface of the sunken fill, after which it was allowed to stand and partially dry out before adding more fill. Water for this purpose was charged at the rate of 0.7 ct. per lineal foot of trench puddled. It was only after some experimenting and considerable argument that the contractor was permitted to proceed in this manner, for the specifications prescribed tamping in layers; but the method allowed proved very satisfactory. It is estimated that about 8,200 cu. yd. compacted fill was required at a special labor cost of about 26 ct. per cubic yard, which of course ignores the work of the teams that worked directly between the excavation and the backfill. A large portion of this expense, amounting to 10.8 ct. per cubic yard of excavated material, or nearly 10 per cent of the unusually high cost of all the trench work, would not obtain in a well co-ordinated job.

Repaving.—The specifications for repaving contained what the contractor termed a "joker;" for in addition to providing as usual that the pavement where disturbed should be restored to its original condition, it was further provided "That no pavement shall be laid on a foundation of less than 4 ins. of gravel or broken stone below the original pavement." As the pavement was oil macadam of substantially its original thickness of 5 to 6 ins., this meant the somewhat unusual thickness for macadam in this locality of from 9 to 10 ins. Coarse gravel being cheaper than macadam rock, the contractor, with the consent of the engineer, innocently chose the former for the underlying ballast; somewhat to his sorrow, however, for not until it had been plentifully fed with screenings did it form a stable bed for the macadam proper.

The sub-grade was trimmed by hand to show a slight crown and vertical edges and compacted by means of a horse roller, followed by 5 and 10-ton steam and gasoline rollers. The gravel ballast was delivered by rail in gondola cars on a siding about ½ mile average haul from the work. It was unloaded by hand direct into bottom dump wagons, deposited on the subgrade in piles, spread by scrapers, finished with shovels and rolled to a level surface to receive the macadam. The cost of preparing the subgrade was approximately ¾ ct. per square foot, and of spreading and finishing the ballast ½ ct. per square foot.

Hauling of Material by Motor Truck.—The bulk of the macadam rock and screenings was delivered by barges holding from 250 to 350 cu. yd. and equipped with a combination belt-and-bucket conveying system for unloading and discharging into a small wharf bunker of about 15 cu. yd. capacity from which 5-yd. auto trucks were loaded in less than 1 minute. The discharging capacity of the barge machinery was about 1¼ cu. yd. per minute. The hauling of the macadam material was contracted at 30 ct. per cubic yard, but some record was kept of the performance of the trucks which may be of interest.

The first barge-load of 274 cu. yd. was hauled during one day by three good trucks, two 5-yd. and one 4-yd., averaging about three trips per hour. The standard charges for motor-truck service were $25 and $30 per 9 hours work for 4-yd. and 5-yd. trucks, respectively, or say 69 ct. per cubic yard capacity per hour. At this rate, if the trucks had been hired by the day, and had given the employer equally good service, the cost of the hauling would have been 23 ct. per cubic yard.

The second barge-load was, owing to unavailability of adequate motor-truck service during the daytime, hauled between 3:00 p.m. and 2:00 a.m., commencing with one 4-yard truck, to which others were added from time to time until ultimately three 4-yd. and four 5-yd. trucks were in commission. For the three 4-yd. trucks, the total truck hours on the job were 23.33, of which 7.5 were time lost in intervals of 1 hour or more on account of breakdowns or necessity of the drivers, leaving the actual working time, including minor incidental delays, 15.83 hours during which they hauled 132 cu. yd. At the standard service rate this would represent a cost of 33.4 ct. per cubic yard. For the four 5-yd. trucks, the total truck hours were 29.25, of which 20 truck hours represented legitimate work during which they hauled 220 cu. yd., which would have cost at the standard service rate 30¼ ct. per cubic yard.

In addition to the inconvenience of working at night, some of these trucks were not in the best of condition, nor were all the drivers expert. Their variable performance is indicated by the fact that the average times per round trip for the three 4-yd. trucks were 24, 30 and 31 minutes, and for the four 5-yd trucks, 21, 27, 29 and 32 minutes, respectively. The haul of this barge-load averaged about 1½ miles.

Macadamizing.—The macadam rock was for the most part dumped on the ballast, the truck moving ahead while dumping, adjusting the speed so as to effect as nearly as might be the proper distribution of the rock along the trench. Where the rock was left in piles it was spread by means of a fresno scraper and the entire surface of the work in place was finished by laborer with shovels and potato hooks. The screenings were then shoveled over the entire surface sufficient almost to cover all the rock, well sprinkled and rolled successively with a 5-ton and a 10-ton steam or 12-ton gasoline roller. Accompanying the roller, a laborer spread additional screenings to fill the principal surface voids. Road oil was then applied to the specified amount of ¾ gal. per square yard, on which immediately were spread screenings and rolled to a compact surface, rescreening as required to take up all surplus oil.

The cost of spreading the macadam rock and screenings as aforedescribed was 42½ ct. per cubic yard, or nearly 1 ct. per square foot of pavement, with labor at $2.50 and team and driver at $6 per day of eight hours.

The 5-ton roller was rented at $7 per day, the engineer was paid $6 and between $3 and $4 per day was expended for fuel. The 10-ton roller, including engineer and fuel, was rented at $2.50 per hour, and the 12-ton roller at $1.90 per hour, including engineer and fuel. The total cost of the rolling, including subgrade and oiled surface, amounted to about 0.6 ct. per square foot.

The oil was furnished and spread with a standard spraying machine by contract with a local paving contractor at $2 per barrel spread. (Hot oil at retort being quoted at $1.65 per barrel.)

Insurance.—The item of employes' compensation insurance is a considerable one in this class of work, the premium rate being high and many companies refusing to take the risk on deep sewer work. The manual rate, endorsed by the State Insurance Fund, was 14.03 per cent of the payroll, although the company insuring the job cut this rate to 7.72 per cent. Every precaution was taken to avoid accident with the result that only one man was injured sufficiently to require unusual attention or to incapacitate him for work for more than a few hours.

Averaged for 8 months duration of work, the general expense, inclusive of overhead, amounted to $104 for material, and $413 for labor per month, or 2¾ per cent and 12½ per cent of the respective net totals excluding insurance. The fact that this total general expense amounted to 15¼ per cent of the actual cost of material and labor is interesting in view of the engineer's interpretation of the contract provision that extra work should be paid for at "actual cost as estimated by the City Engineer" (making no allowance for the use of tools, plant or general superintendence) "plus 15 per cent for profit" Under the engineer's interpretation the contractor was not permitted to apportion any of the time of the superintendent, timekeeper, or other miscellaneous expense, to extra work. It is a not uncommon notion of engineers and architects that a 15 per cent, or even a 10 per cent, allowance, over and above actual cost of labor and material, is ample to cover general expense and profit on extra work. As a rule extra work imposes on the contractor trouble and expense out of proportion to the average for the job and the fact cannot be too clearly impressed upon the minds of engineers and architects that it is this general annoyance and expense that entitles him to a fair, clear profit over all estimable items of expense entering into the work.

Labor Cost of 8-Ft. Concrete Sewer.—The following data are given in Engineering and Contracting, Feb. 14, 1917.

The reinforced concrete sewer, 96 in. interior diameter was built by contract in an eastern city. The excavation was in sandy loam, not difficult to dig.

There was no pavement removed, for this was a section of the city having few residences.

The earth was loaded into buckets that were lifted by a derrick and dumped alongside or into Koppel cars, such portion going into the cars as was not

TABLE II.—SUMMARY OF COST

	Total costs: Material, tools, etc.	Total costs: Labor	Unit costs: Mat'l, etc.	Unit costs: Labor	Unit costs: Comb'd
Excavation and backfill, 19,600 cu. yd	....	....	....	....	$1.138
By steam shovel, 13,000 cu. yd	$ 2,944	$ 2,694	$ .226	$ .207	......
By teaming, 13,000 cu. yd	....	908	....	....	......
By hand, 6,600 cu. yd	1,188	9,052	.180	1.370	......
By teaming 6,600 cu. yd	....	679	....	....	......
Unwatering, 6,000 cu. yd	214	543	....	....	......
Bracing and lagging, 45,000 M. ft. B. M.	822	1,026	18.27	22.80	......
Backfilling, 82,000 cu. yd	28	1,531	.003	.186	......
Teaming, 82,000 cu. yd	....	581	....	.071	......
Forms, 4,142 lin. ft	....	....	.37	.68	1.05
Making—Std. sec., 650 lin. ft	1,400	422	2.15	0.65	......
Handling—Std. sec., 4,142 lin. ft	19	2,135	....	.52	......
All work on curve, 31 lin. ft	....	264	....	8.52	......
Steel top forms, 50 lin. ft	117	....	2.34	....	......
Reinforcement, 87.15 ton	....	....	....	....	45.70
Bars and bending, 87.15 ton	2,774	438	31.70	5.03	......
Placing, 87.15 ton	31	753	.35	8.62	......
Concrete, 3.091 cu. yd	16,625	4,093	5.40	1.32	6.72
Brick invert lining, 12,690 sq. ft	....	....	.122	.040	.162
Vitrified brick, 50.481 M bricks	1,278	501	25.25	9.92	......
Mortar, 50.481 M bricks	261	....	5.15	....	......
Oil macadam, 390 squares	....	....	5.17	2.15	7.72
Subgrade and ballast, 390 cu. yd	310	478	.79	1.22	......
Macadam and screenings, 568 cu. yd	1,338	363	1.39	.38	......
Rolling, 393 squares	232	....	.59	....	......
Oiling, 390 squares	147	....	.38	....	......
Superintendent, timekeeper, engineer and miscellaneous	830	3,304	104.00	413.00	......
Compensation insurance, 8 months	....	1,731	2¾ %	12½ %	......
Totals	$30,558	$31,496	....	....	......

used in backfilling. The derrick was mounted on the forward end of a platform that spanned the trench and ran on wheels. On the same platform, but at the rear, was another derrick used in handling buckets of concrete.

Water was encountered about 2 ft. above the bottom of the trench, and two Pulsometer pumps were usually kept busy handling this water. The pumps received their steam from the boiler that supplied the hoisting engines.

The following was the organization of the gang engaged in building the sewer:

	Per day
1 superintendent at $6	$ 6.00
1 engineman at $3.50	3.50
1 hoister (one engine) at $2	2.00
2 tagmen at $1.65	3.30
10 men excavating earth at $1.65	16.50
2 men on dump cars at $1.65	3.30
1 bracer (carpenter on bracing) at $3	3.00
2 bracer's helpers at $1.65	3.30
2 men laying bottom planks at $1.65	3.30
and moving pumps, etc., $1.65	3.30
3 men pulling sheeting at $1.75	5.25
16 men mixing and placing concrete at $1.65	26.40
3 men on forms at $1.75	5.25
1 water boy at $1	1.00
Total	$85.40

Coal and oil cost about $5 per working day of 10 hours.

During half a year the actual field cost of the labor on this sewer was $7.86 per lin. ft., distributed as follows:

	Per lin. ft.
Excavation	$1.80
Placing sheeting and bracing	0.58
Placing bottom plank	0.17
Pulling sheeting	0.45
Backfilling	0.33
Making and placing concrete invert	1.17
Making and placing concrete arch	1.54
Laying brick in invert	0.29
Bending and placing reinforcing steel in arch	0.20
Bending and placing reinforcing steel in invert	0.09
Placing and moving forms and centers	0.62
Watchmen, waterboy, etc	0.62
Total	$7.86

The excavated section of the trench was 12½ ft. wide and varied somewhat in depth. When it was 12 ft. deep, the cost was $1,61 per lin. ft., which was 29 ct. per cu. yd. for all labor, excepting the labor of backfilling. When the trench excavation averaged 5.56 cu. yd. per lin. ft., the backfill averaged only 1.7 cu. yd. per lin. ft. and this backfilling was done at a cost of about 20 ct. per cu. yd. of backfill. The backfill was not rammed.

The trench sheeting consisted of 4-in. plank, which was subsequently used as a floor or bottom upon which the concrete invert was laid. This plank floor consisted of two layers of plank, giving a thickness of 8 in.

The sheeting was braced with 6 × 6-in. braces, three of which were used to each 16 ft. length of wale. There were two lines of 4 × 6-in. wales. Hence the trench required about 120 ft. B. M. of sheeting and bracing per lineal foot of trench. Since it cost $0.58 per lin. ft. of trench to place this timber, this is equivalent to $4.80 per 1,000 ft. B. M.

The pulling of the sheeting cost $0.45 per lin. ft. of trench, which is equivalent to about $3.75 per 1,000 ft. B. M. of timber removed. The pulling was done with a light tripod on which was mounted a winch operated by two men. A small wire rope from this winch passed over a pulley at the top of the tripod and was fastened to the sheet pile to be pulled. Two legs of the tripod rested on the ground and the third was supported by a plank resting on the bracing over the center of the trench. There were three men in the gang pulling the sheeting.

The concrete was a 1:2:4 mixture, and about 1¼ bbl. of Portland cement were used per cubic yard. Gravel was used for the aggregate. The invert contained 0.8 cu. yd. of concrete per lin. ft., and the arch contained 1.4 cu. yd. per lin. ft., or a total of 2.2 cu. yd. The mixing was all done by hand. The concrete for the invert was shoveled into dump buckets and lowered to place by the derrick above mentioned. The concrete for the arch was delivered in two wheel dump carts pushed by hand.

Referring to the tabulated labor costs given above, we see that making and placing concrete in the invert cost $1.17 per lin. ft., which is equivalent to $1.46 per cu. yd. of concrete invert. The corresponding cost for the arch was $1.54 per lin. ft., which is equivalent to $1.10 per cu. yd. of arch. The combined cost was $2.71 per lin. ft., which is equivalent to $1.23 per cu. yd. of concrete in the sewer.

The greater cost of placing concrete in the invert was due partly to the presence of the reinforcing rods, which interfere with placing the concrete quickly. The labor of the men on the tag ropes swinging the derrick boom, as well as the labor of the derrick hoister, ran up the cost, particularly as the daily output of concrete was low. A bull wheel on the derrick would have eliminated the men on the tag ropes.

Bending and placing the twisted steel reinforcing rods cost $0.29 per lin. ft. of sewer (invert and arch combined); and, as there were 366 lb. of this reinforcement per lin. ft. of sewer, the labor cost was 0.8 ct. per lb. The cost was frequently as low as 0.6 per lb.

The concrete invert was lined with common bricks set on edge, there being about 40 bricks per lin. ft. of sewer. A brick mason was paid 15 ct. per lin. ft. for laying the bricks, and, in addition to this, the cost of labor mixing and delivering mortar, etc., amounted to 14 ct. per lin. ft., making a total of 29 ct. per lin. ft. of sewer.

The cost of labor for placing and moving forms for the invert averaged 9 ct. per lin. ft., and the corresponding cost for the arch averaged 53 ct., making a total of 62 ct. as above given. Later on these costs were reduced to 5 ct. and 46 ct., respectively, making a total cost of 51 ct. per lin. ft. of sewer. At 51 ct. per lin ft., the labor cost on the forms and centers was only 23 ct. per cu. yd. of concrete.

Cost of Mixing and Placing Concrete by Hand for a Four-foot Circular Sewer.—Engineering and Contracting, July 13, 1910, gives the following:

The work on a 4-ft. circular sewer in Louisville, Ky., was carried on entirely by hand. The sewer was located through a park and near a roadway and materials for the work were placed at convenient points. The invert contained 0.21 cu. yds. of concrete and the arch 0.18 cu. yds. per lineal foot, and each was built separately. A light mixing board was made, and was shifted along by the gang as the work progressed.

The gang consisted of 17 negroes and a foreman whose duties consisted of excavation and concreting for the sewer. The successive steps of their work were alternated with another gang which attended to the forms and reinforcement. The length of concrete laid at one operation was 72 ft. of either arch or invert and the time required to do the work averaged 3¼ hours. The men were divided as follows:

2 men on mortar.
4 men on gravel.
2 men on sand.
4 men on mixing board.
1 man on water and cement.
4 men in trench spading.
1 foreman.

All the men received 20 cts. per hour and the foreman received 35 cts. per hour. The cost of concreting 72 ft. of invert or arch was thus:

17 men at 20 cts. per hour, 3¼ hrs.	$11.05
1 foreman at 35 cts. per hour, 3¼ hrs.	1.14
Cost of laying 72 ft. of invert or arch	$12.19

This gives for 72 ft. of complete sewer a cost of $24.38 which divided by 28.08 cu. yds. gives a cost of 87 cts. per cu. yd. In this work there were about 2.23 lbs. of steel reinforcement per lineal foot of sewer. Two men were employed continually to bend the steel and place it in position in the forms.

Cost of Reinforced Concrete Pipe Sewers at Mishawaka, Ind.—The following data published in Engineering and Contracting, Feb. 15, 1911, are from a paper by Wm. P. Moore, City Engineer, Mishawaka, Ind., before the Indiana Engineering Society, Annual Convention, January, 1911.

In the spring of 1909 bids were received by the city for the construction of the Laurel St. trunk sewer which was 3,480 ft. long and 36 ins. in diameter, the average cut being 10 ft. and the excavation sand and gravel.

The specifications were drawn to include brick, monolithic and reinforced concrete pipe. When the bids were opened it was found the lowest bidder proposed to use the Jackson Reinforced Concrete Pipe Co.'s pipe and was awarded the contract. The cost of construction was about as follows for 3,480 lin. ft. of 36-in. reinforced pipe:

	Cost per ft.
1 foreman, 1,740 hrs. at 40 cts. per hr.	$0.20
2 pipe layers, 3,480 hrs. at 25 cts. per hr.	0.25
1 joint maker, 1,740 hrs. at 20 cts. per hr.	0.10
1 pipe lower, 1,740 hrs. at 20 cts. per hr.	0.10
1 mortar mixer, 1,740 hrs. at 20 cts. per hr.	0.10
2 pipe rollers, 3,480 hrs. at 20 cts. per hr.	0.20
2 sheeters, 3,480 hrs. at 25 cts. per hr.	0.25
1 helper, 1,740 hrs. at 20 cts. per hr.	0.10
6 men excav., 10,440 hrs. at 20 cts. per hr.	0.60
1 team and helper, 1,740 hrs. at 60 cts. per hr.	0.30
1 water boy, 1,740 hrs. at 10 cts. per hr.	0.05
Cement, sand and gravel for joints	0.09
City water for flushing trench	0.02
Amount paid the Jackson Reinforced Pipe Co. for the pipe along line of ditch	1.80
Total cost	$4.16

In the above contract the Reinforced Concrete Pipe Co. made the pipe along the line of the sewer and assumed all risk in regard to the pipe and furnished them to the contractor for $1.80 per lin. ft. measured in the ditch.

In the same year the Common Council also received bids for the Logan Street trunk sewer which has 1,690 lin. ft. of 42-in. and 1,450 lin. ft. of 36-in. pipe. The contract was let with Jackson pipe also, the lowest bid being on their construction.

The average cut was 16 ft. in sand and gravel with a small amount of water bearing gravel in the bottom, but not enough to require a pump. In this contract the contractor built the pipe and furnished all common labor and material and the Jackson Pipe Co. furnished the forms, reinforcement and a competent superintendent to see that the pipe were made properly. Their charge being $1.15 per lin. ft. for the 36-in. pipe and $1.45 per lin. ft. for the 42-in. pipe.

Sand and gravel delivered along the line of the contracts cost 60 cts. per cu. yd., common labor 20 cts. per hour, teams 40 cts. per hour and cement $1.25 per barrel. Calculated on the above basis the cost of construction was about as follows for 1,450 lin. ft. of 36-in. concrete sewer

	Cost per ft.
1 foreman, 725 hrs. at 45 cts. per hr	$0.22
2 pipe layers, 1,450 hrs. at 25 cts. per hr	0.25
1 joint maker, 725 hrs. at 25 cts. per hr	0.12½
1 mortar mixer, 725 hrs. at 20 cts. per hr	0.10
1 pipe lower, 725 hrs. at 20 cts. per hr	0.10
2 men rolling pipe, 1,450 hrs. at 20 cts. per hr	0.20
3 men sheeting, 2,175 hrs. at 25 cts. per hr	0.37½
8 men excavating, 5,800 hrs. at 20 cts. per hr	0.80
1 team and helper, 725 hrs. at 60 cts. per hr	0.30
1 water boy, 725 hrs. at 15 cts. per hr	0.07
Cement, sand and gravel for the joints	0.09
City water for flushing trench	0.02
Total	$2.65

Cost of making this pipe follows:

	Cost per ft.
5 men 411 hrs. mixing concrete, etc., at 18 cts	0.12
280 bbls. of cement at $1.25 per bbl	0.24
217.5 cu. yds. of gravel of 60 cts. per yd	0.09
Royalty for forms, reinforcements, supt. paid to the Jackson Pipe Co.	1.15
Cost of making pipe	$1.60
Grand total	$4.25

The cost of 1,690 lin. ft. of 42-in. concrete pipe sewer was as follows:

	Cost per ft.
1 foreman, 900 hrs. at 45 cts. per hr	$0.24
2 pipe layers, 1,800 hrs. at 25 cts. per hr	0.27
1 man making joints, 900 hrs. at 25 cts. per hr	0.14
1 man lowering pipe, 900 hrs. at 20 cts. per hr	0.11
2 men rolling pipe, 1,800 hrs. at 20 cts. per hr	0.21
1 man mixing mortar, 900 hrs. at 20 cts. per hr	0.11
3 men sheeting, 2,700 hrs. at 25 cts. per hr	0.40
2 men helpers, 1,800 hrs. at 20 cts. per hr	0.21
8 men excavating, 7,200 hrs. at 20 cts. per hr	0.85
1 team and helper exc., 900 hrs. at 60 cts. per hr	0.31
1 team and helper filling, 900 hrs. at 60 cts. per hr	0.31
1 water boy, 900 hrs. at 15 cts. per hr	0.07
Cement, sand and gravel for joints	0.10
City water for flushing	0.02
Total	$3.23

Cost of making this pipe follows:

	Cost per ft.
5 men mixing concrete, etc., 1,400 hrs. at 18 cts.	$0.15
384.5 bbls. of cement at $1.25 per bbl.	0.28
313 cu. yds. of gravel at 60 cts. per cu. yd	0.11
Royalty, forms and superintendent	1.45
Total cost of making pipe	$1.99
Grand total for 1,690 ft. of 42-in. pipe	5.34

In regard to the use of the above information I wish to advise that data is only approximately correct, as we were in no position to obtain the exact cost. The total number of men employed and the number of hours worked are correct, but necessarily in large contracts men are shifted and it was therefore necessary to take the average number of men working in the different positions.

Cost of Tile and of Concrete Sewer.—Work was started in December, 1916, on the construction of the Rideau River interceptor, a 17,900-ft. sewer that will drain a portion of south and east Ottawa. The first section was constructed of segment tile, 60-in. in diameter; the next section is of 54-in. pipe, part segment and part concrete. A third section was built of 48-in. concrete pipe. The following cost data on the work, abstracted from an article by L. McLaren Hunter, City Engineer's Department, Ottawa, in The Canadian Engineer, are published in Engineering and Contracting, Feb. 12, 1919.

The larger equipment used during construction included one 45-HP. boiler, one 40-HP. boiler, one derrick and traveler, three syphons, one 4-in. submerged pump (electric) and one 4-in. suction pump (electric).

The costs of various materials used were as follows:

1917—54-in. concrete pipe, per ft.	$4.34
48-in. concrete pipe, per ft.	3.44
1918—48-in. concrete pipe, per ft.	4.30
30-in. concrete pipe, per ft.	2.35
1917—60-in. Natco tile, per ft.	5.65
1916—Cement, per bag	.43
1917—Cement, per bag	.52
1918—Cement, per bag	.73

On the 60-in. Natco tile section, in 18 ft. of excavation, the costs were as follows:

	Per lin. ft.
Excavation and backfilling	$ 8.240
Pipe laying	.375
Natco tile, including underdrain	7.427
Pumping	.766
Shoring	.652
Grading, plant, sundries	1.744
Total cost per lin. ft.	$19.204
Tunnel section (excavation), per ft.	19.37
Manholes (concrete), each	61.46

The cost of 48-in. concrete pipe section, in 4 ft. 6 in. of excavation, in 1918 was as follows:

	Per lin. ft.
Labor:	
Excavation	$1.37
Shoring	.68
Pumping	.20
Backfill	.60
Culvert drains	.16
Rolling pipe	.29
Running hoist	.33
Derrick and track	.44
Grouting	.12
Pipe laying	.34
Sundries (including Saturday afternoon holidays)	.58
Total	$5.11
Material:	
Pipe (including hauling)	$3.60
Coal	.24
Cement	.11
Sundries	.11
Total	$4.06

The above costs on the 48-in. section were taken on 400 lin. ft. of work which was done in August, 1918. Laborers were paid 35 ct. per hour. On the Natco tile section, laborers were paid 27½ ct. per. hour. The work was done by day labor.

Miscellaneous Costs of Concrete Sewer Construction, Louisville, Ky.—Engineering and Contracting, June 22, 1910, gives the following:

Lining a Concrete Sewer With Brick.—This sewer was of concrete, horseshoe section and about 4 ft. in diameter. The brick lining of the invert and side walls contained 8.3 sq. yds. in 65 ft. of its length. The brick were laid on edge and 8½ bbls. of cement were used in the mortar:

6 bricklayers at 62½c. per hr., 3½ hrs.	$13.12½
6 helpers at 20c. per hr., 3½ hrs.	4.20
Cost of laying 8.3 sq. yds	$17.32½
Cost of laying 1 sq. yd. brick lining	$2.087

Potter Machine on Trench 15 ft. Wide 21 ft. deep:

7 men excavating (sand) at $1.75 per day	$12.25
1 engineer at $3.50 per day	3.50
1 fireman at $3.50 per day	3.50
Rental of machine $200 per mo., at $8.00 per day	8.00
Av. output per day 150 cu. yds	$27.25
Cost per cu. yd. 18c.	

Mixing and Placing Concrete by Hand.—Material had to be hauled 300 ft. in wheel-barrows, and was mixed by hand on platforms over the trench. It was poured through chutes to place. The average wages of these men were 22½ cts. per hour. The concrete men are paid more than the ordinary laborers who receive 17½ cts. per hour:

6 men turning	$10.80
2 men mixing mortar	3.60
5 men wheeling	9.00
1 man on water and cement	1.80
2 men handling chutes	3.60
4 men spading	7.20
20 men placing 30 cu. yds. at	$36.00

This gives a cost of \$1.20 per cu. yd. for labor of placing concrete.

Knocking Down the Blaw arch forms, wooden jacket and invert forms for this sewer, moving them ahead and setting them up required 8 hours for 3 men. One man acted as foreman with two helpers. It required 4 hours to set the invert forms, 2 hours to set the jackets for the walls, and 2 hours to set the Blaw arch forms. This is for a 5 ft. sewer.

Placing the reinforcing steel required the time of the above mentioned squad of 3 men. They set the steel for the invert and sidewalls in 5 hours and for the arch in 1½ hours. The foreman was paid 25 cts. an hour and the helpers 17½ cts. There were 53 lbs. of reinforcing steel per running foot. Striking and settling Blaw forms for 60 lin. ft. of horseshoe shaped sewer, 5 foot section:

1 foreman, 8 hrs. at 25c	\$2.00
2 helpers, 8 hrs. at \$17½	2.80
Total	\$4.80

Striking and settling 60 ft. of forms, cost at ½ cu. yd. per lin. ft., per cu. yd., \$0.16.

Placing reinforcement for 60 lin. ft. of sewer:

1 foreman, 7½ hrs. at 25c	\$1.875
2 helpers 7½ hrs. at 17½c	1.3125
Total	\$3.18¾

Placing reinforcement for 60 ft. of sewer at ½ yd. per lin. ft., cost \$0.106 per cu. yd., and at 53 lbs. per lin. ft., \$0.002 per lb.

A summary of the cost of labor per cubic yard in constructing 60 lin. ft. of 5-ft. sewer was:

Cost per cu. yd. mixing and placing concrete	\$1.20
Cost per cu. yd. striking and erecting blank forms	.16
Cost per cu. yd. placing reinforcement	.106
Total cost of labor per cu. yd	\$1.466

Bricklaying Costs for 5 to 10-Ft. Brick Sewers at St. Louis, Mo.—C. L. French gives the following data in Engineering News, Nov. 12, 1914.

The contract for the third section of the Glaise Creek Joint Sewer, consisted of 7,370 ft. of brick sewer, varying from 5 to 10 ft. in diameter and from 13 to 18 in. in thickness. The total amount of brickwork was 10,264 cu. yd., consisting of 9,600 cu. yd. common and 664 cu. yd. of vitrified brick masonry (to line the invert for the dry-weather flow).

It was found that by planning the work so that a certain number of bricklayers could be constantly employed, the best men could be kept. The importance of this feature is nearly always underestimated by contractors. The difference between the work done by a good man and an average man is at least 10 per cent, and where full time can be made the very best men are obtainable.

The next step was to get the maximum of work from the bricklayers. This meant not harder work, but eliminating lost motion: The essentials were proper working room, sufficient materials in the right place, and safe working conditions. Solving each of these problems required much experiment. Too many or too few bricklayers in a given space was found to be equally expensive.

Materials in the right quantity, just where needed, make it unnecessary for a \$9-a-day bricklayer to wait for a \$2.50 laborer.

The elimination of useless labor was one of the greatest problems. Mortar was mixed by machinery at a cost of less than 1c. per cu. yd. for power. Great care was taken to have this mortar of just the proper consistency. It was found that, everything else being equal, the day's work could be increased 2 or 3% by *having the mortar exactly right all the time.* The mortar was dumped directly from the machine into barrows and then poured into chutes. Thus the bottom man had only to direct the mortar into the boxes below. Mortar mixers and mortar lowerers were thus eliminated. Materials were stored as close to the ditch as possible and in the same quantity as would be used in that length of sewer.

The job was started Nov. 4, 1913, and finished Aug. 18, 1914.

The cost data are based on the following prices for labor and material delivered:

Bricklayer	\$ 1.12½ per hr.
Labor	0.31 per hr.
Brick, common	8.50 per M
Brick, vitrified	16.50 per M
Cement	1.40 per bbl.
Sand	0.85 per cu. yd.
Electricity	0.10 per kw. hr.

The constants for each cubic yard of brick were:

	Unit cost	Cost Per cu. yd.
430 common brick at	\$ 8.50	\$3.66
338 vitrified brick at	16.50	5.58
0.65 bbl. cement at	1.40	0.91
0.35 cu. yd. mortar at	0.85	0.30
0.10 kw. hr. at	0.10	0.01

The mortar was 1 part cement to 3 parts sand.

This makes the material cost \$4.88 per cu. yd. for common and \$6.80 per cu. yd. for vitrified-brick masonry.

The monthly records were as follows:

	Cubic yards laid			Cost per cu. yd.		
Month	Common	Vitrified	Per day of 8 hr. per bricklayer	Labor	Total, common	Total, vitrified
Nov., 1913	768	53	9.3	\$2.25	\$7.13	\$9.05
Dec., 1913	1,444	99	10.8	2.02	6.90	8.82
Jan., 1914	1,260	87	11.7	1.90	6.78	8.70
Feb., 1914	60	4	12.0	3.00	7.88	9.80
Mar., 1914	416	29	10.5	1.90	6.78	8.70
Apr., 1914	1,132	78	11.8	1.78	6.66	8.58
May, 1914	970	68	11.0	2.24	7.12	9.04
June, 1914	1,019	70	9.9	2.26	7.14	9.06
July, 1914	1,912	133	12.6	1.77	6.65	8.57
Aug., 1914	619	43	8.5	2.65	7.53	9.45
	9,600	664				

Average cu. yd. per bricklayer per day of 8 hr.		\$11.05
Average labor cost per cu. yd.		2.02
Average cost of brickwork per cu. yd.	common	6.90
	vitrified	\$8.82

The high cost of labor in May is due to tunnel work at night, when double time was paid to bricklayers. The high cost for June is due to bad working conditions, where frequent cave-ins caused much delay. The last month's figures are not significant, as the best men had left for other jobs and lots of cleaning up was necessary.

Labor Cost of Concrete and Brick Sewer Construction in Toronto.—Engineering and Contracting, June 12, 1918, publishes the following, from an article in The Contract Record by W. S. Harvey and R. T. G. Jack.

The storm sewer known as "Sparkhall Ave. relief sewer" was constructed to relieve the congestion in the district bounded by Danforth Ave. on the north, Bain Ave. on the south, Pape Ave. on the east, and Broadview Ave. on the west. The sewer has its outlet at the River Don and terminates at Logan Ave., with provision for a future extension to Pape Ave.

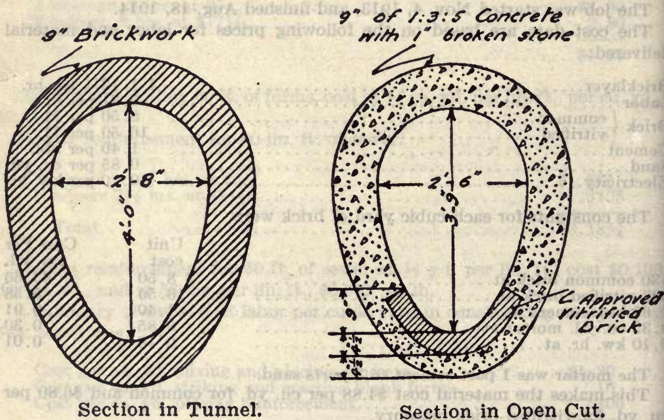


Fig. 7.—Typical cross sections of sewer in tunnel and open cut.

Fig. 7 shows typical cross sections of the sewer in tunnel and open cut. The standard egg-shaped section was adopted as being the most economical under the existing conditions, the ground being good blue clay, which would permit of a minimum width of trench in open cut and minimum dimensions of heading in tunnel, as practically no timbering would be required.

A cross section of the outlet across the Don Flats at Riverdale Park is shown in Fig. 8. A similar section was used under the C. P. R. tracks near the River Don, but heavier reinforcement was required in the roof slab. This section was used on account of the lack of cover available, a minimum of 2 ft. being called for.

Unit Costs.—Under this heading it is the intention to deal with each section of the sewer as constructed and to give a unit cost in hours, using the following key to the distribution of labor:

(A) Excavation; (B) sheeting and timbering; (C) backfilling; (D) handling surplus—excavation; (E) concrete forms; (F) placing concrete, including reinforcing; (G) placing cast iron pipes; (J) pumping; (K) brickwork; (N) mining and sinking shafts; (P) handling supplies; (Q) handling plant; (Z) miscellaneous labor.

Cost of Reinforced Concrete Section, 3 ft. 6 in. × 5 ft.—Work was not commenced until the latter part of the summer of 1916, so that the water in the Don River, which was to be the outlet for the sewer, would be at its lowest elevation. Even with this condition, it gave the contractor a certain amount of trouble. Construction was carried on from the Don to the C. P. R. tracks; here a break was made and resumed on the other side, where, owing to the porous nature of the ground, considerable water was encountered. This portion of Riverdale Park (Don Flats) has been reclaimed by the city with ashes and refuse, and for this reason it was specified that a 2-in. lumber decking be placed in the bottom of the trench before the concrete was poured, and that the trench be tight-sheeted and the sheeting left in place.

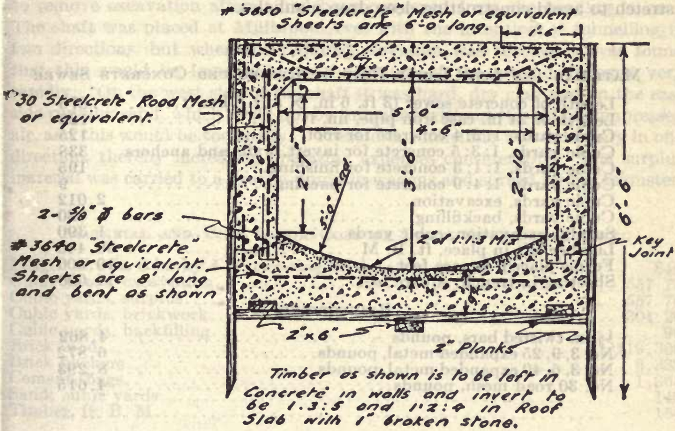


FIG. 8.—Cross section of outlet across Don Flats.

The work was carried on by two distinct gangs of men, each with a separate foreman. One gang attended to excavation, sheeting, handling surplus and backfilling; the other to setting forms, placing reinforcement and pouring concrete.

As the trench was very shallow, no excavating machine was used. The material was cast up on top, where a horse and scraper removed the surplus and spread it out over the park. After the trench had been made ready and the decking and sheeting placed the concreting gang poured the concrete for the invert, leaving it low in elevation so that 3 in. of concrete, mixed in proportion of 1 sand, 1 cement and 3 of very fine stone, could be placed afterwards. When the concrete was properly set forms of the "knock-down" type, made of tongued and grooved sheeting, dressed one side, were placed for the side walls and roof, and all the concrete poured at one running. By this method of working no delays were caused by not having any trench ready, and the concrete gangs were also able to get enough invert concreted, while waiting the required 48 hours for the arch concrete to set, in order to carry on the work successfully.

This procedure was used all the way through this section and good progress was made, notwithstanding the fact that labor and material were scarce and that water gave considerable trouble.

After the concreting of the rough invert side walls and roof had been completed up to the bellmouth (manhole No. 3), the portion under the C. P. R. tracks was completed and the finishing concrete applied. Before doing this, however, a thorough inspection was made, and the invert made perfectly clean, so that a good bond was assured.

While the concrete gang were doing the finishing the excavating gang were placing 24-in. cast iron pipe and building anchors for the support of same, so that the work in this open cut section was practically completed before the severe cold weather set in. The cast iron pipe was used on a short steep stretch to avoid constructing deep drop manholes.

Material and Unit Labor Cost of Reinforced Concrete Sewer

Length of concrete sewer (3 ft. 6 in. × 5 ft.), lin. ft.	876
Length of 24 in. cast iron pipe, lin. ft.	120
Cubic yards, 1:2:4 concrete for roof	125
Cubic yards, 1:3:5 concrete for invert, walls and anchors	338
Cubic yards, 1:1:3 concrete for finishing	195
Cubic yards, 1:4:9 concrete for packing	9
Cubic yards, excavation	2,012
Cubic yards, backfilling	620
Surplus excavation, cubic yards	1,390
Lumber left in place, ft. B. M.	38,440
Forms placed, square feet	10,500
Sheeting in trench, square feet	14,000
Reinforcing	
½ in. twisted bars, pounds	4,862
No. 3, 9, 25 expanded metal, pounds	6,872
No. 3, 6, 40 expanded metal, pounds	8,293
No. 30 road mesh, pounds	4,615

Item	Distribution	Time, hours	Unit cost per sq. ft., hours	Unit cost per cu. yd., hours	Unit cost per lin. ft., hours
Foreman*	A	490	....	.24	.50
Laborers	A	2,933	....	1.45	2.94
Foreman	C	72	....	.12	.07
Laborers	C	723	....	1.20	.75
Foreman	D	81	....	.06	.08
Laborers	D	805	....	.57	.81
Teams	D	320	....	.23	.32
Laborers	E	600	.06	....	.68
Laborers	B	440	.003	....	.48
Foreman	F	700	....	.90	.79
Laborers†	F	1,935	....	2.90	2.21
Laborers	G	268	....	....	2.20
Engineer	J	607	....	....	.68
Laborers	J	135	....	....	.16
Team	Q	42	....	....	.04
Laborers	Q	18	....	....	.02
Team	P	300	....	....	.30
Laborers	P	340	....	....	.34
Foreman	Z	45	....	....	.05
Laborers	Z	750	....	....	.75

* This includes B. † This includes placing reinforcing.

Cost of Two-Ring Brick Sewer in Tunnel (*2 ft.* 8 *in.* × 4 *ft.*)—This section started at manhole No. 4, the tunnel being operated from one portal situated on the east bank and one shaft at Millbrook Ave. Owing to the location of the west portal, it was decided to dispense with an engine and derrick for handling excavation. Tracks were laid along a terrace on the bank and the material brought from the tunnel in cars and dumped over the side of the bank, where it was spread out to make more terraces, thereby beautifying this section of the park. The material used in construction was brought to the top of the bank, where it was stored, and, as required, was lowered down wooden chutes constructed for this purpose, and conveyed into the heading in cars. By this method of procedure the expense of an engineman, engine, and coal was eliminated. At Millbrook Ave. shaft a derrick was erected to remove excavation after it had been conveyed from the heading in cars. The shaft was placed at Millbrook Ave. with the intention of tunnelling in two directions, but when the required elevation was reached it was found that this would be impossible, as the nature of the ground changed very rapidly. On the west side of the shaft it was hard, dry clay and on the east side running sand, which could not be tunnelled without the aid of compressed air, and this would be too costly. Therefore, tunnelling was done only in one direction, thereby increasing operating expenses considerably. The surplus material was carried to a nearby dump in wagons and spread by the teamster.

Material and Unit Labor Cost of Brick Sewer in Tunnel

Length of 2 ft. 8 in. by 4 ft. two-ring brick sewer, lin. ft.	845
Cubic yards, excavation	557.70
Cubic yards, surplus	557.70
Cubic yards, brickwork	304.20
Cubic yards, backfilling	90
Brick used	119,300
Brick packers	6,338
Cement, bags	1,365
Sand, cubic yards	140
Timber, ft. B. M.	154

Item	Distribution	Time, hours	Unit cost per lin. ft., hours	Unit cost per cu. yd., hours
Foreman	N	456	.54	.82
Engineman	N	509	.60	.91
Miners*	N	1,453	1.72	2.60
Laborers†	N	2,080	2.46	3.73
Foreman	K	496	.58	1.63
Engineman	K	286	.34	.94
Bricklayer	K	738	.89	2.43
Laborers	K	2,030	2.40	6.64
Laborers‡	C	207	.25	2.30
Engineer	J	75	.09	....
Laborers	J	220	.26	....
Engineman	Q	48	.06	....
Laborers	Q	170	.20	....
Teams	Q	32	.04	....
Teams	D	427	.50	.75
Teams	P	235	.28	....
Laborers	P	135	.15	....
Laborers	Z	235	.28	....

* Paid on footage basis. † Includes signalmen and muckers. ‡ Backfillers at shaft and pulling timbers.

Cost of Two-Ring Brick Sewer (*2 ft.* 6 *in.* × 3 *ft.* 9 *in.*) *in Tunnel.*—It was the original intention of the City Engineer that the excavating on this section be done in open cut. The contractor, however, decided to carry it out in tunnel, owing to the frost being in the ground to a depth of 4 ft. When the work on the 2-ft. 8-in. × 4-ft. section was completed, the derrick and engine were moved to a point midway on the 2-ft. 6-in. × 3-ft. 9-in. section. Very good progress was made in the east heading, and the required distance would have been completed in tunnel had not the existing local sewer been encountered which necessitated the discontinuance of the work by this method and the completing of same in open cut. In the west heading a layer of wet sand was encountered before the work had proceeded very far, making it more economical to open-cut the work than to proceed with tunnelling.

The material through which the sewer ran was not as good for carrying on the work in tunnel as in the previous section and had to be close-sheeted. The work was done in the same manner as the other section (2 ft. 8 in. × 4 ft.), except that the excavated material was conveyed to the dump in cars after it had been brought to the surface in buckets. The dump was on city property and located close to the shaft.

MATERIALS AND UNIT LABOR COST OF 2-FT. 6-IN. × 3-FT. 9-IN. EGG-SHAPED BRICK SEWER

In tunnel

Length of 2 ft. 6 in. × 3 ft. 9 in. two-ring brick sewer, lin. ft.	180
Cubic yards, excavation	61.2
Cubic yards, surplus	61.2
Cubic yards, brickwork	42.0
Brick used	22,394
Brick packers	2,230
Cement, bags	253
Sand, cubic yards	30
Timber, ft. B. M.	350

Item	Distribution	Time hours	Unit cost per cu. yd., hours	Unit cost per lin. ft. hours
Engineman	N	218	3.40	1.21
Miners	N	409	6.68	2.27
Laborers	N	433	7.00	2.40
Engineman	K	100	2.40	.55
Bricklayers	K	225	5.30	1.25
Laborers	K	446	10.60	2.48
Laborers	D	9	....	.05
Laborers	P	45	....	.25
Engineman	Q	9	....	.05
Laborers	Q	68	....	.38
Teams	Q	72	....	.45

Cost of Brick Sewer in Open Cut.—When it was found impossible to proceed any further with the work in tunnel, the balance of the 2-ft. 6-in. × 3-ft. 9-in. section was constructed in open cut. The excavating was done by hand, and the material conveyed to the rear of the work in ½-yd. buckets on a traveling car, where it was dumped on the finished work as back-filling. A wet, sandy blue clay was encountered in places, which retarded progress to some degree, and, as an extra precaution against settlement, a plank decking was laid and the sewer constructed with a square base. As the work was being carried on in cold weather, it was decided to construct the sewer entirely of brick, instead of concrete, as called for in the contract. Mixing concrete in winter is expensive and not always satisfactory. The manholes and diversion chambers were built entirely of concrete, with the exception of the chamber at Logan Ave.

OPEN CUT

Length of 2 ft. 6 in. × 3 ft. 9 in. two-ring brick sewer, lin. ft.	208
Cubic yards, excavation	815
Cubic yards, backfilling	690
Trench timbered, square feet	7,500
Cubic yards, brickwork	70.7
Brick used	33,357
Cement for brickwork, bags	350
Sand for brickwork, cubic yards	36
Cubic yards Class "B" concrete (in manholes)	28.6
Cubic yards surplus	125

Item	Distribution	Time hours	Unit cost per lin. ft. hours	Unit cost per cu. yd. hours
Foreman*	A	260	1.25	.32
Engineman	A	235	1.13	.29
Laborer	A	1,790	8.60	2.20
Carman	A	324	1.56	.40
Laborers	B	265	1.27	....
Labor	C	412	2.00	.60
Labor	D	40	....	.32
Teams	D	75	....	.60
Foreman	F	5	....	.18
Labor†	F	122	....	.42
Bricklayer	K	235	1.13	3.00
Labor	K	644	3.10	9.10
Labor	P	73	.35	....
Teams	P	54	.27	....

* Including B. † Including E.

Concrete Section (2ft. 2 in. × 3 ft. 3 in.) with One Ring of Brickwork in the Invert.—In this section the excavation was carried on in the same manner as in the 2-ft. 6-in. × 3-ft. 9-in. section, but much more rapidly, as the average depth of trench, which was 14 ft., was considerably less and the class of soil through which the sewer ran did not require much timbering. Just as soon as excavation was completed to sub-grade the concrete was placed in the invert and the following day the brick invert was laid. This was done so that the concrete forms, which were made in three sections, could be braced at the bottom. The concrete in the side walls was then run and, if possible, the concrete was placed in the arch on the same day. If this was impossible, a good key was left and the concreting proceeded with from this point the following morning. The mixing was done in a ½-yd. gasoline mixer and placed by means of chutes. The absence of reinforcing simplified pouring of concrete considerably. After the concrete had set sufficiently, the tongued and grooved forms were removed and any necessary finishing was done.

At the end of this section a special diversion chamber was constructed with a leaping weir and a connection for a future extension. This chamber was constructed entirely of brickwork, which was usually found to be cheaper than concrete, as no form work is required, and therefore no waste, and the work could be continued from day to day without any delays.

Material and Unit Labor Cost of Concrete Sewer with Brick Invert

Length of sewer (2 ft. 2 in. × 3 ft. 3 in.), lin. ft.	878
Cubic yards of excavation	2,050
Cubic yards of backfilling	1,610
Trench timbered, lin. ft	1,756
Cubic yards, surplus	440
Cubic yards, Class "B"	265
Brick used	11,240
Brick, cubic yards	27
Cement for brickwork, bags	126
Sand for brickwork, cubic yards	13
Cement for concrete	1,510
Stone for concrete, cubic yards	310
Sand for concrete, cubic yards	186

Item	Distribution	Time hours	Unit cost per cu. yd. hours	Unit cost per lin. ft. hours
Foreman	A	400	.19	.45
Engineman	A	423	.20	.48
Carmen	A	845	.41	.96
Laborers	A	2,465	1.20	2.80
Laborers	B	600	....	.70
Laborers	C	380	.23	.43
Foreman	C	30	.02	.04
Laborers	D	20	.05	.02
Teams	D	190	.44	.22
Laborers	E	512	....	.58
Laborers	F	870	3.30	1.00
Foreman	F	160	.60	.18
Bricklayers	K	135	5.00	....
Laborers	K	300	11.11	....
Engineman	Q	12	....	.02
Laborers	Q	12	....	.44
Teams	Q	150	....	.16
Foreman	Q	70	....	.12
Labor	Z	135	....	.15

Labor Costs on a 3-Ft. Semicircular Storm Sewer.—E. W. Robinson gives the following records of the actual cost of labor, exclusive of excavation and

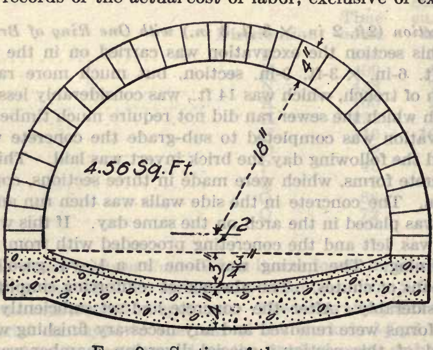


Fig. 9.—Section of the sewer.

back-filling, for constructing 290 ft. of 36-in. semicircular storm sewer, in Engineering Record, Aug. 3, 1912. The arch consisted of one ring of paving brick laid in cement mortar to which had been added a small amount of lime and plastered on the outside to a thickness of about ½ in. The invert was of concrete, 4 in. in thickness, with a ¾-in. surface finish of cement mortar. The centering was made 12 ft. in length, and was wedged up 2 in. from the invert. As soon as this length of sewer was completed, including the plastering, the centering was lowered and pulled ahead and wedged up again, care being taken to avoid disturbing the brick previously laid. Not more than 15 min. was lost each time in shifting the centering.

The concrete for the invert was mixed in the proportion of one part cement to six parts gravel or mine "tailings." A No. 9 Coltrin continuous mixer was used throughout the job and the concrete was shoveled into place from the bank. The mortar for the finish was mixed by hand in the proportion of 1 part of cement to 1½ parts of river sand. The concrete gang consisted of a foreman and seven men.

LABOR CHARGES ON CONCRETE INVERT

1 foreman, 17 hours @ $0.55⅝	$ 9.44
1 finisher, 17 hours @ $0.33⅓	5.67
1 feeding mixer, 17 hours @ $0.22⅜	3.77
1 shoveling from mixer, 17 hours @ $0.22⅜	3.77
1 mixing and carrying mortar, 17 hours @ $0.25	4.25
1 striking-off and tamping concrete, 17 hours @ $0.25	4.25
2 setting forms and trimming bottom, 30 hours @ $0.22⅜	6.67
Total for 290 lineal feet	$37.82
Per cubic yard of concrete	2.35
Per lineal foot of sewer	0.13

The brick-laying gang consisted of two masons and two helpers, who mixed and carried the mortar and carried the brick from piles about 50 ft. from the line of the work. It will be noted that the cost of laying the brick was rather high, which was due to the fact that neither mason was an adept in this class of work, both having done only the roughest kind of work before.

LABOR CHARGES ON BRICK ARCH

2 brick masons, 74 hours @ $0.44⅝	$31.78
2 helpers, 74 hours @ $0.22⅜	16.44
Total for 290 lineal feet	$48.22
Per 1000 brick	$ 4.00
Per lineal foot of sewer	0.166

Costs of Brick and Concrete Sewer Construction.—Engineering and Contracting, June 28, 1911, gives the following data, taken from a paper on Excavation, Foundations and Sewer Work presented before the Western Society of Engineers by Victor Windett.

From an average of 6,000,000 brick laid in two and three ring sewers in and near Chicago it is determined that there are 520 brick required per cubic yard of masonry. This average is taken for brick as counted in cars or wagons, including breakage. As it is customary to lay all bats of one-half brick or greater in the outer rings of the arch, the loss from breakage is trifling. As shipped from the brick yards, sewer brick are uniformly of good quality. Any underburned or soft brick found in the kilns are broken up or sold for building brick. The size of Chicago hard sewer brick will average 8⅜ × 3¾ × 2$\frac{7}{16}$ ins. The use of the bats as indicated is not detrimental to the quality of the work, as the extrados is thickly plastered with cement mortar, and all joints well filled.

Brick Sewers.—The organization of a bricklaying gang is as follows: A foreman, whose duty it is to keep a steady supply of everything needed for the use of the masons, is placed on the berm of the trench. Each 2 bricklayers has a helper in the bottom. According to the depth of the trench there are 1 to 3 scaffold men for each tender and a brick tosser on the bank, and 1 mortar carrier. Two mortar makers will serve 4 masons. From 2 to 6 men are required to take down the arch centering of ribs and lagging, pass it ahead, and set it up again. It is uneconomical to work an odd number of masons, as the same number of auxiliaries can serve 2 masons as easily as one.

The average day's work of a mason working 8 hours was found to be 4,000 brick laid in place. The maximum number laid per day was an average of two days' work on a 2 ft. diameter two ring sewer in a moderately wet trench where an average of 7,583 brick were laid per man. The minimum happened to be on a larger and easier sewer to build where, however, other adverse circumstances cut the day's work to 2,700 brick. A safer average is 3,500 brick per man per day.

Table X, based on 4,000 brick per day, gives the output and rate of construction for various sizes of sewers which ought to be reasonably expected, as it is the rate maintained for four years' time.

TABLE IX.—BRICKLAYING, FORCE AND COST OF 2 RING SEWERS

Diameter of sewer in ft...	2–4		4–8	
	No. men	Cost per day	No. men	Cost per day
Bricklayers	4	$40.00	6	$ 60.00
Tenders	2	7.50	3	11.25
Scaffoldmen	2	5.50	3	8.25
Brick tossers	2	4.50	3	6.75
Brick wheelers	2	4.00	4	8.00
Sand throwers	2	4.50	3	6.75
Mortar mixers	2	5.00	4	10.00
Mortar carriers	2	4.50	4	9.00
Water boy	1	1.50	1	1.50
Team	½	3.00	1	6.00
Foreman	1	5.77	1	5.77
Total	20½	$85.77	33	$133.27
Brick and cement teaming	4½ men at $6.00;	27.00	7 men	42.00
Total	25 men =	112.77	40 men =	175.27
No. of men to 1 bricklayer	6		6½	

TABLE X.—LENGTH OF SEWER PER DAY'S WORK AND COST PER FOOT

	3 Rings		2 Rings	
2 ft.	139 ft.	$0.81	209 ft.	$0.83
2½ ft.	107 ft.	1.05	160 ft.	1.09
3 ft.	102 ft.	1.10	153 ft.	1.15
3½ ft.	88 ft.	1.28	132 ft.	1.33
4 ft.	75 ft.	1.50	112 ft.	1.55
4½ ft.	68 ft.	1.66	103 ft.	1.70
5 ft.	55 ft.	2.08	83 ft.	2.10

Working an odd number of masons is expensive, as 1 tender, tosser, scaffoldman, sand thrower and mortar carrier can attend to 2 masons.

Bricklaying per mason per day, 4,009. (Ave. of 28,177 ft. of work.)

Manholes.—Brick manholes are usually built 3 ft. internal diameter of two bricks in thickness or 9 ins. The inner ring is built with brick standing on end and bonded every fourth course with one course laid flat. The outer ring is built best of half bricks or bats laid flat.

The most economical way of building brick manholes is to use a light wooden *drum*, slightly conical in shape as a *form* against which to lay brick. The taper need not be over ½ in. and is for the purpose of making it easy to raise the form as the brickwork requires. The height of the form or drum is usually 3 ft., so as not to make it too heavy for ease of handling. When iron steps are placed in the manhole, a slot can be cut into the drum 1 in. larger all around than the step for clearance.

In case steps are used they are best spaced approximately 16 ins. apart; a width of 9 ins. is sufficient. The best form of step is that used on telephone poles, in which the foothold or step is bent, or dropped 1 in. below the sides, so as to prevent a user's foot from slipping off sidewise. The ends should project through to the outside of the wall, and bend up 1 or 2 ins.

In building manholes or catch basins, two bricklayers should work together on account of requiring no more helpers than one mason. It is better to *raise* manholes when the bricklayers cannot work on the sewers, so as not to disorganize the main work of the masons; their work is to push construction of the sewer itself at top speed.

Manholes on pipe sewers are best built up to the center line of the sewer as soon as possible after the excavation is made, so that pipe laying may proceed without delay. In some cases it is possible to do this ahead of pipe laying, which is highly advantageous, and then complete the manhole, when the mason is not preparing another *bottom*.

The cost of such holes is shown in Table XI, in which is given average costs for 178 manholes.

TABLE XI.—BRICK MANHOLE COSTS

Size of sewer	Height of manhole	Labor Hours	Labor Cost	Brick	Cement, bbls.	Materials Cost	Total
4 ft. 6 in. brick..	5.8	9.0	$ 5.32	713	1.4	$ 9.70	$15.02
3 ft. 6 in. brick..	5.9	10.4	4.96	727	1.4	9.78	14.74
3 ft. 0 in. brick...	5.3	11.1	4.95	626	1.3	9.81	13.76
2 ft. 0 in. brick...	6.1	9.0	4.80	727	1.4	9.80	14.60
1 ft. 6 in. pipe...	8.8	31.1	13.60	1,262	2.6	13.50	26.80
1 ft. 3 in. pipe...	8.4	31.0	13.75	1,141	2.4	12.81	26.56
1 ft. 0 in. pipe...	7.9	27.9	12.05	1,100	2.2	12.10	24.15
Ave. brick.......	5.7	10.2	4.93	698	1.4	9.83	14.78
Ave. pipe.......	8.2	29.0	12.62	1,168	2.4	12.80	25.42

Height of manholes for brick sewers is measured from extrados of arch; for pipe sewers it is the full height of the brickwork.

A summary of Table XI is as follows:
Average size, 3 ft. diam.; 7 ft. 11 ins. high; 9 in. walls.
No. brick each, 1,080, or 2.52 cu. yds.
No. bbls. cement, 2.3.

Volume of masonry per lin. ft.	0.3
Labor in hrs. per manhole	21
Labor in hrs. per lin. ft. in height	2.65
Labor per cu. yd. masonry hrs	8.3
Labor cost per manhole	$10.67
Labor cost per lin. ft. manhole	$ 1.36
Labor cost per cu. yd. masonry	$ 4.23
Average rate of wages, including masons, helpers and team	$ 0.51

Table XII shows the average costs of concrete manholes.

TABLE XII.—CONCRETE MANHOLE COSTS

Concrete	Hand-mixed	Machine-mixed
Height	13 ft. 0 in.	11 ft. 3 in.
Inside diameter	3 ft. 6 in.	3 ft. 6 in.
Thickness of concrete	8 in.	8 in.
Concrete per lin. ft. of height, cu. yds.	.37	.37
Number of manholes	28	10

COSTS PER MANHOLE

	Hrs.	Cost	Hrs.	Cost
Haul of mixer	....	.....	1.0	$ 0.45
Unloading sand and stone	2.2	$0.39	2.2	0.39
Unloading cement	0.9	0.18	0.9	0.18
Delivering to mixer	6.3	1.20	13.0	2.79
Mixing concrete	4.2	0.99	14.8	3.58
Wheeling concrete	5.2	1.20	11.7	1.95
Spreading and tamping	3.8	0.86	3.8	0.86
Runways	....	.....	2.2	0.50
Forms	15.9	4.16	15.9	4.16
Total	38.5	$8.98	65.5	$14.86
Superintendence	1.5	.97	1.5	.97
Total	40.0	$9.95	67.0	$15.83
Cost per foot of height	3.1	0.77	6.0	1.40
Rate of wages per hour	....	0.25	....	0.234
COST PER CUBIC YARD OF CONCRETE				
Haul of mixer	....	.....	0.2	$0.10
Unloading sand and stone	0.5	$0.09	0.5	0.09
Unloading cement	0.3	0.05	0.3	0.05
Delivering to mixer	2.9	0.63	2.9	0.63
Mixing concrete	2.1	0.52	2.6	0.61
Wheeling concrete	2.5	0.60	1.9	0.43
Spreading and tamping concrete	1.0	0.23	1.0	0.23
Runways	....	.....	0.5	0.12
Forms	3.6	0.99	3.6	0.99
Total	12.9	$3.11	13.5	$3.25
Superintendence	.5	.26	.5	.26
Total	13.4	$3.37	14.0	$3.51

Brick Catch Basins.—Brick catch basins are built in Chicago with a 2-in. plank bottom. The basins are 4 ft. internal diameter for 5 ft. 6 ins. height and draw in to a diameter of 2 ft. in 20 ins. of height. A 9-in. half trap is set with the bottom 3 ft. 6 ins. above the planking. The brick work is 8 ins. in thickness.

Catch basins are best built toward the close of piece of sewer work, as usually the soil is then somewhat drained by the sewer.

A small gang of diggers is organized so as to keep just ahead of the masons. Two men are put to digging each hole; no sheeting need be used, as the hole is open for so short a time as to render caving unlikely. The sides are sloped just enough to prevent slides. In case of wet ground, four to six well-points attached to a diaphragm pump will be needed.

As soon as bricklaying is begun, two men are put to digging for and laying the discharge pipes from the basins to the sewer. The work so organized can be cheaply and quickly built.

The cost of basins and connections are given below:

CATCH BASIN COSTS

Number on which costs are based, 212,—4 ft. diam., 8 ft. high.
Soil, sand.

Labor cost, 345 hours	$13.22
Materials—1,100 brick at $6	6.60
60 B.M. lumber at $10	.72
2.2 bbls. cement at $0.636	1.40
19 in. half trap	1.45
1 cover	5.25
Superintendence	1.26
Total	$29.90

The planks for the bottom were cut out of worn-out short sheeting which had done full service in the sewer construction and hence were charged to the catch basins at a low cost.

CATCH BASIN CONNECTIONS

		Per ft.
Labor, 13.1 hrs.		$ 4.23
Materials—9-in. pipe	$5.50	
Cement	.18	5.76
Jute	.08	
		5.76
Superintendence		0.50
Cost per foot, $0.65½		$10.49

COSTS PER FOOT OF MAIN SEWER

	Brick Sewers	Pipe Sewers
Manholes	$0.090	$0.19
Catch basins	0.253	0.253
Catch basin connections	0.089	0.089
Total	$0.432	$0.532

In sewer work the operations naturally fall under three headings, viz.: trenching, masonry, general labor. Trenching includes excavation, sheeting and bracing, pumping and backfilling. The distribution of expense of the various operations of construction is given in Table XIII, which is based on 55,000 lineal feet of work.

TABLE XIII.—PROPORTIONAL DIVISION OF EXPENSES OF CONSTRUCTION

	Concrete Sewers	Brick Sewers	Pipe Sewers
Excavation labor	12.1 %	20.7 %	22.3 %
Sheeting and bracing labor	7.0	10.0	7.2
Backfilling labor	4.9	3.3	6.0
Pumping labor	.5	2.3	10.0
Total trenching labor	24.5	36.3	45.5
Masonry labor	25.0	20.0	4.9
Operating superintendence	4.5	5.2	4.6
Total labor	54.0	61.5	55.0
Materials and supplies	41.6	30.0	29.6
Office expense	4.4	8.5	15.4
Totals	100.0	100.0	100.0

At the time when the invert is placed in the concrete or brick sewers, the work is 57 and 65 per cent, respectively, completed.

Cost of Large Brick and Concrete Sewers in Chicago.—The following is taken from a paper by H. R. Abbott, before the Illinois Society of Engineers and Surveyors, as reprinted in Engineering and Contracting, Feb. 11, 1914.

With the exception of very small stretches, all of the work, described in this paper is built in good stiff blue clay, in the Sanitary District of Chicago.

West 39th Street Conduit.—The total length of this conduit was 2,346 ft., of which 1,868 ft., was plain concrete, a section of which is shown in Fig. 10, and 478 ft. reinforced concrete, the reinforced section being under railroad property. It is 12 × 14 ft. in size, of elliptical section.

Excavation.—Excavation was started in open cut. A Bucyrus 70-ton steam shovel was used with a 1¾ cu. yd. dipper. The shovel was mounted on five 16 × 18-in. timbers, 30 ft. long, with two 2-in. truss rods to each timber.

The top 4 ft. of trench was excavated about 3 ft. wider than the outside lines of the masonry, since no bracing was put in near the top of the trench. Below this the trench excavation was made to the exact width of the masonry, plus an allowance of 4 ins. for sheeting. Although a variation in and out was unavoidable, it did not exceed 2 ins. in either direction. The trench width was 15 ft. 8 ins.; average cut was 23 ft. 6 ins., making an excavation of 13.7 cu. yds. per running foot. On account of the deep cut, the shovel was equipped with a 36-ft. boom and a 54-ft. dipper handle. As there was liability of slides and cave-ins, the excavation was handled in two lifts. On the first run the shovel excavated the top 10 ft., using 9-ft. sheeting with one set of bracing placed about 6 ft. below the ground surface. The shovel dug ahead of the finished cut from 75 to 100 ft., then backed up and excavated the lower 13½ ft. The lower lift was taken out between steel beams, each built up of two 10-in. I-beams with cover plates, 50 ft. long, held in place by screw braces set 7 ft. back from each end. This replaces the ordinary wooden bracing and allows a free movement of the dipper in the trench for three moves or 36 ft. When a section is finished, the beams are carried ahead by the dipper, the wooden braces are replaced on the top sheeting, and another set of 9 ft. sheeting is placed with two sets of braces for the lower portion of the trench, the lower end of the sheeting being at a point where the invert curve meets the side wall. The lower sheeting back of the concrete was left in permanently. The bottom was trimmed and shaped by four or five bottom men, the material being cast ahead where the shovel could reach it. An iron frame or template built to the dimensions of the outside lines of the masonry was set up every 12 ft. as a guide in trimming the sides. The excavated material was loaded direct from the shovel on to 4-cu. yd. dump cars operating on a 3-ft. gage track. Ordinarily, the upper lift made the backfill, and the lower lift was run to a spoil area in McKinley Park, a haul of about ⅜ mile. The sheeting was 2 × 10 in. hemlock, the braces 8 × 8 in. and 6 × 6 in., with stringers 6 × 8 in. of yellow pine.

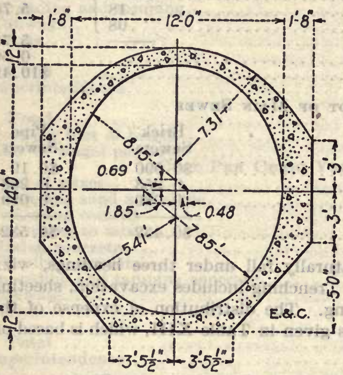


FIG. 10.—Cross section of plain concrete portion of the new West 39th St. conduit, Chicago, Ill.

Concrete.—The concrete mixer was mounted on timbers to span the trench. A No. 2 Chicago mixer, holding 25 cu. ft. of dry material, was used. Adjustable spouts were used for pouring the concrete, the spout-man standing on braces in the trench and deflecting the concrete to any point required. The pouring was made in three runs, each usually being about 16 ft. long. The first or dish extended to 2 ft. above the bottom of the trench; the second, or sides, extended 2 ft. above the springing line; the third or arch completing the section. The invert was shaped up with a wooden template or bulkhead, conforming to the inside and outside lines of the masonry, on which the forms were placed after the concrete was set. The forms were built up of 2 × 6-in.

TABLE XIV.—UNIT COST OF CONSTRUCTING THE PLAIN CONCRETE SECTION OF THE WEST 39TH ST. CONDUIT—SIZE, 12 × 14 FT.—AVG. CUT, 23 FT. 6 INS.

Item	Cost Per lin. ft.	Cost Per cu. yd.
Excavation, labor	$ 2.53	$0.188
Excavation, plant	0.64	0.046
Backfill	0.86	0.143
Waste disposal	0.89	0.120
Miscellaneous	0.75	.....
Coal	1.21	.....
Lumber	0.99	.....
Concrete masonry	10.42	.....
Labor	.....	1.315
Cement	.....	1.055
Sand	.....	0.576
Gravel	.....	1.103
Plant	.....	0.084
Total	$18.29	$4.133

Cost percentages: For material and plant, 54 per cent; for labor, 46 per cent.

TABLE XV.—CONSTRUCTION, FORCE AND RATES OF PAYMENT ON W. 39TH ST. CONDUIT, TO ACCOMPANY COSTS IN TABLE XIV

Employee	Wage per day
1 superintendent	$8.00
1 shovel engineer	7.00
3 dinkey engineers, each	3.60
1 cranesman	4.50
1 fireman	3.00
3 switchmen, each	2.25
2 flagmen, each	1.75
1 coal passer	2.50
3 foremen, each	4.50
1 hoisting engineer	5.60
4 bottom men, each	3.85
50 to 60 laborers, each	2.50
1 team	5.00
1 carpenter	4.80
1 machinist	3.50
1 machinist's helper	2.50
1 office boy	2.00
1 material man	2.50
1 watchman	2.50
3 water boys, each	1.00

lagging, laid on 6-in. channels, bent to shape. At the springing line, a 6 × 6-in. timber rested on angles bolted to the channel, being held in place by a ⅞-in. pin running through both timber and angle. After the sides were poured and set, the braces were removed and the lagging placed for the crown. The channels for the arch were reinforced with two plates.

No manholes were built and no lateral connections were made, but 24-in. tile were set in the arch at intervals for future connections. The contract specified a concrete composed of 1 part Portland cement, 3 parts sand, and 5 parts crushed stone or gravel; the engineer, under the specifications, having the right to vary the proportions of fine and coarse aggregate, but maintaining the proportion of 1 part cement and 8 parts aggregate. Gravel proved very satisfactory. The mix was fairly wet, except on the crown of the arch, where a dry mix was necessary to prevent the concrete running.

The average progress per day of 9 hours was 30 ft. for both shovel and mixer, for the plain section. This means 420 cu. yds. of excavation, with disposal in backfill or spoil bank. The actual cost of excavation, backfill, and spoiling can be seen by reference to Table XIV. The concrete averages 2½ cu yds. per ft. A daily average of 75 cu. yds. was placed. The average progress per day on the reinforced section was 24 ft. per day, the slowing up being due to the time used in placing the reinforcing steel.

On the same platform with the mixer was mounted a small boom derrick and hoisting engine. This facilitated the removal of stringers and braces, and pulled the mixer platform back and forth. The material for concrete was delivered to a platform laid on the ground alongside of the mixer, being hauled in 4-cu. yd. dump cars by dinky engines an average distance of ⅜ mile.

Reinforced Section.—This section is of the same dimensions as the plain, but was reinforced to strengthen the conduit where it passed under railroad property. The same methods of construction were used as on the plain section. The reinforcing steel averaged 44 lbs. to the cubic yard of concrete.

Backfill.—Backfill was made by the 4-yd. dump cars, track being swung in over the conduit as the filling progressed. Centers were left in until the sides were thoroughly compacted and at least 1 ft. of filling had been placed over the top of the arch. Unit costs on the reinforced concrete portion of this sewer are given in Table XVI.

TABLE XVI.—UNIT COST OF CONSTRUCTING THE REINFORCED CONCRETE SECTION OF THE W. 39TH ST. CONDUIT—SIZE, 12 × 14 FT. AVG. CUT, 22 FT.

Item	Cost Per lin. ft.	Cost Per cu. yd.
Excavation, labor	$ 2.43	$0.194
Excavation, plant	0.64	0.046
Backfill	1.24	0.249
Waste disposal	0.31	0.041
Miscellaneous	2.26	.....
Coal	1.21	.....
Lumber	0.99	.....
Concrete masonry	14.85	.....
Labor	.....	1.975
Cement	.....	1.055
Sand	.....	0.576
Gravel	.....	1.103
Reinforcing steel	.....	1.103
Plant	.....	0.084
Total	$23.93	$5.896

Cost percentages: For material and plant, 53 per cent; for labor, 47 per cent.

South 52nd Ave. Sewer (Cicero Section).—This is a three-ring brick sewer with a total length of 10,000 ft., of which 7,300 ft. was 7½ ft. and 2,700 ft. was 7 ft. in diameter; 1,050 ft. of the 7½-ft. section was in tunnel.

With the exception of the tunnel the entire sewer was built on the line of an old 4 × 5-ft. wooden box sewer. The sewage flow was usually held back for periods of 8 to 16 hours, depending on rain fall, by a temporary gate, consisting of an enclosed box 3 × 3 × 12 ft., having a sliding door working vertically about 4 ft. from the upstream end. The old wooden box sewer was first uncovered at a point 600 to 1,000 ft. ahead of the steam shovel. After the top was removed, the gate was lowered into the old box and packed in place with sand bags. The gate was operated by a lever at the ground level, by a night watchman, who generally closed the gate at 6 a. m. and opened it at 7 or 8 p. m. A 45-ton Bucyrus steam shovel, equipped with a 1¼-cu. yd. dipper, excavated the trench, placing the excavated material alongside. The average cut was 21 ft. made in a single cut. The existing box sewer was ripped out by the shovel as the trench advanced.

Sheeting 2 × 10 ins. by 16 ft. long was used with three set of stringers and braces. On about 70 per cent of the work the sheeting and one set of braces and stringers were left in.

During the progress of the work, several severe rainstorms occurred, causing considerable delay and some damage. In a portion of the work where sheeting had been pulled, a severe rain caused the bank to slide, which, together with the added weight of the spoil bank, caused a collapse of 130 ft. of completed sewer. The cost of repairs for this 130 ft. was $11.46 per ft., or 94 per cent of the first cost. On account of storms and the softening of the bank by storm and ground water shorter lengths collapsed. Because of the nearness to building foundations, thereafter, sheeting and one set of braces was left in place at an additional cost of 90 cts. per running ft. of sewer.

On the unpaved portion of the street the excess excavation was spoiled over the street. On the balance of the work it was loaded directly into wagons by the shovel, although a small portion of the excess was handled by a small Thew revolving steam shovel, loading wagons from the spoil bank.

A small amount of pointing-up proved necessary in a number of cases where water was passed over the brick work as soon as laid, and in a special case, when the breaking of the gate had flooded out the bricklayers before the invert could be laid complete. All material was teamed to the work, the average haul being ¾ mile. Connections were made with all lateral sewers and existing house connections.

The average progress per day on the 7-ft. section was 45 ft., equivalent to 330 cu. yds. of excavation, while on the 7½-ft. section the average progress was 70 ft. per day, with 20 ft. cut, or 500 cu. yds. of excavation per day. The difference in the progress between these two sections was partly due to the fact that the 7½-ft. sewer was built in a street 80 ft. wide, with open prairie on one side and unlimited room for work, and the 7-ft. section was built in a 66-ft. street with scant open space adjacent to the street. Tables XVII and XVIII give the unit costs on the 7-ft. and the 7-ft. 6-in. sections respectively.

TABLE XVII.—UNIT COSTS OF CONSTRUCTING THE CICERO SECTION OF THE SO. 52ND AVE. 7-FT. BRICK SEWER—AVG. CUT, 21 FT.

Item	Cost Per lin. ft.	Cost Per cu. yd.
Excavation, labor	$ 2.22	$0.308
Excavation, plant	0.28	0.040
Backfill, labor	0.81	0.226
Backfill plant	0.14	0.038
Waste d'sposal	1.00	0.544
Pumping	0.19	.....
Miscellaneous	0.62	.....
Coal	0.35	.....
Lumber	1.12	.....
Brick masonry	7.60	.....
Labor	.....	$2.63
Teaming sand and cement	.....	0.49
Brick	.....	4.08
Cement	.....	0.57
Sand	.....	0.29
Total	$14.33	$ 8.06

Cost percentages: For material and plant, 49 per cent. For labor, 51 per cent.

The average number of brick laid per day per bricklayer was 4,900 in the 7-ft. section and 5,900 in the 7½-ft. section. Backfilling was done with a Monaghan revolving derrick, equipped with a Page orange peel bucket, capacity 1 cu. yd. This is a very efficient machine for backfilling, but the operator should avoid dropping the load from any distance, as it is liable to crack the masonry, especially when working during wet weather, when the backfilling is saturated with water.

TABLE XVIII.—UNIT COSTS OF CONSTRUCTING THE CICERO SECTION OF THE SOUTH 52ND AVE. 7-FT. 6-IN. BRICK SEWER—AVERAGE CUT, 20 FT.

Item	Cost Per lin. ft.	Cost Per cu. yd.
Excavation, labor	$1.63	$0.226
Excavation, plant	0.28	0.040
Backfill, labor	0.43	0.119
Backfill, plant	0.14	0.038
Waste disposal	0.41	0.417
Pumping	0.15	.....
Miscellaneous	0.81	.....
Coal	0.35	.....
Lumber	0.47	.....
Brick masonry	7.50	.....
Labor	.....	$2.10
Teaming sand and cement	.....	0.30
Brick	.....	4.08
Cement	.....	0.57
Sand	.....	0.29
Total	$12.17	$7.34

Cost percentages: For materials and plant, 53 per cent. For labor, 47 per cent.

TABLE XIX.—CONSTRUCTION FORCE AND RATES OF PAYMENT ON CICERO SECTION OF THE SOUTH 52ND AVENUE 7-FT. AND 7-FT. 6-IN. BRICK SEWERS, TO ACCOMPANY COSTS IN TABLES XVII AND XVIII

Employes	Wage per day
1 superintendent	$ 8.00
2 foremen, each	5.00
1 shovel engineer	8.00
1 hoisting engineer	5.60
1 cranesman	4.70
1 shovel foreman	3.25
1 derrick foreman	2.75
2 pump foremen, each	3.00
1 watchman	3.00
1 bricklayer	12.00
5 bricklayers, each	10.00
3 tenders, ach	3.75
4 cement mixers, each	3.00
5 cement carriers, each	3.25
4 to 8 bottom men, each	3.75
5 bracers, each	4.40
2 center men, each	3.75
1 blacksm th	3.50
1 blacksmith helper	3.00
3 scaffold men each	2.75
3 brick tossers, each	2.25
4 brick wheelers, each	3.00
6 roller men, each	2.80
1 material man	3.00
1 timekeeper	3.00
2 waterboys, each	1.00
10 to 20 common laborers, each	2.00
1 to 3 teams, each	6.00

Some special items may be worthy of mention, such as the cost of hand excavation in a sewer trench of this size, moving plant, etc. At the Illinois Central R. R., where the sewer passed under the tracks, the excavation was made by hand, loaded into wheelbarrows and wheeled to the edge of the right-of-way, at which point it was handled by the orange-peel derrick.

The piling and timbering of the tracks was done by the railroad company at their own expense. This hand excavation cost $1.25 per cu. yd.

In another case the steam shovel could not take out the bottom on account of the proximity of a viaduct. This earth was scaffolded out at a cost of $1.06 per cu. yd., being handled four times before it reached the spoil bank.

The moving of the steam shovel a distance of 1,050 ft. across a railroad yard and over the tunnel section was $560, or 53 cts. per foot. This includes the

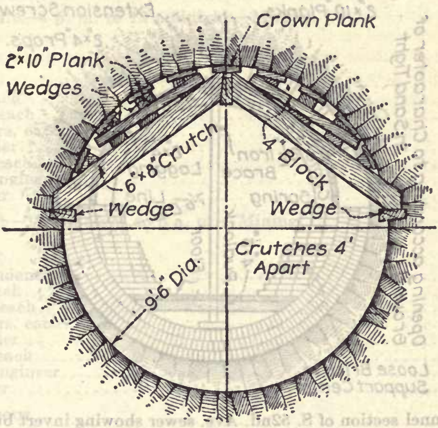


Fig. 11.—Detail of timbering in place to support roof in tunnel section of S. 52nd Ave. sewer.

partial dismantling of the shovel to pass under obstructions. At the start the shovel was taken off the railroad spur, moved ½ mile and placed on timbers to span the trench, at a cost of $750.

Tunnel Section.—The tunnel section, 1,050 ft. long, extends under the Morton Park yard of the Chicago, Burlington & Quincy Railway, and passes directly under five piers of the viaduct carrying South 52nd Ave. over the railroad yard. In places there was only 12 ft. of covering over the roof of the tunnel. The ground was stiff blue clay, containing but one sand pocket, which caused some earth settlement, visible at the ground surface. There were no settlements whatever at the piers. The unit costs for the tunnel work are given in Table XX, and the gang organizations in Table XXI.

The work was carried on by the two night shifts of miners and muckers and one day shift of bricklayers, working 8 hours each, or a total of 24 hours per day. One shaft was sunk, from which two headings were run. In Fig. 11 is shown the method of timbering in good stiff clay. In poor ground, the crutches would be made longer, with the lower end set below the spring line, and the 2 × 10-in. plank at the roof would be placed closer together. The excavated material was dumped from the shaft into railroad cars and hauled 3 miles to Western Ave.

The method of setting up the centers for the arch after the invert is built and timbering removed is shown in Fig. 12. The loose brick seen inside of the invert support the centers, spaced 4 ft. apart; 2 × 4-in. lagging is then placed. The earth at the roof is supported by 2 × 4-in. props resting on the lagging, reinforced by a 2½-in. iron prop extending from the floor of the invert to the crown plank at roof.

The average progress for 24 hours was 12½ ft. in each heading, or 25 ft. per day for both headings. The average number of brick laid per 8 hours per bricklayer was 3,000.

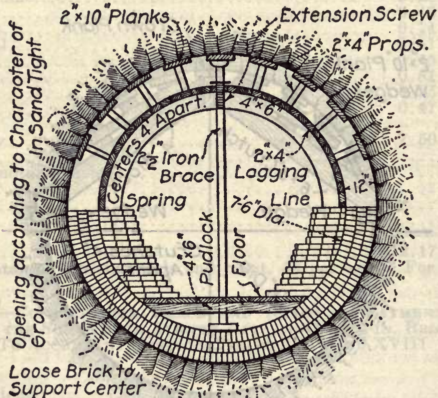


FIG. 12.—Tunnel section of S. 52nd. Ave. sewer showing invert built, timbering removed and centers set for arch.

TABLE XX.—UNIT COSTS OF CONSTRUCTING THE CICERO SECTION OF THE SOUTH 52ND AVENUE 7-FT. 6-IN. BRICK SEWER IN TUNNEL

Item	Cost Per lin. ft.	Cost Per cu. yd.
Excavation	$ 6.49	$2.43
Waste disposal	2.05	0.77
Lumber	0.40	....
Electric power	0.15	....
Miscellaneous	1.26	....
Brick masonry	9.35	....
Labor	.....	$4.40
Brick	.....	4.09
Cement	.....	0.57
Sand	.....	0.29
Total	$19.70	$9.35*

Cost percentages: For materials and plant, 27 per cent. For labor, 73 per cent.

*Note—Masonry runs 1 cu. yd. per lineal foot of sewer.

Table XXI.—Construction Force and Rates of Payment on 7-ft. 6-in. Brick Sewer in Tunnel, to Accompany Costs in Table XX

Note.—The rates are for 8-hour shifts, and each force is for two headings, one-half the force working per shift being in each heading.

(a) First Shift—8 a. m. to 4 p. m.—Bricklaying.

Employee	Wage per day
1 superintendent	$10.00
4 bricklayers, each	10.00
6 tenders, each	3.75
2 assistant tenders, each	3.25
2 cement mixers, each	3.25
2 car pushers, each	2.50
2 shaft tenders, each	2.50
1 hoisting engineer	5.60

(b) Second Shift—4 p. m. to 12 midnight—Mining.

Employee	Wage per day
1 foreman	$6.00
6 miners, each	3.75
4 muckers, each	3.00
2 car pushers, each	2.50
1 shaft tender	2.75
4 laborers, each	2.50
1 hoisting engineer	5.60
1 timekeeper	3.00

(c) Third Shift—12 midnight to 8 a. m.—Mining.

Employee	Wage per day
1 superintendent	$10.00
8 miners, each	3.75
6 muckers, each	3.00
2 car pushers, each	2.50
1 shaft tender	2.75
4 laborers, each	2.50
1 hoisting engineer	5.60
1 timekeeper	3.00

(d) Miscellaneous.

Employee	Wage per day
1 dump foreman	$2.50
6 to 12 laborers, each	2.00
1 blacksmith	3.50
1 electrician	4.00
1 carpenter	4.50
1 carpenter's helper	3.00

The average progress per day was 12½ ft. per heading or a total of 25 ft. per day.

The tables of unit costs given above are intended to cover all field operations, including superintendence, labor, material and plant. Overhead charges of the contractor are not included, such as office expenses, bonding, liability insurance, and discount on municipal bonds on special assessment work.

The item of plant charge is a difficult one. For instance, take the item of steam shovels. There are steam shovels in service today that are 25 years old, whereas others are worth only scrap value at the end of three or four years. Many contractors charge off the entire plant to the job. So far as I see, for machinery such as steam shovels, dinkies, etc., it is fair to spread the plant cost over a period of ten years, allowing interest at 6 per cent on first cost, thus making a depreciation charge of 16 per cent per year. Alterations, fitting up, freight, small tools, etc., are directly chargeable against the job, and should be added to the above 16 per cent on cost of machinery and similar equipment for total plant charges against any piece of work.

In considering the overhead charge to be made, some figures must be taken in making up an estimate. This is more apt to be too small than too large. In Illinois, liability insurance will cost from 7½ to 11 per cent of the payroll, and on work described in this paper, the labor item is about 50 per cent of the total field cost for open cut work, and about 70 per cent for tunnel work. This makes a charge of 3½ to 8 per cent of total for insurance, to begin with. Office rent, telephone, cost of getting work, and other items may increase this to 10 or 15 per cent. Adding 15 per cent for profit, we thus have 25 to 30 per cent to add to the field cost. The cost per lineal foot on the various jobs on which cost data are given in the tables and also the field cost percentages for the component parts of the various jobs are given in Table XXII. With the aid of the data contained in the tables, reinforced by current market quotations on material, the author has made estimates for similar kinds of sewer work, in the aggregate about one-half million dollars. Such estimates agree with the low bid within 4½ to 7 per cent. In transferring the unit costs for work already performed to new estimate, due consideration must be made for differences in the local conditions, character of the soil, increased cost of labor, and the availability of standard types of machine to handle the work.

TABLE XXII.—COST PER LINEAL FOOT OF LARGE CONCRETE AND BRICK SEWERS WITH PROPORTIONAL DISTRIBUTION OF FIELD COSTS

Location	—W. 39th St. conduit—		—So. 52nd. Ave. sewer—	Cicero section	
Size	12×14 ft.	12×14 ft.	7 ft.	7ft. 6 ins.	7 ft. 6 ins.
Type	Plain conc.	Reinf. conc.	Brick	Brick	Brick
Average cut	23 ft. 6 ins.	22 ft. 0 ins.	21 ft.	20 ft.	Tunnel
Total cost per ft.	$18.29	$23.93	$14.33	$12.17	$19.70
Distribution— %					
Brick or concrete masonry	56.9	62	53.2	61.5	47.5
Excavation	17.3	13	17.4	15.7	32.9
Backfill	4.7	5	6.6	4.7	....
Waste disposal	4.8	1	7.0	3.4	10.4
Miscellaneous	4.1	10	4.3	6.7	6.4
Coal	6.7	5	2.5	2.9	....
Lumber	5.4	4	7.7	3.9	2.0
Pumping	....	..	1.3	1.2	....
Power	....	..	....	....	0.8

Cost of Sewer Maintenance at Newton, Mass. (Engineering and Contracting, April 9, 1919.)—During 1918 the city engineer'sdepartment of Newton, Mass., cleaned and repaired 129.78 miles of sewer, the average cost per mile amounting to $75.25. The cost of flushing sewers was $21.20 per mile.

Costs of Operation of a Sewer Cleaner with Motor Operated Cutters.—Engineering and Contracting, March 15, 1911, gives the following:

The cleaner consists of a barrel provided with four runners on which it rides when moving through the sewer. Within the barrel is a water motor, the shaft of which extends out of the front end and carries a series of hook-shaped cutting blades. The rear end of the barrel is provided for a hose connection by means of which the water for operating the motor is delivered. Finally there are rope connections in front and rear. In operation a hose from the nearest hydrant is attached to the barrel and the cleaner is hauled through the sewer between manholes by windlasses as indicated by Fig. 13. As the cleaner advances the cutting blades operated by the motor cut and grind away the sediment which is carried away by the stream of waste water from the motor. The hose has, of course, to be long enough to reach from the hydrant down the first manhole and through the sewer to the second manhole. Four men nominally operate the cleaner, two ahead operating the second windlass to pull the cleaner and two at the first manhole to feed in the hose and back rope.

As indicating the efficiency and cost of operating the cleaner we give the following excerpts from a report by Theodore N. Aish, Engineer in Charge of Comprehensive Sewer System, Kansas City, Mo., of a test run made Dec. 7, 1910: The sewer was an 18-in. pipe sewer and the length cleaned between manholes was 371 ft. At 12:20 p. m., the crew, consisting of 4 laborers, 1 foreman and 1 team began the work of stringing hose to the nearest fire plug, 1,250 ft. distant, and getting rods through the stretch of sewer between manholes No.

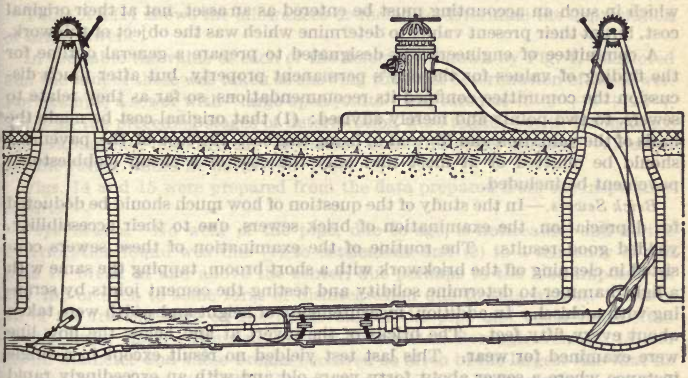


FIG. 13.—Method of using sewer cleaner.

1 and No. 2, preparatory to running the machine through. All preparatory work was done, water turned on and the machine started from manhole No. 2 at 3 p. m. A few minutes after the machine was started a length of hose burst, which caused delay of 12 minutes while a new length was being put in. The machine was taken out at manhole No. 1 at 3:42 p. m. having traversed the 371 feet of pipe in 42 minutes, or deducting the 12 minutes delay for repairing hose, the actual time of cleaning the sewer was 30 minutes. The hose was then taken up and rolled and everything cleaned and put away by 5:30 p. m. That this sewer was actually cleaned was shown by running a Shannon bucket through the sewer after the machine had gone through. In the whole length of this sewer only about ⅓ cu. ft. of dirt was gathered in the bucket. The cost of the cleaning was as follows:

Foreman, 5 hours at 37½ cts.	$1.85
Team, 5 hours at 50 cts.	2.50
Labor, 20 hours at 25 cts.	5.00
Total labor cost	$9.35

The length of sewer cleaned being 371 ft., the cost per foot was 2.52 cts. Another report gives the cost of 14 days' work cleaning 7,801 ft. of sewer as 3.15 cts. per ft., including cost of shifting machine from job to job.

Valuation and Depreciation of the Sewers of Manhattan Borough, New York City.—The following data are taken from an article in Engineering News, Jan. 8, 1914, by Otto Hufeland.

The sewer valuation here described is part of a plan, formulated by the accounting officers of the City of New York, to set up a capital balance sheet which would show the City's assets and liabilities, both bonded and otherwise, offset by its property real and personal, in the same manner as that of a rail-railroad or industrial corporation. The value of such an accounting is not confined to this balance sheet, but is an obvious aid in budget making and in the control of the city's financial affairs.

Among the several classes of "permanent property" owned by the city, the cost of which is largely represented in the outstanding bonds are the sewers. which in such an accounting must be entered as an asset, not at their original cost, but at their present value, to determine which was the object of this work.

A committee of engineers was designated to prepare a general outline for the finding of values for the city's permanent property, but after much discussion the committee confined its recommendations, so far as they relate to sewers, to two points and merely advised: (1) that original cost be made the basis of the valuation and (2) that in fixing this cost, the cost of the pavement should be omitted or at most that only the cost of a cheap (cobblestone) pavement be included.

Brick Sewers.—In the study of the question of how much should be deducted for depreciation, the examination of brick sewers, due to their accessibility, yielded good results. The routine of the examination of these sewers consisted in cleaning off the brickwork with a short broom, tapping the same with a light hammer to determine solidity and testing the cement joints by scraping with a chisel. In addition, measurements of height and width were taken about every fifty feet. The bricks of the invert at and below the flow line were examined for wear. This last test yielded no result except in a single instance where a sewer about forty years old and with an exceedingly rapid flow showed a very slight rounding of the exposed face of the brick at the joints.

A study of the reports of these examinations disclosed that the following defects were noticeable:

1. Cement partly out at water line.
2. Cement partly out above water line.
3. Depressed arch and sewer slightly spread.
4. Large open joints.
5. Loose brick.
6. Bond of brickwork broken.
7. Distorted sides, uneven bottom, joints out of line.

These seven defects show the progressive deterioration of brick sewers in the order in which they occur under the conditions existing here (and probably everywhere else). They are, of course, not sharply defined, and, passing from one step into another and coupled with the difficulty under which sewer examinations are made, cannot be determined with as much accuracy even as would be possible in an exposed structure.

TABLE XXII

Examined by	G	G
Date of construction	1868	1869
Location	46th St. 2nd to Lexington Ave.	Ave. A, 62–66 Sts.
Length in ft	928	1120
Size	4′ × 2′8″	3′0″ arc
Good condition, 0	....	....
Cement out at flow line, 2	x	x
Cement out above flow line 6	x	x
Depressed arch and sewer spread, 12	x	x
Large open joints, 25	x	x
Loose brick, 47	....	....
Bond of brickwork broken, 72	....	....
Distorted sides and joints out of line. Uneven bottom, 100	....	....
Total or average	45	45

Table XXIII shows the allowances deducted to determine the depreciation of brick sewers.

In the table the value of each of the defects, as shown by Fig. 4, was noted and the sum of these was taken as showing the total deterioration of the sewer. For example a sewer with "large open joints" was rated at 45 (2 + 6 + 12 + 25) if all the preceding stages of deterioration were found, but if, for instance the examination disclosed no "depressed arch and sewer spread," valued at 12, the rating would be 33 (2 + 6 + 25).

Figs. 14 and 15 were prepared from the data prepared from the inspectors' reports.

Pipe Sewers.—No wear of the pipe, due to age, is noticeable, and all the deterioration found was due (1) to settlement and (2) to a tendency of the pipe to break at and above the center, due perhaps to the load imposed on the top or even to some form of disintegration due to this weight. Nearly all of the fractures are on the upper half of the pipe and occur more often in the larger sizes. The sizes used in Manhattan Borough were 12, 15 and 18 in. diameter and these breaks occurred so often in the largest size that its use was discontinued in 1887. It occurred less in the 15-in. pipe and still less in the 12-in.

About 2½ miles of various sizes of pipe sewers were examined by "candling," or by fastening a lighted candle to a caliper and slowly pushing this through the sewer from manhole to manhole by means of rods, while the interior thus lighted up was examined by observers stationed at the manholes. The result was unsatisfactory, and furnished insufficient data to be used alone in determining a value.

It was therefore necessary to find some other means before determination could be made. The only data of value, in addition to the little supplied by the examination just described, were those obtained from the experience gained in renewing and repairing such sewers or in inserting spurs for house connections. In this the writer had the benefit of the knowledge of the men who had been in charge of this work for some twenty-five years, and from that and the examinations described, as well as a great many others made under his supervision, the writer formulated the curves shown in Fig. 16.

Due to the varying strength of the three sizes used, three curves were plotted, the 18-in. curve ending at 1887 when the use of such pipe was discontinued. It will be noticed that a rapid decrease in value is shown in sewers built before 1887. This is due to the construction above described. These curves can be used like those for brick sewers, so that values can be directly read off.

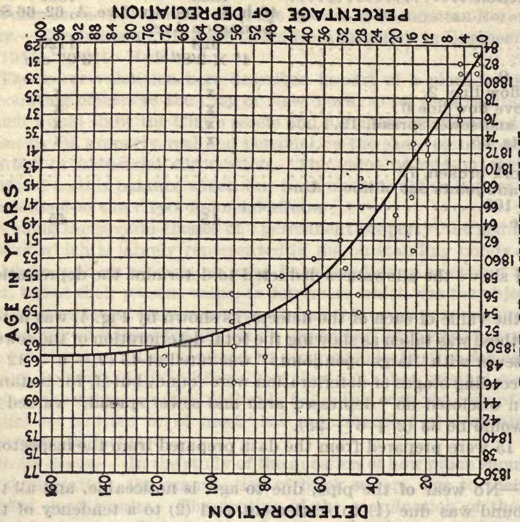


FIG. 15.—Percentage of depreciation based on examination of sewers, use of deterioration curve (Fig. 14) and age of sewers examined.

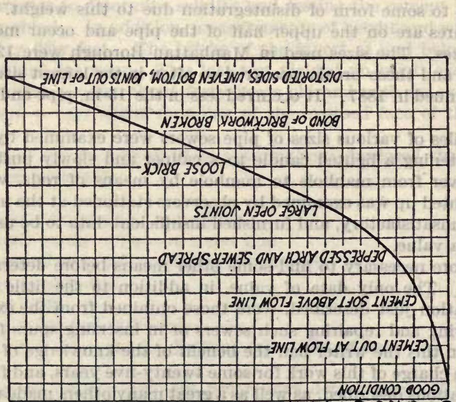


FIG. 14.—Proportionate deterioration from various causes.

FIGS. 14 and 15.—Diagrams used in estimating depreciation of brick sewers due to age, Manhattan Borough, New York City.

Earth Excavation and Backfilling.—In using any of these diagrams, it must be remembered that the deterioration is confined to the structure itself (the pipe and brickwork) and when this has reached a stage where repairs are no longer economical the sewer will have to be rebuilt. This will involve excavation and refilling as well as repaving. The last item has been fixed at the beginning of this statement, but the two preceding ones are important factors in the cost of replacement and consequently in the present value of the sewer.

When such excavation, at the time of original construction, was in earth, the original cost may fairly be used as a basis in the present valuation, because the same quantity of work would have to be done to replace the sewer,

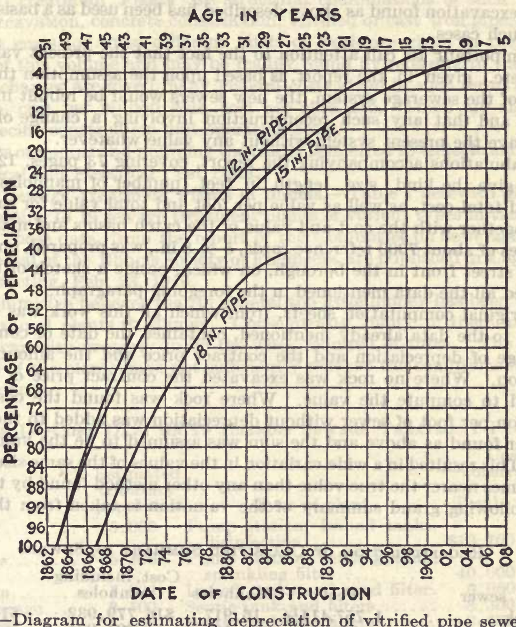


FIG. 16.—Diagram for estimating depreciation of vitrified pipe sewers due to age, Manhattan Borough, New York City.

if the subsequent subsurface structures are omitted from consideration. If, however, the whole or part of the original excavation was in rock, the cost of the reconstruction would be considerably reduced below the original amount, due to its previous removal.

For these reasons I have considered the cost of rock excavation an undepreciated asset and used it as a part of the present value of the sewer. It has been our custom to allow one day's working time for the contractor for every 10 or 12 cu. yd. of rock to be excavated. Such an allowance involved one day's pay ($4) for the inspector as well as increased attention on the part of the engineer in charge and his party in visiting the work and measuring and computing the rock, which may be estimated at $1 per day. Added to the inspector's pay this made $5 for every 10 or 12 yd. of rock excavated, or from 40 to 50c. per cu. yd.

If the cost of earth excavation and refilling be assumed at from 40 to 50c. per cu. yd. it will be offset by the "over-head" charges for rock. For example, if the bid for rock excavation is $4 per cu. yd., the "overhead" charges of 50c. will bring the actual cost to $4.50. If the earth excavation costs 50c. per cu. yd. the difference in cost between the two kinds will be $4, the price bid for rock. If, therefore, in determining the value of a sewer when rock excavation was necessary, the bid price of rock is deducted, the remainder will be the cost of that sewer in earth at the present cost of excavation. The cost of the sewer in earth excavation found as above described has been used as a basis of valuation in such cases.

It is important to call attention to the fact that the present value of the sewers, etc., given in the report, is based upon the assumption that in any changes of the sewerage system, the new sewers would be rebuilt in the same location, and that any such reconstruction involving a change of location would leave the present system without any value whatever.

The tabulations accompanying the report, covering 73 pages, 12 × 13 in. in size, give the kind, size, length in feet, number of manholes, cost per foot, and total cost, as well as value per foot and total value for each size of sewer, together with the cost and value of the catch basins and manholes.

A series of about 7000 reference cards, 5 × 8 in., was prepared, one for each block of street front in the borough, on which, beside a sketch of the block, was noted all the data mentioned in the foregoing paragraph.

The original computation sheets, from which all this work was copied, in addition to the data already mentioned, contained the date of construction, percentage of depreciation and the contract price and the amount of rock excavation. Where no rock was excavated the contract price of the sewer was used to compute the value. Where rock was found the cost of rock excavation per foot of sewer without depreciation was added to the value of the sewer found as above and the sum was assumed to be the value in such cases. This resulted in a wide variation in the values of the same size of sewer. but it comes nearer the true value than any other method found by the writer,

The following grand summary of the valuation is taken from the report:

Recapitulation of Classified Summary of Sewers

Kind of sewer	Feet	Manholes	Cost, including manholes	Value
Brick	1,757,414½	16,917	$16,779,932	$13,532,099
Wood	26,249	168	394,034	334,948
Pipe	767,611½	7,298	5,782,485	4,112,076
	2,551,275	24,383	$22,956,451	$17,979,123
	6172 Catch basins		923,875	685,798
			$22,880,326	$18,664,921
	24,383 Manholes		$ 842,500	$633,304

The foregoing summary includes 125 various sizes of brick sewers, 17 sizes of pipe sewers and 23 sizes of wooden sewers, a total of 165 with all kinds of manholes and perhaps 25 varieties of catch basins.

The work of preparing the report, including the cards, extended over a period of about ten months and involved a total expenditure of $6053. It could probably be kept up to date at an annual expense of about $500.

CHAPTER XII

SEWAGE TREATMENT

Sewage Treatment Plants are structural combinations of such types of work as excavation, concrete construction, vitrified or cast iron pipe, hauling, etc. Unit costs for these different kinds of work are given in the various chapters of this volume and may be readily found by referring to the index.

In this chapter are given many general costs given in such terms as: Cost per capita, cost per million gals, cost per acre, etc. There are also given certain specific construction and operating costs.

For costs of pumps and pumping the reader is referred to Gillette and Dana's "Mechanical and Electrical Cost Data."

Cost of Sewage Treatment Plants in Illinois.—Table I herewith gives cost data pertaining to 19 sewage treatment plants of various types in the state of Illinois. These data, from the report of the Committee on Sewerage and Sewage Disposal of the Illinois Society of Engineers, are published in Engineering and Contracting, Feb. 23, 1916.

The Committee believes that in general too little money has been spent on sewage disposal plants in Illinois. Consequently, many of them are not of sufficient capacity properly to do the work required of them. The result is that some of the plants have not sufficiently relieved the conditions for which they were built.

TABLE I.—COST DATA ON 19 ILLINOIS SEWAGE TREATMENT PLANTS

City	Estimated tributary population	Type of plant	Cost of —construction— Total	Per capita
Moline	5,000	Pump station, Imhoff tanks, disinfection	$10,700	$ 2.14
La Grange	5,300	Pump station, settling tank, sprinkling filter	40,000	7.56
Barrington	1,000	Imhoff tanks and sand filter.	6,000	6 00
North Chicago	3,500	Septic tank and filters	8,300	2.38
Lake Forest	3,000	Septic tank and filters	8,575	2.86
Ft. Sheridan	1,000	Septic tank, sprinkling and sand filters	45,990	45.99
Great Lakes	800	Septic tank and sprinkling filters	35,940	44.80
Morton Grove	1,200	Imhoff tank and sludge bed	12,815	10.70
Sandwich	2,500	Imhoff tank and sand filters.	10,915	4.36
Downers Grove	2,000	Septic tank and sand filters	7,980	3.99
Galva No. 1	800	Septic tank and trickling filter	3,700	4.62
Galva No. 2	1,200	Imhoff tank, trickling filters.	4,700	3.92
Woodstock	4,350	Septic tank, sand filters	10,874	2.50
Harvard	3,000	Septic tank, sand filters	11,980	3.99
Arlington Hgts	3,000	Septic tank, sand filters	11,950	3.98
Aledo	2,000	Septic tank, trickling filters	4,500	2.25
Geneva	2,400	Imhoff tank, Fox River	6,500	2.70
Toulon	2,000	Imhoff tank, trickling filters.	7,790	3.89
Pana	4,000	Imhoff tank, trickling filters.	31,000	7.75

The Committee believes, further, that the engineer should be the first to advise as to the proper size and capacity of plants, and that he should make his cost estimate sufficiently high to cover a plant of reasonable size and proper loadings to do the work for which it was built.

The members of the Committee were Samuel A. Greely, Chairman; Winfred D. Gerber and Frank M. Connolly.

Cost of Sewage Treatment Plants in Ohio.—Tables II, III, and IV are, given in an article published in Engineering and Contracting, Dec. 13, 1911, by R. Winthrop Pratt, formally chief Engineer Ohio State Board of Health.

Cost of Disinfection of Sewage with Hypochlorite.—The following matter is taken from an abstract of the 1912 annual report of the Mass. State Board of Health published in Engineering and Contracting, Jan. 29, 1913.

Three separate counts of bacteria—*i. e.*, total colonies on agar plates incubated four days at room temperature and total and red colonies on litmus lactose agar plates incubated 24 hours at body temperature—have been made on all samples. It has been found that waters in Massachusetts suitable for drinking usually contain less than 100 bacteria per c.c. determined at room temperature, and that the total number of bacteria developing on litmus lactose agar at body temperature is usually less than 10 per c. c., and the number of red colonies on such plates is usually less than 5 per c. c. This we have called the "drinking water" or "100—10—5" standard. For purposes of comparison two other standards containing, respectively, 10 and 100 times as many bacteria as the drinking water standard, and designated the "1,000—100—50" and the "10,000—1.000—500" standards, have been assumed. These latter correspond approximately to the upper and lower limits of bacterial counts on river waters receiving more or less pollution.

Effect of Time of Storage Upon Efficiency of Hypochlorite Disinfection.—In the laboratory experiments, analyses of all samples were made at intervals of 1, 2, 4, 6 and 24 hours after the disinfectant was added, and in the experiments in which the entire volume of settled sewage applied to Filter No. 248 was treated daily with hypochlorites. Many series of hourly samples were collected of the disinfected sewage as it flowed upon the filter. While there is some disagreement in the results of the various experiments, it is possible to determine approximately the relative amounts of disinfectant which would be required to yield similar results with different storage periods. In all cases the greater portion of the work of disinfection occurred during the first hour, after which the elimination of bacteria continued more slowly for some hours. This is especially noticeable in those cases where relatively small amounts of disinfectants were used. A general average of all the results shows the effect of storage to be about as follows: with 2 hours' storage about 84 per cent as much hypochlorite was required to produce the same result as with a storage of 1 hour; with 4 hours' storage about 82 per cent as much hypochlorite was required; with 6 hours' storage about 77 per cent as much hypochlorite was required, and with 24 hours' storage about 61 per cent as much hypochlorite was required to produce the same result as with a storage of one hour.

Cost of Hypochlorite Disinfection.—Commercial bleaching powder or calcium hypochlorite may be obtained packed in sealed drums holding 700 to 800 lbs. each, with a guaranteed strength of 36 to 38 per cent available chlorine, also in smaller drums of 25 to 100 lbs. each, but then bleach of the same strength costs about 1 to 2 cts. more per pound. Commercial bleach losses strength rapidly up to a certain point when exposed to the air, and broken bulk purchases, or drum packages whose contents are not used at once after opening,

TABLE II.—COSTS OF INSTALLATION OF PRINCIPAL OHIO SEWAGE TREATMENT PLANTS

Municipal plants

Location	Population census of 1910	Nominal population or population for which plant was designed.	Cost of installation	Cost Per Capita: Based on tributary population	Cost Per Capita: Based on nominal population	
Alliance (old)	15,083	5,000	$ 22,000	$ 1.80	$ 4.40	Chemical precipitation.
Alliance (new)	15,083	15,000	100,000	8.33	6.67	Sedimentation tanks, contact filters, and secondary filtration through fine cinders.
Ashland	6,795	3,000	6,500	2.16	2.16	Septic tanks, and filters of natural soil.
College Hill	1,979	2,000	20,700	26.00	10.35	Septic tanks, sprinkling filters, and final sedimentation.
Columbus	182,511	200,000	500,000	3.13	2.50	Septic tanks, sprinkling filters, and final sedimentation.
Delaware	9,076	1,600	12,000	3.00	7.50	Sedimentation and contact filters.
Eaton	3,170	2,600	9,400	4.70	3.60	Sedimentation tanks and sand filters.
Fostoria	9,597	4,000	25,000	5.00	6.25	Sand filters and broad irrigation.
Geneva	2,496	1,200	13,500	11.30	11.30	Septic tanks and sand filtration.
Jefferson	1,461	1,600	21,000	26.25	13.12	Septic tanks and sand filtration.
Lakewood	15,181	6,000	24,175	3.02	4.03	Septic tanks and contact filters.
London	3,530	1,300	15,000	30.00	11.50	Septic tanks and contact filters.
Mansfield	20,768	14,000	65,547	5.46	4.70	Septic tanks and contact filters.
Marion	18,232	10,000	43,000	3.58	4.30	Septic tanks, contact filters, and secondary filtration through sand.
Mt. Gilead	1,673	400	3,000	3.75	7.50	Sedimentation and sand filtration.
Oberlin (new)	4,365	4,000	16,000	4.60	4.00	Sedimentation, contact filters, secondary filtration through sand.
Orrville	3,101	4,000	19,000	9.50	4.75	Septic tanks, contact filters, and intermittent sand filters.
Oxford	2,017	2,000	12,000	12.00	6.00	Sedimentation, aeration, and intermittent sand
Ravenna	5,310	3,000	35,000	11.67	11.67	Sedimentation and sand filtration.
Shelby	4,903	1,000	4,000	2.00	4.00	Sedimentation and coarse sand filters.
Wadsworth	3,073	1,500	6,000	4.00	4.00	Sedimentation, contact filters, and secondary filtration through sand.
Xenia	8,706	1,500	6,000	1.00	4.00	Sedimentation and rough sand filters.

*Not quite finished.

TABLE III.—COST OF INSTALLATION OF PRINCIPAL OHIO SEWAGE TREATMENT PLANTS

Institutional plants

Location	Population census of 1910	Nominal population or population for which plant was designed	Cost of installation	Cost Per Capita: Based on tributary population	Cost Per Capita: Based on nominal population	Remarks
Alliance (Fairmount Children's Home)...	150	150	$ 6,000	$40.00	$40.00	Sand filtration without preliminary treatment.
Camp Perry (Ottawa County)..........	1,000[1]	1,000	3,500	3.50	3.50	National Rifle Range. Sand filtration without preliminary treatment.
Circleville (Pickaway Co. Infirmary).....	80	125	1,400	17.50	11.50	Septic tanks and sand filters.
College Hill (Methodist Home for Aged).	75	100	3,000	40.00	30.00	Septic tanks, sprinkling filters and sand filters.
Dayton (Montgomery Co. Infirmary)....	350	350	6,000	17.15	17.15	Sand filtration without preliminary treatment.
Delaware (Girls' Industrial Home).......	600	1,000	12,000	20.00	12.00	Septic tanks, sprinkling filters, sand filters and provision for disinfection.
Gallipolis (Gallia Co. Infirmary).........	40	50	400	10.00	8.00	Sand filtration.
Lancaster (Boys' Industrial School)......	1,000	1,200	8,900	8.90	7.42	Sand filtration without preliminary treatment.
Mansfield (State Reformatory)..........	600	820	1,000[2]	1.67	1.22	Rough sedimentation and sand filtration.
Massillon (State Hospital for Insane)....	1,600	1,600	8,000	5.00	5.00	Sand filtration without preliminary treatment.
Mt. Vernon (State Tuberculosis Sanitorium...........................	100	200	7,500	75.00	37.50	Sedimentation, sand filtration and disinfection.
North Amherst (Ohio Quarries Co.)......	40	100	2,800	70.00	28.00	Continuous filtration through broken stone.
Sandusky (Soldiers' and Sailors' Home)..	1,600	1,200	10,800	6.75	9.00	Septic tanks and sand filtration.
Toledo (State Hospital for Insane).......	1,500	2,000	3,000	2.00	1.50	Sand filtration without preliminary treatment.
Warren (Trumbull Co. Infirmary).......	90	100	1,170	13.00	11.70	Septic tanks and intermittent filtration through fine coke.
Warrensville (Cleveland Tuberculosis Farm Colony)........................	500	1,100	8,000	16.00	7.27	Sedimentation and sand filtration.
Wilberforce (Wilberforce University)....	380	500	2,500	6.58	5.00	Sedimentation and sand filtration.
Wapakoneta (Auglaize Co. Infirmary)...	75	150	5,000	66.67	33.33	Sand filtration without preliminary treatment.
Xenia (Ohio Soldiers' and Sailors Orphans' Home)................................	1,000	1,000	10,000	10.00	10.00	Sedimentation and sand filtration.

TABLE IV.—OPERATING EXPENSES AT FIVE OHIO MUNICIPAL SEWAGE TREATMENT PLANTS

Place	Operating expenses—1907				
			Operating cost per capita		
	Labor	*Total	Based on tributary population	Based on nominal population	Per million gals. per annum
Ashland	$ 302	$ 393	$0.13	$0.13	$ 3.20
Geneva	600	700	0.58	0.58	10.60
Lakewood	229	284	0.04	0.05	1.55
Mansfield	2,800	5,260	0.44	0.38	14.40
Marion	932	1,224	0.10	0.12	5.15

*Interest charges on cost of plants excluded.

will be found to contain less available chlorine. Analyses of a number of samples of broken bulk bleaching powder at the experiment station show that in many cases the strength may be less than 25 per cent available chlorine. The cost of this disinfectant, therefore, depends largely upon the daily amount of hypochlorites required, the extremely large disinfecting plant having the advantage of low price on bleach of guaranteed strength, the full strength of which would be available through immediate use of the contents of the large drums shortly after they were opened. The plant treating a small volume of sewage daily would pay a higher price for smaller packages, or if buying in larger lots to obtain low first cost, would find the ultimate cost increased by loss of strength which the contents of these larger packages would suffer during the period before they were consumed. For the large plant, where large volumes of sewage were to be treated daily, the disinfection costs might be reduced somewhat by the use of sodium hypochlorite manufactured at the plant. Sodium hypochlorite is readily prepared by electrolysis of solutions of common salt. As it exists only in solutions its use has been limited owing to difficulty of transportation. As a disinfectant it is fully as efficient as bleaching powder, and where common salt can be cheaply obtained and the cost of electric power is low there is no reason why the installation of an electrolytic plant should not help to reduce disinfection costs when a large amount of disinfectant is required. For the small disinfection plant, however, the use of commercial bleaching powder would probably be the cheapest in the end. Another factor which enters into the cost of disinfection is the standard of quality required in the effluent from the disinfecting plant.

Assuming a disinfectant containing 33⅓ per cent available chlorine at a cost of 2 cts. per pound, the treatment of a sewage with 0.1 part per 100,000 available chlorine would require 25 lbs. of disinfectant at a cost for chemicals of 50 cts. per 1,000,000 gals. On this basis the cost of disinfecting the various kinds of sewage and sewage effluents to definite prescribed bacterial contents would be about as follows:

To produce complete sterilization the cost would be well over $19 per 1,000,000 gals. for sewages and the effluents from contact and trickling filters, and would vary from $1.50 to over $19 for effluents from sand filters.

To produce a bacterial quality which would conform to the drinking water, or 100–10–5 standard, the cost would vary from $3.75 to over $19 per 1,000,000 gal. for raw sewage and effluents from trickling filters; from \$7.50 to over \$19 per 1,000,000 gals. for settled sewage, from \$15 to \$19 per 1,000,000 gals. for strained sewage and contact filter effluents; would be over \$19 for septic sewage, and would vary between \$1.75 and \$9.50 per 1,000,000 gals. for the effluents from sand filters which were not originally of that quality.

To produce a bacterial quality to correspond to the 1,000–100–50 standard, or one which would be about equal to that of the better class of streams or rivers which are not seriously polluted, the cost would be from \$1.75 to \$5.60 per 1,000,000 gals. for raw sewage; from \$1.75 to \$13 for settled sewage, about \$3.75 for strained sewage; between \$3.75 and \$5.60 for septic sewage; from \$1.75 to \$5.60 for effluents from contact filters, and from \$1.75 to \$3.75 for effluents from trickling filters. The cost of disinfecting sand filter effluents to produce this quality would not be over \$1.75 per 1,000,000 gals., judging from the experimental results.

If it was desired to reduce the bacterial content only to a point where they would approximately correspond with the more polluted rivers, or say within the 10,000–1,000–500 standard, the costs would be from \$1.75 to \$5.60 per 1,000,000 gals. for raw sewages and effluents from contact filters, between \$1.75 and \$7.50 for settled sewages, from \$1.75 to \$3.75 for septic sewage and effluents from trickling filters, and about \$1.75 per 1,000,000 gals. for strained sewage.

These cost estimates are for chemicals only and do not include operating and sinking fund charges.

The Economics of Sewage Filters. *Types of Sewage Filters.*—Sewage filters may be divided broadly into three classes:

(1) Intermittent sand filters or their equivalent. These consist of a body of sand or fairly pervious material of other kinds. The sewage is distributed over the surface of this porous material, and at the bottom the filtered sewage is collected in underdrains. In order to get the benefit of oxidation in the pores of the sand bed, the application of the sewage to the filter is intermittent, with periods of rest and aeration.

(2) The second type is the so-called "contact" filter. This consists of a body of practically any thickness of stone or equivalent material, such as large-sized gravel, pieces of porcelain, brickbats, cinders, or almost any coarse-sized granular material. The sewage is applied to such a filter either from the bottom or from the top, so as to fill the bed. The sewage is allowed to stand in this filter bed for a given time. It is then discharged and the empty bed is allowed to stand for a period.

(3) The third type is the so-called "sprinkling" filter. This consists of a body of stone of a minimum depth of 5 ft., on which the sewage is sprinkled or sprayed and spread by nozzles and distributed in small quantities so that the sewage trickles down over the stones and is collected at the bottom.

All three types of filters effect the purification of the sewage in the same way. Through the action of the bacteria present in the filter bed the sewage is to some extent oxidized and the organic matter is broken up. Unstable forms of matter are changed into more stable forms. While the exact form of action is unknown, it is believed that the three types of filters act in the same way, and the difference is a mechanical one of form of application. rather than one of principle of action. The following article is a reprint publishedin Engineering and Contracting, Oct. 14, 1914, of a paper by George W. Fuller, presented before the annual convention of the American Society of Municipal Improvements.

Performance of Filters.—The output of a filter of any type, measured at any suitable purification unit, is largely a question of local conditions. It depends upon the nature of the sewage, the nature and fineness or coarseness of the filtering material, the method of application of the sewage to the filtering material, temperature, atmospheric conditions, and many other factors. The intermittent sand filter is best used when it is desired to have a very high degree of purification. The other types, the contact filters and sprinkling filters, are used for a rather lesser degree of purification. It is to be understood that the rate of application of the sewage to the various types of filters must be properly proportioned to the ability of these filters to take care of the sewage. By using a suitable rate under suitable conditions any type of filter can be made to give any degree of organic purification that may be desired.

Rate of Application of Settled Sewage to Filters.—The question of the rate of application of sewage to a sand filter is largely tied up with the question of preliminary treatment in the way of tankage or screens. The following tabulation, quoted from Mr. Fuller's book, "Sewage Disposal," gives for several cities in Massachusetts the population whose sewage can be treated per acre of filter bed, and the time of detention in preliminary sedimentation tanks, storage wells, pump wells, or other means of storage. These figures are not to be taken to represent present conditions.

	Period of detention, hours	Population per acre of filter
Andover	1½–3	950
Brockton	12	1,160
Clinton	12	425
Framingham	12	375
Gardner (old)	1½	1,310
Gardner (new)	1½	2,000
Pittsfield	12	605
Stockbridge	8	220
Worcester	1½	1,390
Average of all	6.7	937

The Baltimore Sewerage Commission in 1906 estimated that, using a sand filter with 3 ft. of clean sand over the gravel, an allowance of 150,000 gals. of 6-hour settled sewage per acre in 24 hours, corresponding approximately to 1,200 people per acre, would be a proper rate.

Data for contact filters are relatively scant from American practice, and while many English data are available, the differences, owing to the difference in the strength of the sewage, makes such data rather dangerous as a basis of comparison.

A series of experiments in Columbus, Ohio, indicated that 5-ft. deep stone filters, on the contact principle, could safely be operated at an average rate of 600,000 to 700,000 gals. per acre per day. Reducing this to a 4-ft. depth will give about 500,000 gals. per acre per day, which, on the basis of 100 gals. per capita per day, would give a loading of approximately 5,000 people per acre of stone bed.

A series of tests made at Lawrence on contact beds of various depths from 24 ins. up to 18 ft. showed an average output of some 700,000 gals. per acre per day for a depth of stone on an average about 5½ ft. This is equivalent to an output of about 135,000 gals. per acre for each foot of depth of stone, or, for a 4-ft. depth of bed again, is equal to about 500,000 gals. per acre per day, or say a loading of about 5,000 people to the acre.

The contact filter installation at Plainfield, N. J., with 3.6 acres of stone bed 4½ ft. deep, gave in 1910 an output on an average of 1,700,000 gals. of sewage per day. On the basis of an allowance of 100 gals. per capita per day, this will correspond with a 4-ft. bed, to about 4,200 people per acre of filter.

For sprinkling filters much more satisfactory data can be had. Sprinkling filters have been used very extensively in this country of recent years and their ratings can be fixed with a good deal more dependence than in the case with contact filters. A list of a number of plants or projected plants giving the depths of the stone bed of a sprinkling filter and the loading in population per acre follows:

	Depth of stone in feet	Population per acre of bed
Atlanta	6	20,000
Reading	5	18,000
Columbus	5	18,000
Baltimore	9	20,000
Montclair	7½	15,000
Philadelphia	6	20,000
Fitchburg	10	20,000
Mount Vernon	8	24,000

The average of all these shows a 7-ft. deep bed and an average loading of 19,400 population to the acre.

Not considering special conditions and just taking fair figures, we may safely state the following:

Intermittent sand filters, 3-ft. bed of sand, loading 1,000 population per acre.
Contract filters, 4-ft. depth of stone, loading 5,000 population per acre.
Sprinkling filters, 7-ft. depth of stone, loading 19,000 population per acre.

The rates of loading, then, for these three types of filters, are in the ratio 1, 5, and 9.

Cost of Sewage Filters.—Costs of construction are so much affected by local conditions, such as the amount of excavation necessary, the cost of various classes of materials, the distance from which various classes of materials must be obtained, details of local construction conditions, such as competition, class of work required, and others, that comparative costs for different localities are only to be used with great discretion, and individual cost and even averages are only a guide to comparative costs in various places. Having this limitation in mind, we will examine in a rough way the cost of various types of sewage filters on the per capita basis.

The average cost of the nine Massachusetts intermittent sand filters cited above is $3,260 per acre, as reported in the Massachusetts State Board of Health Report of 1903. This gives a cost per capita connected to the filters of $3.50.

The 1906 Baltimore Sewerage Commission estimates the cost per acre of filters at $6,350, these filters being suitable for a connected population of 1,200 per acre. This corresponds to a per capita cost of $5.30.

The cost of contact filters, varying, of course, with the degree of the fineness of the design, may be taken, for filters equipped with suitable convenient appurtenances, at $30,000 per acre for a 4-ft. deep bed. This corresponds with a loading of 5,000 population per acre to a per capita cost of $6.

For sprinkling filters 7 ft. deep the cost will be about $45,000 per acre. On the basis of a loading of 19,000 population per acre, the cost per capita will be $2.37.

When considering the relatively low cost of the Massachusetts sand filters compared with the estimate made of the Baltimore sand filters, it is to be borne in mind that the conditions in Massachussetts for the construction of sand filters were unusually favorable and do not represent average conditions through the country. In most places the costs would approximate more nearly those estimated for Baltimore.

Taken in a broad way, sprinkling filters are a far more economical installation in the matter of first cost. Intermittent sand filters and contact filters do not stand far apart in this particular.

Relative Costs of Different Depths.—There is not very much known about the relative advantages of filters of shallow or deep construction. The choice of depth is usually made for entirely different reasons from those of obtaining the most economical construction to obtain the desired amount of purification. Very few tests of a comparative kind have been made to give convincing information, and the interpretation of the tests has not been uniform. In some places the conclusion has been made to make filters, say, 10 ft., at other places 6 ft., and some study is worth while to determine what, if any, difference there is in the cost of such construction at different depths, and which would appear to be the better. It is to be assumed in such comparisons that sufficient head would be available in any case for the greatest depth to be considered and that pumping would not be necessitated by building filters of the greater depth.

For intermittent sand filters questions of depth do not arise. The filters are generally made as shallow as is consistent with getting proper results and sand beds are not usually made more than 4 or 5 ft. deep as a maximum. Shallower beds, even, will give about the same output as the deeper beds, and beds are made deep only so that sand may be removed for cleaning without removing the sand for a considerable period.

With contact filters it is recognized that from the nature of the action of the contact filters, where the amount of air that is drawn in between fillings of sewage is practically equal to the volume of the sewage, and where surface clogging cannot be a serious factor and may even be no factor at all, each unit of volume of the stone forming the filter, say each cubic yard, will give the same output of sewage purification, no matter what may be the depth of the filter.

From this it follows that it is economical to build a sewage filter on the contact principle as deep as local conditions of construction will permit, and the limitation of depth which it is economical to use is therefore made by the factors of earth excavation or fill and the possible head available without pumping.

When it comes to sprinkling filters, the problem becomes a little more complicated. The English experience, as recited in the Report of the Royal Commission, seems to indicate that the output per unit of volume of sprinkling filters is the same, no matter what the depth. Our experience in work in this country does not wholly corroborate this information. Our best knowledge seems to indicate that the output per unit of volume of sprinkling filters is somewhat less for deep filters than for shallow filters. For such conditions, with a relatively decreasing efficiency of the stone of the filter beds for greater depths and at the same time a relatively decreasing cost per unit volume of the stone for deep beds, there must come some point where the greatest output per unit of cost will be obtained.

The Report of the Baltimore Sewerage Commission for 1911 gives some information obtained from tests made in Baltimore as to the relative efficiency of various depths of broken stone of sizes of 1 to 2-in. stone, which is the one most commonly used. Figures obtained from that source are as follows:

	Depth of bed 6 ft.	9 ft.	12 ft.
Relative stability	79	87	89
Per cent reduction of oxygen consumed	56	70	72

Giving equal weight to the relative stability and per cent reduction of oxygen consumed, we get the following:

	Depth of bed 6 ft.	9 ft.	12 ft.
Relative stability	1	1.2	1.23
Per cent reduction of oxygen consumed	1	1.25	1.28
Average of the two	1	1.22	1.25
Relative depths	1	1.33	2.00
Relative value of stone per cubic yard	1	.92	.63

Assuming this depth varies at a uniform rate from one end of the curve to the other, we get the following for the relative value of stone per cubic yard

Depth of bed in feet	6	7	8	9	10	12
Relative value of stone per cubic yard	1.0	0.97	0.94	0.92	0.82	0.63

To get comparative figures, then, between the 6, 8 and 10-ft. beds the cost figures for the 8-ft. beds must be divided by 0 94, and the cost for the 10-ft. beds by 0.82, putting them all on the basis of the 6-ft. beds.

For comparative cost a number of factors such as excavation, etc., are naturally omitted, as they are not affected in all places the same way by the depth of the filter. Comparing, then, only those particular costs which are affected per unit of output by the depth of the filter, we get the following:

	Per effective cu. yd. depths 6 ft.	7 ft.	8 ft.
Floor—Take at 40 cts. per cu. yd. for a 6-ft. bed	$0.40	$0.35	$0.32
Tile—Take 11 cts. per sq. ft. for any depth	.49	.44	.40
Walls—Assume cost 17 cts. per cu. yd. for 6-ft. depth	.17	.17	.18
Galleries and Collectors—Assume for 6-ft. depth 25 cts. per cu. yd.	.25	.22	.20
Distribution—Assume 50 cts. per cu. yd. for 6-ft. depth also, as costs theoretically vary only according to quantity delivered, they must be same for all effective depths per cu. yd.	.50	.50	.50
Stone—Assume $1.50 per cu. yd.	1.50	1.55	1.60
Total	$3.31	$3.23	$3.20

Outside factors will depend on quantity only and not on depth.

It appears, then, that there is some slight saving of cost, which, on the figures given in the above tabulation, amount to about 3 per cent in favor of the 8-ft. deep bed as compared with the 6-ft. deep bed. On the other hand, it is to be recognized that a deep bed will give a good deal more trouble with pooling and freezing than a shallow bed. and the advantages in favor of a shallow bed due to this lesser amount of pooling will be considerably more than this 3 per cent difference in cost. Taking everything into account, the writer believes that a sprinkling filter of not less than 6 ft. and not more than 7 ft. in depth will in the greater number of cases prove the most economical to use.

Cost of Constructing and Operating Trickling Filters.—The following is given in Metcalf and Eddy's "American Sewerage Practice."

Capacity of Trickling Filters.—The capacity of trickling filters is dependent upon the strength and character of the applied sewage as well as upon the size and depth of filtering medium. The Royal Commission on Sewage Disposal in its Fifth Report estimated the capacity of coarse filters at approximately 100 to 200 U. S. gal. per day per cubic yard of filtering material, which is equivalent to nearly 1,000,000 to 2,000,000 gal. per acre per day on a bed 6 ft. deep. The maximum limit set by the Royal Commission might be considered a safe estimate for ordinary domestic sewage in the United States, but for industrial wastes or sewage containing unusual amounts of such wastes much lower rates may be necessary.

Fuller has stated that a fair average loading for a filter 7 ft. deep is 19,000 population per acre. (*Proc. Am. Soc. Mun. Imp.*, 1914.) Trickling filters in the United States have been designed generally for between 2000 and 4000 persons per acre per foot in depth. The authors believe that the former is a safe estimate for treating settled domestic sewage by trickling filters 5 to 10 ft. deep composed of broken stone between 1 and 2 in. in size.

Relative Merits of Trickling Filters and Contact Beds.—At Worcester, Mass., where large quantities of sulphate of iron are present in the sewage, it was concluded that four times as much settled sewage could be treated with satisfactory results by trickling filters as by contact beds and that at least 3 contacts would be required to produce as high nitrification by contact beds as by trickling filters.

TABLE V.—COST OF CONSTRUCTION OF CERTAIN TRICKLING FILTERS BUILT OR PROJECTED IN THE UNITED STATES

Place	Area, acres	Depth of stone, feet	Cost per acre	Cost per cu. yd. of filter	Remarks
Reading, Pa (*a*)	1.0	6.3–7.0	$37,500	$3.50	Cost of second unit constructed, including dosing equipment and secondary sedimentation tank.
Columbus, O. (*a*)	10.0	5.3	24,040	2.81	Exclusive of conduits and engineering.
Washington, Pa. (*b*)	1.38	6.8	31,700	2.89	Exclusive of engineering.
Gloversville, N. Y. (*b*)	3.07	4.5	32,632	4.50	Exclusive of conduits, roof and engineering.
Fitchburg, Mass. (*b*)	2.0	10.0	59,650	3.70	Exclusive of engineering.
Chicago, Ill. (*c*)	.....	7.0	45,000	3.98+	Including office and laboratory, excluding engineering.
Paterson, N. J. (*c*)	.....	10.0	50,750	3.14	Complete.
Baltimore, Md. (*c*)	12.0	9.0	50,700	3.49	Exclusive of engineering.
East Orange, N. J. (*c*)	.....	7.5	45,000	3.72	Including foundations and dosing apparatus but excluding engineering. Allowance for foundations $7000.

(*a*) Actual cost.
(*b*) Estimated cost based on quantities from design and contract prices.
(*c*) Estimated cost.

With filters of coarse material not subject to disintegration, the evidence seems to indicate that they will be self-cleansing if properly operated, whereas contact beds usually clog periodically. Hence the cost of treatment by trickling filters is usually much less than that by contact beds.

The effluent from the trickling filter is ordinarily more highly nitrified than the effluent from contact beds and after secondary sedimentation is more uniform in quality than contact bed effluent.

The trickling filter is better adapted for variations in rates of flow than is the contact bed.

The chief advantages in the use of contact beds rather than trickling filters are the relatively low head required, the somewhat simpler method of dosing, minimizing foul odors and avoiding a fly nuisance.

TABLE VI.—ITEMIZED COST OF SEWAGE DISPOSAL PLANT, GLOVERSVILLE N. Y.

	Total cost	Unit cost
Screen chamber substructure	$ 445.27	....
Screen chamber house (total exterior volume, 1,350 cu. ft.)	535.00	$0.40 per cubic foot.
Primary settling tanks (total capacity both tanks, 537,000 gal.)	15,761.45	26.10 per 1,000 gal.
Dosing tank (total capacity, 8,800 gal.)	1,403.52	160.00 per 1,000 gal.
Trickling filters (3.07 acres, area of stone).	106,560.48	34,700 per acre
Secondary settling tanks (total capacity both tanks, 242,000 gal.)	9,292.31	38.40 per 1,000 gal.
Sludge beds (2.63 acres effective sand area).	9,097.23	2,450 per acre
Sand filter beds (2.72 acres effective sand area)	24,716.77	9,090 per acre
Sludge pump well (total capacity, 16,230 gal.)	1,232.61	75.90 per 1,000 gal.
Sludge pump house (total exterior volume, 1,880 cu. ft.)	535.00	0.39 per cubic foot
Sludge pumping machinery	460.00	....
Conduits and pipe lines (sewage, effluent, sludge, water)	11,758.85	....
Grading, drives, walks, trees, cleaning up, etc	3,800.78	....
Creek deepening and straightening	1,396.30	....
Miscellaneous	57.99	....
Extras, claims, incidentals, delays and damages	1,700.00	....
Total cost	$188,753.56	

On basis of 3,000,000 gal. of sewage treated daily, $62,900 per 1,000,000 gal.

Cost of Construction.—The actual or estimated costs of various trickling filters built or projected in the United States are shown in Table V. They vary from $24,000 to $60,000 per acre and from $2.81 to $4.50 per effective cubic yard of filter. Fuller gives the average cost of a trickling filter 7 ft. deep as $45,000 per acre, or $2.37 per capita, based on a population of 19,000 served per acre. (*Proc. Am. Soc. Mun. Imp.*, 1914.) The actual cost of the 10-ft. Fitchburg trickling filter was $58,847 per acre exclusive of excavation, or $2.94 per capita, based on a population of 20,000 per acre of filter. (Hartwell, *Jour. Bos. Soc. C. E.*, vol. ii, 1915, page 221.)

The relation which the cost of trickling filters bears to the costs of the other parts of a trickling filter plant will vary according to the design, as indicated in Tables VI and VII, showing the actual itemized costs of construction at Gloversville, N. Y., and Fitchburg, Mass. The roof system at Gloversville increased the cost of the trickling filter by approxmately $13,336, or $4445 per acre. Of this total, $4406 was for columns, $4550 for beams and $4380 for lumber, etc.

TABLE VII.—ITEMIZED COST OF DIFFERENT FEATURES OF SEWAGE DISPOSAL PLANT, FITCHBURG, MASS.

(Sewage Disposal Commission, Ninth Semi-Annual Report, 1914, page 7)

	Total cost (approximate)	Cost per capita (approximate)
Venturi meter and chamber	$ 2,942.25	$0.053
Imhoff tanks	56,122.53	1.02
Sludge beds	3,054.81	0.055
Dosing tank and apparatus	10,661.52	0.19
Trickling filters	136,545.53	3.41
Pipe lines	9,668.27	0.17
Overflow chamber	901.93	0.016
Secondary tanks	8,969.62	0.16
Pump house and pump	2,007.64	0.036
Effluent channel	1,328.91	0.024
Roadways	10,710.57	0.19
River improvement	5,122.67	0.093
Bonus paid contractor	5,000.00	0.091
Additional work to be done	10,000.00 est.	0.18
Engineering and inspecting	30,000.00 est.	0.54
Total (approximate)	$293,036.25	$6.22

Cost of Operation.—There appear to be few data of the cost of operation of the trickling filters in the United States. In most cases where costs are kept, no attempt has been made to divide the charges among the different parts of the plant.

At Columbus, Ohio, the operation of the entire treatment plant, exclusive of pumping station, for 1913 cost $8286.60; or approximately $2.40 per 1,000,000 gal. of sewage treated during 222 days of the year. (Rept. Div. of Sewage Disposal, 1913.) C. B. Hoover, Chemist in charge, informed the authors that the proportionate cost of operating the different parts of the plant was, approximately, preliminary tanks 4 per cent.; trickling filters, 6 per cent.; final sedimentation tanks, 90 per cent. The comparatively high cost of operating the secondary tanks was probably due to the difficulty of sludge disposal. The sludge from the preliminary tanks was pumped into the river during high stream flow. Hoover has furnished the subdivision of the average cost of operation of the Columbus plant per 1,000,000 gal. of sewage treated, given in Table VIII. The "actual cost" is the total annual expenditure for each of the items divided by the millions of gallons treated, while the "cost for time in service" is the expenditure for each of the items during the 222 days of operation divided by the millions of gallons treated.

TABLE VIII.—COST OF OPERATION OF SEWAGE TREATMENT PLANT AT COLUMBUS, OHIO, PER 1,000,000 GAL. TREATED

	Supervision	Chemical control	Operation of treatment devices	Care of grounds, etc.	All other items[1]	Total
Actual cost	$0.45	$0.32	$0.92	$0.47	$0.43	$2.59
Cost for time in service	0.29	0.21	0.42	0.32	0.30	1.54

[1] Includes transportation, heat, repairs, printing, supplies, light and telephone service.

At Reading, Pa., the net expenditure for maintenance and operation of the sewage pumping and disposal works for 1912 was $15,470.24, equivalent to $9.13 per 1,000,000 gal. of sewage treated. (Rept. City Engineer, 1912.) City Engineer Ulrich advised the authors that the cost of operation of the disposal plant alone for that year was $5215.10, which is equivalent to $3.08 per 1,000,000 gal. treated. E. Sherman Chase, formerly chemist in charge, stated that the labor in connection with the trickling filters was performed by three men working in 8-hour shifts, who act as watchmen, collect samples for analysis and care for the laboratory and grounds. These men are paid $2 per day, so that the labor cost is a little over $1 per 1,000,000 gal. sewage filtered. (*Engineering News*, August 22, 1912.)

Calvin W. Hendrick, Chief Engineer of the Sewerage Commission of Baltimore, stated that the cost of operation of the Baltimore sewage treatment plant, with 12 acres of trickling filters, when working up to its capacity, will probably be between $1.50 and $2 per 1,000,000 gal. The organization at this plant Mr. Hendrick gave as follows: 1 division engineer, who also supervises construction work; 1 mechanical engineer; 1 chemist and bacteriologist; 1 assistant chemist; 3 operating engineers; 1 relief engineer and 4 oilers for the power plant; 1 machinist; 1 carpenter; 1 foreman for laborers; and 12 to 20 laborers.

The organization at the Pennypack Creek disposal works, Philadelphia, Pa., designed to treat 2,000,000 gal. daily, was stated by George S. Webster, Chief Engineer of the Bureau of Surveys, as follows: The assistant engineer of the Sewage Disposal Division has supervision of the operation of the plant, which requires only a small part of his time, and an assistant has immediate charge of maintenance, supplies and records. The force at the plant consists of an operator on duty every day, having immediate charge of the operation, sampling, etc., 4 assistant operators working 8 hours a day, 6 days a week, a watchman for night duty, and a laborer for day duty, such as handling sludge, caring for lawns, shrubbery, etc. The analytical work is done partly at the Bureau of Water laboratory nearby and partly at the Bureau of Surveys Laboratory at the City Hall.

The costs of operating different parts of the plant at Gloversville, N. Y. have been very carefully kept under the direction of H. J. Hanmer, City Engineer. The itemized cost for 1913 and 1914 is given in Table IX. The cost of operating the trickling filters alone constitutes roughly 15 to 25 per cent. of the total for the entire plant. The cost of removing and replacing the roof and sides of the building in which the filter is housed during winter constitutes a substantial part of the trickling filter maintenance charges. The remainder is occasioned by nozzle clogging. About 60 nozzles, or approximately 10 per cent. of those in use, are cleaned each day.

The cost of operation of trickling filter plants, per 1,000,000 gal. of sewage treated, other conditions being equal, will decrease with increasing size of plant. Estimates made by the authors in connection with the joint disposal of sewage from several municipalities in New Jersey ranged from $5.19 per 1,000,000 gal. for an estimated flow of 4,400,000 gal. daily to $2.92 for 14,300,000 gal. E. J. Fort, Chief Engineer of Sewers of Brooklyn, estimated the cost, including interest and depreciation of sinking fund, at $13.81 per 1,000,000 gal. with a flow of 5,000,000 gal. daily, $11.41 for a rate of 10,000 gal., $9.76 for 20,000,000 gal., and $9.50 for 30,000,000 gal.

Thomas Pealer, Borough Engineer of Indiana, Pa., furnished the following information concerning the sewage disposal plant at Indiana, Pa., comprising screen chamber, septic tanks and a trickling filter 220 × 100 × 5½ ft. deep, of ½ to 3½-in. broken stone, with dosing tank and fixed nozzles. It serves 8000 persons and treats 500,000 to 1,000,000 gal. daily of domestic sewage from separate sewers. This plant cost $40,000 and is operated by 1 man at a cost of $750 per annum.

TABLE IX.—COST OF OPERATION OF SEWAGE TREATMENT WORKS, GLOVERSVILLE, N. Y.

	1913	1914
Supervision by city engineer		$ 600.00
Operation of screens, etc.	$ 223.37	574.00
Sludge pumping:		
Labor and repairs	226.00	297.00
Electric power	318.34	214.05
Maintenance of trickling filters:		
Nozzles	897.28	395.00
Removing and replacing covering	278.25	359.00
Maintenance of sludge beds	1,312.46	1,235.00
Cleaning troughs of secondary tanks	35.50	19.63
Maintenance of sand filters	440.33	315.00
Maintenance of grounds	399.97	163.00
Miscellaneous work	169.87	365.00
Chloride of lime and other supplies	835.96	664.27
Telephone		42.00
Cleaning and repairing east primary settling tank (unusual item)		709.00
Total cost for year	$5,137.33	$5,951.95
Cost per 1,000,000 gal. treated, average flow 2,750,000 gal. daily	5.16	5.92
Cost per capita based on estimated population	0.24	0.27
Estimated population	21,600	21,800

The plant at Chambersburg, Pa., as described by Frank H. Clutz, Borough Engineer, consists of Imhoff tanks, a trickling filter 160 × 125 × 7 ft. deep, of 1½ to 3½-in. limestone, with dosing tank and fixed nozzles, and secondary sedimentation tanks. The entire plant cost $46,595.25, exclusive of land, the cost of the trickling filter alone being estimated at $18,500. This plant cares for the sewage from about 5400 persons of the town population of about 13,500, and the average flow of sewage treated, including ground water, is about 1,400,000 gal. per day. Two men are regularly employed, one during the day and one at night, and occasional assistance is required. The cost of operation, maintenance and improvements for 1914 was $4302.54.

The sewage of the State Hospital for the Insane, Norristown, Pa., Oscar L. Schwartz, Steward, is treated by a coarse screen, sedimentation tank, trickling filter 100 × 173 × 6½ ft. deep, of 1½ to 3½-in. limestone, with dosing tank and fixed nozzles, and final sedimentation tanks. The number of persons at the hospital is 3500 and the quantity of sewage treated is 575,000 gal. per day. Two men are employed at this plant and the annual cost of operation is estimated at $1290.

The sewage disposal plant of the State Hospital for the Insane at Warren, Pa., according to Albright & Mebus, consists of an Imhoff tank, a trickling filter 95 × 99½ × 7½ ft. average depth, of stone 2 to 3½ in. in size, with dosing tank and fixed nozzles, and a final sedimentation tank. It serves about 1800 persons and treats about 270,000 gal. per day. The cost of construction was $12,800 or $59,000 per acre. One man is employed about 6 hours each day in caring for this plant.

The trickling filter plant at the United States Naval Training Station, Great Lakes, Ill., according to Lieut. J. B. Earle, Public Works Officer, consists of preliminary septic tanks and roughing filters and 2 trickling filters, each 20 × 60 × 7 ft. 4-in. deep, of ¼ to ¾-in. stone, dosed by splash-plate distributors. The plant serves 900 people and treats 300,000 gal. of sewage per day. The cost of construction of the filters was $35,939.50 and the annual cost of operation is estimated at $300.

Dr. L. Rosenburg, Superintendent of the Montefiore Home County Sanitarium, Bedford Hills, N. Y., reports that the sewage disposal plant at this institution, accommodating 245 persons, consists of septic tanks, 3 small trickling filters of 2-in. stone with 1 nozzle each, and a settling tank for the effluent. This plant cost $10,000 and the cost of operation is stated to be negligible, although the engineer visits the plant each day.

Cost of Intermittent Sand Filtration.—The following is given in Metcalf and Eddy's "American Sewerage Practice."

Where a deposit of free sand or sand and gravel is available in place, it may be used for intermittent filtration by simply grading the surface to receive the sewage. Loam, subsoil and silt are not desirable as filtering media on account of their tendency to hold water by capillarity, preventing successful aeration of the bed, except when very low rates of filtration are used, such as those employed in broad irrigation. Clay and cementitious sands or other comparatively impervious materials are useless for filters.

The removal of loam and subsoil is necessary if any considerable quantity of sewage is to be purified upon beds of a given area. Relative expense will probably determine the extent to which it is desirable to remove the subsoil. Where there are trees, organic matter will be found around their roots at a considerably greater depth than where there are no trees, and care must be exercised to remove this in grubbing out tree roots. Similarly, in gravelly soils containing many large stones, fine sandy material may be found surrounding the stones. Therefore, beds built in such material are not likely to be so homogeneous as those built in ground made up of more uniform material.

The limit for excavation may be determined in several ways: first, by color; second, by loss of weight on ignition, due to the volatilization of the organic matter; third, by taking a small portion of the sand in a glass of water, shaking thoroughly, and permitting it to subside, the amount of organic matter and fine sand found upon the top of the sand, when the material has settled, furnishing a ready guide as to the relative content of objectionable matter.

Uniformity of Material Desirable.—Stratification, or the presence in an otherwise uniform and satisfactory material of sand of different sizes or of cementitious character, is objectionable. When sewage is run onto a bed of uniform material, the suspended matter is arrested upon or near the surface, the water gradually passing through the bed at a comparatively uniform rate without any tendency to clog except at the surface. If the material is stratified, with the coarser sand on top, the bed is likely to become clogged by a film of organic matter on the surface of the fine sand below. This may be caused in part by the passage of very fine suspended matter through the coarser sand and its retention upon the surface of the fine stratum, and also probably by the formation of an organic growth there, due to difference between the quantities of oxygen and water contained in the coarse and fine sands. If the finer material is on top, while there will be no tendency for the fine suspended matter to form a clogging film on the surface of the coarser sand, there may be an accumulation of oxide of iron there due to the difference in the quantities of oxygen present in the two strata. A precipitation of oxide of iron may take place throughout the stratum of coarse material, and if this sand is underlaid with a stratum of fine sand, a film of oxide of iron will form upon the surface of the finer material. An interstratified layer of fine material may act as an air seal, due to capillary action, and thus prevent the satisfactory aeration of the lower portion of the bed.

Cost of Construction.—The cost of constructing filter beds will usually be found to lie between \$2500 and \$5000 per acre, although in some favored localities this cost may not exceed \$1000. If the beds have to be built wholly artificially the cost may reach \$10,000 per acre, if the sand has to be hauled a considerable distance.

Cost of Operation and Maintenance.—This cost will be found to lie ordinarily between \$100 and \$150 per acre, the cost per 1,000,000 gal. of sewage filtered being about \$10, as will be seen from Table X.

TABLE X.—AVERAGE ANNUAL COST OF FILTRATION AREAS IN FOUR MASSACHUSETTS CITIES

(Compiled from Annual Reports)

City	Period	Population	Filter area acres	Mil. gal. filtered daily	Cost per acre	Cost per mil. gal.	Cost per capita
Brockton..........	1896–10	34,500–	21.48–	0.501–	\$178	\$13.50	\$0.10
	....	56,900	35.77	1.297	....	......	.....
Clinton............	1900–10	13,700–	23.5–	0.625–	110	9.26	0.20
	....	13,100	25.0	0.829	....	......	.....
Concord..........	1901–10	5,600–	3.3	0.273–	108	3.33	0.06
	....	6,400	......	0.264	....	......	.....
Worcester[1].........	1904–10	129,500–	3.3–	0.273–	290	10.37	.....
	....	146,000	74.3	4.718	....	......	.....

[1] As only part of the sewage is treated by intermittent filtration, no satisfactory figures of the cost per capita can be given.

Cost of Operating Contact Beds.—The following is given in Metcalf and Eddy's "American Sewerage Practice." Probably the best figures on the cost of operation in America are those obtained at Plainfield, N. J., stated by Fuller (in his "Sewage Disposal") to be as given in Table XI.

TABLE XI.—COST OF OPERATION OF PLAINFIELD SEWAGE DISPOSAL PLANT

Item	1907	1908	1909	1910
Manager-chemist, consulting engineers	....	\$1325.50	\$1818.46	\$1677.67
Night operator..........................	\$ 540.00	....	....	....
Laboratory..............................	41.69	247.87	147.18	80.72
Tools and supplies...................	23.02	103.45	32.63	8.28
Labor......................................	50.59	53.70	....	....
Water guarantee......................	73.20	73.20	73.20	....
Telephone...............................	43.99	25.08	28.58	23.05
Care of contact beds................	1180.53	1189.26	885.09	918.68
Care of septic tanks, including emptying and disposal of sludge..........	662.25	603.50	252.89	269.17
Grading and weeding banks...........	104.22	....	....	....
Screen attendance.....................	....	193.14	298.30	312.23
Farming..................................	236.15	....	....	....
Total..................................	\$2955.64	....	....	....
Farm products receipts..............	248.65	....	....	....
Total cost of maintenance............	\$2706.99	\$3814.70	\$3536.33	\$3289.80
Improvement of contact beds........	....	....	2032.87	935.36
Repair of septic tanks................	101.14	....	151.89	1011.15

In 1910 the number of connections was 3746; assuming 5 persons per connection, there would be a total of 18,730 persons. The flow amounted to 1,800,000 gal. per day, making the cost \$5 per 1,000,000 gal. or \$0.18 per capita per year. There are 8 primary and 8 secondary beds with a total area of 3.6 acres.

At Mansfield, Ohio (Report Ohio State Board of Health, 1908), the costs of operation during 1906 and 1907 were \$5644 and \$5260 respectively, and included removal of sludge from the septic tanks. Furthermore, about one-half of the cost was for coal used in pumping. These figures made the per capita cost \$0.47 and \$0.44 respectively.

At Manchester, England, very complete cost accounts have been kept. In the 1907 report of the Rivers Department is given a table showing the actual cost of a selected area of 6 acres from the starting of the beds until the filtering material was taken out:

Average number fillings	2,690
Gallons (U. S.) of septic tank effluent dealt with by the 6 acres	4,610,000,000
Total maintenance cost	\$4,085
Total renewal cost (\$0.40½ per cubic yard)	\$13,700
Maintenance cost	\$1.05 per 1,000,000 U. S. gal. filtered.
Renewal cost	\$3.57 per 1,000,000 U. S. gal. filtered.
Actuating valves	\$0.30 per 1,000,000 U. S. gal. filtered.
Total working cost	\$4.92 per 1,000,000 U. S. gal. filtered.

Cost of Preparing and Placing Ashes or Cinders for Filtering Material in Contact Beds.—E. G. Bradbury gives the following in Engineering and Contracting, Aug. 31, 1910.

Filtering material is one of the largest cost items in every sewage disposal plant, in which filtration is made a part of the process of purification. Local conditions naturally control the selection of the material to be used. Sand is frequently so expensive as to be almost out of the question, especially in view of the fact that its exclusive use requires much greater area and consequently larger quantity of material than if a coarser material and one of the high rate types of filter be installed.

For contact filters no material is more satisfactory or economical than a good grade of ashes or cinders, those produced by locomotives being particularly good. These are largely either of a vitrified or coky nature and therefore less liable to disintegration than the softer ash produced by some industrial plants. An excellent ash is produced by many iron and steel mills and furnaces.

This material can frequently be purchased from the railroads and can always be found in quantity in large cities, or those having important industrial plants. In Ohio the market price ranges from practically nothing up to \$3 per car at the place of production, and the railroad companies will often furnish round house cinders for the price of hauling, provided they are not using the product for filling along their lines.

During the fall of 1901 the writer was employed as resident engineer in charge of the disposal plant at Mansfield, Ohio, where 1¼ acres of contact filters were filled to a depth of 4.75 ft. with crushed and screened locomotive cinders, the work being done by day labor and all apparatus and material purchased directly by the city. The figures given below are therefore actual costs in real money and not approximations.

The filter beds are laid out in the form of a circle about 280 ft. in diameter, divided into five beds by radial embankments. The crushing and screening plant was erected close to the outer edge of the circle, and a siding was run alongside the crusher; there was, therefore, no hauling of the raw material and the average haul for the finished product was about 160 ft.

The plant for preparing the material consisted of a coke crusher or sizer, in which the cinders pass between two rolls with corrugated faces, removable in segments, a chain and bucket elevator to raise the crushed material to the screen, and the jigling screen, known to the trade as the Columbian Separator. Power was furnished by a traction engine hired by the day, and the whole apparatus housed and provided with bins and chutes, for economical handling of the cinders. This outfit, which was furnished by the Jeffrey Mfg. Co. of Columbus, Ohio, proved in every way suited to the requirements. The shaking screen is the only one which can successfully remove the dust and flake, as the material is usually moist and requires a hard jolting to separate the particles. The screen stands at an angle of 45° and has a movement as recalled by the writer of about 2 ins. at a rate of about 150 per minute. A wire screen cloth of 3 meshes to the in. removed all dust of less than ⅛ in. diameter, and practically none of greater size, the whole plant producing a beautifully clean material from ⅛ to ¾ in. in dimension.

The cinders were received in flat bottomed coal cars with side boards containing an average of about 30 cu. yds. They were shoveled from the cars onto a platform, beneath which the crusher was set, with its hopper on a level with the floor. The siding was extended beyond the plant a sufficient distance to hold 10 cars and on a grade which allowed the cars to be placed at the platform by gravity after a train was set by the switch engine. The product of the screen, which was set about 40 ft. above the crusher, fell into bins, from which the filter material could be drawn by chutes into wagons or into a small car, while the dust was drawn into the emptied flat cars and hauled away by the railroad free of charge.

A strip around the outside of the beds was first filled by wagons to a sufficient width to lay a movable track on the cinders, and the remainder was handled by means of the small car, which held about 1½ cu. yds., dumped from the side, and was run by hand by two men on the track referred to.

Roundhouse cinders were purchased direct from the Pennsylvania R. R. at a price of $8 per car. The weight per cubic yard is from 1,200 to 1,300 lbs., 439 cars, or about 12,970 cu. yds. of the raw material were required to produce the 9,579 cu. yds. of coarse screenings used, showing a loss of 26 per cent. This is slightly better than can be counted on as the cinders were of exceptional quality. It is not safe to figure on more than 65 per cent. of the raw material.

The total cost, including crushing and screening plant, foreman and all expense of every kind was as follows:

Cost of Outfit:	
Machinery	$ 850.00
Lumber	222.63
Labor on bin	87.30
Side track (labor only)	208.10
Awning	5.80
Total	$1,373.83
Repairs, new parts, etc	281.34
Cost of Material:	
438 cars of cinders at $8	3,512.00

Cost of Operation:	
Labor	$2,573.42
Coal	80.00
Use of engine	101.25
Oil	34.43
Insurance	14.00
Total	$2,803.10
Total cost	$7,970.27
Per cubic yard	0.832

The cost per cubic yard of finished material was as follows:

	Per cu. yd.
Crushing and screening plant, bins etc. (applicable only to similar quantities)	$0.144
Repairs, etc	0.029
Cinders	0.336
Handling	0.293
	$0.832

The last item can be subdivided as follows:

	Total	Per cu. yd.
Labor unloading cars	$ 462.27	$0.048
Labor at crusher and placing cinders	2,111.15	0.220
Power	215.68	0.023
Insurance	14.00	

The cost of placing in filters by means of the small cars was about $0.02 per cubic yard.

The price paid for labor varied from $1.50 to $1.75 per day averaging probably $1.60. The foreman received $2.50 per day and the engine man $3. The entire job was handled carefully and close attention to business is necessary to duplicate the results.

Cost of Sewage Treatment Works at Washington, Penn.—Donald M. Belcher gives the following information in Engineering News, Apr. 11, 1912.

The sewage treatment works for Washington, Penn., were built in 1907–8.

The plant consists of septic tanks, sprinkling filters and settling basins and has a capacity of 3,000,000 gal. of sewage per 24 hours. It is located about three miles below Washington, on the Chartiers Creek, near Arden Station.

Screen Chamber.—The sewage first enters the screen chamber, which is situated on the opposite side of the creek from the rest of the purification works. This chamber is open and divided into two sections, each of which may be shut off by stop planks. The sewage passes through two screens, the first having openings of ⅜ in. and the second openings of ¼ in.

Suction Conduit.—The sewage passes under the creek, through a 16-in. cast-iron inverted siphon, and flows, by gravity, to the pumping station, in a conduit consisting of 20-in. vitrified pipe laid in concrete.

Pumping Station.—The building is of pressed brick with sandstone trimmings, resting on concrete foundation walls, which form the lower portion of the station, in which the machinery is located. The roof is of slate carried by steel trusses.

Under pumping machinery is included one 25-hp. and two 15-hp. Gardner gas engines, one 8-in. and three 5-in. Brooks centrifugal pumps and all piping, valves and appurtenances in the pump pit. The gas engines are of horizontal, single-cylinder, two-cycle type and are fitted with hot tube ignition and compressed-air starting devices. The 5-in. and one 8-in. sewage pumps have a

Table XII.—Unit Prices, Sewage-Purification Works, Washington, Penn.

	Quantity	Unit price
Excavation	14,730 cu. yd.	$ 0.28
Concrete, roofs, 1:2:4	353 cu. yd.	11.00
reinforced walls and walls having a minimum dimension of 12 in. or less, 1:2:4	1,280 cu. yd.	7.40
heavy walls and foundations, 1:2½:5½	1,517 cu. yd.	7.00
floors, 1:2½:5½	1,412 cu. yd.	6.00
Ransome twisted steel reinforcement	30.5 tons	45.00
Cast iron pipe	56.5 tons	50.00
Special castings, bell and spigot	6.1 tons	85.00
Special castings, flanged	8.8 tons	105.00
Broken stone filtering material, local	13,730 cu. yd.	1.20
Broken stone filtering material shipped in	1,135 cu. yd.	1.60

Table XIII.—Costs of Various Parts of the Sewage-Purification Works, Washington, Penn.

Land	17 acres		$ 14,000
Screen chamber	826 cu. ft.		323
Suction conduit. 16-in. c. i. siphon	80 lin. ft.	$ 830	
20-in. suction line	257 lin. ft.	1,179	2,009
Pumping station, 28 × 50 ft.			
Building, substructure	22,300 cu. ft.	2,908	
Building, superstructure	25,200 cu. ft.	5,184	8,092
Machinery, engines and pumps		4,827	
Machinery, water supply		3,823	8,650
14-in. c. i. force main	385 lin. ft.		1,070
Septic tanks, 800,000 gal.			
Earthwork, average cut	10.5 ft.	1,379	
Concrete	1,204 cu. yd.	9,087	
Steel reinforcement	16.5 tons	743	
Valves, pipes, etc		2,700	13,909
Dosing chamber	630 cu. ft.		382
20-in. c. i. conduit to filters	190 lin. ft.	....	765
Sprinkling filters	1.5 acres		
Earthwork, average cut	1.5 ft.	1,341	
Concrete walls	454 cu. yd.	3,636	
Flushing galleries	56,700 cu. ft.	8,376	
Distributing system		9,578	
Collecting system		8,806	
Filtering material	14,865 cu. yd.	18,324	
Miscellaneous		238	50,299
Settling basin, 160,000 gal.			
Earthwork		500	
Concrete	164 cu. yd.	1,099	
Valves, pipes, etc		293	1,892
18-in. outfall conduit	165 lin. ft.	....	314
Sludge disposal			
Drying area	1.5 acres	762	
18-in. drain from septic tanks	416 lin. ft.	652	
10-in. drain from settling basin	165 lin. ft.	289	
6-in. c. i. force main	202 lin. ft.	148	1,851
4-in. c. i. water main	430 lin. ft.	....	227
Miscellaneous		....	1,045
Total cost (exclusive of engineering)		....	$104,828
Engineering, 10.1 %		....	10,594
Total cost			$115.422

TABLE XIV.—UNIT COSTS OF STRUCTURES COMPOSING SEWAGE-PURIFICATION WORKS, WASHINGTON, PENN.

	Capacity	Unit price
Pumping station building:		
Substructure	22,300 cu. ft.	$0.13 per cu. ft.
Superstructure	25,200 cu. ft.	0.21 per cu. ft.
Total	47,500 cu. ft.	0.17 per cu. ft.
Septic tanks	800,000 gal.	$17,380 per 1,000,000 gal.
Sprinkling filters	1.5 acres	$33,530 per acre
Settling basin	160,000 gal.	11,820 per 1,000,000 gal.

	Capacity	Cost	
Screen chamber	3,000,000	$ 108	Per
Suction conduit		670	
Pumping station	gallons	5,580	1,000,000
Force main		357	
Purification plant:	per		gallons
Septic tanks		4,636	
Dosing chamber		127	
Conduit to filters	24 hours	255	per
Sprinkling filters		16,766	
Settling basin		630	24 hours
Outfall		105	
Sludge disposal		617	
Water main		76	
Miscellaneous		314	
Total purification plant		$23,526	
Total purification works (except land and engineering)		30,276	
Total purification works (including land and engineering)		38,474	

combined maximum rated capacity of 5,040,000 gal. per 24 hours, against a head of 20 ft., and the 5-in. sludge pump has a maximum rated capacity of 1,080,000 gal. per 24 hours, against a 7-ft. head.

The water supply, to furnish water for cooling the gas engines and for flushing purposes, is obtained from two wells which were driven near the station. The water is lifted from these wells by compressed air into a suction well, of 16,500 gal. capacity, just outside of the station, and pumped from this into a concrete storage tank, situated on rising ground about 175 ft. from the station. This tank has a capacity of 4000 gal. and is 13 ft. above the gas engines.

Under this item is included the cost of drilling two wells (125 ft. deep); a 20-hp. Gardner gas engine; a Gould triplex pump of 150 gal. per min. capacity; a Hall air compressor having a capacity of 50 cu. ft. of air per min., against 50 lb. pressure; an air receiver, 2 ft. in diameter by 8 ft. long; air piping to the wells; concrete suction well and storage tank; 4-in. cast-iron pipe line between the station and the storage tank and the necessary valves, piping and appurtenances in the station.

Septic Tanks.—The sewage is lifted approximately 20 ft. through a 14-in. cast-iron main, into the septic tanks. Four compartments are formed, by reinforced-concrete dividing walls, each being 25 × 100 ft. in plan and 11 ft. deep, and they are covered by a 4-in. flat reinforced-concrete roof, carried on beams and piers. Adjacent to the tanks is a small uncovered dosing chamber in which is a float operating a butterfly valve which automatically controls the flow of sewage from the septic tanks to the filters.

From the dosing chamber the sewage flows, by gravity, through a 20-in. cast-iron pipe line to the sprinkling filters.

Sprinkling Filters.—The filters are four in number, each being 100 × 150 ft. in plan, and are surrounded by concrete walls on all sides. Along both sides of each filter are covered galleries, 4 ft. wide and 6 ft. high, and into these extend the ends of the tile underdrains. A 4-in. cast-iron water main runs the length of each gallery to provide for flushing.

The main distributors consist of 15-in. vitrified pipe embedded in the walls of the central gallery and the lateral distributors are 5-in. vitrified pipe carried in the top of small concrete walls.

Five-inch half-tile, laid on a 4-in. concrete floor, form the lateral collectors. The main collectors, which are built of concrete, run the length of each filter and empty into the effluent conduit, which is formed by vitrified pipe embedded in the walls.

The broken-stone filtering material, except the upper 6 in., was taken from a local quarry and was a low-grade limestone, very close grained and hard, but liable to crumble when exposed directly to snow and ice. For this reason, a better grade of limestone, from Ohio, was used for the upper 6 in. Two sizes of stone were used, the larger being 2½ to 4 in. and the smaller 1 to 2½ in. The average depth was 6 ft. 10 in.

Settling Basin.—This is an open basin, with concrete walls and floor, divided into two parts for purposes of cleaning. The sewage passes out of the basin over a weir and flows by gravity through an 18-in. vitrified pipe, to the creek. There is a flap gate at the end of the pipe protected by a concrete headwall.

Sludge Disposal.—An area of about one and one-half acres was graded and underdrained to provide a drying area for the sludge.

The sludge from the septic tanks flows to the disposal area by gravity through an 18-in. vitrified pipe line. The sludge from the settling basins flows through a 10-in. vitrified pipe, laid in concrete, to the pumping station and is pumped from there through a 6-in. cast-iron force main to the drying area.

Unit Prices.—In Table XII are given the unit prices of the principal items.

Stone for the concrete was taken from a quarry located about 1000 ft. from the plant. The sand was Ohio River sand and was mixed with the crusher dust in equal parts.

Costs.—The costs of all the structures are given in Table XIII. These costs are the total costs of the work to the Borough of Washington and not the actual cost to the contractors. In apportioning the costs to the different structures, all pipes, valves, etc., inside of the outside neat lines of each structure, were considered to belong to that structure.

Unit Costs.—In Table XIV are given the unit costs of some of the structures, based on their capacities.

It is estimated that the present purification works will treat the sewage from a population of about 40,000 and the per capita costs, in the following table, are based on this figure.

	Cost of construction	Cost per capita
Pumping station and works preparatory to purification plant	$20,251	$0.51
Purification plant	70,577	1.76
Total purification works (exclusive of land and engineering)	90,828	2.27
Total (including land and engineering)	115,422	2.89

Cost of Earthwork, Concrete, Filter Media and Drains at the Montezuma, Iowa, Sewage Treatment Plant.—The following data are given in Municipal Journal and Public Works, Oct. 18, 1919.

The town contains a population of about 1,500 and the plant was designed for 2,000, assumed as the population twenty-five years hence. The plant consists of an Imhoff tank, siphon chamber, two intermittent sand filters and a sludge bed.

The tank is of the circular type, with an area of gas vent 23.6 per cent of the whole superficial area of the tank. This is a larger area than is found in most plants, but in view of the trouble that has been caused by too small vents and the extreme freshness of the sewage, liberal allowance for both scum and sludge were thought desirable.

The sludge storage capacity up to within three inches of the bottom of the inverted V beam forming the overlap for the vents is about 1.67 cubic feet per capita on a basis of 2,000 future population, and up to the slots is about 1.88 cubic feet per capita.

On the basis of 100 gallons per capita per day (which allows for ground water infiltration) with uniform flow throughout the 24 hours, the settling period in the tank would be 2.42 hours while 1200 population is connected with the sewers, and 1.45 hours when 2,000 are connected; while if all the sewage be assumed to reach the plant in 18 hours, the settling period would be 1.82 hours and 1.09 hours respectively.

One important and rather new feature provided in this tank, is an 8 in. drain just below the sludge outlet. The flow line of this drain is such that the sewage may readily be drawn below the slots in case it becomes necessary to work upon the walls of the settling chamber. It has been found in actual operation of Imhoff tanks in towns of the size of Montezuma, that not infrequently the sedimentation chamber is allowed to become completely sludged up and thus transformed into a small septic tank. In order to clean out the sedimentation chamber, it has been found necessary to lower the sewage below the slots and then force the sludge down through the slots, carefully squegeeing the walls and sloping aprons.

Prof. Dunlap of Iowa State University (the designer of the plant) gives the cost of the plant on the basis of $4.00 for labor per day of ten hours until late fall, after which the same was paid for eight hours; and teams at $7.00 per day of the same length. The length of haul from the railroad siding to the plant was 1.3 miles, over a fair road with no upgrades. Superintendence, overhead and profit are not included.

EARTH WORK

	Type	Estimated cu. yds.	Cost per cu. yd.
Filter beds	Slip work	1060	$0.47
Siphon chamber	½ slip and ½ hand	187	0.78
Imhoff tank	Hand before banks caved	408	0.82
Imhoff tank	After cave-ins with bracing	408	2.70

Sodding berms of filter beds, $0.20½ per sq. yd.

COST OF 1:2:4 CONCRETE, PER CUBIC YARD

	In Cylindrical Walls of Imhoff Tank	In Siphon Chamber Includes only walls and footings; roof and floor omitted
Cement, at 6.4 sacks per cu. yd. f. o. b. Montezuma ($2.28 per bbl.)	$ 3.65	$ 3.65
Hauling by team—to barn, 8½c., to job, 9c.	0.18	0.18
Sand, 0.45 cu. yd. at $2.65	1.19	1.19
Gravel, 0.90 cu. yd. at $3.59	3.23	3.23
Steel reinforcement	1.49	1.59
Setting forms and reinforcement	2.93	2.18
Mixing and pouring; heating sand, gravel and water.	1.98	1.65
Total cost per cubic yard in place	$14.65	$13.67

COST OF FILTER SAND AND GRAVEL, PER TON

	Filter sand	Filter gravel
Cost f. o. b. sand company	$0.35	$1.25
Freight	0.90	0.90
Unloading from cars (mostly box cars)	0.063	0.095
Hauling by team 1.3 miles	0.39	0.39
Unloading from wagons	0.022	0.022
Leveling and spreading	0.131	....
Total cost per ton in place	$1.86	$2.66
Total cost per cu. yd.	$2.78	$3.59
Total amount required for two beds	1390 cu. yd.	194 cu. yd.
Total required for sludge bed	21 cu. yd.	32 cu. yd.

COST OF 6 IN. VITRIFIED FARM DRAIN TILE IN FILTER BEDS

Cost of tile per ft. f. o. b. Montezuma	$0.08
Hauling by team 1.3 miles	0.005
Trenching	0.039
Laying	0.01
Graveling at $2.66 per ton and spreading at $0.04 per ft.	0.44
Total cost per ft. of trench	$0.574

LAYING 15-IN. VITRIFIED PIPE SEWER MAIN, 1425 FT. IN LENGTH

Cost of pipe per ft. f, o. b. Montezuma	$0.65
Hauling by team 1.3 miles	0.033
Trenching, including back-filling	0.376
Laying, including mortar	0.077
Total cost per ft. of trench	$1.14
Cost of taking up old 15-in. sewer and back-filling per ft.	$0.246

Cost Estimates for Intercepting Sewer and Treatment Plant at Detroit, Mich.—Engineering and Contracting, July 9, 1919, gives the following:

Extensive studies of costs and methods of treatment of Detroit sewage have been made in connection with the recent Report of the Consulting Sanitary Engineer on the Pollution of Boundary Waters. One project recommended the immediate construction of two low level intercepting sewers discharging through pumps to two separate treatment plants.

The treatment plant consists of Imhoff tanks, including inflowing and outflowing channels; grit chambers; sludge drying beds; disinfection plant.

Imhoff tanks were proportioned on the basis of a sedimentation period of two hours, when the rate of flow equals 125 per cent of the average rate of flow, and storage room for sludge of 2 cubic feet per tributary person. The estimate for grit chambers, bar screens, etc., was made by making an allowance of 5 ct. per tributary person, this figure having been arrived at from a review of published information regarding existing plants. The area of sludge drying beds required was based on a load of six persons per square foot of net drying bed area.

The total estimated cost of the treatment works for treating 162.7 M. G. D. from a population of 950,000 is $2,077,200. The cost per million gallons for the different elements is as follows:

Imhoff tanks	$ 8,568
Sludge beds	971
Screens and grit chamber	292
Disinfection	600
Covering ventilation and parking	2,336
Total estimated cost per M. G. D.	$12,767

Cost of Sewage Treatment Works at Dallas, Texas.—The Engineering News Record, July 5, 1917, gives the following data:

The disposal works built at this time consist of a grit chamber, 12 Imhoff tanks, a sludge-drying bed and a discharge conduit. The grit chamber is 100 ft. long and is divided into three parallel sections. Its cross-section is such that, combined with the hydraulics of the channel leading to the tanks, the velocity of the sewage in the chamber varies but slightly, despite a considerable variation in the sewage flow.

The channels leading to the Imhoff tanks were designed for a maximum flow of 22,000,000 gal. daily, and it was expected that the present average sewage flow would be about 11,000,000 gal. daily. During the past year, however, the city water-supply has been completely metered and the water consumption thereby reduced 50%. This has affected the sewage flow, so that only 5,500,000 gal. daily reaches the disposal works.

Tanks' One-Way Flow

The Imhoff tanks are of the rectangular horizontal-flow type and have a combined capacity in the settling chamber of 1,312,000 gal. and a sludge-storage capacity of 440,000 gal. The settling chamber of each tank is 45 × 33 ft. in plan, and the sludge chamber is 29 × 19 ft. The tanks are 33 ft. deep. The sewage is divided into 12 parts, each part flowing through one tank. There is but one sludge compartment to each tank, and therefore no provision is made for reversing the sewage flow. Devices for agitating the sewage with fresh water are provided. Sludge is to be withdrawn through 8-in. pipes leading to a central open sludge channel and thence through a 12-in. pipe by gravity to the sludge bed. The slopes of the bottoms of the sedimentation chambers are 1.36 on 1. The flattest slope in the sludge chamber is 1 on 2.25.

The sludge bed is 141 × 145 ft. in plan. It has 14 in. of graded sand and gravel underdrained by 3-in. vitrified pipe laid with open joints 4 ft. c. to c. Sludge is distributed over the bed through seven concrete channels, each carrying a track on which run small dump-cars used to remove the dried sludge.

Clarified sewage from the tanks unites at a central point and passes over a weir into the discharge conduit and thence to the river. A continuous automatic record of the sewage flow is kept. The discharge conduit consists of 300 ft. of 24-in. pipe and 2042 ft. of 36 × 48-in. monolithic concrete sewer.

The complete plans call also for six acres of sprinkling filter followed by secondary settling tanks of the Imhoff type, but funds for this work were not available, as the city's bond limit (at the time of issuing the sewage-disposal bonds) limited the amount of the issue. The plant as constructed is built with provision made for the addition of the final treatment.

The cost of the work was as follows:

Grit chamber	$ 2,030
Influent channel	547
Imhoff tanks	68,647
Sludge bed	17,957
Water supply and buildings	4,435
Miscellaneous	2,269
Total	$95,885

Activated-Sludge Plant at Escanaba, Mich.—Engineering Record, Feb. 10, 1917, publishes the following:

The 1,000,000-gal. activated-sludge plant built at Escanaba, Mich., is located at the south end of the city, at the outlet of a new 3½-mile trunk sewer and about 2 miles from the outlet of the old trunk sewer. The new trunk serves a district which is not as yet very thoroughly settled except at the extreme north end, and will provide a flow for the next few years not to exceed 300,000 gal. per day. The old sewer, which has practically all the connections it will ever have, serves about 10,000 persons using 100 gal of water per day. Plans and estimates have been made for a pumping station and force main to connect the old system with the disposal plant.

Daily Capacity 1,000,000 *Gallons.*—The general layout consists of two long rectangular aërating tanks with a longitudinal vertical baffle, so that the inlet and outlet are at the same end, the end adjoining the two settling tanks. The total capacity of the aërating tanks is 220,000 gal.; and as one-half of the total flow occurs in nine hours, a four-hour aëration period will give a daily capacity of nearly 1,000,000 gal.

The total capacity of the two settling tanks is 86,000 gal., which will give, with the corresponding four-hour aëration period, 93 minutes for the sedimentation period. By decreasing the aëration period to three hours the sedimentation period will be 70 minutes and the capacity of the plant will be 1,300,000 gal. per day.

Filtros plates having an area of 360 sq. ft. are used in the ridge and valley aëration tank, which has an area of 30,000 sq. ft. Thus the diffusion ratio is 1 to 8.3.

Air is distributed to the base of the plates from a Taylor spiral-riveted, galvanized-steel header, diminishing in size from 8 in. to 6 in. and then to 4 in. The drops from the header are 4-in. Byers galvanized wrought-iron pipe. The blower house is located at the opposite end of the aërating tanks from the settling tanks, and inserted in the main is a Venturi meter with U-tube monometer. Two Connersville blowers will furnish the air. The rated capacities are 1200 and 2400 cu. ft. per minute, and the motors driving them are 40 and 75-hp. General Electric 2200-volt motors.

Four 6-in. drain pipes, laid lengthwise of the aërating tanks, have 4-in. openings at each casting. They are connected with a 6-in. Fairbanks-Morse centrifugal pump located in a pump pit under the blower-house floor.

Sludge will be removed from the settling tanks by Harris nozzles through 8-in. cast-iron pipes back into aërating tanks, or to the sludge tank in the press house, where it may be further aërated from a 1-in. wrought pipe grid with perforations in the pipes 1 in. apart. From the sludge tank the sludge will be pumped by a 3-in. motor-driven centrifugal pump into a 6 × 9-in. Worthington filter press. The cakes will be wheeled to a small shed adjacent and stored on racks until disposed of. The supernatant water in the sludge tank

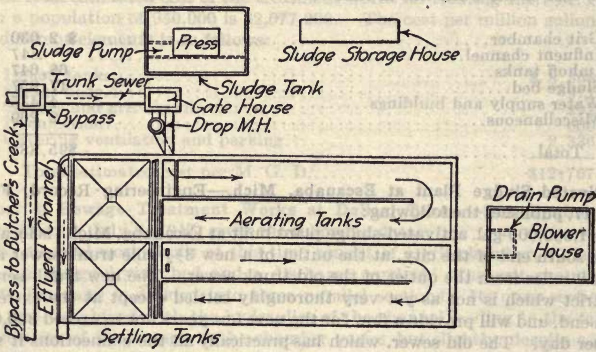


FIG. 1.—Aërating tanks are simple longitudinal basins with single baffle.

will be drawn off by a perforated steel pipe on a flexible elbow, discharging into the drain sump at the blower house.

Excavate Coffer Hydraulically.—High ground-water level was at El. 103, making a head of about 24 ft. for the contractor to work against in getting in the points of the settling tanks. Excavation down to water, (6 ft.) was carried out by team and scraper.

A concrete cofferdam, 24 × 44 ft. in inside dimensions and 5 ft. deep, was then built around the site of the settling tanks.

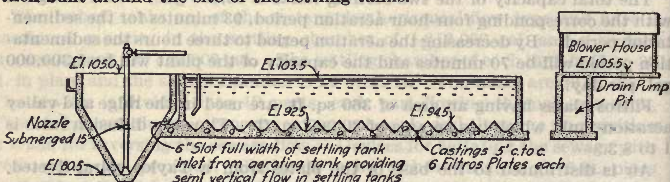


FIG. 2.—Longitudinal section shows connection between settling and aëration tanks.

A 4-in. Morris centrifugal pump, driven by an 8-hp. Novo gas engine, was placed on the cross-bracing. A sump midway between the points of the settling tanks was dug by hand and the pump started. The discharge side had a tee next to the pump, one outlet of which led to the spoil bank and the other to a 1½-in. nozzle on a fire hose. When the water in the sump had been pulled down deep enough, the nozzle was turned on and the sand washed from under the wall into the sump. In this way the first 5-ft. section was lowered its full length. Then a 7½-ft. section was added to it, and after a week's curing pumping was resumed, using this time a 25-hp. motor instead of the gas engine. The cofferdam was sunk as before until the bottom edge reached El. 81.5, when it was a simple matter to place forms and concrete in the dry. The material was uniformly a medium coarse sand. Water from the excavation for the aërating tanks was led to the cofferdam pump, so that one pump took care of practically all the water.

The total cost of the plant, including the press, blowers, motors, and pumps, is $38,750.

Activated-Sludge at San Marcos, Tex.—Henry E. Elrod gives the following in Engineering News, Feb. 8, 1917.

In regular daily service in San Marcos, Tex., there is a practical and highly satisfactory activated-sludge sewage-disposal plant having a capacity for treating 150,000 gal. of domestic sewage per 24 hr. The plant was designed and built by Ashley F. Wilson, engineer-manager for the San Marcos Utilities Co., and has been in operation since about Sept. 1, 1916.

The plant consists of an aëration tank 16 ft. wide by 40 ft. long and about 8½ ft. deep from the flow line of the sewage to the top of the filtros plates. The tank is divided into four channels by longitudinal concrete baffles, each channel having a row of filtros plates 12 in. square at the apex of inverted pyramids down its center. The filtros plates are spaced 3 ft. c. to c., there being 52 plates all told. The opposite end of each channel is open, thus allowing the sewage to flow in series from the inlet at the left to the outlet at the right. The outlet opens into the settling tank, which is 10 ft. wide by 25 ft. long and 25 ft. deep, the walls having a vertical batter of 1 to 2.

Aëration is accomplished by means of a 6 × 10 in. Connersville blower of the Boston type, having a rated capacity for 260 cu. ft. of free air per minute under 5 lb. pressure. It is actuated by an electric motor requiring an average of 4 kw. of current. The sludge lift is operated by air from this blower.

When the plant was first put into operation, the distribution of air through the filtros plates was uniform and satisfactory. Later, however, some of the plates showed signs of erratic action. Upon investigation it was found that one corner of one plate had been cut out by the action of the air and the other plates had become choked to such an extent that their usefulness was destroyed. As each plate failed, a small pipe with its lower end open and the upper end connected to an air line was substituted with satisfactory results.

The total cost of the completed plant, in round figures, was $3500, which sum included the lowering of the bottom of the settling tank after the plant had been in operation for a short time. The plant is near the city, but it produces no offense whatever. The operation of the plant is simple—it requires but a few minutes' attention each morning.

Activated-Sludge Power Costs.—Gustav J. Requardt gives the following in Engineering News, Jan. 14, 1917:

Given the amount of air delivered by a blower (requiring a definite amount of power for operation), the ratio of air to sewage necessary for the degree of treatment desired and the unit cost of power, it is a simple calculation to find the power cost for sewage treatment by the activated-sludge method. When many calculations are to be made at one time, the writer has found that much work may be eliminated by the construction and use of a set of curves in which all factors are considered to vary within limits suited to average conditions.

The curves herewith presented, are from data from only one manufacturer of air blowers (the Connersville Blower Co.) but it is a simple matter to plot on the same sheet the values as given for the several other makes of air blowers and compressors.

Construction of Diagrams.—Fig. 1 is made by plotting as abscissas the power necessary to drive the machine, and as ordinates the corresponding free air delivered, there being separate curves for various air pressures. Plotting thus the information taken from the catalogs of the various makers, a quick comparison of efficiencies may be made.

Fig. 2 is made up from Fig. 1. The ordinates remain the same (free air delivered) while the abscissas are obtained by dividing the power by the

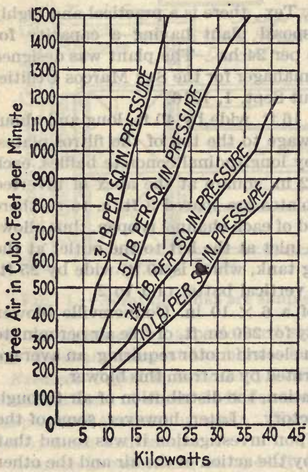


FIG. 3.

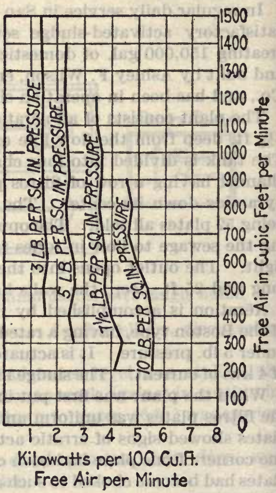


FIG. 4.

FIGS. 3 and 4.—Power required to deliver free air.

corresponding volume of free air in units of 100 cu. ft. For example: At 5 lb. per sq. in. pressure a 22-kw. machine will deliver 900 cu. ft. of free air per minute; therefore, 2.4 kw. of power is required per 100 cu. ft. of free air per minute in a machine capable of delivering air at the rate of 900 cu. ft. per min. It is to be noticed that in the type of blower taken as an illustration for these curves the efficiencies but slightly increase as the machines become larger.

Fig. 3 is made by plotting as ordinates the kilowatts per 100 cu. ft. of free air per minute, and as abscissas the kilowatt-hours per million gallons of sewage, the radiating solid lines giving the various proportions of volumes of free air in cubic feet to volumes of sewage in gallons. The same radiating lines also give relations between sewage flow and volume of free air required for treatment. The relations between kilowatt-hours per million gallons of sewage treated and cost of power per million gallons are also plotted on this sheet, the radiating dotted lines representing the various unit costs of power.

The method of proportioning air supply to sewage flow, volume for volume, is far simpler, in the writer's mind, than any other method. Some engineers prefer to state the volume of air supply to the area of tank surface per unit of time. This brings the dimensions of the sewage tank or container and the length of time of air treatment into the problem, where these elements do not belong; they can be much better handled in the actual design of the plant. It is well to remember, then, in using the curves, that *volume* of air supply is proportional to *volume* of sewage treated, irrespective of the size or shape of tank or of the length of time of air agitation and treatment.

How to Use the Curves.—To illustrate how the curves are to be used, let us assume that the sewage of a city is to be treated by the activated-sludge method and that the cost of power is required. Assume that experiments on the sewage have shown that the necessary purification is obtained by applying 1 cu. ft. of free air per gallon of sewage; that the proper depth of tank requires air

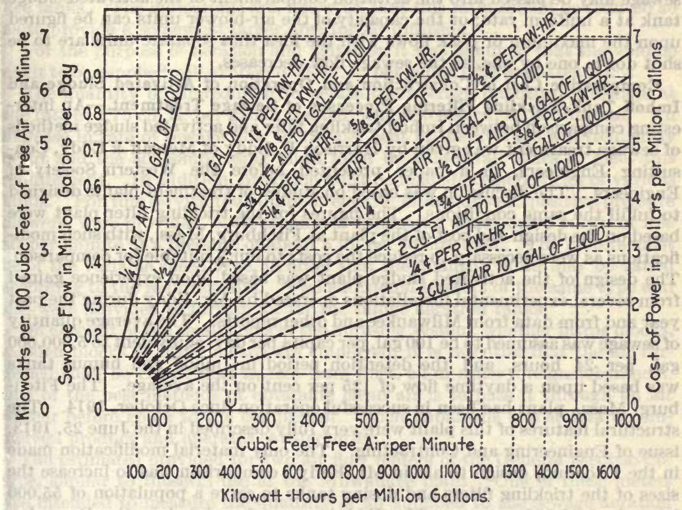


FIG. 5.—Relation between sewage flow, air and power required in activated-sludge plants.
1,000,000 gal. per day = 694 gal. per min.

to be delivered at a pressure of 5 lb. per sq. in.; that current in the locality in question costs ⅞c. per kw.-hr. The sewage flow may be assumed at 1,000,000 gal. per day. It is to be noted here that, for larger flows, a straight-line relation holds between sewage flow and air required and that the air can be supplied by any number of blowers or compressors. Larger problems can thus be split down to smaller units and each solved separately.

With the elements above assumed having been determined, we are now ready to make use of the curves. Enter Fig. 3 at the ordinate for 1,000,000 gal. sewage flow per day and note where this ordinate strikes the radiating solid line for 1 cu. ft. air to 1 gal. liquid, the abscissa at this point reading 694 cu. ft. free air per minute. This determines the size or capacity of air blower required. Now enter Fig. 2 at the ordinate for, say, 700 cu. ft. of free air per minute and note where it strikes the line for 5 lb. per sq. in., the abscissa at this point reading 2.4 kw., of power per 100 cu. ft. of free air per minute. Again using Fig. 3, note where the ordinate for 2.4 kw. per 100 cu. ft. air per minute strikes the radiating solid line for 1 cu. ft. air to 1 gal. liquid. The abscissa at this point reads 400 kw.-hr. per million gallons of sewage treated. Reading upward along this abscissa, note where it strikes the radiating dotted line for ⅞c. per kw.-hr. The ordinate at this point, toward the right-hand margin, reads $3.50 cost of power per million gallons of sewage treated, which is the result desired.

In the example given above, no recognition has been taken of the fluctuation of sewage flow as it reaches the plant. To apply to each gallon of sewage its proper volume of air, a detention chamber can be utilized so that the raw sewage may be passed into the agitation compartment of the activated-sludge tank at a uniform rate; or the capacity of the air-blower units can be figured upon the maximum or peak flows with the idea that separate units are to be shut down, one by one, as the sewage flow decreases.

Comparative Cost of Construction and Operation of Activated Sludge and Imhoff Tank-Trickling Filtering Processes of Sewage Treatment.—An interesting comparison between Imhoff trickling filter and activated sludge methods of sewage treatment was given by Harrison P. Eddy of Metcalf & Eddy, Consulting Engineers, in a paper presented before the Western Society of Engineers. The discussion was based on studies of treatment plants designed to fulfill the same conditions. The figures for the trickling filter plant were based on the design and cost of the plant at Fitchburg, Mass., with such modifications as were necessary to reduce the costs to units suitable for comparison. The design of the activated sludge plant was based upon experience gained from several experimental installations operated by Mr. Eddy during the past year and from data from Milwaukee and other reports. The average quantity of sewage was assumed to be 100 gal. per capita per day, equivalent to 5,500,000 gal. per 24 hours, and the detention period in Imhoff and humus tanks was based upon a daytime flow of 125 per cent on the average. The Fitchburg, Mass., plant has been in successful operation since October, 1914. The structural features of this plant were very fully described in the June 25, 1913, issue of Engineering and Contracting. The only material modification made in the Fitchburg design to aid in Mr. Eddy's comparison was to increase the sizes of the trickling filters and dosing tanks to serve a population of 55,000 instead of 40,000 persons. Mr. Eddy's paper is printed in the December Journal of the Western Society of Engineers, from which the following matter is given in Engineering and Contracting, Feb. 14, 1917.

The plant for the activated sludge process was designed as far as possible to meet the same conditions as those for which the trickling filter plant was built. The same type of structures has been used where applicable, and an effort was made in every way to make the two plants strictly comparable, both being designed to serve 55,000 persons.

The grit chamber, screens and venturi meter equipment are included without change in the activated sludge plant, the requirements being the same in each case.

The sewage aeration tanks were designed to operate on the continuous flow plan. The tanks were rectangular in plan, each unit being 30 ft. wide by 90 ft. long inside, of a type similar to the Imhoff tanks in the trickling filter plant. Compressed air was supplied to the tanks through a piping system leading to a series of filtros blocks located in the bottom of the tank. Each tank unit was divided by means of thin partition walls into four longitudinal channels 7 ft. 2 in. wide. Provision was made for a depth of 10 ft. of liquid above the top of the filtros blocks. It was intended to operate two tank units in series and five double tank units in parallel; that is, the sewage will enter one tank, pass longitudinally back and forth through the four channels in that tank, then to the second tank and back and forth longitudinally through the four channels of that tank to the point of discharge, making a total distance traveled of about 700 ft. Sufficient tank capacity was provided for an average period of aeration of 4½ hours, with sludge capacity amounting to 25 per cent of the total tank capacity. Under these conditions the average horizontal velocity would be about 2.6 ft. per minute. The ratio of total tank floor surface to area of aerating system was 8.5 to 1, which is the basis of the present Milwaukee tanks. The indications are, however, that this ratio should be reduced so as to provide a somewhat larger area for air diffusion.

For the purpose of aeration and agitation it was assumed that the volume of air to be supplied will average 1.75 cu. ft. per gallon of sewage treated.

The quantity of air required to aerate the average quantity of sewage at the rate of 1.75 cu. ft. per gallon treated, will be 6.680 cu. ft. per minute. An increase in rate of sewage flow to 150 per cent of the average will frequently occur and the air compressing plant must be able at all times to meet this requirement. In addition, provision must be made for emergencies of various kinds. For this service four units of electric motor-driven, positive pressure blowers, were provided, each capable of furnishing about 3,200 cu. ft. of free air per minute at a pressure of about 5 lb. per square inch. The motors must be of the variable speed type, in order that the quantity of air may be varied according to the requirements. Two additional blowers of the same type and size were provided to furnish air for the sludge aeration tanks.

On account of the small pores in the diffusing system, whether filtros blocks, wooden blocks or other means are employed, it is essential that the air furnished shall be clean; that is, free from dust, oil or other foreign substances. One of the best methods of obtaining clean air is to pass it through an air washer before going to the compressor. Such apparatus is a standard commercial product and operates satisfactorily.

The estimates provided for two air flow meters of the General Electric Co. type, similar to those in use at the Milwaukee plant. One of these meters was intended to measure the quantity of air supplied to the sewage aeration tanks, and the other the air supplied to the sludge aeration tanks. In a large plant it may be advisable to install additional meters to measure the quantity of air supplied to air lifts, but in the comparison no allowance was made for such additional apparatus.

A building will be required to house the several air compressor units amounting, in this particular case, to six large positive pressure blower units and two small reciprocating units for operating the air lifts. This building may also house the air washer, air meters, transformers and other equipment.

The estimates included six sedimentation tanks. Each was of the vertical flow type, cylindrical in form with inverted conical hopper bottom terminating in a deep well 4 ft. in diameter, similar to the tanks at Milwaukee. The tanks provided for sedimentation for a period of ½ hour, on the continuous flow plan, with space for sludge amounting to 25 per cent of the total tank capacity. The total depth of water and sludge, in the central well, was 35 ft. The tanks at Milwaukee were constructed with hopper bottoms on a slope of 1 to 1, but experience has proven that steeper slopes are necessary if the sludge is to slide easily into the central well. These tanks were so designed that the sewage and sludge will enter the tank at the center, flow downward and under the edge of the distributing cylinder, thence upward and out through collecting weirs arranged around the circumference of the tank. Each of the central sludge wells will be provided with an air lift to raise the sludge from the sedimentation tanks to the sludge aeration tanks, or into the influent of the sewage aeration tanks.

Two units of sludge aeration tanks were provided of a type similar to the sewage aeration tanks, but differing in that the partition walls were made heavy enough to withstand water pressure, thereby making each channel a separate sub-unit. The general dimensions of channels were the same as in the sewage aeration tanks; that is, 7 ft. 2 in. wide and 90 ft. long, provision being made for a depth of 10 ft. The total capacity of sludge aeration tanks provided is 328,000 gal. which is equivalent to 0.8 cu. ft. per capita, or about 60,000 gal. per million gallons of operating capacity.

It was planned to provide one air lift in a well to serve the eight sub-units of sludge aeration tanks, and a similar lift for each of the sedimentation tanks.

It was estimated that the activated sludge process will produce about 4,500 gal. of sludge per million gallons of sewage. Doubtless this quantity will vary considerably under different conditions. It is largely dependent upon the proportion of water contained in the sludge. For the average quantity of sewage for which this plant was designed, 5,500,000 gal. per 24 hours, the quantity of sludge produced daily will be 24,750 gal. For the purposes of this comparison it was assumed that the sludge will be dried on sand drying beds from which it can be removed to a dump.

It is recognized that important experimental work is being done to develop suitable dewatering and drying processes that will make it economically possible to dry the sludge to 10 per cent moisture and thus make it saleable as a low-grade fertilizer or as fertilizer base.

For the purpose of estimates it was assumed that the sludge drying beds can be dosed an average of 15 times per year to a depth of 12 in., thus requiring a total net area of sludge beds of 80,500 sq. ft. To this should be added a sufficient area to care for sludge during the winter months (Dec. 15 to March 15) and to allow for drawing of water collecting on the surface of the sludge. To provide for these contingencies the area should be increased 50 per cent to 120,750 sq. ft., equivalent to 2.76 acres net area, or 2.2 sq. ft. per capita. If sludge bed units of the same size and type as those for the trickling filter plant, are used, there will be required 77 such units, or about 7 times the area required for the trickling filter process. These sludge beds were suitably underdrained and provided with a system of narrow gage tracks and cars for removing the sludge to the sludge dump whence it can be carried to a point of disposal.

Cost of Construction.—The cost of the trickling filter plant was based on the unit costs of construction of the trickling filter plant at Fitchburg, Mass., which was built by contract, bids being received in May, 1913. Cost figures obtained in this way are more nearly representative of normal conditions than if based on the high cost of construction prevailing at the present time. As far as possible the same unit costs of construction have been applied to the estimates of the activated sludge plant, that the two estimates may be comparable.

The estimated cost of the trickling filter plant is given in Table XV. In addition to the main features, a number of items are included which go to make

TABLE XV.—ESTIMATED COST OF IMHOFF TANK-TRICKLING FILTER PLANT

	Cost excl. eng'g and adminis tration. Total	Unit cost, excl. eng'g and administration Per capita	Per M. G. D.
Grit and chamber screen	$ 10,000	$0.18	$ 1,818
Venturi meter chamber	3,000	.05	545
Imhoff tanks, incl. air lifts for sludge	64,500	1.17	11,720
Air compression equipment	800	.01	145
Sludge beds including underdrains	4,800	.09	873
Trickling filters 10 ft. deep (2.75 acres)	188,500	3.43	34,300
Dosing tanks and apparatus	16,600	.30	3,020
Secondary settling tanks	9,000	.16	1,637
Sludge pumping equipment and building	2,000	.04	364
Conduits and pipe lines, incl. overflow	10,600	.19	1,925
Effluent channel	1,300	.02	236
Roadways	9,100	.17	1,655
Laboratory building and equipment	15,200	.28	2,762
Grounds, trees, planting, etc	1,700	.03	309
Miscellaneous work, 4 % of total, excl. land	13,300	.24	2,420
Land	25,000	.45	4,550
Total	$375,400	$6.81	$68,279
Add 15 % for engineering and administration	56,310	1.04	10,221
Grand total	$431,710	$7.85	$78,500

For 55,000 persons = $7.85 per capita.
For 5,500,000 gal. per day = $78,500 per m. g. d.

up the complete plant. It should be noted that the amount included for cost of land, includes not only the land required for the treatment plant, but a total area of about 117 acres, sufficient not only for all purposes of sewage treatment but also more than sufficient to properly isolate the plant. Under miscellaneous work are included such items as extension of the water supply, electric lighting system, and other features of minor importance not covered by the principal items. It is expected that for a plant of this character administration charges may easily amount to 3 per cent and engineering to 12 per cent, making a total of 15 per cent to be added for these items. The total estimate of the Imhoff tank—trickling filter plant for a city of 55,000 population, is $431,710. This is equivalent to $7.85 per capita, or $78,500 per million gallons per day for the assumed flow of 5,500,000 gal.

The estimated cost of the activated sludge plant is given in Table XVI. In addition to the features already described, it will be noted that several items have been included to make the plant complete. As stated in the case of the trickling filter plant, the item of $25,000 for land includes about 117 acres. It may not ultimately prove necessary to isolate the activated sludge plant, in which case a credit in favor of this plant should be made on account of the small area of land required. In this case, as in the other, 15 per cent has been added to cover the cost of administration and engineering charges. It will be seen that the total cost of the activated sludge plant is $313,880, which for a population of 55,000 persons is equivalent to $5.71 per capita, and $57,100 per million gallons per day.

Cost of Operation.—An estimate has been made of the cost of operation of the trickling filter plant, based principally on the experience at Fitchburg, for the years 1915 and 1916. From data furnished by David A. Hartwell, Chief Engineer, deductions have been made for certain expenditures pertaining to construction rather than operation. The items for 1916 (with estimates for November, the last month of the fiscal year) are shown in Table XVII, from

TABLE XVI.—ESTIMATED COST OF ACTIVATED SLUDGE PLANT

	Cost excl. eng'g and adminis-tration. Total	Unit cost, excl. eng'g and administration Per capita	Per M. G. D.
Grit chamber and screen	$ 10,000	$0.18	$ 1,818
Venturi meter and chamber	3,000	.05	546
Sewage aeration tanks	78,100	1.42	14,200
Sludge aeration tanks, incl. air lifts	17,500	.32	3,180
Sedimentation tanks, incl. air lifts	8,300	.15	1,510
Air compressing equipment	22,600	.41	4,110
Air meters—2	700	.01	127
Air washer—1	600	.01	109
Power house	29,700	.54	5,400
Sludge beds, incl. underdrains	31,400	.57	5,710
Conduits, pipe lines and overflow	10,000	.18	1,818
Effluent drain	1,300	.02	236
Roadways	8,300	.15	1,510
Laboratory building and equipment	15,200	.28	2,760
Grounds, trees, planting, etc	1,700	.03	309
Miscellaneous work, 4 % of total, excl. land	9,540	.17	1,735
Land	25,000	.45	4,540
Total	$272,940	$4.94	$49.618
Add 15 % for eng'g and administration	40,940	.77	7,482
Grand total	$313,880	$5.71	$57,100

For 55,000 persons = $5.71 per capita.
For 5,500,000 gal. per day = $57,100 per m. g. d.

TABLE XVII.—ESTIMATED ANNUAL COST OF OPERATION OF FITCHBURG, MASS., IMHOFF TANK-TRICKLING FILTER PLANT FOR THE YEAR 1916

General, including administration	$ 1,800
Laboratory	1,700
Grit chamber	900
Imhoff tanks	1,700
Trickling filters	1,100
Secondary tanks	900
Sludge beds	800
Care of grounds	1,250
Miscellaneous	1,100
Total	$11,250

3 m. g. d. = 1,095 m. g. treated = $10.28 per m. g.
32,500 persons = $0.35 per capita.

which it appears that the total cost of operation has been $11,250, which is equivalent to $10.28 per million gallons treated, averaging 3,000,000 gal. daily, or 35 ct. per capita, on a basis of 32,500 persons actually connected. The total population in 1915 was about 39,656.

Similar figures for the Gloversville trickling filter plant show the following costs of operation per million gallons of sewage treated:

	Annual cost of operation— Per M. G. treated	Per capita
1913	$5.16	$0.24
1914	5.92	.27
1915	5.72	.26

It should be stated here that these expenditures are limited to the barest necessities. No chemical supervision nor other refinements which can be avoided, are included.

The estimate of annual operation cost of the hypothetical Imhoff tank-trickling filter plant to serve a population of 55,000 is given in Table XVIII.

Table XVIII.—Estimated Annual Cost of Operation of Typical Imhoff Tank-Trickling Filter Plant

General, including administration	$ 2,200
Laboratory	1,700
Grit chamber	1,650
Imhoff tanks	3,120
Trickling filters	2,020
Secondary tanks	1,650
Sludge beds	1,470
Care of grounds	1,250
Miscellaneous	2,020
Total	$17,080

5.5 g. d. = 2,005 m. g. treated = $8.50 per m. g.
55,000 persons = $0.31 per capita.

Table XIX.—Estimated Annual Cost of Operation of Typical Activated Sludge Plant

Item		Annual cost
General, including administration		$ 2,200
Laboratory		1,700
Grit chamber		1,650
Tank Treatment—		
1 engineer foreman at $4 per 8-hr. day, 312 days	$1,248	
3 engineers at $4	3,744	
4 laborers at $2.50	3,120	
Repairs	1,278	9,390
Sludge Drawing and Disposal		
Foreman part time	$ 375	
2 laborers at $2.50, 312 days each	1,560	
1 team at $6, 312 days	1,872	
Supplies and repairs	603	4,410
Electric power at 1c per kw. h.		17,040
Care of grounds		1,250
Miscellaneous		2,500
Total		$40,140

5.5 m. g. d. = 2,005 m. g. treated = $20.00 per m. g.
55,000 persons = $0.73 per capita.

The estimated annual cost of operation of the activated sludge plant is shown in Table XIX. Nearly half of the annual operating cost is for electric power, required for compressing the air. It was estimated that in addition to the air required for sewage aeration one-fifth as much would be required for sludge re-aeration and for operating the air-lift pumps. The total annual cost of operation amounts to $40,140, which is equivalent to $20 per million gallons treated, or 73 ct. per capita, based on 55,000 persons.

The item for power is estimated on the assumption that it can be obtained at 1 ct. per kw. h. For many places this is a low price, while for others it is high. Surely it is low enough for use in computing the cost of power in most places upon a project which is to be operated for a generation in the future.

Comparison of Costs.—For the final comparison of costs the interest and depreciation have been computed for both plants, and the total annual cost, made up of operating expenses and interest and depreciation, has been capitalized at 4 per cent and added to the construction cost (Table XX). The result is decidedly in favor of the Imhoff tank-trickling filter plant, in spite of the fact that the estimates of operation of the activated sludge plant have been kept low, probably lower than is justified, that there might be no danger of inflating this cost to the disadvantage of the new process. To eliminate this difference it will be necessary to decrease the operating expenses of the activated sludge treatment by about $11,000, or to decrease them a portion of this amount and in addition thereto to decrease the construction cost materially.

TABLE XX.—COMPARISON OF COSTS OF IMHOFF TANK-TRICKLING FILTER PLANT AND ACTIVATED SLUDGE PLANT

Item	Trickling filter plant	Activated sludge plant
Operating expenses	$ 17,080	$ 40,140
Interest and depreciation*	26,760	19,780
Total annual cost of treatment	$ 43,480	$ 59,920
Total annual cost of operation per m. g.	21.84	29.85
Total annual cost of operation per capita	0.80	1.09
Expenses capitalized at 4 %	$1,096,000	$1,498,000
Construction cost	431,710	313,880
Total	$1,527.710	$1,811,880
Difference		284,170

*Interest at 4 %—Depreciation—Sinking fund at 2½ %.

A reduction in the price of power from 1 ct. to 0.6 ct. per kw. h., the price at which it is estimated power can be purchased at Milwaukee, would effect an annual saving of $6,816. For a plant only large enough for 55,000 persons it is doubtful if power below 1 ct. per kw. h. can be procured in many places.

It is not unlikely that improvements in the methods of diffusion and of holding the air for a longer time in contact with the sewage may result in a decrease in the quantity of air required. This would result in a decrease in cost.

At the present time much attention is being given to methods of converting the sludge into marketable fertilizer. There is reasonable agreement among investigators that activated sludge contains a greater proportion of fertilizing ingredients than the sludges obtained from most other processes of sewage treatment. If the sludge can be converted into commercially dry powder containing only 10 per cent moisture, there is good evidence of a market for it at a moderate price.

If the cost of preparation and sale of sludge should be no more than the return from such sales, the reduction in the foregoing estimates of operation and construction would be $5,030 and $66,000, respectively. If this process should be even more successful and a net profit of $2 per ton or say $1 per million gallons should be derived, the saving thus effected would amount to—

Profit on sludge	$2,007.50
Cost of sludge disposal as per previous estimate	5,030.00
Interest and depreciation on sludge beds	2,270.00
Total	$9,307.50

In addition to this annual saving there would be also the saving in investment cost of $36,000.

Even this profit and saving would not be enough to reduce the cost of the activated sludge process to that of the Imhoff tank-trickling filter process, but the net profit of $1 per million gallons may be substantially exceeded. In any event, this subject should receive, as indeed it is receiving, most careful investigation.

It may be argued that greater economy will be possible in the large plants than in the typical plant designed to serve 55,000 persons. This is undoubtedly true, but it is also true of the trickling filter plant. The proportionate saving in the cost of the activated sludge plant, however, may be somewhat greater.

Further development, particularly in the direction of reducing the quantity of air required, and improving means of distribution, may result in a reduction of construction cost. It seems more probable, however, that the cost of construction will be increased, and in any event there should be no reduction in construction cost at a sacrifice in efficiency.

In spite of the fact that it appears to be somewhat more expensive than other processes, the activated sludge treatment should not be rejected on the ground of cost without giving full consideration to its advantages. It may be that as an oxidizing process it will always be more expensive than the trickling filter, but it may have advantages more important than this disadvantage.

Advantages and Disadvantages of the Two Processes.—If it is assumed that the sludge from the activated sludge process is to be dried and disposed of by means of sludge beds, the total area of land used for the activated sludge plant will not differ greatly from that actually used for the trickling filter plant.

The areas utilized for several trickling filter plants, including a reasonable allowance for walks, drives and general purposes, are shown in Table XXI.

TABLE XXI

Location of plant	Area of land required for plant, acres	Area of trickling filters	Average depth of stone in trickling filters
Fitchburg, Mass.	11.8	2.07	10′ 3″
Schenectady, N. Y.*	19.0	6.1	4′ 7½″
Gloversville, N. Y.	13.5	3.07	4′ 7½″
Typical trickling filter plant, estimated	11.8	2.75	10′ 3″

*Original design; only one-half plant built.

The estimated area required for the typical activated sludge plant is 10 acres, or nearly 2 acres less than that required for the typical trickling filter plant. If some other form of sludge disposal were used, the area would be materially reduced. In the second annual report of the Milwaukee Sewerage Commission, it is stated that the ground area required for the Milwaukee activated sludge plant is 0.4 acre. This plant is capable of treating 1,620,000 gal. of sewage per day, but the area given makes no provision for sludge disposal and practically nothing for walks, drives and other features to be expected in an ordinary, complete plant. As already stated, the activated sludge plant may have some advantage in not requiring as much land for isolation as the trickling filter plant. The corresponding reduction in cost would be to the advantage of the former.

One of the important advantages of the activated sludge process is the small loss of head required for the passage of the sewage through the plant. The resulting saving in cost of sewerage works such as pumping stations and long outfall or intercepting sewers, may be sufficient to make the adoption of the activated sludge process imperative. The amount of head lost in several trickling filter plants is shown in Table XXII.

TABLE XXII.—HEAD LOST IN TRICKLING FILTER PLANTS

Location of plant	Head lost, ft.
Columbus, O	25.34
Fitchburg, Mass	25.40*
Gloversville, N. Y	21.40
Schenectady, N. Y. (original design)	13.70
Schenectady, N. Y. (actual construction)	14.65
Washington, Pa	16.50
Philadelphia, Pa	25.25
Atlanta, Ga., Peachtree Creek Works	20.00

*Actual is 42.1 due to topography.

From this table it will be seen that the head required for a trickling filter plant varies from 14 ft. to a little over 25 ft. The Milwaukee 1.62 m. g. plant requires 0.3 ft. between the inlet to the sewage aeration tanks and the outlet of the sedimentation tank. In addition to this some loss should be added for the grit chamber and screens, but in any event, a total loss of 1 to 2 ft. would appear to be ample.

There is some sentiment hostile to an Imhoff tank-trickling filter plant because of the fear of the dissemination of objectionable odors. That objectionable odors are noticeable in the immediate vicinity of such plants cannot be denied. On the other hand, there is good evidence that they are not noticeable except very close to the treatment plants.

The activated sludge plant appears to have some advantage in this direction. Odors may be noticeable in the immediate vicinity of the aeration tanks, and it is possible that objectionable odors may be given off from some portions of the sludge drying and handling process, whatever it may ultimately be. It is probable, however, that the danger from this source will be less than from the Imhoff tank-trickling filter plant.

The moth flies, so prevalent at certain seasons of the year, are quite objectionable close to the filters, although they are rarely found more than a few hundred feet away from them. While this cause of annoyance may be kept under reasonable control, it is doubtful if it can be wholly eliminated. The activated sludge plant does not seem to be a suitable breeding ground for these pests and therefore has an advantage over the filter.

There is no doubt that the activated sludge process is capable of producing a more highly oxidized effluent than the trickling filter, as ordinarily built and operated, that it will eliminate a much greater proportion of bacteria, and that in appearance its effluent will be decidedly superior to that of the filter. This is a marked advantage under certain circumstances, but these facts alone should not be allowed to control in the adoption of a more expensive process when the accomplishments of the trickling filter answer all purposes.

A disadvantage of the activated sludge process in the minds of many who have studied it is its apparent complexity and need for careful and skillful supervision. While it has been contended by some that this process is exceedingly simple and one which can be operated by a workman of ordinary intelligence, the consensus of opinion appears to be to the contrary. The author's experience in operating several small experimental plants, leads him to feel that of all processes of sewage treatment in practical use in this country today this is by far the most difficult to operate and that it will require the skill of a well-trained engineer or chemist to insure continued satisfactory results with it.

At the present time it appears that the Imhoff tank-trickling filter process is a less expensive means of oxidizing the organic matter of sewage and industrial wastes than the activated sludge process, where oxidation alone is considered. If the areas of land required for isolation, the loss of head in the plant, the danger of objectionable odors and of the fly annoyance, and other disdvantages of the trickling filter process are of marked importance in any specific case the balance may be decidedly in favor of the activated sludge process, even in its present state of development.

Cost of Sludge Removal at Columbus, O. (Engineering and Contracting, July 10, 1918).—During 1917, 2,164 cu. yd. of sludge was removed from sewage treatment works of Columbus, O., at an average cost of 29½ ct. per cubic yard, distributed as follows:

Labor	$0.278
Gasoline	.016
All other expenses	.001
Total	$0.295

The mean cost of labor was 33.1 ct. per hour, and the labor hours per cubic yard were 0.83. The average length of haul was 750 ft.

Cost of Pressing Sewage Sludge.—A comprehensive discussion of the practice of dewatering sewage sludge by filter pressing was presented by Kenneth Allen, Engineer of Sewage Disposal for the Board of Estimate and Apportionment of New York City, in Vol. 1 of the Transactions of the American Society of Municipal Improvements. That portion of the paper relating to sludge pressing, as reprinted in Engineering and Contracting, Feb. 13,1918, follows:

Plate Type of Sludge Presses.—There are several forms of filter presses. That most commonly used consists of a series of parallel plates from 30 to 54 in. square and with depressed surfaces, so that when the rims are in contact they enclose a series of cells from ¾ in. to 2 in. thick. The plates are usually of cast iron from 2 in. to 3 in. thick at the rim and where in contact are machined so as to form a true and tight joint. The depressed surfaces are either grooved vertically, in concentric circles and radially, or else in two directions at right angles to each other forming numerous little pyramids, in order to facilitate drainage. Each plate has a 6-in. hole in the center through which the sludge flows by gravity from a tank or is pumped into a series of cells. The pipe to the press is usually 8 in. in size.

Between each pair of plates there are placed two pieces of cloth with holes 4 in. to 6 in. in diameter in the center, opposite the holes in the plates. The two cloths on the opposite sides of each plate are then sewed or clamped together at the hole to prevent the sludge from entering and escaping between.

A modification of this is the "frame plate" used in Germany, in which a series of plates of uniform thickness, *i.e.*, with plain faces except in the drainage grooves, alternate with frames. The grooves in the plates lead to drainage ducts below and a sieve is placed over each face. The cloth is then folded over each plate and clamped by the adjacent frame. The sludge enters by a continuous duct near the upper edge of the plates and frames.

The plates, usually 50 to 100 in number, are held together tight by tie rods passing through their upper corners or lugs projecting therefrom. A head casting at one end and a follower at the other hold the plates between, while the sludge is subjected to a pressure of from 50 to 120 lb. per square inch. This pressure may be derived directly from the air receiver or it may be applied after the press is filled by means of a screw operated by hand or motor.

As the pressure continues, the drainage liquor, which is putrescible and offensive, flows through a ½-in. hole in the bottom of the plates to a drain pipe by which it is carried back to the sedimentation tank to be again treated with the sewage. Pressure is maintained until the drainage is insignificant, which may be anywhere from 15 minutes to 1½ hours, although at Oberschoeneweide, in order to secure a firm cake from lignite sludge, and elsewhere with greasy sludge, it has been necessary to maintain the pressure for 12 hours or more.

One of the most important sludge pressing plants is that at Leeds, where about 900 tons of cake (containing 317 tons dry solids) are produced in a week of 53 working hours.

The sewage amounts to 21,000,000 U. S. gallons per day, of which 4,600,000 are industrial waste. After passing a screen and a grit chamber, it is dosed with 10 to 100 p.p.m. of lime and the sludge is pumped by Tangye pumps to three sludge tanks of 360 tons capacity, milk of lime being introduced in the pump section, 3⅓ tons per tank. The limed sludge, 90 per cent moisture, is then settled for 12 to 18 hours and the supernatant water drawn off. This usually amounts to from 8 to 12 per cent of the volume. Two pairs of rams 6 ft. in diameter by 12 ft. deep force the concentrated material under a pressure of 100 lb. per square inch to the presses, each feeding four of the eight installed, but this is increased to a final squeeze of about 1,700 lb. per square inch by hydraulic thrust blocks.

Each press has 64 cells 52 in. by 52 in. by 1½ in. in size, and therefore produces about 5 tons per run. The cake drops to bogies below holding 50 cu. ft. each and drawn by a locomotive. Eight laborers attend to the presses and four to the bogies.

At Glasgow the Damarnock plant consists of 18 presses of 41 cells each. The air pressure is 100 lb. 150 tons of cake, 66 per cent moisture, have been produced in five runs per day, equivalent to 2¾ tons or 3¼ cu. yd. per 1,000,000 gal. of sewage. The moisture is reduced from 90 to 66 per cent by the process.

The plant at Worcester, Mass., consists of 4 Bushnell presses of 125 39-in. circular plates each. Sludge is pumped into the presses by two triplex pumps having 6-in. bronze ball valves. Between the pumps and the presses there is a 1,130-gal. equalizing tank supplied with compressed air as a cushion at the top and from the bottom of which a 10-in. main with 6-in. branches feeds the presses. The follower or rear end plate of the press carries a 10-in. hydraulic ram with a 48-in. travel which brings the plates into close contact so as to prevent leakage, and the sludge is then pumped in under a pressure of 80 lb. per square inch. The cake produced is 36 in. in diameter and ¾ in. thick. On falling from the cloths it is carried by a conveyor to a car holding 3 cu. yd., run to a trestle and dumped. Four sludge cars and two motor cars are provided. Each press will produce, with 8 fillings, 16 cu. yd. of cake per day.

In 1916 a daily average of 37,600 gal. of sludge, 93.74 per cent moisture, produced 36.1 tons of cake, 72.8 per cent moisture, containing 1.23 tons of solids per 1,000,000 gal. of sewage. The cost of pressing was $7.05 per 1,000,000 gal. of sewage, or $5.71 per ton of solids.

At Providence there are 18 presses of from 43 to 54 plates each. These are filled with sludge under a pressure of 60 lb. per square inch. The cake, 36 in. square and 1¼ in. thick, amounts to 64 tons per day.

At Spandau the sludge from a population of 80,000 is forced from cylindrical steel receivers under a pressure of 33 lb. per square inch to the 8 presses. The plates and frames are 3.6 ft. square and made of wood. Each plate has 2 inlet slots near the top and vertical drainage grooves leading to drainage ducts in the bottom.

After filling, the presses are subjected to an increased pressure by a hand pump and the sludge is left under a pressure of from 60 to 75 lb. per square inch for 20 hours. The cake is then 1¼ in. to 1½ in. thick and contains 60 per cent moisture. On opening up each press the sludge drops into 4 tip cars for removal. It is then either sold at 4.6 ct. per cubic yard (1913) or air-dried and used for fuel. It has no appreciable odor.

At York, England, where the grease makes the sludge particularly difficult to press, milk of lime is flushed into the press in advance of the sludge, which has already received its dose.

Another plan when dealing with such sludge is to heat the presses by injecting steam and, as at Bradford, heating also the sludge itself in advance. The grease then passes off in large part with the drainage liquor.

It is stated that the cake here contains but 27 or 28 per cent moisture. The power required for pressing is given by Kershaw as from 7 to 13½ b.h.p. per ton (8 to 15 b.h.p. per long ton) of cake pressed per hour, depending on the size of the plant and the moisture and other characteristics of the sludge.

The cloths are a little more than twice the size of the plates over which they are folded. They are made of jute, duck or other fabric; at Worcester of 11 oz. duck 40 in. wide. Their life varies greatly, depending on the sludge, the pressure to which they are subjected, whether they are cleaned periodically, etc., but is usually rather brief from rotting. Elsner states that the life of (probably jute) cloths may be as much as 4 weeks if first treated with a tar composition. At Spandau they were said to last from 1 to 2 months; at Worcester, according to Metcalf and Eddy, 6 to 9 weeks is regarded as reasonable when operating at the rate of 12 cleanings per day of 10 hours. Stated another way, 2.44 sq. yd. of duck are required per ton of dry solids.

A septic sludge or one containing particles of lime—especially if left unslaked—or particles of rust from the plates shortens the life of the cloths. Probably for the last reason wood has been used for plates in Germany instead of iron.

At Leeds it was decided, after trying different cloths, to adopt 54-in. 3-ply twist twilled jute sacking, 30 oz. per yard. Experiments were then made to increase the durability of the cloths, first by shrinking and then by treating with different oils. The best results were secured by oiling an 8-in. strip around the edge of each cloth, around the center hole and where the bosses on the plates meet with "Golden-Bloomless" mineral oil costing 23.7 ct. per gallon or "Black Oil," a crude petroleum costing 10 ct. per U. S. gallon. The effect of oiling seems to be to render the material more elastic and so prevent its rupture under strain. One gallon sufficed for 5 cloths, increasing their average life from 156 to 200 pressings. The saving effected is shown by the following statement:

	Price per yd.	Cost of pressing per ton (2,000 lb.) of cake
Year ending March 31, 1913..............	21.5 ct.	39.8 ct.
Year ending March 31, 1915..............	28.6 ct.	36.5 ct.

It is estimated that about $1,450 is thus saved annually.

After drainage is complete the pressure is released, the plates are separated and the sludge falls or is scraped off the cloths onto a conveyor or into a tip car, by which it is removed for disposal. This operation takes from 10 to 30 minutes or more. The entire operation of filling, pressing and emptying ordinarily takes from 45 minutes to 2 hours.

Sludge Cake.—In practice precipitated sludge is reduced to cake having about 20 per cent its original weight and containing from 50 to 70 per cent moisture. The moisture is not uniform in the cake, being greatest near the point where admitted to the press. The weight of this cake is about 8⅔ tons per 1,000,000 gal. of sewage (Rideal). The cakes run from an inch or less in thickness to 1½ or 2 in. if greasy and well dosed with lime. On breaking it up the weight per cubic yard is reduced to about 1,350 lb. when the voids are found to be about 40 per cent. By air-drying under cover this weight may be further reduced by about 50 per cent.

Analyses of sludge cake as produced at Chorley and Dorking, England, are given in the Fifth Report of the Royal Commission on Sewage Disposal. The sewage in each case is domestic. At Chorley, with combined sewage, 9 grains per Imp. gal. of alumino ferric is used for precipitation, and at Dorking, which is partially sewered on the separate system, 5 grains per Imp. gal. of lime. The cake as delivered contains about 50 per cent moisture, but the samples analyzed were dried at 110° C.

	Chorley	Dorking
Grit	25.30	6.84
Oxides of iron and aluminum	9.37	3.46
Lime	10.32	23.16
Phosphoric acid	0.98	0.66
Nitrogen (total)	1.28	0.89

At Leeds in the year 1913–14 the average composition of the cake was as follows:

	Per cent.
Water	60.1
Volatile matter	16.7
Nitrogen, 5.9 per cent	
Total grease, 6.3 per cent.	
Mineral residue	23.2
Calcium phos., .94 per cent.	
	100.0

The solids from the sewage normally comprised 35.3 per cent of the cake.

The average of 4 analyses of commercially dried (10 per cent moisture) activated sludge, with especial reference to their fertilizing value, are given by William R. Copeland as follows:

	Per cent.
Nitrogen as ammonia	4.68
Available phosphoric acid	0.57

Cost of Pressing Sludge.—The cost of pressing is given by the Royal Commission on Sewage Disposal for two typical groups of towns:

Group I—For towns of 30,000 persons or more employing chemical precipitation followed by sedimentation or sedimentation alone and where no special addition of lime is required on account of industrial waste. Sludges under such conditions will require lime equivalent to from 2 to 4 per cent of the weight of the pressed cake.

Group II—For towns of less than 30,000 persons and for those where, because the sludge is greasy or derived from septic tanks, it is necessary to add lime equivalent to from 5 to 20 per cent of the weight of the pressed cake

The moisture in each cake is assumed to be 90 per cent in the wet sludge and 55 per cent in the pressed cake.

COST OF PRESSING SLUDGE
In ct. per ton of 2,000 lb.

Wet Sludge—	Group I	Group II
Operation	9.6–12.0	14.5–24.4
Operation and fixed charges	13.2–15.6	18.1–28.0
Pressed Cake—		
Operation	43.5–54.4	65.2–109
Operation and fixed charges	59.7–70.6	81.4–125

Moore and Silcock give the cost of pressing in England at from 32.6 ct. to 54.4 ct. per ton of cake; Elsner at $4.50 per 1,000,000 gal. of sewage. According to Schiele the cost of producing 1 ton of cake from 5.8 cu. yd. of wet sludge, including fixed charges, varies from 41½ ct. to $1.28, and averages 85 cts.

In a list of 18 British cities Metcalf and Eddy find the cost of pressing to vary from 6 to 43 ct. per ton of wet sludge or from 27 to 93 ct. per ton of cake.

At the Dalmarnock Works at Glasgow 171,476 tons of crude sludge were pressed to 291,045 tons of cake in the year ending May 31, 1916, at a cost of $2.16 per 1,000,000 gal. of sewage, or 67 ct. per ton of cake.

At the Knostrop works at Leeds in the year ending March 31, 1915, 42,321 tons of cake, 60 per cent moisture, were produced at a cost of $15,480, exclusive of interest and amortization, and $6,681 for disposal or, for pressing, per ton of cake, 36.7 ct.; per ton dry solids, $1.03.

For German conditions, Reichle and Thiesing mention from 63½ to 85 ct. as fair limits (before the war).

Estimates based on foreign practice cannot of course be applied directly to American conditions. The following is the distribution of cost based upon figures estimated for Wimbeldon by Santo Crimp:

	Per cent
Wages	36.0
Lime	40.0
Coal	9.6
Cloths	12.8
Oil, etc	1.6
Total	100.0

American cost data are practically limited to experience at Worcester and Providence, data for which are as follows:

Range	Worcester 1899 to 1912	Providence* 1903	1910	1916
Per mil. gal. sewage	$3.85 to $6.76	$2.44	$4.06	$2.78
Per ton of dry solids	3.39 to 4.64	2 27	2.54	3.38
Per ton of cake	0.91 to 1.37	0.67	0.72½	0.94½

* Costs include disposal.

The above figures are in general based upon precipitated sludge. Owing to the greater amount of lime required it will cost perhaps a third more to press fresh or septic settled sludge.

Disposal of Cake.—The cake may sometimes be disposed of for a nominal sum, say, 10 to 25 ct. per ton, to farmers, but if there is no demand for it, it may be used for filling at about an equal cost. When deposited in depths up to 12 ft. in water-soaked land near Leeds it was observed to shrink about 33 per cent in two years and to generate more or less heat.

While there is more or less odor in the press house this does not carry far, and if kept under cover it is quite inoffensive. Fresh cake kept moist by rain, especially if the weather is warm, will give off a certain amount of odor, but, if first air-dried to 20 or 30 per cent moisture, objectionable odors are usually prevented.

An advantage in lignite sludge, besides being inodorous, is that it can be utilized by burning under the boiler, and experiments by W. L. Stevenson at Philadlephia show that by the addition of a small amount of combustible material to ordinary air-dried sludge from plain sedimentation there will be obtained a material having a moderate value as fuel.

The foregoing remarks have been confined to the plate type of press, often spoken of as the "Johnson" filter press, this having been almost universally used for the pressing of sewage sludge heretofore. There are, however, several other more recent types which deserve mention.

The Kelley Filter Press.—The Kelley Filter Press consists of a steel frame supporting a cylindrical "press shell" at one end and a carriage for inserting into and withdrawing from the other end a series of longitudinal filter leaves. Each leaf consists of a horizontal pipe above connected to a similar pipe below by a mesh of double crimped No. 0.105 gage wire. This wire mesh enters a slot in each pipe for the removal of the filtrate, to which it is strongly riveted or welded. A bag of extra heavy twill or duck is drawn over each leaf and the end sewed up by hand, forming the filtering medium. The leaves are uniformly spaced, but of different heights, depending on their position with reference to the press shell.

At each end of the filter carriage are plates for supporting the leaves, one of these providing the head of the press shell when the leaves are inserted. By means of a groove in the head plate corresponding to an annular projection on the end of the shell, which are forced together on a gasket and held by special locking mechanism, all leakage during operation is prevented.

In operation the carriage and leaves are inserted in the shell and the head is locked. The shell is then filled with sludge by a pipe, while the air is released by an overflow valve at the top. This, it is claimed, takes but about four minutes. When filled the overflow valve is closed and about 40 lb. pressure applied to the sludge pipe. The cake forms on the surface of the bags as the filtrate passes through and is carried off by the frame pipes and drains.

After the cake is built up the sludge supply is shut off and compressed air admitted from above, displacing the remaining wet sludge and aiding in drying the cake. This is then removed from the bags by shaking, by loosening with a wooden spade, or by compressed air introduced through the drainage pipes.

The following data are taken from a circular of the manufacturer:

Size of shell	30″ × 72″	40″ × 108″	48″ × 120″
Capacity of shell—			
Cu. ft.	32	75	120
Gal.	240	560	900
Number of leaves	4–9	6–8	6–10
Filter area, sq. ft.	60–130	180–250	260–450
* Weight of cake 1½ in. thick	667	1,333	3,333
* Average weight of cake in tons per 24 hours	3⅓–6⅔	13⅓–26⅔	33⅓–66⅔

* Assuming weight of cake 66⅔ lb. per cu. ft.

The economies claimed for this press are due to the small amount of labor required, lack of wear on filter cloths and the avoidance of breakage of plates.

The Sweetland Filter Press.—This consists of a number of parallel circular leaves consisting of a heavy wire screen hung from a casting above. Each leaf has an outlet nipple at the top connecting with a drainage duct in the above casting, is bound by a stiff U-shaped frame on the edge and covered with suitable canvas. The entire series of leaves is enclosed in two semi-cylindrical castings, the lower of which can be swung to one side on a hinge.

The sludge is forced in through a channel in the bottom of the lower casting and flows up between the leaves and as the filtrate passes through the canvas and out through the drainage duct the solids form a cake on each side of every leaf. When the process of filtering becomes slow, compressed air is introduced, blowing the wet sludge in the bottom of the cylinder back into the storage tank and drying the cakes. The lower casting is then swung to one side and the dewatered sludge drops out, aided by reversing the air pressure through the leaves. This back pressure serves as well to keep the filter surfaces clean. The operation of dumping is claimed by the manufacturer to occupy but from 8 to 20 minutes.

In a press of this kind used by R. W. Pratt at the Cleveland Sewage Testing Station the leaves were 2 ft. in diameter. The average moisture in the wet sludge was about 86 per cent and that of the cake between 62 and 76 per cent. Mr. Pratt mentions the importance of keeping the cakes from adhering to each other by providing sufficient clearance. Where the leaves were even as much as 3 in. between centers no cake was obtained with less than 70 per cent moisture, and it was concluded that there should be a clearance of not less than 3 in. nor more than 4½ in. Pressures of from 30 to 35 lb. were sufficient except for short periods at the end of the run when as much as 50 lb. were sometimes used. As to the time required the best results were with a half hour for forming the cake, ¾ hour for drying or 1¼ hours for the entire run.

These tests were mostly with Imhoff sludge, but as there is no exposure of the sludge to the air, Mr. Pratt is of the opinion that "in large installations the Sweetland press could be operated without odors or nuisance" with ordinary sludge.

Results of Pressing Imhoff Sludge

Condensed from Table 61, Report Sewage Testing Station, Cleveland, 1914

Number of leaves	16	16	14	14
Spacing center to center	1½″	3″	3″	4½″
Number of runs averaged	4	7	2	4
Time in hours:				
Pressing	.94*	1.15	1.65†	.50
Drying	.12½	.36	.58†	.75
Total	....	1.51	.....	1.25
Specific gravity of raw sludge	1.05	1.06	1.11	1.07*†
Per cent moisture:				
Raw sludge	89	86	82	86
Cake	68	72	75	64
Pressure—lb. per sq. in.	53*†	43	43	42
Lb. cake per run	242*†	314	139	90

* Average from 2 runs. † Result from 1 run. *† Average from 3 runs.

The Worthington Filter Press.—The Worthington or "Berrigan" press has been tried out in particular at Milwaukee in connection with activated sludge.

The sludge is placed in each of a number of unbleached muslin bags inclosed in a bag of special fine canvas. The bags are hung vertically between two plates, which, being drawn together by means of a toggle joint, squeeze the superfluous water from the sludge and through the bags. As the pressure continues, the motion, which is automatically controlled, decreases, but the pressure may be increased very greatly.

The plates are grooved and faced with wire to facilitate drainage. In size they are manufactured 36 in. by 48 in., 72 in. by 108 in., and 96 in. by 120 in.

The Milwaukee experiments were made with a 72-in. by 108-in. press with 10 bags. The sludge, 98 per cent or 99 per cent of water, is first concentrated to 96 or 97 per cent. The best way to accomplish this, whether by decanting the supernatant water after settling from 1 to 3 hours or scraping or sucking up the deposited sludge, remains to be settled. It is a material factor in the economy of operation, as every per cent reduction means a large saving in the volume of sludge to be handled and consequently in the cost of the plant.

The concentrated sludge is fed into the bags without any addition of lime and then subjected to a pressure gradually increasing to about 60 lb. per square inch. After draining the pressure is released, the bags are lifted out and emptied by gravity. They keep fairly clean in this way, but, if sludge adheres to the surface, it is removed by a jet of steam.

The Milwaukee machine will produce from about 2,000,000 gal. of sewage a ton of cake 1 in. thick per run, which, by further drying to 10 per cent moisture, will yield about 1,000 lb. in a condition, after grinding, to be used as fertilizer, for which it is said to be particularly well adapted. The tim required is about 5 hours per operation, so that the above press will produce some 5 tons of cake per 24 hours of 75 per cent moisture.

One laborer, according to Mr. T. C. Hatton, Chief Engineer of the Milwaukee Sewerage Commission, can attend to 5 presses, so that the cost of attendance is low, and as to the power required, the designer, Mr. Berrigan, claims that a 15-h.p. motor will suffice for 5 machines.

The following conclusions were based upon the Milwaukee experiments with activated sludge: "Sludge can be dewatered satisfactorily from 96 per cent to 75 per cent moisture by either a plate press or pressure press without the addition of lime or other base.

"The filter bags used in the presses must be cleansed frequently to maintain efficiency. This can be done by soaking in a bath of dilute caustic soda and hot water.

"Sludge after pressing can be stored in a building without creating offensive odors more than 50 ft. away, and can be easily handled."

After drying (to 10 per cent) this sludge contains from 4.5 to 5 per cent of ammonia, for which there is ample market as a fertilizer.

The cost of a press such as has been described complete is stated to be about $4,000, exclusive of overhead charges, to which should be added $800 for an accumulator, or $500 for a pump of capacity to serve 20 presses.

An estimate of the cost of operation is given by Mr. Hatton in the Report of the Commission for 1916, as follows, based upon a plant capable of handling the sludge from 100,000,000 gal. daily of sewage:

	Per ton of cake
Labor (3 shifts of 8 hours)	$1.36
Bags (cleaning and upkeep)	.64
Power	.09
Contingencies	.16
Overhead charges, 10 per cent of cost	1.21
Total	$3.46

or, since 1,000,000 gal. daily of sewage produces ½ ton of cake, the cost of pressing is about $1.73 per 1,000,000 gal. of sewage.

According to Mr. G. W. Fuller, the cost is about $3 per ton of dry solids, or $2.70 per ton with 10 per cent moisture.

Estimated Cost of Pressing Activated Sludge.—In the Stockyards District, Chicago, by Langdon Pearse and W. D. Richardson. Based on 96 tons of dry material per day. Cost per dry ton.

Supplies:			
Duck at $1.75 per lin. yd., 120 in. wide	$1.37		
Miscellaneous	.24		
		$1.61	
Labor	$1.13		
Power 3.24 h.p., equals 2.42 kw.-hr. at 0.7 ct. per hr	.41		
		1.54	
Operating expenses			$3.15
Fixed charges			2.57
Grand total			$5.72

While this press has been shown to be well adapted to the dewatering of activated sludge, Mr. Berrigan claims that it will also be found satisfactory with plain settled or septic sludges without the addition of lime, but the writer is not aware that this has been conclusively demonstrated as yet.

Conclusion.—Dewatering sewage sludge by filter pressing with the plate type of press has been brought to a point where its efficacy and cost can be closely predicted. With fresh settled or precipitated sludge and the addition of from 0.5 to 3 per cent of lime and a pressure of 70 or 80 lb. per square inch a firm, satisfactory cake can be produced.

Cost of Flushing Sewers.—The following data are taken from an article published in Engineering and Contracting, April 24, 1912.

Methods and Apparatus for Flushing Sewers.—Flushing consists of admitting a sudden rush of water at a high velocity into the sewer. This can be secured by collecting water in a manhole or tank and then suddenly admitting it to the sewer by (a) opening a valve, (*b*) removing a plug, etc., or (*c*) breaking an air seal or lock in a siphon. Filling and discharging the tank may be done automatically, semi-automatically, or by hand.

In the case of very large sewers, the sewage itself may be used instead of water from an outside source. Here a plug or gate is put in the outlet and the incoming sewage allowed to dam up in the bottom of the tank or manhole. When a small head has been accumulated it is allowed to flow down the sewer. This method of flushing has several drawbacks, (*a*) The unsanitary character of the work, (b) the high cost of labor, (c) the time required for the sewage to accumulate, and (d) since the head can be built up it is limited by the grade of the inlet sewer, a low flushing velocity. As a result flushing with accumulated sewage is only employed on mains of large size.

Hand Flushing.—In flushing by hand, several methods of filling can be used: (1) By means of a water cart; (2) by a hose connection to a hydrant; (3) by a permanent connection from the water main.
A stopper is placed in the outlet of the manhole or tank and if it is not a dead end of a sewer a stopper is also placed in the inlet.

When the tank or manhole has been filled by the water from the cart, from the connection to the hydrant or water main, it is shut off, the plug or similar contrivance removed from the sewer and the water allowed to flush it out.

Automatic and Semi-Automatic Flushing.—In flushing by means of automatic apparatus, water is fed to the tank by a service pipe fitted with an appliance for regulating the rate of feed, and discharged by some form of siphon, which flushes when the water has reached a predetermined level in the tank. The operation of the siphon is entirely automatic. The water may be fed to the tank in a continuous stream of such volume that the tank fills and discharges entirely automatically at predetermined intervals of 24 to 48 hours, etc., or else the water may be fed only when desired so that flushing occurs at any frequency whatever. In the first case a regulator controls the feed to the desired rate, and in the second case, this regulator is replaced by a cut-off device designed to permit the filling only when opened by pulling a chain. The flush then follows automatically, and at the same time the feed is automatically cut off. As the name implies with automatic flush tanks no labor at all is required. With the use of the cut-off valve to permit semi-automatic flushing, labor is necessary but it is merely that of pulling a chain from the outside of the tank by means of a hook passed through the manhole cover.

Cost of Flushing.—Three items go to make up the cost of sewer flushing (1) Cost of water; (2) cost of labor; (3) fixed charges against the apparatus.

Items 1 and 2 are independent of the frequency of flushing, that is, whether flushing is performed once a day or once a month, the cost per flush for water and for labor are practically the same. This is not true of item 3. The fixed charges on the apparatus include interest on the money invested and sinking fund. The charge per flush, therefore, is governed by the frequency with which flushing is performed, the interest on sewer bonds and local conditions.

Assume a case where water costs 3 cents per 1,000 gals., and that the amount of flushing water required is 333 gals., so that the cost per flush for water is one cent. This is an extremely low cost for water. This figure can be assumed here, however, as the same cost will be taken in each method of flushing. Where the apparatus used for flushing wastes water, as for instance, where poorly operating automatic tanks discharge 2 or 3, or more, times a day, where once every 2 or 3 days would be sufficient, the money value of the water wasted will add up to a large amount in a year.

Flushing With Water Cart.—Two men with a water cart can flush about 20 tanks per day and the cost for labor is as follows:

2 men at $2.00	$4.00	
2 horses and cart at $2.00	4.00	
Total per day	$8.00	
Labor per flush		40 cts.
Water per flush		01 ct.
Total		41 cts.

To this must be added the fixed charges against the apparatus used for flushing. As we are only making a comparative study and a tank or manhole of masonry of concrete is required in all the methods considered, we can eliminate charges on that investment. The charges against the investment on water carts is included in the cost for horse and cart, which is considered as rental.

Hose Connection.—Using this method the labor to handle about 20 tanks would be:

2 men at $2.00	$4.00	
1 horse, hose and cart at $2.00	2.00	
Total per day	$6.00	
Total labor per flush		30 cts.
Water per flush		01 ct.
Total cost per flush		31 cts.

Flushing Manhole.—The number of flushing manholes or tanks with hand flap valves that may be operated in a day, depends largely on their distance from one another, on the time required to fill them and on the rapidity with which the attendant removes and replaces manhole covers, etc. A special report on the time taken to operate flushing manholes in a large city in the south shows that one man flushed 44 tanks in one day.

Assume as an average, that one man with a horse and wagon can attend about 40 tanks daily. In many cases a horse and wagon might not be used, the attendant walking or riding bicycle from tank to tank. However, as it will be assumed that a horse and wagon are also employed with the semi-automatic tank in the analysis following, it is consistent to set down that item here. The cost per flush would then be made up of the following items:

1 man	$2.00
1 horse and wagon	2.00
Total labor per day	$4.00
Cost for labor per flush	10 cts.
Cost for water	01 ct.
Cost per flush exclusive of fixed charges	11 cts.

To this must be added the fixed charges on the investment for the water connection and the lift valve. Assuming $15 as the first cost for the water connection and flap valve, the fixed charges at 10 per cent = $1.50 per year. The fixed charge per flush depends upon the frequency of flushing. We will first consider a frequency of 365 flushes per year. The cost per flush for various frequencies from 1 to 365 times per year is given by Table XXIII.

TABLE XXIII.—COST OF FLUSHING IN CENTS PER FLUSH, WHEN FLUSHING AT FREQUENCIES FROM 1 TO 365 TIMES A YEAR

Number of flushes per year	Hand operated* cents	Automatic* cents	Cost per flush with flushing manhole cents	Cost per flush with hose connections cents	Cost per flush with cart cents
1	303.00	....	261.0	31.0	41.0
25	15.00	....	17.0	31.0	41.0
50	9.00	....	14.0	31.0	41.0
100	6.00	....	12.5	31.0	41.0
150	5.00	....	12.00	31.0	41.0
200	4.50	2.50	11.75	31.0	41.0
250	4.20	2.20	11.60	31.0	41.0
300	4.00	2.00	11.50	31.0	41.0
365	3.82	1.82	11.41	31.0	41.0

* Cost per flush with semi-automatic tank.

For flushing 365 times a year the fixed charge is $= \frac{\$1.50}{365} = .41$ cents and the complete cost is as follows:

Labor per flush	10.00 cts.
Water per flush	1.00 cts.
Fixed charges	.41 cts.
Total cost per flush (flushing 365 times per year)	11.41 cts.

Automatic Flush Tanks.—With this method, the cost of water per flush is as before, one cent. The cost for labor is zero. The fixed charges on the flushing siphon are dependent upon its first cost, the life of the apparatus and the value of money. The investment for an automatic siphon and regulator as installed would be about $30. Setting down yearly fixed charges at 10 pe cent as before, we have the fixed charge per tank as $3.00 and for flushing 36 times per year, .82 cents per flush. The total cost per flush is then:

Labor	.00 cts.
Water	1.00 cts.
Fixed charges	.82 cts.
	1.82 cts.

Table XXIV summarizes the cost of various methods of flushing at a fre quency of 365 times a year.

TABLE XXIV.—COST OF FLUSHING, IN CENTS PER FLUSH, AT A FREQUENCY O 365 TIMES A YEAR

Method of flushing	Water cost per flush, cents	Fixed charges per flush, 365 flushes per year, cents	Labor cost per flush, cents	Total cos per flush, cents
Water cart	1	0	40.0	41.0
Hose connection	1	0	30.0	31.0
Flushing manhole	1	.41	10.0	11.41
Automatic flush tank	1	.82	0.0	1.82

* For the purpose of comparison fixed charges against the masonry tank c manhole can be neglected and with the flushing manhole and automatic tanl 10 per cent of the cost of the apparatus are set down for interest sinking fund an maintenance.

Semi-Automatic Flush Tanks.—We have now to consider the cases wher flushing is required less frequently, once or twice a week or less. Under thes circumstances, the semi-automatic tank is the most economical method c flushing. Furthermore, this type of tank can be used when desired, as a fu automatic tank, flushing at frequent periods or less frequently, the only labc required for flushing in this manner being the pulling of a chain from th outside of the manhole.

The cost for water is again, one cent per flush. As to labor—a man with horse and buggy, costing in all $4 per day, can pull the chain and set off 20 tanks which would be only five times as many flushes as was assumed with th ordinary flushing manhole. This would make the cost for labor per flush cents. The number of semi-automatic tanks that can be operated in a da by one man, are dependent, as was the case with the flushing manhole, o the distance between tanks and the time consumed in operating the tank itsel With the semi-automatic tank, the time required to pull up the chain is bu a fraction of a minute, as contrasted to the time required to remove a manhol cover, turn on the water, wait till the tank fills, open the flap valve and di charge the tank and replace the cover, as is the case with flushing manhole

To the cost of 2 cents per flush for labor, must be added as before the fixe charges against the apparatus. The first cost of the semi-automatic tank ove and above the first cost of masonry may be set down, as was the case with th automatic tank, at $30 at 10 per cent, so that the fixed charge is $3 per yea The fixed charges *per flush* depend upon the number of times per year th tanks are operated. If set off only once, it will be $3 and adding in the cost c the labor and water, the total cost will be 303 cents. If it is set off 52 time a year, the fixed charges will be 5.77 cents and adding water and labor, th total cost will be 8.77.

In the first column of Table XXIII is set down the number of times per year flushing is performed. Corresponding to these frequencies, are set down the various costs per flush. The second column gives the cost with a semi-automatic tank; when flushing less frequency than 200 times a year the tank is hand operated and at frequencies greater than 200, the tank is operated either automatically or by hand, the cost by both methods being given. The cost with flushing manhole and other methods is also given.

Under practically all conditions either the full automatic or semi-automatic ank is the most economical means of sewer flushing. These figures of course

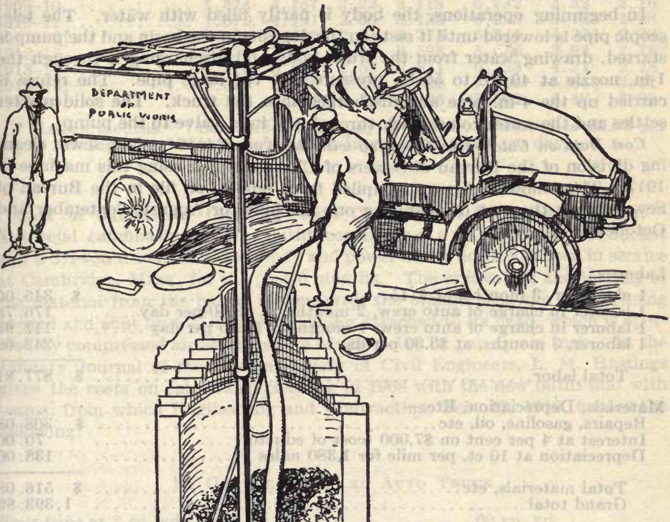


FIG. 6.—Method of cleaning catchbasin with auto-eductor.

are subject to market price of labor in any particular locality. They indicate, however, that where flushing is to be performed more than 15 to 20 times and less frequently than 200 times a year, the semi-automatic tank is the most economical apparatus to use. For flushing at intervals of every 48 or 24 hours or more frequently the full automatic tank is adaptable, and is the most economical.

Cost of Cleaning Sewer Catchbasins with an Auto-Eductor.—A catchbasin cleaning machine working on the hydraulic ejector principle has been employed with excellent success in a number of cities. This machine was invented by George W. Otterson, a mining engineer. It is known as the auto-eductor. It consists essentially of a pump and suction device attached to a Kelly

Springfield motor truck. The suction device is a 4-in. telescopic pipe con nected at its lower end with a 3-in. pipe leading from the discharge of a 4-in American centrifugal pump. A 1-in. nozzle from the 3-in. pipe is led into th 4-in. pipe and turned upward, thus throwing the stream of water at high veloc ity through a contracted throat, creating a vacuum and causing suction. Th pump is driven from a power take-off on the driving shaft of the truck. Th inlet valve on the pump suction is attached to an opening in the bottom of th truck body. This truck body is a water-tight steel box equipped with baffl plates so arranged as to hasten the settling of solid matter in the refuse take from the catchbasin.

In beginning operations, the body is partly filled with water. The tele scopic pipe is lowered until it rests on the deposits in the basin and the pump i started, drawing water from the truck body and discharging it through th 1-in. nozzle at 40 lb. to 50 lb. pressure into the large pipe. The refuse i carried up the 4-in. pipe and discharged into the truck. The solid matte settles and the water comes back through the inlet valve to the pump.

Cost Data on Catchbasin Cleaning with the Auto-Eductor.—The sewer clean ing division of the Bureau of Sewers of Chicago began using this machine i 1917. The following figures compiled from reports on file in the Bureau o Sewers show the cost of operating one machine for August, September an October:

Labor—	
1 chauffeur, 3 months, at $115	$ 345.0
1 laborer in charge of auto crew, 2 months, at $3.60 per day	176.7
1 laborer in charge of auto crew, 1 month, at $4.60 per day	112.9
1 laborer, 3 months, at $3.30 per day	243.0
Total labor	$ 877.8
Materials, Depreciation, Etc.—	
Repairs, gasoline, oil, etc	$ 308.0
Interest at 4 per cent on $7,000 (cost of eductor)	70.0
Depreciation at 10 ct. per mile for 1,380 miles	138.0
Total materials, etc	$ 516.0
Grand total	1,393.8

The average cost per catchbasin cleaned was $1.299; the average cost pe cubic yard material removed was 79 cts. The average cost of cleaning catch basins by hand methods during the past 4 years has been $3.24 each.

During three months the machine cleaned 1,073 sewer catchbasins. Th total mileage of streets traversed was 1,073 and the total yardage of materia removed from catchbasins was 1,763 cu. yd. The machine had a 5-yd.body mounted on a 5-ton truck body.

The city of Louisville, Ky., began cleaning its catchbasins with an auto eductor early last year. During the period from Jan. 17 to Dec. 31, 1917, th machine was in operation 265 days. In this time it cleaned 5,388 basins, a a total cost of $4,573 or 84.8 ct. per basin. The total cost figure is made up o $3,327 for wages of driver and two laborers, gasoline, oil, etc., and $1,246 fo depreciation at the rate of 20 per cent per annum. The average cost o cleaning the basins in 1916 by hand methods was $3.40 per basin.

Cost of Cleaning Catchbasins at Cambridge, Mass.—Cost data on clean ing catchbasins by the Sewer Department of Cambridge, Mass., are given in the 1916 annual report of L. M. Hastings, City Engineer. The figures, covering the period 1905–1916 inclusive, are reprinted in Engineering and Contracting, as follows:

Date	No. of C. B. cleaned	Quantity: Total loads	Quantity: Loads per C. B.	Quantity: Total cu. yd.	Cost: Total	Cost: Per C. B.	Cost: Per cu. yd.
1905	2,169	5,213	2.40	3,909	$6,089	2.80	1.55
1906	2,340	5,609	2.82	4,206	6,050	2.58	1.44
1907	1,948	4,704	2.40	3,528	5,070	2.60	1.44
1908–9*	2,742	5,906	2.15	4,429	8,090	2.95	1.82
1909–10	1,874	4,157	2.22	3,118	6,732	3.32	2.16
1910–11	1,672	4,181	2.50	3,135	6,225	3.72	1.98
1911–12†	1,466	3,676	2.51	2,775	6,344	4.33	2.30
1912–13	1,438	3,463	2.41	2,598	5,656	3.93	2.18
1913–14	1,479	3,802	2.58	2,851	6,223	4.21	2.18
1914–15‡	1,335	3,862	2.89	2,896	7,559	5.66	2.61
1915–16	1,128	3,247	2.88	2,436	7,309	6.48	3.00

* Sixteen months. † September 1911, pay of cleaners increased to $2.25 per day. ‡ October 14, 1914, pay of cleaners increased to $2.50 per day.

Cost of Catchbasin Cleaning With Orange Peel Bucket and Truck.—A special catchbasin cleaning outfit, consisting of a small orange peel bucket and a 3½-ton truck, with steel body and power dump hoist, has been in service at Cambridge, Mass., for the past 6 months. The excavating and loading of the material from the basins is done with the orange peel, the bucket being opened and shut by a piston and cylinder attached to its head, which is operated by compressed air at a pressure of about 100 lb. per square inch. In the January Journal of the Boston Society of Civil Engineers, L. M. Hastings gives the costs on catchbasin cleaning in 1908 with the new outfit and with teams; from which Engineering and Contracting, Feb. 12, 1919, quotes the following:

By Orange Peel and Auto Truck

Four trips at 3 cu. yd. × 5	60 cu. yd.	
Saturday, 2 × 3 × 1	6 cu. yd.	
	66 cu. yd. weekly, or 11 cu. yd. daily average.	
Chauffeur, at $4	$ 4.00	
2 laborers, at $3.25	6.50	
Gasoline, 7 gal., at 25 ct	1.75	
Oil	.20	
Grease	.15	
		$12.60 per day
Tires	$ 250.00	
Repairs	300.00	
Depreciation, $6,000 at 20 per cent	1,200.00	
Interest on investment, $6,000 at 4 per cent	240.00	
Yearly overhead costs	$1,990.00	
Yearly overhead costs / Assuming 250 working days	$1,990.00 / 250 =	7.96
Cost per day		$20.56

20.56 ÷ 11 = $1.87 per cu. yd.

BY HORSE CARTS

5 to 6 loads daily average 5½ loads, 1 1/6 cu. yd. per load.

1.16 × 5.5 loads × 5 days	32.0 cu. yd.	
1.16 × 5.5 loads × ½ day Saturday	3.2 cu. yd.	
	35.2 cu. yd. weekly or 5.86 cu. yd. daily average.	
Labor, 4 men, at $3.25	$ 13.00	
2 horses, at $1.50	3.00	
		$16.00 per day
Interest, $575 × 2, at 4 per cent	$ 46.00	
Depreciation, $575 × 2, at 15 per cent	172.50	
Yearly overhead	$ 218.50	
Working days	$ 250 =	.87
Cost per day		$16.87

$16.87 ÷ 5.86 = $2.88 per cu. yd.

CHAPTER XIII

GARBAGE DISPOSAL

Cost of Collecting, Hauling and Transporting Municipal Refuse.—A very important element in the collection, haul, transfer and transportation of refuse materials is the cost. Many local factors enter into the cost element, and unless these are considered and understood, the cost data are misleading. Standard forms for recording cost data of refuse collection are not used extensively, so that the data presented should not be taken without qualification. Samuel A. Greeley in a paper before the 1914 annual convention of the American Society of Municipal Improvements, gave methods of analyzing the cost of the various parts of the service, and the following matter is taken from a reprint of this paper published in Engineering and Contracting, Oct. 21, 1914.

***Elements of Cost.*—The elements of the cost of each part of the collection service can be segregated and studied advantageously by the following method. The unit quantities used in the computations were assumed for certain local conditions and will not necessarily apply everywhere. They are presented here to illustrate the method of analysis.**

***Loading.*—The cost of loading will vary with the character of the material, the district served, the season of the year, the unit cost for labor in each locality and other local conditions. The method of analysis for loading garbage follows:**

a. Number of people per house or per collection made	10
b. Number of minutes required to make one collection or to give service to ten people	1
c. Interval of days between collections	2
d. Capacity of garbage wagons in tons	2
e. Quantity of garbage produced in tons per 1,000 population per day	0.273
f. Quantity of garbage after two days' interval between collections, tons per 1,000 population per day	0.546
g. To make collections from 1,000 people requires 100 collections, taking 100 minutes' time.	
h. Time in minutes required to load a wagon with two tons of garbage in accordance with the date above equals $\frac{2}{0.546} \times 100$	367
i. The time required for loading is thus 6.1 hours. If the cost of the team, wagon and collector be taken at 75 cts. per hour, the cost for loading one 2-ton wagon will be $4.57 and the cost per ton for loading garbage ($2.28)	2.28

The analysis can be applied to the loading of ashes, rubbish, mixed refuse or any refuse material, if the proper unit quantities and basic data be first determined. The cost per ton for loading other refuse materials in accordance with assumed data will be as follows:

Materials	Cost of loading per ton
Ashes	$0.415
Rubbish	2.62
Mixed refuse	0.56

Motor Trucks.—The cost of loading a motor truck can be studied in similar way. The cost of operation will be greater per hour and the rate of loading will have to be increased proportionately to make the cost comparable with loading a team drawn wagon. The cost of haul by motor truck will be less.

The use of motor trucks in refuse collection service will increase. A relatively high loading cost can be reduced by limiting the motor truck to transportation after the loading of the wagons by the so-called traction and trailer system now being tried on a large scale in New York City and used in quite a number of European cities.

Hauling.—The refuse material loaded in the collection wagon must be hauled to the transfer station or place for final disposal. This will be done by horse-drawn vehicle or by motor. The length of haul will be from the point of last collection to the place of final delivery. This distance or haul must be covered twice for each complete load.

The cost of haul will depend on the rate of travel, the weight of the load and the cost of the team and the driver, or motor and mechanic. The cost of team haul may be analyzed as follows:

Assumed:	Per hour
Rates of travel, miles	3.0
Cost of outfit	$0.75
Cost per mile of travel	0.25
Cost per mile of haul	0.50
Cost per ton-mile haul with a 2-ton load	0.25

The cost of haul by gasoline or motor truck may be analyzed as follows:

Assumed:	Per hour
Rate of travel, miles	6.0
Cost of outfit	$2.40
Cost per mile of travel	0.40
Cost per mile of haul	0.80
Cost per ton-mile haul with a 5-ton load	0.16

The rate of travel will vary considerably from different sections of a large city, being slower through streets congested with a large volume of traffic. In such districts, collection work should be done at night or during the early morning hours.

Transfer Stations.—The operation of transfer stations should also be considered as a part of the cost of transportation. A transfer station to handle 600 cu. yds. a day, or 375 tons, may cost, depending upon type of building and local conditions, about $50,000, including land in a fairly well-built up section.

The annual cost of operation may be estimated as follows:

Interest at 5 per cent	$ 2,500
Depreciation of plant	1,250
Labor:	
1 foreman	1,200
4 laborers	3,600
Repairs and supplies	2,500
Total	$10,800

This is equivalent to a cost of 9.4 cts. per ton.

Cost of Transportation.—The cost of transportation of refuse from the transfer station to the place of final disposal depends upon the method used. The cost for several methods is discussed below.

Trolley Transportation.—Assume a typical transfer station receiving 600 cu. yds. of refuse material per day. Assume trains to be made up of one motor car which carries no load and two trailers. Assume each trailer to have a capacity of 25 cu. yds. To move 600 cu. yds. 24 trailer loads are required. If the place of disposal be so located that each train can make two trips a day, six trains will be required. Assume that three motors can handle the six trains. The daily cost of operation will then be:

	Per day
Motor cost, three at $25	$ 75.00
Trailers, twelve at $6	72.00
Total	$147.00

If the 600 cu. yds. of refuse weigh 375 tons, the cost of trolley transportation will be 40 cts. per ton.

Barge Transportation.—A good, serviceable tug will cost about $30,000 and deck scows about $7,000 apiece. The annual cost of operating a fleet may be as follows:

Annual cost of tug:		
Interest at 5 per cent		$ 1,500
Depreciation on 15-year life		1,389
Labor:		
Captain	$2,100	
Engineer	1,800	
Fireman	1,000	
Deck hands	1,800	6,700
Repairs		2,500
Fuel		3,500
Supplies		1,000
Insurance		200
Total		$16,789
Annual cost of barge:		
Interest at 5 per cent	$ 350	
Depreciation	324	
Deck hands	1,800	
	$2,474	
Assume that 1 tug serves 4 barges		9,896
Total annual cost of fleet		$26,685

If each barge makes one trip per day, carrying 100 tons of refuse, the cost per ton amounts to 22 cts.

In like manner the elements of cost can be determined for other methods of transportation.

Steam Railroad Transportation.—The cost of transportation by steam railroads depends principally upon the switching charges. These will range from $5 to $15 per car. A car will hold about 40 tons of garbage, so that the switching charge will average about 20 cts. per ton.

Available Collection Costs.—Actual cost data should be studied to check the costs estimated above, but these are not available for a large number of cities. The costs for collection service are generally recorded to include both loading and hauling in one figure, while costs of transportation are frequently given separately. The cost data for some cities in which the itemized cost of collection is available have been summarized in Table I.

Chicago Data.—Jacobs and Senfield have made a careful analysis of the cost of collecting garbage, and ashes, and rubbish in Chicago. These data are compiled in excellent detail and accuracy. The average cost for the five years—1908 to 1912—are given in Table II.

TABLE I.—COSTS OF COLLECTION (LOADING AND TEAM HAUL) OF MUNICIPAL REFUSE

City	Year	Population served	Total annual cost	Total annual tonnage	Total annual yardage	Unit cost— Per ton	Unit cost— Per yard	Cost per capita
Garbage:								
Boston	1913	480,000	$131,648.40	54,215	....	$2.43	.....	$0.27
Chicago	1912	2,300,000	381,174.00	119,159	....	3.20	.....	0.17
Cleveland	1912	596,400	127,800.24	43,555	....	2.93	.....	0.21
Columbus	1912	192,700	34,779.23	18,789	....	1.85	.....	0.18
Dayton	1908	110,300	21,000.00	9,941	13,479	2.11	$1.56	0.19
Detroit	1910	465,766	66,865.67	34,065	....	1.96	.....	0.15
Evanston	1910	24,978	3,186.00	2,800	4,670	1.14	0.68	0.13
New York	1910	4,406,000	275,380.00	336,984	....	0.82	.....	0.06
Winnipeg	1911	151,918	19,371.90	15,510	....	1.25	.....	0.13
Ashes:								
Boston	1913	480,000	346,396.01	247,203	....	1.40	.....	0.73
Evanston	1910	24,978	2,174.00	....	13,461	.....	0.16	0.09
Winnipeg	1911	151,958	5,793.73	5,227	....	1.11	.....	0.04
Rubbish:								
Columbus	1912	192,700	47,887.12	....	75,096	.....	0.64	0.25
Evanston	1910	24,978	5,108.00	....	29,479	.....	0.17	0.21
Ashes and rubbish:								
Cleveland	1909	543,000	119,982.00	84,547	202,752	1.42	0.59	0.22
Cincinnati	1909	360,000	116,631.68	87,611	222,634	1.33	0.52	0.32

References: These data are all from annual reports.

TABLE II.—AVERAGE COST OF REFUSE COLLECTION, LOADING AND HAULING, AT CHICAGO, ILL.

Year.	Cost per ton of garbage	Cost per cu. yd., ashes and rubbish
1908	$3.78	$0.56
1909	3.76	0.57
1910	3.43	0.59
1911	3.19	0.62
1912	3.20	0.60

If ashes and rubbish together weigh 1,000 lbs. per cubic yard, the cost of collection per ton amounts to $1.20.

IMPROVED METHODS FOR RECORDING COST DATA

The value of unit cost data for loading, hauling, transferring and transporting refuse materials should be realized by city officials. Accurate records should be kept and published in similar forms in different cities, so that comparisons can be made and a check secured on the efficiency of the local work

Cost of Motor Truck Operation for Refuse Collection.—In connection with a study of refuse collection at Rochester, N. Y., the Rochester Bureau of Municipal Research, Inc., of which James W. Routh is Director, collected a considerable amount of data on the use of motor trucks in municipal service. These data are given in a report issued recently by the Bureau, from which the matter following is abstracted in Engineering and Contracting, July 2, 1919.

In 1914 a 5-ton truck equipped with a specially designed 10-yd. collection body was given a trial in house to house collection of garbage and ashes on a 3-mile haul in the Borough of the Bronx, New York City. It was given a further trial in hauling garbage from relay stations in the outlying sections of the Borough. On the 3-mile haul in making house-to-house collections the truck did not prove as economical as the 1-horse carts generally used. But in hauling from relay stations on the longer haul the truck showed a considerable saving over horse-drawn carts. The haul for this work was approximately 7 miles. The truck made four round trips for a total of 54.2 miles and hauled 27.6 tons of garbage as against about 1½ trips made in the same length of time by a 1-horse cart hauling approximately 1½ tons (9/10 tons per load). On the shorter haul the cart made three round trips per day for a total distance of 18 miles, including house-to-house collections and hauled 5.4 tons; the truck made five round trips for a total distance of 32.7 miles and hauled 23.85 tons.

The poorer showing of the truck on house-to-house collection was attributed to the time spent in loading. Although four helpers were provided the time so spent represented more than one-half the total time. The time spent in traveling to and from the dump was only one-fifth the total time. On relay work, however, the loading time was only 35 per cent of the total time.

The 1-horse cart outfit cost $4.32 per day. The total daily cost of operating the truck was $13.70, distributed as follows:

Item	Total cost	Per cent of total
Gasoline	$ 2.41	17.6
Oil	0.75	5.4
Truck depreciation (cost $5,000, life 5 years)	2.78	20.3
Interest on investment at 6 per cent	0.83	6.1
Repairs, labor, materials, tires, grease and miscellaneous	4.07	29.7
Garaging	0.30	2.2
Driver's pay	2.56	18.7
Total	$13.70	100.0

The New York Department of Street Cleaning has used large tractor-trailer motor propelled collection units to some extent. These are giant outfits hauling 25 cu. yd. of refuse per load. Collections of ashes, rubbish and garbage are made simultaneously, but in separate compartments. The average haul is about 1½ miles. Special equipment is provided for unloading the refuse onto scows. The principal factor tending to produce economy from the collection standpoint is the fact that all refuse is dumped at a common point of disposal. For this reason all refuse may be collected at one time by providing separate refuse compartments on the collection vehicles.

In Philadelphia a part of the collection equipment has been motorized. Five-ton trucks equipped with 12-yd. bodies have proven economical in the collection of ashes and rubbish from sections where the haul to the dump averages 6 miles.

In a report by the Efficiency Division of the Chicago Civil Service Commission made public in July, 1915, it is stated that after a thorough study of the question of motorizing Chicago's collection equipment the continued use of horses in garbage collection was found to be justified. The report states that the data assembled for gas and electric trucks warrant their adoption only for hauling after horse-drawn carts have made the house-to-house collection. These figures are based on a $5.50 daily wage per team. If the cost of teaming were increased to $6 per day, it is stated that there would be a slight saving by using motor equipment, but this would not be sufficient to warrant the change at least for some time to come. The report states that the haul in Chicago varies from 1½ to 5 miles. As between the gasoline and electric trucks, the latter were found to be the more economical. The haul below which a 3-ton electric truck would not be economical when measured against a $5.50 team was found to be 1.8 miles. Against a $6 team it was 0.8 mile. Three-ton gasoline trucks were found to be not as economical as either a $5.50 or $6 team.

The fixed and mileage charges for gasoline and electric trucks were as follows:

Item	Total cost Gasoline	Total cost Electric
First cost of 3-ton truck or tractor	$4,000.00	$ 4,000
Fixed charges:		
Fixed charges on investment per year at 4 per cent	160.00	160.00
Garage	300.00	300.00
Insurance (fire and liability)	190.00	183.00
State license	4.00	4.00
Driver	960.00	960.00
Obsolescence, 5 per cent	200.00	200.00
Contingencies (interest on operating stores, general superintendence, etc.), 2 per cent	80.00	80.00
Total fixed charges per year	$1,894.00	$1,887.00
Total fixed charges per day (1/300 year)	6.31	6.29
Variable expenses per mile:		
Depreciation	$ 0.0573	$ 0.0340
Tires	.0600	.0600
Maintenance and repairs	.0300	.0300
Lubrication (oil and grease)	.0050	.0050
Energy (gasoline 13½ ct. per gal., electricity ½ ct. per kw. hour)	.0344	.0050
Total variable expense per mile	$ 0.1767	$ 0.1340

The cost for hauling with horses was given as follows:

Item	Teams costing $5.50 per day	$6.00 per day
Fixed charges for equipment	$0.021	$0.021
Horses and driver	5.500	6.000
Wagon depreciation, life 22,000 miles	0.084	0.084
Maintenance and repairs at 5 per cent	0.021	0.021
Total daily expense	$5.626	$6.126

In Los Angeles motor trucks are used in the collection of all non-combustible refuse. Two 2½-ton trucks are used to haul garbage from the outlying districts where the haul averages 8 miles or more. One driver and two helpers compose the crew and two loads are collected daily. For the remainder of the city on the shorter hauls teams are still used. The cost of garbage collection with motor trucks on the long hauls is given as $2.76 per ton. On the shorter hauls the cost is $2 per ton using teams.

A certain firm in Rochester employing both horses and motor trucks in lumber and building material deliveries states that the economical low limit of haul for motor trucks is found to be 2¼ miles.

The average cost of truck operation by this firm for the last three years has been $11.20 to $12.30 per day. (This includes the cost of two 3-ton and 2-ton trucks.) Items included are fuel, lubricants, tires, repairs, license fee, liability insurance, garaging, drivers' wages and depreciation. Drivers were paid $17 to $19 per week. Twenty per cent was allowed for depreciation.

C. V. Montgomery, who has charge of a large fleet of motor trucks on paving work in Philadelphia, in a statement appearing in the Engineering News of Jan. 11, 1917, places the cost of operating a 5-ton truck 50 miles per day at $17.91. Fixed charges amount to $5.39 per day or 30 per cent of the total. This cost evidently applies to 1916 conditions. The distribution is as follows:

Fixed charges	Per day	Per cent of total cost per day
Depreciation* ($4,100 first cost—$400 scrap value/1,200 days)	$0.46	2.6
Insurance (liability, fire, collision)	.58	3.2
License fee	.10	0.6
Truck foreman (supervising 3 trucks)	1.25	7.0
Driver	3.00	16.7
Total fixed charges	$5.39	30.1

Variable charges	Per mile	Per day at 50-truck-miles	Per cent total cost per day
Depreciation* ($4,100 first cost—$400 scrap value/15,000 miles)	$0.0629	$ 3.14	17.6
Gasoline at 25 ct. (3 miles per gal.)	.0833	4.17	23.3
Lubricating oil (64 miles per gal.)	.0055	0.27	1.5
Tires	.0386	1.94	10.8
Repairs	.0600	3.00	16.7
Total variable charges	$0.2503	$12.52	69.9
Fixed charges (at 50 miles per day)	0.1078	5.39	....
Total cost per mile	$0.3581	......	.....
Total cost per day	....	$17.91	100.0

* About 15 per cent of first cost depreciates with passage of time, while about 85 per cent is proportional directly to mileage run.

The cost of operating a 5-ton truck used in the delivery of sand and gravel on the Pacific Coast during a 5-months' period in 1917 was approximately $13.40 per day. This includes all charges. Capacity loads were hauled an average distance of 6.1 miles over roads of various kinds, equally divided between gravel and dirt, with many hills, some of them steep. The average distance traveled daily was about 60 miles. The costs were distributed as follows:

Item	Total cost	Per cent of total
Fuel	$ 303.25	18.1
Oil and grease	69.79	4.2
Tires	154.93	9.3
Repairs and parts	21.06	1.3
Wages	508.75	30.4
Interest at 6 per cent	218.78	13.1
Depreciation at 20 per cent	394.66	23.6
Total	$1,671.22	100.0

The cost of hauling paving materials in Detroit with a 5-ton truck during 1917 was $14.85 per day, including all costs. The truck hauled an aggregate of 35 tons in seven trips, the average haul being 4½ miles.

The cost of operating a 3½-ton truck under average service conditions on the roads of Southern California over a considerable period of time was found to be $9 per day. This includes all cost of upkeep, supplies, depreciation, wages of drivers, etc. The first cost of the truck was placed at $3,500 and its life at 10 years, assuming that the truck traveled 25 miles per day. Gasoline was purchased at 16 cts per gallon and the driver's salary was $960 per year. Roads were good and operating conditions generally very favorable. Itemized costs (for the estimated life of 10 years) follows:

Item	Total cost	Cost per day	Per cent of total
Insurance	$ 1,350	$0.45	5.0
License and taxes	380	.13	1.4
Interest at 6 per cent	2,100	.70	7.8
Depreciation	3,500	1.17	12.9
Administration	415	.14	1.5
Storage	960	.32	3.5
Gasoline at 16 ct. per gallon	2,400	.80	8.9
Oil, grease, waste	750	.25	2.8
Tires (less first cost)	2,345	.78	8.7
Driver's salary	9,600	3.20	35.5
Maintenance	3,250	1.08	12.0
Total for life of truck	$27,050	$9.02	100.0

The first cost of a truck with a collection body would be somewhat higher than is here given. As a matter of fact, the city of Rochester awarded a contract to the Selden Motor Vehicle Co. in December, 1917, for two 3½-ton trucks each equipped with a special 6-yd. collection body at $5,031 each. Other costs also have increased proportionately since the above estimate was made. It is believed, however, that a competent driver could be employed at less than $960. It should be possible to employ a truck driver at $900 annually if he were given permanent employment. Also interest rates on the investment should not amount to more than 5 per cent. The life of a truck used in house-to-house collection work would probably not be as long as in other work due to frequent starting, stopping and generally hard usage. A life of 5 years with a daily average mileage of 25 miles would seem to be a fair estimate for the useful service derived from the truck. At the end of that time the estimated scrap value would be $500. With these data the following estimate is made of the daily cost of operating a truck in ash collection.

ESTIMATED DAILY COST OF OPERATION OF A 3½-TON MOTOR TRUCK IN REFUSE COLLECTION

	Total daily cost	Per cent of total
Fixed charges:		
Depreciation: First cost, $5,031.35, life 5 years, scrap value $500	$0.45	3.5
Insurance (liability $120, fire $45 per year)	.55	4.3
Storage	.30	2.4
Driver ($900 per year)	3.00	23.6
Interest (5 per cent annually)	.84	6.6
Overhead supervision (same organization as for city stables	.40	3.2
Total fixed charges	$5.54	43.6

Variable charges:	Per mile	Per day at 25 miles	Per cent of total
Depreciation: First cost $5,031.35, life 5 years, scrap value $500	$0.1027	$ 2.57	20.2
Gasoline at 22 ct. gal. (3 miles per gallon)	.0733	1.83	14.4
Lubricants (oil, grease, waste)	.0100	.25	2.0
Tires	.0500	1.25	9.9
Repairs and sundries	.0500	1.25	9.9
Total variable charges	$0.2860	$ 7.15	56.4
Total fixed charges at 25 mile per day	.2216	5.54	43.6
Total daily cost of operation	$0.5076	$12.69	100.0

It is assumed that a certain small amount of depreciation is due directly to the passage of time. In the estimate, therefore, 15 per cent of the total depreciation is included as a fixed charge and distributed over 1,500 days, the estimated useful life of the truck. The remaining 85 per cent depreciation is assumed as being directly proportional to the mileage run. Operated 25 miles per day with a life of 1,500 days' service, the total distance that the truck would travel would be 37,500 miles. The estimated depreciation for the life of the truck on this basis is 23.7 per cent of the total daily cost of operation. This is rather a big allowance for depreciation, but when the nature of the work is considered it is not high in comparison to depreciation of trucks used in straight commercial hauling work. A truck used in house to-house collection work must be started and stopped many times in the course of each loadting. The motor must be kept in constant motion because each stop is of short duration. On account of the many starts and stops also the truck must of necessity cover a considerable distance each day at a speed much slower than its economical speed of operation. Combined with all of these factors the truck must be operated continuously in the presence of grit and cinders from ashes and dust from street dirt. For these reasons not only is depreciation sure to be high, but the unit cost of fuel, lubrication, tires and repairs is also bound to be more than similar costs under normal commercial operating conditions.

Cost of Collection and Removal of City Wastes in Chicago.—The following data, from a report by the Efficiency Division of the Chicago Civil Service Commission for the removal of garbage, ashes, refuse and other wastes for the year 1914, were published in Engineering and Contracting, Dec. 3, 1913.

During 1912 about 1,400,000 cu. yds. of rubbish were collected and hauled to dumps at an average cost of 60 cts. per cu. yd. During the same year about 119,000 tons of garbage were collected and removed at an average cost of $3.20 per ton.

Dead Animals.—Dead animals are removed and disposed of in Chicago by contract. A contract of this character was awarded in August, 1912, and was for a period of five years, for which the city is paid an annual rate of $25. The contract provides that the contractor shall remove within twelve hours all dead animals from streets, alleys and the river, and dispose of them at least three miles outside the city limits.

An estimate of the number and weight of dead animals removed and disposed of each year in the city is given herewith, as follows:

Total number of dead horses, average weight 1,300 lbs.	9,253
Total number of dead dogs, average weight 25 lbs.	20,782
Total number of dead cats, average weight 5 lbs.	3,603
Total number of other animals, including cows, goats, sheep, rabbits, etc., average weight 100 lbs.	448
Grand total number of dead animals removed	34,086

Total estimated weight of all dead animals removed, 12,611,265 lbs., or 6,305 tons

Quantity of Garbage and Rubbish.—The house collection is made by wagons equipped with covered steel tanks having a capacity of about 2½ tons of

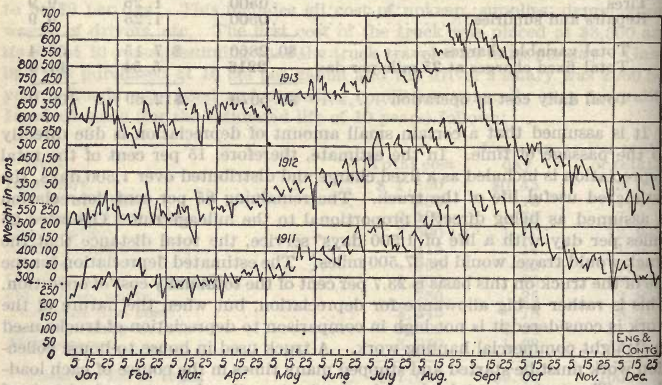


Fig. 1.—Curves showing daily variation in tonnage of garbage in Chicago for the years 1911, 1912 and 1913.

garbage. The wagons and tanks are owned by the city, while the teams are hired from contractors on a per diem basis. Each ward is divided into garbage districts and collections are made from each district according to the density and character of population and district. The wagons are taken to the loading stations from which the tanks are transported to the place of final disposition.

The curves shown in Figs. 1 and 2 indicate the variation in the amounts of garbage and rubbish collected and the problems which must be met in order efficiently to handle this work. These curves indicate that the minimum quantity of garbage is reached during the winter months, and the maximum quantity during the summer months, especially during the month of September. This necessitates that the organization maintained be flexible and easily adapted to the ever-changing conditions. Analysis of the garbage collections made in this city for the past five years indicates that the quantity to be collected from the several districts for different years is not a constant figure, depending upon the local conditions such as change of character of population, growth of residence, business or manufacturing property.

Field study of the average time required by drivers to collect a load of garbage indicates that it takes about 3 hours and 55 minutes to collect a full load of garbage in summer and 4 hours and 45 minutes to collect a full load of garbage in the winter months. These units have been taken as standards

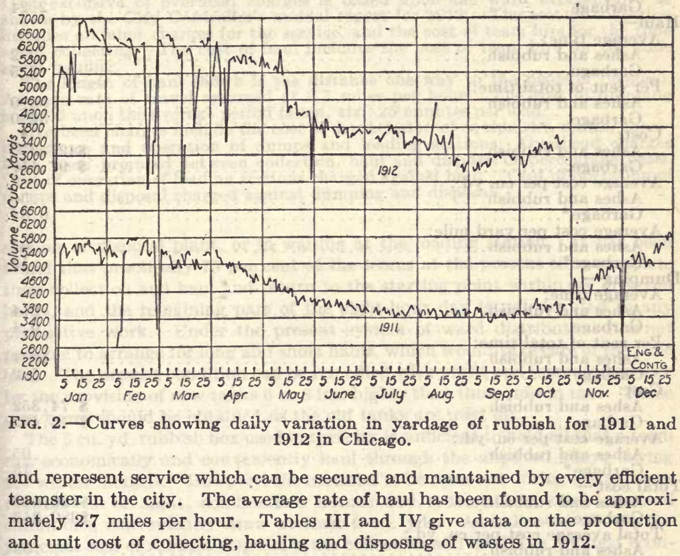


Fig. 2.—Curves showing daily variation in yardage of rubbish for 1911 and 1912 in Chicago.

and represent service which can be secured and maintained by every efficient teamster in the city. The average rate of haul has been found to be approximately 2.7 miles per hour. Tables III and IV give data on the production and unit cost of collecting, hauling and disposing of wastes in 1912.

Table III.—Data on Production of Municipal Refuse in Chicago During 1912

Production	Ashes and rubbish	Garbage
Minimum month	68,023*	6,256†
Maximum month	166,007*	14,960†
Total for year	1,399,716*	119,176†
Total team days	131,475	54,152.5
Total number of loads	271,760	56,048
Average loads per team-day	2.06	1.04
Total average time per load	3.91	7.75
Average haul in miles	2.9	3.4

*Cu. yds.
†Tons.

The larger number of collectors collect one load per day and the remaining time over the 3 hours and 55 minutes is spent in going to and from the loading

TABLE IV.—DATA ON THE COST OF COLLECTING, HAULING, DUMPING AND DISPOSAL OF ASHES, RUBBISH AND GARBAGE IN CHICAGO IN 1912

(Cost Exclusive of Overhead Charges)

Collection—	
Average time:	
Ashes and rubbish	1.3
Garbage	4.8
Per cent of total time:	
Ashes and rubbish	33.7
Garbage	62.9
Cost:	
Ashes and rubbish	$334,970
Garbage	$267,800
Average cost per cu. yd.:	
Ashes and rubbish	.24
Garbage	2.24
Haul—	
Average time:	
Ashes and rubbish	2.2
Garbage	2.5
Per cent of total time:	
Ashes and rubbish	56.0
Garbage	32.0
Cost:	
Ashes and rubbish	$421,350
Garbage	$ 97,157
Average cost per cu. yd.:	
Ashes and rubbish	.30
Garbage*	0.81
Average cost per yard mile:	
Ashes and rubbish	.05
Garbage*	.12
Dumping—	
Average time:	
Ashes and rubbish	0.4
Garbage	0.4
Per cent of total time:	
Ashes and rubbish	10.4
Garbage	5.2
Cost:	
Ashes and rubbish	$ 74,352
Garbage	$ 15,462
Average cost per cu. yd.:	
Ashes and rubbish	.05
Garbage*	.13
Total cost—	
Ashes and rubbish	$830,680
Garbage	$380,353
Total average cost per cu. yd.:	
Ashes and rubbish	.59
Garbage*	3.19

(Cost Including Overhead Charges)

Collection—	
Cost:	
Ashes and rubbish	$352,194
Garbage	$290,648
Average cost per cu. yd.:	
Ashes and rubbish	.27
Garbage*	2.44
Haul—	
Cost:	
Ashes and rubbish	$476,875
Garbage	$154,823
Average cost per cu. yd.:	
Ashes and rubbish	.33
Garbage*	1.30
Average cost per yard mile:	
Ashes and rubbish	.05
Garbage*	.10

Dumping and disposal—	
Cost:	
Ashes and rubbish	$133,829
Garbage	$ 64,807
Average cost per cu. yd.:	
Ashes and rubbish	.09
Garbage*	.54
Total cost—	
Ashes and rubbish	$962,898
Garbage	$510,278
Total average cost per cu. yd.:	
Ashes and rubbish	.69
Garbage*	4.29

Note.—*The unit cost for garbage collection, hauling and disposal is the ton. Cost exclusive of overhead charges is based upon the ward expenditures as shown by the City Controller's annual report for 1912. The cost of collection includes all labor charges for the service, and the cost of team hire for the time spent collecting. The cost of haul includes the cost of team hire for the time spent hauling.

The length of haul shown is the distance one way to the place of disposal. Average rate of travel assumed at 2.7 miles per hour. The cost of dumping is based upon the average period taken, viz.: 25 minutes per load.

Overhead charges include the cost of depreciation of equipment, rental, superintendence and operation of dumps and loading stations. Overhead charges have been prorated between collection, haul and disposal on percentage basis. Cost of operation of loading stations charged against haul. Cost of operation of dumps and disposal charged against dumping and disposal.

station or disposal plant, or in waiting at the loading station. It has been found that practically 75 per cent of the teams at the present time complete their collection and haul and return to the starting point within six or seven hours, and the remaining part of the eight-hour day is not devoted to any productive work. Under the present system of ward distribution it is not possible to arrange for long and short hauls, which would take care of the time lost. The present condition can be remedied with profit and increased service by the provision of new tanks 6 or 8 ins. higher than those now in use. These new boxes should be obtained as the old tanks are used up.

The 5 cu. yd. rubbish box used in this city is sufficient to hold all that a team can economically and conveniently haul through the unpaved alleys during the winter months. However, the material to be removed during the summer months is of light, combustible nature and a team can, under normal conditions, conveniently draw at least 9 cu. yds. As indicated above, the principal cost of rubbish disposal is the collection and haul; the greatest economy will, therefore, result when a team can collect the maximum possible quantity in one load. Wagons designed with lower bodies will allow of larger loads. At the same time the height required to raise the pail to empty the rubbish is reduced, with the result that the efficiency of labor will be greatly increased. Provision whereby sideboards can be hinged to the ordinary rubbish box will adapt the box to a 5 cu. yd. load during the winter months and to larger loads during the summer season.

Economic Methods of Waste Disposal for Cities of Different Sized Populations.—In his report made to the mayor and city council of Davenport, Iowa, John W. Alvord gave the following diagram (Fig. 3) showing the relative availability of various methods of disposal of city wastes under average economic conditions for cities of different sized populations.

It must be remembered that the reduction process is applicable to garbage alone. The cremation process is applicable to garbage mixed with some fuel, while incineration is applicable to and requires the collection of all of the

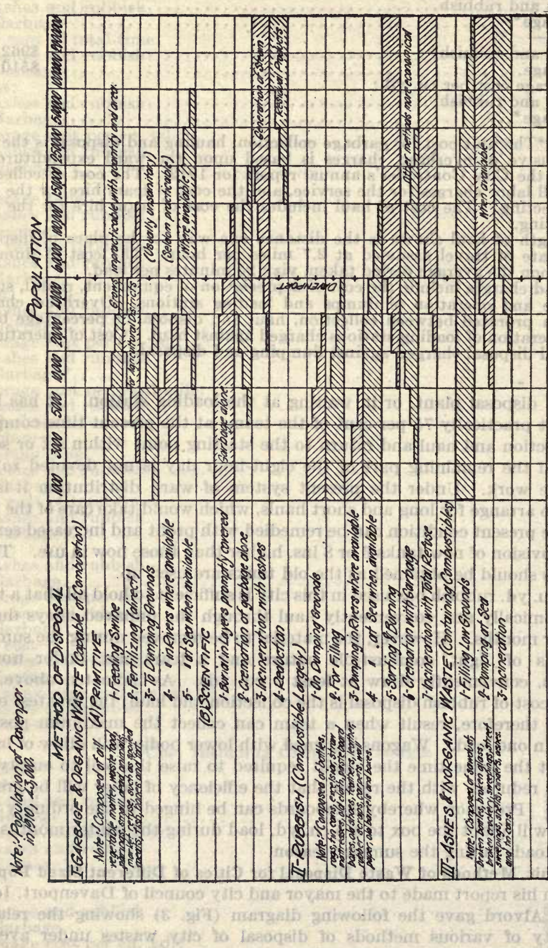


FIG. 3.—Diagram showing economic methods of city waste disposal according to population.

municipal wastes in order to destroy the same by combustion with success. There is, therefore, a fundamental difference between these methods which should not be lost sight of.

Cost of Garbage Disposal by Incineration, Reduction and Feeding to Swine.—Important facts concerning garbage disposal methods and costs in various cities are given in a report prepared by the Springfield Bureau of Municipal Research of Springfield, Mass. The following main features of the report regarding the various methods of disposing of garbage are taken from Engineering and Contracting, Sept. 12, 1917.

INCINERATION

Fuel Used in Incineration.—By incineration is meant the disposal of garbage by burning. The fuel may be only the garbage and other refuse, or it may be coal, wood or other fuel, depending upon the proportion and character of the refuse to be burned. The classes of refuse disposed of in incinerators and the amount of fuel required were as follows in 1915 for the cities named:

	Av. amount burned per day				Amount fuel used per year	
City	Garbage, tons	Ashes, tons	Rubbish, tons	Other mat'l	Amt.	Cost
San Francisco, Cal.—						
Garbage, rubbish, ashes, manure	229	49	188	...[1]	...	......
Cairo, Ill.—						
Garbage	24	...	...	...	360*	$ 720
Fort Wayne, Ind.—						
Garbage, small animals	33.47	...	...	...	1,027*	2,824
Paterson, N. J.—						
Ashes, garbage, rubbish	23	...	...	...	.....[2]	108
Trenton, N. J.—						
Anything combustible	50	...	...	...	250*	750
Wilmington, N. C.—						
Garbage, rubbish, dead animals	3	...	37	...	....[3]	......
Portland, Ore.—						
Garbage, manure, rubbish	123	...	19	...[4]	....[5]	......
Erie, Pa.—						
Garbage, rubbish	24[6]	...	...	...[7]	724*	1,865
Richmond, Va.—						
Garbage, combustible matter 2 (plants):						
	35	...	5	...[8]	290*	1,000
	35	...	5	...[9]	594*	2,050
Spokane, Wash.—						
Garbage, rubbish, manure	9.71	...	4.13	...[10]	144[17]	720
Wheeling, W. Va.—						
Garbage	20	...	...	...	....[11]	1,200
London, Ont.—						
Garbage, ashes	20–50	...[12]	...	...	...[13]	......
Montreal, Que	116	...[14]	...	...	......	......
Moose Jaw, Sask.—						
Garbage, manure	19.2	...	...	...[15]	....[16]	......

*Tons. [1]Manure 31 tons. [2]18 cd. wd. [3]6 tons and 44 cords. [4]Manure 4¼ tons. [5]None. [6]Includes rubbish. [7]Small animals. [8]Small animals. [9]Small animals. [10]Manure and small animals 0.72 tons. [11]25 million cu. ft. gas. [12]Ashes dumped in winter, burned rest of year. [13]None. [14]Includes all refuse. [15]Manure, etc., 22.5 tons. [16]None. [17]Cds.

Thus, 9 out of the 14 cities listed use other fuel in addition to the garbage and other refuse.

Cost of Construction.—The cost of construction varies, according to one report from $600 to $1,000 per ton capacity. The Worcester Commission reports that "the cost per ton daily capacity varies from $230 to $1,000, the average being between $600 and $700." The cost in a number of cities was as follows:

City	Designer or builder	Capacity, tons	Construction cost	Construction cost per ton capacity
Berkeley, Cal	Sterling	50	$61,500	$1,230
Oakland, Cal	Decarie	100	60,000	600
Fort Wayne, Ind	Dixon	40	15,000	375
South Bend, Ind	Dixon	25	6,800	272
Terre Haute, Ind		50–75	15,000	200
Covington, Ky		100	25,000	250
Grand Rapids, Mich	Angle Imp. No. 3	100	14,656	147
Duluth, Minn	Decarie	25	35,000	1,400
Minneapolis, Minn		150	50,000	333
Paterson, N. J	Destructor Co	60	80,000	1,333
Wilmington, N. C	Decarie	40	35,000	875
Portland, Ore	Smith	150	99,900	660
Allentown, Pa	Dixon	25–30	14,700	490
Erie, Pa	Morse-Boulger	100	27,000	270
Richmond, Va., No. 1	Decarie	50	40,000	800
Richmond, Va., No. 2	Morse-Boulger	50	12,000	240
Spokane, Wash	Decarie	120	90,000	750
Wheeling, W. Va	Decarie	50	35,000	700
Milwaukee, Wis		300	210,000	700
London, Ont	Heenan & Froude	50	39,750	795
Montreal, Que	Thackeray	150	41,000	273
Moose Jaw, Sask	Heenan & Froude	50	31,811	636
Average for 22 plants				$ 600

Cost of Operation.—The reports of charges for operation and maintenance were given for the following cities:

City	Total	Salaries	Repairs	Renewals	Supplies, except fuel	Fuel
Ft. Wayne, Ind	$ 7,150	$ 3,680	$ 157	$183	$ 325	$2,824
Paterson, N. J	9,527	7,060	1,849	....	510	108
Portland, Ore	15,383	13,805	1,330	....	248	......
Erie, Pa	5,835	3,880	40	200	50	1,665
Richmond, Va., No. 1	3,700	2,250	350	....	100	1,000
Richmond, Va., No. 2	5,050	3,000	......	....	......	2,050
Spokane, Wash	3,930	3,165	45	....	......	720
Wheeling, W. Va	5,690	3,540	800	....	150	1,200
London, Ont	10,596	9,096	600	....	900	......
Montreal, Que	23,445	....	......	....	......	......
Moose Jaw, Sask	14,106	11,951	......	....	2,174	......
Milwaukee, Wis	68,892	....	......	....	......	......
Minneapolis, Minn	43,000*	....	......	....	......	......

* Approximately.

The Ohio State Board of Health reported the following costs including interest, depreciation, maintenance and repair charges, for the cities named for a period of years:

	Per ton
Canton	$1.95 to $2.50
Marion	2.00 to 2.66
Steubenville	1.00 to 1.84
Zanesville	2.58

J. W. Turrentine, of the U. S. Department of Agriculture, reports the average net cost of incineration per ton for a number of cities as $2.11.

Venable gives the operation expenses as about 50 cts. per ton of kitchen garbage destroyed and nothing to $1.00 per ton for maintenance.

From the facts available it appears that the lowest probable cost of disposal of garbage by incineration is $1.59 per ton.

Revenue from Incinerator.—The products of the disposal of garbage in destructors are steam and clinker. The following are the earnings of incinerating plants reported from Milwaukee and Minneapolis:

City	Amount	Use
Milwaukee	$10,000	Operates pumping station.
Minneapolis	27,000	Heats buildings, lights buildings and streets.

As to the utilization of the heat from incinerators for the development of power, the Chicago Waste Commission states that it has not been easy to work out an economical arrangement for the use of steam from incinerating plants because of the infrequency with which the period of need of steam by a plant will coincide with the period of operation of the incinerator. It is difficult to have the incinerator produce steam power during the hours that it is needed by the plant that is to use it, and vice versa. The installation should be so arranged that this source of power may be used to supplement other sources of power. This is done in Montreal, where the refuse destructor is used in connection with a municipal electric light plant. The destructor is operated only at night when additional power is required by the light plant because of the lighting load then in demand.

Minneapolis uses the steam generated to light and heat its hospital and workhouse buildings, and to light 31 miles of streets.

Savannah is reported as saving 96 per cent of the coal fuel formerly used at the pumping station, now providing the power from the destructor and using the clinker in road building.

Sanitary Aspects.—Incineration of garbage is sanitary and where properly conducted, permits of the disposal of garbage without odors. Thus, of the 13 cities disposing of their garbage by incineration, 12 reported no odors and one made no report. This freedom from odor and other insanitary features makes it possible to locate incinerating plants in the central part of a city and decrease the length and cost of haul. Since different kinds of refuse can be disposed of at the same time, they can all be collected at the same time and thus save the added expense of separate collections.

Reduction

Sanitary Aspects.—In theory reduction plants should be operated in a sanitary manner, without creating a nuisance and without carrying offensive odors. In practice they are not so operated.

In the New York State report the following replies were obtained from cities disposing of garbage by reduction to the question as to whether odors came from their plants:

No	New Bedford.
Yes	Schenectady-Pittsburgh.
Slight	Columbus-Dayton.
Occasionally	St. Louis-Bridgeport.
Very little	Utica-Cleveland.
At times	Syracuse.
Much	San Francisco.
Some	Springfield.
40 miles away	Washington.
No reply	New York, Rochester, Cincinnati, Detroit, Baltimore, Boston, Newark, Indianapolis.

Thus, of the 21 cities, 8 did not report as to odors, 10 reported the presence of odors to a greater or less degree, 1 did not state whether there were odors or not but did state that the disposal plant was 40 miles away from the city, and 1 city reported no odors though officials from the city of Springfield visited the plant of this city and noted the odors coming from it. Four of the cities named above operate their own plants and all of them report odors. Thus, the fact of private or public ownership and operation does not appear to affect the nuisance.

That it is the expectation that reduction plants will cause offense and complaints is evident from the location of the plants with respect to the city, as follows:

Name of city	Distance of plant from center of city
Berkeley, Cal	3 miles
Washington, D. C	40 miles
Cleveland, Ohio	8 miles
Columbus, Ohio	4½ miles
Dayton, Ohio	About 6 miles

Cost of Construction.—The cost of construction of reduction plants in cities for which the information is available was as follows:

City	Capacity, tons in 24 hours	Cost of construction and extensions	Cost per ton
Los Angeles, Cal	300	$100,000	$ 333
Chicago, Ill	800	725,000	906
St. Louis, Mo	400	300,000	750
Cleveland, Ohio	20–25	110,000	4,400
Schenectady, N. Y	200	272,000	1,360
Columbus, Ohio	160	236,000	1,475
Dayton, Ohio	50	55,000	1,100

According to the New York State report the cost of construction varied from $1,500 to $3,000 per daily ton capacity.

The average cost of construction per daily ton capacity is $287 for these cities, excepting Schenectady, where the cost was reported to be $4,400.

Cost of Operation.—One authority, Parsons, places the cost of reduction at $1.80 to $2.00 per ton of garbage; Turrentine at $2. 41; the New York State report at $1.50 to $2.50. In Columbus, Ohio, the cost per ton of garbage was as follows for the years indicated:

Year	Cost	Year	Cost
1911	$1.852	1914	$1.589
1912	2.050	1915	1.940
1913	1.910	1916	2.215

In Dayton, the cost per ton was $1.89 in 1916. Under normal conditions it would appear that the minimum cost of reduction per ton of garbage should be placed at $2.00

Revenue from Reduction.—Adequate data concerning receipts and expenditures of reduction plants are available for three cities only:

City	Expenditures	Receipts	Profit
Columbus	$ 48,423	$ 88,564	$40,140
Cleveland	153,084	224,725	71,641
Dayton	30,938	41,200	10,262

The city of Cleveland reports a profit of $1.49½ per ton of garbage. The profit for Columbus in 1916 was $1.836 per ton, while that from Dayton's new plant is $0.63. The annual profit per ton of garbage in Columbus for each of the last six years was:

Year	Profit per ton	Total profit
1911	$1.50	$26,239
1912	1.24	23,224
1913	.83	17,239
1914	1.225	26,501
1915	.477	10,910
1916	1.836	40,140

Those in charge of the Columbus plant have estimated their annual interest and depreciation charge at 6.92 per cent or $21,271. To get a true idea of the relation between revenue and cost of reduction, these items should be taken into account.

Year	Profit	Interest and depreciation charges	Net profit	Loss
1911	$ 26,239	$ 21,271	$ 4,967	....
1912	23,224	21,271	1,963	....
1913	17,239	21,271	....	$ 4,032
1914	26,501	21,271	5,229	....
1915	10,910	21,271	....	10,361
1916	40,140	21,271	18,069	....
Total	$144,236	$127,631	$16,625	....

It is assumed that the depreciation charges were the same for each year since data are not available showing when additions may have been made. The charge of $21,271 was as of 1914 and so does not include additions made since then. So that the inclusion of depreciation and interest charges for items not purchased in the early years should very nearly be counterbalanced by the omission of items purchased after 1914. The net profit for the six years is $16,625, an average of $2,771 per year.

The revenue of Cleveland per ton of garbage was given as $4.695, that of Columbus as $4.051 and that of Dayton, $2.522. Without doubt the amounts for Cleveland and Columbus are large because of the prevailing high prices. The revenue from Dayton is small probably because the plant has recently begun operations. It will be long, however, before prices drop to their former amounts.

Reduction in Columbus, Ohio.—Because the Columbus plant has been so successful, the following data have been taken from the annual report of the disposal plant:

ACTUAL COST OF OPERATION

	For the year 1915	For the year 1916	Per ton garbage 1915	Per ton garbage 1916
Supervision	$ 5,201	$ 3,000	$0.227	$0.137
Clerk hire	....	656	......	.030
Foremen	....	2,349	.... .	.107
Foremen included in supervision of 1915.				
Firemen	2,638	2,970	.115	.136
Operators	4,592	4,248	.200	.194
Ordinary labor	11,223	13,123	.490	.600
Office supplies	....	122	......	.007
Fuel	7,021	9,145	.306	.418
Clothing	....	60	......	.003
Mechanical supplies	1,212	795	.053	.036
Motor vehicle	....	256	......	.012
Chemical supplies	2,485	3,063	.108	.140
Other supplies	....	493	......	.023
Traveling expense	....	3	......	.000
Telephone and telegraph	....	71	......	.003
Advertising	....	16	......	.001
Insurance	....	197	.... .	.009
Taxes and rent	....	55	......	.003
Light and power	1,364	1,686	.060	.077
Other service	298	312	.013	.014
Maintenance buildings	....	3	......	.000
Maintenance railway tracks	....	10	. ....	.001
Maintenance equip., labor	2,455	2,059	.107	.094
Maintenance equip., material	4,589	3,555	.201	.163
Maintenance motor vehicle	....	161	......	.007
Other maintenance	....	4	......	.000
Office expenses	316	....	.014	......
Transportation	501	....	.022	......
Miscellaneous	550	....	.024	....
Total	$44,453	$48,423	$1.940	$2.215

ACTUAL PRODUCTION

(Receipts corrected from inventories)

	For the year 1915	For the year 1916	Per ton garbage 1915	Per ton garbage 1916
Grease (lbs.)	1,014.572	1,344.789	44.28	61.52
Tankage (lbs.)	4,596.140	4,506.640	200.62	206.14
Hides (No.)	220	156	....	....
Grease (value)	$38,048.57	$69,451.53	$ 1.661	$ 3.177
Tankage (value)	16,081.86	17,672.12	.702	.808
Hides (value)	1,233.56	1,440.42	.054	.066
	$55,363.99	$88,564.07	$2.417	$4.051

Items	Cost	Est. life, yrs.	Annual per cent deprec.	Value, 1914
Buildings—				
Reduction building, green garden building, gasoline storage, office and one-half of stable....	$ 71,177	50	2	$ 64,771
Percolator building.............	10,218	50	2	9,605
Brick chimney...................	4,600	30	3⅓	3,910
Digestors, roller presses, grease separating and storage tanks, hot well, screw press, liquor storage tank..................	36,615	15	6⅔	25,631
Receiving hoppers, jet condensers...	1,000	10	10	550
Dryers and equipment............	12,650	15	6⅔	8,855
Evaporators.....................	9,400	8	12½	4,112
Boilers and stokers...............	7,615	12	8⅓	4,759
Conveyors and elevators...........	12,556	15	6⅔	8,789
Percolator, vaporizing tanks, condenser..........................	6,030	12	8⅓	4,522
Gasoline storage tanks............	1,045	20	5	888
Reinforced concrete condenser tank.	946	20	5	927
Motors and switchboard...........	2,903	30	3⅓	2,467
Boller feed pumps................	574	20	5	444
Steel boiler flue..................	373	12	8⅓	233
Open feed water heater............	944	12	8⅓	500
Water supply pump...............	1,317	..*	...*	300
Air displacement pumping equipment........................	4,046	..*	....*	1,000
Pipe lines........................	5,852	20	5	4,535
Oil storage tanks................	172	15	6⅔	120
Railroad track scales.............	987	20	5	764
Railroad track trestles............	5,182	20	5	4,024
Miscellaneous new equipment purchased from operating fund:				
In 1911.........................	4,516	15	6⅔	3,462
1912.........................	1,426	15	6⅔	1,189
1913.........................	734	15	6⅔	660
1914.........................	1,416	15	6⅔	1,368
Total and averages..........	$204,309	19½	....	$158,484
Engineering and miscellaneous.....	32,571	....	4.98	25,265
	$236,880	....	....	$183,749

* Not used any more. Value based on what could be secured for them if sold as second-hand machinery.

Annual charge for depreciation at 4.98 per cent..........................	$11,796
Annual charges for interest on bonds at 4 per cent........................	9,475
Total fixed charges at 8.98 per cent....................................	$21,271

Municipal vs. Private Operation of Reduction Plants.—The majority of reduction plants are owned and operated privately and dispose of garbage under contract with the city. The arrangement in 22 cities was as follows in 1906:

——Private——		Municipal—
New York	Rochester	Schenectady
Syracuse	Utica	Columbus
Cincinnati	Detroit	Cleveland
Washington	St. Louis	Dayton
Baltimore	Bridgeport	Chicago
Pittsburgh	Boston	
New Bedford	Newark	
San Francisco	Los Angeles	
Indianapolis		

Only two cities that dispose of their garbage under contract with a concern employing the reduction method report any revenue in return for the privilege. These cities are Los Angeles and New York. The reduction company in Los Angeles pays the city $0.51 per ton. New York receives $112,500 a year. It is to be noted that Los Angeles also reports that it received $1.00 per ton from farmers for garbage delivered for feeding to hogs.

Feeding to Swine

Cities Using This Method.—According to the New York report, 34 out of 112 cities were employing this method in 1915. According to the Municipal Journal the following cities of from 100,000 to 300,000 population employ the methods named:

Feeding to pigs	Albany, Cambridge, Denver, Grand Rapids Hartford, Providence.
Reduction	Bridgeport, Columbus, Dayton, Indianapolis, Rochester.
Incineration	Portland, Ore.; Reading, Trenton, Paterson.
Dumping at sea	Oakland, Cal.

Turning Garbage Over to Private Pig Farms.—A city may turn its garbage over to farmers—for nothing or for a remuneration—to feed to pigs, or it may operate its own pig farm. The majority of cities feeding their garbage to pigs do so under the former arrangement. A few cities, including Worcester, Taunton, Brockton and New Haven, operate their own hog farms.

Revenue from Turning Garbage Over to Private Farms.—Many cities not only dispose of their garbage at no cost by the use of this method but also make it the source of a large amount of revenue. The following receipts are reported for the cities named:

Grand Rapids, Mich	45 ct. per ton	$ 4,450
Denver, Colo	Gets its collection and disposal for nothing	
Cambridge, Mass	70 ct. per cd. ft	17,382
Colorado Springs, Colo	Gets its collection and disposal for nothing, and	1,440
Salem, Mass		* 2,651
Somerville, Mass	50 ct. per cd. ft	
Lawrence, Mass	$1.25 per load	† 8,865
Lowell, Mass	$1.25 per load	5,405
St. Paul, Minn	80 ct. per ton	
Los Angeles, Cal	$1 per ton	
Springfield, Mass	Average per year, 1907–1911	4,262

* $13,255 in 3 yrs. † Estimated.

Many cities receive no revenue from garbage so disposed of. Thus, the revenue from this method of disposal varies from nothing in many cities to $17,400 in Cambridge. However, Denver, with a population of 265,000, has its 21,600 tons of garbage collected as well as disposed of by a hog growers' association; and Colorado Springs has its garbage collected and disposed of by hog growers and receives in addition $1,440. Assuming that the cost of collection in these cities was $0.30 per capita, which was two-thirds the per capita cost of collection reported in 1915 by 59 cities, the city of Denver saved $64,500 in 1916 and Colorado Springs saved $9,600 plus the $1,440 actually received.

Feeding Garbage on Municipal Hog Farms.—Worcester, Brockton and New Haven are among the cities that operate farms where they feed city garbage to pigs.

New Haven reports that during 1916 the department of streets fed to pigs the garbage collected from 52,100 of the population. $16,000 was received from the sale of pork.

Brockton paid $29,952 for the collection of its garbage and the operation of its pig farm. It received $15,761 from the sale of swine and of garbage. Thus, it both collected and disposed of its garbage at a cost to the city of $7,191.

From Dec. 1, 1916, to May 31, 1917, the city of Worcester has disposed of its garbage at an approximate cost of $7,500 and has received over $21,000. These figures were given by the superintendent in charge of the hog farm. He also estimated that during the year beginning Dec. 1, 1916, the city will spend $15,000 on account of the pig farm and receive $50,000 from the sale of products, thus making a profit of $35,000 on the disposal of garbage.

Initial Investment.—The probable cost of establishing today a piggery similar to that at Worcester was given as follows by Dr. Frederick Bonnett, Jr., of the Worcester Polytechnic Institute:

Stock	$ 49,700
Buildings	60,000
	$109,700

This means that an investment of $5,485 per daily ton would be required to establish the plant capable of disposing of a daily production of 20 tons. This does not include the cost of land which should run from $5,000 to $10,000.

S. A. Greeley, a sanitary engineer, of Chicago, Ill., submitted in 1916 the following estimate of cost of establishing a hog farm to handle an average daily production of 50 tons:

Pigs	$ 25,000
Buildings and other structures	110,000
Engineering and contingencies	25,000
Land	30,000
	$ 190,000

Cost of Operation.—The cost of operation per year was estimated as follows for Worcester:

Labor	$ 5,760
Grain and bedding	2,640
Medicine and disinfectants	5,040
Miscellaneous	1,000
Administration	2,500
Total	$15,000

At this rate to dispose of an average of 20 tons per day or 7,300 tons per year, the cost per ton of garbage would be $2.65. The cost reported by Greeley was at the rate of $1.98 per ton.

Revenue from Feeding.—The revenue from the Worcester Pig Farm is estimated at $50,000 for 1916. This is at the rate of $6.85 per ton of garbage.

Greeley estimated the yearly revenue from a 60-ton per day plant at $80,000. This would make the revenue per year per ton of garbage $3.65.

The revenue at Worcester is estimated on the basis of present prices; that by Greeley on prices last year. A fair estimate should be $3.75 per ton.

Operation of Garbage Piggery at Grand Rapids, Mich.—The following abstract, of a paper read before the 1912 convention of the Michigan Health

Officers by T. M. Koon, M. D., a member of the State Board of Health, was published in Engineering and Contracting, Sept. 18, 1912.

After the garbage is collected and loaded on cars by the city, the contractor ships the garbage to his farm. The farm, which contains about 100 acres, is located about three miles out of the city, and lies adjacent to the Pere Marquette Railway. The soil is sandy and well drained. There are about 40 buildings on the farm, including the farm house, horse barn, office building, boiler room, garbage kitchen, employes' restaurant, feeding houses, and farrowing houses.

The boiler room is 34 × 36 ft. in plan. The garbage kitchen adjoins the boiler room and is 64 × 40 ft. in plan. There are three cooking pans in this kitchen 24 ft. long, 6 ft. wide and 3 ft. deep, and three cooking pans 30 ft. long, 6 ft. wide, and 4 ft. deep. This kitchen is devoted to cooking garbage and meal for feeding the hogs. The garbage from the entire city is not sufficient to feed the 7,000 to 9,000 hogs kept here, so $1,000 worth of corn is fed each week. The next building is the restaurant where the 20 employes are fed. There are three farrowing houses, each 336 ft. long by 30 ft. wide. These buildings have cement floors and troughs, water throughout and are steam heated. These houses shelter 1,200 brood sows, each having a separate stall; 40 sows bring forth a litter of pigs each week, over 10,000 being born each year. There is another building 234 ft. long by 56 ft. wide. There are over 100 breeding pens with a yard for each. There are two buildings 100 ft. long by 20 ft. wide. They have cement floors and troughs. These building are called the restaurants. Here the hogs are fed cooked corn meal while being fattened for market. A small railroad runs throughout the grounds and buildings to carry the garbage and corn meal to the swine. The granary, numerous yards and ranges and the reservoirs for storing water to supply the buildings, complete the piggery. Everything is well kept and orderly. Here all the garbage from the city of Grand Rapids is disposed of. From this place 200 hogs are shipped to market each week. Over 10,000 fattened hogs are turned out each year. The value of this output is about $135,000 a year.

It has been only a few years that so many hogs could be kept safely on account of the liability of the herd becoming infected with cholera and destroyed. Therefore this method of garbage disposal was very hazardous as a money making undertaking. Now that it is possible to immunize against hog cholera, this danger is obviated. All of the pigs at this place are immunized while nursing, so there is no danger of the herd being destroyed with hog cholera.

More recent information in regard to the disposal of the garbage of Grand Rapids was given in the Conference of the Federal Food Administration held in Chicago, Dec. 7, 1917. The following is given in a report of the conference published in Engineering News-Record, Dec. 27, 1917.

The garbage of Grand Rapids is collected and loaded on cars by the city. Alvah H. Brown ships it every day 27 miles to his 80-acre farm in an isolated section, located on sandy soil. He pays 45cts. per ton for freight and 25cts. to the city. He feeds inside a long building, on concrete platforms, onto which garbage is dumped directly from the cars. Glass from electric-light bulbs are the worst "foreign" matter in garbage. Sheep and cattle have also been fed garbage in winter, but not in summer. Corn silage is fed on Sundays and a cheap "fire sale" grain is usually part of the bill of fare.

Mr. Brown believes that hogs could be fed without nuisance in a building within the city limits if proper attention were given to ventilation. One ton will feed 100 pigs. He employs 12 men to care for 6,000 hogs. Hotel garbage is worth ten times as much as household garbage, in his estimation. Cooking is not desirable, as it reduces the garbage to a slop in which the pig gets no chance to discard grapefruit and things which do not agree with his digestion. All feeders agreed that cooking is a mistake for household garbage. For hotel wastes, rich in recoverable fats, it is practical. Mr. Brown gets daily 500 lb. of bones worth 1c. a pound. In October 1,015 tons of garbage were fed.

Operation of Garbage Piggery at Worcester, Mass.—The following data are from an article by Prof. Frederic Bonnet, Jr. of Worcester Polytechnic Institute, published in Engineering News-Record, Aug. 30, 1917.

Worcester is one of the old and well established cities of New England with a population of about 175,000. It is an industrial city with many diversified industries but with no unusual characteristics. Its foreign population, according to the census 1910, is only 33.5%.

In 1872 (population 44,000) the superintendent of the municipal poor farm began sending a wagon into the city now and then to collect enough garbage to feed the pigs. The work developed with the growth of the city until today about 70% of the garbage of Worcester (20 to 30 tons per day) is taken to the Home Farm and fed to 2,000 to 3,000 pigs. The garbage disposal has developed and continued along this one line for a longer time than has usually been the case in American municipalities. There has been a striking absence of unwise and unsuccessful experiment.

The Home Farm proper consists of 376 acres owned by the city. In addition, the city leases a farm of 220 acres, at a rental of $1,500 a year. The farm is located in the northeastern part of the city. To get to it, the garbage teams coming from the center of the city have to pass over a ridge about 140 ft. high.

The city is divided into 21 districts from which the garbage is collected twice a week without charge to the householders or business men. There is also a special collection for the fish offal and rotten eggs from markets and commission houses, which collection is made daily in special cans with tight-fitting covers. These cans are provided by the dealers. Since this material is not fed to swine but is buried, as described later, no revenue is derived from it and it is a direct tax on the scavenger department of $1,760 per year.

Hitherto, most of the hotel, restaurant and hospital garbage was privately collected, but owing to the recent falling off of the quantity and quality of the garbage, more of this is gradually being collected by the city. Some private collectors also obtain the privilege of collecting in certain outlying districts. All such collectors must first obtain a license from the Board of Health, and this is only given by the board after consultation with the superintendent of the Home Farm, who includes in his duties the supervision of the scavenger department, the sole purpose of which department is the collection and disposal of the garbage collected by the city. The arrangement with private collectors has not been wholly satisfactory.

For the city collectors, one load is considered a day's work. Each collector unloads his wagon and washes it. He also beds down his horses and curries them. The feeding is not done by the collectors but by a farm employee especially assigned to this task.

The teams leave the Home Farm at 7 a. m. and have on an average a 13-mile haul daily (max. 18; min. 10). It requires from 2 to 4 hours to make a load. Owing to the fact that Worcester has practically no alleys the average time per house collection is 1.65 minutes (max. 3.9; min. 0.4).

Of 2,276 hogs sold to a packing house only 11 were condemned by the United Stated Government meat inspectors, an average of only 0.48%, which is much lower than on hogs shipped in from the West to the same packing company.

Operation of Garbage Piggery.—The following description of the operation applies to Worcester's garbage-disposal plant as now operated under the able direction of Thomas Horne, superintendent, who has aided the writer in the preparation of this paper. The garbage as it comes to the farm is neither washed nor steamed. Washing is uneconomical because so much valuable food material is washed away and wasted; it is unnecessary since no material advantage is gained thereby. Cooking or steaming the garbage has been found by experience to be bad since the garbage is thereby made more acid than it ordinarily is and substances are incorporated in the food which are harmful to the hog and which would not be eaten in the raw garbage. A hog is more capable of picking over and culling garbage than any man or machine can be.

Pigs are kept with the sow in individual pens until they are six weeks old, although the pigs begin to eat garbage when about three weeks old. Boars are castrated when about five weeks old and are then left with the mother another week. The pigs remain in pens until they are about 6 months old and are fed from troughs. They then weigh about 75 to 100 lb.

Inoculation Against Cholera.—The entire stock is treated by the so-called double-treatment method (virus and serum). Pigs 5 to 6 weeks old are inoculated with serum only. This treatment carried them for about 7 weeks when, at a weight of about 40 to 50 lb., they are given the double treatment, virus and serum. State veterinarians under the State Bureau of Animal Industry do this work free of charge, the department merely paying for the serum and virus used and for the necessary help. The cost of treatment depends upon the size of the animal since more serum is used the larger it is.

The serum costs 1¾cts. per c.c. and about 20 c.c. are used for a 40 to 50-lb. hog, live weight, so that the total cost of treatment exclusive of help is therefore about 70cts. per pig. The place for injection (between the hind legs) is scrubbed with soap and water containing lysol or similar disinfectant and swabbed with tincture of iodine after puncture. Not one hog in 500 is lost and there is no trouble from ulcer formation if the inoculation is properly done. One veterinary with five helpers can treat 250 pigs of 40- to 50-lb. weight in a day.

To prevent itch the hogs are all sprayed about once in six weeks with a mixture of 3 parts of kerosene and 1 part of turpentine.

Out-of-Door Feeding Platforms.—After six months the pigs which have grown to shoats are turned into hog lots (100 pigs to about 3 acres) with out-of-door feeding platforms made in 8 × 8-ft. sections of 2-in. plank. These are mounted on skids and have a half round timber on two sides to prevent the garbage from being pushed off. The cost per section was $7, with farm labor. Several sections are placed end to end and when the ground around the platforms becomes fouled the sections are skidded to another location and the ground at the former location plowed up. By this means the garbage trampled into the ground is kept from decaying and producing foul odors. The platforms are shovel cleaned daily and the material removed is composted or buried. The hogs are kept for about 15 months, when they are sold. They then weigh 250 to 300 lb. The last lot sold (May, 1917) brought 16.35c. per lb. on the hoof or 21c. per lb. dressed.

The sows are bred by turning about 300 of them into the same lot with about 30 boars for about five weeks. This makes it possible to control the farrowing so that there may be a sufficient number of pens. The first lot of brood sows are put with the boars from about Oct. 20, until Dec. 1. This brings the farrowing at the end of January, February and early March. After a month or six weeks a second lot of sows are bred and so on. During farrowing and sometimes during inoculation a little grain and middlings are fed. Boars are rarely kept more than two years and only prolific sows that are good mothers are kept for repeated breeding.

Old and New Pig Houses and Other Buildings.—Up to 1914, there were 12 pig houses scattered about the farm. Seven of these old piggeries are shelter sheds for outside hogs and have been torn down or are being used for other purposes. At present there are four pig houses in use, the dimensions of which are given in Table V, and two shelter houses. To provide additional pens for late spring farrowing 100 small portable take-down colony houses have been built at a cost of $20 each. These have proven excellent.

The floors of all piggeries are of concrete. At one end of each pen there is a slightly raised wooden platform for bedding to keep the pigs warm and dry.

Piggery No. 1 is the only one which is steam heated and is used for early farrowing. It is a well-built house erected about 25 years ago at an approximate cost of $4,000.

Piggeries Nos. 5 and 6 are identical in construction and were built about 15 years ago at a cost of about $3,000 each.

Piggery No. 11 is the newest, having been built in 1913 at a cost of $3,000.

TABLE V.—PRINCIPAL DIMENSIONS OF GARBAGE PIGGERIES AT WORCESTER HOME FARM

Piggery no.	1 right wing	1 left wing	5	6	11 right wing	11 left wing
Inside dimens., ft.:						
Length	180	190	241.0	241.0	100.0	106.0
Width	19	25	30.0	30.0	20.0	20.0
Walk width, ft.:						
Side	6	...	.....	.....	5.5	5.5
Center	...	5	5.0	5.0	.....	.....
Pens:						
Number	30	76	80.0	80.0	15.0	16.0
Width, ft	6	5	6.0	6.0	6.0	6.0
Length, ft	12	10	12.5	12.5	13.5	13.5
Height, ft.*	8	8	.....	.....	.....	.....
No. windows†	30	38	40.0	40.0	24.0	24.0
No. doors‡	3	2	2.0	2.0	7.0	7.0
Partitions between pens	Wood	Wood & wire	Wire	Wire	Wire	Wire

* Height to ceiling. † 3 × 3 ft. ‡ 4 × 6 ft.

The pens are cleaned out daily. The cleanings, which consist of pig manure, urine, uneaten garbage and soiled bedding are carted away to the compost heap, which is inclosed by concrete walls. The cleanings, when not properly handled, may give trouble from odor. The commission already mentioned experimented with this material and found that when composted in layers with an equal volume of dry top soil, the rotten manure odor was wholly destroyed and only a slight musty odor remained after 10 days. The cleanings are quite wet and unless spread alternately in fairly thin layers with dry soil it takes a much longer time to mineralize the odor-giving substances. Objectionable odors may be carried a considerable distance when uncomposted material is spread on the ground as fertilizer, while the composted material is unobjectionable.

Since the bad odors are probably highly nitrogenous, composting by retaining these substances and mineralizing them would tend to increase the fertilizing value of the manure. About five cords of cleanings are produced daily (1,500 to 1,600 cords per year) and have a value of about $4 a cord as fertilizer at the farm. The Home Farm has never bought fertilizer in any material quantity for its farm land or truck garden and the scavenger department has never been credited with the value of the pig manure from the piggeries. There are two caretakers in each piggery except No. 11, which has one. One caretaker can care for about 250 to 300 pigs a day—feed them, bed them, and clean out the pens.

Out-Door Hogs Improve The Farm.—The out-door hogs are utilized in cleaning off the scrub from waste land and improving it. They chew and rip off the bark of practically all deciduous trees and thus kill them but coniferous trees are not touched. After chewing and stripping the bark they burrow around the roots, chew this bark and uproot the smaller stumps. In a remarkably short time (about two seasons) the scrub disappears and only the larger stumps must be pulled out before plowing is possible. Most of the cleared land of the Home Farm has thus been cleared and made into a very productive farm. Hog growers claim and it has been the experience at Worcester that such scrub acts somewhat as a tonic for the hogs and keeps them in good condition.

Tables VI and VII give the cost of collection and disposal for one year. Table VIII shows the operating cost and income of the scavenger department over a number of years. Including the years 1902 and 1910, which showed a clear profit over and above the cost of collection, the average net cost of disposal per year for 19 years was $10,169, or $0.074 per capita per year. From Tables VI and VII it will also be seen that the total cost of collection and disposal per year is $60,435. About 1,500 swine are sold each year and with the present price of pork will bring about $40 each or a total of $60,000. This will just about pay for the cost of collection and disposal. Table IX gives the estimated first cost of building and stocking a 20- to 30-ton garbage piggery.

Table VI.—Yearly Cost of Garbage Collection at Worcester, Including Capital Charges

1 Foreman, $45 per month		$ 540
1 Fish offal collector, $42 per month		504
1 Inspector, $2.50 per day (not found)		780
21 Collectors, $37 per month		9,324
6 Helpers, $35 per month		2,520
29 Men's board and lodging, 52 weeks, $5.60		8,445
44 Horses' board, $27 per month		14,256
		$36,368
Interest on investment:		
2 Horses and wagons, $800 each	$ 40	
Depreciation on teams, 10 %	80	
Horseshoeing	50	
Wagon repairs	76	
Veterinary, hardware, etc	32	
Total for 1 team	$278	
For 22 teams		$ 6,116
Total cost		$42,785

TABLE VII.—COST OF GARBAGE DISPOSAL PER YEAR AT WORCESTER, INCLUDING CAPITAL CHARGES

7 pig caretakers, 2 manure men, 1 compost man @ $37 per month	$ 4,440
Additional occasional help	1,320
Grain and bedding	2,640
Medicine (serum, virus, disinfectants)	3,040
Time of superintendent, farm foreman, office*	2,560
Miscellaneous—light, heat, water*	1,000
Interest on investment, 5 %, buildings, $13,000	650
†Stock 2000 hogs, @ $20, $40,000	2,000
Total	$17,650

*Estimated. †Estimated that 2,000 hogs are a necessary minimum for 20 tons daily capacity.

In September, 1915, when the farm was restocked after the hoof-and-mouth disease, 1,200 shoats of an average weight under 20 lb., 100 sows and 5 boars were purchased for $7,700. All the garbage collected was not consumed by this herd and additional stock was purchased, which brought up the total stock purchased to about $10,000.

From September, 1915, to January, 1917, $16,000 worth of pork was sold, and from Jan. 1 to June, 1917, $21,000 worth of pork was sold. There is on hand at the present time stock valued at $50,200.

TABLE VIII.—YEARLY QUANTITIES OF GARBAGE COLLECTED, NUMBER OF PIGS AND FINANCIAL RESULTS AT WORCESTER, 1898 TO 1916

Year	Garbage collected per day, cubic yards	No. of Pigs on Nov. 30 of each year	Financial summaries for each year: Total expenditures	Total receipts	Net cost	Net profit
1898	....	.....	$14,804.34	$ 7,674.02	$ 7,130.32	....
1899	....	.....	17,109.00	10,641.52	6,467.48	....
1900	52.8	.....	17,715.21	11,947.91	5,767.30	....
1901	52.8	.....	18,935.86	13,933.03	5,002.83	....
1902	52.8	.....	18,765.03	18,766.99	....	$ 1.96
1903	52.8	.....	18,140.57	11,941.55	6,199.02	....
1904	57.5	.....	22,326.02	7,327.00	14,999.02	....
1905	57.5	.....	20,515.83	12,539.20	7,976.63	....
1906	57.5	.....	23,525.49	19,321.00	4,204.49	....
1907	....	2,850	30,491.93	24,830.71	5,661.22	....
1908	....	.....	34,475.73	24,321.22	10,154.51	....
1909	....	.....	37,737.79	29,257.25	8,480.54	....
1910	....	.....	37,039.68	43,224.25	....	4,184.57
1911	....	1,388	41,021.74	25,579.58	15,542.16	....
1912	....	2,057	45,750.28	22,863.27	22,887.01	....
1913	....	2,167	53,109.10	38,376.11	14,732.09	....
1914	....	2,502	53,325.62	38,838.67	14,486.95	....
1915	52.5	1,300	55,718.43	39,994.36	15,724.07	....
1916	....	.....	57,680.03	16,692.99	40,987.04	....

* Note.—Hoof-and-mouth disease. For 5 months in 1915 the garbage was buried. Farm restocked late in 1915 and early in 1916.

TABLE IX.—ESTIMATED COST OF GARBAGE PIGGERY WITH CAPACITY OF 20 TO 30 TONS A DAY

Based on conditions existing at Worcester, Mass. Land not included.

Four buildings with a pen capacity of about 300 pens, 6 × 12 ft., including small heating plant for one house, water-supply, drainage, platforms and fencing		$30,000
3 horses, wagons and sleds for disposal work		1,500
Stock on hand June, 1917:		
1,100 swine @ $30	$33,000	
100 sows @ $25	2,500	
800 shoats (50–100 lb.) @ $12	9,600	
900 pigs @ $5	4,500	
30 boars @ $20	600	50,200
Total		$81,700

The feeding method is very plastic and no part of the plant is idle or running below capacity part of the year. When the quantity of garbage becomes less hogs are sold off, and as the quantity increases, the herd increases to take care of it. In winter there are about 2,000 swine on the farm and in summer 3,500. About 100 to 150 pigs, depending upon size, will consume one ton of garbage per day.

Experience has shown that feeding garbage to hogs is the most economical and satisfactory method of disposal at Worcester and that it can be done in a sanitary manner without appreciable odor if given intelligent care.

At the conference on the subject of wastes disposal held in Chicago, Dec. 7, 1917 by the Federal Food Administration, Thomas Horne gave the 1917 figures of operation for the year ended Nov. 30 as follows:

There was sold $51,800 worth of pork raised on 6,501.4 tons of garbage. The cost (after collection) at the farm was $2.30 per ton, leaving a net pork value of $5.66 per ton for the garbage delivered at the farm. Mr. Horne values the equipment at $67,000, itemized as of Nov. 30, as follows: 40 acres land, at $100, $4,000; buildings and platforms, $20,000; 2,096 hogs, $42,000; miscellaneous, $1,000.

Cost and Operating Data of High-Temperature Refuse Incinerators.—The following data are given by Samuel A. Greely in an article published in Engineering News, Aug. 26, 1909.

Cost of Incinerators.—The data presented in Tables X and XI are taken from a paper by J. T. Fetherston, read before the American Society of Civil Engineers, December, 1907; from the "Minutes of Evidence," Vol. 5, 1908, of the Royal Commission on Sewage Disposal, and from "Refuse Disposal and Power Production," by W. Francis Goodrich. The individual results differ widely and show how local conditions affect the cost of construction. There may be conditions for which a top-charged plant is the more economical. In general, however, the results point to the fact that the top-charged incinerators cost about 10% more than bottom-charged incinerators.

A mechanical-charging device fitted to a top-fed plant is an added element of cost. The incinerator at Newcastle, fitted with the Horsfall tub-feed, cost about $48,000, and has a rated capacity of 67 tons; which gives a cost per ton of about $715. At Greenock, the incinerator, with Horsfall tub-feed, cost $95,000, and has a rated capacity of 120 tons, giving a cost per ton of $790. The cost of the mechanically-charged plant at Leeds was only $375 per ton; but this plant was built adjacent to an old hand-charged incinerator where it was possible to use the flues, boilers and chimney of the old plant. Mr. George Watson, of the Horsfall Co., figures roughly on $17,000 as the cost per cell of a tub-fed incinerator. This, on a basis of 26 tons per cell per day, as at Leeds, gives a cost per ton of about $650. These figures indicate that a mechanically-charged incinerator may cost in the neighborhood of $650 to $700 per ton under conditions which would require an expenditure of about $550 per ton for the hand-fired bottom-charged plants. This difference, at 5% annual interest and 310 working days per year, reduces to about 2 cts. per ton. The figures given for the cost of construction are for the whole plant, including cells, building, chimney, runway, crane and hopper; but do not include land or any adjacent electric plants, sewage-pumping stations, etc.

Operation.—Data showing the force required to operate the different types of plants and the cost of repairs have been obtained and are presented in Tables XII and XIII, which follow. Table XII, hand-charged incinerators, gives the tons of refuse which can be handled per man per hour. All of

Table X.—Average Cost of Construction of Bottom-Charged Incinerators

Plant	Rated capacity, tons of 2,000 lbs. per day	Cost Total	Cost Per ton	Authority
Aldershot	50	$ 5,800	$ 116	Goodrich
Burslem	33	18,950	574	Fetherston
East Ham	67	61,700	920	Goodrich
Eccles	53.5	22,000	412	Goodrich
Epsom	53.5	22,100	412	Goodrich
Fulham	135	82,124	610	Fetherston
Heywood	27	24,300	900	Goodrich
Hyde	80	34,000	425	Goodrich
Ilkey	22.5	7,020	312	Fetherston
Kettering	28	25,480	910	Fetherston
Kings Norton	100	73,500	735	Fetherston
Lytham	27	11,700	434	Goodrich
Manchester	33	12,700	385	Goodrich
Radcliffe	40	16,000	400	Goodrich
Rathmines	67	35,200	525	Fetherston
Salisbury	30	14,600	485	Goodrich
Seattle	60	36,000	600	Morse
Sheerness	26	17,150	635	Fetherston
Swansea	71	53,900	756	Fetherston
Taunton	60	19,500	325	Goodrich
Vancouver	48	35,000	730	Author
Watford	53.5	33,000	618	Goodrich
West New Brighton	60	about	1,000	Nutting
Weymouth	53.5	19,500	365	Goodrich
Worthing	28	21,450	765	Fetherston
Wrexham	53.5	11,324	211	Fetherston
Average			$ 568	

Table XI.—Average Cost of Construction of Top-Charged Incinerators

Plant	Rated capacity, tons of 2,000 lbs. per day	Cost Total	Cost Per ton	Authority
Accrington	60	$ 60,000	$ 670	Goodrich
Belfast	134	49,000	366	Fetherston
Brentford	60	40,000	670	Goodrich
Bristol	120	60,000	500	Goodrich
Bromley	50	23,900	478	Fetherston
Burton on Trent	28	23,000	820	Fetherston
Dalmarnock, Scotland	84	66,700	794	Goodrich
Eastbourne	75	33,000	442	Goodrich
Leamington	75	30,500	405	Goodrich
Leyton	100	43,160	430	Goodrich
Llandudno, Wales	28	27,980	990	Fetherston
Ruchill, Scotland	89	100,220	1,130	Fetherston
Saltley	95	52,000	547	Fetherston
Shoreditch	112	100,500	900	Fetherston
Southwick	62	45,000	725	Goodrich
Stafford	50	19,500	390	Goodrich
St. Pancreas	160	102,900	644	Fetherston
Stockton on Teas	22.5	15,000	670	Fetherston
Walthamstow	112	49,000	438	Fetherston
Wandsworth	78	24,500	315	Fetherston
Westminster Boro	80	50,180	630	Fetherston
Winchester	20	12,400	620	Goodrich
Average			$ 615	

TABLE XII.—LABOR REQUIRED IN THE OPERATION OF HAND-CHARGED INCINERATORS

Plant	Top charged or bottom-charged	No. of men per shift	Tons of 2,000 lbs. burned	Tons per man-hr.
Accrington	top	5	40	0.34
Saltley	top	3	60	0.83
Seattle	bottom	4	60	0.63
Vancouver	bottom	2	50	1.00
Watford	bottom	2	30	0.63
Westmount	top	3	30	0.42
Wood Green	bottom	2	35	0.73
Zurich	top	10	160	0.67

TABLE XIII.—LABOR REQUIRED IN THE OPERATION OF MECHANICALLY-CHARGED INCINERATORS

Plant	No. of men per shift	Tons of 2,000 lbs. burned per day	Tons per man-hour
Greenock	4	110	1.14
Hamburg experimental plant	2	60	1.25
Kiel	8	125	0.65
Leeds	2	53.5	1.12
Newcastle	3	60	0.83
Wiesbaden	5	110	0.90
Average			0.98

the hand-fired plants are grouped together and averaged for comparison with the mechanically-charged plants. There is no great difference in this respect between the hand-fired bottom charged plants and the hand-fired top-charged plants.

Actual quantities of refuse burned, instead of rated capacities, are used in reducing the results to a man-hour basis.

Omitting Accrington, which has a close, poorly ventilated clinkering room where clinkering is hot and heavy work, and Westmount, where the plant is working considerably below the rated capacity, the average output in tons per man-hour is 0.75. Including all the plants the average is 0.66 ton per man-hour.

Mr. Fetherston sums up his study of 27 plants, only one of which was mechanically charged by saying "each man employed would handle 0.88 short ton per hour. At an easy rate of working there should be no trouble in destroying 0.75 ton per man per hour."

These tables indicate that with a mechanical charging device about ⅕ of a ton more per man per hour can be handled than without it. Assuming 25 cts. an hour for labor, this difference amounts to 5 cts. per ton in favor of the mechanically-charged incinerators. For plants fitted with the Horsfall tub-feed this may be slightly greater.

The cost of repairs for incinerators varies considerably from year to year and no very definite results can be expected. The mechanically-charged plants have most of them been built within the last two years and there are very few data on cost of repairs. The plants were grouped in Tables XIV and XV according to whether they are bottom-charged or top-charged, because top charging in general is harder on the grate and hearth and because the top-charged plants are more nearly analogous to the mechanically-charged plants. The costs given in the tables are taken from the testimony of Mr. W. F. Goodrich before the Royal Commission on Sewage Disposal, from Mr. Fetherston's paper, or were furnished by Mr. H. Norman Leaske, of Manchester, England. A few of them were taken from English pamphlets on refuse incineration.

On a basis of 310 working days in a year, these average results reduce to about 0.5-ct. per ton for repairs for the bottom-charged plants and 2.5 cts. per ton for hand-fired top-charged plants, a balance of 2 cts. per ton in favor of the bottom-charged incinerator.

For the mechanically-charged plant at Leeds, now in its fifth year and burning 53.5 tons per day, the repairs for the year 1908 amounted to $90, or about $1.68 per ton per year, which is equivalent to 0.54 cts. per ton of refuse burned.

TABLE XIV.—APPROXIMATE COST OF REPAIRS FOR BOTTOM-CHARGED INCINERATORS

Plant	Tons of 2,000 lbs. burned, per day	Cost of repairs per year Total	Per ton
Aldershot	13	$ 0.90	$0.07
Birmingham	37	40.00	1.08
Burslem	40	7.00	.17
Gosport	33	243.00	7.38
Grays	12	25.00	2.08
Hereford	12	21.00	1.75
Levenshulme	50	8.00	.16
Lytham	13	5.00	.38
Manchester	60	122.50	2.05
Radcliffe	39	85.00	2.18
Sheerness	14	14.00	1.00
Watford	30	50.00	1.67
Weymouth	20	8.40	.42
Worthing	21	32.00	1.52
Wrexham	33	21.00	.64
Average			$1.50

TABLE XV.—APPROXIMATE COST OF REPAIRS FOR TOP-CHARGED INCINERATORS

Plant	Refuse burned, tons of 2,000 lbs. daily	Cost of repairs per year Total	Per ton
Belfast	90	$490.00	$ 5.45
Bolton	50	68.00	1.36
Cambridge	29	290.00	10.00
Fulham	118	14.80	12.50
Hackney	142	22.50	15.80
Leamington	39	73.00	1.87
Rotherham	56	315.00	5.62
Royton	16	146.00	9.15
Southampton	45	340.00	7.55
Average			$ 7.90

Mr. Greeley gave tables showing that the annual saving in coal, due to the use of steam generated from incinerators is greater in the bottom-charged than in the top-charged type, the average saving being 31.1 cts. for the bottom-charged and 15.5 cts. for the top-charged incinerators for each ton of refuse burned. This saving will depend upon a number of conditions among which are the use made of the steam generated and the quality of the refuse burned.

Tables XVI and XVII indicate the extent to which the useful heat energy returned is influenced by the method of charging.

Mr. W. F. Goodrich, in his book entitled "Refuse Disposal and Power Production," presents a table showing the number of electrical units generated per ton of refuse destroyed at twenty combined electricity and destructor works. If the top-charged and bottom-charged plants listed in these tables be averaged separately, the results would show an output of 30 kw.-hrs. per short ton for the top-charged incinerators as against 40 kw.-hrs. per short ton for the bottom-charged incinerators.

These results have been bettered considerably in more recent installations. Tests made on the top-charged plants at Bradford and Hackney and on the mechanically-charged plant at Greenock developed 60, 50, and 80 kw.-hrs. per short ton of refuse burned respectively, the average being 63.3 kw.-hrs. per ton. The bottom-charged incinerators at Stoke-upon-Trent, Woolwich, Preston, and St. Albans developed, on tests, 97, 90, 90, and 92 kw.-hrs. per ton respectively, the average being about 92 kw.-hrs.

TABLE XVI.—EVAPORATIVE RESULTS OBTAINED IN TESTS OF HAND-FIRED, TOP-CHARGED INCINERATORS

Plant	Date of erection	Pounds of water evaporated per pound of refuse from and at 212° F.
Accrington	1900	1.39
Ashton on Lyne	1901	.78
Birmingham (Montague St.)	1879	1.56
Bradford (Humerton St.)	1898	1.25
Bury	1901	.94
Canterbury	1899	1.54
Fleetwood	1900	1.19
Fulham	1901	1.30
Hackney	1902	1.42
Llandudno	1898	.86
St. Helens	1899	1.54
Shoreditch	1897	.96
Saltley	....	1.82
West Hartlepool	1901	1.25
Wandsworth	1897	1.24
Westmount	1899	1.36
Average		1.27

TABLE XVII.—EVAPORATIVE RESULTS OBTAINED IN TESTS OF BOTTOM-CHARGED INCINERATORS

Plants	Date of erection	Pounds of water evaporated per lb. of refuse from and at 212° F.
Ayer	1903	1.58
Burnley	1902	2.00
Burslem	1889	2.16
Darwen	1899	1.48
Eccles	1904	1.35
Grays	1901	1.22
Gloucester	1902	1.74
Kings Norton	....	2.63
Hereford	1897	1.67
Lancaster	1901	1.63
Mansfield	1903	1.80
Nelson	1900	1.77
Northampton	1903	1.32
Preston	1903	1.70
Rathmines	....	1.78
Rochdale	1894	1.81
Salesbury	1902	1.23
Seattle	1907	1.
Watford	1903	1.56
West New Brighton	1908	1.32
Average		1.67

Mr. Greeley summarized the various points as follows:

1. Cleanliness: Mechanical charging offers the greatest opportunity for cleanliness, within and about the plant, of any type of incinerator and causes no more nuisance to the community.

2. Construction: A mechanically-charged incinerator, other things being equal, will cost about $125 per ton of rated capacity more than a bottom-charged incinerator. This is equivalent to a difference of about 2 cts. per ton of refuse burned.

3. Operation: By using a mechanical-charging device, about one-fifth of a ton of refuse per man-hour can be handled more than with hand firing in bottom-charged incinerators. This is equivalent to about 5 cts. per ton of refuse burned. A mechanically-charged plant may cost from 1 to 2 cts. more per ton for *repairs* than the bottom-charged plant.

4. Value of Output: There is little difference in the value of the clinker from the different types of incinerators. The useful heat energy from the hand-fired bottom-charged plants is worth from 13 to 15 cts. per ton of refuse burned more than the useful heat energy from mechanically-charged incinerators.

Within the range of capacities of the plants investigated (say up to 100 tons daily capacity) and in communities where steam has a distinct value, the evidence presented indicates that hand-fired bottom-charged incinerators are the most economical type. In communities where steam raising is not of prime importance, or where power cannot be readily marketed, mechanical charging has many advantages. Some of these cannot be expressed in terms of money value. Thus for each community, the controlling factors must be determined and the type of incinerator best adapted to these conditions must be selected.

Cost of Collecting and Incinerating Garbage at Racine, Wis.—The following information is taken from an abstract, published in Engineering and Contracting, Sept. 15, 1915, of a paper before the Wisconsin League of Municipalities by P. H. Connolly.

The plans and specifications together with the use of all patent rights in connection therewith for the 40 ton plant cost $1,000.

The site for the incinerator was purchased by the city in April, 1912 for the sum of $2,800. It is a strip of land 57 ft. wide and 240 ft. long. This site is almost the geographical center of the city at the present time. On October 28, 1912, the contract for the construction of the plant was awarded the sum of $21,000.

Description of Plant.—The plant consists of an absolutely fireproof building, two stories in height. The foundations and the lower story are of reinforced concrete and the upper story is of brick. The floors are reinforced concrete, the rolling doors and the window frames and sashes are of steel and the roof is of tile on steel purlins. The building is 40 ft. square. The entire upper floor is used for a dumping floor, except a small space in one corner which is used for an office. The incinerator is on the lower floor and consists of two units with a nominal capacity of 20 tons, each, in 10 hours. The stack is of radial brick and is 150 ft. in height. It is lined with fire brick for its entire height.

Each unit consists of two grates, two drying hearths, two storage bins, two emergency hoppers, a combustion chamber and a dust pit. Each furnace is also equipped with a hot water heater and a steel tank for storing the hot water, which is used for washing the wagons, steel baskets, floors, etc.

Dampers are arranged so that the heat can be turned onto the hot water boilers or direct into the stack. The storage bins are connected with the sewer and all wet garbage is dumped into them. These storage bins are equipped with mechanical stokers, operated by electric motors and the garbage is fed onto the drying hearths as needed. All dead animals and dry combustible refuse is dumped into the emergency hoppers.

The plant was completed and accepted by the city on Dec. 20, 1913. For some time previous to this the city had been burning all garbage that was hauled to the plant but the city did not install its system of collection until Jan. 7, 1914.

Garbage Collection System.—The collection system at the start was an experiment. We did not know the amount of garbage we would have to collect nor the number of men, horses and wagons it would require. The council on July 15, 1913, passed an ordinance regulating the collection of garbage and placed the same under the jurisdiction of the Board of Public Works. This ordinance provides that the garbage shall be collected in the business districts, three times a week during the month of June, July, August and September and twice a week during the balance of the year; and in the residence districts twice a week during June, July, August and September and once a week the balance of the year.

On Jan. 9, 1914, we started collecting with three one-horse wagons, with the driver alone on the wagons. We found that we could not cover the city, as provided in the ordinance, with this force, so on January 20 we put a helper on each wagon. This force was sufficient until May 8, when an additional wagon with driver and helper was put on. Previous to May 18 but one furnace had been in use, but at this time we found it necessary to run both furnaces, so an additional fireman was put on.

On June 1, 1914, we started to carry out the provisions of the city ordinance for a tri-weekly collection in the business districts and twice a week in the residence districts, so two more wagons were started, making six wagons with 12 men collecting and two firemen and the superintendent at the plant, which is the same force that we have at the present time (August, 1915). These men worked nine hours per day. We found that during the months of July, August and September, the amount of garbage increased so much that it was necessary to work the men 12 hours instead of nine. After September, the amount of garbage collected began to decrease and the men were placed again on their regular time and during the winter months some of the wagons were taken off for a portion of a week and only one furnace was used. The men are now working 11 hours per day. Each wagon is making from 5 to 7 loads per day, according to the district the wagon serves.

The city is divided into collection districts and each wagon has certain districts to take care of. The wagons are steel bodied, steel covered dump wagons, with a capacity of 37 cu. ft. The wagons and horses are owned by the city, the barn for the horses being located in the rear of the plant. The cost of collection and disposal is borne by the city at large, provision therefor being made in the annual budget.

When we first began operating the plant, we were handicapped by the fact that we had no scales to weigh garbage, coal, etc., as it was brought to the plant. The city council authorized the Board of Public Works to install a modern 10-ton scale and on Aug. 13, 1914, we started weighing every pound of garbage that was brought to the plant, also all coal, hay, feed, etc.

Quantitative and Cost Data.—From Aug. 13, 1914, to Aug. 13, 1915, there was brought to the plant and disposed of 3,392 tons of garbage, an average of practically 11 tons per day. There was used to incinerate this garbage 807,639 lbs. of soft coal screenings or practically 235 lbs. of coal per ton of garbage consumed.

From Jan. 1, 1914, to Jan. 1, 1915, there was practically 2,900 tons of garbage collected and disposed of, the total cost of which was $10,775.63, being $7,009.44 for collecting and $3,766.19 for incineration, or $2.42 per ton for collection and $1 29 per ton for incineration.

The amount of coal consumed per ton of garbage greatly exceeds the guarantee, which provided for 150 lbs. of coal per ton of garbage. But this guarantee was given on the condition that 500 lbs. of coal for each furnace be allowed before the test was started, to heat the furnace to the proper temperature. If we figured this 500 lbs. to each furnace or 1,000 lbs. for both furnaces, for the 309 days on which we collected garbage, it would mean 309,000 lbs. of coal which, if deducted from the total, would make the amount of coal consumed per ton of garbage about equal to the guaranteed amount.

In figuring the cost of collection I have included all expenses of every kind in connection with the collection and the same is true in connection with the cost of incineration with the exception of two items, viz., the interest on the investment and depreciation. The amount appropriated for garbage disposal for the year 1914 was $9,360 and the total cost was $10,775.63, leaving a deficit of $1,415.63, which was taken from the general fund of the city. The amount appropriated for 1915 is $11,000, and judging from the expenses thus far I think we will have a small credit balance in the fund at the end of the year. However, for the year 1916 I am afraid that the cost of garbage disposal will be nearly double what it will be this year, as then we will be operating under an 8-hour work day law with time and one-half for all overtime. The wages now paid are as follows:

Grade	Weekly wage
Superintendent	$21.00
Fireman	15.00
Assistant fireman	14.00
Head teamster	15.00
Teamsters and helpers	13.00

The city collects garbage only. The clause in the ordinance defining garbage is as follows:

Garbage shall be held to include all refuse, animal, fruit and vegetable matter, and tin cans used for the storage of said animal, fruit or vegetable matter, also all rags, paper and other combustible refuse, and it shall be deemed unlawful to place in the garbage cans any ashes, earth, waste or other materials of a different nature whatsoever.

Annual Operating Record of Refuse Disposal of Palo Alto, Calif.—The following statement from the annual report of the Board of Public Works, Palo Alto, Calif., giving the operating record for the year 1916–17 is given in Engineering News-Record, March 7, 1918.

OPERATIONS OF PALO ALTO REFUSE DESTRUCTOR

Receipts from refuse collection		$6,879.95	
Penalties		18.50	
Sundry material, etc., sold to city departments		190.00	
Miscellaneous receipts		159.80	
			$7,248.25
Destructor plant wages	$1,909.65		
Power	89.04		
Maintenance	15.99	$2,014.68	
Refuse collectors' wages	3,778.63		
Repairs	3.00	3,781.73	
Salaries	480.55		
Printing and stationery	119.00	599.55	
Bond interest		823.09	
Depreciation		700.13	$7,919.08
Net loss			$ 670.83

Remarks:

Number of furnace grates in incinerator	2
Total grate area (sq. ft.)	33
Weight of refuse burned (tons)	2,011.61
Weight of residual clinker, ash, etc. (tons)	400.18
Percentage of residue	19.9
Average amount of refuse burned per hr. (tons)	0.75
Average amount of refuse burned per sq. ft. of grate area per hr. (lb.)	45
Total weight of water fed to boiler (lb.), not including water for cleaning and blowing down boilers	779,539
Water evaporated per lb. of refuse (140 lb. per sq. in. boiler working pressure)	0.19
Horses cremated, 8; dogs cremated, 28; cows cremated, 1.	
Average water per ton of refuse, lb	1,088
Average combustible matter per ton of refuse, lb	512
Average non-combustible matter per ton of refuse, lb	399

The Palo Alto destructor is of the Dundon high-temperature type. It has a nominal daily capacity of 30 tons of mixed refuse and cost about $18,000. The population of Palo Alto is estimated at 5,900.

Cost of Operating Destructor with Steam Utilization, at Savannah, Ga.—The following matter is taken from an abstract (Engineering News, Feb. 11, 1915) of a paper by E. R. Conant read before the American Society of Municipal Improvements, Boston, Mass, Oct., 1914.

The population of Savannah, about 80,000, is some 60% white and 40% colored. From Mar. 23 to Oct. 1, a total of 18,033 tons of refuse was collected, including household, hotel and restaurant garbage and rubbish, paper and rubbish from stores, material from street receptacles, and some household ashes. The mean daily collection varied from 54 tons in March to about 100 tons in July. The average cost of collection was $2.29, including labor, care of stock, repairs to carts and harnesses and the purchase of small appliances for use in collection work. At the height of the watermelon and cantaloupe season, the percentage of garbage, by weight, was about 55%. During the remainder of the year, the percentage of garbage varies from 40 to 45%. In winter the ashes collected do not amount to more than 10% of the total collection, if that. Early in 1913, E. R. Conant, Chief Engineer of Savannah, recommended to the city council that a high-temperature furnace or destructor be installed. This the council decided to do. General specifications were prepared and bids secured. In July, 1913, the council awarded to the

Destructor Co. of New York City, a contract for a 130-ton incinerator of the Heenan (British) type. The final cost of the plant was $126,271, about $970 per ton of rated capacity. The plant was accepted by the city and final payment was made in October, 1914.

General Description of Destructor.—The destructor was located near the city water-works pumping station—60 ft. between building walls, with 140 ft. from the destructor boilers to the main steam header in the pumping station.

The main features of the plant are: A 260-yd. refuse-storage pit, 11 × 32 ft. in plan and 20 ft. deep, into which the refuse is dumped from the collecting wagons; an electric traveling crane and hoisting grab bucket, for lifting the refuse from the pit and carrying it to and dumping it into the refuse containers, located over the destructor cells; two 65-ton destructor units, each having four trough-grate cells about 28-in. wide on the bottom, 34 in. wide on top, 16 in. deep and 8 ft. long; two 200-hp. Wickes water-tube boilers; a Foster preheater; a cylindrical centrifugal fan for supplying forced draft; a radial-brick stack 150 ft. high and 6⅔ ft. in diameter at the top; hydraulically operated clinkering devices, which discharge into clinker carts of special design; a steam turbo-generator for supplying electric current for works light and power purposes; various recording instruments; a wagon scale for weighing the incoming refuse; and a building to house the whole.

The cells have a burning area of 20 sq. ft. over each grate. The refuse containers over the cells have a capacity of about 1 cu. yd. each and are closed by horizontally sliding doors, in two parts, hydraulically operated. Stoking is done through a supplementary door, which makes it unnecessary to open the large clinkering door.

The clinker is pulled out by means of a hydraulic winch, attached to a plate which forms "an upturned hoe placed on the bottom of the grate before the first charge of refuse is deposited in the cell." The sides of the grate diverge slightly from the rear to the stoking door. A clinkering operation is performed in three to four minutes. Usually the clinker is drawn once for each six charges of refuse. The average time burning a charge is 20 min.

During July and August, about 10% of cinders from manufacturing plants were added to offset the excessive moisture in the refuse due to the melon season.

With the destruction of 60 to 75 tons of refuse per day, which comprised the collection in 1914, only one unit was operated, so as to supply steam to the pumping station continuously. The plant is operated in three shifts.

Operating Costs under Working Conditions, Mar. 24 to Sept. 30, 1914.—During a period of just over six months, 14,364 tons of refuse were burned at a total cost of $8,988, including $428 for a weighman and $370 for a laborer at the pit, supervising the dumping of cars. This gives an average cost of 62½c., but in comparing this with the guaranteed cost of 40.4cts., it must be remembered that the guaranteed price was based on the plant working at full capacity. Deducting the value of fuel saved at the pumping station, the net cost was 41.6 cts., per ton.

With dry refuse the clinker varies from 20 to 25% of the refuse, but during July and August it runs from 25 to 30%.

About $3,000, or $500 per month, was saved in fuel from Mar. 24 to Sept. 30. Changes at the plant, it is expected, will raise this saving to $600 per month. Operated at full capacity, it is estimated that the fuel saving would be $1000 per month. It may be added that the pumping-station equipment consists of two 10,000,000-gal. Holly-Gaskell duplex compound pumping engines and two cross-compound air compressors, all of which are operated condensing.

TABLE XVIII.—COMPARISON OF OPERATIONS BETWEEN THE CHICAGO MUNICIPAL REDUCTION PLANT AND THE CLEVELAND MUNICIPAL REDUCTION PLANT

Year	Total green garbage received, in tons	Total tankage produced, in tons	Total grease produced, in pounds	Percentage of tankage to green garbage	Percentage of grease to green garbage	Income per ton of green garbage from products	Total net profit (+) or loss (−) per ton of green garbage	Total operating expense. See Note "A"	Cost of operating per ton of green garbage. See Note "A"
From Chicago Records									
1915	152,892	—See Note "B"—		....	...	$1.19	−0.36	....	......
1916	134,292	9,156	3,792,880	6.8	1.4	2.57	−0.56	....	......
1917	100,000	22,674	4,023,480	22.6	2.0	4.25	−0.31	$456,493	$7.34
1918	84,974	15,774	2,908,580	18.6	1.7	6.73	+0.95	489,570	5.78
1919	82,820	14,618	3,393,360	17.7	2.1	3.46	−3.17	548,687	6.63
1920	80,132	11,410	2,208,620	14.2	1.4	2.56	−6.11	695,247	8.67
From Cleveland Records									
1915	62,357	6,879	3,731,770	11.0	3.0	$3.60	+1.17	$151,503	$2.43
1916	60,717	7,038	3,819,325	11.6	3.14	5.10	+2.54	155,585	2.56
1917	56,121	6,241	3,071,092	11.1	2.36	5.22	+1.81	191,001	3.41
1918	57,754	6,329	2,726,786	11.0	2.56	7.58	+2.97	265,243	4.61
1919	60,932	7,094	3,116,797	11.6	2.56	4.87	+ .96	238,202	3.91
1920	60,645	7,243	3,367,037	10.5	2.45	6.06	+ .58	375,949	5.48

Note "A"—Charges for water, maintenance and depreciation are included in figures tabulated for Cleveland but not for Chicago.

Note "B"—All collections were converted into com. dried garbage.

The destructor-plant steam pressure is carried up to 150 lb. with 100° superheat. As the steam pressure for the pumps is only 90 lb., a reducing valve is used between the destructor and the pumps.

Comparative Operating Costs of the Chicago and Cleveland Reduction Plants.—The following is taken from an abstract in Engineering and Contracting, May 11, 1921, of a report of Major I. S. Osborn upon the means of increasing the efficiency and economy of the Chicago reduction plant.

The reason for using Cleveland was that the total tonnage reduced annually compares more closely with that of Chicago than the total reduced by any other city. Furthermore, the Cleveland plant was the first to be municipally operated, and has been so used for the past 16 years. Thus the results achieved have undergone the test of time more fully than any other municipally operated plant. The data available are therefore, more representative than that of any other city, as to what can be accomplished by municipal management and methods.

Although the "Digester" process, whereby the garbage is first cooked before drying, is not used in Chicago, yet the equipment used by Cleveland for drying and extracting is very similar. This difference of method, however, does not appreciably affect the basis for comparing results.

Comparison of Labor Distribution of Cleveland Municipal Plant with That of Chicago.—Although during the past year the quantity of garbage disposed of by Cleveland was within 12,000 tons of that handled by Chicago; and although the rate of wages paid in Cleveland was higher than in Chicago except in the case of mechanics; the payroll in Cleveland, nevertheless, was less than half. The following comparison of the organization of the employes in the two plants illustrates, in one way, why the Chicago plant is not as economically operated:

Cleveland		Chicago
68,645	Tons garbage reduced in 1920	80,132
	SUPERINTENDENCE	
1 Superintendent.		1 Foreman in charge.
	OFFICE	
1 Clerk and stenographer. 1 Bookkeeper. 1 Laboratory assistant in city chemical laboratory. Note.—Bookkeeper keeps books for both collection and disposal.		1 Head clerk. 1 Principal clerk. 1 Senior clerk. 1 Senior clerk. 1 Junior clerk. 2 Junior stenographers. 1 Senior sanitary chemist. 1 Assistant chemist on payroll as garbage handler. 1 Janitress, G. H. payroll. 1 Office assistant, G. H. payroll. 1 Office boy, G. H. payroll.
	FOREMEN	
3 General foremen—one for each shift.		1 Assistant general foreman. 1 Foreman garbage plant. 2 Foremen garbage handlers. 1 Foreman mill house. 1 Assistant foreman mill house. 1 Foreman extractor plant (1 shift) or (3 shifts).
	ENGINEERS	
3 Engineers (1 for each shift) power plant (electric power generated).		1 Second assistant operating engineer. 2 Third assistant operating engineers. 9 Junior operating engineers. 1 Hoisting engineer (electric power purchased).
	POWER HOUSE	
3 Firemen. 3 Coal passers. 1 Ash handler.		4 Firemen. 14 Garbage handlers used in handling coal and ashes (day shift). 5 Garbage handlers (2nd shift). 4 Garbage handlers (3rd shift).
	MECHANICS	
2 Machinists. 3 Machinist helpers. 2 Steamfitters. 1 Steamfitter helper. 1 Carpenter. 1 Carpenter helper. 1 Electrician.		8 Machinists. 2 Steamfitters. 1 Steamfitter helper. 2 Carpenters. 1 Blacksmith. 1 Blacksmith helper. 6 Electricians (3 used on cranes)
	OPERATORS	
11 Equipment operators for dryers, digesters and extractors.		10 Equipment operators for dryers, extractors, etc.
	WATCHMEN	
None.		2 Watchmen in addition to garbage handlers carried as watchmen.
	LABOR OR GARBAGE HANDLERS	
13 Receiving building. 21 Dryers and digesters. 6 Extractor plant. 6 Mill house. 7 Utility.		28 Receiving building. 22 Dryers. 10 Extractor plant. 39 Mill house and finishing dryers. 22 Utility.
92	Total number employes on payroll	213

Cost of Garbage Collection and Reduction at Cleveland, O.—The cost of collecting and reducing garbage in 1917 at Cleveland, O., increased materially, according to the 1917 report of F. L. Stockberger, Engineer of Reduction.

The amount of garbage collected and reduced during 1917 was 56,121 tons, which is a decrease of 4,596 tons in comparison with the year 1916. The amount of finished material produced from this garbage was 3,071,022 lb. of grease and 6,241 tons of tankage. This is a decrease of 796 tons of tankage and of 748,303 lb. of grease. The decrease, states the report, was caused by the decrease in the quantity of green garbage collected, the high price of all foodstuffs and by the conservation movement which was in vogue during the greater part of the year.

The cost of collection was as follows:

	Amount	Per ton green garbage
Supervision:		
Labor—collecting	$157,071	$2.7988
Labor—shoeing	4,164	.0742
Supplies:		
Shoeing	1,501	.0267
Office	146	.0026
Fuel, light and power	1,529	.0272
Feed	25,330	.4514
Barn	777	.0138
Motor vehicle	2,468	.0438
Mechanical	133	.0024
Cleaning and toilet	33	.0006
Other miscellaneous	147	.0025
Miscellaneous Expense:		
Transportation—employes	....	....
Telephone and telegraph	169	.003
Team hire	1	....
Insurance	736	.0131
Taxes	199	.0035
Rented land	1,919	.0342
Damages	3	.0001
Freight on garbage	12,393	.2208
Other miscellaneous	12	.0002
Total operating cost	$208,741	$3.7189
Maintenance:		
Cars and wagons—labor	$ 3,398	$0.0605
Cars and wagons—material	3,326	.0593
Harness—labor	1,249	.0223
Harness—material	1,608	.0286
Buildings—material	1,820	.0324
Office furniture and fixtures	2	....
Machinery, tools and implements	299	.0053
Motor vehicles	839	.015
Other miscellaneous equipment	2,765	.0493
	$ 15,309	$0.2727
Total collection cost	225,850	4.0243
Loss on horses	1,211	.0216
Depreciation	8,973	.1599
Entire cost, including depreciation	$236,035	$4.2058

CHAPTER XIV

STREET SPRINKLING, CLEANING AND SNOW REMOVAL

Further data on the costs of street sprinkling and cleaning are given in Gillette's "Handbook of Cost Data," pages 457 to 474.

Time Studies and Factors and Standards for Street Cleaning in Chicago.—Time studies were made during 1912–13 in Chicago to determine the effectiveness of street cleaning methods and the efficiency of street cleaners and teamsters. These studies were conducted by the efficiency division of the Civil Service Commission and have been used to compute factors and standards by which appropriations can be attested. They present a number of facts which are of more than local interest and the following matter is taken from an abstract in Engineering and Contracting, Nov. 19, 1913, of the commission's report.

General Conclusions.—Analysis of the time records disclosed that a proportion of the street cleaners had no notion of how to perform their duties with minimum waste of time and energy. It was ascertained that there are at least 38 distinct motions which a cleaner makes in street cleaning work. Of these some were found unproductive, resulting in loss of time and energy. As an example, the practice of hitting the broom on the pavement at the end of each stroke was found unnecessary. By bringing the brush down forcibly at the beginning of each stroke the same result is attained and the labor reduced at least 15 per cent. It was also disclosed that wheeling push carts in to alleys or to other temporary dumping places consumed 20 per cent of the cleaners' time. The time lost by cleaners in dodging vehicular traffic was found not to exceed 8 per cent in streets of dense traffic and not to exceed 2 per cent in outlying business streets. It was disclosed that unnecessary sweeping was done on light traffic asphalt pavements. After the morning cleaning, three-fourths of the area to be covered during the remainder of the day does not require thorough cleaning. The time studies showed that street laborers in gangs did not work as efficiently as single laborers each having his individual assignment; time is lost in conversation and by the pace being set to accommodate the poorest laborer. Generally, the time studies showed that street cleaning is handicapped by lack of control, instruction and supervision and lack of incentive due to non-recognition of ability and efficiency.

From the time studies of 1912–1913, a perfect standard of work was computed; they also showed that able street cleaners working regularly and under instructions in proper methods were able to do more than the *attainable* standard which was set at 85 per cent of the *perfect* standard. Under employment conditions as they exist at present it was felt that the *attainable* standard of 85 per cent could not be expected, and so for 1914 computations are based on a standard of 74.4 per cent.

Standards and Factors.—The conditions and factor which control the amount and frequency of cleaning of any pavements, other conditions being the same, may be summarized as follows:

(1) Density of horse-drawn vehicles and other traffic; (2) width of streets; (3) character of district and population; (4) location of streets: (5) proximity to unpaved streets and alleys; (6) location of public buildings, parks, etc. (7) kind and condition of pavements.

As a result of the study, it has been definitely determined that the density of horse traffic, which is the total number of horses passing through a given street divided by the width of the street, is the principal factor which determines the number and frequency of cleaning which one street should be given. The experiments made to determine what relation the yardage of dirt collected in any street had to the number of cleanings indicates that this factor is not definite, but is a direct function of all the other factors above noted.

As the traffic conditions on a street determine to a great extent the number and frequency of cleanings which should be provided, in order that the service be always distributed uniformly and equitably, it will be necessary that traffic census be made regularly each year in the different streets of the city. Traffic census taken at regular intervals each year will show any changes in the character of the districts and the necessary changes in cleaning service.

From the studies made the street cleaning constants given in Table I were determined.

Upon the above factors the number of cleanings per week which any street having permanently improved pavement will receive is expressed by the equation:

$$N = \frac{E}{C\,W}$$

where N = number of cleanings per week.
E = total number of horse-drawn vehicles per 8-hour day.
W = width of roadway in feet.
C = constant of cleaning.

In the case of streets where investigation gives data of traffic of vehicles and pedestrians and restricted roadway due to standing vehicles and general special considerations which necessitate the modification of the value of the constant C in the above equation the schedule should be arranged so that the cleaning service is in accordance with requirements and standard maintained.

For residence and street railway streets, or streets on which churches, schools, hospitals, playgrounds and general public institutions are located, the application of the constants (Table I) to traffic conditions might give results below the necessary minimum. In such cases the formula is used, but the minimum number of cleanings for streets having these characteristics has been determined by a separate basis, as shown further in Table I.

TABLE I. STREET CLEANING CONSTANTS

Wards—	Av. res.	Av. bus
Inlying	2.1	2.6
Outlying	2.5	2.8

MINIMUM CLEANINGS PER WEEK ON HARD PAVEMENTS

	Cleanings per week
Inlying wards	3.0
Outlying wards	1.0

MINIMUM CLEANINGS PER WEEK ON CAR TRACK STREETS

	Head way up to 3 min.	Head way 3 to 10 min.	Head way 10 min. or more
Inlying wards	6	5	4
Outlying wards	6	3	3

MINIMUM CLEANINGS PER WEEK ON STREETS HAVING PUBLIC BUILDINGS, ETC.

Churches		Schools		Hospitals, parks, public institutions	
L.	6	L.	6	L.	6
M.	3	M.	5	M.	4
S.	2	S.	4	S.	2

L = Large. M = Medium. S = Small.

In cases where the streets or alleys surrounding the foregoing are unimproved, the minimum number of cleanings has been increased by one-twelfth of the number of cleanings calculated for the improved pavements.

From an analysis of the time studies of the work of street cleaners, definite data have been secured upon which is based the relative difficulty of cleaning the different kinds of pavements with varying physical conditions. The standards and equivalent areas which it is assumed can be cleaned by one man in one eight-hour day follow:

Pavement	Condition of pavement	Standards	Equivalent sq. yds.
Asphalt	Good	100 per cent average perfect standard.	34,000
Asphalt	Good	85 per cent attainable standard......	28,900
Asphalt	Good	74.4 per cent of attainable standard assumed for 1914................	21,500
Asphalt	Fair	90 per cent of good asphalt..........	19,300
Asphalt	Poor	80 per cent of good asphalt..........	17,200
Creosote blk.	Good	Good asphalt....................	21,500
Brick	Good	Good asphalt ÷ 1.35..............	16,000
Brick	Fair	63 per cent of good brick...........	10,000
Brick	Poor	50 per cent of good brick...........	8,000
Granite	Good	Good asphalt ÷ 1.60..............	13,400
Granite	Fair	75 per cent of good granite.........	10,000
Granite	Poor	60 per cent of good granite.........	8,000

Analysis of the data also indicates that the presence of car tracks in a street increases the difficulty of cleaning the street, and that under similar conditions, the street car right of way is approximately 15 per cent harder to clean than the pavements outside of the car tracks. In instances where the pavement of the right of way has been found to be different from the pavement of the balance of street, the area of the right of way has been increased by 15 per cent and the paving factors applied.

In cases where alleys are paved with improved pavements and where conditions exist similar to those on streets, the same standards and equivalents as given for the cleaning of streets having similar factors are used, the resulting number of cleanings per week being divided by six. In some instances, the number of cleanings per week that an alley would receive, based upon traffic conditions alone, would give absurd results, and therefore a minimum of two cleanings each week has been fixed for all improved alleys in the city with the exception that the improved alleys in business sections which receive a minimum of six cleanings per week.

Experimental work in connection with the cleaning of improved alleys has demonstrated that the traffic on alleys does not control the number of cleanings to be given, that there is practically no difference in the time required to clean the various kinds of pavements in alleys and that a reasonable eight-hour day's work for an average laborer is eight blocks or approximately one mile of improved alleys.

The oiling of macadam streets during the past few years has had an excellent effect upon the surface of these streets. The surface of many has become sufficiently smooth to require more cleaning than could heretofore be given to the plain macadam streets. Analysis of the standard of work which one man can perform on oiled macadam streets indicates that the rate of cleaning 1¼ miles of oiled macadam in an eight-hour day can be reasonably expected of any man, and this standard has been assumed in the preparation of estimates for the 1914 appropriations. The number of cleanings which are to be given to these oiled macadam streets is as follows:

	Cleanings per week
Inlying wards	3
Intermediate wards	2
Outlying wards	1

The number of cleanings which it has been assumed will be given to the plain macadam and cedar block streets exclusive of country roads is as follows:

Inlying wards	6 times during the cleaning season, or approximately 1 cleaning per month
Intermediate wards	4 cleanings per year
Outlying wards	3 cleanings per year

Analysis of the records of the cost of cleaning the macadam and cedar block pavements has shown the following relationship between the total cost of cleaning such pavements and the cost of the spring cleaning of the same pavements, which is shown under Spring Cleaning. In wards where the macadam and cedar block pavements are cleaned three times per year, the total cost of cleaning these pavements is approximately twice the cost of the spring cleaning. In wards where the macadam and cedar block pavements are cleaned four times per year, the total cost of cleaning these pavements is approximately 2½ times the cost of the spring cleaning. In those wards where the macadam and cedar block pavements are cleaned six times during the cleaning season, the total cost of cleaning of these pavements is approximately four times the cost of the spring cleanup.

A general spring cleaning is provided for all streets of the city which do not receive attention during the winter months. The heavy dirt which is washed from the center of the street and which accumulates in the gutters during the winter season is piled up and removed from the street before the regular block cleaning work is begun.

Study has been made of a number of different methods which are used in the removing of the dirt in the spring cleaning. The unit costs of such work indicate that the assignment of one man to a definite length of street or the assignment of a small gang of not exceeding three men to definite lengths of street are most effective and economical. Where a gang of three men is assigned to this work, team work is developed by the use of one man in removing the dirt from the roadway and one man each for the gutters. On the granite and brick pavements considerable more brooming is necessary on the roadway. The granite and brick pavements and the cedar block pavements require that the dirt be scraped from the center of the street to the gutters before piling of the dirt in the gutters can be commenced.

It has been found that the rate of spring cleaning of the center of streets varies with the conditions of the pavement and that the rate of piling dirt in the gutters is practically independent of the condition of the improved pavements, but varies directly with the traffic. In providing the spring cleaning for improved pavements, standards have been determined which are based on the rates in Table II.

TABLE II.—CENTER CLEANING RATES

Class of pavement—	Car track, sq. yds. per day	Outside car track, sq. yds. per day
Good asphalt	16,500	18,500
Fair asphalt	12,900	14,800
Poor asphalt	9,200	11,100
Good brick	4,400	5,550
Fair brick	3,340	3,700
Poor brick	1,850	2,960
Good granite	4,400	5,550
Fair granite	3,340	3,700
Poor granite	1,850	2,200
Cobblestone	1,470	......

SINGLE GUTTER RATE IN MILES PER DAY

Times cleaned per week	Asphalt	Good brick	Poor brick and granite of all kinds
2	1.8 miles	1.4 miles	1.4 miles
3	1.4 miles	1.1 miles	0.7 miles
6	0.7 miles	0.5 miles	0.3 miles
9	....	0.3 miles	0.2 miles
12	....	0.2 miles	0.2 miles

In preparing the estimate of the cost of spring cleaning of the macadam and cedar block streets, it has been assumed that where the average traffic per eight-hour day is less than 400 vehicles the street has been termed a light traffic street and where the traffic per eight-hour day exceeds 400 vehicles the street has been termed a heavy traffic street. On this basis it has been found that the unit cost of spring cleaning the macadam and cedar block streets of different physical conditions is as follows:

First-class condition, cost for cleaning 100 lin. ft. — Traffic		Fair condition, cost for cleaning 100 lin. ft. — Traffic		Poor condition, cost for cleaning 100 lin. ft. — Traffic	
Heavy	Light	Heavy	Light	Heavy	Light
$1.18	$0.90	$1.97	$1.46	$2.25	$1.69

Cost of Street Cleaning at Philadelphia.—Engineering and Contracting, Sept. 5, 1917, publishes the following interesting data on street cleaning costs at Philadelphia, contained in the 1916 annual report of the Bureau of Highways. Special block tests on various types of pavements were made with machine brooms, the average costs being as follows:

	Per 1,000 sq. yd., cts.
Granite block	24.6
Brick	19.3
Wood block	16.6
Sheet asphalt	15.9
Average per all classes	22.6

The dirt removed per 1,000 sq. yd. of pavement was 0.158 cu. yd.; 98 gal. of water were used per 1,000 sq. yd. cleaned. On the regular work the average cost of street cleaning with machine brooms, based on the district reports, was 28.2 ct. per 1,000 sq. yd.

The unit costs per 1,000 sq. yd. of street cleaning by other methods were as follows:

District, number	Squeegee, Average from block tests	Squeegee, Average from district reports	Flushing, average from district reports	Hose flushing, average from district reports	Blockmen, average from district reports
1–A	$0.131	$0.223	....	......	$0.083
1–B	.174	.204	....	......	.081
2	.130	.196	.156	......	.179
3	.118	.094	.157	$0.474	.282
4–A	.176	.126	.174	......	.216
4–B	.115	.115	....	......	.140
5	.218	.192	.148	......	.111
6	.137	.182	.150	......	.174
Average	$0.148	$0.156	$0.157	$0.474	$0.152

The squeegee used 240 gal. of water per 1,000 sq. yd. cleaned and the flusher used 522 gal. The amount of dirt per 1,000 sq. yd. removed by the squeegee was 0.031 cu. yd. the blockmen removed 0.051 cu. yd. per 1,000 sq. yd.

The squeegees were used on sheet asphalt and wood block streets only.

Flusher dirt was removed by blockmen.

The cost of labor and equipment per day was assumed as follows:

Superintendent	$4.00	Squeegee	$ 6.00
Foreman	2.50	Auto flusher	15.00
Gangmen	1.75	Dirt—	
Blockmen	1.50	Wagon	5.00
Dumpmen	1.50	Cart	3.50
Machine broom	5.50	Sprinkler	5.00

Street Cleaning Costs at Houston, Texas.—Engineering and Contracting, Sept. 5, 1917, gives the following data taken from the 1916 annual report of the Street and Bridge Commissioner of Houston, Tex.

Street Sprinkling.—The motor sprinkling covered 250 blocks twice daily and 57 blocks four times daily. The total yardage sprinkled each day was 1,083,000 sq. yd. In 1916 the motor sprinkler was in operation for 262 days. The total yardage sprinkled was 283,746,000 sq. yd. and the total cost was:

	Per day	Total, 262 days
Chauffeur	$3.00	$1,080
Gasoline	1.80	372
Lubricants	.50	131
Repairs and renewals	4.20	1,255
Total	$9.50	$2,838

This gives a cost of approximately 1 ct. per 1,000 sq. yd. of street surface sprinkled.

About 1,632,000 sq. yd. of street surface were sprinkled each day by mule-drawn sprinklers. Six of these outfits were in use at a daily cost of $25, made up of the following items:

6 drivers	$12.00
12 mules	12.00
Renewals	1.00
Total	$25.00

The team outfits sprinkled 350 blocks twice daily and 97 blocks four times daily, and were operated for 300 days, making the total area of street sprinkled in this way 489,600,000 sq. yd. The cost was as follows:

300 days operation	$7,500
66 days idle mules	780
Total	$8,280

This makes the cost per 1,000 sq. yd. 1.75 ct.

Street Sweeping.—The street sweeping was carried out with mule-drawn sweepers, truck-drawn sweepers and combination sprinkler-sweepers. The unit costs by each of these methods were as follows:

	Per 1,000 sq. yd., ct.
Mule-drawn sweepers	12½
Truck-drawn sweepers	12⅛
Combination sprinkler-sweeper	6⅔

In all 177,000 sq. yd. of street surface were swept daily by three mule-drawn sweepers preceded by one team sprinkler. These outfits operated 294 days in 1916, during which time 52,000,000 sq. yd. of street were swept. The cost of the work was:

	Total per day	Total, 294 days
4 men	$8.00	$2,352
8 mules	8.00	2,352
Brooms, renewals and repairs	2.20	740
½ foreman	1.50	490
Total		$5,934
8 mules, idle 72 days		506
Total		$6,440

The trucks, each trailing one sweeper and preceded by a motor sprinkler, cleaned 300,000 sq. yd. of street surface daily. These outfits operated 270 days at a daily cost of—

2 chauffeurs	$ 7.00
Gasoline	3.60
Lubricants	1.00
Repairs and renewals	4.00
Broom repairs and renewals	4.35
2 men riding brooms	4.00
½ foreman	1.50
	$25.45
Motor sprinkler ahead	9.50
Total	$34.95

The two combination sprinkler sweepers covered 161,000 sq. yd. of street surface each day and were operated for 294 days in 1916. The cost was as follows:

	Total per day	Total 294 days
2 men	$4.00	$1,176
4 mules	4.00	1,176
Broom renewals and repairs	1.70	288
Total	$9.70	$2,852
4 mules, idle 72 days		288
Total		$3,140

White Wings and Pick Up.—In the business district a force consisting of 13 men and a foreman cleaned 222,000 sq. yd. of street surface daily except on Sunday, when they cleaned about one-half this amount. The total cost was as follows:

Men, $185.90 weekly	$10,126
Supplies	500
Total	$10,626

About 47,645,000 sq. yd. were cleaned in the year, making the cost 22½ ct. per 1,000 sq. yd.

The force employed on pick-up work on the business streets consisted of the following:

	Per day
6 men	$12.00
6 mules	6.00
Renewals and repairs	1.00
Total	$19.00

This gang picked up sweepings last year from 20,878,000 sq. yd. street surface at a cost of 33¼ ct. per 1,000 sq. yd. surface. It removed 6,184 cu. yd. sweepings at a cost of $1.10 per cubic yard.

General pick-up work was handled by an outfit consisting of two trucks, two chauffeurs, 10 men and foreman; also six mule teams, 12 men and foreman.

Daily cost operating two trucks—

Two chauffeurs	$ 7.00
Gasoline	3.60
Lubricants	1.00
Depreciation, renewals and repairs	4.00
Foreman	3.00
Ten men	20.00
Total	$38.60

Picking up daily sweeping from 128,700 sq. yd. street surface. Removing 20 cu. yd. sweepings.

Operating cost working 270 days last year picking up sweepings:

Two chauffeurs	$ 2,160.00
Gasoline	972.00
Lubricants	362.00
Renewals and repairs	1,080.00
Foreman	936.00
Ten men	5,400.00
Total	$10,910.00

Picked up last year (270 days) sweepings from 34,750,000 sq. yd. street surface at a cost of 31¾ ct. per 1,000 sq. yd. Removing 5,700 cu. yd. sweepings at a cost of $1.91 per cubic yard.

Daily cost of six-team pick-up equipment—

12 men	$24.00
12 mules	12.00
Foreman	2.50
Repairs and renewals	2.00
Total daily	$40.50

Picking up sweepings from 185,900 sq. yd. street surface. Removing 45 cu. yd. sweepings.

Team pick-up equipment cost last year, operating 294 days—

12 men	$ 7,056.00
12 mules	3,528.00
12 mules, idle 72 days	864.00
Foreman	810.00
Repairs and renewals	600.00
Total last year	$12,858.00

Street Cleaning Practice in Cities of From 50,000 to 100,000 Population.—The following notes, taken from Engineering and Contracting, Sept. 20, 1911. were given by the officials of the various cities.

TABLE III.—SUMMARY OF GENERAL PRACTICE IN MACHINE CLEANING

City	Number of sweepers to a sprinkler	Area covered by sweeper in working day,* sq. yds.	Total length of street covered in miles per day*	Number of men sweeping behind each machine sweeper	Number of men picking up sweepings for each machine sweeper	Number of carts picking up sweepings for each machine sweeper
Altoona, Pa	2	....	68[1]	6	4	2[2]
Bayonne, N. J	1	95,000[3]	3½	10	4[4]	3[4]
Charleston, S. C	1	465,000[5]	....	12	5	5
Dallas, Texas	..	....	....	1	1[6]	2[6]
Des Moines, Ia	2	98,000	....	2	3	3
East St. Louis, Ill	..	....	2	4	8	4
Fort Worth Tex	..	........[1]	....	....	1	1
Hoboken, N. J	1	63,347	4	12	5	5
Houston, Tex	4	75,200	1½	....	5½	..[7]
Huntington, W. Va	2	82,400	2⅗	4	4[8]	2[8]
Jacksonville, Fla	2	....	....	2⅓	..[9]	..[9]
Oklahoma City, Okla	3	....	....	....	1	1
Springfield, Mass	2	50,000	....	2	2	1
Troy, N. Y	3[10]	30,000	4[11]	2[13]	..[13]	..[13]

* Altoona, Pa. and Huntington, W. Va. have 10-hr. day, all others have 8-hr. day.

[1] 68 blocks for one sweeper; 85 blocks for two sweepers. [2] 2-yd. dump wagons. [3] On bitulithic; on Belgian block about one-fifth less. [4] Three carts with one additional man to help load. [5] Per week; includes granite blocks and cobbles. [6] The night force of 4 men, 8 teams and 1 foreman handles the sweepings [7] Double teams with wagons [8] Large drop bottom dump wagons, 2 men to each wagon. [9] Sweepings picked up by regular garbage carts in morning, 45 carts being engaged for 1½ to 2 hours taking up sweepings of entire area swept. [10] 3 to 5 sweepers. [11] 4 miles for gang. [12] 2 men follow gang of 3 machines. [13] Sweepings gathered into cans by patrolman on his beat and removed by teams that gather house refuse.

As to the comparative costs one city reported that the cost of sweeping by machine and by hand was about the same, while 12 cities reported that machine sweeping was not more expensive than hand sweeping. At Charleston, S. C., the cost of sweeping with horse sweeper and gang was placed at 74 cts. per 10,000 sq. ft. This cost does not include new equipment but does include removal of sweepings.

Patrol System.—Practically all of the 21 cities, reported, employ the patrol system in cleaning the streets by hand sweeping. At Altoona, Pa., the patrol system is used on 51 blocks of streets, the area covered by one man being eight blocks. The patrolman uses a broom and a scraper to lift the sweepings into patrol carts.

At Bayonne, N. J., one man generally covers a given section but sometimes two men are used, depending on character of section. One man covers about 10,000 sq. yds. in residential sections in the working day. For cleaning up the dirt the patrol sweepers use brooms with can and carriers. Hand pickup machines with a revolving drum have been used by the patrol sweepers at Bayonne with fair results.

At Charleston, S. C., five patrols cover about 36,800 sq. yds. of brick pavement per day. For gathering up the dirt the patrol sweeper uses a scraper on asphalt pavements, a hand pickup machine on brick, and a broom and push cart on granite block pavement. The results obtained with the hand pickup machine are reported to be very satisfactory. Five of these machines each day cover 36,800 sq. yds. of brick pavement, and the report states that the streets are swept cleaner with the machine than by hand. The cost of the cleaning with the hand pickup is about 27 cts. per 10,000 sq. ft.

At Dallas, Tex., a day force of 46 "white wings" is employed to cover all paved streets of the city. The men are assigned to districts the size of which depends on the traffic. In connection with the day force 16 one-horse carts are employed. Each cart takes about five loads of sweepings per day. The average area covered by each patrol sweeper is 6 or 8 blocks. Both brooms and scrapers are used for gathering up the dirt.

Des Moines, Ia., has a "white wing" service in the business district, each man being assigned about three blocks or 1,200 lin. ft. of street. The patrol sweeper uses broom and scraper to gather up the dirt.

At Harrisburg, Pa., the crew engaged in hand sweeping consists of 110 sweepers, three foremen and 11 horses and carts. The total length of streets covered by this gang per day is 43.28 miles. Each sweeper is assigned a section, depending in sizes upon the amount of travel. For gathering up the dirt, the sweeper uses a broom in the business section, and a broom or scraper or both in residence sections.

Hoboken, N. J., uses the patrol system on every street not swept by machine. About 18 men are employed in the 18 districts. The men are equipped with push carts and can and clean the district once a day. The average area of a district is 14,700 sq. yds. For gathering up the dirt brooms are used on wood block and Belgian block pavement; on asphalt scraper and broom are used.

Houston, Tex., employs hand sweeping only in the business district, the work being done during the daytime. The patrol system is employed, each man being assigned four blocks or 1,200 ft. of 60-ft. street. A broom and scoop is used to gather up the dirt into can carriers.

At Huntington, W. Va., the patrol gang, consisting of seven men, covers 8,500 ft. of 53-ft. street per working day. A scraper is used to gather up the dirt.

Jacksonville, Fla., employs hand sweeping only on the principal business streets, about 36 blocks being covered in this way. Each patrol sweeper has four or five blocks to cover. Hand push brooms are used to gather up the dirt.

At Lawrence, Mass., the hand sweeping is done by 33 patrol sweepers, each man covering an area of about 1,100 sq. yds. Three single teams and nine men are employed in taking care of the sweepings. For gathering up the dirt the patrol sweeper uses a broom with scraper back.

New Bedford, Mass., employs both the gang and patrol systems in hand sweeping. The gangs are composed of from six to ten men, each gang being given a district. The area covered by a patrol sweeper is from 6,000 to 10,000 sq. yds. Brooms are used for gathering up the dirt.

At Portland, Me., the area covered by a patrol sweeper is 700 sq. yds. Brooms are used for gathering up the dirt.

At St. Joseph, Mo., 100 blocks of streets are cleaned by hand sweeping, the patrol system being employed. Each patrol sweeper covers about five blocks and uses both broom and scraper in gathering up the dirt.

Springfield, Mass., employs both gang and patrol systems in its hand sweeping. The city is divided into four sections, six men and two single teams being assigned to each section. This is for the macadam and gravel streets. The cleaning is done with brooms and hoes. Horse sweepers are also used in cleaning the macadamized streets. About two miles of streets are covered in a working day; about ¼ mile is covered per man. Brooms and short-handled shovels are used to gather up the dirt.

At Troy, N. Y., a patrol sweeper is assigned from 3,000 to 4,500 sq. yds. according to traffic. They use both broom and scraper for gathering up the dirt. This city has tried the hand pickup machine with revolving drum. The machine gave satisfactory service but was not used on large enough scale to get any figures as to costs, etc. It was found, however, that the machine takes off the fine dust better than brooms.

Hand Sweeping by Gang System.—Of the 21 cities reporting, East St. Louis, Ill., and Fort Worth, Tex., appear to be the only cities employing the gang system alone in hand sweeping. East St. Louis employs hand sweeping on only the down town streets, the area covered in a working day being about two miles. The sweeper uses broom and scraper to gather up the dirt. At Fort Worth, Tex., hand sweeping is employed on the two principal streets and on the cross streets between these two. Hand sweeping is used in the daytime and the streets are washed at night. In the hand sweeping the men are worked in gangs of three, one man on each side of the street and one cart man. The gang begins at one end of street one day and doubles back if they have time. The next day the gang begins at the other end and doubles back. Each gang covers 64 blocks (200 ft. to block) of 60-ft. street, or 768,000 sq. ft. per day. A large pan and small broom are used for gathering up the dirt.

Flushing With Hose.—Of the 21 cities six reported that they flushed their streets with hose. At Altoona, Pa., this work is done by a gang of six men, covering about 10 blocks per day. Six 50-ft. lengths of fire hose with 1⅛-in. nozzle are used in the work.

Flushing by Machine.—At Fort Worth, Tex., a flushing machine is being used to clean a brick-paved street. This pavement is in bad shape, being full of holes and depressions, and the street will soon be repaved. On the street the machine in a working day covers 10 blocks, each block being 200 ft. long and 60 ft. wide. Six tanks (600 gals. to the tank) of water to the block are used for cleaning this street. In the work one man cleans up after the machine, scraping gutter, and one team is used to haul off the dirt. The cost of cleaning this 10 blocks of street averages as follows:

1 team at	$ 3.75
1 laborer at	2.00
1 team at	3.50
36,600 gals. water at $3 per 1,000	10.80
Total	$20.05

This makes the cost per 1,000 sq. yds. about $1.51. Regarding the success obtained with the machine the report states that it is "rather unwieldy to handle but does the work."

At Reading, Pa., 18 to 20 blocks are flushed every night in the week except Sunday. Flushing machines, 600 gals. capacity, are used. About 1,500 gals. of water are used per block. The material is flushed into the gutter and is swept up by regular cleaners in that section in the morning.

Machine flushing is also employed at Troy, N. Y., the area covered per hour by one of the flushers being 3,500 sq. yds. The machines have proved very satisfactory. At Troy all dirt from these machines is taken care of by the patrol sweepers.

At Springfield, Mass., the squeegee is used for cleaning smooth-surface pavements. The success obtained at Springfield with the machine is reported to be very good, and much better than the old method of hand flushing. The squeegee is used at night with the best results. The patrol sweepers take care of the dirt swept up by the machine.

Fort Worth, Tex., at present has two squeegees in operation and will soon put in a third. The daily cost of operating one of these machines in Fort Worth is stated to be as follows:

1 team at	$ 3.75
1 laborer at	2.00
1 team at	3.50
26 tanks of water, 400 gals. per tank, 10,400 gals. at $3 per 1,000	3.12
Total	$12.37

The average length of street covered per working day is stated to be 24 blocks. These machines have proved very satisfactory in Fort Worth.

Cost of Street Cleaning at St. Paul by Patrol System.—Engineering and Contracting, Sept. 4, 1918, gives the following:

During the season of 1917, 58 miles of streets (1,347,051 sq. yd.) of pavements were cleaned by the patrol system (White Wings). The other paved streets were cared for by the ward crews. The total cost of the patrol system, according to the 1916 annual report of M. N. Goss, Commissioner of Public Works, was $70,178 or an average cost of $52.09 per 1,000 sq. yd. per season. The above figures include the cost of shovelers and teams hauling away the street sweepings. The area handled by one man was from 3,200 to 17,600 sq. yd. The force consisted of an inspector at $100 per month, an assistant inspector at $90 per month, from 105 to 125 sweepers, 14 teams at 66⅔ cts. per hour and 15 shovelers at 25 cts. per hour. The working day was 8 hours.

Life of Street Push Brooms.—Engineering and Contracting, Mar. 19, 1913, states that in a discussion of a paper on street cleaning in downtown Chicago, presented before the Western Society of Engineers, Richard T. Fox, General Manager of the Citizens Street Cleaning Bureau said that he had found that the average life of a push broom when used in cleaning granite pavement was 7 days. On asphalt the life of a broom ran up as high as 12 to 15 days. On asphalt in addition to the broom, the sweepers use a scraper with which most of the work is done, so that the broom is not in use continuously. The broom generally used by the Citizens Bureau is made of two rows of African bass with a row of Bahia grass on either side. Heavier brooms, made entirely of African bass, have been used, but it was considered that these did not pick up the fine dust as well as brooms with fine fibrous material on the outside.

Motor-driven Squeegees for Street Cleaning Show Saving.—Engineering and Contracting, March 1, 1916, publishes the following data which are based on tests made by the Municipal Research Bureau of Milwaukee, Wis., comparing costs of horse-drawn and motor-driven squeegee street cleaning:

The cost data show the operating expense of the horse-drawn and the motor-driven squeegees, and that the latter type will perform twice the amount of work of the former at a reduced unit cost.

A careful analysis of the traffic condition of the streets cleaned by squeegees shows that 1,105,324 sq. yd. are subject to this process of cleaning and that from the total yardage the amount of

413,825 sq. yd. should be cleaned 6 times,
308,133 sq. yd. should be cleaned 3 times, and
385,365 sq. yd. should be cleaned 2 times

each week, or a daily cleaning of approximately 700,000 sq. yd.

Average square yards cleaned per day by motor-driven squeegee	80,000
Cost per 1,000 sq. yd., cts	16.5
The assessment per front foot based on a street 30 feet wide and cleaned 50 times a season would be	1.37

The average yardage covered per day by a horse-drawn machine being 35,000 sq. yd., it will require 20 machines, or an additional 8 over the present equipment, to perform the work; but if the motor-driven type were substituted the purchase of only four machines would be necessary.

The difference in operating cost of the two types would be as follows:

Horse-drawn type, average cost per 1,000 sq. yd., cts	25.5
Motor-driven type, average cost per 1,000 sq. yd., cts	16.5
Reduction in cost per 1,000 sq. yd., cts	9

If the motor-driven squeegees were not available, the cost of operating the eight additional horse-drawn machines would be greatly in advance of the motor-driven type, as the following data shows:

8 machines × \$9.635 cost per machine = \$77.08 × 150 days = \$11,562.

By operating these 8 machines it would eliminate the service of—

9 white wings at \$2 per day × 150 days	\$ 2,700.00
8 sprinklers at \$6.34 per day × 150 days	7,608.00
Total	\$10,308.00
Twice weekly squeegee cleaning	3,854.00
Grand total	\$14,262.00
Less the cost of operating 8 squeegees	11,562.00
Effecting a season's saving of	\$ 2,700.00

4 motor-driven machines × \$13.26 cost per machine × 150 days = \$7,956.

Saving over cost of operating 8 horse-drawn machines = \$11,562 − \$7,956, or a saving of \$3,606.

With the same services eliminated for the motor-driven as for the horse-drawn squeegee, the total saving would be

\$14,262 − \$7,956 = \$6,306.

*This item is included because certain streets are only cleaned twice a week that require the service six times weekly; and if performed the maximum number of times would eliminate the stipulated number of white wings and sprinklers.

Cost of Cleaning with Vacuum Cleaners, at San Diego, Cal.—In some of our western and southern cities where the problem of street cleaning is largely one of removing dry dust, vacuum street cleaners have been successfully employed. Engineering and Contracting, Oct. 3, 1917, gives the following data furnished by F. M. Lockwood, Manager, Operating Department of the city of San Diego, Cal.

The city of San Diego, Cal., has operated vacuum street cleaning machines for the past four years. The first machine was purchased in the fall of 1912 and the second in March, 1913, at a cost of $2,200. The apparatus is drawn by three horses; the vacuum arrangement being run by a small gas engine. The outfit is handled by one gas engineer and one teamster. The machines are worked two shifts a day. The costs of street cleaning with the vacuum machines for the first 7 months of 1917, were as follows:

Vacuum No. 1

	Operation	Maintenance	Total cost	Yardage cleaned	Cost per 1,000 sq. yd.
January	$ 317.61	$ 33.16	$ 350.77	2,923,000*	$0.12
February	397.19	41.34	438.53	3,654.417*	.12
March	398.33	86.47	484.80	4,048.069	.11976
April	406.44	44.73	451.17	2,292,853	.196772
May	418.46	137.61	556.07	3,130,837	.17761
June	41.43	493.07	534.50	In shop	....
July	365.78	186.35	552.13†	2,257,354	.244593
Totals	$2,345.24	$1,022.73	$3,367.97	18,306,620	....
Averages	335.03	146.10	481.13	3,051,103	$0.18397

Vacuum No. 2

	Operation	Maintenance	Total cost	Yardage cleaned	Cost per 1,000 sq. yd.
January	$ 350.74	$ 20.77	$ 371.51	3,377,364*	$0.11
February	294.13	23.44	317.57	2,887,000*	.11
March	369.19	16.43	385.62	4,174,581	.092373
April	431.03	38.85	469.88	4,256,759	.11038
May	373.75	27.08	400.83	3,442,492	.116436
June	356.62	.85	357.47	2,985,323	.119743
July	263.74	8.29	272.03	2,947,462	.0923
Totals	$2,439.20	$ 135.71	$2,574.91	24,070,981	....
Averages	348.46	19.39	367.85	3,438,712	$0.106974

* Estimated; no figures available for actual yardage. † This total cost includes a complete overhauling and rebuilding of the entire apparatus.

The above costs include teams at actual cost of feed, care and maintenance of harness, labor, fuel, oil and repairs, but do not include depreciation or interest on the investment.

Suggested Procedure and Cost with Machine Flushers.—The following useful suggestions on motor flushing procedure, published in Engineering and Contracting, Feb. 5, 1919, are given in a report on street cleaning at Rochester, N. Y., submitted by the Rochester Bureau of Municipal Research, Inc., of which James W. Routh is Chief Engineer.

Motor Flushing Practice and Costs at Rochester.—In 1916 the city purchased one motor flusher of 1200 gal. capacity, and in 1917 an additional one of 1,500-gal. capacity was put into service. The first of these is mounted on a 5-ton truck; the second has a 5½-ton truck. A comparison of the two flushers follows:

	Flusher No. 1	Flusher No. 2
Capacity	1,250 gal.	1,500 gal.
Weight filled	12 tons	13½ tons
Indicated horsepower	30	40
Speed (estimated)	6 to 10 miles	10 to 15 miles
Pump (centrifugal)	Direct conn.	Direct conn.
Nozzles	4	4
Strainer	None	2½-in. crane
Time to connect, fill and get away	5 minutes	7½ minutes
Time to empty tank (2 nozzles)	3½ minutes	3½ minutes
Working pressures (on level ground)—		
2 nozzles	18 to 30 lb.	30 to 42 lb.
3 nozzles	18 to 23 lb.	26 to 30 lb.
4 nozzles	10 to 15 lb	22 to 25 lb.
Fuel used per shift—		
Gasoline	7 gal.	9 gal.
Oil	1 pint	1 pint

The two machines are used for flushing some of the main streets. Two men, a driver and an assistant, are used on each machine. The assistant makes the hydrant connections and operates the nozzle levers. When the 1917 season started the flushing was done with new operators on the machines. Both men were experienced motor drivers, but neither knew anything about street flushing; as a consequence they did not always obtain the best possible results.

During the four months, June, July, August and September, 1917, the two machines flushed a total of 12,399,734 sq. yd. of pavement, the total number of flushing miles traveled being 1,319.18, of which machine No. 1 covered 533.52 and machine No. 2,785.66. The average cost per 1000 sq. yd. for the flushing was 9.62 ct. This figure does not include the costs of the water. An average of 338.6 gal. of water was used per 1000 sq. yd. flushed. The average yardage flushed per hour amounted to 14,515 sq. yd. Of the total yardage flushed, 5,777,000 was asphalt pavement, 600,000 sq. yd. of Medina block and 6,000,000 sq. yd. asphalt and Medina block. On the asphalt pavement the average number of gallons of water used per 1000 sq. yd. was 299.2, and the average yardage covered was 14,976 sq. yd. per hour. The average cost per 1000 sq. yd. was 10.124. In flushing the Medina block an average of 365.4 gal. of water per 1000 sq. yd. was used. The average yardage flushed per hour was 13,171 sq. yd. The average cost was 8.57 ct. per 1000 sq. yd. The cost of operating the flushers for the four months was as follows:

	No. 1 machine	No. 2 machine
Gas*	$ 99.63	$142.71
Oil†	4.84	14.75
Labor	462.75	467.69
Flushing, miles	533.52	785.66
Miles flushed per gal. gas	1.375	1.471
Labor cost per mile	$ 0.8673	$0.5953
Total cost per mile	$ 1.0722	$0.7956

* 388 gal. for No. 1 machine, 534 gal. for No. 2. † 9.75 gal. for No. 1 and 30 gal. for No. 2.

General Comments as to Motor Flushing.—In general, it appears, as a result of tests made, that only two nozzles should be used together on either flusher. In order to save one trip, three nozzles may be used on a narrow street or for flushing the center of a very wide street, if an effective pressure can still be maintained. This qualification is important because it was found that where three nozzles were used together instead of two, less effective pressures, and consequently less side wash, were obtained. The result was that dirty spaces sometimes were left near the center of the street. When four nozzles were used together, water was wasted and, moreover, the nozzles were not all effective, because the two in front interfered with each other and pushed the water straight ahead instead of to one side. The resultant loss of pressure alone is sufficient cause to prohibit the use of four nozzles together at any time, with these machines. A suggested combination of nozzles for different conditions is indicated in Fig. 1.

The efficient operation of flusher trucks depends to a large extent on the drivers, who have expensive pieces of apparatus in their care. Flushers will give good service only when carefully handled and kept in good repair.

Motor Flushing Results.—The cleaning results obtained by motor flushing, with 30 lb. pressure or more, proved to be very satisfactory on asphalt streets. This was not the case, however, on Medina block pavements. These pavements are laid on a sand cushion, and the joints of most of them are not grouted; hence the sand and dirt work up from the bottom through the interstices and make them difficult to clean and hard to keep clean. Where car tracks are paved with Medina blocks without a concrete base, the area included is still harder to clean, because the rails are all on a level, and because dirt and sand deposited on the rails are caught in the grooves. On a rainy day it can be seen plainly how much cleaner are the sides of such streets than is the car track area.

As the motor flushing results obtained on these Medina block car track streets were not all that might be desired, means should be provided for improving the work. With the present apparatus, better results could be obtained by making more trips on such streets. The flushing strokes then could be lapped more. This would make them narrower and more effective, because the side throw would not have to be so far for each individual stroke. (Increasing the number of trips, of course, would increase the cost in direct proportion to the number of extra trips.)

In order to aid in obtaining the desired results, diagrams, based on past performances of the local motor flushing apparatus and needs, have been prepared in the hope that they may be adopted for the guidance of flusher operators. These proposed procedure diagrams, for motor flushers producing a maximum pump pressure of 40 lb., are shown as Fig. 1. If additional flushers are purchased, higher working pressures should be specified. The use of such apparatus would necessitate a modification of the suggested procedure, as fewer trips would then be necessary to obtain the same results. Higher pressures thus would tend also to reduce the unit costs for the work.

As experience elsewhere has proved that on rough pavements the best results can be obtained by hose flushing, it is suggested that certain Medina block pavements be flushed by hose rather than by machine, even if the suggested procedure for motor flushers be adopted and new machines are purchased. Streets paved with Medina block require the use of more water, because they are rougher and dirtier than other pavements. With hose, the water can be concentrated on the dirty spots, and rough places can be given special attention.

Suggestions for Bettering the Service.—The following suggestions are made with reference to obtaining better results from present equipment, as well as to point out desirable factors in purchasing and operating new equipment:

As much valuable time is lost in filling the tanks with water, 4-in. intake pipes and hose, instead of the 2½-in. size now used, would save considerable time. It takes 7½ minutes to stop and fill a 1500-gal. tank, and only 3½ minutes to empty it. Many of the local hydrants now have 4-in. connections, and 4-in. strainers and hose can be obtained on specifications. A recent quotation on 4-in. rubber hose capable of withstanding 140 lb. pressure was $2.21 per foot, without connections. It weighs 2 lb. per lineal foot. This question should be given consideration in purchasing new equipment.

Mileage records are necessary for obtaining good cost data. No speedometers are used on the flushers, and it has been shown that they are hard to keep in order, on account of the vibrations of the trucks. However, hub odometers will give satisfactory service on trucks of this size, and should be supplied so that the proper records can be kept.

A worth while saving could be made in gasoline consumption if the motor were stopped while the tanks are being filled, which is approximately one-half of the time. As starters are little used on heavy trucks, the engine would have to be cranked 25 or 30 times a shift in such an event.

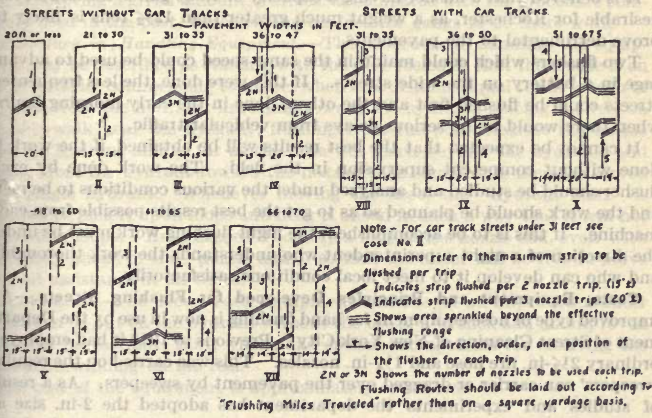


FIG. 1.—Proposed machine flushing procedure for equipment developing a maximum of 40-lb. pressure.

The following data were obtained from a consumption test on the No. 2 flusher to determine the amount of gasoline wasted by running the engine while filling the water tanks:

Total time of test	1 hr. 17½ min.
Less time not running	11 min.
Time to consume ½ gal	1 hr. 6½ min. including 6 starts
Time to consume 1 gal	2 hr. 13 min. or 133 minutes

At 7½ minutes a filling for 28 fillings per 7-hour shift, the flusher is standing 210 minutes. This means that the machine is standing half the time and is then consuming one gallon every 133 minutes. For 210 minutes a shift, the possible saving should be 1.58 gal. For the 65 shifts in a season, the saving would be 102.7 gal., costing $26.70 with gasoline at 26 ct. a gallon. The total gasoline cost for this one truck for the 1917 season was $142.71, and if this were reduced by $26.70 there would be a saving of 18.7 per cent. This saving, of course, would be multiplied by more extensive use of one flusher and by the use of several flushers.

The life of hose could be prolonged if more care were exercised in turning on the hydrants slowly, and also if hanging the hose over one hook were discontinued. If possible, the hose should be hung around the tank of the flusher without kinks. (These points are largely matters of instruction and discipline which should be given constant attention.)

Sometimes sprinkling 15 to 30 minutes before flushing would increase the effectiveness of the results obtained, especially in removing horse droppings. This would soften up the dirt, which then could be flushed off readily. However, the necessity for sprinkling should be determined by the judgment of the man directly in charge of the flushing work.

It is believed that a flusher having a capacity of 1,500 gal. is the largest size desirable for Rochester, as a weight much greater than 12½ tons is likely to prove detrimental to the pavements.

Two flushers which could maintain the same speed could be used to advantage in a battery on the wide streets. If this were done, the less frequented streets could be flushed first and the others done in the early morning hours, when there would be no serious delays from vehicular traffic.

It cannot be expected that the best results will be obtained if the work is done without competent supervision in the field. The work done by each flusher should be studied and analyzed under the various conditions to be met, and the work should be planned so as to get the best results possible from each machine. If this is to be accomplished, the night flushing work must be under the direction of a night superintendent who understands the work thoroughly and who can develop it to meet local conditions satisfactorily.

Costs, Equipment and Principles Developed for Flushing Streets.—An improved type of hose equipment for hand flushing is now in use by the Department of Street Cleaning of New York City. Previous to 1915 it had employed ordinary 2½-in. fire hose and 1¼-in. nozzles. This was carried on the regular sweepers' can carrier or dragged over the pavement by sweepers. As a result of studies and experiments the department has adopted the 2-in. size as standard for the city, and has developed a new hose reel and new hydrant equipment. Engineering and Contracting, Jan. 3, 1917, gives the following description of the New York equipment and principles taken from a paper by Raymond W. Parlin, formerly Engineer with the New York Bureau of Municipal Research, prepared for the 1916 annual convention of the American Society of Municipal Improvements.

As a result of the experiment the following general principles for hand flushing appear to have been established:

General Principles of Hand Flushing.—(1) The economical size of equipment is dependent upon the hydrant pressures available and the length of hose used.

2. When the pressure at the nozzle is in excess of 25 lb. per square inch, water is delivered through a ¾-in. or 1-in. nozzle faster than it can be properly used by two men and it is accompanied by excessive splashing.

3. When the pressure at the nozzle is less than 18 lb. per square inch, water is not delivered fast enough to keep up with the men nor with force enough to enable them to do effective work.

4. The smallest size hose which will give pressure at the nozzle between 18 and 15 lb. is the most economical for use.

5. Better results can be secured by spraying ahead as far as the stream will

reach, to give the material on the street a preliminary soaking prior to the direct flushing, than can be secured by the direct flushing of a dry pavement.

6. Larger quantities of water are required to clean rough pavement than smooth, and therefore a slightly larger nozzle may be used to advantage. (It is estimated that a ¾-in. will be satisfactory for asphalt and a 1-in. for rough Belgian block.)

7. Shut-off nozzles are necessary whenever working in traffic, both to save water and to prevent accidents.

8. Where water mains are large enough for proper domestic and fire supply, flushing will not interfere with the ordinary household use.

9. A hose reel will enable the gangs to do more work with the same expenditure of energy and at the same time lengthen the life of the hose.

10. By the adoption of procedure which prevents any "back tracking" of the equipment, over four miles of walking can be saved per gang per 8-hour day in covering a given amount of street, as compared with the procedure commonly used in the past, which saving enables the gangs to do more work.

Procedure in Handling Equipment.—The procedure in handling the equipment may be described as starting with the hose reeled so that the nozzle is on top or outside; commencing to unreel when at a distance equal to the length of the hose from the hydrant; unreeling toward the hydrant; placing the reel on the side-walk near the hydrant; flushing from the point nearest the nozzle past the hydrant and as far as the hose will reach beyond the hydrant; and reeling from the hydrant toward the nozzle; thus completing the area served by a single hydrant. Whenever moving the hose, the "hydrant man" is required to pick it up in loops and drag it ahead in such a way that it will not cross other loops. He is expected to keep a loop at the nozzle end, even with or slightly ahead of the "nozzle man," so that the latter will be free to move without assistance at all times.

Equipment.—The New York equipment consists of an improved reducer which can be put on the hydrant without the use of a wrench and an improved reel with its tool box, third wheel, and special arrangement for receiving the reducer in winding on the reel.

The cost of the equipment is approximately as follows:

Three 50-ft. lengths 2-in. rubber hose at 60 ct. per ft.....	$ 90.00
One ¾-in. shut-off nozzle..............................	7.00
One 2½-in. to 2-in. reducer, hand swivel type..........	2.25
One hydrant key..	.15
One hose reel..	30.00
	$129.40

(Rubber-covered hose is preferable to cotton-jacket hose for this work.)

The cost of operating with this equipment is as follows:

Annual and Unit Costs Based on 200-day Season and One 8-hour Shift Per Day

Dirty Belgian block pavement; night work.
Force, 1 gang.
First cost equipment, $130; hose, $90.
Life hose, 250 working days; other equipment, 1,200 working days.
Interest at 5 per cent. Water at 5 ct. per 1,000 gal.
Area flushed per shift, 23,000 sq. yd.
Area flushed per year, 4,600,000 sq. yd.

Fixed Charges

	Per year
Depreciation reserve (hose not included)	$ 7.00
Interest	6.50
Maintenance:	
Repairs and painting	15.00
Storage:	20.00
Operations:	
Hose	72.00
Laborers, 2 at $2	800.00
Water, 900 gal. per 1,000 sq. yd	207.00
Total annual cost	$1,127.50
Cost per 1,000 sq. yd	24.5 cts.

When cleaning 30,000 sq. yd. per day the cost per 1,000 sq. yd. is 19.8 cts.

Upon less heavy work and smooth pavements, New York gangs have been able to flush effectively 30,000 or more square yards in 8 hours, making as many as 45 connections to hydrants.

Comparison of Various Types of Street Flushing Equipment.—Mr. Parlin also gives comparative annual and unit costs for cleaning with various types of equipment. These figures are based upon actual experience in the following cities, with equipment noted: Automobile pressure pump, Chicago, Los Angeles, Cal., and Rochester, N. Y.; Street car, pressure pump, Worcester, Mass.; Horse-drawn, pressure pump, Detroit, Mich., and Milwaukee, Wis.; Horse-drawn, air pressure, Detroit, Mich., and Washington, D. C. He concludes that the most economical examples of the various types of equipment as shown by the cost comparisons are: 1. New York, hose equipment. 2. Milwaukee, horse-drawn equipment. 3. Chicago, auto equipment. 4. Worcester, street railway equipment.

To determine the relation of these various types of equipment to each other a diagram, Fig. 2, was drawn, which shows the unit cost of cleaning various areas with the four types of equipment. The data used in constructing the diagram were based upon that obtained from the cities noted above and the assumption that the area represented the schedule area to be covered each day for 200 days.

This diagram shows that hose flushing on small areas was the most economical method; that up to 40,000 sq. yd. the horse-drawn equipment was next in economy; that from 40,000 sq. yd. to 90, 000 sq. yd. the hose was about as economical as the automobile; that from 90,000 sq. yd. to 120,000 sq. yd. the automobile was supreme, and for daily schedule areas of over 120,000 sq. yd. the automobile and street car equipment give nearly the same economy.

This means, states Mr. Parlin, that small cities which do not have over 40,000 sq. yd. of hard pavement to clean each day can better afford to use hose equipment if hydrants are close enough together and plenty of water is available. If local conditions prevent the use of hose, then horse-drawn equipment is economical if only flushing is required. If both flushing on the hard pavements and sprinkling on the macadam or gravel streets is desired, the automobile appears to be by far the most economical equipment.

In large cities there appears to be no doubt that the automobile and street car equipment are the most economical, perhaps with the possible exception of those small or inaccessible areas which the larger equipment cannot reach. On such areas hose equipment can well be used as auxiliary to the machines.

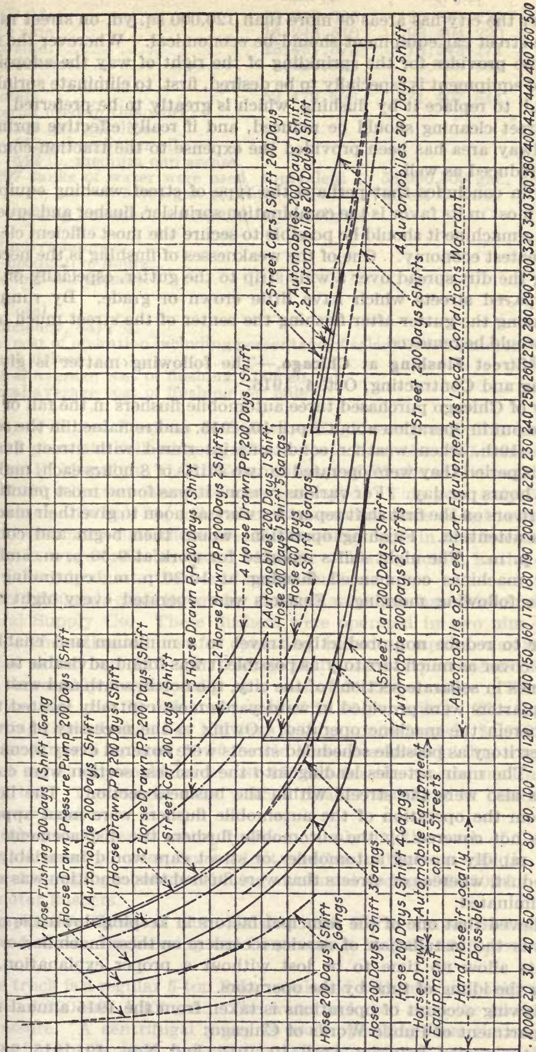


Fig. 2.—Comparison of various types of street flushing equipment.

Wherever the city has areas of more than 120,000 sq. yd. on street railway streets the street car equipment should be economical. Wherever the street car franchise provides for the sprinkling of the right of way the adoption of this type of equipment is especially to be desired, first, to eliminate sprinkling, and, second, to replace it by flushing, which is greatly to be preferred. The costs of street cleaning should be reduced, and if really effective sprinkling of the railway area has been provided the expense to the traction company should be reduced as well.

Mr. Parlin concludes that perhaps the type of street washing equipment which has most in its favor is the combination sprinkler, flusher and squeegee. With such a machine it should be possible to secure the most efficient cleaning and the greatest economy. One of the weaknesses of flushing is the necessity for leaving the dirt spread over a wide strip to the gutter, especially on dirty smoothly paved streets which have little crown or grade. By running a squeegee along the gutter after flushing the center of the street much of this objection would be removed.

Cost of Street Flushing at Chicago.—The following matter is given in Engineering and Contracting, Oct. 4, 1916.

The city of Chicago purchased three automobile flushers in the fall of 1914. These were put in operation about April 10, 1915, and remained in the service until Nov. 19th, when weather conditions interfered with street flushing. During this period they were operated in two shifts of 8 hours each, making a total of 16 hours per day. For various reasons it was found most practical to have the drivers on the first shift report for work at noon to give their machines one hour's attention. Flushing operations would then begin and continue until 9:30 p. m. The night shifts reported for work at 9:30 p. m. and after caring for machines commenced flushing at 10:30 p. m., continuing until 7 a. m. the following morning. Flushers were operated every night except Sunday.

In order to reduce non-productive travel to a minimum and enable the flushers to cover as much territory as possible it was found advisable to house the machines in separate sections of the city, the north, south and west sides. Suitable quarters were provided in ward yards most centrally located to the section wherein the machine operated. Owing to the necessity of covering as much territory as possible scheduled streets were covered every second day or night. The main arteries leading into the business section were covered nightly, as also were the streets within the business section. The benefits derived from the operation of the automobile flushers were most apparent. On streets not covered by the automobile flushers the displacement of air caused by rapidly moving automobiles or street cars would invariably raise a cloud of dust, whereas on streets that were flushed this condition was almost entirely eliminated.

It is believed that one of the principal factors in keeping down the cost of flushing was the installation of service recorders on these machines. These instruments allow no time to be lost without a proper explanation, thus preventing the idling of time by the operators.

The following account of operations is taken from the 1915 annual report of the Department of Public Works of Chicago:

During the period between April 10, 1915, and Nov. 19, 1915, 9,939.52 miles of streets were flushed, with a total of 271,407,644 sq. yd. cleaned, divided as follows:

	Lin. ft.	Sq. yd.	Cost
North side	19,213,606	96,961,529	$ 3,303.45
South side	16,248,540	93,404,220	3,375.15
West side	15,491,575	73,543,171	3,161.87
Loop district	1,525,976	7,768,661	946.40
Totals	52,479,696	271,407,644	$10,786.87

Material used in this work:
12,547 gal. gasoline.
572 gal. cylinder oil.
642 lb. medium cup grease.

39,297 tanks of water were used, equivalent to 58,990,500 gal., or an average of 5,865 gal. of water per mile of street flushed.

The working hours are accounted for as follows:

	Hours
Productive hours	7,745.08
Non-productive hours	435.01
Time lost (all causes)	1,356.45
Total	9,536.54

Efficiency, 83⅓ %.

Total cost of operation including percentage of salary of head motor truck driver	$11,209.87
General average cost of flushing 1,000 sq. yd.	.041
General average cost of flushing per mile	1.13

Cost of Motor Flushers at Ottawa.—Engineering and Contracting, April 3, 1918 gives the following significant facts from the 1917 annual report of Andrew F Macallum, C. E., Commissioner of Works of Ottawa.

In 1916 82 street sweepers were employed. This year only 55 sweepers were hired, although 2¾ miles of new pavements were added to the sweeping area. Assuming that there are 170 working days in the season, the total saving in wages will be about $12,400. This reduction in the cost of the work is largely due to the use of motor flushers.

Two 1,200-gal. capacity motor flushers were purchased in April from the General Supply Co. These flushers were operated in two nine-hour shifts daily. The estimated cost for operating, including repairs, was $32 per day, and the actual cost $31. An average of 18 miles of pavements of all widths were thoroughly washed daily at a cost of $1.72 per mile. (The estimated daily average was 20 miles at a cost of $1.60 per mile.) The total cost for operating these flushers for 150 days will be approximately $4,650.

These flushers replaced 20 of the old horse-drawn sprinkling wagons which, if used regularly, would have cost $16,800 for the season, making a saving of $12,150. The streets were washed cleaner and kept in better condition than ever before.

In other words, each motor flusher not only did the work of 10 sprinkling wagons drawn by horses, but made it possible to dispense with the services of 14 street sweeping laborers, effecting an annual saving of $8,500 for each of the two motor flushers.

Comparative Costs of Auto Flusher and Horse-drawn Sweeping Outfit, Portland, Ore.—Engineering and Contracting, May 31, 1916, gives the following:

The truck is a regular 5-ton Riker equipped with tank, capacity of which is between 1,200 and 1,300 gal. The water is forced onto the street under 50 lb. pressure. A centrifugal pump is used, operating from the engine. The tire equipment is 40 × 6 Goodrich Demountable all around. This truck cost the city $5,500, complete, and operates with a crew of three men at a cost of $0.1384 per 1,000 sq. yd. It leaves very little refuse for carts to pick up, the largest portion of this going into the sewers. By this process the streets stay clean longer, as no sediment is left to turn to dust as in the case with sweepers. The sweeping outfits represent an outlay of $5,620 as follows:

3 sweepers	$1,200
1 sprinkler	400
Carts	500
12 horses at $250 each	3,000
8 sets of harness at $50 each	400
4 sets of harness at $30 each	120
	$5,620

The sweeper required a crew of 12 men and the average cost per 1,000 sq. yd. was 31 cts.

Portland has 370 miles of paved streets, with 20,800 square yards to the mile. One of the trucks will cover 6 miles a day at a cost of $17.27. The sweepers covered the same ground in an equal time at a cost of $38.69. Thus the truck is saving the city $21.42 in a working day of eight hours. Allowing two eight-hour shifts with an average of 300 days to the year, it will be seen that a saving of $6,426.00 is effected, or enough to pay for the truck. These operating costs do not include depreciation.

Costs of Flushing and Scrubbing at St. Paul, Minn.—The following is taken from Engineering and Contracting, Nov. 1, 1916.

The equipment used by the Bureau of Sanitation of St. Paul, Minn., for flushing and scrubbing paved streets consists of five Studebaker power flushers, two 2-horse-drawn Hvass squeegees, one 2-horse Kindling squeegee and one 3-horse Hvass squeegee. According to the annual report of M. N. Goss, Commissioner of Public Works, the area of paved streets flushed and scrubbed in 1915 was 1,493,000 sq. yd. This does not include the pavement laid in 1914 or 1915 on which very little flushing was done in 1915. The cost of this service was as follows:

Team hire	$6,389	
Labor	2,504	
Gasoline, 9,308 gal	912	
Lubricating oil	123	
Water (32,145,850 gal.)	1,285	
Repairs	1,469	
		$12,685
Miscellaneous labor	357	
4 new engines for flushers	1,400	
1 Hvass squeegee	950	
1 Kindling squeegee	1,200	
		3,907
		$16,592

The Street Railway Co. paid its proportion of this cost which was 24.2 per cent, or the ratio of the street railway area to the entire area of streets flushed.

In the congested business district bounded by St. Peter St., Eighth St. and Third St. and Broadway all streets are flushed every night during the season. This district comprises 7.12 miles of streets or an area of 146,400 sq. yd. The crew consists of one foreman, three teams at 60 ct. each per hour and two gutter cleaners at 25 cts. each per man. The cost of one night's flushing (8 hour shift) in this district amounts to $27.61. This includes gasoline, lubricating oil and water, but not repairs, interest or depreciation. This is 19 ct. per 1,000 sq. yd. for one flushing. The flushers are used on the day shift on streets outside of the so-called congested district. The day shift work nine hours. Paved streets are flushed or scrubbed at least once a week during the season.

As a matter of comparison of cost, the W. Seventh St. district, with an area of 89,700 sq. yd., 68,000 sq. yd. of which is sandstone, on the level, with street car tracks and very heavy traffic and with intersecting traffic streets as follows: 8,500 sq. yd. of asphalt, 10,800 sq. yd. of creosoted wood block and 2,400 sq. yd. of brick, costs for one flushing $39.80 or 44 ct. per 1,000 sq. yd. This district is flushed once a week and is one of the hardest districts to clean.

The E. Seventh St. district with an area of 150,400 sq. yd., of which 109,800 sq. yd. are brick, steep gradient, street car tracks, automobile traffic and light miscellaneous traffic with intersecting streets as follows: 25,600 sq. yd. of asphalt and 15,000 sq. yd. of sandstone, cost for one flushing $43.56 or 29 ct. per 1,000 sq. yd. The crew in each of the above cases was one foreman, three teams and two gutter cleaners working one 8-hour shift.

The squeegees are operated only in the day time on smooth pavements, such as creosoted wood block or asphalt. The 3-horse squeegee scrubs 42,000 sq. yd. of pavement in one 9-hour shift and uses 11,000 gal. of water, the resulting cost being 17½ ct. per 1,000 sq. yd. scrubbed. The 2-horse squeegees do a slightly less amount. The total amount of water used for street flushing purposes during the 1915 season was 32,145,850 gal. for which the department was charged $1,286.

Street Flushing at Worcester, Mass., by Trolley Flushers.—Engineering and Contracting, April 4, 1917, gives the following:

For many years the city of Seattle has been celebrated for its cleanliness and low death rate (8 per 1,000). Seattle has used flushing wagons that hurl powerful streams of water upon the pavements and wash them as clean as a kitchen floor. The flushers work at night. Worcester, Mass., has adopted the same method, but with a variation that is worthy of notice. In Worcester trolley cars, instead of wagons, are used.

Each flushing car has a 2,900-gal. tank that is filled from sub-surface hydrants. For flushing, a centrifugal pump on the car, driven by a 45-H. P. motor, delivers 600 gal. per min. at a pressure of 80 lb. per sq. in. Three nozzles on the car itself and two on swinging arms that reach almost to the curb, flush the widest street clean.

The best results are obtained by sprinkling the street with the car about an hour before flushing, for this softens up the dirt. A 40-ft. street requires about 3,000 gal. per mile for the sprinkling and 10,000 gal. for the subsequent flushing, or a total of 13,000 gal. per mile. A car will sprinkle and flush 9 miles of street (averaging about 30 ft. wide) per night of 8 hours, using 95,000 gal. of water.

The American Car Sprinkler Co., of Worcester, has the contract for this work, and its annual charge for a 30-ft. street is about $550 per mile.

A few push-cart men clean up the gutters in the morning, but the rest of the street is left perfectly clean by the flushing.

Previous to the use of the trolley flushers, when day sprinkling was required, three car sprinklers, making several trips over each street every day, covered the same area now covered by the two flushers, which make one trip nightly for sprinkling and flushing combined. The flushers work 8 hours and the sprinklers under the old method 14 hours.

The amount of water used under the flushing system is about 60 per cent of that used under the old style day sprinkling, while the present combined sprinkling and flushing uses about 85 per cent of the amount.

The cost of catch basin cleaning has been just about doubled on streets which are flushed. The average cost per catch basin per year for cleaning was $1.95, and on streets flushed this has been increased to $3.90.

The method of flushing by cars is not only cheaper than hand cleaning with brooms, but what is even more important is the fact that flushing is far more effective than brooming. Moreover, sprinkling during the day is no longer necessary to keep down the dust.

Comparative Costs of Street Sprinkling with Motor Trucks and Horse Drawn Tanks.—Engineering and Contracting, Sept. 5, 1917, publishes the following comparative costs of street sprinkling with motor-driven sprinklers and with team-hauled tanks, given in a report of the Board of Public Works, Los Angeles, Cal.

Savings in money and water, more efficient sprinkling and relief of traffic conditions were among the benefits reported after a year's use of the motor-driven trucks.

Teams:	
Total team days of 8 hours each	10,910
Loads of water used, 550 gal. per load	303,722
Average loads of water used per day (per team)	*27.8
Miles of streets sprinkled	47,209.7
Miles of streets sprinkled per day, average (per team)	4.33
Cost for team hire	$51,301.16
Cost for team hire per mile of street sprinkled	$ 1.087
Motor Sprinkling:	
Total truck days of 8 hours each	1,178.25
Loads of water used, 1,200 gal. per load	49,618
Average loads of water used per day (per truck)	†42.11
Miles of streets sprinkled	20,303.38
Miles of streets sprinkled per day, average (per truck)	17.23
Cost for truck hire	$17,519.98
Cost for truck hire per mile of street sprinkled	$ 0.863

* This is a rate of a load in 17 min. for the team tank, sprinkling 820 ft. of street.

† This is a rate of a load in 11 min. for the truck tank, sprinkling 2,170 ft. of street.

Comparative Cost of Bituminous Surface Applications and Water Sprinkling in New York City.—Engineering and Contracting, May 15, 1912, gives the following data from a paper by William H. Connell before the A. S. C. E.

The results from tar have been very satisfactory, about ⅓ or ½ gal. per sq. yd. being applied and covered with torpedo sand or fine wash gravel. This formed a very desirable surface, at a cost of $0.035 for ⅓ gal. and $0.045 for ½ gal. per sq. yd. In these treatments the tar was applied cold.

The Grand Boulevard and Concourse was treated with a heavier tar, which was applied under pressure through a hose at a temperature of 220° F., ⅗ gal. per sq. yd. being used, and then covered with torpedo sand or fine washed gravel. This road has been in use for 6 months, and although it has been subjected to very heavy, high-speed automobile traffic, it is now in first-class condition. The cost was $0.138 per sq. yd., which is high, owing to the lack of proper facilities for handling the bituminous material and the numerous delays which occurred. In the Borough of the Bronx a fair cost would be from $0.09 to $0.10 per sq. yd. for this treatment. Before the application of tar in these treatments, the road was thoroughly swept with horse-drawn and hand brooms.

Asphalt road oil of about 20° Baumé gravity was applied to a number of macadam roads, using ¼ gal. per sq. yd. On roadways having light or medium traffic, one application a year was sufficient to keep the road dustless; heavily traveled roadways required two and, in some instances, three applications. The cost of this treatment was $0.013 per sq. yd. when ¼ gal. per sq. yd. was used. The oil was applied with a pressure distributor on a number of roadways, and the cost was $0.009 for ⅕ gal. per sq. yd. This method of treatment is both economical and desirable. Just enough pressure was applied (about 15 lbs.) to drive the oil into the interstices of the stone to a sufficient depth to avoid having a mushy road surface. Before the application of the asphalt road oil, the surface was swept with a horse-drawn sweeper only.

Preparations are now under way to equip the Bituminous Application Division with a sufficient number of pressure distributors to do all the bituminous surface work in 1912. For the cold treatments, the distributing device can be attached to an ordinary water sprinkler. The heavier materials will require the use of heater wagons.

The bituminous material applied to the different roadways was selected from the standpoint of its adaptability for each particular case. The stone used consists largely of Rockland Lake and Clinton Point crushed trap rock.

The following table gives a comparison of the cost of surface treatments and water sprinkling in the Borough of the Bronx, the water sprinkling being based on sprinkling from three to four times a day for 180 days, at $5 per day for a team, and water at $0.10 per 100 cu. ft.:

Tar, ⅓ gal. per sq. yd.	$0.035
Tar, ½ gal. per sq. yd.	0.045
Asphalt road oil, about 20° Baumé gravity, ¼ gal. per sq. yd.	0.013
Two applications	0.026
Asphalt road oil, about 20° Baumé gravity, pressure distributor, ²⁄₁₀ gal. per sq. yd.	0.009
Two applications	0.018
Water sprinkling	0.051

The following figures relate to material and wages paid to laborers in the Borough of the Bronx:

Foreman, per day	$4.00
Laborers, per day	2.25
Average price of tar at freight yard, per gal.	0.061
Average price of asphalt road oil at freight yard, per gal.	0.04
Torpedo sand on work but not spread, per cu. yd.	1.30

With the use of pressure distributors in 1912, the cost of applying the tar will be greatly reduced. The former method required the services of three laborers, whereas a distributor will need only one man to operate it, and moreover the time required to apply the tar will be reduced.

Further costs of oiling road surface are given in Chapter XV.

Cost of Calcium Chloride as Dust Preventive on Gravel Roads.—The Connecticut Highway Commission has obtained excellent results from the use of calcium chloride as a dust preventive on gravel roads passing through sparsely settled sections. The methods employed in making the applications are described by W. Leroy Ulrich, Superintendent of Repairs, of the State Highway Commission, in Public Roads, from which the matter following is abstracted in Engineering and Contracting, June 4, 1919.

The material is put up in metal drums, holding about 350 lb. per drum, and costs at the present time between $20 and $30 per ton at the point of shipment.

The price varies with the amount purchased. The drums will be painted by the shippers without extra charge if requested. If this is done, material may be stored for future use in any reasonably dry place. If it is not done, the drums, being very light-gauge material, quickly rust out, exposing the chloride to the air, from which it immediately attracts moisture and solidifies, in which form it is very expensive to handle. If properly sealed and handled, when the drum is opened it will roll out in the form of kernels about the size and appearance of popcorn.

In order to obtain the best results the surface of the road to be treated should be kept in shape by the use of a drag for about two weeks previous to the application of the material. This will insure proper cross section and a reasonably smooth surface for receiving the material. The application may be made by laborers spreading with shovels, but this is not satisfactory on long sections as it is too slow and expensive. A uniform distribution can not be obtained by this method. Any ordinary lime sower will spread the chloride, but it is economical to purchase a special machine for this purpose. These machines may be purchased in different widths for use with a single horse or a pair.

In making application with the use of horses the drums are distributed along the road at regular intervals, one at a point if a narrow machine is used, and two if the wider. The necessary interval is determined by the amount of material to be applied. About 1½ lbs. per square yard is necessary for the first application, which should be followed by a second treatment at 1 lb. per square yard. The interval between applications depends upon the quality and condition of the surface on which the material is spread and the character and volume of the traffic carried. Under moderate traffic a good surface would not require more than two applications per year; under heavy traffic three may be necessary. The best results are obtained if the material is spread on the road after a rain, when it is wet, as a better penetration is obtained at this time.

In making an application with a 2-horse machine with a spread of 10 ft., two drums are distributed every 220 ft. This machine will hold the contents of two drums and after filling is run up one side and down the other and then up the middle of the road, stopping at the point where the next two drums have been placed. This applies a little less than 1 lb. per square yard on each edge of the road and nearly 2 lb. on the center 10 ft. This method has proven more satisfactory than making an even distribution over the entire surface. The same method may be followed with the one-horse machine.

In order to eliminate the necessity for the distribution of the drums, the machine may be hauled behind and fed directly from an automobile truck. Eighteen drums may be carried on a 3-ton truck, which, running continuously in one direction, will cover one width for about 6,200 ft. Three trips will complete the treatment of this length of road. This has proven a little more economical than distributing the drums and spreading with horses.

During the handling of the material, all workmen should wear rubber boots, as the chemical action of the chloride is very detrimental to leather. It is also well to provide cotton gloves, otherwise the hands will soon become sore. The hoofs and hocks of the horses, which are working on the distributor, should be cleaned and greased night and morning. After the chloride is melted on to the surface of the road, it will not cause injury to horses or to automobile tires.

Proper application of calcium chloride results in a smooth and practically dustless surface, making a road with almost ideal riding qualities. While not considered as a binder this treatment does toughen the surface, making it less liable to ravel. One of the great advantages of roads treated in this manner is the ease with which the resulting surface may be maintained. All that is required is a light dragging at intervals in order to keep the surface smooth. On account of the moisture held in the surface this may be done whenever necessary without waiting for a rain.

The surface of most gravel roads softens up in the spring when the frost is leaving the ground and the calcium treatment does not overcome this condition. The results in Connecticut show that the treated roads do not mud up any more than untreated roads of the same quality and not as much as roads of this quality which have geen treated with a nonasphaltic oil. The continued use of chloride has an accumulative effect. After two or three years, with two applications per year, the effect of the material is plainly noticeable in the spring, after the road has settled.

During the year of 1918, with labor at approximately $2.75, teams at $7.50, 3-ton trucks at $25, the cost of this treatment in Connecticut per square yard per year (two applications) has been $0.031, divided as follows: Chloride $0.026, handling and application $0.005.

Snow Fighting vs. Snow Removal at New York City.—The following is given in Engineering and Contracting, July 4, 1917.

New methods of snow removal inaugurated in New York City by Mr. J. T. Fetherston, Commissioner of Street Cleaning, have more than trebled the rate of removal and also have reduced the cost 68 per cent. Under the new plant the old system of removal by contractors has been amended so that the city now does the larger part of the work by the direct employment of labor and the use of department equipment. The following outline of the methods employed is taken from the recently issued report of the Department of Street Cleaning, covering the year ending Dec. 31, 1916:

Owing to contracts in existence when the present administration assumed direction, application of the new principles was confined in the winter of 1913–1914 to a limited use of sewers for snow removal. As a result of the winter's experience and tests that were made, it became apparent that the city had had available for years a possible solution of the problem of rapid snow removal, through the extensive use of sewers, not alone after a snowfall, but during the progress of the storm. The experience of that winter demonstrated to the satisfaction of the administration that snow work should be started with the storm and clean snow dumped into the sewers as it falls. Such methods imply an attempt to keep pace with a storm, instead of trying to dig the city out after a block has occurred.

In the summer and fall of 1914 the Department made preparations to apply during the following season its new programme for handling snow. This preparation included a thorough survey of the city's sewer system, specialized instruction of the Department's forces, enlargement of standard equipment, enrollment of emergency workers as "snow fighters" and the plotting of the city so that practically 50 per cent of its entire area could be cared for by the simultaneous attacks of the "snow fighting" gangs, within four hours after the call to go to work. Plans called for pushing snow into sewer manholes by the use of panscrapers operated by hand, and drag-scrapers, each drawn by a single horse.

These plans did not eliminate contract snow removal, as large quantities of snow still had to be carted to the river dumps or main sewers; nor did they release the city railways from their obligations to clear the snow from certain streets carrying railway tracks. But up to this time the city had depended upon trucks alone to haul snow from the streets to water front dumps and, consequently, the speed of snow removal had depended upon the supply of trucks available for the work.

Results of the application of the new system during the winter of 1914–1915, as compared with preceding winters, showed the rate of removal doubled as compared with the best previous record, and that the cost per cubic yard decreased 67 per cent compared with lowest previous unit cost record. The total fall of snow for the winter was 22.4 in., and the total cost of removal was $523,892. If the entire snowfall of the winter had been handled by contractors' trucking forces alone, at the lowest previous contract rate ($0.367 per cubic yard), the cost of the season's work would have amounted to $1,584,822. The total area of the streets in the three boroughs scheduled for snow work in in the winter of 1914–1915 was 32,607,081 sq. yd., or 927 miles of streets.

When the first snow of the winter of 1915–16 arrived, it found the Department further strengthened by valuable additions to its equipment and better trained organization; but the beneficial effects of these improvements were counteracted, to some extent, by the shortage of labor available for emergency snow work. Schedules called for 14,737 emergency laborers, working in 9-hour shifts, while storms were in progress. The average number of men secured was 9,060, or 61 per cent of the required number. Use of snow plows, designed by the Department and attached to commercial motor-driven trucks, aided in reducing the effect of the shortage of labor. These plows were used for piling snow in the center or on the sides of streets.

Over 50 in. of snow fell during that winter, compared with the average fall of 32.2 in. The total area scheduled for snow work in the three boroughs had increased to 33,311,899 sq. yd., which represented 946.17 miles of streets. Nearly 12,000,000 cu. yd. of snow (truck capacity basis) were removed at a gross cost of $2,521,299.55, or at the rate of 21.2 ct. per cubic yard. This was more than double the quantity (truck capacity basis) removed by the city during any previous winter season, and the cost was less than half the average cost per cubic yard for the previous 7 years. No serious complaints were made regarding snow removal during the season, which is creditable to speedy action in opening main arteries with automobile snow plows, employment of the largest procurable force of emergency laborers during storms and the use of sewers for the disposal of snow.

Including the statistics of the snow storm of Dec., 1917, the total fall of snow for the calendar year 1916 was 54.6 in.; average for the previous 47 years, 32.16 in. The daily rate of removal during 1916 was 198,000 cu. yd., compared with the grand average, 1907 to 1915, inclusive, of 71,886 cu. yd. Rate of daily removal during and following the storm of Dec. 15 last surpassed all previous records. There was a snowfall of 12 in. The cubic yards removed totaled 2,178,301. Nine days were required for completion of the task, the daily removal approximating 242,000 cu. yd. This record was achieved despite a shortage of labor, because of the almost perfect working of the system established by the Department. An important feature was the use of 120 city snow plows driven by commercial motor trucks.

The following tables present statistics of snow storms and snow removal work during 1916. The tables showing the area assigned to each of the three forces engaged upon snow work show only slight changes from the tables showing corresponding statistics in 1915.

TOTAL AREA AND MILEAGE OF STREETS

Borough	Street area, sq. yds.	Length, miles
Manhattan	16,201,019	460.25
The Bronx	3,774,456	106.89
Brooklyn	13,250,053	376.68
Totals	33,225,528	943.82

SCHEDULE FOR SNOW FIGHTING FORCE

Borough	Street area, sq. yds.	Length, miles
Manhattan	12,542,820	356.33
The Bronx	3,031,165	86.11
Brooklyn	8,885,701	252.43
Totals	24,459,686	694.87

CONTRACT SCHEDULE, MANDATORY STREETS

Borough	Street area, sq. yds.	Length, miles
Manhattan	2,508,981	71.27
The Bronx	309,079	8.78
Brooklyn	2,930,400	83.25
Totals	5,748,460	163.30

STREET RAILWAY SCHEDULE

Borough	Street area, sq. yds.	Length, miles
Manhattan	1,149,218	32.65
The Bronx	434,212	12.00
Brooklyn	1,433,952	41.00
Totals	3,017,382	85.65

DEPTH AND WEIGHT AND DENSITY OF SNOW

1916	Depth	Density, per cent	Weight per cu. yd.
February 2, 3	6.0	.16	269.46
February 13, 14	6.4	.15	253.80
March 2	3.2	.09	151.20
March 6, 7	7.6	.13	218.7
March 8	4.0	.14	234.9
March 10	1.4	.10	167.4
March 15, 16	4.1	.11	186.3
March 21	2.1	.04	67.5
March 22	2.9	.23	386.1
April 8, 9	2.3	.20	337.5
December 15	12.0	.05	84.4
	52.0		

SNOW FIGHTING VERSUS SNOW REMOVAL

	Day's work	Cubic yards removed	Cost	Av. cost per cu. yd.	Cu. yds. removed per day
Contract snow removal	48	2,681,289	1,366,952	$0.509	55,860
City snow fighting	56	9,754,479	1,129,517	0.116	174,187
Total	..	12,435,768	2,496,469	$0.201	

SNOW EQUIPMENT ON DEC. 31, 1916

Borough	Auto plows	Horse-drawn plows	Sand spreading machines	*Bags with auto plow parts	†Boxes with auto plow parts	*Boxes with tools	Pan-scrapers	Shovels	Picks
Manhattan	113	61	3	64	12	11	7,677	4,038	4,730
The Bronx	17	4	..	10	3	3	1,529	617	574
Brooklyn	39	18	1	26	5	5	4,058	2,869	2,132
Total	169	85	4	100	20	19	13,264	7,524	7,436

	Borough	Red flags	Flashlights	Hydrant pumps	Hydrant keys	Nozzles	Reducers	Hose lengths
Manhattan	484	11,984	104	210	925	306	171	665
The Bronx	90	2,860	14	43	139	43	30	105
Brooklyn	311	7,477	76	82	346	62	54	180
Total	885	22,321	194	335	1,410	411	255	940

*Carried on auto trucks for making minor repairs to auto plows in the field.
†Carried in stables for making repairs to auto plows.

The average daily rate of removal for the two years under the old method was 51,390 cu. yd., at an average cost to the city of $0.535 per cubic yard. Under the new method, the average daily rate of removal for the two years was 234,211 cu. yd., at an average cost of 0.188.

Cost of Snow Removal by South Park Commissioners, Chicago, was given by H. F. Richards, in a paper presented March 4, 1918, before the Western Society of Engineers. Extracts from the paper, as given in Engineering and Contracting, April 3, 1918, follow.

The areas covered by the South Park Commissioners in their snow cleaning work include about 67 miles of drives and 175 miles of walks and 90 to 95 acres of skating ice.

The South Park snow handling equipment includes five 3-wheeled tractors fitted with detachable V-shaped plows having wing extensions and with detachable revolving street brooms, one 4-wheeled tractor equipped with both V-shaped and straight moldboard attachments, some very large snow hauling wagons, 20 large 4-wheeled iron plows of the road grader type, 17 large wooden 4-wheeled tractors fitted with detachable revolving street brooms, one 4-wheeled tractor equipped with both V-shaped and straight moldboard attachments, 17 large wooden, 4-wheeled plows similar to the road graders, 6 small iron-wheeled plows used mainly for cleaning snow off sidewalks around the smaller parks, several straight moldboard attachments for auto trucks, and a considerable number of large ajax scrapers, triangle plows, ice shaving machines, etc., for cleaning the fields of skating ice.

The following statement shows the cost of cleaning snow from the park driveways, the time required for carrying out the work being 3 days:

First Day (*A. M.*).—Plowing snow to the gutters from Washington Park stables to 12th St. and Michigan Ave., over the following driveways:

	Width, ft.	Area, sq. yd.	Miles
Washington Park (part)	40–50	30,000	1.20
Grand blvd. (center drive)	55	64,416	2.00
South Park ave. (35th to 33rd)	42	6,122	0.25
33rd st. (South Park to Michigan)	42	8,282	0.31
Michigan ave. (33rd to 12th)	50	67,320	2.25
	.....	176,140	6.01
Cubic yards of snow on drive, at 4 in.			19,571
Cubic yards of snow on drive, at 6 in.			29,357

For a 4-in. snowfall it is estimated that 40 horses (5 right 4-horse hitches and 5 left 4-horse hitches) will be required to plow these drives in 5 hours before noon. At the rate of $6 per 8-hour day for team and driver, the cost will be $75.

For a 6-in. snowfall it is estimated that 48 horses (6 right 4-horse hitches and 6 left 4-horse hitches) will be required. At the rate of $6 per 8-hour day for team and driver, the cost for 5 hours' work will be $90.

Cost of Plowing Snow Off Above Driveways

	Per mile of drive	Per 1,000 sq. yd. pavement	Per cu. yd. of snow
For 4-in. snowfall	$12.49	$0.427	$0.00384
For 6-in. snowfall	14.98	.512	.00307
Total cost (without overhead) for 4-in. snowfall			$75.00
Total cost ((without overhead) for 6-in. snowfall			90.00

First Day (*P. M.*).—In the afternoon half of the teams which plow from the park stables to 12th St. and Michigan Ave., in the morning will plow snow to the sides of the drives on—

	Width, ft.	Area, sq. yd.	Length, miles
Drexel Blvd. (both drives)	40*	70,224	3.00
Oakwood Blvd	50	17,060	0.50
Washington Park (part of drives)	40–50	20,000	0.80
The other half of the teams will plow..			
Garfield Blvd. (South Park to State)	40	11,733	0.50
Michigan Ave. (55th to 33rd)	50	82,228	2.75
	..	201,245	2.75

* Each.

Cubic yards of snow on drive at 4 inches	22,360
Cubic yards of snow on drive at 6 inches	33,541

The cost of the afternoon's work (5 hours) will be the same as for the morning's plowing—$75 for a 4-in. snowfall and $90 for a 6-in. snowfall. These drives will not be gone over twice, but it is intended to go over the drives between the Washington Park stables and 12th St. on Michigan Ave. twice in order to get them as clean as possible, as the first trip over the drives usually does not remove all of the snow.

COST OF PLOWING SNOW OFF DRIVES CLEANED IN THE AFTERNOON OF THE FIRST DAY

	Per mile of drive	Per 1,000 sq. yd. of pavement	Per cu. yd. of snow
For 4-in. snowfall	$ 9.94	$0.373	$ 0.00336
For 6-in. snowfall	11.93	.448	.00268
Total cost (without overhead)			$75.00
Total cost (without overhead)			90.00

Second Day (*Nine Hours' Work*).—Half of the teams will plow to the gutters on—

	Width, ft.	Area, sq. yd.	Length, miles
Garfield Blvd. (south drive—State to Western)	40–25	56,691	3.00
Garfield Blvd. (north drive—South Park to Western)	40–25	68,424	3.50
Other half of the teams will plow snow on—			
A. M.—(From park stables to 79th St. and Bond Ave.)—			
Washington Park (part of drives)	40–50	10,000	0.40
Midway (south drive)	40	21,910	1.00
Jackson Park (part of drives)	40	44,000	2.00
Yates Ave. (71st St. and Bond Ave. to 79th St.)	32–38	36,500	1.75
P. M.—In the afternoon over the following drives:			
Fifty-first St. (including Drexel Sq.)	40	31,976	0.94
East End Ave	50	18,700	0.65
Jackson Park (rest of drives in "outer" circle)	40	70.000	3.00
		358,201	16.24

Cu. yd. of snow on drive: At 4 in., 39,800; at 6 in., 59,700.

As this is a 9-hour day, the cost of plowing the snow after a 4-in. snowfall, using 40 horses, will be $135, at the rate of $6 per 8-hour day for team and driver; in case of a 6-in. snow the cost will be $162, 48 horses being used.

COST OF PLOWING SNOW OFF DRIVES CLEANED ON THE SECOND DAY

	Per mile	Per 1,000 sq. yd.	Per cu. yd.
For 4-in. snowfall	$8.31	$0.378	$0.00340
For 6-in. snowfall	9.98	.453	.00272
Total cost (without overhead) for 4-in. snowfall			$135.00
Total cost (without overhead) for 6-in. snowfall			162.00

Third Day (*Nine Hours' Work*).—One-half of the teams will plow snow to the sides on the following drives:

	Width, ft.	Area, sq. yd.	Length, miles
66th and 67th Sts. (Jackson Park to Ashland)	28	67,518	4.10
* Normal Ave	32	63,580	2.10
Other half of the teams will plow—			
Grand Blvd. (side drives)	25†	58,432	4.00‡
Washington Park (rest of "outer" circle of drives)	40–50	45,000	1.60
		234,530	11.80

* Cu. yd. of snow on drive: At 4 in., 26,060; at 6 in., 39,090. † Each. ‡ Together.

At the rate of $6 per 8-hour day for a team and driver, the cost of plowing a 4-in. snowfall, using 40 horses, will be $135; for a 6-in. snowfall the cost will be $162, 48 horses being in use.

COST OF PLOWING SNOW OFF DRIVES CLEANED ON THIRD DAY

	Per mile of drive	Per 1,000 sq. yd. of pavement	Per cu. yd. of snow
For 4-in. snowfall	$11.44	$0.576	$ 0.00518
For 6-in. snowfall	13.74	.692	.00415
Total cost (without overhead) for 4-in. snowfall			$135.00
Total cost (without overhead) for 6-in. snowfall			162.00

The above costs are based on a rate of 75 ct. per hour—$6 per 8-hour day—for a team and driver. They do not provide for finished cleaning over the various driveways of the South Park system, but cover primarily the clearing away of the "roughage" after snowstorms, such as can be accomplished by a single trip of the battery of plows over the different drives. Where two teams are used on a grader plow, the second driver operates the plow adjustments, so no laborers are necessary in such cases. As will be seen, the cost per mile for cleaning, outside of the downtown district, ranges from $8.331 per mile as the minimum for a 4-in. snowfall to $14.98 per mile as the maximum cost for a 6-in. snow, two teams being used on each grader.

In some instances but one team is used on a grader and then a laborer is required to man the plow. It has been found that this reduces the cost of a single trip, cleaning of a certain driveway, making it from $5.40 per mile for a snow of 4 to 5 in. to $7.20 per mile for a fall of from 5 in. to 1 ft., when the team hire is $6 per 8-hour day and the rate for labor is 30 ct. per hour.

Use of Tractors.—Carefully kept records show that the work of cleaning snow off drives with tractors after ordinary snowfalls can be done at a cost somewhat less than with horse-drawn machines and with them the work progresses much more rapidly, too. In breaking up packed snow and ice the tractor outfits have proved themselves particularly adapted, while they are able to pile the snow over the curbing better than horseplows, leaving the gutters open.

Operating Cost of 20-Ton Caterpillar Tractor in Snow Removal Work.—(Engineering and Contracting, March 3, 1920).

Ten Caterpillar trucks operated in Michigan during the winter of 1919–20, on duties incidental to snow removal and the keeping of state trunk line highways open for traffic. These machines equipped with a 120 hp. motor are rated as a 20-ton tractor, their weight being 13 tons. The following statement from a bulletin of the State Highway Department shows the operating costs for a 2-weeks' period for one of the tractors, used in pulling snow roller and plow:

Gasoline, 175 gal. at 25 ct.	$ 43.75
Lubricating oil, 36 qt. at 17 ct.	6.12
Grease, 3 lb. at 12 ct.	.36
Alcohol, 20 gal. at 90 ct.	18.00
	$ 68.23
Labor, 52 days at $4.00	208.00
Total	$276.23
Number of miles of road opened, 55.2.	
Unit cost per mile of road, $5.004.	

The above costs do not include fixed charges. There were no repairs or renewals during this period.

Cost of Snow Removal With Rotary Plow.—The following is from Engineering and Contracting, May 5, 1920.

A rotary snowplow has been used at Outremont, Que., in clearing the streets of snow. The plow is mounted on sleds, and is drawn by horses.

The blades are operated by a 60-HP. marine engine. The snow is pulverized by the blades and projected upward and then out through specially devised outlets. In a discussion of a report presented to the 1919 convention of the American Road Builders' Association, Capt. J. A. Duchastel, City Engineer of Outremont, gave the following data on work done by the machine in 1917–18:

In one instance the work consisted of removing a bank of snow on each side of Cote St. Catherine Road. This snow had been piled up at a distance of 10 ft. from the car track by the Montreal Tramways snow leveler. The bank was about 10 ft. wide and 1 ft. 9 in. high; the snow was very compact. The cost was worked out in the following manner:

After allowing a depreciation of 10 per cent on the cost of the machine, interest at the rate of 7 per cent, and $241 per year for repairs, it was figured that the fixed charges per day for the machine for a period of 50 working days during the season, was $14. Figuring the cost of gasoline, the time of the operator, the corporation teams and helpers, as well as the time of a grader and snowplow used in connection with this work to remove whatever accumulation of snow was deposited on the sidewalks by this machine, it was found that the cost per lineal yard of cleaning one side only was 7.65 cts. This work covered a period of 23 hours and a bank of snow 6,775 ft. long, 10 ft. wide, and 1 ft. 9 in. high, was cleared in that time. Naturally that was not continuous work.

As a parallel to this work, the cost of removing snow on the same date on another section of the same road, under exactly the same conditions, was kept, the snow being loaded by hand in sleighs and removed to a dump less than ¼ of a mile away. The cost per lineal yard was 23.7cts. This work covered a period of 10 hours and a bank of snow 950 ft. long, 10 ft. wide, and 1 ft. 9 in. high was cleared. As a check on these figures, the cost of clearing Cote St. Catherine Road by the second method in the previous year was looked up, and it was found that the cost was 27.4 cts. Probably the bank was, on the average, a little bit higher.

Cost of Loading Snow by Steam Shovel at Rochester, N. Y.—John T. Child gives the following data in Engineering and Contracting, April 7, 1920.

After snow had accumulated on the ground for over two months a local contractor put his steam shovel grader into commission and attacked the huge accumulations of snow to prove the value and desirability of a steam shovel for loading heavy snow. The results obtained are summed up as follows:

Equipment—

Keystone steam shovel with ½-yard skimmer bucket on 18-ft. boom.

Shovel Cost per Day—

Rent, including operator and fireman	$40.00
Coal, ⅓ ton at $8.75, supplied by city	2.25
2 men to release bucket and help move—hired by city	6.08
Total daily cost	$48.33

This cost is equivalent to 16 men at $3.04—the prevailing rate here when the work started. The rate is $3.36 a day now, which would reduce the equivalent to 14 men.

Working Conditions—Day shift—8 hours.

Straight work loading from a bank of compact snow 3 ft. or 4 ft. high and 8 ft. to 10 ft. wide. Motor and electric railway—traffic heavy on Main St., East, near Stillson St.

Work Done—

Loaded 155 3-yard wagons in 8 hours, or 465 cu. yd.
Cost per load, $0.314.
Cost per yard, $0.104.
Time per load, 480/155 = 3.1 minutes.
Actual loading time—2 min. 6 buckets to a load.

Corresponding Labor Costs are $0.107 and $0.12 for hand labor at the two rates.

After the successful try outs with the ½ yd. bucket the contractor purchased a 1 yd. bucket so as to speed up the loading capacity of the shovel. The first few days several moves were necessary and 30 to 40 per cent of the time was lost because there were not enough trucks available to keep the shovel busy. Under these more or less unfavorable conditions as many as 44 9-yd truck loads were easily handled at a cost of 12.2 ct. per cubic yard.

This shovel was not used early enough in the season to make any prolonged record but it has proven its value under certain conditions and undoubtedly all the available local apparatus of this kind will be listed for emergency snow work next year.

In any event, the steam shovel can be used as a substitute for men at the same cost or less. The larger bucket decreases the actual loading time, and it has several advantages over hand labor. A longer boom will be used next year to reduce the number of moves and give more clearance in loading.

The advantages of the steam shovel for snow loading may be summarized as follows:

1. It can work 3 shifts and better at night in lighter traffic.
2. It could be used to advantage with railway flat cars.
3. It will remove ice and compact snow to the pavement where hand work requires picking and breaking up of the lumps at a greatly increased cost.
4. It can load a higher and hence larger hauling unit.

Motor Trucks for Snow Removal in Chicago.—Motor trucks gave excellent service during the winter of 1917–18, stated W. J. Gilligan in a paper presented before the Western Society of Engineers. In fact, it was found that one motor truck would haul as much snow as five teams.

The following matter, given in Engineering and Contracting, April 3, 1918, is from Mr. Gilligan's paper.

The blizzard of Jan. 6, followed by the storm of Jan. 12, made it necessary for the Bureau of Streets to use methods other than those ordinarily employed. As the budget of the Bureau did not carry a provision for the employment of motor trucks in snow removal work, consent was obtained from the City Council to use motor trucks and the rate fixed at $25 for a 9-hour day. Only patent dump trucks of large capacity were used. The trucks were made up into squads of ten each, each squad being in charge of a ward superintendent, a card puncher and two subforemen. Five loaders were assigned to each truck. In that way trucks were quickly loaded and kept moving, and by working day and night shifts the principal streets in the loop were cleaned in 72 hours. For the reason that transportation lines were scouring the haunts of labor, bidding as high as $1 per hour and meals, and because of the extremely cold weather, it was difficult for the Bureau to keep men at work after it got them, and in order to compete somewhat with the other agencies that were bidding frantically for help it picked out the likely looking material, kept them for the night forces and paid them time and a half, which amounted to $3.97 for 8 hours. In addition, on the coldest nights hot coffee and sandwiches were distributed to the gangs under the direction of a hastily organized commissary department.

The employment of motor trucks in the work of snow removal has shown to the officials of the Bureau of Streets that the results obtained by their use is far superior to that of teams. The large amount of creosote block pavement in the loop made the handling of teams extremely difficult. Unskilled drivers and poorly shod horses made the task of proper maneuvering very hard, and as a consequence traffic was constantly interrupted. With motor trucks no such situations were encountered. The limited dumping spaces handy to the loop is also a strong factor in favor of the employment of motor trucks. The Graham & Morton docks at the foot of Wabash avenue is the largest loop dump, and it will accommodate about 75 teams. At the height of a snow-dumping day or night this spot was a bedlam of yelling, cursing drivers, with the work being often interrupted by staggering and falling horses. It was also necessary to shovel the snow from the tail end of the wagon into the river, while bottom dump wagons deposited their loads on the dock, making it necessary to rehandle it into the river. As many as 66 trucks, which equals 330 teams, used the Graham & Morton dock in one night, coming in and out of the dump without a minute's confusion or delay.

The labor this year was fairly plentiful and of a high caliber. The suspension of building and allied industries threw many good laborers on the market, and the Bureau was able to use them to advantage in loading trucks. The Italian laborer, who comprises 95 per cent of the regular street cleaning force, being as a rule too short and overclothed to be efficient in that kind of work, was carefully excluded from our loading forces. The rapidity with which the Bureau was enabled to handle snow with motor trucks can be judged by the record of Jan. 29, a typical night at the Graham & Morton docks, when 680 loads of snow were dumped in the river by trucks in 480 minutes, an average of one load every 45 seconds for 8 consecutive hours. It might be of interest to note that the record of delivery at the dock was distributed as follows:

Hours between	Loads
6 and 7	118
7 and 8	96
8 and 9	76
9 and 10	70
10 and 11	97
11 and 12	85
12 and 1	75
1 and 2	63

It will be noticed the number of loads decreased as the vitality of the loaders ebbed until after the time coffee and sandwiches were distributed, when it took a strong upward turn.

During the blizzards of Jan. 6 and 12 the Bureau hauled out of the loop 14,611 wagon loads of snow, or 67,202 cu. yd., together with 5,644 motor truck loads, containing 44,179 cu. yd., a total of 20,255 loads, of 111,381 cu. yd., at a cost of $61,004.11. This averaged about 54 ct. per cubic yard.

Snow Removal from Connecticut Highways.—Engineering and Contracting, Nov. 6, 1918, gives the following:

About $40,350 was expended by the State Highway Department of Connecticut for removal of snow from trunk highways in 1917. The mileage covered was 970, and, including the cost of equipment, the rate per mile was about $45. Under normal conditions of snowfall, this cost would probably have been less than $30 per mile. For its work last winter the Department planned to use 18 snow plows attached to the front of its trucks. These proved inadequate because of the unusual winter conditions, and were supplemented by tractors and road machines. On heavily traveled routes practically all the snow was removed while on mixed traffic roads about 3 in. were left. As the result of experiments made in 1917, the Department found that the removal of snow decreased the cost of bituminous repairs the following spring by at least one-third. This is accounted for by the fact that when the snow is not removed the truck traffic is confined to one or two sets of ruts, which ultimately are worn into the road surface.

Costs of Breaking Country Roads with Snow Rollers.—Charles A. French gives the following in Engineering News-Record, Nov. 23, 1918.

Snow rollers have been successfully used by the street department of Laconia, N. H., for several winters past. Four were in operation during the past winter. The rollers are 6⅓ ft. in diameter made in two sections 5-ft. long and have an effective snow-compacting width of about 12 ft. At present prices such rollers would cost $150 to $200 each. The roller weighs 4,750 lb. with nothing on it. When the snow is not too deep it can be operated with four horses and one man. The rollers are used chiefly in breaking country roads. For that purpose they are sent out when there is a snowfall of 4 in. or when a lesser depth has drifted. One man drives the four or six horses attached to the roller and others are sent to shovel when drifting occurs. Sliding places and chuck holes are roughly leveled by the shovelers, and the roller passing over compacts the snow so that it will hold up a team, and the road requires no more attention until the next storm.

An average trip requires six horses, three to four men, and they cover 12 to 15 miles in nine hours, so that, with labor at $2.75 and team with driver at $6.00 for a 9-hr. day, the cost is about $20.75 for 15 miles of road, or about $1.40 per mile. Of course the character of the snowstorm varies this cost.

In this climate if the roads are rolled after each snow or blow they build up through cuts where snow drifts so that the snow blows over the roadway and little hand labor is required. They make a hard path which is wide enough for sleighs to turn out when meeting without getting into the soft snow. Rollers also pack the snow on exposed places that would blow bare and spoil the sledding. In many places we have excellent roads on top of drifts 6 to 8 ft. deep.

In the spring, when the snow softens, some of the deeper drifts have to be cut out with a road machine mounted on runners, but it is surprising how much is saved in hand labor by the use of rollers.

CHAPTER XV

ROADS AND PAVEMENTS

References.—Additional matter on the cost of constructing roads and pavements is given in Gillette's "Handbook of Cost Data" pages 258 to 474, also in Gillette and Thomas' "Highway Construction and Maintenance." Further data on the methods and costs of excavation and grading may be found in "Earthwork and Its Cost" and "The Handbook of Rock Excavation" by Gillette.

Estimating The Cost of Paved Surfaces for Highway Improvement.—Robert E. Thomas of the Illinois State Highway Department, gives the following discussion in Engineering and Contracting, May 2, 1917.

In some instances where bonds have been issued for road building, or where such action is pending, it has been deemed advisable to conduct the program in two distinct steps: one complete issue for the grading and building of all drainage features, and at a later date, another for the construction of the paved surface. Because of the fact that such surfaces often amount to as much as 75 per cent or 85 per cent of the total financial value of the work, it is imperative that investigation should be made relative to the probable cost of this feature before any concerted action is taken. It is hoped that the following information not only will be of assistance in making such an investigation, but also will furnish a method whereby reasonable results may be obtained without a detailed consideration of every individual element.

Because of the many operations and the several ingredients necessary in constructing a paving slab, it appears feasible to divide the estimate of cost into two parts, namely, that on materials and that on labor.

Materials.—The quantities of materials necessary in building a slab of any type are calculable with comparatively slight chance of error after an inspection of the cross-section to be used, and a study of the specifications relating to the same. This is particularly true for such types as macadam (either waterbound or bituminous) or gravel, where the quantity of stone is merely the volume of the completed slab, increased by an allowance for compaction due to rolling. This allowance will vary with the condition of the subgrade, the quality of the stone and the manner of rolling, but under normal conditions will average approximately 20 per cent. The volume of stone screenings for waterbound macadam is also subject to variation, but can safely be estimated at from 15 per cent to 20 per cent of the total amount of macadam stone required. In the case of screenings for bituminous macadam, a proportionately greater quantity is necessary, and the percentage will probably vary from 20 to 25. Practically all specifications state the amount of bituminous material to be used per square yard for bituminous macadam, so no difficulty will be encountered with this item.

The materials making up a cement grouted brick pavement either with a sand or a sand-cement bed, or of the monolithic type, can be estimated by applying a few well-known principles. By reason of the size of brick usually specified for paving purposes, and the space provided for grouting, it will be found that 40 bricks are needed to cover a square yard. For the concrete base it is first necessary to determine the volume of concrete required. By an application of Fuller's Rule, or reference to tables published in any first-class book on concrete, it is possible to secure the quantities of cement, fine and coarse aggregate in a cubic yard of rammed concrete of any desired proportions. In this connection, it might be well to add that the table based upon there being 3.8 cu. ft. of cement in a barrel and 40 per cent voids in the coarse aggregate will most nearly fit average conditions. The product of the total volume in the base and the three figures obtained from the table will be the corresponding quantities of materials necessary. If a sand cushion is specified, the volume is directly obtainable from its dimensions. When the bed is to be a mixture of sand and cement, the quantities of each may be calculated, by using the proper table, in a similar manner to that described for the base. It is practically impossible to compute the quantity of sand and cement to be used for grouting, but experience has shown that a barrel of cement, in a 1 to 1 mix, will cover from 20 to 25 sq. yd. of pavement.

Cement concrete slabs present no difficulty, as the ingredients are computed identically as is the base for a brick pavement.

The materials in a wearing surface of bituminous concrete can usually be computed directly from information contained in the specifications. It may be possible so to modify Fuller's Rule as to make it applicable without gross error to mixtures of this type. The base course of a bituminous concrete pavement is usually of cement concrete or of macadam, and can readily be analyzed by the methods already given.

Undoubtedly some allowance should be made for loss of materials in handling and in transporting, and although a fixed percentage may be greatly in error for any particular case, it is thought that from 5 per cent to 10 per cent for coarse and fine aggregate will represent good practice.

When the estimated quantity of all material has been computed, prices of each F.O.B. the railroad station or siding nearest the improvement site should be obtained. Simple calculation will then permit the total material estimate to be reduced to a square yard basis.

In the foregoing discussion no mention has been made of water, a very important factor not only physically, but, in many instances, financially as well. The availability and cost of water is so affected by local conditions that but few generalities are possible. However, it can be safely stated that a pipe line laid along the right-of-way, supplied by water from nearby streams or driven wells, through the medium of a small pump, will prove uneconomical on types of roads other than those involving the use of cement concrete. When this method is proposed, some use has been made of various formulæ for estimating the cost. On macadam and gravel roads where water is applied in conjunction with the rolling, it is customary to haul the water in sprinkling wagons, and in such cases it is usually secured by pumping from streams or from neighboring farm wells. The cost by either method is incurred mostly by labor, and has been provided for in the data under that division.

Table I has been compiled with the object of giving some idea relative to the amounts of materials in highway surfaces regulated by specifications of proven satisfaction.

Labor.—It has been found by combining the estimated cost of the various operations involved in constructing slabs of different types for highway improvement, that the total labor cost, including the team haul on materials, for any rate of labor, or for any length of haul, may be expressed in terms of an equation:

$$P = ALH + BL + CH + D$$

where,

P = total labor cost per square yard in cents.
H = length of average haul in miles.
L = index number representing labor and team rate per hour.
A-B-C-D = constants for a particular type of slab.

TABLE I.—QUANTITIES OF MATERIALS PER SQUARE YARD OF PAVEMENT

	Brick (sand cushion)	Brick (sand-cement bed)	Brick (monolithic)	Cement concrete	Bitu. concrete, concrete base	Bitu. concrete, macadam base	Bituminous macadam	Water-bound macadam	Gravel
Brick, No.	40	40	40	....	....	....	....	....	....
Cement, bbl	.147	.188	.169	.313	.111	....	....	....	....
Bitumen, gal	....	....	....	....	2.55	2.55	2	....	....
Sand, cu. yd	.092	.087	.070	.092	.094	.037	....	....	....
Screenings, cu. yd	....	....	....	....	....	.042	.068	.060	
Gravel, cu. yd	.099	.099	.099	.161	.167	....	....	....	.240
Broken stone, cu. yd	.099	.099	.099	.161	.167	.250	.270	.272	....
Filler, lb	....	....	....	....	9	9	....	....	....

The quantity "P" in this equation is graphically represented by the ordinate to a warped surface that had first been defined and located by computing the total labor cost for all limiting conditions. The equation was derived through the assumption of a straight line variation between the computed limits, and this theory has been corroborated by comparison with a number of actual cases.

It was deemed advisable to indicate the labor and team rate by an index, as the numbers involved would be smaller and calculation therefore facilitated. For rates other than are represented in Table II the corresponding indices may be determined by proration.

The estimating data used in establishing the various constants for A, B, C and D, as shown in Table III, are entirely trustworthy for conditions as those existing in Illinois, and have been used for the guidance of bidders on a vast amount of highway work.

TABLE II.—INDICES FOR VARIOUS LABOR RATES

Labor per hr., cts.	15	17½	20	22½	25	27½	30	32½	25
Teams per hr., cts.	30	35	40	45	50	55	60	65	70
Index No. "L"	0	1	2	3	4	5	6	7	8

TABLE III.—CONSTANTS FOR VARIOUS TYPES OF PAVED SURFACES

Type—	A	B	C	D
Brick: Sand-cement bed or sand cushion	.9633	4.082	5.779	29.494
Monolithic brick	.9051	3.172	5.431	24.032
Cement concrete	.8341	2.909	5.005	23.452
Bituminous concrete, concrete base	.7481	4.353	4.488	30.120
Bituminous concrete, macadam base	.8646	3.664	5.187	22.985
Bituminous macadam	.9189	2.832	5.513	17.992
Water-bound macadam	.8450	2.281	5.070	13.689
Gravel	.6900	1.635	4.140	9.810

Finally, to obtain the total estimated cost per square yard for the slab, it is only necessary to combine the two costs as determined for materials and labor.

It must be remembered that no provision has been made, as yet, for profit, so before a final figure is established, an allowance should be made for this item that is entirely commensurate with the work to be done.

As an example, assume that for a particular case it is proposed to improve 4 miles of graded and drained roadway by the addition of a cement concrete slab. Sand and stone are available F.O.B. a railroad siding 1 mile from the nearest end of the improvement at $1 per cu. yd., and cement under the same conditions at $1.65 per barrel net. Assume, furthermore, that the prevailing rates are 20 ct. per hour for labor and 40 ct. for teams. An analysis to determine the probable cost per square yard could be conducted some what as follows:

Materials:	
.313 bbl. of cement at $1.65	$0.52
.092 cu. yd. of sand at $1	.09
.161 cu. yd. of stone at $1	.16
	$0.77
Profit	.08
Total for materials	$0.85
Labor:	
H = 3 B = 2.909	
L = 2 C = 5.005	
A = .8341 D = 17.452	
P = (.8341 × 2 × 3) + (2.909 × 2) + (5.005 × 3) + 23.452 = 5.0046 + 518 + 15.015 + 23.452	$0.49
Profit	.10
Total for labor	$0.59
Total estimated cost for the slab, $1.44 per sq. yd.	

There are several items such as depreciation and repairs on machinery, the cost of which is directly traceable to the slab or metaled way, but which has not been included heretofore. Rather than reduce these items to a yardage basis, it is more satisfactory to provide a lump sum covering the whole improvement.

Cost of Maintenance of Road Building Outfits (Engineering and Contracting, June 4, 1913).—During the years 1908–1912 the Illinois Highway Commission built 1,022,159 sq. yds. of experimental roads. Of this total 397,244 sq. yds. were bituminous macadam. The 1912 report of the commission gives the following data on the cost of maintenance of the road outfits, owned and operated by the commission for the construction of the experimental roads:

Cost of 11 macadam outfits	$37,579
Cost of 6 bituminous outfits	6,628
Cost of 2 concrete outfits	5,381
Total	$49,588
Cost of maintenance of macadam outfits	$ 3,272
Cost of maintenance of bituminous outfits	1,273
Number of outfit seasons covered by maintenance charges on macadam outfits	52
Number of outfit seasons covered by maintenance charges on bituminous outfits	12
Cost per season for outfit for maintenance of macadam outfits	$ 61.80
Cost per season per outfit for maintenance of bituminous outfits	106.00
Cost per sq. yd. for maintenance of macadam outfits	0.003
Cost per sq. yd. for maintenance of bituminous outfits	0.003

Depreciation Charges on Road Building Equipment.—According to Engineering and Contracting, Sept. 3, 1919, the regulations governing work of the State Highway Department of Arizona provide that upon completion of a project depreciation shall be charged to the project, the equipment being rated on the following basis:

	Per cent per year
Engines, gas and steam	20
Fresnos	100
Graders	20
Mixers, concrete	20
Mules	10
Pile drivers	20
Plows	20
Rock crushers	20
Steam shovels	10
Tents	75
Wagons	20
Wheelbarrows and concrete carts	50

Trucks on daily rate on basis of life of three years. All small equipment such as picks, axes, shovels, etc., on value at time of transfer to new project. The following data, are from Engineering and Contracting, Jan. 3, 1917.

With the exception of mules, the life of the equipment is not solely dependent on the lapse of time. The length of the road building season, the continuity of the work and the care given in handling and maintenance, are all important factors in determining the life.

As for tents, it is not unusual to have them whipped to ribbons by strong winds in three months or less. On the other hand, if used only in dry weather, and where winds are not high, a tent may last several road building seasons.

In this connection it seems wise to point out that annual depreciation rates, such as those above given, are often assumed to include current repair costs, although usually the depreciation rate is intended to relate solely to the loss of life of the entire machine and not to loss of life of its parts. Railway locomotives, for example, have had an average life of about 25 years, or a straight-line depreciation rate of 4 per cent per year, assuming no scrap value. But the current repairs on railway locomotives have averaged about 18 or 20 per cent per annum.

Apparently the rates of annual depreciation above given do not include current repairs. Yet, if not, why is the annual depreciation of a steam engine put as high as 20 per cent? A steam engine will surely last as long as a steam shovel, yet the latter is given a depreciation rate of 10 per cent.

The fact is that not a great deal has been published on the lives and maintenance costs of construction equipment. Dana's "Handbook of Construction Plant" gives data on this subject. The startling fact is brought out there that for one year (1908) repairs on steam shovels on the Panama Canal amounted to nearly 50 per cent of their first cost! This was equivalent to nearly 3 cts. per cubic yard excavated. This, of course, was under unusually expensive conditions and where the work was continuous. Dana puts the average life of a steam shovel at 20 years.

In calculating depreciation and repairs, it is usually desirable to separate the two. Estimate depreciation for the full years, but estimate repairs by the month of actual work. Thus, in the case of a steam shovel, the annual depreciation may be estimated at 6 per cent, and the repairs may be estimated at 2 per cent per month of single-shift work. Then if it is estimated that the shovel will actually work six months during a year, the depreciation amounts to 1 per cent and the repairs 2 per cent per month of actual work.

Roadbuilding equipment averages less than 6 months' actual work in the northern states—probably about 4 months. This runs up the interest and depreciation charges per month of actual work. Thus, with annual interest at 6 per cent and depreciation at 12 per cent, we have 18 per cent for the year, or 4.5 per cent per working month if charged entirely against the working time. Add to this, say, 2.5 per cent for repairs, and we have a total of 7 per cent per working month for interest, depreciation and repairs.

Many a road building contractor has "gone broke," and many a highway engineer has erred grievously in his cost estimates, through failure to estimate correctly fixed charges and repairs on road building equipment. Add to this sort of underestimate one or two others of similar nature, and we have an almost complete explanation of why a new crop of road-building contractors buds forth each spring only to wither permanently each autumn.

Costs of Grading in Earth Road Construction.—The following is given in a U. S. Dep't of Agriculture bulletin on "Earth, Sand, Clay and Gravel Roads" prepared by Charles H. Moorefield of the U. S. office of Public Roads and abstracted in Engineering and Contracting, April 18, 1917.

TABLE IV.—GRADING MACHINE WORK

Assumed conditions: Original cross section flat; team to consist of six to eight well-trained horses; no material moved longitudinally.

Character of soil	Cost per mile
Light prairie, free from stumps, roots, etc.	$ 60 to $ 80
Average clay loam	100 to 150
Heavy clay, moderate amount of sod and roots, plowing necessary throughout	200 to 250
Heavy clay, exceptionally difficult conditions	From $250 up
Crowning and shaping road which has been graded with scrapers, etc.	50 to 75

TABLE V.—EXCAVATION AND EMBANKMENT

Assumed conditions: All material to be loosened with plows or by blasting, and to be moderately dry when handled. Hauling to be done by means of drag scrapers, wheeled scrapers, or wagons.

Kind of material	Average haul length, feet	Method of hauling	Average cost per cubic yard, cents	Remarks
Light sandy loam, free from roots, etc.	50	Drag scrapers	10 to 15	Material assumed to be such that little or no plowing is necessary.
	100	Drag scrapers	12 to 20	
	300	Wheeled scrapers	16 to 25	
	1,000	Wagons	25 to 40	
Average clay loam free from roots, etc.	50	Drag scrapers	15 to 20	Material such as to be loosened with plow drawn by two horses.
	100	Drag scrapers	17 to 25	
	300	Wheeled scrapers	23 to 35	
	1,000	Wagons	32 to 50	
Heavy clay	50	Drag scrapers	18 to 25	Four horses required for plowing.
	100	Drag scrapers	21 to 30	
	300	Wheeled scrapers	28 to 38	
	1,000	Wagons	40 to 55	
Hard pan or loose rock.	300	Wagons	40 to 65	Low prices apply where material may be loosened with 4 horses and hardpan plow. High prices where blasting is necessary.
	1,000	Wagons	45 to 75	
Solid rock	300	Wagons	$0.65 to $1.50	High prices apply where stone is hard and excavation shallow.
	1,000	Wagons	.75 to 1.75	

Tables IV and V are intended to furnish a rough guide in making estimates of grading cost at a flat rate per cubic yard. They are based on labor at 15 cts. per hour; horses at 12½ cts. per hour. The depreciation of grading equipment and repairs are figured at 5 per cent per month while in use, and it is expected that the force will be organized economically and managed efficiently.

Cost of Small Steam Shovel Work in Road Grading, California.—J. E. Bonersmith, gives the following in Engineering and Contracting, July 19, 1916.

The work described was on the California State Highway between Tormey and Eckley in Contra Costa County, California, and was done in 1915. The road graded was four miles in length and contained 72,000 cu. yd. of excavation through a rather rough country. The material consisted of earth, soft and hard shale.

The method of work was as follows: After the culverts were constructed, two fresno gangs (each gang having a six-horse plow and from four to six fresnos) were started and made the fill over the culverts; also moved the dirt in all cuts where the hauls were 200 ft. and less. A Model 31 Marion Revolving Shovel followed the fresno gangs and loaded all the material that had to be hauled into dump wagons. The number of wagons varied from six to twelve. Behind the steam shovel, a small fresno with four muckers did all the finishing work.

The road was graded to a width of 21 ft. and through the thorough cuts the shovel had to turn through a full 180°. On this work, the average output of the shovel for an 8-hour day was 375 cu. yd., as there was considerable loss of time in spotting the wagons; but where the shovel was only going through 90°, it handled 510 cu. yd. The local water was the cause of some delay and since the water is a very serious question in the cost of equipment on any job, we now make it a rule to have the water analyzed and the proper boiler compound on hand before the shovel starts to work.

Costs to job in day rentals: Horses rented to job at $1.25 per working day; fresnos, wagons, etc., at $0.25 per working day; wagon and fresno drivers at $2.50 per day; Marion steam shovel, including fuel, runner, etc., $50 per day. These costs of equipment are used on all our work as we have found from many years of experience that it is the only way we can arrive at a true cost. Take the shovel as an example; its rental is based on the following charges:

First cost, $8,200; life of shovel, 1,000 working days in six years; cost per day	$ 8.25
6 per cent interest on $8,200 for three years, $1,476; interest per day	1.48
Repairs (when the shovel is broken down the engineers', firemen, etc., time is charged to repairs), per day	2.00
Freight, knocking down, etc. (this cost was arrived at by cost kept on another shovel), per day	3.00
Fuel, ¾ ton of coal per working day at $12 per ton	9.00
Water wagon with four horses and driver, per day	7.75
Water and oil, per day	.85
Engineer per day	6.75
Fireman, per day	3.00
Two pit men at $2.50 per day	5.00
Incidentals	2.92
Total cost per day	$50.00

Following is the total cost of the above mentioned grading of the State Highway between Tormey and Eckley:

Horses, 8,756 days at $1.25 per day	$10,945.00
Equipment, 1,842 days at 25 ct. per day	460.50
Driver labor, 1,842 days at $2.50 per day	4,605.00
Steam shovel 104 days at $50 per day	5,200.00
Foreman 120 days at $5 per day	600.00
Timekeeper 4 months at $75 per month	300.00
Muckers and slopers, 500 days at $2.25 per day	1,125.00
Muckers, slopers, etc. 212 days at $2 50 per day	530.00
Purchases (picks, shovels, lanterns, oils, etc.)	182.60
Insurance	280.00
Total cost	$24,248.10
Cost per cu. yd	$ 00.3367

Costs on Street Grading with a Steam Shovel, in Minneapolis, Minn.—Fred T. Paul gives the following data in Engineering and Contracting, June 7, 1916.

The work under consideration was done by force account in 1915 under the City Engineer's Department, W. J. Walsh, Acting Engineer in charge. The material moved was a conglomerate with a medium fine sand predominating. The cut was from 2 to 15 ft. deep, 70 to 80 ft. wide, and about 3,500 ft. long. A Marion-Osgood No. 18, ¾-cu. yd. traction steam shovel placed the material in ordinary 1½ cu. yd. dump wagons, and these in turn deposited it in the fills on the street, making an average haul for the job of 1,000 ft.

The work was started June 12 and finished on Aug. 20, covering a period of 55 full working days of eight hours each, and five part days. On these part days, little, if any, dirt was moved, but the engineer, foreman, fireman, watchman and timekeeper received full time—while the laborers and teams were given only part time. A total of 21,500 cu. yd. of material were handled in the 55 full days, making an average day's output of 391 cu. yd. The maximum was reached during five days in the heaviest cut when 611 cu. yd. per day was moved.

The total material cost of the job was $199.56, distributed as follows:

27.45 tons of soft coal at $5.05 per ton	$ 138.62
50 gal. steam cylinder oil at $0.294 per gal	14.70
Blacksmith repairs	17.64
New shovel parts	.82
Miscellaneous, including waste, packing, hose, grease, etc	27.78
	$ 199.56

The average daily pay roll was as follows;

1 foreman at $4 per day	4.00
1 engineer at $6 per day	6.00
1 fireman at $2.50 per day	2.50
1-20th timekeeper at $4 per day	.20
1 watchmad at $2.50 per day	2.50
2 laborers on dump at $2.50 per day each	5.00
2 laborers in pit at $2.50 per day each	5.00
1 laborer on coal and water at $2.50 per day	2.50
6 laborers straightening and leveling up at $2.50 per day each	15.00
7 teams on dump wagons at $5 per day each	35.00
Total average daily payroll	$ 77.70
Grand total payroll for sixty days	4,553.61
Total material as above	199.56
Interest and depreciation on plant	70.00
	$4,823.17

DISTRIBUTION AND UNIT COSTS

	Amount	Per cu. yd.
General—		
Foreman. 60 days at $4	$ 240.00	$0.01116
1-20th timekeeper, 60 days at 20 cts	12.00	.00056
Total general	$ 252.00	$0.01172

EXCAVATING AND PLACING MATERIAL IN WAGONS

Labor—		
Engineer, 60 days at $6	$ 360.00	$0.01674
Fireman, 60 days at $2.50	150.00	.00698
Watchman, 60 days at $2.50	150.00	.00698
2 pit laborers 58 days at $5	290.00	.01349
Laborer on coal and water, 58¼ days at $2.50	145.61	.00676
6 laborers on cleanup, 58 days at $15	870.00	.04047
Total labor	$1,965.61	$0.09142
Material and supplies as above	199.56	.00928
Interest and depreciation on plant, 10½ per cent on $4,000 for 60 days	70.00	.00325
	$2,235.17	$0.10395

HAULING, INCLUDING PLACING IN DUMP

7 teams, 58½ days at $35	$2,046.00	$0.09516
2 laborers, 58 days at $5	290.00	.01349
	$2,336.00	$0.10865
Grand totals	$4,823.17	$0.22432

Based on the total cost of moving 21,500 cu. yd. an average distance of 1,000 ft., the cost per cubic yard hauled 100 ft. would be .0221. However, the actual hauling cost per cubic yard per 100 ft. was only .0108.

Steam Shovel Excavation in Shallow Cut for Road.—Engineering and Contracting, June 21, 1916, gives the following:

A road grading cut 1.6 miles long and nowhere exceeding 18 in. in depth was made Oct. 1 to Dec. 10, 1915, or in 54 days, for a brick on concrete base pavement on Ocean Ave., Deal, N. J. The total amount of excavation was 30,000 cu. yd. The shovel used was Bucyrus with ⅝-cu. yd. dipper, and between the dates named it excavated 17,704 cu. yd. Working a 10-hour day, the greatest yardage was 477 cu. yd.; the average yardage, excluding lost time, was 33 cu. yd. per hour. During the 54 working days 25½ hours were lost, due to rain or other causes. Some partial records were as follows: In 9 days two blocks 700 ft. long and 50 ft. wide were cleaned up. Again, in one week, in a cut running from 9 to 18 in. deep, an advance of 200 ft. per day was registered, or an average of about 350 cu. yd per day. The haul averaged about a half mile. The shovel had to wait for wagons at times from two to three minutes.

Methods and Costs of Constructing Three Sections of Sand-clay Road.—Engineering and Contracting, April 28, 1915, publishes the following:

The work considered is three sections of sand clay "object lesson" road built in 1912 in North Carolina. The construction methods are described and the costs are computed from data given in the Report for 1913–14 of Joseph Hyde Pratt, State Geologist, North Carolina.

The first section of road extends from Calypso, N. C., southeast toward Kenansville. The adjacent land is slightly rolling and the soil is sandy throughout the length of the section. The grading consisted in plowing the ditches and bringing the road to the proper cross-section with a road machine. A small amount of material was moved for an average distance of 50 ft. with drag scrapers. For 1,650 ft. the road was graded 24 ft. wide and surfaced 14 ft. wide, making the area graded 4,400 sq. yds. and the area surfaced 2,563 sq. yds. The crown of the finished roadway was three-fourths inch to 1 ft. Clay to the amount of 248 cu. yds. was hauled an average distance of 2,400 ft., and 55 cu. yds. of sand was hauled an average distance of 1,760 ft. Farm wagons having an approximate capacity of 1 cu. yd. were used for hauling both sand and clay. They were loaded and unloaded with shovels. Two corrugated-iron culverts were ordered for this work, but were not received before the surfacing was completed.

The equipment consisted of 1 road machine, 1 rooter plow, 1 turn plow, 1 split-log drag, 2 drag scrapers, 1 disk harrow, farm wagons, and hand tools Labor cost $1 and $1.50 per day and teams cost $1.20 and $2.50 per day. The cost of grading and shaping 4,400 sq. yds. of subgrade was $3,860 or 0.88 cts. per square yard. The costs for 2,563 sq yds. of surfacing proper were as follows:

Item	Cost
Loading sand	$ 3.75
Hauling sand	6.25
Spreading sand	1.50
Loading clay	22.65
Hauling clay	49.25
Spreading clay	5.50
Mixing clay and sand	4.80
Final shaping with drag	1.60
Total	$ 95.30
Add grading	38.60
Grand total	$133.90
Cost per square yard, 5.21 cts.	

The second section constructed extends from Cooleemee northeast to Jerusalem, N. C. The land adjacent to the road is rolling and the soil varies from "black-jack" gravel to micaceous clay. This road had been graded to a width of 24 ft. in cuts and 18 ft. in fills, and the drainage structures were all completed before the object-lesson work was begun.

The sand for use in surfacing was loosened with plows, loaded with hand shovels, hauled approximately 1¼ miles in slat-bottom wagons, and spread with grader and by hand. The subgrade prepared for surfacing was 20,020 ft. long and 16 ft. wide, making a total area of 35,590 sq. yds. The same area was given a sand-clay surface 6 ins. thick after compacting, with a crown of ¾ in. to 1 ft. For the surfacing 4,820 cu. yds. of material were used, about 3,000 cu. yds. of which were purchased. The wages per day were labor $1.25, and teams $3. The costs were:

Item	Cost
Loading sand at 6.05 cts. per cu. yd	$ 291.61
Mixing surfacing at 0.1 ct. per sq. yd	37.25
Shaping at 0.15 ct. per sq. yd	53.25
Spreading sand at 1.37 cts. per cu. yd	66.00
Hauling sand at 25.46 cts. per cu. yd	1,227.00
Sand pits	105.25
General expense	19.25
Total	$1,799.61
Per square yard, 5.06 cts.	

The cost of superintendence, which is included above, was 6.33 per cent of the total cost.

The third section of road was constructed in Lexington, N. C. The adjacent land is rolling and the natural soil is clay of a plastic nature, but lacking in toughness. The first work was grading. The earth was loosened by a traction engine and a road plow; loaded and hauled with drag scrapers, wheel scrapers, and wagons, and spread with shovels. The maximum cut was 4 ft. and the maximum fill 3 ft. The maximum grade was reduced from 3 per cent to 1 per cent.

The equipment consisted of three No. 2 wheel scrapers, six No. 2 drag scrapers, two plows, three 1½-cu. yd. dump wagons, one 12-HP. traction engine, picks, shovels, etc. The average haul for excavation was 150 ft. and the maximum haul 400 ft. The sand mixed with the clay for surfacing was obtained from a pit and hauled for an average distance of 3 miles in 1-cu. yd. slat-bottom wagons. The quality of the sand was excellent for the purpose for which it was used. Free labor cost $1.25 and $1.50, and foreman $3 per 10-hour day. Convict labor was estimated at $1 per day, and teams cost from $2 to $3 per day.

The total length graded was 3,000 ft., and the width graded, both in cuts and fills, was 30 ft., making the total area graded 10,000 sq. yds. The entire length of 3,000 ft. was surfaced for a width of 18 ft., making the area surfaced 6,000 sq. yds. The compacted depth of surfacing material was 4 ins. and the crown ¾ in. to 1 ft. The earth excavation amounted to 3,975 cu. yds., and the sand used for surfacing amounted to 815 cu. yds. The cost of the work was:

Item	Cost
Excavation at 11 cts. per cu. yd.	$ 440.35
Hauling sand at 80 cts. per cu. yd.	652.00
Spreading at 1.6 cts. per cu. yd.	12.75
Mixing sand and clay	60.60
Sprinkling	6.00
General expenses	5.75
Total	$1,177.45
Per square yard, 19.6 cts.	

Methods and Cost of Constructing a Sand-Gumbo Road in Nebraska.—Engineering and Contracting, Feb. 4, 1914, gives the following data, taken from Bulletin No. 53 issued by the U. S. Department of Agriculture.

On August 19, 1912, work was resumed on the construction of the sand-gumbo road extending northwest from the Platte River toward Columbus, Neb. A section of road 3,002 ft. long was added to the section constructed during the fiscal year 1912. The roadbed was graded to a width of 32 ft. in cuts and 24 ft. on fills. A sand-gumbo surface 16 ft. wide was constructed having an area of 5,337 sq. yds. The section was completed on Sept. 4, 1912.

Earthwork.—The maximum grade was reduced from 13.2 per cent to 4.4 per cent. The adjacent land is level and the soil is sandy. The earth was loosened with plows and hauled in drag, Fresno and wheeled scrapers. The average haul was 160 ft. and the maximum haul was 350 ft. In the excavation 760 cu. yds. of earth were moved and the maximum cut was 1.3 ft. and the maximum fill 2.7 ft.

The construction outfit consisted of 4 drag scrapers, 2 Fresno scrapers. 1 wheeled scraper, one 8-horse road machine, 1 steel road drag, 1 plow, 1 disk harrow, 1 spike harrow and the necessary hand tools. Labor cost $2 and teams $4 per 10-hour day. Table VI gives the cost of the earthwork.

TABLE VI.—COST OF EARTHWORK FOR SAND-GUMBO ROAD IN NEBRASKA

Item—	Amount	Unit cost per cu. yd	Unit cost sq. yd. wearing surface
760 cu. yds. excavation	$120.00	$0.158	$0.0225
Shoulders and ditches	46.40	.....	0.0088
5,337 sq. yds. shaping subgrade	28.20	.....	0.0052
Miscellaneous	1.40	.....	0.0002
Superintendence	4.20	.....	0.0008
Total	$200.20	.....	$0.0375

Materials and Methods Used in Making Wearing Surface.—The surfacing material consisted of a good quality of black gumbo and sharp clean sand. The gumbo was spread to a depth of 7½ ins. and the sand to a depth of 6 ins., both measured loose. The two materials were then mixed by means of plows and harrows and shaped with a steel drag and a road machine. The compacted depth of the finished surface was 8 ins. and the crown was ¾ in. per foot. In this work 1,165 cu. yds. of gumbo and 890 cu. yds. of sand were used. The gumbo was hauled approximately 2 miles in slat bottom dump wagons having a capacity of 1 cu. yd. The sand was hauled a distance of 4,000 ft. in the same wagons. The cost of the wearing surface was as given in Table VII.

TABLE VII.—COST OF SAND-GUMBO WEARING SURFACE FOR A ROAD IN NEBRASKA

Item—	Amount	Unit cost per cu. yd.	Unit cost sq. yd. wearing surface
Purchase of gumbo pit	$ 41.35	$0.035	$0.008
Loading gumbo	180.40	0.155	0.034
Hauling gumbo	698.80	0.600	0.131
Spreading gumbo	34.00	0.029	0.006
Loading sand	93.60	0.105	0.018
Hauling sand	299.00	0.336	0.056
Spreading sand	10.60	0.012	0.002
Mixing sand and gumbo	37.20	0.018	0.007
Shaping	4.00	.....	0.0025
Rolling	13.60	.....	0.001
Miscellaneous	12.60	.....	0.002
Superintendence	37.80	.....	0.007
Total	$1,462.95	.....	$0.2745

The following is a summary of the cost:

	Amount	Unit cost per sq. yd. wearing surface
Earth work	$ 200.20	$0.0375
Wearing surface	1,462.95	0.2745
Total	$1,663.15	$0.3120

Data on the Construction of 23 Sand-Clay Roads.—Table VIII, taken from Engineering and Contracting, Jan. 17, 1912, is based on data given in the annual report of Logan Waller Page, Director of the Office of Public Roads, for the fiscal year ending June 30, 1911.

TABLE VIII.—SOME DETAILS OF THE CONSTRUCTION OF 23 SAND-CLAY OBJECT LESSON ROADS

Place	Length surfaced, ft.	Width surfaced, ft.	Grading, cu. yds.	Cost grading, per cu. yd., cts.	Depth surfacing laid, ins.	Surfacing used, cu. yds.	Cost of hauling surfacing, including loading, etc., per cu. yd., cts.	Cost of spreading surfacing, per cu. yd., cts.	Total labor cost surfacing, per sq. yd., cts.	Grand total, including grading, etc., per sq. yds., cts.	Laborers, per 10-hr. day.	Team with driver, per 10-hr. day.
Mobile, Ala.	3,000	16	360	38.8	6	708	43.3	5.9	6.5	11.1	$1.50[1]	$4.00[1]
Vernon, Fla	5,280	16[2]	2,400	15	6	856	....	....	3.4	7.1	1.50	2.00[3]
Chalybeate Springs, Ga	2,100	16	1,752	8.8	7	444	....	....	...	17.4	.50[4]	1.00[5]
Eastman, Ga	6,200	30	5,395	9.3	..	.....	....	1.4	...	4.1	.36[4]	.45[5]
Lumber City, Ga	5,280	16	1,538	11.1	8	2,115	26.5	4.8	7.1	10.6	1.25[6]	.75[7]
Reidsville, Ga	5,280	16	.....	.....	..	2,870	....	....	3.8	4.75	.30[4]	1.30[8]
Washington, Ga	.....	15	.....	.....	8	1,640	5.15	.26	1.2	2.3	.30[4]	1.20[8]
Mullinville, Kan	3.640	14	3,635	11.2	12	1,758	31.4	1.6	...	18.4	1.80[1]	3.60[1]
Wichita, Kan	2,640	16	950	15.5	10	950	...	....	7.6	14.2	2.00[9]	4.50
Coffeeville, Miss	5,280	..	3,410	20.8	..	148	42	4.7	...	13.7	1.00	2.50
Gulfport, Miss	2,640	50	4,500	35	..	1,759	49.5	24.4	...	24.3	1.00	3.00
Elizabeth City, N. C	5,280	..	1,208	21.6	..	.....	....	....	...	3.31	.60[4]	1.00
Morehead City, N. C	1,200	14	.....	.....	6	311	30.3	2.1	6.6	11.9	....	....
Williamston, N. C	3,000	16	3,471	23.1	..	622	39.4	1.6	4.8	27.5	1.00	2.50[3]
Wilson, N. C	4,300	16	1,387	15.7	8	.....	62.4[10]	.8	10.7	16	.60[4]	4.00
Carnegie, Okla	8,800	14	3,352	8.8	..	3,156	25.5	3.22	10.8	20.34	1.60[9]	2.80[9]
Cordell, Okla	4,500	16	.....	.....	6	2,666	....	....	2	5.8	.18[4] [1]	.85[1]
Aiken, S. C	5,255	30	315	14	8	1,000	....	.04	...	2.3	.40[4]	1.00
Allendale, S. C	3,070	22	350	12	10	.....	....	....	...	33.6	.50[4]	.75[8]
Kingstree, S. C	800	20	.....	.....	..	345	23.5	1.8	5.7	6.3	5.00[11]	....
Waterloo, S. C	5,280	..	3,654	6.06	..	1,630	20.2	1.4	...	10.28	.50[4]	1.00
Center, Tex	2,300	30	1,225	15	..	.....	23.2	1.4	...	8.7	1.50	3.50
Livingston, Tex	1,100	12	184	20	9[12]	500	30.8	2.0	...	15.00	1.50	3.50

[1] 9-hour day. [2] 3,820 ft., 16 ft., 1,700 ft., 30 ft. [3] Without driver. [4] Convict labor. [5] Mule teams. [6] For free labor, 60 cts. for convicts. [7] Prison camp teams. [8] County teams. [9] For 8-hour day. [10] Include stripping. [11] Per hour, convicts; 10 cts. per hour for teams. [12] 9 in. to 12 in.

Macadam Road Construction Using Industrial Railway for Hauling.— R. P. Mason gives the following matter regarding the construction of a macadam road about 9.5 miles long in Delta County, Mich., in Engineering and Contracting, April 7, 1915.

The hauling outfit consisted of a 30 HP. locomotive and 50 Koeppel side dump cars. There was also one track laying car which carried the track, which consisted of 15 ft. sections of 24 gage track, 20-lb. rails, with 7 steel ties to the section. In all there were 4 miles of track with necessary curves and switches.

Cars were loaded with 1¼ cu. yds. of stone which when dumped at a standstill just made one course of large stone. The haul averaged 3½ miles each way and, at first, with 20 cars, 8 trips were made per day. After the operation was running smoothly 25 cars were handled on each trip.

The stone was spread with road machine hauled by 2 teams. Unloading the stone took about 10 mins. and the machine finished the spreading while the train made another trip. Very little dressing with rakes put the surface in A1 condition for rolling and the machine spreading gave a uniform distribution and smooth roadway. However, it is only by handling a large volume of stone per day that this system can be made profitable. It is necessary that all units of the force be proportioned and kept busy and as it takes two teams to handle the road machine it is essential that they have enough stone to make it an object.

After the preliminary rolling a train of screenings was poured from the train in motion, making a windrow near the track sufficient to cover the course and spread by hand. This pouring, with the help of the spreaders, took about the same time as dumping the stone.

Three 10-ton rollers worked constantly and by utilizing all the lost time of the train due to bad weather, moving, and shortage of stone and occasionally working nights, they were able to keep up their end. Two sprinklers, filled by a gas rotary pump, were used and, as the water was convenient along the road they furnished abundance and it was not always necessary to work them both.

All the ordinary hazards of road building entered into this job, wet weather, soft subgrades and a number of railroad crossings which meant delay as well as extra expense for watchmen. A hill 5.1 per cent, 1,000 ft. long with a 16° curve about the center made it necessary to put in a spur at the foot and take the train up in two or three sections. As this work was entirely new to this locality an entire crew had to be broken in and it is evident that costs can be materially lessened in the future, now that the organization is complete. The fastest mile was laid in six days towards the end of the season, compared with the first mile on the same haul which took fourteen days. The crew required was about as follows:

Loader	4 men
Train	2 men, engineer and brakeman
Spreading	2 teams and teamsters
Spreading	5 to 7 men
Rolling	3 men
Sprinkling	2 teams and teamsters
Foreman	1
Watchmen	1 or more
Tracklaying	4

Wages were $2 per day for laborers, $5 for teams with teamsters, $3 for rollermen, engineer, $90 per month.

Compared with team haul the method described shows a saving of about 30 cts. per cubic yard, or nearly $700 per mile. We also saved 39 cts. on our stone and 10 cts. on the unloading, making a total of about $1,800 per mile over previous prices. The saving on haul alone would be more marked on a longer haul. We also used the outfit in grading where material had to be moved some distance and found it extremely convenient and economical. Another very decided advantage of road building by this method is seen in the fact that there is no hauling over the road during construction and it is opened to traffic in perfect condition. It is also easier to keep the subgrade from being cut up and therefore takes less stone for a given thickness.

The costs in Table IX include everything that is a proper charge to the work, the cost of moving outfit from one point to another, laying up, and tracklaying includes taking up as well. Loading includes setting up loader and in one case building a siding 1,000 feet long. The number of watchmen makes the hauling cost high; a greater output will cut down the spreading and the overhead in this case is high on account of the short season.

TABLE IX.—MACADAM COST SHEET, DELTA COUNTY, MICHIGAN

No. of days worked	93
Miles of finished road	9.44
No. yards stone used	21,920
No. yards stone used per mile	2,310
No. days to build mile of road—average	9.4
No. yards stone per day	236
Cost of tracklaying per mile of finished road	$108.10
	Cost per cu. yd.
Cost of stone at our siding	$ 0.860
Loading trains	.052
Tracklaying	.047
Engineer	.020
Brakeman	.013
Watchmen	.017
Coal	.012
Oil, grease and waste	.002
Repairs	.003
Total	$ 0.114
Interest and depreciation on hauling outfit	.052
Spreading	.114
Sprinkling	.043
Rolling	.082
Foreman and timekeeper	.030
Total	$ 0.269
Int. and dep. on all other machinery	.040
General expense	.031
Total	$ 0.071
Total cost per yard (loose) of finished road	$ 1.418
Cost per mile	$3,275.58

Cost of Constructing Macadam Pavement at Hamilton, Ont.—The following figures, published in Engineering and Contracting, Sept. 4, 1918, from the report of E. R. Gray, City Engineer of Hamilton, Ont., for 1916–17 show the unit cost of constructing 2,361 sq. yd. of macadam on the northerly half of Burlington St. The macadam consisted of 5 in. of bottom stone and 3½ in. of top stone, requiring 897 cu. yd. stone and screenings loose measurement, or 559 cu. yd. in place. This was 1.6 cu. yd. of stone, loose measurement, for each cubic yard in place. The cost of work was as follows:

Operation	Quantities, etc.	Cost	Cost per sq. yd.
Grading	2,361 sq. yd	$ 347.52	$0.147
Bottom stone	45 loads tailings at $1.50	67.50	
	169 loads bottom stone at $2.20½	372.65	.186
Hauling bottom stone	221 loads at $1.87½ ($7.50 per day, 4 trips). Incline tickets $13.00.	427.37	.181
Laying bottom stone	520 hours at 35 cts	181.93	.077
Rolling bottom stone	2 days	13.60	.006
Top stone	From Dundas, 7 cars	400.25	
	From quarry, 19 loads at $2.95½	56.15	.193
Unloading from cars and hauling 370.8 tons, 156.3 loads		142.48	.060
Hauling from quarry	19 loads	34.44	.015
Spreading top stone		31.22	.013
Screenings	34 loads from quarry at $2.02½	74.98	
	18 loads from Ward 6	43.73	.050
Hauling screenings		85.04	.036
Placing screenings		36.57	.016
Road roller, foreman, time keeper, watchman, coal, etc.		139.92	.059
		$2,455.35	
5 per cent on labor for tools, 5 per cent of $1,360		68.00	.029
		$2,523.35	$1.068

The labor cost of unloading the stone from cars using hoppers was 22.8 ct. per ton or 54 ct. per load, the latter averaging 2.37 tons. The labor time for nuloading 370.8 tons from 7 cars was 24½ hours at 35 cts. per hour.

Effect of Length of Haul on Cost of Surfacing Macadam and Gravel Roads.—The following curve, taken from an article by K. I. Sawyer in Engineering and Contracting, June 17, 1914, is based on costs of road construction in Michigan.

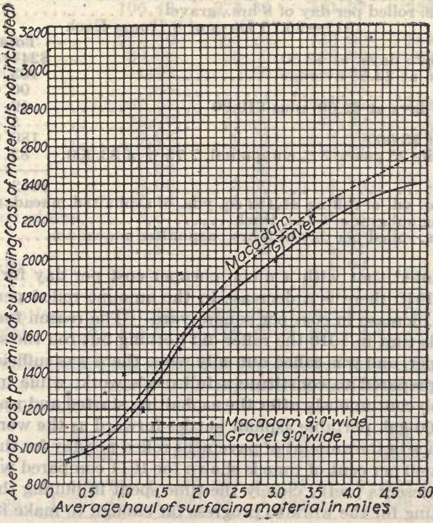


Fig. 1.—Curve showing the effect of length of haul on the cost of surfacing.

Cost of Operating a Steam Road Roller.—E. W. Robinson, gives the following costs of operating a 15-ton macadam road roller for the two seasons of 1910 and 1911 in Engineering and Contracting, March 20, 1912. The roller was bought new in 1906 at a cost of $3,000, these two years making the fourth and fifth seasons, respectively, in use. In all it has been used to roll 150,000 sq. yds. of water bound macadam, gravel and asphalted macadam pavements, and in addition was used on some three or four miles of county road work. It has also been used to a small extent to pull plows and rooters in opening side ditches and making street excavation, and for rolling down refilled sewer trenches. As nearly all the macadam roads and pavements in this locality are constructed of hard flint rock the large wheels are pretty well worn and will need replacing after another season or two. With that one exception the roller is in very good condition, considering the number of different men who have handled it, and only a few minor renewals have been necessary.

1910—67.4 Days of 8 Hours Each

	Total	Per day
Engineman, 67.4 days, at $2.50	$168.50	$2.500
Coal, 32.59 tons, at $4.00	130.36	1.934
Water, free	00.00	0.000
Repairs and supplies	105.26	1.562
Interest, 6 % of $3,000	180.00	2,671
Depreciation, life 25 years, 3 % compound, 2.75 % of $3,000	82.50	1.224
Total	$666.62	$9.891
Cost per sq. yd. of rolling 26,006 sq. yds. of asphalted macadam, including subgrade, 6 ins. thick		$0.0156
Cost per sq. yd. of rolling 15,062 sq. yds. of gravel pavement, including subgrade, 6 ins. thick		0.0126
Average sq. yds. rolled per day of 8 hrs., asphalted macadam		630
Average sq. yds. rolled per day of 8 hrs., gravel		787

1911—96.75 Days of 8 Hours Each

	Total	Per day
Engineman, 96.75 days, at $2.50	$241.88	$2.500
Coal, 40.5 tons, at $2.55 average	103.26	1.067
Water, free	00.00	0.000
Repairs, 11.85 days at $2.50, plus $19.90	49.53	0.512
Oil and grease	5.40	0.056
Interest, 6 % of $3,000	180.00	1.858
Depreciation, life 25 years, 3 % compound, 2.75 % of $3,000	82.50	0.851
Total	$662.57	$6.846
Cost per sq. yd. of rolling 34,152 sq. yds. of asphalted macadam, including subgrade, 6 ins. thick		$0.0176
Average sq. yds. rolled per day of 8 hrs., asphalted macadam		388

It will be noted that with a much cheaper cost per day for operation in 1911 than in 1910 there is a decrease in the amount rolled per day, with a corresponding increase in cost per square yard. The reason for this seeming inconsistency is that in 1910 the roller did nothing but roll the sub-grade and pavement proper, and was called out only when there was sufficient sub-grade or pavement prepared to constitute a full day's work, while in 1911 it was kept on the job continuously after the asphalting started and was also used to pull the two 500-gal. portable asphalt kettles forward as the work progressed. By the difference in the amount of pavement rolled per day for the two seasons a loss of about 40 per cent of time is shown for 1911 compared with 1910, and that figure represents pretty closely the time spent in pulling the kettles and lying idle waiting for the work to progress far enough to make it worth while to move back and roll the completed pavement.

There are several reasons for the difference in cost of operation per day for the two seasons. The same engineman was employed both seasons at the same wages, and that item as well as interest and depreciation remain the same for both years. In 1910 the coal was purchased of local dealers at retail prices, while in 1911 a far better grade was obtained at a much lower price by buying a full car. The reason for the large difference in cost of repairs and supplies was due to the fact that the man who ran the roller in 1909 did not take proper care of it and when the present engineman took hold in 1910 a pretty thorough over-hauling was necessary. It might be well to state that the average man whose only experience has been with a threshing engine is not very apt to be fit to run and maintain in good condition a road roller. The present engineman, who is an old locomotive engineer and a good machinist, did practically all the repairing on rainy days and Sundays, and the roller had to be taken to the machine shop only once in the last two years. The reason so good a man was secured at such a low price is because he gets straight time the year around, and when not out with the roller is employed at other work.

Cost of Road Roller Operation and Maintenance.—Engineering and Contracting, Jan. 1, 1913 publishes table X taken from the annual report of the Board of Public Works of Grand Rapids, which shows the cost of maintenance and operation, during the fiscal year ending March 31, 1912, of five steam road rollers owned by the city.

TABLE X.—COST OF ROAD ROLLER MAINTENANCE AND OPERATION FOR ONE YEAR

	No. 1 Roller	No. 2 Roller	No. 3 Roller	No. 4 Roller	No. 6 Roller
Maintenance:					
Total maintenance	106.48	275.30	581.27	259.80	124.36
Operation:					
Labor, running	717.10	681.20	743.00	769.10	809.20
Labor, cleaning	30.00	26.00	30.00	60.00	18.40
Labor, piloting	1.92	.60	.60	1.32	.60
Tools	.48	....	.78	.26	1.23
Coal	267.51	227.66	246.83	152.99	277.05
Kindling	24.70	21.90	22.30	11.60	20.95
Oil	5.96	9.74	8.90	7.32	4.21
Waste	3.52	3.33	3.84	1.44	2.77
Packing	1.80	.80	....	....	.97
Cartage	3.80	3.30	4.75	1.00	2.30
Boiler compound	7.56	5.46	3.90	1.50	2.76
Lanterns and globes	2.37	.05	1.23	.92	....
Matches	.20	.05	.05	....	.05
Grease	.21	.90	1.74	.15	.60
Delay penalty	....	....	1.00	....	....
1-inch pipe	....	....	....	.25	....
Hose	....	....	....	....	5.80
Total operation	1,061.13	980.99	1,068.92	1,007.85	1,146.89
Grand total	$1,173.61	$1,256.29	$1,650.19	$1,267.65	$1,271.25

The total maintenance and operating expenses for these rollers for the year ending March 31, 1911 (taken from Engineering and Contracting, May 22, 1912) were as follows:

	No. 1 Roller	No. 2 Roller	No. 3 Roller	No. 4 Roller	No. 6 Roller
Total maintenance	$ 466.74	$ 479.23	$ 421.11	$ 255.33	$ 159.53
Total operation	1,251.42	1,290.29	1,188.87	1,149.38	1,162.48
Total	$1,718.16	$1,769.52	$1,609.98	$1,404.71	$1,322.01

The average cost of maintenance was $356.39 for 1911 and $269.44 for 1912.

The weight of the rollers and number of hours operated in the year ending March 31, 1912 are as follows:

	Weight, tons	No. hours operated in year
No. 1 roller	15	1,793
No. 2 roller	13	1,703
No. 3 roller	14	1,857
No. 4 roller	8	1,922
No. 6 roller	10	2,023

The cost of maintenance and operation of these rollers per hour in operation were as follows:

	Total	Per hour
No. 1 roller	$1,173.61	$0.605
No. 2 roller	1,256.29	.737
No. 3 roller	1,650.19	.888
No. 4 roller	1,267.65	.659
No. 6 roller	1,271.25	.628

A full day's work at Grand Rapids was 10½ hours: 10 hours actual operation, and the balance firing up in the morning.

Comparative Cost of Operating Steam and Gasoline Rollers. (Engineering and Contracting, Feb. 26, 1913).—The road building outfit of the Highway Commissioners of York County, Ontario, includes two 12½-ton and two 11½-ton steam road rollers and a 12-ton 2-cylinder gasoline road roller. In the report of the Commission covering the year 1912, E. A. James, Chief Engineer of the Commission, gives the following figures to show the cost as nearly as can be judged of operation of the steam and gasoline machinery, both rollers working under similar conditions:

Cost of Operating Steam Roller

For 10 Hours' Rolling

Fuel—	
Kindling wood	$0.05
Coal, 380 lbs. at $6.85 per ton	1.30
Water—600 gals.; hauling 3 hrs. at 50 cts. per hr	1.50
Oil, etc	0.05
Engineer—11½ hours at 30 cts. per hour	3.45
Total	$6.35

For 10 Hours' Spiking and Scarifying

Fuel—	
Kindling wood	$0.05
Coal, 480 lbs. at $6.85 per ton	1.64
Water—800 gals., hauling	2.00
Oil	0.05
Engineer—11½ hours at 30 cts	3.45
Total	$7.19

Cost of Operating a Gasoline Roller

For 10 Hours' Rolling

Fuel—12 gals. gasoline at 15 cts. per gal	$1.80
Water—Cooling	0.12½
Oil	0.07
Engineer—10¼ hours at 30 cts	3.07½
Total	$5.07

For 10 Hours' Spiking and Scarifying

Fuel—20 gals. gasoline at 15 cts. per gal.	$3.00
Water—For cooling	0.15
Oil	0.07
Engineer—10¼ hours at 30 cts.	3.07
Total	$6.29

Cost of Shaping Up and Rolling Old Macadam.—Engineering and Contracting, Sept. 4, 1918, gives the following:

The cost of dressing up 12-ft. wide limestone macadam roads in Putnam County, Indiana, with a steam roller having a scarifier attachment ranged from $9.24 to $5.35 per mile in 1916. The average cost for the months of May, June, July and August of that year was about $7.08 per mile. The average total cost per day for the roller for this period, including coal, was $6.73. The cost of coal per day was $1.39. The above figures are based on the following costs:

Coal	$3 per ton
Roller operator	30 ct. per hour
Helper	25 ct. per hour
Teams for hauling coal	35 ct. per hour

The average number of days operated per month was 24.6, the average number of miles covered during this time being 23.5 or about 0.95 mile per day.

Cost of Renewing Surface of Old Macadam.—Engineering and Contracting, Nov. 7, 1917, gives the following:

Most of the suburban roads in the District of Columbia are water-bound macadam which have had a surface treatment either of oil or light tar. Three methods of renewing the surface on these old and worn macadam roads are employed, depending upon the condition of the road to be repaired.

When the surface has been treated formerly with oil or tar and is in generally good repair, except for a few potholes or ruts, these places are patched with a mixture of stone, of a size corresponding to the depth of the depression, and a cold bituminous material. This material may be either a tar of the heaviest consistency which can be used cold, such as Tarvia K-P or Ugite C; or it may be an asphaltic emulsion such as Headley's Cold Patching Material No. 1. The largest size of stone possible is used, well mixed with about 1 gal. of bituminous material to each cubic foot of stone. The patches are rolled with a steam roller and covered with a thin coat of stone chips to prevent adhesion to wheels while they are still moist.

When the surface of a macadam road, which has been previously treated with oil or tar, is very much worn or rutted, the entire surface is loosened to the depth of about 2 in. with a scarifier, as much as possible of the top coat containing the bituminous material being entirely removed. The fine stone may be screened out of the material which is removed if it is sufficiently pulverized, but it is usually reserved for use in repairs to little traveled roads. Sufficient new stone is then added to restore the proper cross section of the road, and the surface is brought to the condition of new water-bound macadam. This is opened to travel and kept watered until the surface is firm and compact. It is then swept clean of dust and the new surface is treated with the bituminous material in the same manner as a new road. About ¼ gal. per square yard of bituminous material (either oil or tar) is spread by means of a sprayer, and the surface is then covered with stone chips or pea gravel.

When the surface is much worn and it is desired to renew it with a strong new surface, the old macadam road is scarified to a depth of about 3 in. and reshaped to a surface about 2 in. below and parallel to the finished surface. A layer of 2-in. stone is then added and rolled to restore the cross section. About 1½ gal. per square yard of hot tar of heavy consistency is then applied, covered with stone ¾ in. to 1 in. in size, and rolled. After this a second coat of tar of about ⅔ gal. per square yard is applied and covered with ½-in. stone chips and rolled. This is, of course, the well-known penetration method, applied to the re-surfacing of old roads, and its use is advisable in cases where the road sustains a fairly heavy traffic of both horse-drawn and motor vehicles of all classes, say from 500 to 1,500 vehicles in 24 hours for a roadway 20 ft. wide.

The cost of the above treatments depends largely upon the condition of the roads when repaired, and also upon the cost of labor and material at the particular location under consideration. In a general way, in the District of Columbia, the mixed bituminous material used in the first method costs from $1.40 to $1.50 per cubic foot in place in the road. If it will average 1 in. deep, then it will cost 12 to 12½ cts. per square foot or $1.08 to 1.12½ per square yard of patch (not of roadway surface). This applies to small patches. Larger patches would cost somewhat less per square yard. To patch a roadway, 2 per cent of whose surface required repair to an average depth of 1 in., will therefore cost about 2 cts. to 2½ cts. per square yard of roadway surface.

The second method will cost probably 10 cts. per square yard for the preliminary work and from 5 to 6 cts. per square yard for the new surface treatment, or a total of 15 to 16 cts. per square yard of roadway surface.

The third method, including the work of scarifying and reshaping and the cost of material and labor, will cost from 60 to 75 cts. per square yard, depending on many and various factors.

The costs are based on labor at about 30 cts. per hour, teams at $5.50 per day, stone at 10 cts. per cubic foot at the road, and bituminous materials at 10 cts. to 15 cts. per gallon at the work.

Repairing Ruts in Macadam Roads.—Engineering and Contracting, May 29 1912, gives the following method used by the Road Commissioners of Alger County, Michigan, L. E. Adams, County Road Engineer, in repairing ruts which had developed in some of the macadam roads of the county road system: The macadam was loosened with a pick to the bottom course of rock and the hole cleaned out. Rock from 1½ to 2½ ins. was placed in the hole, well wet and tamped so that the top was a trifle above the level of the surrounding road. Screenings were then placed on the rock, thoroughly dampened and tamped with a 25-lb. iron rammer. The ruts on about 3½ miles of road were repaired in this way at a cost of $60 per mile. Screenings and rock were delivered in cars on spurs near the work for 10 cts. per cu. yd., and were hauled in wagons and deposited along the side of the road where needed. The average haul was one mile. Team and driver cost $4.50, foreman $2.50 and labor $2 per day.

Cost of Maintenance of Macadam with Roller and Scarifier.—George E. Martin gives the following matter in Engineering Record, Nov. 4, 1916.

Putnam County, Indiana, has a very large mileage of macadam roads. Many of these roads were built with but little attention to grades or drainage. Greencastle, the county seat, is in the center of a region producing a good grade of road-building limestone, and comparatively large amounts of stone have been placed on the roads of the vicinity.

The county, in 1915, purchased a steam roller with a scarifier attached to it.

This outfit has been used to dress up the roads at the following costs for operation:

	Total cost per day	Coal cost per day	Miles operated	Days operated	Cost per mile
May	$6.56	$1.23	16.75	23.6	$9.24
June	6.69	1.54	19.50	25	8.56
July	7.25	1.35	27.75	25	6.84
August	6.43	1.85	30.25	25	5.35
Average	6.73	1.49	23.56	24.65	7.50

The costs are based on coal at $3 per ton; wages of roller operator, 30 cents per hour; wages of helper, 25 cents per hour; and teams for hauling coal, 35 cents per hour.

The roads were about 12 ft. wide. In most cases they were both graded and rolled at this cost. About 50 per cent of the mileage was scarified and 12 miles were rolled only.

The work was done under the direction of Alva E. Lisby, Putnam County road superintendent, who collected the data quoted.

Maintenance Cost of Water Bound Macadam at Hartford, Conn.—Interesting data on the maintenance of waterbound macadam streets at Hartford, Conn., were given by Leon F. Peck, Superintendent of Streets of that city, in a lecture delivered Jan. 9, 1920 before the post-graduate students in civil engineering at Yale University. The matter following is abstracted from the address in Engineering and Contracting, Feb. 4, 1920.

Waterbound macadam comprises 73 per cent of the streets of all kinds, paved and unpaved, in the city of Hartford. The macadam maintained over the 10 fiscal years 1907 to 1916, inclusive, averaged 97 miles per year. In area this amounted to 1,321,000 sq. yd. per year. Probably 50 per cent of of these streets have been macadamized more than 20 years. Over most of this 10-year period, labor cost 25 ct. per hour, and a team with driver 62½ ct. per hour.

	Per sq. yd. per year
Average cost for the 10 years of maintenance, including restoration or renewals	$0.0343
Cost of depreciation at 10 per cent and interest at 4½ per cent on $13,400 worth of equipment	0.0015
Total, including depreciation and interest, averaged over the entire macadam area	$0.0358

The average annual cost, not including interest and depreciation for the first three years of this 10-year period, was $0.0340 per square yard, for the middle four years $0.0365 per square yard, and for the last three years $0.0317 per square yard.

Thus it is seen that the direct cost of maintenance did not increase during the 10 years notwithstanding the great increase in the number of motor vehicles.

During the next three years the cost of labor, teams and materials increased until the rates for the fiscal year ending March 31, 1919, stood as follows:

Labor, 37½ ct. per hour, an increase of 50 per cent.
Teams with drivers, 87½ ct. per hour, an increase of 40 per cent.
Repair materials increased about 40 per cent.

The actual cost for that year of maintaining 107 miles of macadam or 1,416,000 sq. yd. was $0.0551 per square yard, an increase of 60 per cent over the average for the 10-year period. This percentage of increase is in excess of that for labor and materials. It is believed that the excess is entirely due to the fact that war restrictions prevented the securing of the customary amount of asphaltic road oil, thus the usual maintenance benefit of the oil was lost.

Taking the present cost of new macadam at Hartford, which is 99 cts. per square yard and distributing it over a period of years long enough to bring in the average maintenance costs, say 20 years, then the ultimate cost can be determined as follows:

Interest at 4½ per cent on first cost for 20 years = $0.045 × $0.99 × 20, per sq. yd.	$0.8910
Sinking fund to repay original outlay at end of 20 years, compounded annually at 4 per cent = $0.03358 × $0.99 × 20	.6649
Present annual cost of maintenance including depreciation and interest, $0.0566 per square yard, for 20 years. $0.0566 × 20 =	1.1320
Ultimate cost per square yard for 20 years	$2.6879
Ultimate cost of Hartford's macadam per square yard per year	0.1344

Rate of Scarifying Macadam Road with "Allen" Scarifier.—In a paper, presented at the 1918 annual conference of Ontario Road Superintendents, R. Crawford Muir described the reconstruction of Dundas Street, the chief means of access to Toronto.

The old road was scarified 4 to 6 in. deep for its full length and width, and the loose stones were drawn to the sides to form the shoulders, thus reducing the crown necessary for the new surface.

The type of scarifier used was the "Allen" attached to the side of the roller. This scarifier consisted of 2 picks or teeth and was capable of picking up 800 to 1,200 sq. yd. a day.

Estimating Gravel Road Material Quantities and Cost of Hauling.—Engineering and Contracting, Jan. 5, 1916, publishes the following extract from Iowa State Highway Commission Service Bulletin December, 1915.

TABLE XI.—NUMBER OF LINEAR FEET OF 9-FT. ROAD A LOAD OF A GIVEN SIZE SHOULD COVER FOR VARIOUS LOOSE DEPTHS

Weight of load— Granite, lb.	Limestone, lb.	Size of load, cu. yd.	Length spread for loose depth in inches— 3-in.	4-in.	5-in.	6-in.
2,800	2,500	1	12 ft.	9 ft.	7.2 ft.	6 ft.
3,500	2,125	1¼	15 ft.	11.25 ft.	9 ft.	7.5 ft.
4,200	3,750	1½	18 ft.	13.5 ft.	10.8 ft.	9 ft.
4,900	4,375	1¾	21 ft.	15.75 ft.	12.6 ft.	10.5 ft.
5,600	5,000	2	24 ft.	18 ft.	14.4 ft.	12 ft.
6,300	5,625	2¼	27 ft.	20.25 ft.	16.2 ft.	13.5 ft.
7,000	6,250	2½	30 ft.	22.5 ft.	18 ft.	15 ft.
7,700	6,875	2¾	33 ft.	24.75 ft.	19.8 ft.	16.5 ft.
8,400	7,500	3	36 ft.	27 ft.	21.6 ft.	18 ft.

TABLE XII.—NUMBER OF CUBIC YARDS OF MATERIAL PER MILE TO MAKE GIVEN LOOSE DEPTH FOR VARIOUS WIDTHS OF ROAD

Depth of loose material in inches	Width of surfacing— 9-ft. cu. yd.	14-ft. cu. yd.	15-ft. cu. yd.	16-ft. cu. yd.	18-ft. cu. yd.
1¼-in. screenings)	180	280	300	325	367
3-in.	440	684	733	782	880
4-in.	587	913	979	1,043	1,174
5-in.	734	1,141	1,222	1,304	1,468
6-in.	880	1,369	1,466	1,565	1,760
Square yards of surface per mile	5,280	8,213	8,800	9,387	10,560

Knowing the cost of gravel in any community the cost of the material for the road can be easily determined. The cost of hauling the gravel varies also between rather wide limits but the following may be considered as average prices where teams cost forty cents per hour and where ordinary earth roads are hauled over:

TABLE III.—AVERAGE COST FOR HAULING GRAVEL BASED 40 CTS. AN HOUR FOR TEAMS

Length of average haul	Cost, cts. per cu. yd.
One-quarter mile	21
One-half mile	28
One mile	40
Two miles	63
Three miles	86

Motor Truck, Scarifier and Road Graders on Gravel Road Maintenance.— Thomas H. Edwards gives the following data in Engineering Record, July 15, 1916:

Montgomery County, Ala., has 650 miles of public roads, 450 miles of which are of gravel. In 1914, in order properly to maintain them, the County Board of Revenue decided to motorize the maintenance work. Material economies have been effected. One truck, it has been found, takes the place of from 16 to 20 mules for pulling a scarifier. The five trucks now in use make it possible to scrape practically the entire system after each rain, each truck pulling three road machines and being able to make 30 miles a day. A great saving has been accomplished in the hauling of the gravel. Four trailers are provided for each truck for this purpose.

Scarifying.—The use of the motor truck has made scarifying a comparatively easy matter. As previously stated, where formerly from 16 to 20 mules were required to pull the scarifier, one of the trucks now accomplishes the work with ease.

Recently there has been completed 6 miles of scarifying and reshaping at a cost of $24 per mile. This includes rebinding. The writer understands that in a neighboring county a contractor bid as much as $400 per mile for similar work. The detailed costs follow:

COSTS OF SCARIFYING 6-MILE ROAD

Gasoline for truck, 146 gal., at 25c	$ 36.50
Oil for truck, 35 gal., at 56c	19.60
Laborers' time, 31.5 days, at $1	31.50
Engineer's wages, 7 days, at $3	21.00
Foreman's wages, 7 days at $3	21.00
Total cost of scarifying	$129.60
Cost per mile	21.60
Cost of shaping 6 miles with truck followed by road machine	14.78
Cost of shaping per mile	2.46
Total cost, per mile, of finished road	$ 24.06

It is very important, in the maintenance of gravel roads, to scrape them after each rain. With the five trucks now in use it is possible to cover practically the entire system before the roads become too dry to accomplish any good.

With the truck we are in position to completely scrape 30 miles of road per day. To do this there is hung to each truck a fleet of three road machines. A round trip completes the road.

The cost per mile of this class of work is about 50 cents. The cost for the 30 miles is:

Truck driver	$ 3.00
Laborers, 3 at $1	3.00
Foreman	3.00
Gasoline, 20 gal. at 25 ct	5.00
Oil, 2 gal. at 50 ct	1.00
Total for 30 miles at 50 ct	$15.00

The replacing of chains, repairs to trucks, etc., necessary to truck upkeep cost about $400 per year.

Hauling Gravel.—In connection with each truck there are four Troy reversible 3-yd. trailers. While the truck and two of the trailers are at the dump the other two trailers are being loaded. Therefore only about ten minutes are lost per trip, this being consumed in loading the truck.

By this method of hauling, it has been possible to place gravel on the roads for from 7 to 11 cents per yard-mile, as against from 30 to 40 cents for mule haul, and includes spreading the material on the road.

With an increase of late in the price of gasoline from 11 to 25 cents per gallon it has been possible to keep the costs per yard-mile around 10 or 11 cents.

The unit costs of operating one of the trucks for hauling gravel during a week, shows a gasoline consumption of about 35 gal. per day. This is from 10 to 12 gal. more than the truck uses on the average haul, due to very long 12-per cent grades on the particular road traveled.

The first truck, a White 6-cylinder, latest type road truck was purchased in the latter part of 1914. It proved such an economy to the county that four others were purchased, together with trailers and equipment. All of the trucks are of 5-ton capacity.

Cost of Boulevard Oiling in Kansas City, Mo.—C. W. Redpath gives the following data in Engineering and Contracting, Nov. 20, 1912.

Approximately 50 miles of macadam roadways are oiled twice a year by the Park Board of Kansas City. The method of oiling employed has been very successful and economical.

Nearly the entire boulevard system is of 12-in. macadam, constructed of native limestone, which is used both for base and wearing surface. The roads have been carefully constructed, have a 12-in. crown on a 40-ft. roadway, and have excellent drainage.

The conditions for oiling are as follows:

(*a*) Before oiling, such repair work as is necessary should be done on the roadway, as the oil forms a cushion over the patch and protects it from raveling.

(*b*) The road surface should be hard and clean and all loose material removed.

(*c*) The road surface should be dry.

(*d*) Only one-half of the roadway should be oiled at a time, if for no other reason than a protection and courtesy to the public.

(*e*) The weather should be warm, with no prospects of rain, as rain on a freshly oiled surface will wash away much of the oil, sometimes completely ruining the job.

The oil used is a residuum of Kansas oils, which has an average specific gravity of 93 at 60° F. and which must register 19 to 21° B. by high grade hydrometer. The oil is received in tank cars from the Standard Oil Co. and pumped into two steel receiving tanks of 8,000 gals. capacity each, whence it is heated by steam coils and discharged by gravity into distributing tanks.

The cost of the oil this year, including freight, was about 2¼ cts. per gallon. It was charged out at 2½ cts. per gallon, the difference being the approximate cost of operating the distributing station.

The oil is distributed by steel tank wagons, of about 600 gals. capacity. To the back of each wagon is attached a sheet iron trough into which the oil is discharged by three 2-in. valves, flowing evenly upon the roadway through small holes in the bottom of the trough.

On all previously oiled roadways, with which this article deals, a smooth oil cushion has been built up. This surface is thoroughly swept with a rotary street broom, preparatory to distributing the oil. The oil is distributed lightly from the tank wagon upon the roadway, and the tank is immediately followed by the rotary street broom, which spreads the oil over the surface in a thin even coat. Two to four men with hand brooms are necessary to keep the oil from running into gutters, and to spread oil on uneven places in roadway, and at intersections with streets.

The oiled surface is then covered with a thin coat of limestone dust, the finest product of the crusher. This is spread from the rear of an ordinary wagon by two men working from the ground with No. 2 scoop shovels. The dust coat first protects vehicles and pedestrians from the dangerous and nasty oiled surface, and after a few days under traffic forms with the oil a cushion surface.

TABLE XIII.—COST OF BOULEVARD OILING AT KANSAS CITY

	Benton Blvd. 55,010 sq. yds.		Paseo. 51,200 sq. yds.		Gillham Road 19,920 sq. yds.	
	Hrs.	Per sq. yd.	Hrs.	Per sq. yd.	Hrs.	Per sq. yd.
Foreman	19½	$0.00026	26	$0.000159	8	$0.00013
Man-hrs. on brooms	58½	.00011	86	.000419	24	.00031
Man-hrs. spreading dust	89½	.00040	122	.000595	39	.00048
Man-hrs. oil wagons	19½	.00009	26	.000127	8	.00010
Man-hrs. extra water, etc	28½	.00011	39	.000190	15	.00019
Team-hrs. on dust	77	.0007	75½	.000737	37½	.00094
Team-hrs. on broom	21½	.00019	27	.000263	8	.00010
Team-hrs. oil wagons	31	.00029	34	.000332	14	.00035
Cost of delays	....	.00005	....	.000062	.....	.00010
Oil, at 2½ cts. per gal.	3,590*	.00163	4,828*	.002357	356*	.00170
Dust, at 30 cts. per cu. yd	54†	.00029	54†	.000316	24†	.00036
		$0.00412		$0.005557		$0.00476

* Gallons. † Cu. yds.

Average haul miles

	Benton Blvd.	Paseo.	Gillham Road
Dust	2	2.5	1.0
Oil	1.75	1.0	2.0

Rates of wages—Foreman .... $2.50 per day
Labor .... 0.25 per hr.
Teams .... 0.50 per hr.

The oiling crew usually consists of one foreman at $2.50 per day, two to four men hand brooming oil, four men spreading dust, one man spreading oil, one extra man, two oil tank teams, two to four teams hauling and distributing dust. All labor is paid at the rate of 25 cts. per hour, but teams including drivers at the rate of 50 cts. per hour.

Daily reports are made out by the foreman; from these reports Table XIII has been compiled. This table is for three boulevards which represent average conditions when haul of materials is taken into account.

Under ordinary circumstances, the cost per square yard for oiling on The Paseo should be between \$.004 and \$.005, but on this boulevard there was 8,280 sq. yds. of new roadway, which requires much more oil and labor than the old cushion surface. There are also 4,968 sq. yds. of this boulevard used as a traffic way, on which the travel is exceptionally heavy, so that more labor is required in cleaning same, and a thick coat of oil and dust is required.

Cost of Applying Emulsifying Oil in Carlisle, Pa.—John C. Hiteshew gives the following data in Engineering and Contracting, June 9, 1915.

In 1914 Emulsifying Oil was selected because of its previous success. It had very little odor and after a few hours dried sufficiently not to track onto the sidewalks. Also the price played a large part in the selection.

The manner of applying the oil was as follows: An overhead siding was used from which the oil was run from tank car to sprinkler by gravity. An ordinary water sprinkler of 500 gals. capacity was used, and filled about one-half full, the sprinkler was then taken to the block to be oiled and the other half filled with water at the nearest fire plug. The oil and water were the thoroughly mixed with a hoe, but later on it was found that time was saved and as perfect a mixture was secured by placing the hose connected with the fire plug in the bottom of the sprinkler and turning on full pressure of the water, which would then literally "boil up" and thoroughly emulsify.

The sprinkler distributed the oil so uniformly that no brooming was required after oiling. The streets were lightly swept before oiling in order to clean them but to leave sufficient dust for the oil to take hold or penetrate.

The cost of oiling approximately 160,000 sq. yds. or 34 blocks, or eight miles of street averaging 45 ft. in width, giving the whole two applications, was as follows:

Materials—	
26,509 gals. emulsifying oil at .0446cts	\$1,182.31
Demurrage	16.00
Total	\$1,198.31
Labor—	
Foreman, 5 hrs. at 20 cts	\$ 1.00
Labor, 65 hrs. at 16 cts	10.40
Labor, 97 hrs. at 15 cts	14.55
Labor, 5 hrs. at 10 cts	.50
Team, 103 hrs. at 15 cts	15.45
Team, 25 hrs. at 10 cts	2.50
Collector, 21 days at \$1.00	21.00
Collector, 6 days at \$1.50	9.00
Total	\$ 74.40
Grand total	\$1,272.71
Per square yard	\$0.008

Cost of Asphaltic Oil Surface Treatment at Portland, Me.—During the season of 1912 an area of 39,066 sq. yds. of macadam at Portland, Me., was given a surface treatment with asphaltoilene. The following costs on this work, given in Engineering and Contracting, Oct. 1, 1913, were rearranged from the annual report of the Commissioner of Public Works. The asphaltoilene cost 7½ cts. per gallon. Labor was \$2 per 9-hour day, and team and driver \$5.

Job No.	Cleaning and application	Sanding	Asphalt-oilene	Total cost per sq. yd.	Gals. per sq. yd.
5	$0.008	$0.003	$0.019	$0.030	0.26
7	.004	.005	.025	.034	.33
1	.010	.002	.027	.039	.36
2	.006	.005	.029	.040	.39
8	.006	.004	.030	.040	.40
4	.013	.003	.031	.047	.41
6	.013	.006	.031	.050	.41
3	.018	.005	.048	.071	.64

Cost of Tarvia Treatment at Queen Victoria, Niagara Falls, Park System (Engineering and Contracting, Dec. 5, 1917).

About 28,000 sq. yd. of the Niagara River Boulevard in the Queen Victoria Niagara Falls Park System, Ontario, were given a surface treatment with tarvia A in September, 1916. The cost of the work was 6.6 ct. per square yard, according to the annual report of the Park Commission. The average haul was 1½ miles, and the surface treated was 18 ft. wide and 14,000 ft. long. About ¼ gal. of tarvia was applied per square yard of surface. The detailed cost of treatment was as follows:

Labor	Cts. per sq. yd.
Teaming, ½-in. stone	0.69
Loading and spreading stone	.56
Sweeping and brushing roadway	.10
Heating tarvia	.40
Distributing and rolling	.10
Miscellaneous	.09
Total labor	1.94
Materials:	
½-in. stone chips, 348 tons at $1.10	1.37
Tarvia A, 6,500 gal. at 10 cts	2.32
Freight, $115; car service, $19	.48
Coal, 19.7 tons at $7	.49
Total materials	4.66
Grand total	6.60

Teams were paid for at rate of 45 cts. per hour; laborers received 20 cts. per hour and foremen 30 cts. per hour.

Cost of Asphalt Macadam Construction with Telford Base at Carlisle, Pa.— C. A. Bingham gives the following data in Engineering and Contracting, Dec. 20, 1911.

During the season of 1911 the Street Department of Carlisle, Pa., under the direction of the writer constructed about 10,000 sq. yds. of asphaltic macadam, of which 6,129 sq. yds. was on new work with a telford base and 3,529 yds. was on an 8-in. resurfacing on old macadam.

The grading for the new work was considerable, one grade being reduced from 5 per cent to 2.40 per cent, necessitating cuts up to 7 ft. for the full width of the 60-ft. street. This work was done by heavy plowing by double teams or power and hauling in dump wagons to fill adjacent streets. The grading force averaged eight men and 4,150 cu. yds. was cut at a cost of 32 cts. a yard as shown in the table following.

Simultaneously another gang of about eight men quarried 4,425 perch of limestone (a perch is 25 cu. ft. in this locality) at one of the town quarries near by. This cost 31 cts. a perch, not including stripping of clay which was done in opening a new street. The average rate was 7 perch per man day in low breast work. Only four perch was obtained from a pound of dynamite on account of much blistering.

The rock was then crushed by the department crusher into bins and hauled to this and other jobs. The crusher had a 10 × 22 opening and was portable and low setting. Sufficient power could not be produced by a 13-ton roller so a 16 H. P. traction engine was leased. Three men loaded three carts on a 400-ft. haul and three men fed the crusher and one man operated bins. The average amount crushed was 86 perch in ten hours and the cost was 27 cts. a perch. Coal was purchased by carload and a half ton per day was used.

Owing to a large amount of necessary work in other sections the laying of telford was given to a contractor whose quarry and plant was on the street and who could bid even with the department and yet make considerable profit. All other work was done by the municipal forces.

Prior to laying the telford the entire subgrade was trimmed to crown and contour and rolled thoroughly by a 13-ton three-wheel roller. At the same time the banks in deep cuts were sloped back to the building lines which will account for the large cost of 11 cts. per sq. yd. for trimming. The telford stones were broken about 8 ins. in height and were laid very close and well keyed with stone wedges. The average amount laid was 40 sq. yds. per man in 10 hours. After a stretch of 300 ft. (36 ft. between curbs) was ready it was rolled in a day by the large roller which crushed off projecting corners and imbedded the stones until the telford was 6 ins. above subgrade as called for. About 4 ins. of 1½ to 2½-in. stone was then spread over by a spreading wagon and when rolled into the interstices of the base there remained room for 2 to 3 ins., loose, of ¾ to 1½-in. stone. This top course was only rolled two or three times to smooth it up and no screenings were allowed.

The representatives of the asphalt company claimed that the top stone should be about 2½ ins. in size, but upon experiment it was found that this size required nearly 50 per cent more asphalt and produced only slightly better penetration and gave more danger of a flat stone tilting up. It was also claimed that no rolling whatsoever on the top course should precede the pouring but it was found that undulations would then not be found until too late for correction except at considerable cost.

The force used on the asphalt work was only five men. One man attended the wood fires, two men carried the hot asphalt and one man poured. The fifth man spread screenings, leveled stones ahead of pouring and on close work helped to pour. Fires were started at sunrise and pouring commenced at 7 A. M. The gang took very little time for lunch and at night always filled the kettles with fresh asphalt for the next day's work.

The kettles used were two caldrons on tripods holding nearly a barrel apiece and one 150-gal. asphalt heating tank on wheels. With this meagre outfit an average of over 400 sq. yds. a day was maintained. During the hot weather the barrels were suspended on trestles over the caldrons and set directly on the large kettle and thus emptied by gravity, but as the weather grew cooler this was too slow a process and the barrels were broken apart and the asphalt cut up in chunks. This of course could not be done in warm weather. It was found that with the time gained and by the burning of the broken barrels that more money was saved than by the slow method and the buying of fuel wood and returning the barrels. The barrels which had been drained in warm weather were well cleaned, when it became cooler by jarring the asphalt loose which had clung to the inside.

The only fault found with the material was the foreign matter contained in the barrels; sometimes a quart of paint or a dipperful of sticks would be found in one barrel which sometimes clogged the valve of the barrel and once caused a leakage of half a barrel, and necessitated a constant cleaning of the can spouts.

The asphalt was of natural lake origin and was heated to 360° F. so that it would reach the road at nearly 350° F. The weather temperature was from 80 to 98° F. The shipments of asphalt were so delayed that some extra work on an approach had to be completed when the temperature was down to 40°.

The asphalt was all poured by hand and was carried in large buckets and poured into the spreading can which had a fan-shaped spout 4 ins. wide and a ⅜-in. opening. A good 2-in. penetration was secured with 1⅛ gal. to the square yard by heating to a high temperature and having the stone clean and warm. Screenings from ¾-in. down were then spread over a depth of about ½ in. and the surface thoroughly rolled with a 6-ton tandem roller until the road was solid and set. At first a board was placed along the concrete curbs to protect them from splashings of asphalt, but after a little practice the men could spread along the curb without the board. The asphalt cost 15 cts. per sq. yd. and applying cost 6 cts. per sq. yd. It is hoped that next spring an appropriation will be made to clean off the screenings with a horse sweeper and place a seal coat over the entire street.

The resurfaced section was done in two layers, each of about 6 ins. loose which rolled to 4 ins. making the completed work average 8 ins. Every 20 ft. cross-stakes were set 6 ft. apart to correct crown and the road metal was placed about 25 per cent higher than the required depth to allow for compression. Every load of stone was dumped a few feet away from the desired location and then shoveled back to place so that no solid cores would be formed. This gave a smoother surface even on the resurface work than was produced by spreading wagons on the telford section. The stone for resurfacing was 1½ to 2½ ins. except top course of 3 ins. (loose), which was ¾ to 1½ ins. The resurfacing cost 24 cts. per sq. yd. This section was rolled and asphalted similar to the telford section.

In the following cost table data are given on a section of water-bound macadam which was placed at the end of the asphalt work and will make good comparison. It will be noted that no sprinkling cost is given, the reason being that the department sprinklers are operated by fire department horses and the water is also free because of semi-municipal ownership. As all macadam streets here are thoroughly wet until waves run ahead of the roller the sprinkling item if paid for would bring the water-bound macadam up to 37 cts. a yard. In other words, we construct an asphalt macadam for 8 cts. per yard additional over a water-bound macadam, or for the amount spent in annual repairs for two years on the inferior road we can build it right and enjoy a perfect road for many times that period.

The detailed cost of constructing the asphalt macadam was as follows:

QUARRYING STONE (4,425 PERCH)

	Rate, cts.	Per perch
Labor, 6,933 hours	17	$0.2663
Dynamite, 1,035 lbs	14	.0327
Fuse, 2,975 ft	½	.0033
Caps, 2,000	9–10	.0040
Blacksmith		.0080
Total (quarrying)		$0.3145

CRUSHING STONE (4,425 PERCH)

	Rate, cts.	Per perch
Foreman, 26 hours	20	$0.0011
Labor, loading, 1,550 hrs	14	.0492
Labor, feeding, 1,866 hrs	15	.0632
Carts, 1,810½ hrs	24	.0982
Power and engineer, 540½ hours	40	.0488
Coal, 31½ tons	$2.36	.0169
Total		$0.2773

EXCAVATION (4,150 CU. YDS.: 6,206 SQ. YDS. AND SIDEWALK AND SLOPES)

	Rate, cts.	Cu. yd.	Sq. yd.
Foreman, 610 hours	17	$0.0249	$0.0167
Labor, 5,492 hours	14	.1852	.1239
Teams, 84 hours	35	.0070	.0047
Carts, 1,692 hours	24	.0978	.0654
Roller engr., 72 hours	20	.0034	.0023
Dynamite, 98 lbs	14	.0033	.0022
Coal, 4,000 lbs	2	.0019	.0013
Total	..	$0.3239	$0.2166

SUB-GRADING (TRIMMING, 6,206 SQ. YDS.)

	Rate, cts.	Per sq. yd.
Foreman, 619 hours	17	$0.0169
Labor, 3,039½ hours	14	.0685
Teams, 50 hours	35 and 40	.0031
Carts, 475½ hours	24	.0183
Roller engr., 81 hours	25	.0032
Coal, 3,000 lbs	$4.50	.0018
Total		$0.1113

MACADAM (8 IN. RESURFACING ON OLD MACADAM, UNROLLED ON SURFACE, 3,529 SQ. YDS.)

	Rate, cts.	Per sq. yd.
Labor, 477 hours	14*	$0.0192
Carts, 505 hours	24	.0343
Roller engr., 205 hours	25	.0145
Coal, 8,000 lbs	....	.0026
Stone, 998 perch	59.2	.1715
Total	....	$0.2424

* 14 and 15 cts.

	Rate, cts.	Per sq. yd.
Telford stone, 1,471 perch	31.45	$0.0755
Foreman laying, 490 hrs	.25	.0200
Labor laying, 870 hrs	.15	.0212
Team hauling, 440 hrs	.35	.0252
Rolling Telford, 40 hrs	.25	.0016
Coal, 2,600 lbs	.02	.0008
Macadam stone, 932 perch	59.18	.0900
Team hauling, 330 hrs	.35	.0188
Spreading, 365 hrs	.25	.0148
Rolling, 190 hrs	.25	.0078
Coal, 12,000 lbs	.02	.0039
Profit	....	.1502
Total	....	$0.4300

ASPHALT BINDER AND APPLYING

	Rate, cts.	Per sq. yd.
Labor, unloading, 109 hours	*	$0.0017
Team, 44 hours	†	.0009
Fuel wood, heating, 9 cords	*†	.0039
Foreman, 178½ hours	20	.0037
Labor, 1 304 hours	*	.0196
Screenings, 231 perch	59.18	.0142
Carts, 77 hours	24	.0019
Asphalt, 12,810 gals	11.57	.1536
Rolling, 188½ hours	75	.0146
Total		$0.2142

* 14 and 15 cts. †10 and 24 cts. *† $3 to $6.

Summarizing we have the following costs:

ASPHALT MACADAM WITH TELFORD BASE

	Per sq. yd.
Excavation	$0.2166
Subgrading	.1113
Telford and macadam	.4300
Asphalt binder	.2142
Total	$0.9721

ASPHALT MACADAM ON 8-IN. RESURFACING

	Per sq. yd.
Resurfacing, 8-in	$0.2424
Asphalt binder	.2142
Totals	$0.4566

The following costs were for the construction of a section of resurfaced water-bound macadam at the end of the asphalt macadam work. The total area was 2,240 sq. yds.

	Rate, cts.	Per sq. yd.
Labor, 322 hours	14 to 20	$0.0208
Carts, 97 hours	24 to 35	.0147
Roller engr., 103 hours	25	.0115
Crushed stone, 923 perch	59 to 90	.2727
Coal, 7,500 lbs	2	.0066
Total		$0.3265

Output and Organization Used in Operating Asphalt Mixer in Constructing 2-in. Asphaltic Concrete Surface.—The following data are taken from an abstract published in Engineering and Contracting, April 3, 1918, of a paper by R. Crawford Muir presented at the 1918 annual conference of Ontario Road Superintendents.

Mr. Muir described the reconstruction of Dundas Street which is the chief means of access to Toronto.

The wearing surface mixture was prepared in a Cummer standard 1-car protable paving plant of 2,000 sq. yd. of 2-in. top per day (10 hours) rated capacity, having a twin-pug mill (10 cu. ft.) capable of handling a 1,000-lb. batch of material. The total weight of this plant ready for transporting is 100 tons.

When the plant is working at its full capacity, 3 tons of coal are required per day.

The organization at the plant is as follows:

1 Foreman.
1 Engineer.
1 Fireman and 1 blacksmith.
2 Men at scales weighing materials.
2 Men feeding stone to elevator to drier.
2 Men feeding sand to elevator to drier.
2 Men shoveling stone from car.
2 Men shoveling sand from car.
2 Men stripping barrels, etc.
1 Man with horse, conveying sand from pile to elevator.
1 Man with horse, conveying stone from car to elevator.

On a good day's work (8 hours) the following quantities of material were used: 16 tons of asphalt, 132 tons of stone, 47 tons of sand, 11 tons of dust or filler, making a total of 206 tons of mixture.

The materials were mixed in a batch as follows:

	Weight, lb.	Per cent
Stone (½-in.)	625	64.10
Sand	225	23.07
Dust (filler)	50	5.13
Asphalt cement	75	7.70
		100.00

These weights, of course, were modified from time to time, in order to take care of the variations in the materials as delivered. Special care was exercised to see that there was always a high percentage of filler and that the mix carried all the asphalt cement possible without being sloppy.

When the quantity of asphalt cement in the mixture exceeded 7¾ per cent of the total weight there was trouble in some places with waving and ridges in the pavement, also with more or less bleeding. On the other hand, if the percentage fell below 7, the pavement had a tendency to crack.

The hot mixture was hauled from a portable plant, which was located at a railway station, to the road in the usual asphalt spreading wagons, dumped on the foundation at a temperature varying from 250° to 350° F. and conveyed to its final resting place by means of shovels. In shoveling the hot mixture into place, the material was shoveled from the bottom of the pile, thereby preventing the lower layer of the pile from becoming chilled. When the lower part of the pile becomes chilled, an uneven distribution and compression results. On a number of loads, especially on a long haul the larger particles of the mixture settled to the bottom of the load; when this occurred, the mixture on being dumped was remixed by turning over with hot shovels. The mixture, after having been deposited roughly in place by shovels, was spread by means of hot iron rakes to a depth of 2¾ in., thus allowing for an ultimate compression of 2 in. During this operation the rakers did not stand on the hot mixture any more than was necessary. Care was taken that all lumps were broken and a uniform consistency and even grade maintained, so as not to have depressions in the finished pavement. Raking is a most important factor in the construction of an asphaltic concrete pavement. With a hot mixture, 300° F. or more, 4 to 6 minutes were necessary for raking, but with a cold or stiff mixture 10 to 20 minutes were sometimes required. Cold or extra stiff mixtures should be avoided as insufficient compression and inconsistency results.

The largest number of loads dumped in one day was 65 (228 tons), covering an area of 1,800 sq. yd. or a length of 940 lin. ft. This was on the shortest haul, ⅓ of a mile. On the longest haul, 2 miles, 36 loads (126 tons) were dumped, 9 teams each making 4 trips in 8 hours, covering an area of approximately 1,130 sq. yd. On an average on a full day's work, 46 loads (106 tons) were deposited on the road, covering an area of approximately 1,300 sq. yd. These quantities would have been increased had the contractor placed more teams on the work.

Cost of Asphaltic Macadam at Waynesboro, Pa.—Engineering and Contracting, Oct. 4, 1916, publishes the following data, relative to the street improvements at Waynesboro, Pa., carried out by the city street force undei the supervision of G. C. Brehm, City Engineer.

The organization consisted of two foremen at 21 cts. per hour, a roller engineer at 25 cts. per hour and labor at 18 cts. per hour.

Of the 25,000 sq. yd. of asphaltic pavements laid, one block (1,170 sq. yd.) was constructed on Cleveland Ave., the cost of which follows:

It was found upon examination that the old macadam was so badly worn than an entire new base was necessary, and in order to bring the contour of the road to its proper place, about 8 in. of grading had to be done, the rough grading being handled by means of the road roller and plow. The average haul was 1 mile.

Upon the thoroughly rolled sub-base, run of crusher limestone 6 in. thick (after compression with a 10-ton roller) was used as a base.

Three inches of crushed stone (after compression) 2 to 3 in. in size was placed upon this base and after being thoroughly rolled with a 10-ton roller the asphalt, which was Aztec, was applied by means of pouring cans. Just enough ¾-in. stone to take up the voids was then spread over the hot asphalt and the whole was again thoroughly rolled. After applying ½ gal. of asphalt per square yard, the surface was covered with ½-in. chips and rolled.

The ¾-in. and ½-in. stone contained a great deal of dust and screening was necessary before they could be applied to the road. The cost of the work was 85 ct. per square yard, as follows:

GRADING (312 CU. YD.)

Unit	Amount	Rate	Per sq. yd.
Teams	122 hr.	$0.50	$0.0522
Labor	50 hr.	.21	.0088
Labor	332½ hr.	.18	.0514
Roller engineer	21 hr.	.25	.0044
Insurance	....	.....	.0013*
Supervision	....	.....	.0119
Coal	2,465 lb.	4.50	.0048
Oil	1 gal.	.50	.0004
Dep. machinery	....	.....	.0179
Total			$0.1531

* Rate, $1.74 per $1,000.

BASE, 6 IN. (1,170 SQ. YD.)

Unit	Amount	Rate	Per sq. yd.
Stone	250 tons	$0.75	$0.1603
Hauling	99 hr.	.50	.0423
Spreading	108 hr*	....	.0173
Rolling	7 hr.	.25	.0015
Coal	828 lb.	4.50	.0015
Oil	¼ gal.	.....	.0001
Supervision	....	.....	.0060
Insurance	....	.....	.0004
Dep. machinery	....	.....	.0060
Total			$0.2354

* 25 hours at 21 cts.; 83 hours at 18 cts.

SURFACE, 3 IN., OF 3-IN. AND 2-IN. STONE (1,170 SQ. YD.)

Unit	Amount	Rate	Per sq. yd.
Stone	164 tons	$0.75	$0.1051
Hauling	65 hr.	.50	.0280
Spreading	116 hr*	.....	.0186
Rolling	11 hr.	.25	.0023
Coal	1,291 lb.	.....	.0024
Oil	½ gal.	.....	.0002
Supervision		.....	.0096
Insurance		.....	.0005
Dep. machinery		.....	.0094
Total			$0.1763

* 30 hours at 21 cts.; 86 hours at 18 cts.

ASPHALT

Unit	Amount	Rate	Per sq. yd.
Asphalt	2,381 gal.	$0.08½	$0.1729
Hauling	37 hr.†	......	.0073
Applying	128 hr.‡	......	.0204
Wood	3 cords	4.00	.0103
Oil and waste§	....	......	.0019
Supervision	....	......	.0029
Insurance	....	......	.0005
Dep. machinery	....	......	.0026
Total			$0.2188

† 6 hours at 50 cts.; 31 hours at 18 cts. ‡ 28 hours at 21 cts.; 100 hours at 18 cts. § 12 gal. oil at 12 cts.; 5 lb. waste at 15 cts.

STONE, 1 IN. AND ¾ IN.

Unit	Amount	Rate	Per sq. yd.
Stone	15 tons	$0.75	$0.0096
Hauling	13 hr.	.50	.0056
Spreading	17 hr.*	.....	.0027
Screening	23 hr.	.18	.0035
Rolling	4 hr.	.25	.0009
Coal and oil†	468 hr.	.....	.0009
Supervision	....	.....	.0030
Insurance	....	.....	.0002
Dep. machinery	....	.....	.0034
Total			$0.0298

* 4 hours at 21 ct.; 13 hours at 18 cts. † Oil, ⅛ gal.

STONE, ½ IN.

Unit	Amount	Rate	Per sq. yd.
Stone	6 tons	$0.75	$0.0038
Hauling	7 hr.	.50	.0030
Spreading	11 hr*	.....	.0018
Screening	11 hr.	.18	.0017
Rolling	4 hr.	.25	.0009
Coal and oil†	468 lb.	.....	.0009
Supervision	....	.....	.0030
Insurance	....	.....	.0001
Dep. machinery	....	.....	.0034
Total			$0 0186

* 2 hours at 21 cts.; 9 hours at 18 cts. † Oil, ⅛ gal.

MISCELLANEOUS

Unit	Amount	Rate	Per sq. yd.
Teams	21 hr.	$0.50	$0.0089
Labor	49 hr.*	.....	.0079
Blacksmith, repairs, etc	....	.....	.0013
Total			$0.0181

* 14 hours at 21 cts.; 35 hours at 18 cts.

SUMMARY

	Per sq. yd. pavement
Grading	$0.1531
Base	.2354
3-in. surface	.1763
Asphalt application	.2188
Stone, 1-in. and ¾-in.	.0298
Stone, ½-in.	.0186
Miscellaneous	.0181
Total	$0.8501

Cost of Removing an Asphaltic Macadam Road Surface, Reworking the Old Material and Relaying it as Asphaltic Concrete.—G. C. Dillman published the following data in Engineering and Contracting, Dec. 9, 1914.

A poured process asphaltic macadam surface 16 ft. wide was laid on the extension of Woodward Ave., Detroit, in 1912. This road is a trunk line between Detroit and Pontiac and is subjected to a heavy traffic. Holes began to appear in the surface soon after its completion.

The original improvement was made by Royal Oak township of Wayne Co. Mich., which did not make the repairs required by the state reward road law and in July, 1914, the surface was reconstructed under the direction of F. H. Rogers, state highway commissioner. The new work consisted of tearing up the old asphaltic surface, heating it with necessary new material added and relaying on the old slag macadam base.

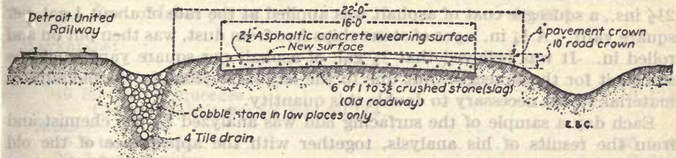


FIG. 2.—Typical cross section of roadway improved.

Removing Old Surface.—The asphaltic surface to be removed was first swept clean. Twelve men, picking, lifted and picked into small chunks and shoveled into wheelbarrows, the material covering about 250 lin. ft. of roadway surface each day.

In scalping off the old bituminous top, two places were broken up at the same time to hasten the work. At first the men picking stood on the surface already broken up, pulling the chunks as picked up, toward them. This did not work out satisfactorily so another method was tried, in which the men stood on the old surface, driving the pick beneath the broken edge. The surface coat was then readily lifted and broken into pieces that could be handled. These large pieces were then thrown back where three men picked them into still smaller ones to save time in the mixers. The old material broke up readily in the morning but towards noon softened and more time was needed in breaking. Although the depth of penetration was far from being uniform, the bituminous top separated readily from the slag foundation.

Long stretches of the old surface were laid when the foundation was wet, and the bad effects of water present could be seen. The asphalt had not penetrated to a sufficient depth, and there was practically no bond in the pavement in such places. In other places a 6-in. penetration was observed.

When the old surface was broken up the stone was often covered with moisture and the asphalt could be peeled from the stone. This presence of moisture may be partially accounted for in that the general drainage of the road was poor, yet it is probable that the foundation had not been in a dry condition since the pavement was laid. When the road was resurfaced, the foundation was allowed to dry out and the general drainage was also taken care of.

Mixing and Placing.—The equipment for mixing and placing consisted of 2½-cu. yd. hot mixers, 1 500-gal. heating kettle, 1 5-ton roller, carts, small tools, etc.

The old surface picked into small chunks was delivered to the mixers in wheelbarrows. An average batch consisted of sufficient material to lay 3½ sq. yds. of 2½ in. surface, and contained 728 lbs. of old top, 252 lbs. of new stone and 15.92 lbs. of new asphalt.

The old top was charged into the mixer with about 25 per cent. of ½ to ¾ in. stone added and about 0.45 gals. per square yard, or about 1.6 gals. per batch, of new asphalt. Mixing was usually continued 8 mins. at the end of which time the temperature of the material would average about 240° F. Two high-wheeled carts were used to convey each batch to the point where it was to be laid.

The base, after removing the surface material, was found to be very rough due to the original poor grading, and to the varying depths of penetration of the asphalt. All depressions in the bottom layer were filled with ¾ in. stone, after which it was thoroughly compacted by rolling.

After the bituminous macadam had been laid and rolled to a thickness of 2½ ins., a squeegee coat of asphalt was applied at the rate of about 1 gal. per square yard. A ¼ in. layer of stone chips free from dust, was then put on and rolled in. It was believed that ½ gal. of asphalt per square yard would be sufficient for the squeegee, but due to the large size stone in the old surface material, it was necessary to double this quantity.

Each day a sample of the surfacing laid was analyzed by the chemist and from the results of his analysis, together with the appearance of the old material, the mix was determined. Almost constant attention had to be given the mix on account of the varying composition of the materials. An attempt was made to keep the per cent of bitumen between 5 and 6, but it was low at times due to the large stones in the sample tested.

The road was closed to traffic July 13, 1914 and opened to traffic August 12, 1914, about an hour after completion. Thirty-eight men were required 24 working days to tear up, remix and relay 9,055 sq. yds. In a 10-hour day a maximum of 510 sq. yds. was laid.

Cost and Personnel.—Table XIV gives an itemized statement of the costs per square yard of pavement laid. These figures were compiled from the daily expenses as gathered by the state inspector and are very close to the exact cost. The contract price for laying the bituminous pavement was 73 cts. per square yard, $500 being allowed for the extra asphalt used for squeegee.

The prevailing rate of wages was $2.25 a 10-hr. day for ordinary labor; $2.50 and $3.00 being paid enginemen, firemen and rollermen, and $4.00 for raker. The teams cost $5.00 per day

The estimate for foreman is based on 30 days at $10.00. The contractors had two foremen on the work at all times, both being members of the contracting firm.

The equipment cost cannot be stated in exact figures, since it was owned by the contractor, but the figures given represent an average rental price.

TABLE XIV.—UNIT COSTS OF WORK

		Cost per sq. yd.
LABOR:		
Preparing old bituminous top—		
2 engineman		$0.016
2 firemen		0.014
2 platform men		0.013
6 wheelers		0.029
12 pickers		0.064
Total	$0.136	
Placing new material—		
4 cartmen		$0.020
1 kettleman		0.008
1 raker		0.013
1 rollerman		0.008
Total	$0.049	
Preparing grade—		
3 grademen		$0.015
Putting on squeegee and chips—		
3 squeegeemen		$0.021
Other labor—		
2 helpers		$0.012
1 waterboy		0.003
1 nightwatchman		0.007
Incidental labor		0.016
team (steady)		0.017
Total	$0.055	
Cost of labor per sq. yd	$0.276	
MATERIALS:		
Asphalt—		
20.53 tons in mix		$0.051
49.80 tons in squeegee		0.123
Cost of asphalt per sq. yd., $0.174.		
Stone—		
325.9 tons in mix		$0.068
90.5 tons in chips		0.019
12.7 tons in grade		0.003
Cost of stone per sq. yd., $0.090.		
Incidentals—		
Fuel, insurance, freight on equipment, etc		$0.073
Equipment (estimated)—		
Roller and kettle		$0.023
Two mixers		0.100
Small tools		0.006
Total	$0.129	
Foreman (estimated)		$0.033
Grand total		$0.74

SUMMARY

Item	Average for 2,586 batches	Totals
Length surfaced, lin. ft	1.97	2,586
Area surfaced, sq. yds	3.50	9,046.5
New asphalt added, lbs	15.92	41,065
New asphalt added, per cent	1.6	....
Old bitu. top, lbs	128	1,882,835
Old bitu. top, per cent	73.1	....
New stone in mix, lbs	252	651,790
New stone in mix, per cent	24.3	....

Comparative Cost of Mixing Bituminous Road Materials by Machine and by Hand.—In an article in Engineering and Contracting, Feb. 26, 1913, Herbert C. Poore gives the following costs:

Mixing work previous to the 1912 season has generally been done by hand on wooden platforms with hot shovels. During 1912, however, 18 mechanical batch mixers were used. These mixers are portable and are either set up in connection with the crushing plant or else moved along the road as the work advances. To handle the stone economically the crusher bins at a stationary plant discharge directly to both wagons and to the mixer hopper by gravity and the mixer discharges the coated stone to the wagon by dropping from a spout.

The apparatus most generally used is one manufactured by the Municipal Engineering & Contracting Co. of Chicago, known as the Chicago Improved Cube Mixer. When provided with the Austin oil torch heating attachment the stone may be dried for use in bituminous road construction. The machine consists of an iron cube, revolving on its diagonal axis and gear driven from a steam engine mounted on the same portable frame. A small belt-driven air compressor furnishes the necessary pressure for operating the crude oil torch. The two ingredients are mixed in the cube chamber by kneading and folding rather than by stirring and the action is rapid and complete.

The broken stone is first dumped or shoveled into the measuring hopper which is then raised on an inclined slide by a small cable hoist. After depositing the charge in the mixing chamber the stone is turned for several minutes under the oil torch blast before the hot Tarvia is poured in. To discharge the mixture, the engineer operates a single lever which tips the revolving cube and allows the material to drop by gravity to the wagon or wheelbarrow.

The mixers, generally of ½ yd. capacity, in unit with the stone crusher, run three batches in 10 to 15 mins. with four men; namely, an engineer, a tar man, a loading man and a helper. A wagon of 1½ cu. yd. capacity waits for the three batches to be mixed and then hauls them to the road, unually not more than a mile distant from the plant.

When the mixing machine is used on the road, the stone is dumped on a board platform at the mixer, placed some 200 ft. ahead of the point where the tar macadam is being laid, and moved as the work progresses. The loading skip of the mixer is filled by hand and the mixed macadam wheeled in barrows to the road. Portable kettles holding 100 or 200 gals. are in use at both the stationary and portable plants. The Tarvia is shipped in steam coiled tank cars, run off into barrels, and conveyed to the road in the barrels to be used as required. Contractors are asked for bids on both water-bound macadam and tar macadam. The latter price is always stated in a square yard price over and above the cost of water-bound macadam. For example, on a 6,300 sq. yd. job a price was give of $3.25 per cubic yard of stone in place with 18 cts. per square yard for bituminous work. On this 6-in. road, 1.18 gals. of Tarvia were used in the top 2 ins. of hand-mixed macadam, making a total cost of $0.935 per square yard of finished road. The contract prices average about $7,600 per mile for a 14-ft. road, or approximately $0.92 per square yard exclusive of binder. The following are the contract prices on several roads:

Coventry, R. I., length road 3.16 miles; contract price, including binder, $1.01 per square yard; Warwick, R. I., length road 4.00 miles; contract price, including binder, $0.98 per square yard. Foster, R. I., length road 4.88 miles; contract price, including binder, $0.87 per square yard. These sections were mixed by machine and the work progressed from 150 to 400 ft. per day.

The following figures, based on careful observation of the various jobs, are a close approximation of the relative costs by the two methods:

No. 1—Portable Plant on Resurfacing—2 Ins. Thick, 440 Sq. Yds.

	Per day
Foreman, ½ time	$ 2.50
Engineer	2.50
6 laborers at $1.85	11.10
Kettle man	2.25
2 men spreading at $1.85	3.70
	$22.05

This gives a cost of $0.05 per square yard for labor of mixing and spreading stone and Tarvia. The mixer turned seven to eight batches per hour, which covered 50 sq. yds. of surface. Observation of two other portable plants gave approximately the same labor cost.

No. 2—Hand Mixing on Board Platform: Resurfacing 2 Ins. Thick, 280 Sq. Yds.

	Per day
Foreman, ½ time	$ 2.50
10 laborers at $1.85	18.50
1 kettle man	2.25
	$23.25

This gives $0.085 per square yard as the cost for labor of mixing and spreading.

In work of similar nature done by the writer the labor cost for mixing and spreading a finished 2-in. course has varied from $0.12 to $0.18 per square yard. The difference of $0.05 and $0.085, or $.035, per square yard, is further increased by the saving in bitumen in the machine mix over the hand mix, amounting to .75 gal. per square yard, of approximately $0.06 per square yard. On the other hand the machine mix costs are increased by interest and depreciation and the cost of installing and moving the plant.

Cost of Asphaltic Macadam Construction on the Boulevard System of Kansas City, Mo.—C. W. Redpath gives the following in Engineering and Contracting, May 21, 1913.

The boulevard system of Kansas City (in 1913) comprised some 55 miles of improved roadways practically all of which were of macadam construction, maintained by the use of road oil which tested 19/21 B. by high grade hydrometer. This oil was applied hot from a tank by gravity or by spraying at a pressure of about 20 lbs. This was essentially an improvement in maintenance and while satisfactory to a degree has had several drawbacks, viz.:

(*a*) Oiling must be done from two to four times a year at an average cost of 1 ct. per square yard per application.

(*b*) Constant oiling has built up a thick oil cushion.

(*c*) Satisfactory repairs are impossible on this cushion.

(*d*) The thick cushion has become wavy and uneven under traffic.

Some of these roadways have been reconstructed by removing 2 ins. of the top course and replacing with a 2-in. asphalt bound wearing surface applied by the penetration method. This has proved a satisfactory solution for the improvement of the old oiled macadam pavements.

First Method.—8,300 sq. yds. of macadam were put down on Gillham Road and bound with asphalt, the asphalt being applied by the penetration method.

Most of the asphalt was received in car lots on a railroad siding near by and was hauled by wagon to a large asphalt agitator tank. It was loaded into this tank with a hand derrick, after as many of the hoops and staves as possible had been removed, the remaining pieces of the barrel being taken from the tank when the asphalt was melted.

The liquid asphalt at about 350° F. was then pumped into a small portable kettle of about 300 gals. capacity, which was supplied with a fire box to keep the asphalt at the proper temperature for pouring, and in this kettle was hauled by team to a convenient location for distribution. Here it was loaded into small hand kettles and carried to the man who poured it upon the prepared rock surface.

It was necessary to have an engineer at $3.00 per day on the agitator tank to fire and operate the pump. Only one portable kettle was used and some time was lost by the pouring gang each time it was taken away to be filled. This has been made note of in Table I, which is the complete cost report on labor and materials for applying two coats of asphalt on 8,300 sq. yds. of pavement.

Several types of small hand kettles were tried, but one which gave the best results holds 5 gals. and was made specially for this work. The liquid asphalt is spread from this kettle with a long swinging motion of the arm from right to left. The asphalt used was Texaco 96 Paving Cement, which weighs 8.25 lbs. per gallon and costs $21.30 per ton, f. o. b. Kansas City. It was delivered in ordinary wooden barrels and was very hard to strip when the weather was warm.

TABLE XV.—COST OF LABOR AND MATERIALS—APPLYING ASPHALT ON MACADAM BY PENETRATION METHOD

	First coat		Squeegee coat	
8,300 Square yards	Hours	Cost per sq. yd.	Hours	Cost per sq. yd.
Foreman, 31.2 cts. per hour	56	$0.00210	46	$0.00173
Stripping barrels and loading into big kettle	162	.00488	103	.00310
Firing large kettle and loading small kettle	97	.00438	65	.00293
Transporting small kettles	8	.00048	4	.00024
Lost time of gang	47	.00142	24	.00072
Loading and carrying hand kettles	98	.00295	49	.00148
Pouring asphalt	87	.00262	49	.00148
Spreading and wheeling Joplin flint	51	.00154	65	.00196
Roller, 50 cts. per hour	54	.00325	38	.00229
Joplin flint from car to work	......	.00158	.....	.00247
Asphalt from car to work	......	.00182	.....	.00060
Brooming Joplin flint from first coat	164	.00494	.....	....
Total labor	......	$0.03196	....	$0.01900
Asphalt ... gals.	12,732[1]	$0.13478	4,283[2]	$0.04534
Joplin flint ... cu. yds.	57[3]	.00890	89.3[4]	.01397
Total materials	......	$0.14368	.....	$0.5931
Total labor and materials	......	.17564	.....	.07831

[1] 1.534 gal. per sq. yd. [2] .516 gals. per sq. yd. [3] 18.6 lbs per sq. yd. [4] 29.1 lbs. per sq. yd.

The first coat of asphalt was covered with a layer of ¼ or ¾ in. Joplin flint, a very hard stone which is found in the lead and zinc mines at Joplin, Mo. It costs $.048 per 100 lbs., f. o. b. Kansas City, or $1.30 per cubic yard. A cubic yard of the flint weighed about 2,700 lbs. This also was received in cars on a railroad siding near by. After rolling this first coat thoroughly, all the loose Joplin flint was swept off by hand with street brooms and the road surface was ready for the second or squeegee coat of asphalt, which was applied in the same way as the first coat and covered with Joplin flint. After rolling, the surface was ready for traffic and while some loose screenings were removed afterward, most of them worked into the asphalt under traffic. All finish rolling was done with a 7-ton Springfield-Kelly tandem roller. The engineer was paid $3.00 per day and the roller is charged in the cost report at 50 cts. per hour.

As this was the first work of this kind done, some difficulty was experienced in training the laborers to handle and pour the asphalt. The foreman was paid $2.50 per day, two engineers at $3.00 per day and all labor at 25 cts. per hour. Teams were paid for at the rate of 50 cts. per hour. When asphalt was poured only part of the day, the gang was put at other work.

Second Method.—In continuing this work, 6,184 sq. yds. of pavement were laid just as the above with the exception that a different method of heating and distributing the asphalt was used. The advantages of these changes is shown in Table XVI in the reduced cost of labor per square yard. Part of this difference, however, is due to the better organization and greater skill pouring and handling the asphalt.

TABLE XVI.—COST OF LABOR AND MATERIALS—APPLYING ASPHALT ON MACADAM BY PENETRATION METHOD

6,184 Square yards	First coat Hours	First coat Cost per sq. yd.	Squeegee coat Hours	Squeegee coat Cost per sq. yd.
Foreman, 43.8 cts. per hour	27	$0.00191	16	$0.00113
Stripping barrels	27	.00109	18	.00073
Loading and firing kettles	80	.00324	45	.00182
Loading hand kettles	27	.00109	17	.00069
Carrying hand kettles	65	.00263	38	.00154
Pouring asphalt	53	.00214	30	.00122
Wheeling Joplin flint from piles to work	28	.00113	42	.00170
Spreading Joplin flint	15	.00061	27	.00109
Roller, 50 cts. per hour	27	.00219	17	.00138
Joplin flint from car to work		.00166		.00259
Asphalt from car to work		.00134		.00048
Brooming Joplin flint from first coat	115	.00465		
Total labor		$0.02368		$0.01437
Asphalt, gals.	8,720[1]	.12390	3,210.5[2]	.04560
Joplin flint, cu. yds.	41[1]	.00859	64[1]	.01341
Total materials		$0.13249		$0.05901
Total labor and materials		.15617		.07338

[1] 1.410 gals. per sq. yd. [2] 0.519 gals. per sq. yd. [3] 17.9 lbs., or 0.00663 cu. yds. per sq. yd. [4] 27.94 lbs., or 0.01035 cu. yds. per sq. yd.

Two large kettles of 500 gal. capacity and supplied with fire boxes were manufactured to order, at a cost of $300 apiece. They proved very satisfactory. The kettles were placed side by side with space enough between for a platform, the top of which was about level with the top of the kettles. A long incline plane was attached to the platform so that it could be readily removed. The barrels were stripped from the asphalt, which was rolled up the plane to the platform where it was cut up and dropped into the kettles. One kettle was loaded while the liquid asphalt was taken from the other.

The melting plant, as above described, could be quickly moved as the work progressed, so that when the distance between the kettles and the point of pouring became more than 150 ft., it was moved.

The advantages of this asphaltic macadam pavement are:

1. It does not disintegrate under impact or suction.
2. It is not slippery.
3. It is entirely waterproof.
4. Its wearing properties are excellent.
5. Its surface can be readily renewed by another squeegee coat.
6. It is easily cleaned.
7. Cuts can be quickly and neatly repaired.
8. The disagreeable feature of oiling two or more times a year is eliminated.
9. The maintenance cost is low.

The results obtained on this roadway have been very satisfactory and after six to nine months under heavy traffic it affords a smooth, resilient, waterproof and dustless pavement, which shows very little wear. It is now proposed to gradually change the entire boulevard system of Kansas City from a water bound macadam maintained with road oil to an asphaltic macadam by surfacing with a 2-in. asphalt wearing surface.

Cost of Tarvia-Macadam at Fredericton, N. B.—The following data, published in Engineering and Contracting, March 15, 1911, were given by J. L. Feeney.

During the past season two blocks of tarvia-macadam were laid by the city of Fredericton, N. B., the total amount being 5,582 sq. yds.

The broken stone used in the work was nearly all 1½ to 2-in. trap rock, though a small amount of sandstone was of necessity used. The stone was purchased from the city roads and streets department at a cost of $1.30 per ton for crushed trap rock and $1.00 per ton for sandstone.

The binder material, Tarvia X, was applied hot, the penetration method being used. Two applications of the binder were used on the wearing course and also on the top dressing. The amount of Tarvia used per sq. yd. of surface was 3.07 U. S. gals. Of this amount, 2.4 gals. were used on the wearing course and .67 gal. on the top dressing. The Tarvia cost $5.25 per cask of 48 U. S. gals., delivered in Fredericton. The total amount of Tarvia purchased was 378 casks. Of this amount, 357 casks were used in constructing the two blocks of pavement, leaving 21 casks in stock. Of the empty casks, 345 were returned to the company, this netting the city $94.15. Thus the total net cost of the Tarvia used in this work will be seen to be $1,780.10, or about 10.4 cts. per U. S. gal.

Sand was spread on the finished surface of the pavement, the amount used per 100 sq. yds. of surface being 1.55 cu. yds. The total amount of sand used was 45 loads. The cost of the sand was $1.25 per load.

The following tabulation shows the cost of material and labor for constructing the macadam, this work including a small amount of grading:

	Per sq. yd.
1,603 tons crushed trap rock at $1.30	$0.372
130 tons sandstone at $1.00	.023
Labor	.083
Teaming	.074
Rolling	.021
Engineering and superintendence	.054
Sundries	.008
Totals (5,582 sq. yds.)	$0.635

The following is the average organization of the gang engaged in grading and constructing the macadam proper:

11 laborers at $1.50 per day	$16.50
2 double teams at $3.50 per day	7.00
2 single teams at $2.25 per day	4.50
Total	$28.00

This force placed on an average 180 sq. yds. of macadam per 9-hr. day.

The cost of the tarvia treatment was as follows:

	Per sq. yd.
17,136 gals. tarvia at 10.4 cts	$0.319
Labor, heating, applying, etc	.057
Cost of plant, tools, etc	.024
45 loads sand at $1.25 per load	.010
Totals (5,582 sq. yds.)	$0.410

The gang employed in heating and spreading the binder was as follows:

6 laborers at $1.75 per day	$10.50
1 single team at $2.25 per day	2.25
Total	$12.75

With this force the binder was applied to about 185 sq. yds. of macadam each 9-hr. day. The total thickness of the completed Tarvia-macadam was 7 ins. and its total cost was $1.04½ per sq. yd. This is a rather low cost when it is considered that this Tarvia-macadam work was the first attempt in the city in the construction of this kind of pavement. The cost of the Tarvia was also somewhat high, being 12½ cts. per imperial gallon, whereas the same product can be obtained at less cost in New England cities. The essential features in the low cost of construction were the comparatively low cost of crushed stone, the short haul (the cost of hauling amounted to 31 cts. per ton mile) and the small amount of excavation necessary.

Costs of Plant and Equipment for Building Bituminous Roads.—The cost of a portable plant for asphaltic concrete roads in Chicago is given in Engineering and Contracting, Oct. 14, 1914, as follows:

Within the city limits of Chicago there are approximately 500 miles of macadam streets and roads. To accomplish the work of resurfacing the outlying roads a portable, one-car asphalt plant with a rated capacity of 2,500 sq. yds. of 2 in. asphaltic concrete in 9 hours was purchased from the Warren Brothers Co., Boston, Mass., at a cost of $13,000.

The plant was put in operation in May, 1914, and since that time has operated continuously. The rated capacity has been exceeded upon several occasions, 3,240 sq. yds. of surfacing being the maximum output in one day.

Several changes were made in the plant after its erection by W. H. Barton, the foreman, to better adapt it to the work in hand. The whole plant was changed so as to use fuel oil for heating purposes, avoiding the smoke and other inconveniences from burning coal. Also all the small lubricators were displaced by one central steam pressure lubricator with lead pipes to the various points requiring lubrication.

Operation.—In operation, the sand and stone mixed in the proper proportions are run into the dryer where the mixture is heated to 300° F. From there it is conveyed to the storage bins and thence to the measuring bins, whence it is drawn off as required to the 15-cu. ft. mixing drum. Materials are proportioned by weight.

The force employed at the mixer consists ordinarily of 1 foreman and 34 men, as follows: 1 chief drum man, 1 drum man, 1 kettle man, 1 mixer man, 1 timekeeper, 1 material man, 25 laborers, 1 assistant chemist, and 2 watchmen. The total cost of labor employed at the mixer averages $90 a day.

To facilitate the quick delivery of material at the plant a car tracer is employed who locates and keeps the cars in transit. This tracer uses a motorcycle and usually covers a distance of 75 miles each day.

Mixture.—The mixture used averages approximately as follows:

Item	Percentage
Bitumen	6.5
Sand	37.2
Stone	52.3
Filler	4.0
Total	100.0

The stone aggregate consists of clean crushed Wisconsin granite ranging from ¼ to 1 in. in diameter which cost delivered $2.25 per cubic yard. Torpedo sand is used. Portland cement serving as filler to make up the deficiency in fine material. The Mexican liquid asphalt used for binder (penetration 60 to 70) is delivered in tank cars.

Hauling.—Ordinarily about 18 teams are employed in hauling. Recently, however, 5 ton Pierce-Arrow motor trucks have been used to advantage. Material hauled in motor trucks is handled more quickly and arrives at the point where it is to be laid in better condition than when hauled by teams. The newly laid road is, however, subjected to excessive loads due to their use, all materials being, as far as possible, hauled over the completed surface.

Laying Surfacing.—Surfacing material is delivered hot in tarpaulin covered wagons, or motor trucks, and dumped directly into the prepared base. The material is raked, smoothed and tamped, to a uniform surface 2 ins. thick and finished by rolling with a 6-ton tandem roller. No paint, or finish coat of bitumen is applied, a slight roughness of surface being desired.

Force Employed.—The day labor force employed in preparing the old surface and laying the asphaltic concrete is ordinarily organized as follows: 1 asphalt foreman, 2 rakers, 2 smoothers, 2 tampers, 15 helpers, 2 watchmen, and 2 roller engineers. By far the larger part of the work consists of laying the surfacing.

Output and Cost.—As a rule, in excess of 2,000 sq. yds. of 2-in. surfacing, or about 1,000 lin. ft. of roadway 18 ft. wide, has been covered each working day of 9 hours. The average cost of all work completed, including the preparation of the old roadway and laying the 2-in. asphaltic concrete surface, has been approximately 70 cts. per square yard.

Suggestions for Selection and Use of Bituminous Paving Equipment.—The following matter is taken from a paper by W. S. Godwin and published in the Proceedings A. S. C. E., Vol. XXXIX, and reprinted in Engineering and Contracting, Dec. 31, 1913.

Hot Surfacing and Penetration Methods.—If pressure distributors are equipped with interior steam coils, and sufficient steam is supplied to keep the bituminous material at a uniform temperature of about 280° F., they are capable of distributing the heavier grades for either the hot surfacing or the penetration methods of construction.

The equipment generally used in the penetration method has been portable or semi-portable melting kettles, having capacities ranging from 50 to 500 gals., and hand-distributing pots. This method of heating and applying is expensive and the results obtained are invariably crude. The bituminous material is often too cold, and, in some cases, is overheated and damaged.

The arrangement and equipment for penetration work is most satisfactory when the contractor receives the bituminous material at the nearest railroad siding, in 6,000, 8,000, or 12,000-gal. tank cars, equipped with interior steam coils. A 20-HP. boiler may be attached to the steam coils in the tank car and thus heat the material to the desired temperature. If this arrangement is provided at the railroad siding, the hot material may be run by gravity into the distributing wagons. If this is not practicable, the material may be pumped from the car to the wagons. A horse-drawn distributing wagon may be hauled from the railroad to the work and then may be attached to a steam roller. Bituminous material received in barrels costs the contractor an additional sum of at least 2 cts. per gal. for each barrel and also the freight on the barrels, which is about 15 per cent of the gross weight. Besides, he has two or more melting kettles to operate and a very large bill for fuel to heat them.

A 20-HP. boiler and a 600-gal. distributing wagon will cost about $1,000, and, with an average haul from the railroad siding, should cover 800 sq. yds. per hour. Two 400-gal. melting kettles, at $400 each, and a dozen buckets and pouring pots will cost about $850, and will not cover one-half as great a yardage.

Should the extent of the work not warrant the purchase of such a plant, there should be secured a strong, well-built 500-gal. melting wagon and a hand distributor, having a capacity of at least 30 gals. mounted on wheels, and having a regulating distributor at least 20 ins. wide. A distributor of this kind costs $65, and should pour 250 sq. yds. per hour, using 1½ gals. in the initial pouring and ½ gal. in the flush coat. The use of pouring pots should be avoided if possible.

Mixing Method.—The cost of heating and mixing plants depends principally on their capacity and the care and material used in their construction. A small portable batch heater and mixer, similar to a concrete mixer, and capable of heating and mixing about 7½ tons per hour to a temperature of 200° F., costs $1,500. Mixers of this class are only capable of mixing stone which is larger than ¼ in. As the bituminous material is placed in these mixers hot, a 500-gal. melting kettle is required. For close or dense mixtures, stationary, semi-portable and railroad plant are used. Semi-portable plants, comprising the heating drum, mixer, melting tank, etc., cost $7,500, exclusive of any building, and have a capacity of about 75 sq. yds., or 7½ tons, of sheet-asphalt mixture per hour. The improved railroad plants, which cost about $12,000, are capable of heating and mixing sufficient asphalt and sand to a temperature of 325° F., to lay 175 sq. yds., or 17½ tons, of sheet asphalt mixture per hour. The modern duplex stationary plant, in which the large dryers, 15 cu. ft. mixers, conveyors, etc., are operated with independent motors, cost about $33,000, including a steel building. These plants have a capacity of 500 sq. yds., or 50 tons, of sheet-asphalt mixture per hour.

As mixtures of stone are laid at a lower temperature and require less bituminous material than sheet asphalt, the capacity of plants increases about 18 per cent when heating and mixing for paving of this class.

In buying a bituminous mixing plant of any kind, the contractor or municipality should receive bids only from companies which have had considerable experience in the manufacture of such machinery. It should be required that the plant be erected and operated under the direct supervision of the builder until it has met the guaranteed requirements. The guaranty should be for a certain number of pounds of properly heated paving mixture at a specified temperature, per day of 10 hours, and not a certain number of square yards. As all dense bituminous mixtures, when compressed to 2 ins. weigh very nearly 200 lbs. per sq. yd., this portion of the guaranty can easily be changed from square yards to something which is definite and easily ascertained. The contract should also state the maximum quantity of fuel to be consumed in 24 hours, and last, but not least, the date when the finished plant will be completed, erected, tested, and ready to run to the guaranteed capacity.

Cost of Asphalt Block Pavement Laid on Sand and Loam Base.—Engineering and Contracting, Feb. 6, 1918, publishes the following data:

Asphalt block pavements laid at Savannah, Ga., on a natural base have proved remarkably successful. The earliest pavement of this type was put down on Gaston street in 1906 and is now in excellent condition. On several streets where this pavement has been laid there has been no maintenance cost.

The success at Savannah is attributed largely to the character of the soil upon which the block is placed. This foundation consists of sand intermixed with a small amount of loam. Where clay has been encountered there have been some failures, due to moisture getting under the blocks and allowing a rocking motion. With the sand loam streets excellent drainage is afforded, which is absolutely necessary for the success of asphalt block pavement laid on the natural base. It is stated that success is not attained if the block is placed upon pure sand, for there is a creeping movement and the blocks are not held firmly in place.

The method employed in Savannah in laying the asphalt block pavement is as follows:

The street upon which the block is to be laid is graded to approximately the established sub-base grade, curbing and catch basins are installed and then the street is thoroughly puddled and then rolled over and over with a 10-ton roller. If any portion settles below the sub-grade base, material is added and this is compacted firmly by rolling and puddling. Grade pegs are then instrumentally set and the surface is carefully screeded or shaped to the sub-base grade with templates, care being taken that no foreign material is left upon the surface of the base. After this the blocks are carefully laid, one man following the pavers driving the blocks on the edge so as to have as tight joints as practicable. Then the surface of the block is rolled with the 10-ton roller. River sand is then used for filling the joints, and is left on the surface for 10 days to two weeks before it is cleaned off.

The average cost per sq. yd. of asphalt block pavement laid in 1916 was as follows:

	Per sq. yd.
Labor:	
Watchman	$0.010
Grading	.080
Shaping base	.010
Rolling foundation	.010
Laying block	.112
Paving backs at street intersections	.002
Placing sand and filler	.002
Cleaning up	.008
Total	$0.234
Material:	
Asphalt block	$1.540
Sand	.005
Use of equipment	.030
Small tools, coal, etc	.001
Total	$1.576
Grand total, per sq. yd	1.81

The asphalt block paving gang consisted of a foreman who was paid $4 per day, block layers paid $3 per day and ordinary laborers at $1.75 per day. The steam roller men were paid $3 per day. The size of the gang usually consisted of 20 to 25 laborers, including the drivers of teams or carts.

Cost of Asphalt and Brick Pavements, at Flint, Mich.—The following data are taken from an article by Clarence E. Ridley in Engineering Record, June 10, 1916.

Quantity of Work Completed.—The total amount of pavement built by the city by day labor during the 1915 season was 90,031.8 sq. yd., of which 73,799.6 sq. yd was sheet asphalt. In addition the city also constructed sewers, sidewalks, bridges and other work, bringing the total cost to $322,920.08. At the same time there was spent on contract work $135,320.42, thus making the total cost of improvements for the fiscal year ended Feb. 29th, 1916, $458,240.50.

The overhead engineering on all of the foregoing work amounted to $7,095.76, or 1.5 per cent of the value of the work done.

In order to afford a comparison of the figures on unit costs there are given in Table XVII the cost of materials and labor used in the construction of pavements, all the material prices being f.o.b. Flint, except that for cement, which is the price delivered on the line of work.

TABLE XVII.—UNIT COSTS OF ROAD WORK

Asphalt, per ton:	
Bermudez	$29.36
Standard	13.91
Trinidad	21.37
Texaco	14.11
Fluxing oil, per ton	8.85
Binder stone, per ton	1.28
Limestone dust, per ton	4.10
Asphalt sand, per cu. yd	1.09
Concrete gravel, per ton	0.83
Paving brick, per sq. yd	0.88
Cement, per bbl	1.29
Laborers, per hr. for 10-hr. day	0.25
Teams, per hr. for 10-hr. day	0.55

As the total excavation for paving was more than 50,000 cu. yd., and as but one steam shovel was available, it was necessary to use hand labor on about two-thirds of the work. In the selection of streets the hand labor was favored at all times, which makes the saving shown by the steam shovel even larger than is indicated by the figures in Table XVIII. In addition to the excavation it was, of course, necessary to have a hand crew working ahead of the steam

TABLE XVIII.—COMPARATIVE COSTS OF STEAM-SHOVEL AND HAND EXCAVATION

Steam-Shovel Excavation	
Total cubic yards	16,838.9
Labor cost	$ 4,965.01
Average cost per cu. yd	0.295
Average cost per sq. yd., finish grading	0.042
Total average labor cost per cu. yd	0.377
Average cost of fuels, oils, etc., per cu. yd	0.015
Reimbursement of equipment fund for depreciation and repairs	0.033
Total average cost of excavation per cu. yd	0.425
Hand Excavation	
Total cubic yards	34,464.5
Labor cost	$15,913.43
Average cost per cu. yd	0.46
Average cost per sq. yd., finish grading	0.063
Total average labor cost per cu. yd	0.570
Reimbursement of equipment fund for depreciation and repairs	0.028
Total average cost of excavation per cu. yd	0.598

roller putting the subgrade in condition for concrete. It will also be noted that the cost of this finished grading on work done by the steam shovel is one-third less than on the streets excavated by hand.

These costs show that had all the excavation been done by steam shovel a saving in cents of 17.3 times 34,464.5 would have been made, which amounts to $5,962.36. Thus, if a new machine had been bought, its cost would have been saved in a single season.

Cost of Curb Work.—With the exception of six streets on which brick pavement and stone curbing were used, and two others having straight concrete curbs, a combined curb and gutter was used. Two gangs of fifteen men each were working on this feature of the paving almost all season. By having a finisher on either side of the street the graders could follow the curb gangs very closely. An average of 400 ft. per day was placed. The unit cost of labor and material for this work is as shown in Table XIX.

TABLE XIX.—COST OF COMBINED CURB AND GUTTER

Total lin. ft. curb and gutter	47,967
Total number of wagon loads (1½ cu. yd.) gravel	2,371
Average cost gravel per load at pit	$0.93
Average cost of delivery on job per load	0.93
Average length in ft. built per load of gravel	20
Average cost of gravel per ft	$0.0924
Average length in ft. of curb and gutter per bbl. of cement	10.7
Average cost of cement per ft	$0.1206
Average cost of labor	0.1300
Reimbursement of equipment fund for depreciation and repairs	0.0214
Total average cost of curb and gutter per ft	$0.3644

Cost of Concrete Foundations.—A 6-in. concrete base of 1:3:6 mixture was placed on all the streets. The gravel was unloaded from cars and delivered on the line of the work by teams and wagons. The average length of haul was 0.47 miles, and the average cost per ton-mile was 39.6 cents. It will be noted that for this length of haul the cost falls very close to the ton-mileage curve plotted for hauling asphalt. Table XX gives the cost of the concrete work for the year.

TABLE XX.—COST OF CONCRETE FOUNDATIONS

Total number sq. yd. foundation	90,031.8
Total number carloads gravel	554.0
Total weight of gravel, in tons	26,420.0
Average weight of gravel per car, in lb	95,300.0
Average cost of gravel on tracks per car	$39.55
Average cost of unloading cars:	
(1) Shovelers (hand)	4.50
(2) Teaming	9.00
Total number wagon loads (1½ cu. yd.) gravel	10,819.0
Average number wagon loads per car	19.5
Average weight of wagon load, in lb	4,880.0
Average cost per wagon load on track	$ 2.03
Average cost per wagon for delivery on job	0.69
Cost of gravel on tracks per ton	0.83
Average cost of unloading gravel per ton	0.091
Average cost of hauling gravel per ton	0.182
Amount of gravel per sq. yd. foundation, in lb	587.0
Cost of gravel per sq. yd. on track	$ 0.244
Cost of unloading and delivering on street per sq. yd	0.08
Total average cost of gravel per sq. yd	0.3240
Cost of water per sq. yd	0.0075
Number of sq. yd. foundation per bbl. cement	5.47
Average cost of cement per sq. yd	$ 0.2350
Amount of depreciation on equipment	0.0007
Average cost of labor per sq. yd	0.0850
Total average cost of foundation per sq. yd	$ 0.6522

Brick Surfacing.—It has already been stated that but 16,232.2 sq. yd. of brick pavement was laid. As this amounted to only about 18 per cent of the total paving and was made up of comparatively small jobs, its cost is not as low for this class of work as the main surfacing costs are for asphalt paving work. The average cost of brick paving, with a stone curb and 6-in. foundation, excluding the cost of excavation, was $2.128 per square yard. The amount of material per square yard of surface was 40 brick, $\frac{1}{40}$ bbl. of cement. $\frac{1}{25}$ load of cushion sand and $\frac{1}{200}$ load of slushing sand. The cost of material and labor for these items per square yard is shown in Table XXI.

Table XXI.—Cost of Brick Surfacing

Brick, f. o. b. Flint	$0.88
Delivering brick on line of work	0.08
Cement	0.03
Cushion sand	0.04
Slushing sand	0.01
Fixing sand bed, laying, rolling and slushing brick	0.16
Total average cost of brick surface	$1.20

Saving on Sheet Asphalt.—The greatest saving was made on sheet-asphalt surface. Enough money was made on this work alone to more than pay for the plant and equipment twice over. Exclusive of grading, the average cost of asphalt paving was $1.51 per square yard. All of the sheet-asphalt pavements were laid in residence districts with widths of 24 and 26 ft. Texaco asphalt was generally used in the binder with an average penetration for the season of 75.5. Mexican asphalt mixed half and half with either Bermudez or Trinidad was chiefly used in the top with an average penetration of 65.3. An average of 24.9 per cent of the sand used passed an eighty-mesh screen, and 29.3 per cent of the total aggregate used passed this screen.

The percentage of bitumen for the season averaged 10.9. The total cost of the plant and equipment is listed in Table XXII.

Table XXII.—Cost of Asphalt Plant

Original cost of plant erected	$9,245.00	
Cost of foundation	380.76	
Kettle shed	493.92	
Buildings (office, engine room and limestone dust shed)	742.88	
Flux oil tank	302.89	
Miscellaneous equipment for plant and street	638.14	
Total cost of plant and equipment		$11,803.59
Cost of five asphalt wagons	$ 824.76	
Cost of asphalt roller	2,350.00	
Total cost of street equipment		$3,174.76
Grand total		$14,978.35

Of the above items of plant, the equipment, asphalt plant, wagons and roller were allowed a depreciation of 20 per cent, and the rest a depreciation of 10 per cent, amounting in all to $2,803.63. The asphalt plant is located on the Pere Marquette Railroad, as near the center of the city as possible. The average hauling distance during the past season was 0.96 miles, but one haul of more than 2 miles and one of less than $\frac{1}{4}$ mile occurred. The average cost of delivering the asphalt during the year amounted to 23.7 cents per ton-mile. The asphalt surfaces placed consisted of $1\frac{1}{2}$ in. of binder and a 1-in. top. The average amounts of material used and cost per square yard of surface are given in Table XXIII.

The total yardage of sheet asphalt, 73,799.6, times the difference in the contract price offered for the work and the actual cost, 38 cents per square yard, equals $28,043.85. Less $2,803.63 depreciation, this amounts to $25,240.22 saved on the asphalt surfacing alone.

TABLE XXIII.—AVERAGE AMOUNTS OF MATERIAL USED, AND TOTAL COST PER SQUARE YARD

	Amount per sq. yd.	Cost per lb.	Cost per sq. yd.	
Binder Material				
Texaco asphalt	5.47 lb.	$0.007055	$0.03859	
Fluxing oil	.15 lb.	0.004425	0.00066	
Sand	16.35 lb.	0.000425	0.00695	
Binder stone	89.70 lb.	0.000640	0.05740	
Cost of material in binder				$0.1036
Top				
One-half Trinidad and one-half Mexican	18.50 lb.	0.008820	0.16317	
Fluxing oil	2.20 lb.	0.004425	0.00973	
Sand	147.15 lb.	0.000425	0.06254	
Limestone dust	15.20 lb.	0.002050	0.03116	
Material in top				$0.2666
Coal, electric power and water				0.0200
Labor at plant				0.0844
Labor on street				0.0668
Teaming				0.0330
Salary of expert, engineer in charge and assistants				0.0300
Total average cost of asphalt pavement per square yard				$0.6044

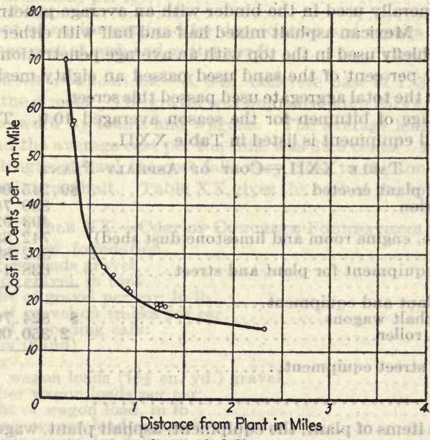


FIG. 3.—Cost of delivering asphalt.

Cost of Sheet Asphalt Pavement at Montreal, Que.—Engineering and Contracting, Jan. 3, 1917, publishes the following data.

The introduction of a cost keeping system and a consequent better method of handling construction has resulted in a marked reduction in the cost of sheet asphalt pavement in the city of Montreal, Que. In 1914 the total cost of this pavement was $2.79 per square yard. In 1915 it was $2.13, a reduction of 23.6 per cent over the cost of the previous year, and in 1916 it was $1.93. The pavement consists of a 6-in. 1:3:6 concrete base, a 1-in. binder and a 2-in. wearing surface. The city has the following asphalt plants:

Division	Plant built, year	Daily capacity, yds.	Cost
East	1903	1,000	$16,000
West	1909	1,500	22,000
North	1914	2,000	28,000
Portable	1914	1,500	26,000

During 1915, 600,000 sq. yd. of sheet asphalt pavement were laid. The detailed cost of the work, according to a paper presented at the annual convention of the American Society of Municipal Improvement by Paul E. Mercier, Chief Engineer of the city, was as follows:

	Per sq. yds., cts.
Grading	
Foremen	2.4327
Timekeepers	.1166
Engineers	.1590
Layers	.0477
Drillers	.0689
Water boys	.0742
Watchmen	1.9186
Laborers	26.9240
Teamsters	17.5536
Material	......
Sundries	0.4081
Repairs, int., etc	3.2913
Total grading	52.9947
Foundation	
Foremen	1.6340
Timekeepers	.1140
Engineers	.6555
Layers	.0285
Watchmen	1.9000
Laborers	11.6565
Teamsters	13.1195
Autos	.0380
Stone	16.2830
Sand	15.0575
Cement	27.8350
Sundries	2.2705
Repairs, int., etc	4.8080
Total foundation	95.4130
Surface	
Foremen	.5873
Timekeepers	.1097
Engineers	.6454
Spreaders	1.4263
Tampers	.8003
Watchmen	.4131
Laborers	2.8913
Teamsters	.7099
Autos	1.2849
Material	......
Asp. bin. and wear	52.2193
Sundries	1.4844
Repairs, etc	1.9878
Total surface	64.4754

	Grading, per sq. yd., ct.	Foundation, per sq. yd., ct.	Surface, per sq. yd., ct.	Total per sq. yd., ct.
Labor	49.2953	29.1590	8.7839	87.2382
Material	......	59.1755	52.2193	111.3948
Sundries	3.6994	7.0785	3.4722	14.2501
Total	52.9947	95.4130	64.4754	212.8831

The cost of material and the wages in 1915 were as follows:

Bitumen—$14.25 per ton f.o.b. plant.
Sand—75 to 98 cts. per ton f.o.b. plant.
Stone—$1.10 to $1.70 per ton f.o.b. plant or works.
Stone dust—$5.45 per ton f.o.b. plant.
Flux—10¾ cts. per imperial gallon.
Cement—$1.71 per barrel f.o.b. plant or works.
Laborers—25 cts. per hour.
Teamsters—60 cts. per hour.

As noted previously, the unit cost of the sheet asphalt laid in 1916 was $1.93 per square yard. In further detail the cost was—

	Grading, per sq. yd., ct.	Foundation, per sq. yd., ct.	Surface, per sq. yd., ct.	Total, per sq. yd., ct.
Labor	32.8257	26.9681	12.8364	72.6302
Material	.6571	50.3405	60.6638	111.6614
Sundries	3.8084	3.7504	1.4692	9.0280
Total	37.2912	81.0590	74.9694	193.3196

The cost of material and wages for 1916 was as follows:

Bitumen—$19.33 f.o.b. plant.
Sand—75 cts. to $1.10 f.o.b. cars or wharf.
Stone—$1.00 to $1.40 f.o.b. plant or works.
Stone dust—$4.90 f.o.b. plant.
Flux—10¼ cts. f.o.b. plant per imperial gallon.
Cement—$1.76 f.o.b. plant or works per barrel.
Laborers—25 cts. per hour.
Teamsters—60 cts. per hour.

Cost of Constructing an Asphalt Surface Drive with Sunken Concrete Curb.—W. T. Colman and M. H. West furnished the following information and costs published in Engineering and Contracting, Feb. 15, 1911.

Among the numerous improvments and extensions made in the drives of Lincoln Park, Chicago, was the construction of a 40 ft. drive, which extended the Sheridan Road pavement for a distance of 4,631 ft. The design of the street is unique in that it is so built as to allow the water to run off the street onto the lawn at the side, which is graded so as to form a hollow along each side of the road. The road is 40 ft. wide with a 7-in. crown, and has 2 ins. of asphalt on an 8-in. base of crushed stone. At the sides of the drive are reinforced concrete curbs 5 ins. thick, extending from the surface of the street 24 ins. deep. The top ½ in. of the curb is surfaced with a grout containing ½ lb. of lamp black per bag of cement, for the purpose of giving the top of the curb the same appearance as the asphalt street.

The material upon which the road was built consists of a gumbo clay. A stretch of about 300 ft. of this had to be taken out to a depth of from 3 to 5 ft. because the 15-ton roller, used on the crushed stone base, could not produce a satisfactory surface on account of the soft clay. A 15-ton Springfield roller was used for the stone and a 5-ton roller on the asphalt. The stone was brought in barges from the Artesian Stone Co.'s plant on the Chicago Drainage Canal and landed at the park docks. At the docks the barges were unloaded with a clamshell bucket operated by a derrick and the material dumped into an elevated bin of about 10 cu. yds. capacity. Troy wagons were driven under the bin to receive their loads. The road work paralleled the shore line of the lake at only a short distance from it so the length of haul was not great.

Curb.—The concrete curb was formed by 16 ft. panel forms of which there were about 500 lin. ft. employed. The curb was reinforced with three ½-in.

square bars as shown in the accompanying section of the street. These were 20 ft. long and lapped 6 ins. at the ends. They were suspended in the forms in templets made of a ¼-in. piece of pine, which was left in place to form the expansion joint.

The cost of excavation for the curb is included in the cost given for the curb itself, and that for placing the stone includes the cost of the preparation of the road bed for receiving the stone. In this work a large amount of local rubble stone was mixed in with the crushed stone, the object being to fill up the deeper places, as far as possible, with local material.

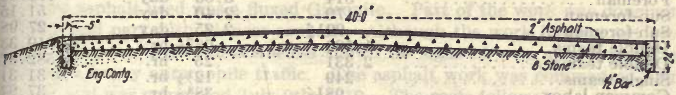


FIG. 4.—Section of asphalt surfaced drive showing sunken concrete curb.

The building of the concrete curb was started on April 14, 1910, and was completed June 29th. The costs of the 9,263 lin. ft. of curb follow. Foremen's rates are monthly and sub-foremen daily:

Labor	Time,	Rate		Total
Engineering	hrs.			$ 136.47
Foreman	91	$125.00	mo.	48.60
Sub-foreman	666½	3.00	day	222.16
Dump wagons	343	.66⅔	hr.	228.67
2-wheeled wagons	112	.12½	hr.	14.00
Common labor	24	.38½	hr.	9.20
Common labor	932	.30	hr.	279.60
Common labor	382	2.50	day	106.11
Common labor	17,500	.25	hr.	4,395.00
Skilled labor.				
Carpenters	253	.62½	hr.	157.50
Carpenters	56	.60	hr.	33.60
Timekeepers	13	55.00	mo.	3.06
Timekeepers	73	55.00	mo.	20.40
Teamster	3	2.62½	day	.87
Teamster	320	60.00	mo.	81.56
Tools				19.24
Total cost				$5,881.59
Labor cost per lin. ft.				$0.64

Material	Quantity	Price
Cement at $1.25 per bbl.	495	$ 621.88
Crushed stone at $1.50 per cu. yd	318	477.00
Torpedo sand at $1.60 per cu. yd	213	340.80
Lamp black at $0.08 per lb	124½	9.94
Reinforcement rods at $43.00 per ton	12.64	543.52
Total		$1,993.14
Cost of material per lin. ft		.21

The cost of form lumber is not included.

UNIT COSTS OF CURB

	Cost per lin. ft.
Engineering	$0.005
Foremen	.029
Carpenter labor	.022
Common labor	.517
Transportation	.055
Miscellaneous	.015
Total labor	$0.643
Material	.21
Total cost per lin. ft.	$0.85

Crushed Stone Base.—The work of placing stone was carried over from the previous year at which time some stone had been deposited for use at various intervals of time. The stone was placed on the road about 8 ins. thick and covered an area of 23,160 sq. yds. The costs of this work, which follow, include the local rubble stone which was also placed in the work to help fill out.

Labor	Time, hrs.	Rate		Total
Engineering	....	....		$ 220.37
Foreman	13½	$150.00	mo.	8.67
Foreman	284	125.00	mo.	144.87
Foreman	514	3.00	day	171.50
Sub-foreman	170	2.40	day	51.15
Sub-foreman	99½	2.25	day	27.98
Double teams	1,529	.66⅔	hr.	1,019.33
Double teams	2,331	.25	hr.	582.87
Single teams	249	.12½	hr.	31.31
Common labor	98½	.38½	hr.	37.94
Common labor	59	.30	hr.	17.70
Common labor	332	2.50	day	92.53
Common labor	257	.25	hr.	6,314.25
Skilled labor				
Steam roller engr	928½	.50	hr.	464.25
Timekeeper	28	.55	hr.	56.54
Timekeeper	27	65.00	mo.	7.48
Teamster	153	2.62½	day	44.77
Teamster	2,445½	60.00	mo.	619.76
Tug	28	3.85	day	107.80
Scows	50 ds.	4.34	day	217.00
Derrick	24 ds.	20.47		473.88
7 stone scows	....	45.00		315.00
Tools	....	....		564.71
Total cost				$11,500.66
Total labor cost per sq. yd				$ 0.498

Material	Quantity	Price
Crushed stone at $1.65 per cu. yd	17.5	$ 28.87
Crushed stone at $1.50 per cu. yd	3,453.78	5,181.68
Crushed stone at $1.40 per cu. yd	464.25	649.95
Crushed stone at $1.00 per cu. yd	167.50	167.50
Crushed stone at $0.70 per cu. yd	3,885	2,719.50
Crushed stone at $1.50 per cu. yd	71.64	107.56
Total		$8,855.06
Cost of material per sq. yd		$ 0.394

UNIT COSTS OF CRUSHED STONE BASE

	Cost per sq. yd.
Engineering	$0.010
Foremen	.020
Skilled labor	.049
Common labor	.284
Transportation	.089
Miscellaneous	.046
Total labor	$0.498
Material per sq. yd	.394
Total cost per sq. yd. 8″ deep	$0.892

The 70 ct. stone was that brought by barges from the Drainage Canal and the price is for stone at the quarry. The $1.00 stone was purchased from a material yard and does not include hauling. The other stone items show the prices paid for stone delivered from various material yards at different seasons of the year.

Asphalt.—The total amount of asphalt upon the street amounted to 22,318 sq. yds. and was placed 2 ins. thick. The material was mixed in a Link Belt Co. asphalt mixer in the following proportions:

	Lbs.
1 part torpedo sand	168
1 part bank sand	168
3 parts ½" stone	504
Asphalt	81
Total 7 cu. ft. or 1 box	921

The asphalt used was a fluxed Gilsonite. Part of the work was done with Sarco and part with Pioneer asphalt. Although the work has not yet been laid one year, it has nevertheless shown no signs of wear or deterioration under a heavy automobile traffic. The asphalt work was commenced April 29th, and was completed July 9th, 1910. The costs follow;

Labor	Time hrs.	Rate		Total
Engineering				$ 57.18
Foreman	566½	$150.00	mo.	$ 362.01
Sub-foreman	2	125.00	mo.	1.07
Sub-foreman	28	3.00	day	9.33
Sub-foreman	4	2.50	day	1.10
Troy dump wagons	439	.66⅔	hr.	159.29
Troy dump wagons	421½	.25	hr.	105.38
Two-wheel carts	469	.12½	hr.	57.63
Common labor	1,579	.38	hr.	608.10
Common labor	18	.35	hr.	5.30
Common labor	1,510	.30	hr.	453.00
Common labor	13	2.50	day	3.61
Skilled labor	16,122½	.25	hr.	4,030.63
Timekeeper	97	65.00	mo.	25.25
Steam roller engr	1,836½	.50	hr.	918.25
Machine man	438	3.15	day	153.12
Machine man	325	2.80	day	100.17
Teamsters	8	2.62	day	2.34
Teamsters	878	60.00	mo.	224.70
Tools				479.88
Derrick				60.00
Total cost				$7,817.34
Labor cost per sq. yd				$0.352

Material	Quantity	Price
Torpedo sand at $1.60 per cu. yd	495.2	$ 724.37
Bank sand at $1.60 per cu. yd	459.2	505.12
Crushed stone at $1.50 per cu. yd	371.0	556.50
Crushed stone at $0.70 per cu. yd	940.1	658.08
Granite screenings at $3.75 per cu. yd	109.5	409.59
Sarco asphalt at $24.00 per ton	52.91	1,269.84
Pioneer asphalt at $19.44 per ton	239.85	4,663.32
Total cost of material		$8,786.82
Cost of material per sq. yd		$ 0.394
Cost of labor and material per sq. yd		0.746

	Per sq. yd.
Engineering	$0.003
Foreman	.017
Skilled labor	.234
Common labor	.048
Transportation	.026
Miscellaneous	.024
Total labor per sq. yd	$0.352
Material	.394
Total cost per sq. yd	$0.746

SUMMARY OF COSTS

Labor on stone, per sq. yd.	$0.498
Labor on asphalt, per sq. yd.	.352
Stone for base, per sq. yd.	.394
Asphalt material, per sq. yd.	.394
Total cost per sq. yd.	$1.638
Labor cost on curb, per lin. ft.	.64
Material cost on curb, per lin. ft.	.21
Total cost of curb per lin. ft.	$0.85

The above figures are based upon a nine hour day.

Plant.—The plant used on the work is the property of the Lincoln Park System. All repairs and operations are charged into the work but no charge for depreciation is made against the work.

The cost of the plant is as follows:

Link Belt Co., asphalt mixer	$ 5,590
Gasoline tractor	1,200
6-ton roller	1,800
15-ton roller	1,500
Asphalt tanks and tools	1,000
Total value of plant	$11,090

Cost of Asphalt Street with Concrete Base and Gutters.—The following data, given in Engineering and Contracting, March 15, 1911, refers to a half-mile extension of a street bordering Lincoln Park, Chicago. The work comprised the removal of an old pavement, the preparation of the subgrade for the new pavement 27 ft. wide with a 6-in. concrete base and 2-in. wearing surface of asphalt and a combination concrete curb and gutter.

The work was done by force account by the Lincoln Park Commissioners, of which M. H. West was Superintendent and Fred Howitt Engineer of Parkways.

Curb and Gutter.—The concrete curb and gutter work was commenced Sept. 29 and completed Dec. 1, amounting in all to 4,708 lin. ft. The cost was as follows:

Labor	Cost per lin. ft.
Engineering	$0.0196
Foreman, per mo. $75	0.0270
Double teams, per hr. $0.66⅔	0.0091
Single teams, per hr. $0.33⅓	0.0000
Common labor, per hr. $0.25	0.1908
Skilled labor, per hr. $0.30	0.0925
Timekeeper, per mo. $65	0.0019
Total labor	$0.3409

Material	Cost per lin. ft.
117 cu. yds. gravel at $1.50	$0.0373
98 cu. yds. torpedo sand at $1.60	0.0331
24 cu. yds. stone at $1.50	0.0076
273 bbls. cement at $1.35	0.0782
Lumber	0.0079
Steel	0.0172
Lamp black	0.0045
Tools	0.0015
Total material	$0.1873

Excavating Subgrade.—The excavation and preparation of the subgrade was not begun until the curb and gutter work was about half completed on Nov. 1. The preparation of the subgrade involved the removal of old macadam and some old cedar block pavement. It is estimated that the entire area was excavated about 6 ins. deep. The surplus material was loaded by hand into wagons and was carted about ½ to ¾ mile to the lake front. A 15-ton roller was used to finish the subgrade. The costs of this work were as follows:

	Cost per sq. yd. pavement
Engineering	$0.0035
Foreman	0.0144
Skilled labor	0.0124
Common labor	0.1378
Teams	0.1328
Timekeeper	0.0015
Steam roller, 20 days	0.0122
Total	$0.3146

Concrete Base.—Following upon the preparation of the subgrade the 6-in. concrete base was placed. This work was started Oct. 31 and completed Nov. 22. The materials were distributed along the street and the mixer was moved forward as the work progressed. One of the interesting parts of this work was the use of a wood template. It was with difficulty that the men were induced to use this template in beginning the work, but after a few days the men found it indispensable. The boards used to shape the pavement are arranged to be raised and lowered by means of thumb screws. By this means the layers of the concrete base were shaped up, and later, the asphalt. During the construction of the concrete base, each day's work was covered with manure and canvas as it was feared that freezing weather might suddenly set in. The cost of the concrete work follows: There were 7,427 sq. yds. 6 ins. thick or 1,238 cu. yds.:

Labor	Cost per sq. yd.
Engineering	$0.018
Foreman	0.017
Double teams	0.004
Single teams	0.007
Common labor	0.133
Skilled labor	0.108
Totals	$0.197

The cost per cubic yard for labor was thus $1.182.

Materials	Cost per sq. yd.
Cement at $1.35 bbl	$0.206
Stone at $1.40 yd	0.294
Torpedo sand at $1.50 yd	0.004
Lumber, expan. joints, etc	0.007
Wood template	0.004
Tools and sundries	0.003
Mixer, rent $162, hauling $15, fuel $12	0.025
Canvas	0.007
Oil and waste	0.0004
Totals	$0.550

The cost per cubic yard for materials was $3.30.

Asphalt.—The asphalt used consisted partly of Sarco brand and partly of Pioneer brand. A Link Belt Co. asphalt mixer, which was purchased by the park at a cost of $5,590, was used. It was operated by belt from a gasoline traction engine. A 6-ton roller was used on the asphalt, giving a compression of 266 lbs. per sq. in. The asphalt work consisted of 7,427 sq. yds. of 2-in. surface. It was started on Nov. 7 and completed Dec. 1, 1910. The costs were as follows:

Labor	Cost per sq. yd.
Engineering	$0.009
Foreman	0.016
Teams	0.032
Common labor	0.240
Skilled labor	0.043
Timekeeper	0.003
Total	$0.343

Materials	Cost per sq. yd.
Stone at $1.40	$0.085
Sand at $1.60	0.050
Sand dug at site $1.00	0.022
Asphalt, "Sarco," at $24 ton	.....
Asphalt, "Pioneer," at $19.44 ton	0.301
Lumber for exp. joints	0.002
Brooms, 4	0.001
Coke	0.033
Gasoline	0.008
Engine oil, waste, etc	0.002
Tools	0.004
Steam roller	0.009
Link Belt mixer	0.027
Total	$0.544

A summary of the costs of the road work is as follows:

Labor per sq. yd. concrete base	$0.197
Material per sq. yd. concrete base	0.55
Labor per sq. yd. asphalt	0.343
Material per sq. yd. asphalt	0.544
Preparation of subgrade per sq. yd	0.314
Total	$1.948

Cost of Asphalt Paving Repairs in St. Paul, Minn.—Engineering News, July 9, 1914, gives the following data from the report of the Commission of Public Works.

In 1912 the city of St. Paul, Minn., purchased a municipal asphalt plant at a cost of about $15,000. The plant consists of a Warren Bros. portable asphalt plant, one 8-ton asphalt steam roller, one scarifier, one Lutz surface heater, one fire wagon, one gyratory stone crusher, two portable melting kettles, six 2-cu. yd. steel-lined asphalt wagons, four ¾-cu. yd. concrete spreaders, one set of curb cutter's tools, nine asphalt rakes, testing scales, and the necessary small tools. The accompanying table gives an itemized cost of the plant.

	No.	Rate	Cost
Warren Bros'. portable asphalt plant...........	1	....	$4850
Steam roller, 8-ton..........................	1	....	2250
Scarifier....................................	1	....	365
Lutz surface heater..........................	1	....	1800
Fire wagon...................................	1	....	112
Melting kettles..............................	2	$425.00	850
Asphalt wagons, 2 cu. yd.....................	6	171.50	1029
Concrete carts, ⅔ cu. yd.....................	4	117.00	468
Koehring concrete mixer, No. 14..............	1	....	1950
Tandem steam roller, 8-ton...................	1	....	2200
Koehring paver, No. 14.......................	1	....	1900
Chain belt paver, No. 15.....................	1	....	1770
Chicago concrete mixer, No. 5................	1	....	481
Tinius-Olson brick tester....................	1	....	475

The plant was put into operation Apr. 25, 1912, and during the season of 1912 was worked a total of 92 days. The amount of asphalt pavement turned out during the season was 19,428 sq. yd.; 15,040 sq. yd. of this was cut out work and 4388 sq. yd. burner work. Besides this, 5459 sq. yd. of asphalt pavement were put down for paving contractors in repairing pavements built under a guaranty; of this, 2363 sq. yd. was cut out work and 3095 sq. yd. burner work. The total cost was $6013, which was charged to and collected from the contractors.

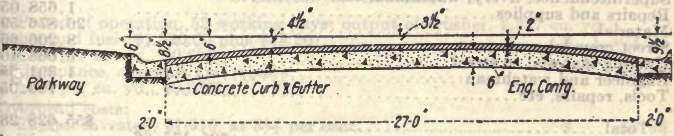


FIG. 5.—Cross section of street and gutter.

All asphalt-paving repairs during the year 1913 were made by this municipal asphalt plant. The plant was put in operation March 30, and during the season worked 178 days. Asphalt paving to the amount of 44,194 sq. yd. was turned out; 43,296 sq. yd. of this was cut out work and 897 burner work. Asphalt repairs for contractors were made to the extent of 16,832 sq. yd., of which 16,039 sq. yd. was cut out work, and 793 sq. yd. was burner work. The total cost was $21,613, which was collected from the company which had guaranteed the pavement.

For the City Ry. Co., 7370 sq. yd. of asphalt pavement were laid, and the cost, $11,031, collected from the company. For other public-service corporations, 1250 sq. yd. of asphalt pavement and 148 sq. yd. of concrete foundation were laid. This work cost $2340, which was collected from the various corporations.

About 246 sq. yd. of asphalt pavement was laid on bridges on which the city maintains the wearing surface; this cost $430, and was charged against the bridge building and repair fund at $1.75 per sq. yd. Small repairs were made for other city departments and charged against those departments at $1 per sq. yd. The repairs to asphalt pavements on which the guaranty period had expired and for which the city paid, amounted to 14,487 sq. yd. of cut out work. This repair work cost the city $18,490, an average of $1 per sq. yd.

The following shows cost and relative data regarding asphalt repairs for the year 1913.

Total area of pavements on which repairs were made in sq. yd.	222,327
Area or repairs in square yards	18,733.18
Per cent. of area repaired	8.42
Cost of repairs	$ 18,921.34
Average cost per square yard of total area	0.085

Cuts in asphalt pavement made by the City Water Department, heating, lighting and telephone companies, sewer contractors and others, were repaired, at a cost of $2340, which was collected from the various companies.

Cost of Operation.—The operating crew at the plant consisted of one foreman, one engineman, one tank man, four laborers, and a night watchman. Four teams were employed hauling asphalt from the plant to the work.

The street crew was made up of one foreman, one timekeeper, one roller man, two rakers, two tampers, one smoother and one cement man laying new pavement; and two shovelers, six scrapers and two teams removing and hauling old paving. The total expense was divided as follows:

Operation of plant, labor		$ 5,889.02
Fuel		1,024.47
Hauling material		1,559.18
Superintendence, livery, watchman, etc		3,164.21
Repairs and supplies		1,658.05
Material		26,876.59
Street crew labor		8,206.66
Hauling material to street		5,068.40
Engineer and watchman		1,391.65
Tools, repairs, etc		790.05
Total		$55,628.28
Total labor	$25,175.66	
Total material	30,452.62	
		55,628.28
Charged to outside parties	$34,194.23	
Charged to bridges	430.49	
Material on hand	2,512.71	
		37,137.43
Total cost to city of work		$18,490.85

Cost of Operating Municipal Asphalt Plant of District of Columbia.—Engineering and Contracting, June 6, 1917, publishes the following:

All minor repairs of asphalt pavements in the District of Columbia are made from the output of a portable municipal asphalt plant. This plant also is employed in furnishing product for the construction of an asphalt macadam wearing surface on old macadam streets. The plant, a Warren Bros.' portable asphalt plant, with a nominal capacity of 100,000 lb. per day was purchased and installed in 1912 at a cost of $6,900. Since that date it has been operated from 220 to 240 days per year, with an average output of about 80 per cent of its capacity.

During the fiscal year ending June 30, 1916, the plant was operated 236 working days, with an average daily output of 715 cu. ft. and a total output of 168,684 cu. ft. Old material was used to considerable extent. Old asphalt topping removed from the streets in resurfacing was crushed to a finely broken product to which was added the new material. The use of this old topping resulted in a substantial saving. A Noyes crusher was used for breaking up the old material. The cost of the crusher, including a portable engine and boiler, was $1,910.

The following data on the work of the municipal asphalt plant for the fiscal year are taken from the report of the operations of the Engineer Department of the District of Columbia:

The following amounts of materials were purchased for use in manufacturing the output during the year:

Sand, 2,160.50 cu. yd. at	$ 1.03
Asphaltic cement, 461.74 tons at	10.00
Limestone dust, 205 tons at	2.53
Screenings, 855 tons at	1.32

There was purchased for use in operating the crusher and mixer the following large items:

Fuel oil, 23,927 gal. at	$0.031
Coal, 170 tons at	3.45
Wood, 80 cords at	5.00

The costs of operation, including material and labor, are kept from day to day, and the summary of this data for the fiscal year ending June 30, 1916, develops the following unit costs for the year's operations:

OPERATION OF CRUSHER

Period of operation, 52 working days; output of crusher, 2,327 cu. yd.	
Labor and fuel ($1,320.06 plus $83.20)	$ 1,403.26
Cost per cu. yd., $0.603.	
Maintenance, renewals and repairs	83 04.
Cost per cu. yd., $0.0357.	
Overhead costs:	
Capital invested, $1,910, at 3½ per cent	$ 66.85
Obsolescence, 5 years, at 20 per cent	382.00
Cost per cu. yd., $0.193.	
	$ 448.85
Cost of crushed product, per cu. yd.:	
Labor and materials	$ 0.603
Repairs to plant	.036
Overhead	.193
	$ 0 832

OPERATION OF PLANT

Period of operation, 236 days; total output, 168,684 cu. ft.	
At plant:	
Labor (3.56 cts. per cu. ft.)	$ 6,004.18
Fuel oil (0.50 cts. per cu. ft.)	776.68
Coal (0.27 cts. per cu. ft.)	455.80
Wood (0.13 cts. per cu. ft.)	223.60
Binder stone	82.50
Tool repair (0.20 cts. per cu. ft.)	329.66
Total (4.71 cts. per cu. ft.)	$ 7,872.42
Haul from plant to street:	
Labor (3.85 cts. per cu. ft.)	$ 5,904.05
On street:	
Labor (12.3 cts. per cu. ft.)	$18,905.53
Painting joints (0.15 ct. per cu. ft.)	236.00
Wood (0.13 ct. per cu. ft.)	223.60
Tool repair (0.10 ct. per cu. ft.)	164.63
Total (12.68 cts. per cu. ft.)	$19,529.96

Maintenance and repairs:	
At plant (0.22 ct. per cu. ft.)	$ 365.93
On street (0.15 ct. per cu. ft.)	228.94
Total (0.37 ct. per cu. ft.)	$ 594.87
Overhead:	
Capital invested, $6,900, at 3½ per cent	$ 241.50
Obsolescence, 5 years, at 20 per cent	1,380.00
Total (1 ct. per cu. ft.)	$ 1,621.50
Supervision:	
Foremen and overseers (3.7 cts. per cu. ft.)	$ 6,239.67
Total manufacturing costs per cu. ft.:	Cents
Plant, labor	4.71
Hot haul	3.85
Street work	12.68
Maintenance of plant and tools	.37
Overhead—	
Interest and obsolescence	1.00
Supervision	3.70
	26.31

The sand used was bought under a contract at 44 ct. per cubic yard and hauled from the wharf to the plant at a cost of $1,266.26 for 2,160.5 cu. yd., or 59 ct. per cubic yard, a total of $1.03 per cubic yard. All other material was delivered at the plant site at the costs shown below.

The cost of cubic foot of old material mixture was as follows:

0.67 cu. ft. crushed material, at 83.2 ct. per cu. yd	$0.0206
0.27 cu. ft. sand, at $1.03 per cu. yd	.0103
3.89[1] lb. asphaltic cement, at $10 per ton	.0195
Total material	$0.0530
Manufacturing and placing cost	.2631
Total (cu. ft.)	$0.3161
Asphaltic concrete mixture:	
0.5 cu. ft. screenings, at $1.32 per ton	$0.0330
0.5 cu. ft. sand, at $1.03 per cu. yd	.0190
4.2 lb. limestone dust, at $2.53 per ton	.0053
9.16[1] lb. asphaltic cement, at $10 per ton	.0458
Total material	$0.1031
Manufacturing and placing costs	.2631
Total per cu. ft	$0.3662

[1] Includes 10 per cent tare.

The plant operating force consisted of one foreman at $100 per month and the following per diem employes:

1 Steam engineer (operating mixing plant) at	$3.50
1 Steam engineer (operating crusher) at	3.00
1 Timekeeper at	3.00
7 Laborers (operating plant) at	1.75
12 Laborers (operating crusher) at	1.75
4 Laborers (miscellaneous, including watchman) at	1.75
12 Carts* (hot haul) at	2.50

* Hauling hot material from plant to street operating or patching gangs.

There are two patching gangs, each of which consists of the following units of per diem employes:

1 Foreman at	$4.00
5 Skilled laborers (1 shoveler, 2 rakers and 2 tampers) at	2.25
5 Skilled laborers (rollermen, cutting out and miscellaneous) at	2.00
10 Skilled laborers (miscellaneous) at	1.75
2 Wagons (hauling old material to dump and hauling barricades) at	5.00
1 Cart (hauling tool and fire wagons) at	2.50

In connection with the supervision of the above there are two inspectors, one of whom is employed at a salary of $125 and the other at $100 per month. These men are held responsible for the character and performance of all the work, prepare all statements and reports in connection therewith and map out the various routes to be followed.

Reference Note: In Engineering and Contracting, March 5, 1913, data are given on the operation of municipal asphalt plants in 20 cities as abstracted from the report of David E. McComb upon an investigation of the desirability

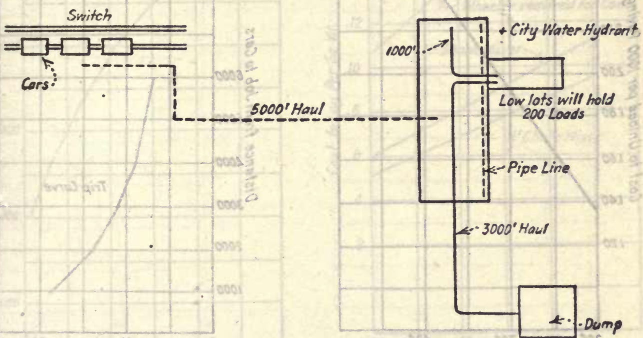


FIG. 6.—Sketch showing various conditions relating to paving job.

and cost of establishing a municipal plant for the District of Columbia.

Labor Hour Requirements on Brick Paving Work.—D. B. Davis gives the following in Engineering and Contracting, May 5, 1920.

In estimating the cost of paving work, while the labor market is constantly changing from month to month, estimators who have an indefinite knowledge of the labor hour requirements for the divisions of work necessary, are liable to have their estimates incompatible with the true value of the work. A knowledge of the labor hours necessary to do a certain work together with accurate price quotations on the materials which enter into it, will give the estimator much more faith in his estimates.

In making an estimate of a certain work a chart showing the various conditions relating to the work will help to guarantee against omission of important details. This chart can be a rough sketch, which in case of a brick paving job in a city, will show the length of haul from the nearest switch to the job; the length of haul from the closest dump to the job; the kind and nearest water supply and other matters of interest one will record on making an inspection of the site. An example of a chart of this kind is shown in Fig. 6.

A brief study for determining the labor hour requirements for some divisions of work connected with a brick paving job in a city will be undertaken. The excavation in this case will be assumed to be completed.

To estimate the cost of unloading and hauling brick from the cars to the job, it is first necessary to figure on the cost of unloading them. It has been the experience of the writer on a number of his jobs that a working unit consisting of five men loading from the cars to the wagons and six men at the job, unloading these wagons as they come, will unload approximately on an average of 19,300 paving brick in a 10-hour day. Or it requires approximately 5.7 labor hours to handle the brick from the cars to the pile. Fig. 7 shows the cost to unload brick to the pile at different rates of wages for labor

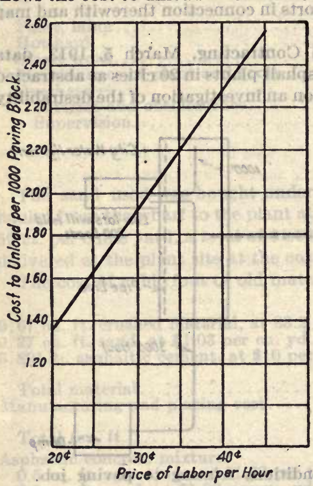


FIG. 7.—Cost of unloading brick from cars and on job.
Assumption: 5.7 labor hours per M.

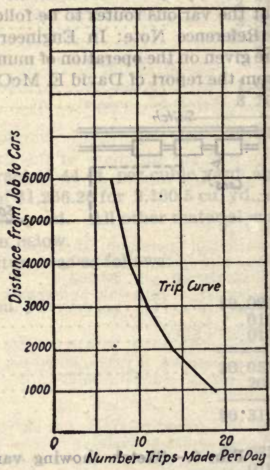


FIG. 8.—Curve showing number of loads per day.
Extra wagons provided to prevent idle time.

To haul the brick from the switch to the job, extra wagons are provided, so that the teamster after having hauled the loaded wagon to the street to be unloaded can immediately hitch to an extra empty one and proceed back to the switch. In this way no team time is lost while waiting for loading or unloading the wagons.

The number of loads that can be hauled in a given length of time can be determined by the formula:

$$\text{Number of loads hauled} = \frac{T}{\frac{L}{r} - z}$$

In which T = total working time in minutes.
L = length of haul (round trip).
z = lost time in minutes, unhitching, etc. (this will average 17 minutes).
r = rate of team travel (180 ft. per minute).

Fig. 8 shows this formula plotted for different lengths haul.

Now to find the teams required; find from Fig. 8 the number of trips per day corresponding to the length of haul. Then the number of trips × the capacity of each load equals the number of brick that one team will haul. Then

$$\frac{19{,}300}{\text{number brick hauled by one team}} = \text{number of brick required.}$$

Fig. 9 shows the cost of hauling brick for various lengths haul. In this case team hire is figured at 80 cents per hour and the capacity of each load at 665 brick.

The total cost of handling and hauling the brick may be found by adding the values from Figs. 7 and 9.

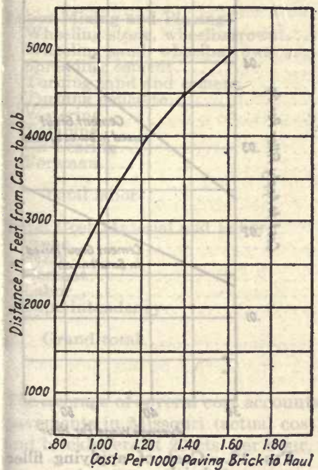


FIG. 9.—Cost of hauling brick. Team, $8 per day; 665 brick per load.

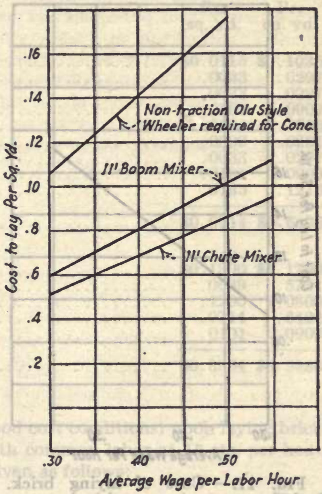


FIG. 10.—Cost of laying 1 : 7 6-in. concrete base.

To estimate the labor required to lay a concrete base 6 in. thick the required organization should first be outlined. Such an organization, where the concrete mix is 1 part cement and 7 parts gravel and a 1-sack steam chute mixer is used, is as follows:

1 Engineer mixer.	3 Gravel wheelers.
1 Fireman mixer.	3 Gravel shovelers.
2 Concrete spreaders.	1 Water boy.
1 Handling cement.	1 Foreman.

This gang will lay concrete base requiring approximately 0.20 labor hours per square yard. Fig. 10 shows values platted when using a 1-bag chute, boom and an old-style non-traction mixer which requires men to wheel the 1-bag mixed concrete from the mixer to the bed.

To estimate the labor required to lay the brick in the pavement, it is well to remember the divisions of labor required. For the ordinary city pavement it will require five divisions. The following table gives these divisions with coefficients relating to each:

Sand bed mixers	0.00742
Brick carriers	0.01320
Brick setters	0.00214
Batting in closures	0.00200
Cement grouting, by hand mix	0.00797
Cement grouting, machine mix	0.00460

To find the number of men needed for each division of work to balance the whole gang, multiply the required output by the factors opposite each division in the table and take the closest even number.

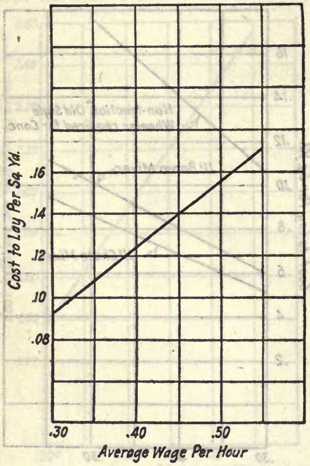


FIG. 11.—Cost of laying brick. Includes preparing sand-bed, carrying brick, laying brick, batting in closures and foreman.

Assumption: 0.31 labor hours per sq. yd.

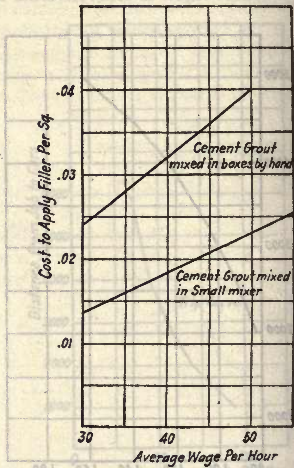


FIG. 12.—Cost of applying filler to brick pavement.

Assumption: Mixing by hand, 0.080 hrs. per sq. yd.; mixing by machine, 0.046 hrs. per sq. yd.

For example, to find the number of men needed to carry brick in order to lay 1,000 sq. yd. in 10-hour day: Multiply 1,000 yd. by 0.0132, which makes 13.2 or 13 men needed.

Fig. 11 shows the costs of laying brick in pavements at different rates of wages. It is figured on the assumption that the operations named require 0.31 labor hours per square yard.

Fig. 12 shows the cost of applying cement grout filler. The lower line shows the cost when using a small grout mixer and the upper line shows the cost when using the old-style grouting boxes, which require mixing by hand. With labor at 50 ct. per hour it can be seen that a saving of 1¾ ct. per square yard is made by using the gasoline grout mixer.

The labor hours required for these various operations were obtained from the writer's experience and represent work that has been done by energetic, enthusiastic workmen. The proximity which another gang could approach these values would depend wholly on the morale of the workmen and the experience and "pep" of the man in charge.

Cost of Brick Paved Roads.—The following data, published in Engineering and Contracting, May 29, 1912, have been taken from a Road Bulletin of the Highway Department of the Missouri State Board of Agriculture. The following figures are the actual cost, not including miscellaneous items, etc., upon 12,000 sq. yds. (1,333 cu. yds.) of hand-mixed 1:4:7 street concrete base 4 ins. thick, put down under average good conditions in Missouri.

	Per sq. yd.	Per cu. yd.
Labor Mixing and Placing:		
Wheeling stone, wheelbarrows	$0.0115	$0.1035
Wheeling sand, wheelbarrows	.0033	.0297
Spreading cement	.0033	.0297
Turning sand and cement	.0101	.0909
Turning concrete	.0134	.1206
Watering	.0029	.0261
Tamping	.0033	.0297
Off-bearing	.0101	.0909
Foreman	.0135	.1215
Total labor	$0.0714	$0.6426
Total Cost Material and Labor:		
Stone	$0.1300	$1.1700
Sand	.0639	.5751
Cement	.1200	1.0800
Labor	.0714	.6426
Superintendency	.0101	.0909
Grand total	$0.3954	$3.5586

The average of several cost accounts (good cost conditions) upon laying brick pavements in Missouri (actual cost) with common labor at 15 cts. per hour and bricklayers at 20 cts. per hour, is given as follows:

	Per sq. yd.
Labor for Laying Brick:	
Preparing sand cushion	$0.0095
Stacking brick	.0060
Wheeling brick	.0105
Laying brick	.0075
Culling brick	.0035
Batting and grouting	.0045
Cleaning	.0030
Foreman	.0025
Total labor	$0.0470
Material:	
Sand	$0.1000
Brick	.7000
Grout	.0180
Total material	$0.8180
Superintendency	.0050
Grand total, labor and material	$0.8700

Other costs for brick pavement on concrete base show the following:

	Per sq. yd.
Shaping subgrade	$0.10
Concrete base, 4-in.	.45
Sand cushion, 2-in.	.10
Brick, 45 per sq. yd.	.95
Total	$1.60

Labor Cost of Monolithic Brick Pavement.—The following data are taken from Engineering and Contracting, Sept. 4, 1918.

Monolithic brick pavement was constructed on the Highline Road in King County, Washington, at a labor cost of about 23 cts. per square yard. The paved section was 20 ft. wide. The concrete base was a 1 : 3 : 6 mix, 3 in. thick at the sides and 5½ in. at the crown. The blocks for part of the work were vertical fiber bricks, 4 × 8½ in. × 2¾ in. deep; for the remainder standard paving blocks 4 × 8½ in. × 3½ in. deep, laid flat, were used. The average labor cost for 91,500 sq. yd. of pavement laid between June and October, 1916, was as follows:

	Per sq. yd.
Concrete base, 4⅜ in. thick	$0.086
Sand-cement cushion	.018
Laying brick	.072
Grouting	.033
Sprinkling	.005
Curb forms	.012
Total	$0.226

The above figures include the cost of covering the completed pavement with 1 to 2 in. of earth and removal of same. The average paving crew was as follows:

	Per day
Superintendent	$6.00
Mixer crew:	
1 foreman	4.00
1 mixer engineer	5.00
2 subgrade men	2.75
4 shovelers	2.75
8 wheelbarrow men	2.75
2 cement men	2.75
2 concrete spreaders	2.75
1 concrete rodder	2.75
Cushion crew (5 men)	2.75

	Per day
Brick crew:	
1 bricklayer	$7.00
1 batter-in	3.00
1 liner	2.75
6 carriers	2.75
4 pilers	2.75
Grout crew (8 laborers)	2.75
Covering, uncovering and sprinkling (2 men)	2.75
Curb forms:	
1 man	4.00
1 helper	2.75
1 water boy	1.50

The concrete for the base was mixed in a 21 cu. ft. Koehring mixer of the boom and bucket type. The 1 : 3 sand cement cushion was mixed in a 3-ft. Little Wonder mixer. The bricks were handled by laborers with brick clamps.

Organization and Output of Brick Paving Gang in Vermilion County Roads.—Engineering and Contracting, Sept. 4, 1918, gives the following.

In the construction of the monolithic brick pavement for the Vermilion County, Illinois, Bond Issue Roads, the average gang consisted of 32 men distributed as follows:

CONCRETE GANG	PAVING GANG
Ahead of Mixer:	1 Brick setter.
1 Form setter.	3 Stackers.
5 Wheelers.	1 Starter (also helps with tamping).
3 Shovelers.	1 Batter.
1 Cement man.	5 Carriers.
At Mixer:	1 Culler.
Mixer operator.	1 Roller.
Fireman.	3 Men grouting.
Behind Mixer:	1 Man wetting down pavement and pulling forms.
2 Men spreading concrete.	
1 Man tamping concrete and carrying forward boards for mixer runway.	

With this organization about 800 sq. yd. of pavement was laid per day. The pavement is 10 ft. wide and consists of a 4-in. wire-cut-lug paving brick laid directly on a fresh concrete base 4 in. thick at the side and crowned 1 in.

The gang, as given above, did not deliver the materials from the freight cars to the road. Materials were delivered on a narrow gage (2 ft.) track laid alongside the pavement. The sand and stone were dumped from cars on the subgrade, and the brick was stacked in piles on the other side of the track. In stacking brick and in delivering brick onto the road, the bricks were handled with tongs.

Labor Cost of Brick Paving on Country Roads.—The following data, based on the experience of the New York State Highway Commission, were published in Engineering and Contracting, Feb. 19, 1913.

The cost of brick paving on country roads varies according to local conditions. Highway contractors make use of various labor-saving devices to decrease the cost of construction. All unloading of stone and sand is done by machines. Many contractors are using traction engines for the hauling of material; some use small gage tracks with locomotives and cars. A modern concrete mixer is very necessary.

From the data obtained from various roads, a fair estimate of cost, based on labor at 17½ cts. per hour, teams at 50 cts. per hour, and foreman at 35 cts. per hour, would be as follows:

Labor cost per square yard, brick paving in place, exclusive of concrete base:

	Per sq. yd.
Unloading and piling brick	$0.035
Hauling brick one mile	0.040
Laying and rolling	0.070
Making sand cushion	0.020
Grouting	0.028
Expansion joints	0.007
Culling, replacing, etc.	0.005
Total labor	$0.205

No office or incidental charges are included in the above.

The manipulation of the concrete for the base varies from 40 cts. to 60 cts. per cu. yd., using batch machines and depending on gravel or stone concrete. (The average bid price for brick pavement in Western New York, including concrete base 5 in. thick, but excluding excavation, was $2.05 per sq. yd.)

Cost of Vitrified-brick Pavement on an Old Macadam Base, Carlisle, Penn.—John C. Hiteshew gives the following matter in Engineering News, Dec. 24, 1914.

During the 1914 season 2,493 sq. yd. of vitrified-brick pavement were laid by the Street Department of Carlisle, Penn., under the supervision of the writer.

Track Section.—The section paved comprised one block on High St., the main business street, through which the tracks of the Cumberland Valley R.R. run. The railroad company was unwilling to pave between and along the tracks, but it agreed to construct a concrete curb, 6 × 18 in., set 2 ft. from outside face of curb to rail. The concrete was a 1 : 2 : 3 mix with a 1 : 1 finish coat, and was constructed by contract at a price of 35c. per lin. ft.

Pavement Base.—The old macadam with which the street was paved was used as a base for the new brick paving. The macadam had a depth, before excavation, of at least 18 to 20 in.

In grading, the old macadam was spiked up with a 13-ton steam roller, excavated to subgrade, and thoroughly dry rolled, as with wet rolling the macadam showed a tendency to push ahead of the roller, causing waves.

In shaping the base spikes were set to subgrade at 7-ft. intervals across the street, and the final shaping done by hand picking. After rolling, new spikes were set, which supported the 3 × 8-in. by 16-ft. guides for a striking template.

Concreting Filled-in Trenches.—The Gas & Water Co. had recently renewed a great many trenches along the street, and poor foundations existed in the old gutters, so it was deemed advisable to fill all these new trenches and the gutters with concrete 5 in. deep.

Stone Cushion.—The cushion was composed of limestone dust and screenings, 1½ in. in thickness; and was struck off by means of a short striking template drawn by three men. The cushion was then rolled with a 250-lb. roller drawn by hand.

Laying Bricks.—The bricks were laid by one foreman and two men, one of the men breaking half-brick to fill in ends of courses. Usually there were three men carrying to each brick layer. An average of 7000 bricks were laid by each man per day. Vitrified-shale paving blocks were used.

Rolling Bricks.—Rolling was done with a 5-ton horse roller drawn by 12 men.

Grouting.—The joints were grouted with a 1 : 1½ portland-cement grout.

Expansion Joints.—A ¾-in. "Elastite sandwich" joint was used longitudinally along the four curbs and transversely over 75 ft.

"Elastite" was found to be a great improvement over the old pitch expansion-joint filler, doing away with the boards, wedges, heating the pitch, etc., and the first cost of the joint was practically the entire cost, as it took very little time to place it in position.

Sand Covering.—The green pavement was covered with ½ in. of sand for several days. Traffic was turned on the pavement at the end of five days.

Cost Data.—The following is an itemized list of cost data:

	Cost per sq. yd. of pavement
Unloading and hauling brick	$0.0777
Grading and rolling subgrade	0.1126
Concreting trenches	0.0848
Crushed stone cushion	0.0543
Brick	0.8600
Laying brick	0.0376
Rolling brick	0.0062
Grouting	0.0845
Expansion joints	0.0356
Covering with sand	0.0047
Total	$1.358

Dump wagons were charged at the rate of 10 and 15c. per hr. The reason for this was that they were fire teams; one was paid 10c. per hr.; for the use of the other the Street Department paid the driver's salary, which was $1.50 per day, or 15c. per hr.

The bricks were purchased in March at a reduction of $1 per M. The great advantage in this was that we got a better run of bricks and had them when needed, and we saved $1 per M, or $100 on the year's work.

All macadam excavated was used in resurfacing streets adjacent to the work. Approximately 20,000 sq. yd. were thus resurfaced.

It will be noticed that a stone cushion was used instead of sand. The reason was that when first tried as an experiment the stone formed a compact cushion without becoming too solid, and at the same time reduced the cost by one-half.

During the season of 1913 5,689 sq. yds. of vitrified brick pavement were laid. Mr. Hiteshew gives the cost of this work in Engineering and Contracting, April 15, 1914, as follows:

COST OF BRICK PAVING AT CARLISLE, PA. IN 1913

Item—	Cost per sq. yd.	
Unloading, hauling & piling bricks	$0.065	
Grading & rolling macadam base	.091	
Stone cushion and rolling with 500-lb. roller	.052	
227,560 brick at $21 per M	.840	
Laying and rolling brick	.034	
Cement grout filler	.068	
Expansion joint	.010	
Totals	$1.16	
Total number of sq. yds.		5,689
Cost per sq. yd.		$1.16

Note.—An average of 7,000 brick per man per day were laid.

COST OF LABOR AND MATERIALS FOR BRICK PAVING AT CARLISLE, PA.

Item—	Rate
Foreman, per hour	$ 0.25
Laborers, per hour	0.16
Roller engineer, per hour	0.25
Cement, per bbl. (net)	1.32
Sand, per ton	1.50
Brick, per M	21.00

In 1909 the cost of 2,070 sq. yds. of similar pavement, given in Engineering and Contracting, Feb. 2, 1910 by C. A. Bingham, was as follows:

SPIKING UP AND CARTING OFF OLD MACADAM

	Per sq. yd.
Roller engineer, 45 hrs. at $0.20	$0.0046
Foreman, 55 hrs. at $0.17	.0048
Laborers, 261 hrs. at $0.14	.0188
Carting, 192 hrs. at $0.25	.0238
Coal, 2.5 tons at $4.00	.0052
Total (1,935 sq. yds.)	$0.0572

RAKING, LEVELING, ROLLING, ETC., MACADAM BASE

Foreman, 34 hrs. at $0.17	$0.0029
Roller engineer, 39 hrs. at $0.20	.0040
Laborers, 56 hrs. at $0.14	.0041
Crushed stone, 69 cu. yds. at $0.98	.0349
Coal, 2 tons at $4.00	.0041
Total (1,935 sq. yds.)	$0.0500

Dust Cushion

Foreman, 25 hrs. at $0.17	$0.0020
Laborers, 50 hrs. at $0.14	.0033
Crusher dust, 66 cu. yds. at $0.98	.0312
Total (2,070 sq. yds.)	$0.0365

Unloading, Hauling, Stacking Blocks

Foreman, 45 hrs. at $0.17	$0.0037
Laborers, 390 hrs. at $0.14	.0264
Carting, 363 hrs. at $0.24	.0421
Total (2,070 yds.)	$0.072

Block

85,660 at $19.00 M.......... $1,627.54 or $0.786 yd.

Laying Blocks

Foreman, 127 hrs. at $0.17	$0.0104
Laborers, 402 hrs. at $0.14	.0271
Total (2,070 sq. yds.)	$0.035

Rolling and Inspecting

Team, 15 hrs. at $0.20	$0.001
Laborers, 63 hrs. at $0.14	.004
Total (2,070 sq. yds.)	$0.005

Grouting

Cement, 44 bbls. at $1.20	$0.0254
Sand, 11 tons at $1.40	.0074
Foreman, 32 hrs. at $0.17	.0071
Laborers, 106 hrs. at $0.14	.0091
Sand covering, 5 tons at $1.40	.0034
Total (2,070 sq. yds.)	$0.0459

Recapitulation

	Per sq. yd.
Excavation	$0.057
Grading	0.050
Cushion	0.036
Haul, etc	0.072
Blocks	0.786
Laying	0.037
Rolling	0.005
Grouting	0.046
Grand total	$1.089

Cost of Grouting Brick Pavements.—H. E. Bilger, Engineer of the Illinois State Highway Department gives the following data in an article published in Engineering and Contracting, Dec. 6, 1916.

Quantity of Grout Required per Unit Area.—With a grout composed of 1 part cement and 1 part sand, it has been found that 1 barrel of cement, with an equal volume of sand, will make sufficient grout to cover the areas below under the two types of bed for the brick:

4-In. Brick on Ordinary Sand Cushion

32 sq. yd. if repressed brick is used.
24 sq. yd. if wire-cut lug brick is used.

4-In. Brick on 3/8-in. Mortar Bed

30 sq. yd. if repressed brick is used.
22 sq. yd. if wire-cut lug brick is used.

It will be noted that by using the mortar bed instead of the customary sand cushion, an equal volume of grout covers a smaller number of square yards, this being due to the fact that when the sand cushion is used, some of the sand finds its way up between the brick and prevents the entrance of the grout for the full depth of the brick.

It has been found that 10 gals. of water are necessary to build complete a 4-in. brick pavement with a grout filler on a 4-in. concrete base.

Labor Cost for Grouting Brick.—In some of the state jobs the labor cost varies from about 1.6 cts. per square yard to 3.9 cts. These matters are so dependent upon the efficiency of the organization rather than upon the rate per hour, that the cost is largely dependent upon the foreman in charge. As a fair average figure for estimating purposes, when labor is 25 cts. per hour, the actual labor cost without making any allowance for overhead, etc., is about 2½ cts. per square yard of brick pavement.

Cost of Grouting Brick Pavements.—Engineering and Contracting, Oct. 20, 1915, publishes the following:

The cost of 1-1 grout filling for 58,000 sq. yds. of brick pavement at Centerville, Iowa, as reported by M. A. Hall, city engineer, was as follows:

Item	Cts. per sq. yd.
Screening sand at 20 cts. per hour	0.05
Dry mixers at 22½ cts. per hour	0.15
Wet mixers at 20 cts. per hour	0.20
Rubbers at 20 cts. per hour	0.43
Wheelers at 20 cts. per hour	0.13
Other men at 20 cts. per hour	0.03
Water boy at 10 cts. per hour	0.04
Foreman at 40 cts. per hour	0.14
Total labor	1.17
0.017 bbl. cement at $2	3.40
0.034 ton sand at $1.05	0.35
Total materials	3.75
Grand total	4.92

On 26,500 sq. yds. of this pavement the labor cost of grouting joints is reported to have been only 0.9 ct. per square yard.

The costs of 1-1 *grout filling* and *sand covering* for six sections of the Byberry and Bensalem service test road built by the Philadelphia department of public works are reported as follows:

Section 4	Cts. per sq. yd.
Cement at $1.30	3.51
Sand at $1.885	3.67
Labor	3.49
Total:	10.67

Section 8	Cts. per sq. yd.
Cement at $1.30	3.64
Sand at $1.885	3.34
Labor	2.08
Total	9.06

Section 10	Cts. per sq. yd.
Cement at $1.30	3.65
Sand at $1.885	3.32
Labor	3.50
Total	10.47

Section 13	Cts. per sq. yd.
Cement at $1.30	3.66
Sand at $1.885	3.31
Labor	1.86
Total	8.83

Section 18	Cts. per sq. yd.
Cement at $1.71	3.56
Sand at $2.015	4.67
Labor	3.14
Total	11.37

Section 26	Cts. per sq. yd.
Cement at $1.65	4.56
Sand at $1.82	3.24
Forms at $32 per M	0.32
Labor	3.63
Total	11.75

The volumes, per square yard, of sand used for *grout and covering* on these six sections were as follows:

Area, sq. yds.	Cu. yds. sand	Sand, cu. yds. per sq. yd.
462.5	9	0.0195
535.5	9.5	0.0177
534.4	9.4	0.0177
621.4	10.9	0.0175
430	7.6	0.0177
1,004.4	17.87	0.0177

The cost at Carlisle, Pa., of 1-1½ grout filler for brick pavement laid in 1913, with wages at $1.60, cement at $1.32 and sand at $1.50, was 6.8 cts. per square yard.

The labor cost of grouting brick pavement laid at Fort Worth, Tex., in 1914, was 1.7 cts. per square yard. The methods were: The grout for the filler was composed of equal parts of cement and sand and enough water to make it flow properly. An average of 0.021 bbl. of cement per square yard was used. Two grout boxes were used when a full gang was working, and where the work was extensive and the weather permitted fast bricklaying, a third box could have been used to advantage. To keep the men around the boxes from standing idle waiting for a batch to be mixed, the cement and sand were mixed dry on the concrete base or on the finished pavement and wheeled to the boxes as fast as needed. This shortened the length of time of mixing in the box and made it about equal to the time it took for the other box to be emptied, thus keeping the whole gang employed. To keep the cement and sand from separating the grout was agitated continuously until the last bit had been dipped out. The first pouring was made thin enough to flow into all cracks and was kept swept ahead by means of steel street brooms. After the first pouring had progressed 25 to 40 ft., depending upon the weather and whether or not the brick were thoroughly dry, one box was turned back to apply the second and final coating. This second pouring was mixed thicker than the first and rubber squeegees were used to fill the joints flush and keep the blocks free from surplus grout. To obtain the ¼-in. joint at the rail it was necessary to fill it flush with the top as with the rest of the pavement and then, before it has set hard, to clean the grout out with pointed stick or trowel. Soon after the second coat of grout was placed the whole surface was covered with about ½ in. of damp sand. On dry, hot days the brick were well sprinkled before pouring the grout, considerable water being used for this purpose.

Labor Cost of Laying Brick Gutter.—The following costs, published in Engineering and Contracting, May 1, 1918, cover the work of laying 850 sq. yd. of brick gutter, 12-in. wide, and include all labor except for the delivery of materials. The gutter was laid as a water course for asphalt pavement on a very flat surface. The curb and base were, of course, previously in place. The items covered include sorting and laying bricks, cleanup, grouting, sand cushion, etc. The work was done during good weather by a good foreman but indifferent crew. The total hours for the three items listed are correct, but the work of spreading cushion, laying brick, etc., was not separated, and is, therefore, included under the single item of "Labor." The usual standard specifications governed the work and they were strictly enforced, particularly as regards grouting. The cushion was spread dry 1½ in. thick, previously thoroughly mixed in the proportions of 1 part cement to 5 parts sand. Grout was mixed 1:1 in small quantities to the consistency of cream, and spread immediately after mixing. The labor cost of the work was as follows:

	Per sq. yd.
Foreman, 85 hrs. at 50 ct	$0.049
Labor, 729 hrs. at 30 ct	.257
Cleanup, etc., 61 hrs. at 36 ct	.021
Total (850 sq. yd. brick gutter)	$0.327

Cost of Tearing up and Replacing Brick Pavement for Trench.—F. L. Shidler gives the following data in Engineering and Contracting, June 2, 1915.

The trench was as near as possible to the curb and crossed under two sets of street car tracks and two street intersections. The costs given are for tearing up brick pavement down to grout base, trenching sand cushion and replacing same, relaying brick pavement and slushing with cement filler for laying a wire conduit for ornamental street lights. They also include the cost of sixteen 1 ft. 4 in. square holes about 16 ins. deep, cut through cement and stone sidewalks, filling these holes with concrete and setting four base bolts in each hole. The cost for the post holes, etc., was as follows:

Item	Per hole
Labor cutting, 25 hrs. at 50 cts	$0.78
Labor concreting	0.31
Total labor	$1.09
12 wood templets for base bolts	0.19
2 cu. yds. concrete at $3.60	0.45
Miscellaneous	0.07
Total materials, etc	$0.71
Grand total	$1.80

The cost of the trench 1½ ft. wide and 1,130 ft. long was as follows:

Item	Lin. ft.
Tearing up and cleaning brick	$0.019
Relaying brick	0.025
Teaming	0.004
Total labor	$0.048
2 cu. yds. cushion sand	......
4 bbls. cement	......
300 new brick	......
Miscellaneous	......
Total materials	$0.016
Grand total	$0.064

Removing Block Pavement Between Track Rails by Plowing.—(Engineering and Contracting, June 7, 1916.) For two years the Cleveland Ry. Co. has used a special plow for rooting up block pavement between rails whenever reconstruction of track was required. The plow first built was experimental and somewhat crude in detail. The apparatus consists of a cast steel spear-shaped blade with shallow mold boards attached to the front end of a steel frame truck mounted on car wheels. The truck has a wooden body in which the necessary counter weighting load can be placed. In operation the truck is pulled by a work train and the plow blade loosens the pavement as illustrated. The designer of this plow, Chas. H. Clark, Engineer Maintenance of Way, Cleveland Ry. Co., furnishes the following data: Cleveland Railway Co. has had one of these pavement plows in operation for the past two years, during which time we have made some very remarkable records; the following are only a few of the many instances in which the plow has worked and the time in which it has taken up the pavement:

4,500 ft. on Woodland Ave. in 28 minutes.
3,200 ft. on Woodland Ave. in 30 minutes.
1,500 ft. on E. 55th St. in 12 minutes.
1,000 ft. on Euclid Ave. in front of Hotel Statler to E. 9th St. in 4 minutes.
1,475 ft. on Lorain Ave. in 13 minutes.

Cost of Cleaning Old Paving Brick by Compressed-Air Hammers.—Charles S. Butts gives the following data in Engineering News, July 23, 1914.

The construction of the Rocky Branch joint district sewer at St. Louis, Mo., involved the disturbance of a considerable extent of paved street. The work is 5,724 ft. long (on Blair, Palm and Glasgow Aves.) and was done by the James Black Masonry & Contracting Co., at a price of about $500,000.

Of the total length, 4,600 ft. was in streets having brick paving grouted with cement, the paved width being 17 to 30 ft., and the total paved area being about 10,000 sq. yd., with about 530,000 brick. The specifications require the contractor to repave the streets and leave them in as good a condition as before the construction of the sewer.

The question was (and always has been) whether it pays to clean vitrified paving brick (cement grouted) for use in repaving streets. In cleaning them by hand a man can clean about 300 a day. And at $4.50 per 1,000 (which was paid for this method of cleaning) he would make only $1.35 per day. In order to make it any inducement to clean them by hand about $9 per 1,000 would have to be paid. The contractor finding this method not only slow but also unsatisfactory, abandoned the hand-cleaning method and adopted the following machine method which has proved very satisfactory.

An old vacuum-cleaning wagon was obtained and set up in a convenient location at the pile of brick to be cleaned and used as an air compressor. A ½-in. supply pipe was run to a cleaning board, and to it were connected ¼-in. hose, to each of which was attached a 6½-lb. stone-mason's vibrating air hammer. The hammers had 1-in. chisel points for cleaning the portland-cement grout from the brick. A bench was built and about 70 bricks placed on it with the side upward. One side and one end were cleaned first; then they were turned and other side and other end were cleaned. As there was no cement on top or bottom it required only one turn to complete the cleaning. The capacity of this particular machine is three hammers, and, as the following table shows, the more hammers operated, the cheaper the brick can be cleaned.

	1 hammer	2 hammers	3 hammers
No. brick cleaned per day	1,200	2,400	3,600
Cleaning brick, $2 per 1,000	$2.40	$4.80	$7.20
Turning brick, $1 per 1,000	1.20	2.40	3.60
Gasoline for machine	1.40	1.40	1.40
Cost	$5.00	$8.60	$12.20
5 % for care of tools, etc	0.25	0.43	0.61
Total cost	$5.25	$9.03	$12.81
Cost per 1,000 brick	4.375	$3.762	$ 3.3558

The difference in cost per 1,000 is due to the gasoline used, it costing $1.40 per day to run the machine whether one, two or three hammers are used. To the above costs per thousand for cleaning must be added about $2 for hauling to the pile and back on the street, which would make the cost (using the two-hammer price) $5.76 per 1,000. This against $16 per 1,000 for new brick makes a saving of $10.24 per 1000 for the small-size brick (2¾ × 4 × 8¼ in.). The large paving brick now in use (3¼ × 8½ × 4⅜ in.) would cost about $4.50 per 1,000 to clean, plus $2 for hauling, making $6.50 per 1,000 against $22 for new brick, a saving of $15.50 per 1,000.

Cost of Cleaning Paving Brick by Compressed Air Power.—C. G. Cummings gives the following matter in Engineering and Contracting, March 7, 1917.

An interesting application of a portable, self-contained, engine-driven air compressor was developed some four years ago by C. F. Crowley, Commissioner of Public Works, of the city of Troy, N. Y. This consists in removing and cleaning old paving brick. The equipment used for this work, which was purchased in 1913, consisted of a 15-H.P. Sullivan Class WK-3, portable, single stage air compressor, the compressor being operated by a gasoline engine, mounted on the same truck with the compressor, and operating the compressor through a gear and pinion.

This outfit furnished compressed air for a Sullivan "DA-15," 25-lb. plug drill, and a Sullivan "DB-13" hand bushing tool equipped with bits like that on a cold chisel. The larger of the two tools is used for tearing up the brick, and the smaller for cleaning the old mortar and grout from them. With the plug drill one man can remove 4 sq. ft. of pavement in 15 or 20 minutes, taking the bricks up either one brick at a time or several, as desired. When doing this work by hand, the workmen were frequently obliged to break several bricks, which were perfectly good, in order to get out one, so that the loss was considerable.

Before the purchase of this outfit the cost of removing and cleaning bricks by hand was $24 per thousand and a crew of 10 men was able to handle about 1,000 bricks per day. The detailed cost of operating the compressor and drill outfit was as follows:

1 compressor engineer	$ 3.00
7 gallons of gas at 18 cts	1.26
4 operators at $1.85	7.40
Lubricating oil	.25
Total cost per day	$11.91

The above, of course, does not include interest or depreciation. Mr. Crowley estimates that about 2,000 bricks are removed and cleaned in eight hours with the two tools. This brings the cost of taking up and cleaning to $5.96 per thousand bricks. On work done with this outfit in 1914 a crew of 40 men was cut down to 18 men. It is estimated that this outfit pays for itself on every 100,000 bricks taken up and cleaned. Savings included labor on the brick, saving in the sand cushion, saving in time in making the bed under the brick and in laying the brick. Cement and grouting are also saved.

Mr. Crowley gives the following table showing the number of bricks cleaned each year and the saving made by the use of this outfit:

	Brick cleaned	Saving
1913	229,000	$ 4,122
1914	82,200	1,480
1915	356,000	6,400
1916	100,000 (Est.)	1,800
	767,200	$13,802

Cost of Toothing Brick Paving with Air Compressor.—The Highways section of the Department of Public Improvements of Baltimore, Md., is using air compressors in connection with its work of toothing brick pavements. The following information on this work, given by R. M. Cooksey, is published in Engineering and Contracting, April 4, 1917. In doing this work by hand, stone cutters are employed in preference to laborers, this having been found to be more economical, as the latter class ruined much good paving. The average day's work for a stone cutter is 25 lin. ft. of toothing at $4.50 per day, which equals 18 cts. per ft. The average day's work by machine is 300 lin. ft. of toothing at a cost of $6.79 per day or about 2.26 cts. per ft. The cost of the machine work includes the following items:

5 gal. of gasoline	$10.5
1 gal. cylinder oil	.26
1 gal. Polarine oil	.23
1 special laborer	2.50
1 special laborer	2.75
Total	$6.79

The equipment consisted of one No. 2 portable compressed air outfit, with hose connections for hammers, made by Chris. D. Schramm & Son, Philadelphia, Pa., and two No. 2 Thor chipping hammers. The city purchased three Thor hammers, so that it would have one in reserve, should the one in use get broken or out of order.

Cost of Concrete Road, Allen County, Ind.—The following data, are taken from Engineering and Contracting, Feb. 6, 1918.

The road was built in the period from June 11 to Oct. 12, 1917. The pavement was 12,263 ft. in length and 16 ft. wide, the total surfaced area amounting to 21,801 sq. yd. The average spacing of the transverse expansion joints was 25 ft. Armored joint protection plates and ⅜-in. joint filler were used. The average thickness of the concrete was 7.3 in.

The equipment employed on the paving work include a Koehring No. 11 paver of the boom and bucket type, a Ward gasoline pressure pump and 3,000 ft. of 2-in. water line. Wooden sideforms and wooden stakes were used.

The concrete was a 1:2:3 mixture, washed sand up to ¼ in. in size and washed gravel ¼ in. to 1½ in. being used for aggregate. The organization of the paving gang was as follows:

No. of men	Distribution (variable)
2	Setting forms.
1	Installing armor plates.
2	Handling cement.
10	Handling aggregates.
2	Operating mixer (1 fireman).
2	Placing concrete (sometimes 3 or 4).
1	Finishing pavement.
1	Foreman.

One team hauled the cement. The subgrade usually was kept leveled by one or more men. When necessary one man was specially detailed for grading. The forms were removed and the pavement covered by the entire force.

The cost of the materials, all prices being f.o.b. Fort Wayne, Ind., was as follows:

Cement, per bbl., net	$1.69
Aggregates, per ton	0.5275
Protection plates, per joint-foot	0.125
Joint filler, per ft.	0.04

A 10-hour day was worked, the wage basis being as follows:

Motor trucks (3- and 4-ton)	$30.00
Teams	6.00
Experienced men	3.00 to 3.50
Ordinary labor	2.75
Foreman	4.50

Grading.—This covered the bringing of an old gravel roadbed on red clay soil to the proper grade. The material was loosened with plow and road grader and shoveled into dump wagons. It was spread with shovels and road machine. The cost was as follows:

	Per cu. yd.
Loading wagons	$0.26
Plowing and grading	0.083
Spreading on dump	0.076
Hauling first 100 ft.	0.06
	$0.479

Hauling Aggregate.—The hauling was done with 3-ton and 4-ton trucks, the average length of haul being 1.7 miles. A 5-ton Galion power unloader was used in handling the material. The cost of loading the trucks was approximately 9 cts. per cubic yard. The actual cost of hauling was 42 cts. per cubic yard.

Paving, Labor Costs.—A 2-bag batch (12 cu. ft.) was mixed in drum from ½ to ¾ minute. Five No. 2 wheelbarrows were used for supplying the mixer. The batch of concrete was dumped from the bucket and shoveled into place. The surface of the pavement was hand floated, the joints luted and troweled and the edges of the slab rounded. The maximum cost of this work was 16 cts. per square yard or 79 cts. per cubic yard of concrete. The minimum cost was 9.6 cts. per square yard or 47.3 cts. per cubic yard.

Covering Pavement.—Earth ranging in texture from loose top soil to hard soil was shoveled from the berms and ditches and spread on the concrete. The average depth of the covering was 2 in. The maximum cost of covering was 3.1 cts. per square yard, and the minimum cost was ½ ct. per square yard.

Summary of Costs.—The following summary represents the average cost for 20 days' work:

Item	Cost per sq. yd. pavement	Cost per cu. yd. concrete
Cement	$0.54	$2.66
Cost of aggregates	0.19	0.95
Hauling aggregates	0.011	0.54
Loading aggregates	0.023	0.115
Expansion joint complete	0.063	0.31
Paving operations	0.133	0.651
Covering pavement	0.015	0.074
Removing earth cover	0.005	0.024
Overhead and miscellaneous	0.065	0.319
Totals	$1.144	$5.643

The item "Miscellaneous" includes fuel, oil, repairs, depreciation and one-way moving expense of plant.

The total number of hours on the work was 1,065. The number of hours lost due to rain, lack of materials, and miscellaneous delays was 498. This makes the actual number of working hours 567. The miscellaneous delays include minor delays due to mechanical troubles of plant, short intervals of waiting for materials, etc. The average yardage of pavement laid per working hour was 38.4 sq. yd.

Cost of Arizona Federal Aid Concrete Road.—The following data given in Engineering and Contracting, Feb. 4, 1920, relate to the construction of a concrete pavement on the Phoenix-Temple, Ariz., highway, Arizona Federal Aid Project No. 2. The work was done during January and February, 1919, by forces of the Arizona State Highway Department under the supervision of Clyde E. Learned, Senior Highway Engineer, U. S. Bureau of Public Roads, who furnished the matter in this article.

The cost data cover about three-fourths of the length of road construction. The work involved 2.92 miles of 18-ft. wide, 5-in. thick, 1:2:4 concrete pavement. The total number of cubic yards of concrete placed was 4,397, equivalent to 31,658 sq. yd. of pavement, giving a ratio of 1 cu. yd. to 7.2 sq. yd.

The subgrade was composed of an old surfaced road of caliche conglomerate and mixture of decomposed granite and caliche, which was very hard to work. The preparation of the subgrade for the concrete was very expensive, but an exceptionally good piece of work was performed.

The mixing was done with a new No. 22 Koehring paving mixer, using a 3-bag batch. 1.57 bbl. of cement were used per cubic yard of concrete in place; 0.48 cu. yd. of sand, and 0.89 cu. yd. of stone. The wooden side forms were 2 in. × 5 in. and were left in place.

Water was pumped a maximum distance of 1½ miles. Trouble was experienced with the pumps as they were of too small a capacity. The pipe was old, and the line was poorly laid.

Common labor and teamsters were paid $3.50 per 8-hour day. State teams were used and were figured at $6 per day for team and driver. The hauling costs were exceptionally high due to poor handling of teams. The crushing costs also were high, due to poor setting of crushing plant, constant breakdowns and changing of foremen.

The organization of the concrete gang was very good, the average daily run being 450 lin. ft. and the maximum daily run 540 lin. ft. The gang was made up as follows:

	Per day
1 foreman	$ 6.00
1 mixer engineer (gas engine)	5.50
1 bucket man on boom of mixer	4.00
1 pump man	4.00
2 finishers, rolling, belting and finishing joints	9.00
2 strike board men (screening and tamping) at $4	8.00
2 concrete spreaders at $3.75	7.50
1 handy man, installing joints, wetting subgrade, etc	3.50
4 men wheeling and loading stone wheelbarrows at $3.50	14.00
2 men wheeling and loading sand at $3.50	7.00
4 extra men loading stone to wheelbarrows at $3.50	14.00
1 extra man loading sand to wheelbarrows at $3.50	3.50
1 man, cement to hopper, from side forms	4.00
1 water boy, also spotting piling of cement	3.00
1 watchman wetting down concrete	3.50
2 men dyking for curing and wetting down concrete at $3.50	7.00
27 men. Total	$103.50

An additional pump man required nights for about one-third of time.

The itemized cost of the pavement was as follows:

	Cost per cu. yd., concrete
Labor:	
Supervision (foreman and timekeeper)	$ 0.08
Preparation of subgrade, including dragging, rolling, wetting down, harrowing and trimming	0.57
Setting wooden side forms, including trenching for same. (Forms remain in place)	.45
Loading materials, mixing, placing and curing concrete, pumping water, watchman, cleaning off pavement and cutting expansion joint filler	1.12
Dumping and spreading sand and stone on subgrade	.06
Pipe line, hauling, laying and removing (estimated)	.16
Assembling and dismantling mixer (estimated)	.01
Total labor	$ 2.45
Concrete Materials:	
Cement—	Per bbl.
F. o. b. Phoenix (net)	$ 3.17
Loading and unloading	.13
Hauling, average haul 1 mile	.11
Return freight and bag losses (estimated)	.05
Total cost per bbl	$ 3.46
Cost (1.57 bbl.) per cu. yd. concrete	5.43
Sand—	Per cu. yd.
Premium	$ 0.10
Hand screening at pit (part of supply)	.40
Loading at pit (total supply)	.40
Hauling pit to crusher (¼ mile bad haul)	.32
Screening at crusher (part of supply)	.20
Hauling to road (3-mile average haul)	1.40
Cost per cu. yd. on road	$ 2.82
Cost (0.48 cu. yd.) per cu. yd. concrete	1.35

Gravel (State Plant):	Per cu. yd.
Premium	$ 0.10
Loading at pit	.48
Hauling, pit to crusher (¼ mile bad haul)	.32
Crushing and screening	1.02
Hauling to road (3-mile average haul)	1.40
Cost per cu. yd. on road	$ 3.32
Crushed Stone (Tempe Commercial Plant):	
Cost in bin, $1.85 per ton × 2460/2000	$ 2.28
Haul to road (3-mile average haul)	1.40
Cost per cu. yd. on road	$ 3.68
Composite price of gravel and crushed stone	3.50
Cost (0.89 cu. yd.) per cu. yd. concrete	3.11
Total cost cement, sand and stone, per cu. yd. concrete	9.80
Expansion joints (Carey's Elastite)	.10
Materials and Repairs:	Cost per day
Mixer—	
Gasoline, 22 gal. at $0.25	$ 5.50
Oil, grease, waste, etc	1.00
Cost of 50 days	300.00
Pumps—	
Gasoline, 8 gal. at $0.25	2.00
Oil, grease, waste, etc	.50
Cost per day	$ 9.00
Cost of 50 days	450.00
Crushing Plant:	
Coal, ¾ ton per day at $7.50	$ 5.00
Oil, grease, waste, etc	1.00
Cost per day	$ 6.00
	Lump sum
Repairs on mixer (estimated)	$ 20.00
Repairs on pumps (estimated)	200.00
Repairs on crusher (estimated	500.00
Total cost, fuel and repairs	$1,470.00
Side Forms and Stakes:	Per station
Side forms, 200 ft. B. M. at $45.00	$ 9.00
Stakes and nails	1.00
Total cost for 28 yd. concrete	$ 10.00
Interest and Depreciation:	Lump sum
Mixer cost, $4,360, at 10 per cent	$ 436.00
Two pumps and engines, $400, at 10 per cent	40.00
Pipe line, connections, etc., $5,000, at 10 per cent	500.00
Car subgrader, $400, at 10 per cent	40.00
Small tools, hose, etc., $500, at 50 per cent	250.00
Cement house, $300, at 50 per cent	150.00
Crushing outfit, $4,000, at 15 per cent	600.00
Dump wagons, $3,000, at 10 per cent	300.00
Total interest and depreciation	$2,316.00

SUMMARY OF COST

	Per cu. yd. concrete in road
Labor	$ 2.45
Cement	5.43
Sand	1.35
Gravel and crushed stone	3.11
Expansion joints	.10
Materials and repairs for plant	.33
Side forms and stakes	.36
Interest and depreciation on plant	.40
Total per cu. yd. concrete	$ 13.53
Total cost of concrete pavement per cu. yd	13.53
Total cost of concrete pavement per sq. yd	1.88

The finished concrete road was an exceptionally good piece of work.

Cost of Federal Aid Concrete Pavement in Colorado.—Engineering and Contracting, Feb. 4, 1920 publishes the following information given by Clyde E. Learned, of the U. S. Bureau of Public Roads, under whose supervision the road was built.

Colorado Federal Aid Project No. 1 comprised the construction of a concrete pavement on the Denver-Littleton road. The pavement was a 1:2:3 mix, 16 ft. wide, and 5½ in. thick at sides, and 6½ in. thick at the center. The total number of square yards was 36,974 which required the placing of 6,325 cu. yd. of concrete giving a ratio of 1 cu. yd. to 5.85 sq. yd. of pavement. The work was done by contract. It was commenced in July, 1918, and finished in November of that year.

The mixing was done in a No. 514 Smith Chicago paver with rotary distributor. The size of batch was 3½ bags. This mixer had been in use for 7 years. The side forms were wood, and they were used over again.

The fine grading and preparation of subgrade were very poor, and this occasioned delays in front of the mixer. The concrete pavement work was delayed considerably owing to lack of facilities for furnishing materials fast enough to keep the mixer in continuous operation.

Common labor and teamsters were paid $4 to $4.50 per 9-hour day. Team and driver were paid at the rate of $7 per day. The average haul on cement was ¾ mile; on sand ¾ mile, and on gravel ⅞ mile.

The size of the concrete gang was dependent, to a great extent, on the ability of the contractor to get and keep enough laborers to carry on the work. From the beginning of the pavement work on July 19 to the last of August, the concrete gang was made up as follows, and the following scale of wages prevailed per 9-hour day:

	Per day
1 foreman	$ 7.00
1 mixer operator (attends to firing)	6.00
1 man regulating water for batch and dumping mixer	4.00
1 boy on revolving distributor spreading concrete and wetting subgrade	3.75
1 man spreading concrete and assisting installing joints	4.25
2 men on strike board, striking off and tamping concrete, at $4.00	8.00
1 finisher, rolling, belting, hand floating and edging	6.00
1 man shaking out and bundling cement sacks; also assisting finisher to belt concrete and move bridge	4.00
2 grade men around mixer leveling up subgrade and tamping where necessary, at $4.00	8.00
2 men moving and setting forms also installing joint material, at $4.00	8.00
2 men carrying and putting cement into mixer hopper, at $4.00	8.00
2 men on mixer hopper assisting in dumping wheelbarrows, moving mixer runways, and taking care of hose from pipe line to mixer, at $3.75	7.50
6 men on two sets of gravel wheelbarrows, loading and wheeling, at $4.25	25.50
2 men on one set of sand wheelbarrows, loading and wheeling, at $4.25	8.50
2 extra men loading gravel in wheelbarrows, at $3.75	7.50
1 extra man loading sand in wheelbarrows	3.75
3 men covering and wetting concrete, at $3.75	11.25
1 water boy	1.50
1 night watchman, wetting concrete and taking care of fire on mixer	4.00
33 men. Total	$136.50

The average daily run of this gang, when material was on hand, was 480 lin. ft. of pavement per day, the maximum run being 70 lin. ft., the above runs being equivalent to the placing of 146 and 173 cu. yd. of concrete.

From the first part of September to the end of the work on Nov. 5, the concrete gang was smaller, averaging about 25 men, and differed from the above organization as follows:

The man spreading concrete was eliminated, his work being done by the strike board men, who were advanced to $5 per day.

Where two men had previously been used, one man was now used on each of the following: grading in front of the mixer, handling cement to material hopper, and moving and setting forms. These men were advanced 50 cts. to $1 per day. The men used for covering up were eliminated, as this work was performed each morning by the whole gang before any concrete was laid. One of the extra men loading wheelbarrows was also eliminated, and the pay of the wheelbarrow men was raised to $4.50 per day.

The total wages per day for these 25 men were $112.50, and the average and maximum daily runs were 420 and 505 lin. ft. of pavement, this being equivalent to the placing of 128 and 154 cu. yd. of concrete. This gang had the maximum weekly run of 2,370 lin. ft. of pavement, which was accomplished in 5½ working days.

The organization of the concrete gang was very good, and the work went along very smoothly, the only serious trouble being the lack of materials.

The following table shows the cost of the pavement:

	Cost per cu. yd., concrete
Labor:	
Supervision (foreman and timekeeper)	$0.175
Preparation of subgrade for concrete	.059
Setting and moving forms	.066
Loading, mixing, placing and finishing	.994
Covering, cleaning off, cutting joints	.095
Pipe line, hauling, laying and removing	.063
Assembling and dismantling mixer	.012
Mixer—to and from job—Denver	.010
Total labor	$1.472
Concrete Materials:	
Cement—	Per bbl.
F. o. b. mill	$1.98
Freight	.32
Loading, hauling and unloading	.15
Freight return bags and losses	.05
Total cost per barrel	$2.50
Cost per cu. yd. concrete (1.70 bbl.)	4.25
Sand—	Per cu. yd.
Average cost screened in piles or at pit	$1.00
*Loading and hauling to road	.50
Cost per cubic yard	$1.50
Cost per cu. yd. concrete (0.60 cu. yd., which allows for waste)	.90
Gravel—	
Average cost screened in piles or at pit	$1.20
*Loading and hauling to road	.60
Cost per cubic yard	$1.80
*Loading and hauling combined, as drivers helped load materials.	
Cost per cu. yd. concrete (0.80 cu. yd., which allows for waste)	1.44
Total cost cement, sand and gravel per cu. yd. concrete	$6.59
Water—From Denver and Littleton water mains	$0.06
Joints—Carey's Elastite, ¼ in. premoulded asphalt	.065

Materials and Repairs:		Cost per cu. yd. concrete
Mixer—		
Coal, price $8.00 per ton		$0.051
Oil, waste and packing		.006
Repair parts		.012
Total mixer		$0.069
Side Forms—Lumber and pins		.016
Total cost of materials and repairs		$0.085
Interest and Depreciation:		
Mixer, $2,300.00, at 15 %	$345.00	$0.055
Pipe line and connections, $750, at 15 %	112.50	.018
Small tools, hose, etc., $140, at 50 %	70.00	.011
Total interest and depreciation		$0.084

SUMMARY OF COST

	Per cu. yd. concrete in road
Labor	$1.472
Cement	4.250
Sand	.900
Gravel	1.440
Water	.060
Joints	.065
Materials and repairs foı plant	.069
Side forms	.016
Interest and depreciation on plant	.084
Total per cu. yd. concrete	8.356
Total cost of concrete pavement per cu. yd.	$8.356
Total cost of concrete pavement per sq. yd.	$1.427

Crew Organization for Concrete Pavement Work.—An organization capable of turning out 600 to 700 sq. yd. of concrete per day for road construction under conditions prevailing in Western Washington is outlined in Concrete Highway Magazine, from which the matter following is abstracted in Engineering and Contracting, Oct. 2, 1918.

Materials.—In many cases sand and pebbles have been obtained near the road to be paved, and as a rule the sand and gravel banks have sufficient elevation to allow sluicing the material into bunkers. With the many streams in western Washington, water is usually near by in large quantities.

Under these conditions and with the following crew at the pit and bunkers, 250 cubic yd. per day can be turned out.

1 man for pump and engine.
1 man at nozzle sluicing in pit.
1 man helping nozzle man removing large rocks, roots, etc.
1 man at bunkers looking after sand box and keeping chutes clear.

Grading.—Supposing the road to be paved is a well developed highway with proper grades established, and that only light grading is to be done prior to paving, the following men will do the rough and fine grading:

1 foreman in charge of grading and ribbon setters.
1 engineer for caterpillar and roller.
1 teamster for Fresno and wheeler.
4 laborers, pick and shovel work.

When caterpillar is hooked to road grader and scarifier one of the above laborers is used on grader as helper. One of the above laborers also is used at times as teamster's helper.

Ribbons.—The grading foreman has:

1 man setting ribbons.
1 man helper.

Placing Material.—Where the maximum haul is 4 miles, 3 five-ton trucks will handle the output of bunker and put material on ground to run 1 three-sack batch mixer.

Final Subgrade.—Two men are required back of mixer bringing subgrade to exact depth and dragging subgrade template on ribbons.

MIXER CREW FOR THREE SACK MACHINE

1 foreman in charge of concrete crew.
6 men used on wheelbarrow for gravel, 3 wheelbarrows with 2 men to each barrow.
2 men are used on wheelbarrows for sand, 1 man for each wheelbarrow.
2 men are used for cement, 1 man carries cement to bench, 1 man empties sacks into hopper.
2 men for spreading concrete.
2 men for rodding.
1 man for finishing.
1 engineer on mixer if gas engine is used. If steam mixer is used a fireman is necessary.
2 men for covering finished concrete with 2 in. of earth.
2 men watering earth covering on concrete less than 10 days old.
1 man watering subgrade.
1 man for water supply to mixer.

Presuming that the road to be paved is 20 ft. wide with a 1:2:3 mix and a thickness of 6-in. side and 8-in. center, the crew of 23 men as outlined above should lay 600 to 700 sq. yd. of pavement per day.

Four Examples of Concreting Gang Organization for Road Work.—The following information, collected by special committees of the National Conference on Concrete Road Building is given in Engineering and Contracting, Feb. 23, 1916.

Example I: Pennsylvania, Easton—Bethlehem Model Road.—The best results were obtained with a gang organization as follows:

Gang	Cost per day
1 foreman at $3	$ 3.00
1 mixer operator at $3	3.00
1 fireman at $2.50	2.50
2 templet men at $2	4.00
3 men spreading at $2	6.00
2 men floating at $2	4.00
1 man finishing at $2	2.00
2 men on forms at $2	4.00
1 man changing chute at $2	2.00
2 men handling cement at $1.75	3.50
7 men on wheelbarrows at $1.75	12.25
7 men shoveling at $1.75	12.25
1 utility man at $1.75	1.75
1 waterboy at $1.50	1.50
32 men in total gang	$61.75

This list schedules the men according to their special duties. The first task in each day's work was from the previous day's work to bring forward the forms and other working appliances and to cover the previous day's concrete with earth. All men, such as templet men, floaters and finishers, were employed in this task. The three men handling concrete also placed the expanded metal reinforcement and the expansion joints. Laying a slab 7 in. thick and holding the material in the drum for a 90 sec. mix, this gang averaged 525 sq. yd. per day at a cost of approximately 11.7 cts. per square yard. A No. 16 Koehring paving mixer, with boom and bucket delivery, was used. With a shorter mixing time, say 45 sec., it is suggested that the gang be increased three to five men on wheelbarrows; with such an increase it is estimated that the yardage could be increased 50 per cent. Data reported by William D. Uhler, Chief Engineer, State Highway Department.

Example II: Illinois State Aid Road Work Practice.—The data given are based on experience on 25 to 30 jobs of state aid road work representing approximately 500,000 sq. yd. of pavement. Assuming excavation complete and all material delivered on the work and that the subgrade is in average condition, the following crew is considered to be most efficient under average conditions on work similar to state aid road work in Illinois.

General—	Number
Superintendent	1
Foreman	1
Front End of Mixer—	
Wheeling sand	2
Wheeling stone	4
Extra shovelers	2
Handling cement	2
Bundling cement sacks	1
Trimming subgrade	1 or 2
Rear End of Mixer—	
Shovelers	3 or 4
Finisher	1
Curing concrete	2
On Mixer—	
Engineer	1
Fireman	1
Forms—	
Setters	2
Water—	
Pumpman	1
Miscellaneous—	
Watchman	1
Waterboy	1
Total	27 or 29

The list given needs some explanation to be entirely plain. First the assignment of only one or two men to trimming subgrade assumes that the subgrade is already practically correct. Of the three or four shovelers at the rear end of the mixer, two also handle the strike-board and one also occasionally assists the finisher. At times of any delay in mixing operations, practically the entire gang is turned to covering the concrete with earth. Under ordinary conditions, however, it is necessary to assign two men to covering and sprinkling concrete in addition to the work done by the whole gang. The gang is for a two-bag batch mixer, and with this machine its average daily output of 18 ft. wide and 7 in. thick pavement is about 800 sq. yd., working day 9 hr., mixing time per batch, 35 sec. The average cost of mixing and placing concrete and of setting forms and joints is 10 cts. to 12 cts. per square yard. A single day's cost may run as low as 8 cts. per square yard, but an average job of any size, figuring repairs, fuel and depreciation on mixer, brings the cost between 10 and 12 cts. where labor receives from 20 to 25 cts. per hour. A smaller gang will reduce the unit cost slightly if no account is taken of interest, overhead,

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etc. The slower progress, however, runs up these fixed charges so that in the end, the cost is greater rather than less. Data reported by H. B. Bushnell, Division Engineer, State Highway Department.

Example III: Wisconsin, Milwaukee. County Roads.—An efficient gang organization for conditions prevailing in Milwaukee County has been found to be about as follows:

Gang	Cost per day
1 foreman at $5	$ 5.00
1 timekeeper at $5	5.00
1 engineer at $5	5.00
1 fireman at $2.50	2.50
1 pumpman at $2.50	2.50
1 form setter at $2.50	2.50
1 finisher at $3	3.00
2 strikeoff men at $2.50	5.00
2 puddlers at $2.50	5.00
2 cement handlers at $2.50	5.00
1 boy bundling sacks at $1.50	1.50
1 waterboy at $1	1.00
6 sand laborers at $2	12.00
12 stone laborers at $2	24.00
1 man removing forms at $2	2.00
2 men covering concrete at $2	4.00
1 man sprinkling at $2	2.00
1 man trimming subgrade at $2	2.00
38 men Total	$89.00

The particular road on which this gang worked contained 17,280 sq. yd., was 18 ft. wide and averaged 7 in. in thickness. The subgrade was clay and required little sprinkling before laying the concrete. Wheelbarrows were wheeled directly on the subgrade without planks. Sand and gravel were placed in the middle of the road and cement on the side. Water was available at the job and was pumped through 2-in. pipe by a steam pump. A 16-ft. paver was used with an open spout for distributing the mixed material. The mix was 1:2:3½, two bags of cement being used to a batch, and 11 cu. ft. of aggregate. Protected joints were placed every 50 ft.

The actual number of days consumed in the construction of this particular piece of work was 33, of which five were Sundays. Of the remaining working days, two were lost because of rain and a defective pump. This left 26 days for actual construction work. During this period, the maximum output for one day was 1,000 sq. yd. and the minimum 264 sq. yd. The average output was 665 sq. yd. per day or 332½ lin. ft. per day. The actual labor cost for mixing and placing was $0.1396 per square yard, which included labor incurred in supplying water covering and sprinkling concrete and also a watchman during the construction period. The cost to the contractor for lost time, moving plant to and from the job, the laying of pipe, etc., amounted to $0.0201, giving a total cost per square yard for labor of $0.1597. The timekeeper looked after the ordering of materials, spotting of cars and unloading and placing of materials on the job. A cheaper engineer might have been employed but it is believed that the results obtained justified the additional expense. The man employed in trimming the subgrade saved more than enough in materials to pay for his wages. Data reported by F. W. Whitlow, Superintendent of Construction, County Highway Commission, Milwaukee County, Wisconsin.

Example IV: California Highway Commission.—(1) Specific crew organization employed on recent jobs.

DIVISION III—MAINTENANCE REQUISITION 155, AUBURN BOULEVARD

Concrete Crew:

1 mixer engineer at $4.00	$ 4.00
1 foreman at $4.00	4.00
1 water boy at $2.00	2.00
1 cement man at $2.75	2.75
2 finishers at $3.00	6.00
2 men on tamp. at $2.75	5.50
4 spreaders at $2.75	11.00
15 laborers at $2.50	37.50
Total	$72.75

Average for 20 good days' run = 118.9 cu. yd. per day.

$$\frac{\$72.75}{118.9} = \$0.613 \text{ cu. yd.}$$

Note.—Mixer rent of $10 not included in above.

DIVISION III—STANISLAUS COUNTY, ROUTE 13, SECTION A

Concrete Crew:

1 mixer engineer	$ 3.63
1 foreman	4.50
1 finisher	3.00
6 spread tampers at $2.75	16.50
13 shovelers and wheelbarrow men at $2.50	32.50
Total	$60.13

16 days' average run = 101.4 cu. yd.

$$\frac{\$60.13}{101.4} = \$0.592 \text{ cu. yd.}$$

2. Conditions and amount of work, plant used and other reasons influencing choice of organization employed.

See (3) for conditions and amount of work. No special conditions influenced the choice of organization. The organization (see 1 above) is customary where a two-bag mixer is used, and an output of from 100 to 150 cu. yd. per day is expected. The following crew can probably be considered as typical of work throughout the state:

1 foreman	$ 4.00
1 mixer engineer	4.00
1 cement man	2.75
1 finisher	3.00
2 tampers and strike off men at $2.75	5.50
6 men spreading, shoveling up loose materials, checking up subgrade, etc., at $2.75	16.50
13 men on wheelbarrows and shovels at $2.50	32.50
25 men. Total	$68.25

This crew could easily turn out an average of 125 cu. yd. of concrete per day at a cost of $0.54 per cubic yard. Delays due to shortage of material, supplies, water and mixer trouble generally tend to keep the average from 10 to 20 cts. per cubic yard higher. The figures given above are for average conditions, and for the average run of labor. There have been times when contractors with an especially capable and experienced crew of men and no other difficulties have been able to mix and place concrete for as low as 40 cts. per cubic yard, and even lower, and on force account work (work done by the State under day labor) we have done the work for as low as 48 cts. per cubic yard on a single day's run. But out of over twenty contracts under way in Division III this summer not one mixed and placed concrete as low as 50 cts. per cubic yard, and the average was much higher.

The Auburn Boulevard job consisted of laying a concrete base 4 in. thick, for the most part, on an old oil macadam base. The old pavement was first scarified and the top 2 in., which consisted of a mushy mixture of oil, dirt and a small amount of rock, was removed. The remaining base, on account of the amount of rock and oil contained, was rather difficult to prepare accurately for a 4-in. base. On this account the header and subgrade charge is higher than is customary on work of this nature.

3. Records of output or costs indicating efficiency of crew organization as employed.

M. R. No. 155 Auburn Boulevard

		Per cu. yd.
1. Length of concrete pavement, 18,273 lin. ft. = 3.46 mi. (Part 18 ft. × 4.5 in.; part 15 ft. × 4 in.)		
2. Total yardage, 3,963.5 cu. yd.		
3. Labor cost of mixing and placing (not including water supply or curing or repairs)	$2,994.73 =	$0.730
4. Cost of curing concrete	837.23	0.211
5. Cost or running pump and water supply	310.09	0.076
6. Cost of laying and removing water pipe	95.43	0.024
7. Cost of headers	1,277.89	0.322
8. Cost of shaping subgrade	1,073.50	0.270
9. Cost of unloading and hauling rock, sand and cement	4,480.35	1.130
Total cost		$2.763

10. Average haul = 0.7 miles.
Items 3 to 9 = $11.069.22, or $3,200.00 per mile.

The mixer used on the Auburn Boulevard was old and as the work progressed the break-downs were numerous, causing disorganization of crew and consequent increased costs. Delays due to shortage of materials toward the latter end of the work added unfairly to the cost of the concrete. The total cost of $2.76 per cubic yard of concrete in place is not excessive, but is higher than should be on a large job and where there are no serious difficulties to be overcome.

6. Discussion of specific or general questions of crew organization that experience indicates needs enlightenment or investigation.

No suggestions can be made along this line, as there are no particular crew organization problems connected with concrete paving work. The only real problem is the problem of the superintendent always to organize the layout of his work so as to prevent serious delays in any one part of the organization. Thus, he must plan his grading crew to keep ahead of the subgrade crew, the finishers must keep ahead of the hauling of materials, and the material men must keep ahead of the concrete crew. If each outfit can see only one day's work laid out ahead, there is from 25 per cent to 50 per cent loss of efficiency. On the day labor work in Stanislaus County, Contract D-50, the work was so regulated at the start that each unit of the work was at least one-half mile (representing four or five days' work) ahead of the other units. Data reported by A. B. Fletcher, Highway Engineer, California Highway Commission.

Summary from Examples.—Using modern paving mixers, a concreting gang for road work will consist of from 30 to 40 men. These are round numbers.

In instances fewer than 30 men will suffice and in more rare instances a greater number than 40 may be required. The exact number will depend upon the nature of many controlling conditions. Also the number of men allotted to the several duties required to be performed is likewise determined by the nature of these conditions. As illustrating the vagaries of organization recorded in practice, Table XXIV has been compiled from data readily at hand. Doubtless some of the wide variation exhibited is due to inequalities of organizing skill but with all reasonable allowance for this cause, there remain important differences caused entirely by differences in conditions controlling the concreting work.

TABLE XXIV.—DISPOSITION OF MEN IN CONCRETING GANGS FOR CONCRETE ROAD WORK

Job		Genl.	Front	Rear	Mixer	Forms	Water	Misc.
I		1	16	9	2	2	..	2
II		2	12	7	2	2	1	2
III		2	22	8	2	2	1	2
IV		2	13	6	2	2	1	2
V	Base	1	15	4	2	..	..	..
		(2)	(29)	(9)	(5)	(1)	..	(3)
	Top	1	14	5	3	1	..	3
VI		1	5	10	1	..	..	..
VII	Base	1	9	5	1	..	..	..
		(2)	(13)	(11)	(3)	(2)	..	..
	Top	1	4	6	2	2	..	..
VIII		1	10	11	3	2	..	..

Concreting is but one operation in the process of concrete road building. The economic target is the lowest cost for the whole process, and the concreting operation must so co-ordinate with other component operations that the mark is hit. It may often be, therefore, that the most efficient concreting gang organization is not the one that would mix and place most cheaply a cubic yard of concrete in finished road slab considering this one operation as the beginning and end of all effort. The law of co-ordination has influence in an even more minute way. Consider for the moment the concreting operation to be independent of all others. On the Pennsylvania road work described later, it is the requirement that the batch shall turn 90 sec. Under this requirement, the most efficient gang organization has been found to be that of column one in Table XXV. Could the mixing period be cut in half the most efficient gang organization would be that of column two in Table XXV. Again, considering the gang organization for Illinois road work as given in Example II. By reducing this gang by a few men it is stated that a

TABLE XXV.—GANG ORGANIZATION AND OUTPUT AS INFLUENCED BY TIME OF MIXING

Thus—	1	2
Mixing time, seconds	90	45
General labor	1	1
Men in front	16	21
Men in rear	9	9
Men on mixer	2	2
Men on forms	2	2
Miscellaneous	2	2
Total men	32	37
Output sq. yd. average	525	787

smaller unit labor cost could be obtained but the slower progress would increase interest and overhead costs enough to exceed the saving.

Gang organization is determined then, first by the controlling construction conditions and second by the work organization as a whole. These determining factors are seldom constant outside of a single job and are often variable on a single job. No general formula is possible for solving all problems of concreting gang organization. The organization of each gang is a separate problem and must be so solved.

Bonus System Cuts Cost of Laying Concrete Pavement.—Engineering and Contracting, June 5, 1918, gives the following:

The city of Flint, Mich, is constructing 10 miles of pavement and 30 miles of sewers by day labor under the direction of the city engineer. Common laborers' wages are $3.50 a day, and the men engaged in paving were not efficient until a bonus system was applied. For example, a gang of 16 men and a foreman operating a concrete mixer averaged only 47 cu. yd. of concrete base (6 in. thick) per day, when actually working, at a cost of $1.23 per cu. yd. for labor; but upon the payment of a bonus system a gang of 12 men and a foreman averaged 90 cu. yd. a day when actually working, and at this rate the labor cost, including the bonus, was less than 60 ct. per cu. yd., or 10 ct. per sq. yd.

The bonus payment was 1 ct. to each of the 13 men for each square yard of concrete in excess of 500 sq. yd. per day. At this rate, if 600 sq. yd. were laid in a day, each of the 13 men would earn $1 bonus, but each of these extra 100 sq. yd. would cost the city only 10 ct. for labor.

It is well within the capacity of a gang of 13 men to run 100 sq. yd. of 6-in. concrete per hour, and this rate was attained.

There are few classes of construction work to which it is so easy to apply a "bonus system" as to paving work. This is because of the fact that the number of units of work done each day is readily ascertained and because each gang is usually engaged continuously upon the same sort of work. In view of this it is rather astonishing that some sort of bonus payment is not made to all gangs engaged in laying pavements. Engineers in charge of pavement construction by day labor should invariably apply a bonus system. Otherwise the men are almost certain to loaf, for they reason that the city, or county, or state for whom they are working can afford to foot any bill and is not likely to scrutinize the cost very closely, anyway.

Method of Reducing Labor Cost of Concrete Mixing.—A novel method employed by the Independent Asphalt Paving Co. of Seattle, Wash., in handling aggregate for the construction of 3½ miles of concrete pavement on the Pacific Highway in Thurston County, Washington, made it possible for the company to materially reduce the size of its mixing crew. The plan is described in the Concrete Highway Magazine, and abstracted in Engineering and Contracting, May 1, 1918, as follows:

The company was well equipped with all kinds of road-making machinery and had a number of automobile trucks for the delivery of material. At the town of Lacey, which is approximately in the center of the work, they received their sand and pebbles by railroad. At this point a stiff leg derrick with ¾-yd. clamshell bucket was erected. This derrick lifted material directly from cars to stock piles of approximately 3,000 cu. yd. of gravel and 2,000 cu. yd. of sand. No paving was started until about this amount of material was on hand, it being intended that when concreting commenced it should be continuous.

While this reserve of material was being assembled a small loading bunker was built, designed to hold about 5 yd. of sand and 10 yd. of gravel, filling being accomplished by means of the stiff leg derrick. It was equipped with 5 measuring boxes for sand and 5 for gravel, so situated that they would discharge simultaneously by gravity 5 measured batches of sand and gravel into compartments built into the truck bodies for this purpose. Each batch of sand contained 6 cu. ft. and each batch of gravel 9 cu. ft., this being the necessary sand and gravel to make up a batch of 1 : 2 : 3 mix for the 3-sack mixer used on the job.

The trucks for delivering the material were of 3-yd. capacity, having their bodies or boxes divided into 5 compartments by means of wooden partitions. Each compartment received one full batch of sand and gravel for a 3-sack mix. The lower half of each partition was hung on strap hinges and was held in place by a simple catch, which could be easily released when the body was raised ready to discharge into the hopper of the mixer.

The partitions and sides of the truck were built up 6 in. above the required depth necessary to hold a batch, in order that when the body was raised for discharging the material would not run from one compartment to the other.

The trucks were accurately loaded at the bunkers, transported 5 full batches of sand and gravel to the mixer and dumped these batches directly into the loading hopper of the machine, a batch at a time, without even letting the material touch the subgrade.

The contractor was able to reduce his mixing crew of men from 22 to 10, and the 10 men easily accomplished the work. All question of material loss on the subgrade was eliminated, and the resulting concrete was entirely free from clay balls or other foreign material.

From actual timing records kept on this work, each truck is delayed at the mixer from 9 to 10 minutes on each trip, or for 25 per cent of the working time. The commercial rate for this size truck if rented would be $2.50 per hour. Thus the waiting time of 4 trucks necessary to keep the mixer going, at 2 hours each, or a total of 8 hours, would at the rate of $2.50 per hour be $20 per day; while under the usual system there would be necessary to accomplish the same work 12 men, costing, at $3.25 per day, $40; to which should be added the loss of material, amounting to at least $10—or a total of $50 per day.

It is thus seen that an approximate saving of $30 per day, or a little better than 5 cts. per square yard, has resulted from this plan of operation, originally intended to meet an expected shortage in labor.

Concrete Delivered Wet by Motor Trucks Shows a Large Saving as Compared with Customary Methods.—The following matter is taken from Engineering News-Record, May 1, 1919.

Delivery of wet concrete, from a central crushing and mixing plant, to the road surface, by motor trucks, over hauls ranging from ¼ mile to four miles, was satisfactorily accomplished on the Belair Road of the Maryland State Road Commission. By this method extensive rehandling of materials was dispensed with, thus reducing the cost, and the speed of the trucks was such that for the distances named there was no apparent injury to the quality of the concrete mixture. The maximum time required to transport the concrete from the mixer to the road was 35 minutes.

The work under consideration, was the building of a 3-ft. strip of concrete 8 in. thick on each side of the macadam road and connecting it with the old road with new macadam. It was undertaken to overcome the spreading action of the traffic by giving support needed at the edges and at the same time widen the road which had become too narrow for the heavy motor truck freight route.

After both shoulders were completed, the entire road received a seal coat of bituminous material and stone chips, which was allowed to cover the concrete shoulder, giving a pavement 20 ft. wide of uniform appearance.

As there was excellent stone in most of the hills adjacent to the road, the contractor decided to save handling labor by mixing the concrete at the quarry and hauling it to the road in motor trucks. A location about midway of the contract was selected, a quarry was opened and a crushing and mixing plant was set up.

Two portable boilers of the locomotive type were used; one, a 25-hp. boiler and engine, furnished power to run the crusher and mixer, the other, an 18-hp. boiler, furnished steam for the rock drills at the quarry and for pumping the necessary water for the boilers and the concrete.

A jaw crusher was placed under the platform upon which the stone from the quarry was dumped. After being crushed, the stone was elevated into the bin and separated into the desired sizes by a rotary screen. There were three general sizes of stone: The chips which passed a ¾-in. screen went into the sand bins; the crushed rock passing a 2½-in. screen went into the coarse aggregate bin, while the larger stone went out as tailings. What tailings could not be used for repairs on the construction road were taken out and again fed through the crusher. As the crusher did not produce enough fine material, sand was also delivered upon the platform and fed through with the stone and elevated into the sand bin.

Gravity was utilized to the utmost throughout the operations, from the quarry to the mixed product in the truck body. The plant was situated at the foot of a hill down which the quarried rock was hauled in carts to the crusher platform. After crushing, the stone and sand were fed directly into the mixer from the bins, care being taken to proportion them properly. Water was supplied from the elevated tank shown in the sketch. The bin and the platform for the concrete mixer were placed at such height that the mixer could discharge directly into the trucks.

On the road the dumping of the concrete followed a different plan than would be employed if the entire road section were being covered, as in the case of constructing a concrete road. As the shoulder which was being constructed was of small section, it was necessary to dump the mixed concrete upon the surface of the old road and shovel it into the forms on the side. One truck load of concrete filled about 35 ft. of forms, and extra handling was necessary, which of course increased the cost above what it would be if an entire road surface were being built.

Convict labor was utilized for common labor upon this road, a camp being built at the quarry to house and feed the laborers. Guards were provided by the prison officials for watching the convicts, but the contractor furnished the foremen to supervise the work. The contractor reported that this labor was quite satisfactory. In the construction of the shoulders steel forms were used.

Approximate costs for carrying work on under this system are given in the following table, based upon an average haul of 3.5 miles and the construction of 6,975 ft. of shoulder which was laid in a period of 13 working days. The average days work was thus 535 lin. ft. or 179 sq. yds. The cost per day of equipment include interest and depreciation.

Itemized Cost of Laying Three-Foot Concrete Shoulders for Macadam Roads

Quarrying and Crushing Stone per Day

1 foreman at 65cts. per hour	$ 5.85
1 engineer at 44⅘cts. per hour	4.00
1 blacksmith at 44⅘cts. per hour	4.00
17 laborers at 27⅐cts. per hour	42.50
3 carts at 55⅚cts. per hour	15.00
Equipment at $7.50 per day	7.50
25 lb. dynamite at 30cts. per pound	7.50
Total cost per day for 36 cubic yards of stone and 4.4 cubic yards of dust	$86.35
Cost of rock per cubic yard in quarry	$ 2.137
Royalty	.15
Total cost rock per cubic yard	2.287

Sand per Day

Sand in pit, 13.6 cubic yard at 85cts. per cubic yard	$11.56
Hauling sand and cement by truck, $30 per day	30.00
Three laborers at 27⅐cts. per hour	7.50
Total cost per day	$49.06
Total cost per cubic yard	$ 3.61

Mixing Concrete per Day

3 men at 27⅐c. per hour	$ 7.50
Equipment $7.50 per day	7.50
Total cost per day for 40 cubic yards	$15.00
Total cost per cubic yard	.375

Hauling Concrete to Road per Day

1 truck at $18.00 per day	$18.00
1 truck at 25.00 per day	25.00
1 truck at 27.50 per day	27.50
Total cost per day for 40 cubic yards	$70.50
Total cost per cubic yard	$ 1.762

Placing Concrete per Day

1 foreman at 55⅚cts. per hour	$ 5.00
2 laborers, build forms 27⅐cts. per hour	5.00
Placing, 4 laborers at 27⅐cts. per hour	10.00
Total cost per day for 40 cubic yards	$20.00
Total cost per cubic yard	.50

Cost of Concrete in Place per Square Yard

Cement, 1.5 bbl. at $2.50	$ 3.750
Sand, 0.34 cubic yard at $3.60	1.227
Dust, 0.11 cubic yards at $2.287	.252
Stone, 0.9 cubic yard at $2.287	2.058
Mixing, per cubic yard	.375
Hauling, per cubic yard	1.762
Placing, per cubic yard	.500
Total cost per cubic yard	$ 9.924
Total cost per square yard, 8 in. thick	2.205

Grading per Square Yard

1 foreman at 55⅚cts. per hour	$ 5.00
8 laborers at 27⅐cts. per hour	20.00
Total for 180 sq. yd	$25.00
Cost per square yard	$ 0.138
Total cost per square yard	2.343

The construction cost upon the Baltimore-Washington Boulevard for similar work but using the ordinary methods was $3.24 per sq. yd. The largest saving was in handling materials. Mixing, placing, forms, curing and protection on the Boulevard cost 84 cts. per sq. yd., while the same operations on the Belair Road cost about 20 cts. per sq. yd. (The average haul for the entire road was about 2½ miles, and the costs given were taken for an average haul of 3½ miles. This would also decrease the average cost per square yard in place for the entire road.)

Time Cost of Reinforced Concrete Pavement Construction at Plymouth, Wis.—W. G. Kirchoffer gives the following in Engineering and Contracting, Aug. 6, 1913.

Description of Pavement.—The pavement was 40 ft. wide between gutters, which were 18 inches wide built integral with the curbs: making total width of roadway between curbs 43 ft. The base of the pavement was a 6-in. layer of concrete composed of 1 part of cement, 3½ parts of sand and 6 parts of crushed rock. Upon this base the reinforcement was laid, which consisted of American Steel Wire & Fence Co.'s woven wire mesh No. 7. This was laid in strips at right angles to the direction of the street and covered the entire surface from gutter to gutter.

The surface or wearing coat was 1½ ins. in thickness and was placed directly upon the fabric. It was composed of 1½ parts of crushed granite and 1 part of cement. The crushed granite was in two sizes; ½ to ¾ in. and ¼ in. down to dust. These were proportioned so as to make the most dense mixture.

The surface coat was troweled smooth after being brought to the proper crown by a screed. It was then sprinkled with dry cement, if in a wet condition, after which the surface of the pavement was covered with granite chips ranging in size from ½ to ¾ in. These were cast on by hand or with a shovel. Wherever these did not sink into the surface of the pavement, they were lightly tamped with a float or trowel.

The pavement was cut up into squares 40 ft. each way by expansion joints. In place of the usual joint of tar or asphaltum, 1-in. "pecky" cypress boards were used. These were 8 ins. wide and placed along each gutter and every 40 ft. at right angles to the street. "Pecky" cypress is a species of cypress that has the appearance of being worm eaten or partially rotten. It was adopted because of its durability.

Methods of Construction.—The curb and gutter were constructed previous to the excavation for the pavement. After the subgrade has been completed and rolled for a distance of a block or more, the laying of the pavement was begun. The cypress boards which were to constitute the expansion joints were used as an outside form for the curb and gutter and as templates in forming the crown of the street, thus saving the use of considerable lumber as well as time in placing and removing it.

The base concrete was laid in sections 40 ft. square and enough in advance of the wearing coat to allow the cement to get its initial set. Then the reinforcement and wearing coat were placed in 40-ft. sections. No travel was allowed on the completed work for a period of 10 days after laying and the surface was kept moist by spraying with garden hose.

Time to Complete Work.—Work on the excavation for curb and gutter was begun May 25, 1910, and on the curb and gutter proper June 4 and was complete on June 12, a total of 25 working days. The grading for the pavement was begun June 13 and the laying of the pavement on July 19. The entire pavement was complete Sept 3, a total time of 80 working days from the time of beginning the curb and gutter.

During the time this pavement was under construction, a careful record was kept of the actual time put in upon each kind of work. The total number of square yards in the pavement was 10,786.22 and the total number of feet of curb and gutter was 4,648.2; the time required to perform each part of the work and the hours required to lay 1,000 sq. yds. of pavement or 1,000 lin. ft. of curb and gutter is given in the accompanying table.

This pavement is now nearly three years old, has passed through three winters and there is not the sign of a crack or a flaw in it any place, not even along the street car tracks.

The use of the woven wire mesh has demonstrated the fact that it is possible to construct a concrete pavement so that it will not crack along the center of the street, a thing which has happened so generally in other places. This new form of surface is not slippery and does not wear perceptibly. The expansion joints have worn off some but not enough to show any abrasion of the concrete along the edges of the boards.

This pavement was designed by Mr. Kirchoffer, and was constructed by contract under his supervision. The contract price was 48 cts. per linear foot for the curb and gutter and 1.23½ per square yard for the pavement complete, including the excavation.

TABLE XXVI.—ACTUAL TIME IN HOURS PER 1,000 SQ. YDS. AND PER 1,000 LIN. FT. FOR CONSTRUCTING CONCRETE PAVEMENT AND CURB AND GUTTER, PLYMOUTH, WISCONSIN

	Grading for curb and gutter	Concrete work for curb and gutter	Grading for pavement	Laying concrete pavement	Totals for pavement	Totals for curb and gutter
Teams	4.3	159.4	48.3	108	156.3	163.7
Laborers	271	93.5	212	696	908	364.5
Foreman	19.4	140	9.3	98	107.3	159.4
Timekeeper	15.2	6.0	.....	41.8	41.8	21.2
Engineer and roller	15.2	.....	16.5	.....	16.5	15.2
Carpenter's setting:						
Forms for curb and gutter	.....	125	.....	.....	.....	125
Expansion joints and stakes	.....	.....	.....	39.1	39.1	.....
Engineer and mixer	.....	6.0	.....	56.8	56.8	6.0

Total square yards pavement, 10,786.22; linear feet of curb and gutter, 4.648.2. Wages paid: Laborers, $1.90 per day; foreman, $4.00 per day; timekeeper, $2.00 per day; engineers, $2.25 per day; teams, $4.50 per day; carpenters, $2.00 per day.

Cost of Concrete Road with Bituminous Wearing Surface in California.—The following data, taken from an article by C. L. Rakestraw published in Engineering and Contracting, Feb. 11, 1914, were accumulated in constructing 14 miles of state highway from Healdsburg to Santa Rosa, California.

Breaking up Old Roads.—Most of the construction was over old roads, and the breaking up of the old road surface was necessary. These old surfaces were often quite hard, due to years of compacting by traffic. When old macadam is 6 to 10 ins. thick and has been compacted from three to five years, it is practically impossible to break up the crust by teams and plows. First, the line of teams (16 to 20 horses) will be so long that three or four drivers are necessary, and it is much trouble to turn the line around. Second, the power from this line of teams will be so unsteady that it is very hard for the four plow men to guide the rooter or plow. The following, based on actual work, is the cost of hard rooting, using teams:

Item—	Cost per day
20 head, rent with harness, at 50 cts	$10.00
20 head, feed and lodging, at 50 cts	10.00
4 teamsters, at $3.25	13.00
4 plow men, at $2.75	11.00
Depreciation on equipment	0.32
Sharpening 10 plow points, at 20 cts	1.00
Supervision, supt. $1 and foreman 50 cts	1.50
Total	$46.62

This outfit would root about 1,000 ft. per day, and the cost per lineal foot was therefore about 4.7 cts. Compared with this, an 18-ton Kelly Springfield road roller would, with the same rooter and points, but with only three plow men, root 1,500 ft. per day at the following cost:

Item	Cost per day
Roller, including depreciation	$10.00
Engineer	4.00
Fuel, oil, grease	2.35
Depreciation, plow and points	0.32
Sharpening 13 plow points, at 10 cts	1.30
Supervision, supt., $1, and foreman, 50 cts	1.50
3 plow men at $3.75	8.25
Total	$27.72
Total per lineal foot	1.85 cts

Comparison of the two statements shows in favor of road roller rooting a saving of 2.83 cts. per lineal foot, or $149.42 per mile of road. These figures are for hard rooting. When a roadway has only about 2 ins. of macadam on the surface it can easily be rooted with twelve head of horses and a road plow or rooter at a very reasonable cost, as shown by the following statement:

Item	Cost per day
12 head rent with harness, at 50 cts	$ 6.00
12 head, feed and lodging, at 50 cts	6.00
2 teamsters, at $3.25	6.50
3 plow men at $2.75	8.25
Depreciation in plow, points, etc.	0.32
Sharpening 15 points at 10 cts	1.50
Supervision, supt., $1, and foreman, 50 cts	1.50
Total	$30.07
Total per lineal foot	1.67 cts

This outfit will plow 1,800 ft. per day, and the unit cost given above is based on this output of work. For thin macadam, rooting by horses is the cheapest method, and it has the additional advantage that the travel of the horses breaks up the clods from the plow. When a rooter is used for rooting it is generally the practice to run a 6-horse plow back and forth through the material until all the larger lumps are broken, and it is in shape for the road graders and fresnoes to handle readily. The difference in hardness of the macadam will not affect the output of the steam roller, because the roller has a fixed rate of speed, and can accomplish only the fixed amount of rooting, whether in a soft or hard material.

Rough Grading.—After breaking up the old road surface, it was rough-graded to within 0.1 ft. of the required grade when rolled for the whole width of the road, including the shoulders. If the shoulders are graded at this time the material is handled with fewer teams than if the grading is done after the concrete is laid. Also the constant compacting of the shoulders by work teams during the concreting puts them in better shape, and ensures a more uniform appearance.

Staking and Placing Side Forms.—After the rough grade had been brought to within 0.1 ft. of exact elevation, the grade and line stakes were set. The road being particularly described had a 15-ft. pavement 4 in. thick with a 4½-ft. shoulder on each side. The concrete base has a crown of 2½ ins., the arc of the crowning being a parabola. From the edges of the concrete slab the shoulders slope straight, dropping 4 ins. in 4½ ft.

The location of the side forms was 7½ ft. from the crown, and with their top edges 2½ ins., or 0.21 ft., lower than the crown elevation shown in the profile. Two lines of grade stakes were employed, a line 9½ ft. each side of the center line and 2 ft. out on each side from the side forms for the concrete roadway. These 2-ft. intervals gave ample room to set and peg the side forms without disturbing the grade stakes; also the carpenters in setting the side forms with a 30-in. spirit level could notch the level 2 ft. from the end, and with it alone adjust the form board both to distance and grade, working from the grade stakes. The carpenter setting side forms required only a spirit level and a hammer.

The side forms were handled usually by two men at $2.75 per day and two men at $2.50 per day. These could place, line up and fasten about 800 ft. on each side, or 1,600 ft. of side forms per day at the following costs:

Item	Cost per day
2 carpenters at $2.75	$ 5.50
2 helpers at $2.50	5.00
* 1,680 ft. 2 × 4-in. plank at $26 per M ft. B. M.	9.27
Nails, etc.	0.23
200 stakes at 1 ct	2.00
Interest and depreciation	0.15
Superintendent, $1; foreman, 50 cts	1.50
Total for 800 ft. of road	$23.65
Per lineal foot of road	2.96 cts.

* Boards used three times, so one-third of total cost is charged.

Subgrade Construction.—After the side forms were placed and checked, material was filled between them to the proper depth to give the correct cross-sectional profile when properly rolled. When the rolling was completed, the surface was checked by means of a template and when there were variations of consequence from the true grade the surface was harrowed and material added or removed as required.

The cost of reshaping subgrade varies so much with the material that its tabulation by items is impossible. It runs, however, about ¾ ct. per square foot for a 15-ft. pavement; this cost is exclusive of grading, excavation and fill. Excavation, where it consists of shaving off a thin layer of crust here and there, costs about 80 cts. to 90 cts. per cubic yard.

Mixing and Laying Concrete.—The specifications called for a 1:2:4 broken stone concrete and stated the sizes of stone and sand. With the undertaking of work it was found that a natural gravel pit existed at Healdsburg and that the company operating this pit had facilities for furnishing promptly this gravel in any quantity demanded by the work. The gravel was exceptionally clean washed gravel, well graded and dense. Gravel was, therefore, substituted for broken stone. It cost delivered to any railway siding along the work 72 cts. per cubic yard. The average haul from railway to the work was 1½ miles, and the cost of hauling was 63 cts. per cubic yard, or 41 cts. per yard mile. This cost of haul seems high, but it is accounted for by the weight of the gravel, 3,300 lbs. per cubic yard, and by the fact that crooked roads prevented haulage in wagon train by traction engines and made team hauling necessary.

Using this gravel and a 1:6 mixture, it was determined that 96 sacks of cement would make 100 ft. of 15 ft. by 4 in. pavement. The plan adopted was to pile the gravel continuously along the middle of the subgrade and place the cement in four-sack piles spaced 4 ft. apart. A cleat was riveted to the inside of the mixer charging hopper to indicate a two-sack batch of 1:6 mix. Six men using square-pointed shovels charged the gravel and one man charged the cement. Golden Gate cement in cloth bags was used; paper sacks broke easily and carried water, and also the fog loosened the paste, letting the sacks open and admit dampness.

The mixer traveled on 3 ft. × 3 in. redwood sills, which could be shifted easily and often enough to guide the mixer well. This runway was located midway between side forms, which shifted the discharge chute slightly off center, but not enough to inconvenience the concreters. As the mixer was operated some 1½ days behind the subgrade finishing crew, the subgrade surface had opportunity to dry out, and consequently it was wetted down ahead of the concrete laying, so that moisture would not be sucked by the soil from the concrete.

The concrete was distributed by the chute, and also shoveled against the side forms, special care being taken to well spade and dump the concrete against the forms, so as to ensure an exceptionally dense and strong concrete next the shoulders, where severest wear comes. No expansion joints were used.

By leaving out the expansion joints and letting the expansion of the pavement itself break the pavement, we have the maximum of this pavement in the largest possible slabs. Now, after cleaning the concrete slab for the application of the wearing surface, specially clean these cracks and pour hot or heavy asphaltic road oil into them; this will form a perfect expansion joint.

The cost of the concrete base laid as outlined above was as follows:

Item	Cost per day
1 foreman at $4	$ 4.00
1 engineman at $3	3.00
10 shovelers at $2.75	27.50
1 cement man at $2.75	2.75
2 finishers at $3	6.00
Depreciation of plant and tools	9.00
Cost of water	6.13
Total	$57.38

The average daily run of concrete pavement was 550 lin. ft., or 101.85 cu. yds. The above statement of costs is a statement of costs with concrete materials—cement and gravel—delivered onto the subgrade ready for use, and they give the following unit costs:

Per lin. ft., 15-ft. roadway	10.4 cts.
Per cu. yd. of concrete	56.3 cts.

Method and Cost of Securing Water.—All water used on this work had to be pumped. A line of 2-in. boiler pipe in 8-ft. lengths was laid along the work and provided with 1-in. taps at 50-ft. intervals. This pipe line was torn up and laid ahead as pumping stations were moved and as the work progressed; two men at a daily cost of $5 were employed continuously at this work. All pumping stations but one were located at adjacent streams, and the water supply cost nothing except for pumps and pumping. In one case an 180-ft. well was bored at a cost of $380; this well supplied 100,000 gals. per day during the driest part of the year for about five miles of the road. The cost per day of supplying water was as follows:

Item	Cost per day
1 gas engine pump man at $2.75	$ 2.75
2 gas engine pump men at $2.50	5.00
2 pipe layers at $2.50	5.00
Int. and dep. on 17,000 ft. of pipe and engine	2.00
Fuel and oil on gasoline pump	2.15
Superintendent, $1; foreman, 50 cts	1.50
Total	$18.40

Water was used in about equal quantities for (1) mixing concrete; (2) curing concrete and (3) wetting subgrade; of the above total cost, therefore, one-third or $6.13, was charged to each service.

Finishing and Curing.—Several methods of finishing and curing the concrete slab were investigated. The first plan was: Six hours after placing to broom with a steel broom the surface and so roughen it that the bituminous covering would cling. After twelve hours sprinkling began and the concrete was kept moist. While this plan might have been satisfactory in winter or wet weather it did not give good results in the summer which was the time of year the work was done. The concrete could not be kept evenly moist and also much water ran off and was wasted. The second plan was to broom the concrete as in the first plan, then build earth dams along the pavement edges, then wet down the concrete, then cover it with 2 ins. of earth and water the covering until saturated and the water showed in pools. By this plan the moisture was better distributed, it was more obvious to common laborers when more wetting was needed, and there was less loss of water by evaporation and run off. A third plan tried and abandoned was: after brooming the concrete, to sprinkle it and cover it with heavy building paper held down by clods and stones. The idea was to remove the paper, resprinkle and replace the paper every night for seven nights, the standard curing period. It was anticipated that the paper would prevent evaporation, reduce labor as compared with shoveling in earth and building dams, be quick in application, eliminate attention during the day and offer several other advantages. The plan did reduce labor but the paper was torn off in places by the wind and did not protect the pavement from drying out in spots. It was no better than the first plan.

A fourth plan was finally devised which eliminated most of the faults of preceding plans. First, levees were built along the edges and over the side forms in such position that about one-third the width of the embankment fell inside the form board and over the concrete. These side levees were built high enough to hold a depth of water of 2 ins. over the crown of the slab. At suitable intervals depending upon the grade, cross levees connecting the side levees were built. These levees divided the pavement into a series of basins which could be filled with water. On superelevated curves in addition to cross levees a number of parallel longitudinal levees were built.

Referring to some of the details noted above: The purpose of building the side levees two-thirds outside the side forms is two-fold: First, about one-third the width of the levee becomes saturated and this third is over the concrete slab which requires wetting. Second, the form boards can be lifted out for reuse leaving two-thirds of the levee intact to maintain the reservoir. Besides being required for hydraulic reasons the division by cross levees into small basins serves the purpose of confining loss of water by a levee break to a small area of pavement; restoration is also thus facilitated. Also in construction the workman can let one basin be filling while he is building the succeeding levees.

This method of watering concrete pavement had the following advantages over the second described and next most successful method: (1) It required less labor to construct cross levees than to cover the slab all over with 2 ins. of earth; (2) the wetted black earth covering suffers greater loss by evaporation than does the heat reflecting water surface; (3) all the pavement is water covered while an earth covering may dry out in spots and absorb water from the concrete; (4) all work is done at night when water is needed for no other purpose, while an earth covering has to be sprinkled continuously; (5) one filling of the basins suffices for the total curing while an earth covering has to be wetted frequently; (6) the levees suffice as barriers notifying drivers not to cross the work, while with earth covering separate barriers are necessary; (7) the filling of the basins, however, must be more carefully done so as not to wash the concrete than when earth covering is used; the best method is to let the hose stream run on a sack laid on the pavement.

The cost of curing concrete pavement by the methods described are given by Table XXVII; in this table method three being considered not practical is omitted, also its cost is about the same as that for method one. It is seen from Table XXVII, that method four is far the cheapest.

TABLE XXVII.—COST OF CURING CONCRETE PAVEMENT

	Method No. 1	Method No. 2	Method No. 4
1 man at \$2.75 per day	......	\$ 2.75	\$ 2.75
Men at \$2.50 per day	\$12.50	17.50	10.00
Depreciation, shovels, etc	0.40	0.80	0.65
Cost of water	6.13	6.13	6.13
Supervision, supt. & foreman	1.50	1.50	1.50
Total cost 1st day	\$20.03	\$28.68	\$20.53
Lineal feet covered	300	550	650
Cost per lin. ft., 1st day	\$0.067	\$0.052	\$0.037
Cost of each consecutive day	0.067	0.052	0.005
Total cost of curing, 7 days, per lin. ft. pavement	0.469	0.364	0.067

The side form boards were removed seven days after placing the concrete; this work cost about 1 ct. per lineal foot of pavement. The earth levees were left in place about a week longer and were then removed, usually with a four-horse road scraper and at a cost of about 0.3 ct. per lineal foot of pavement. With the same scraper the shoulders were brought as near as practicable to grade and then they were finished by hand. Constructing shoulders cannot easily be figured in cubic yard units but if they are brought to shape with the rough grading as previously described the work will cost exclusive of rolling, about 5 cts. per lineal foot of pavement and including rolling about 6 cts. per lineal foot of pavement.

SUMMARY OF COST

Summarizing the costs previously given, the following tabulation is obtained:

	Per ft. road
Tearing up old roadway with rooter and plows	$ 0.0283
Placing form-boards (after exc. and emb. have been done)	0.0296
Handling and preparing sub grade with rolling	0.0375
Cost of pouring and finishing 4-in. concrete base	0.1043
Cost of curing and finishing (Method No. 4)	0.0670
Cost of removing form-boards	0.0100
Cost of cleaning earth off pavement	0.0030
Cost of preparing shoulders	0.0600
Actual cost per lineal foot	$ 0.3397
Actual cost per mile	$1,793.62
10 pct. for contingencies	179.36
Total cost per mile	$1,972.98

These costs are exclusive of costs of materials and of excavation and fill.

Organization and Output of a Gang Laying Concrete Base for Asphalt Pavement.—W. D. Jones gives the following in Engineering and Contracting, July 5, 1916.

In paving a street with 6 in. of concrete, 1 in. of binder, and 2 in. of asphalt wearing surface at Los Angeles Harbor, California, the contractors for the work, had the following output, plant and organization for one working day of 8 hours with good clear running and no important stops.

The mix was 1:3:6 of cement, sand and crushed rock, respectively, and was mixed in batches by a No. 14 Chicago Street Paver having a charging skip and a revolving spout for discharge. The base on which concrete was laid had previously been prepared and stakes driven with tops 2 in. under the subgrade in order that they might be worked over. Planks 2 in. × 10 in. were laid out ahead and concrete materials, in quantity necessary per foot of street, piled on these for ease in shoveling to wheelbarrows. Cement was piled alongside the street at intervals necessary for handling to the mixer, as the work progressed, by hand. Fourteen wagons hauled the necessary materials from stock piles about ¼ mile away, over dirt road. Occasionally an extra load had to be brought in close to the mixer or one taken away in order to correct error in gaging the quantity necessary, by wagon loads, but as a rule the measurements checked out pretty well. Two men shoveling into one sand barrow and four men into two rock barrows kept the mixer supplied with sand and rock, the men taking turns at wheeling the barrows up the incline to dump into charging skip. One cement man fed mixer and his helper carried sacks from the storage piles mentioned above to the platform on which he stood. One wagon with body removed, one teamster and two men were kept busy taking out planks after the mixer had passed over and before they were covered with concrete, and hauling them ahead and placing them for additional material as the work progressed. One man put in and maintained the header boards which limited the edge of the pavement and another was kept busy between grading and cleaning up in the wake of the mixer and in driving stakes to the grade of the finished surface of the street; this was done by measuring up from the tops of stakes previously driven below

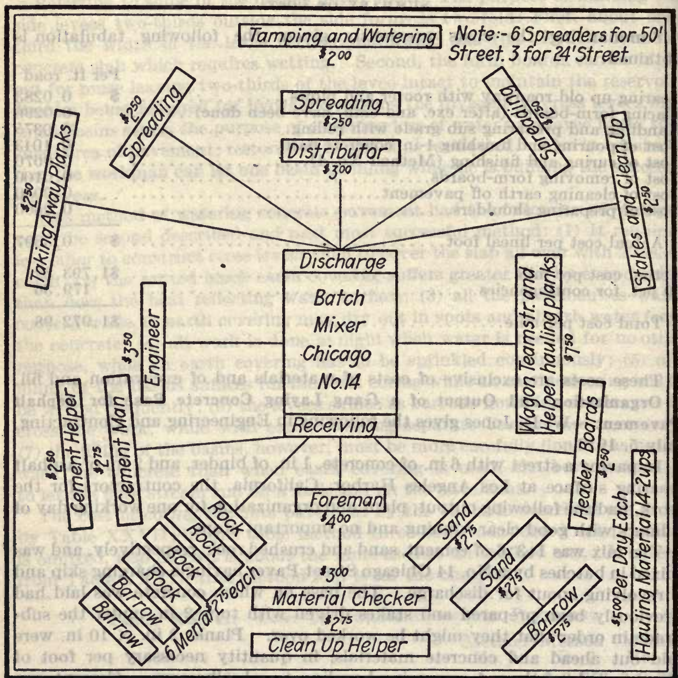


FIG. 13.—Diagram of gang organization.

subgrade, all stakes having been driven the same distance below finished grade. One man attended to the discharging spout and three men to leveling and working the concrete to place 3 in. below the finished surface of the street. Three men took care of this end when the street was 24 ft. wide or narrower but more men were necessary in laying a wider pavement, six being necessary on a 50-ft. street, the cost having been observed on a 24-ft. section. One man followed up after concrete was fairly hard and roughened the surface of the concrete with a triangular stamp in order to give a better bond with the binder; he also put up barriers and wet down the concrete. In eight working hours 13,000 sq. ft. of 6-in. base was laid with this mixer and organization. This amounts to 241 cu. yd. for the day and to 1 cu. yd. every 2 minutes. The organization and cost summarized is as follows:

1 foreman at $4	$ 4.00
1 engineer at $3.50	3.50
1 checker at $3	3.00
1 cl. helper at $2.25	2.25
14 teams and drivers at $5	70.00
6 rock men at $2.75	16.50
3 sand men at $2.75	8.25
1 cement man at $2.75	2.75
1 cement helper at $2.50	2.50
1 header, boards, at $2.50	2.50
1 team, driver and helper at $7.50	7.50
1 plank man at $2.50	2.50
1 stake man at $2.50	2.50
1 spout man at $2.50	2.50
3 leveling at $2.50	7.50
1 tamp and water at $200	2.00
Total labor	$139.75
241 cu. yd ... Per cu. yd.	0.58
Total labor exclusive of hauling material to site	69.75
Total labor exclusive of hauling material to site. Per cu. yd.	0.29

The diagram, Fig. 13, shows distribution of organization about the mixer.

Comparative Cost of Concreting Pavement of Street Railway Right of Way, Using Batch Machine, Continuous Mixer and Hand Mixing.—The following costs, given by S. Gausmann, formerly Roadmaster of the Brooklyn Rapid Transit Company, New York, in Engineering Record, April 10, 1915, are based on doing work with no car interference. These costs will be somewhat increased under car operation, with machines outside the tracks, or decreased with machines of larger capacity.

The freight rates for hauling machines to and from work are in accordance with rates approved by the Public Service Commission of the State of New York, First District, and include the total cost of maintenance of the car equipment, cost of trackage and overhead line rights and office expenses of the freight department. These rates vary according to the length of haul, the figures given being for an average haul. This haulage cost would be considerably reduced where the track department does its own handling of material, etc., and where only the wages of crews are charged against it instead of having the freight department make a general charge per car-mile.

Cost with Batch Mixer.—The batch mixer, for which the following costs for operation are given, is of 0.5 cu. yd. capacity. It can be bought for $1300, mounted on a car, and is electrically operated as to mixing only, so that it must be hauled to and from the work daily.

The number of men employed and their rates per hour in operating a machine of this character are: One assistant foreman, 25 cents; one operator, 25 cents; four laborers, 20 cents; six laborers, 18 cents; fourteen laborers, 16 cents; one checker of time and material, 15 cents, or a total cost of $47.70 for one day of ten hours. This cost is distributed to the various operations as follows:

COST PER DAY FOR GANG ON ONE BATCH MACHINE

Operation of the machine	$ 2.50
Watching mix and dumping	4.25
Handling material to the machine	13.50
Removing and placing the track	22.10
Ramming and tamping under the rail	3.85
Checking	1.50
Total	$47.70
Add other charges:	
Overtime for cleaning	$ 0.90
Interest on investment	.58
Freight to and from work	6.25
Lubricants, repairs and incidentals	2.33
	$10.06
Total	$57.76

A gang of this size will average in a ten-hour day approximately 675 ft. of single track with concrete 7 in. deep. The area, with 6 × 8-in. × 8-ft. ties spaced 2 ft. center to center is equal to 94.22 cu. yd., making the unit cost $0.613 per cubid yard, exclusive of material.

Cost with Continuous Mixer.—A good continuous mixer of a standard make can be purchased for $560. Although such mixers are supplied on wheels for use at the side of the track, a good car with old pony wheels and a wooden frame can be made for approximately $30, thus bringing the total cost to less than $590. This cost is for a gasoline-operated machine, but an electrically operated one is preferable. Provided an old motor is obtainable, the first cost will vary but little from gasoline, whereas the cost of operation will be less.

As a machine of this kind is easily derailed it need not be removed from the street daily, and can be left on the work continuously ready for use at any time, with no outlay for freight charges until it is required at other points.

The number of men employed, and their rates per hour, in operating one of these machines are: One assistant foreman, 25 cents; one operator, 25 cents; two laborers, 20 cents; three laborers, 18 cents; eight laborers, 16 cents; one checker of time and material, 15 cents, or a total cost of $28.70 for a ten-hour day. This cost is distributed to the various operations as follows:

COST PER DAY FOR GANG ON CONTINUOUS MIXER

Operation of machine	$ 2.50
Handling material to machine	10.20
Distributing in track	12.10
Ramming and tamping under rail	2.40
Checking	1.50
	$28.70
Add other charges:	
Overtime for cleaning	$ 0.50
Interest on investment	.26
Freight to and from work	1.25
Gasoline, oil and repairs	2.25
	$ 4.26
Total	$32.96

This gang will average 430 ft. of single track per ten-hour day, with concrete 7 in. deep. This area, with 6 × 8-in. × 8-ft. ties spaced 2 ft. center to center is equivalent to 60.054 cu. yd., making the unit cost $0.5488 per cubic yard, exclusive of material.

Mixing by Hand.—Of course, in mixing by hand the number of men employed may vary, but for an illustration we may assume that as many are employed as on the continuous mixer, exclusive of the operator. The cost then would be distributed to the various operations as follows:

Mixing by Hand

Distributing material and mixing	$10.50
Distributing in the track	11.80
Ramming and tamping under the rail	2.40
Checking	1.50
	$26.20

This number of men in a ten-hour day will average 225 ft. of single track with concrete 7 in. deep which, with 6 × 8-in. × 8-ft. ties spaced 2 ft. center to center, amounts to 32.77 cu. yd., equivalent to a unit cost of 80 cents per cubic yard.

The foregoing figures were obtained from many years' experience in this line and from carefully collected data. While they may not apply to all locations, the costs can be easily adjusted to meet any conditions from the information given.

Portable Frame for Canvas Covering for Concrete Road Construction (Engineering and Contracting, Dec. 3, 1919).—A simple portable frame for supporting the canvas covering used in concrete road construction before the earth protection is applied is described in a recent issue of The Concrete Highway Magazine. Details of the arrangement are shown in Fig. 14.

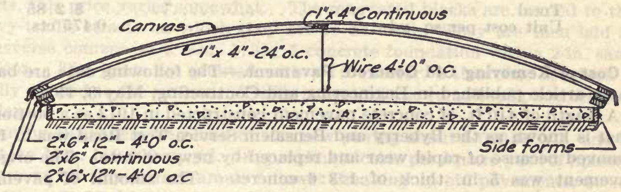


Fig. 14.—Cross section showing construction of frames and methods of supporting them on side forms.

A sawhorse of the required height was set up in the center of a completed section of concrete road and 1 by 4-in. transverse members laid across it. The ends were then bent down until they touched the side forms and nailed to 2 by 6-in. longitudinal runners. A 1 by 4-in. continuous strip was nailed to the truss members at the top so as to hold them rigidly and uniformly spaced.

The lower or horizontal wire was attached to one side by winding it around a cleat securely nailed in place. In order to spring the other side into position, a crowbar was used. The wire was wrapped around a cleat and then attached to the bar, which was used as a lever until the wire was taut enough and the cleat had been nailed down. This was continued until all horizontal wires had been placed. Additional strength and rigidity were obtained by connecting the crown of the truss with the horizontal wire by a vertical wire. Cleats 2 by

6 by 12 in. were placed under the side braces at intervals of 4 ft., to facilitate handling. Eight of these supports were made in units 25 ft. long.

The cost of 200 lin. ft. of the supports was:

Lumber, 1,500 ft. B. M. at $50	$ 75.00
Wire, nails, etc.	3.00
Labor, 3 men, 2 days, at $4	24.00
Total (200 lin. ft. at 51 cts.)	$102.00

The frame was devised by G. J. Lynch of Reagon & Lynch, Contractors Uniontown, Pa., and was used on the construction of a portion of State Highway Route No. 116, near Smithfield, Pa. Mr. Lynch gives the following figures showing the cost of shifting the canvas:

Eight men and one foreman working one hour were necessary to shift 200 ft. of canvas until these supporting frames had been devised. Now the same work is accomplished in 15 minutes. The covering is moved three times a day. The following table gives comparative costs between old and new methods:

Cost of shifting canvas without supports:	
8 men, 3 hours, at 40 cts.	$ 9.60
1 foreman, 3 hours, at 60 cts.	1.80
Total	$11.40
Average daily yardage	600
Unit cost per sq. yd	1.9 ct.
Cost of shifting canvas with supports:	
8 men, ¾ hour, at 40 cts.	$ 2.40
1 foreman, ¾ hour, at 50 cts.	.45
Total	$ 2.85
Unit cost per sq. yd	0.475 cts.

Cost of Removing Old Concrete Pavement.—The following data are based on an article published in Engineering and Contracting, May 3, 1916.

A length of 410 ft. of concrete pavement constructed in 1913 as a portion of what is known as the Byberry and Bensalem Service Test Road was in 1915 removed because of rapid wear and replaced by new concrete. The original pavement was 5 in. thick of 1:3:6 concrete. The amount of pavement removed was 792 sq. yd. or 110 cu. yd. It was removed by hand using bars and sledges. The cost of removal was 29.67 cts. per square yard or about $2.08 per cubic yard. The labor cost of reconstructing this pavement was 21.46 cts. per sq. yd., thus the cost of removing the old concrete cost about 38.2 per cent more than the labor cost of a new pavement.

Cost of Redressing Granite-Blocks for Pavements.—The following data, published in Engineering and Contracting, Oct. 14, 1914, are taken from a discussion of the use of blocks from old granite block pavements by Wm. A. Howell before the American Society of Municipal Improvements.

The old blocks used on the 1914 jobs in Newark range in length from 10 to 14 ins.

A blockmaker can in a day's work of 8 hrs. nap and reclip 175 large blocks into 350 small ones. It costs the contractor $15.00 per thousand for the small blocks, or $30.00 per thousand for the large ones. These blocks run 21 to the square yard, or 42 to the yard for the small ones.

A rough detailed estimate of the cost of this kind of pavement, which would permit of a variation of possibly 10 to 15 cents, would be about as follows:

Item	Cost per sq. yd.
Paid city at 3 cts. each	$0.63
Paid clippers for work	.63
Laying and handling	.20
Sand	.05
Concrete	.65
Grading	.10
Hauling	.10
Grouting	.12
Cost per sq. yd. (21 blocks required)	$2.48

The following is taken from Engineering Record, Dec. 14, 1914. During the last two years extensive areas of granite block pavement have been taken up, redressed and relaid by the Baltimore Municipal Paving Commission. The expense of removing, dressing and relaying the block has been less than two-thirds the prevailing price for new granite-block surface.

The old stones were of the usual heavy type, many as large as 14 in. in length, 6 in. in width and 8 in. in depth. The broken blocks are from 4½ in. to 6 in. deep, and those which are less than 3 in. in either surface dimension are not used.

As much of the old block was laid on streets bearing a light traffic only, little trouble is experienced because of the operations of the working gangs. From the old pavements the blocks, which are sand filled, are removed with crowbars and placed convenient to the cutters, who work in the street, producing about 225 of the small blocks per 8-hr. day. The price for redressing is about 2½ cents per block, although, as the work has been let in many contracts, this price varies somewhat. The renovated blocks are carried to the heavy-traffic streets on which they are to be used. They are then laid in transverse courses on a 6-in. 1:3½:7 concrete foundation with a 2-in. sand cushion. The joints are grouted with a 1:1 mortar, a thin coat of which is finally applied to the surface. Traffic is kept off the completed pavement for 14 days.

During 1913 there were laid of this new paving about 5,000 sq. yd., and in 1914, to Nov. 1, 3,900 sq. yd. Approximate costs per square yard of finished pavement for this surface are as follows: Breaking up old pavements, $0.09; recutting, $1.00; hauling, laying and grouting, $0.71; total unit cost, $1.80. As the old blocks have practically no value unless used in this way, the cost of laying the recut prisms, exclusive of foundation, may be compared with that for improved granite block, exclusive of foundation. As an average figure for the latter in Baltimore is $2.80, recutting means a saving of 36 per cent.

Paving Blocks Cut from Old Granite Block Wall (Engineering and Contracting, July 3, 1918).—The problem of disposing of a masonry wall around the old City Hall at San Francisco was solved by cutting the stone into paving blocks. The work was done by hand and the paving blocks were produced at a cost of $37.50 per 1,000. The men were paid $6 per day. About 75,000 6 in. deep by 7 to 8 in. long and 3 to 4½ in. wide paving blocks were obtained.

Cost of Grouting Granite Block Pavement.—The following matter is given in Engineering and Contracting, Nov. 3, 1915.

The value of grout joint filler for granite block pavement has been much discussed with great difference of opinion. Grout filling is extensively employed and this discussion considers only that fact in presenting methods and costs of grouting. As no general and much less no standard practice has been determined, information is best given by citing individual examples. These do not cover all places in which grouted granite block paving is employed but they fairly represent grouting practice.

Lawrence, Mass.—The method of grouting is as follows: After the blocks, 3½ to 4 ins. wide, 7 to 8 ins. deep and 11 to 13 ins. long are set, they are stiffened in place by ramming with a small amount of pea gravel, perhaps an inch in depth, in the joints. The grout is a 1 cement and 1 sand mixture and is mixed in iron boxes designed and patented by Paul Hannagan, Director of Engineering. When thoroughly mixed, the grout is discharged onto the pavement and then broomed grout is removed from the tops of the blocks. In a test made in 1912, it was found that 0.108 bbl. of cement was used per square yard of pavement. The cement cost $1.08 per barrel; pea gravel cost about $2.30 per cubic yard and sand cost $1.00 per cubic yard. With wages at $2.25 per day, the labor cost of grouting was 6.4 cts. per square yard of pavement; the total cost per square yard was 26¾ cts. Data reported by City Engineer Arthur D. Marble.

Lowell, Mass.—This city has about 8½ miles of grouted granite block pavement on concrete base. The average cost of grouting joints is 24¼ cts. per square yard. The amount of material per square yard of 4½ ins. deep blocks is 0.295 bags sand and the same volume of cement. The essentials for securing good grouted granite block pavement are stated as follows:

1. Have sub-grade well rolled and all soft places eliminated; 6 ins. of crushed stone spread over the sub-grade and rolled to a true crown; mixture for foundation, 4 parts sand and 1 part cement.

2. Sand to a uniform thickness of 2 ins. should be spread over the foundation.

3. The blocks, after careful culling, should be well rammed and at the same time pea stone should be broomed into the joints.

4. For the grouting, be sure the cement is good and the sand clean and sharp. A small percentage of clay is good to use as a binder.

5. Be careful to use the correct proportions of sand and cement. Use 1 part cement and 1 part sand for mixture.

6. If a mixing machine is not used, keep the mixture constantly agitated in the box. Remove the grout from the box with scoop shovels. Never dump the contents of the box upon the street. Whenever this is done there will be a bare spot in the grouting.

7. Wet blocks thoroughly before applying grout.

8. As the grout is poured upon the blocks throw in pea stone and broom it into the grout, bringing the whole to an even smooth surface.

9. Never do any grouting during cold or frosty weather. Good results can seldom be obtained after Nov. 15 in New England.

10. If the grouting is done during very hot weather, precautions should be taken to keep grout moist. This can be done if the weather is extremely hot by covering it immediately with ½ in. of sand and frequently sprinkling with water.

11. Do not allow any traffic upon pavement for at least seven days after grouting.

12. For best results use a medium soft granite, similar to New Hampshire granite.

13. If old blocks are used, see that they are thoroughly cleaned before

grout is poured; this mixture being one part cement and two parts sand to give best results with old blocks.

Data reported by Stephen Kearney, City Engineer.

Worcester, Mass.—Grouted pavement in this city requires per square yard about 0.36 cu. ft. of cement and 0.36 cu. ft. of sand mixed with enough water to run freely. The mixture is spread with pails or spout and is broomed into place, the brooming being continued until the joints are filled and the surplus is largely removed from the tops of the blocks; trap rock screenings are finally employed to prevent tendency of the grout to run. Grouting costs about 24 cts. per square yard of pavement, including materials and labor. Data reported by F. A. McClure, City Engineer.

Albany, N. Y.—The following information is reported for grouting dressed granite block of the following size, length 6 to 10 ins., width 3½ to 4½ ins., depth 4¾ to 5¼ ins., end and side joints not exceeding ½i n. in width The grout or filler is one part of fine, clean, sharp sand and one part cement, no pea stone being used in the joints. Preparatory to grouting, the entire gang is first put to filling bags with sand, and placing same alternately with bags of cement along the curb adjacent to the space to be grouted. This is usually done half to three-quarters of an hour before starting the machine. This gives a good start. Three men are left filling bags and distributing same, and one on cement. The gang on the machine, which is a Marsh-Capron grouting mixer, consists of:

2 men carrying cement and sand to machine.
1 man carrying water.
1 man emptying material into machine.
1 man ahead of spout brooming in grout.
1 man operating.
3 men on sand bags.
1 man on cement.

10 laborers—total for operation.

A gang of this size will grout at least 1,100 sq. yds. per day, at the following cost:

10 laborers 8 hrs. each—80 hrs. at 20 cts. per hr......	$ 16.00
1 foreman..	4.00
107 bbls. cement at $1.10 per bbl....................	117.70
16 cu. yds. sand at $1 per cu. yd.....................	16.00
	$153.70

Including material and labor, this is a cost per square yard of 13.9 cts. or 14 cts. The cost of labor per square yard with machine for a total of over 2,000 sq. yds. has been on an average of $0.015 compared to $0.0525 by hand or a saving of over 3¾ cts. per square yard. For full 4-in. joints without pea stone it requires 0.4 bag cement and same amount sand (1 to 1 mix) per square yard of pavement. Data reported by Frank R. Lanagan, City Engineer.

Cost of a Wood-Block Pavement, Cambridge, Mass.—L. M. Hastings gives the following matter in Engineering News, May 21, 1914. The work consisted in repairing with wood block having cement grouted joints a portion of Massachusetts Ave., and was done in 1912 and 1913.

Base.—The base was formed of 5 in. of cement concrete mixed by machine in 1:2½:5 proportions. Bank sand and power-screened gravel stone were used for aggregates, the gravel being of excellent quality and somewhat cheaper than broken stone.

Blocks.—The blocks were of southern long-leaf yellow pine, having 80 per cent heart wood of satisfactory texture and containing not less than five annual rings per inch. The wood was impregnated with 20 lb. of preservative oil per cu. ft. of wood, by any satisfactory process which would give the required results. The oil had a specific gravity of not less than 1.12 at 38° C. and contained not more than 5 per cent of soluble matter and was free from petroleum or asphaltic residues.

During the hot weather of the first year, "bleeding" of the heavy oil from the blocks occurred. A heavy coat of sand was spread over the pavement where needed, which absorbed the tar and made a tough sheet or scat, some of which still adheres to the wood blocks as a kind of wearing surface.

Laying Blocks.—The blocks were laid on a 1-in. bed of equal parts of cement and sand mixed dry, "struck" by a movable board to a true surface. After laying, the blocks were given a final inspection and any imperfect ones were thrown out. The blocks were finally thoroughly rammed by hand rammers. Expansion joints were placed at each curb, and transverse expansion joints were put in every 30 ft. These joints were ½ in. to ¾ in. wide and were run nearly full of an asphaltic compound, which was fairly soft and elastic, yet did not run in hot weather, making a very satisfactory filler indeed. At the first rain after the blocks were laid, many of these joints closed up entirely and in some a slight raising of the paving occurred. With continued traffic, however, most of the joints were forced back into place.

The joints between blocks were thoroughly filled with a 1:1 cement and sand mixture applied dry in two layers; afterward the pavement was wet with a hose and thoroughly flushed, and the grout broomed into the joints, the water causing the cement in the joints and bed to fill all interstices.

One portion of Massachusetts Ave. was unusually wide and carried a rather heavy traffic; upon this portion, 4-in. blocks were used, the rest of the blocks were 3½ in. in depth.

Pavement Crowns.—The street has a longitudinal grade of about 0.60 per cent. It was found that a crown of 1¼ in. per ft. gave excellent drainage and made the most effective looking street. This crown was adopted as standard where possible. The crown as actually used varies from ⅛ in. to nearly ⅝ in. per ft. This last seems and looks excessive but as a matter of fact it has not been found to make the pavement dangerously slippery.

With regard to that bugbear of wood-block pavement—*its slipperiness*—experience here indicates that trouble from the cause is usually exaggerated. When conditions make the pavement slippery, the remedy is simple, viz., sprinkling with sand. This is not often required. During the two winters of 1913 and 1914, sanding was required only 8 or 10 times each season.

Cost Data.—The entire work of excavating, grading, laying the base, laying blocks, ramming, grouting, etc., was done by city day labor without much previous experience, working 44 hr. per week at $2.25 per day, or at about 31cts. per hr. for common labor. The 4-in. blocks cost by contract $2.59 per sq. yd. and the 3½-in. blocks cost $2.29 per sq. yd., delivered on the work. In all 15, 276 sq. yd. of 4-in. block pavement was laid at a total cost of $4.11 per sq. yd., and 12,051 sq. yd. of 3½-in. block pavement was laid at a cost of $3.81 per sq. yd.

Cost of Wood Block Pavement in Wenatchee, Wash.—F. J. Sharkey gives the following data in Engineering and Contracting, Oct. 20, 1915.

During the summer and fall of 1913 Wenatchee Ave., the main business street of Wenatchee, Wash., was paved with creosoted wood block. The improvement is approximately ¾ of a mile in length, the south ½ mile being 62 ft. between curbs and 90 ft. between property lines, the balance being 53 ft. between curbs and 70 ft. between property lines, making a total of approximately 27,500 sq. yds. of pavement, including intersections.

Concrete Base and Sand Cushion.—The pavement consists of a 5-in. concrete base, a 1-in. sand cushion and 4-in. creosoted wood blocks. The concrete in the base is mixed 1:3:6, the specifications for cement, sand and gravel or broken stone being the usual standard specifications for such materials. The specifications for gravel or broken stone called for material ranging uniformly in size from that which passed a 2-in. ring to that which was held on a ¼-in. ring.

Wood Blocks.—Immediately after the preparation of the cushion the wood blocks were laid, culled and rolled with a five-ton roller.

Due to the fact that the blocks were allowed to stand for some time in piles at the side of the street, in the hottest part of the summer, before being laid, a large number of the blocks curled slightly, even though kept damp in the piles at all times. These blocks split in two when rolled, but a number of the split blocks were used as bats at the beginning of courses. The expense of culling, however, was materially increased over what it would have been had the blocks been laid and filled immediately upon arriving on the street.

Five longitudinal rows of blocks were laid next to the curb on each side of the roadway for gutter courses, and the remainder were laid perpendicular with the curb. Three ½-in. expansion joints were placed on each side of the roadway. These expansion joints were cast the required thickness, from the filler asphalt, by laying a wood strip of the required width and thickness in a bed of damp sand, removing the strip and filling the resulting trench with asphalt. The expansion strips thus made were 3½ ins. wide by ½ in. thick and were laid on the cushion between the longitudinal or gutter courses of blocks. No transverse expansion joints were provided for. The remaining ½-in. between the top of the expansion strip and the surface of the blocks was filled with hot asphalt, to seal the surface.

An asphalt filler with a high melting point was used. It was heated in a portable kettle of 400 gals. capacity and was poured over the blocks with hand pouring pots. As soon as the asphalt cooled and congealed it was cleaned off the blocks with hot shovels, collected in small piles and again placed in the heating kettle. Immediately following the filling the pavement was covered with a ½-in. layer of sand.

The costs of laying wood block pavement are given in Table XXVIII.

Maintenance.—Due to the fact that the work of filling was not completed until after extremely cold weather set in, the asphalt did not fill the joints as thoroughly as was desirable. In the spring of 1914 the pavement was cleaned, the sand cover and excess asphalt filler that had been forced out by the expansion of the blocks being removed. This was later found to be a mistake, as it developed that the blocks were in a more serious condition, from being improperly filled, than had been judged. A large percentage of the joints had received very little asphalt, and as a consequence the blocks became loose in the pavement. To remedy this condition, which was rendered more serious from the fact that a loose sand cushion had been used, a 1-inch covering of fine sand was spread over the surface and allowed to remain until worn off by traffic. This seems to have solved the problem as far as filling the joints and tightening the blocks are concerned, but it has caused some trouble in making the pavement heave, due to lack of proper provision for expansion.

In the spring of 1915 several heaved places were noted. All the trouble experienced, however, seemed to be caused by transverse expansion, and occurred within 8 ft. of the curbs on each side of the street, affecting approximately 300 sq. yds. of pavement in all. This heaving was taken care of in two ways: Where the blocks were heaved badly, they were taken up and relaid, a good grade of pitch filler being used in refilling the joints; while where the heaving was only slight the joints were blown out with dry steam from the road roller, at a boiler pressure of 200 lbs., and the blocks were rolled down to place and the joints refilled with paving pitch.

The latter method was in the nature of an experiment, but has accomplished the purpose satisfactorily and at a trifling cost. To supplement this work and provide against future heaving at the same locations a ¾-in. expansion joint has been dug out with a chisel in the gutter courses of blocks along each place where heaving occurred, this joint being filled with paving pitch. Also eight courses of blocks have been taken up clear across the street each 400 ft. in length of street, and the blocks have been cut off for a 1-in. expansion joint, relaid with equal spaces between the blocks and refilled with paving pitch. The blocks have also been kept damp all summer by flushing the street at night and sprinkling in the daytime when necessary. This has kept the blocks from drying out and shrinking and has also kept further sand and dirt from the joints. From the present excellent condition of the surface of the street, no further heaving is anticipated.

TABLE XXVIII.—DISTRIBUTION OF COSTS OF WENATCHEE AVENUE WOOD BLOCK PAVEMENT

Division	Materials: Kind and unit	Unit cost	Units per sq. yds.	Cost per sq. yd.
Base	Gravel, cu. yd.	$ 1.30	.0973	$0.1263
	Sand, cu. yd.	1.00	.0486	.0486
	Cement, bbl.	2.10	.125	.2625
	Water	....	......	.01
	Mixer (Int. & Depr.)	....	......	.0152
Cushion	Sand, cu. yd.	1.00	.0278	.0278
Top	*Blocks, sq. yd.	1.794	1.0	1.794
	Asphalt filler, ton	37.75	.0031	.1153
Total per sq. yd.		....	......	$2.3997

Division	Subdivision	Labor: Sq. yds. per hour foreman	Sq. yds., per hour labor	Labor cost per sq. yd.
Base	Mixing	120.5	8.9	$0.0523
	Placing	253	19.9	.0205
Cushion		.....	21.8	.0141
Top	Laying	.....	87.2	.016
	Helping	.....	88.0	.0435
	Rolling	.....	73.7	.0159†
	Filling	.....	5.9	.0599
Total per sq. yd.		.....	....	$0.2222

Labor, $2.50 per 8-hr. day; block layer, $10.00 per 8-hr. day. Block layer was foreman of cushion, laying, and filling gangs. *Wood blocks, $1.75 per sq. yd., f.o.b. Wenatchee, × $1.10 per M for unloading and hauling (42¼ blocks per sq. yd.). †Including roller rent, $3.50 per day.

Operating Costs of Tractor, Trucks and Sand Screen and Loader in Road Maintenance.—Engineering and Contracting, Jan. 1, 1919 publishes the following information given in a bulletin of the Colorado Highway Department by James E. Maloney, Chief Engineer.

In maintaining county roads in the vicinity of Denver the Colorado Highway Department is employing a tractor, trucks, and a sand elevator, screen and loader. The complete outfit consists of the following: One C. L. Best caterpillar gas tractor of 40-h.p. drawbar capacity, weight 28,000 lb., costing $6,000; one grader with scarifier and blade attachment, costing $800, and two light drags; 2 White 5-ton trucks and a Kelly-Springfield 5-ton truck, costing $6,000 each; and a Gallion sand elevator, screen and loader, costing $1,500.

The tractor, grader and one drag are generally used together and can be operated by two men. If the work is simply dragging, or smoothing with the grader, a distance of 20 miles might be covered; that is, if one round trip is made they would cover 10 miles of road; if two round trips were necessary, then 5 miles of road would be covered. The latter figure might be taken as an average in all kinds of materials for the dragging.

In many places it is necessary to scarify the surface in order to reshape it and remove the chuckholes and waves. On work of this latter class the tractor and grader are used very successfully, except on macadam or very solid gravel roads, where it is found that the scarifier is too light and it is necessary to use the heavy-toothed scarifier. On scarifying and reshaping it has been found that about ½ mile per day would be an average day's work.

The sum of $50 per day has been taken as the cost of the operation of this particular outfit. This figure is obtained as follows:

Caterpillar tractor, expense per day:		
Gas and oil	$17.00	
Maintenance	9.50	
Operator	5.00	
Depreciation (based on assumption of life of 4 years for engine and 180 working days in each year)	8.50	
		$40.00
Grader and scarifier, expense per day:		
Maintenance	$ 3.00	
Labor	4.50	
Depreciation (based on 180 working days per year)	2.50	
		$10.00
Total		$50.00

Some unsatisfactory features should be noted: The tractor is very heavy and an unsafe load on many of the old bridges. It is unwieldy, requiring a cross-road intersection or a full width road for turning. The lighter size tractor of 25 h.p. at the drawbar is free from these objections, and will do most of the work that can be done with the larger size.

The two trucks and screening and loading plant have been used in resurfacing some pieces of road with sand and gravel, and the trucks have used the drags occasionally. The use of the trucks on anything but the lighter forms of drags has not been entirely satisfactory, so the Department employed them largely on hauling and spreading materials for repairs of surfacing. The trucks are both of the dumping and spreading type and are working satisfactorily.

In charging up the work to the various roads the following has been adopted:

Expense for the year:	
Operator, 10 months, at $100	$1,000
Maintenance, oil and gas	2,000
Depreciation, 25 per cent of the cost	1,500
Overhead and incidental	900
Total	$5,400

For 180 working days this equals $30 per day. This charge for the sand elevator and loader is based on the following:

Operator, 180 days, at $3.50	$ 630
Gas and oil, 180 days, at $1.50	270
Repairs and maintenance	450
Depreciation, 20 per cent of cost	300
Overhead, labor, teams and incidentals	2,850
Total	$4,500

For 180 working days this equals $25 per day, and this rate is charged to the road upon which the work is being done.

Cost of Removing Asphalt Pavement with Hammer Drills.—Hand air-hammer drills were used by P. J. Moran, a contractor of Salt Lake City, Utah, for removing a strip of asphalt and concrete pavement alongside the tracks of a street railway so that the rails might be shimmed and new pavement laid. A description of the job is given in Mine and Quarry, Dec., 1916 from which the following notes are taken.

In order to reduce time and labor in this work, Mr. Moran purchased two Sullivan DC-19, 40-lb. hammer drills, operated by a small steam-driven air compressor.

A line was laid out a foot from the outside of the rails and the drills were equipped with a special channeling bit to cut off the asphalt. When a sufficient distance had been channeled a gadding bit was used and the surfacing material was removed, exposing the concrete. The gadding bit was again used in breaking up the concrete. This was done by holding the drill in a nearly vertical position for wedging off pieces of the concrete. In this manner pieces from 4 to 8 in. square were broken off.

One man with the Sullivan drill was able to take up the asphalt and concrete at an average rate of 6 lin. ft. in 15 minutes; while the three men, "double-jacking," by the old method of hand work, required an average of 40 minutes to remove a like amount; that is, hand work required two hours to accomplish the same results secured in 15 minutes with the machines.

The following comparison, based on the job described above, may be interesting:

MACHINE WORK COSTS

(Based on costs and prices in June, 1914)

Cost of Plant

1 Sullivan WK-3 portable compressor outfit (20 h.p.)	$1,780.00
2 DC-19 hammer drills	170.00
Hose, steel, etc	50.00
Total	$2,000.00
Interest on plant at 6 per cent	$ 120.00
Depreciation, 15 per cent	300.00
Total	$ 420.00
Operating, 175 days per year, per day	$ 2.40
Engineer, per day	3.50
2 drill operators at $2.50	5.00
Gasoline, 20 gal. at 23 cts	4.60
Oil, waste, etc	.50
Total	$ 16.00
Progress per day, 8 hours	384 ft.
Cost per foot of work	$ 0.0416

HAND WORK COSTS

6 laborers at $2.25	$ 13.50
Progress per day, 8 hours	144 ft.
Cost per foot of work	$ 0.0937
Saving on machine over hand work, per foot	.0521

Cost of Cutting Pavements with Pneumatic Machine.—The following is taken from Engineering and Contracting, July 24, 1912.

Trials were made at Los Angeles this spring by the Los Angeles Ry. Co. in cutting street pavements with a pneumatic machine. The company used a truck equipped by the Rix Compressed Air & Drill Co. with a gasoline engine and compressors and by the Hardsocg Wonder Drill Co., Ottumwa, Ia., with a pneumatic machine. The experiment was described by A. S. E. Beall in Western Engineering. After a number of trials with different cutting devices on the asphalt and concrete a chisel tool, 4 ins. wide, and gads of 1¼-in. steel, 18 ins. long, with shanks on each to fit the machines were used. In removing grouting or pavement laid under older specifications, the minimum figures of actual cost, with hand labor, per lineal foot of trench was 17 cts. In removing pavement laid under the latest specifications and consisting of 5 ins. hydraulic concrete base, 1 in. asphalt binder and 2 ins. asphalt wearing surface, the actual cost per lineal foot of trench by hand labor was 20 cts. These figures are based on a trench 18 ins. wide. In the experiments of the Los Angeles Ry. Co. the asphalt pavement cut had been laid under the latest specifications. The results of the experiment were as follows:

One Hardsocg machine, with two men at 15 cts. each per hour, cut 46 lin. ft. of trench in asphalt per hour, the cost per lin. ft. being .6 ct.; one Hardsocg machine, with three men at 15 cts. each per hour, cut 45 ft. of trench in the concrete per hour, at a cost of 1 ct. per lin. ft. The cost of the plant to operate the three Hardsocg machines was $1,600, and the three machines cost $225, making a total of $1,825. Interest on this investment at 6 per cent, and allowing depreciation at 10 per cent, makes $292 per year. On the basis of 300 working days in the year interest and depreciation would amount to 97 cts. per day or 12 cts. per hour for an 8-hour day. The operating expenses of the plant were:

	Per hour
Engineer, per hour	$0.30
Feed and lubrication	.35
Total	$0.65

Adding the 12 cts. per hour for interest and depreciation brings the cost to 77 cts. per hour. The average execution per hour for one machine was 45½ ft., and the cost of operating the plant (77 cts) divided by three (the number of machines working) gives a cost of .56 ct. per lin. ft. of trench for plant operation. Summarizing we have:

	Per lin. ft.
Cutting asphalt, 2 men at 15 cts	$0.0060
Cutting cement, 3 men at 15 cts	.0100
Engineer	.0022
Fuel and lubrication	.0024
Interest and depreciation	.0010
Total	$0.0216

In the experiments it was noticeable that several improvements could be made to benefit the operating materially. For instance, the men used for this work were Mexicans from the track gang. They were pick and shovel men only; better labor would give better results. A slight rearrangement could be made that would facilitate the work by utilizing the weight of the men, which would make the work very light and assist the machine materially. When the work was being finished, a run was made with the asphalt cutters in concrete, instead of using the gads, and it was found that they worked much faster and better. No doubt a number of such improvements could be made that would expedite the work and so lower the cost.

Pneumatic Hammers for Tearing Up Street Pavements.—Frank Richards in Engineering News, Aug. 10, 1911, states that four men each operating a pneumatic hammer accomplished as much work as 16 to 20 men working entirely by hand. The work in question consisted of cutting out solid hard concrete along the tracks of The City Tram Co. of Zurich, Switzerland.

In cutting an asphalt pavement in Brooklyn, N. Y. for opening a trench for laying gas mains the following results were obtained.

From observation of about 3,000 linear feet of cut (1,500 ft. of trench), with two men and sometimes three using the hammers, the average asphalt cut was 20 ft. per man per hour.

On June 1, 1911, on a 45-minute hand test (hand-held chisel and sledge) we cut at the rate of 12 ft. per man per hour, but the men were exhausted and had to stop.

The material under the asphalt was macadam, close and hard, and for breaking up this also the "coal picks" did good service. The chisels were exchanged for pointed picks for this work.

Reference to "Handbook of Cost Data."—On pages 442 to 445, of Gillette's "Handbook of Cost Data," quantities of materials required for constructing sidewalks are given, and on pages 446 to 457 further cost data on walks and curbs may be found.

Maintenance Cost of Plank and Tar Concrete Sidewalks.—According to Engineering and Contracting, Oct. 11, 1916, an investigation by the City Engineer of Newton, Mass., shows that an average of 3 per cent of the total area of coal tar concrete sidewalks in that city have been repaired each year during the past 7 years and that the average cost of maintenance of these sidewalks is about 2 ct. per square yard per year. The cost of maintenance of the plank sidewalks has been about 14 ct. per square yard per year.

Cost of Resurfacing Macadam Walks with Asphalt, Lincoln Park, Chicago, is given by M. D. Blumberg, Engineering and Contracting, June 9, 1915, as follows:

In Lincoln Park proper there are about 50,000 sq. yds. of walks built principally of cinders, limestone macadam, and gravel macadam. In 1913 the attention of the commissioners was drawn to the difficulty of keeping these walks in condition for foot travel. In wet weather pools of water would stand in the walks, in dry weather the protruding large stones caused a great deal of discomfort to the pedestrians, thereby causing many of them to walk on the grass, while in winter the removal of snow was unnecessarily difficult. In deciding upon what methods to use to eliminate the above difficulties the following considerations were born in mind: (1) Low first cost and low maintenance; (2) The walks should be in harmony with the park surroundings; (3) The utilization of the foundations of the walks as they stood; (4) The walks should be of such a nature as to induce people to use them rather than the grass.

With these considerations in view the choice was narrowed down to building Portland cement concrete walks or resurfacing with an asphaltic mixture. It was finally decided to build some experimental sections with an asphaltic top. These experiments proved so successful in 1913 that in 1914 enough money was appropriated to cover nearly 40,000 sq. yds. of walks with an asphaltic wearing surface.

The plant used for this job consisted of one portable asphalt plant of 1,600 cu. yds. capacity (inch thick) manufactured by the Link Belt Co. and a combination roller which furnished the power for the plant. The material was wheeled in barrows up an elevated platform from which it was dumped into the hopper. The plant was centrally located and the binder and top were hauled to the job in two-yard dump wagons. The wagons were covered with canvas to retain the heat in the mixture. The average haul was one-half mile. Sufficient teams were used to keep up with the output of the plant. The greatest number used per day was five teams.

About one-third the area, or 13,329 sq. yds. of walk, were sufficiently compact and rough to pave with a wearing surface only. The balance, or 26,657 sq. yds., required a binder and top. The binder used was composed of ½-in. to ¾-in. stone and asphalt. A number of tests showed that the percentage of asphalt used by weight was as follows: Minimum 3.85 per cent, maximum 5.15 per cent, average 4.25 per cent. The binder was laid so that it was ¾ in. thick after being rolled with a 5-ton roller. The wearing surface mix consisted of asphalt, limestone screenings, stone dust and bank sand in the following proportions:

	Per cent.
Asphalt	10.50
Passing 200-mesh	12.50
Passing 80-mesh	18.00
Passing 40-mesh	36.00
Passing 10-mesh	13.00
On 10-mesh	10.00
	100.00

The wearing surface was laid ¾ in. thick after being rolled with a 5-ton roller. Immediately after rolling Portland cement was brushed over the surface and then rolled with the 5-ton roller. The cement fills the minute voids in the surface and also improves the appearance of the walks.

It will be noticed from the cost report, Table XXIX, that there is a torpedo sand charge. At the beginning of the work it was found that the mix contained too large a percentage of coarse material. Limestone dust was substituted in place of the torpedo sand and the mix proved very successful. No forms of any kind were required for the work.

From the cost report it can be seen that asphalt walks can be laid at approximately 60 per cent of the cost of concrete walks where both binder and top are used, and at about 35 per cent of the cost of concrete where a wearing surface only is used.

TABLE XXIX.—COST OF BASE AND WEARING SURFACE FOR 26,657 SQ. YDS. OF WALK, LINCOLN PARK, CHICAGO

BASE

	Per sq. yd.
Labor:	
Shaping bed of walk	$0.023
Mixing	.080
Spreading	.020
Rolling	.006
Total	$0.129
Material:	
Asphalt	$0.050
Stone	.051
Coal	.012
Miscellaneous supplies	.002
Total	$0.115

Teams:	
Hauling (surplus material after shaping walk)	$0.014
Hauling (binder)	.019
Total	$0.033
Overhead charges:	
Plant	$0.015
Superintendence	.004
Total	$0.019
Total cost per sq. yd.:	
Labor	$0.129
Material	.115
Teams	.033
Overhead charges	.019
Total	$0.296

WEARING SURFACE

	Per sq. yd.
Labor:	
Mixing	$0.054
Spreading	.021
Rolling	.006
Total*	$0.081
Material:	
Asphalt	$0.105
Screenings (limestone)	.028
Stone dust	.016
Sand (torpedo)	.001
Sand (fine)	.043
Cement	.001
Miscellaneous	.001
Coal	.013
Total	$0.208
Teams:	
Hauling	$0.018
Overhead charges:	
Plant	$0.019
Superintendence	.004
Total	$0.023
Total cost per sq. yd.:	
Labor	$0.081
Material	.208
Teams	.018
Overhead charges	.023
Total	$0.330

* In 13,329 sq. yds. not included in the above there was an additional labor charge for "shaping bed of walk" 0.022. The total cost of this section was $0.35 per sq. yd.

Cost of Cement Tile Sidewalk at St. Paul, Minn.—The following data are taken from an article by E. G. Briggs, Engineering and Contracting, Oct. 6, 1920.

The constructing, relaying and repairing of cement sidewalks in the city of St. Paul has for several years been done by contract, the work being let by the City Council to the lowest responsible bidder. The volume of work executed through the City Department increased approximately 400 per cent during the 4-year period prior to the world war, when in 1917 the total cost of sidewalk work executed by the contractor amounted to approximately $100,000.

Approximately 98 per cent of all walks constructed are of the pre-cast tile method. These tile are constructed under careful city inspection at the shop of the successful bidder, generally during the winter months and made in sizes, 2 ft. square or 4 sq. ft. and 1½ ft. square or 2.25 sq. ft., thus allowing three squares of one for a 6-ft. walk, designated as a standard width of three squares of the other for a 4.5-ft. walk, which is often approved for narrow streets or where walks are less frequently used.

The construction cost, of cement tile sidewalks, includes the cost of the tile, the cost of excavating 8 in. for foundation, the foundation and finishing of the walk. The foundation consists of 4 in. of broken stone, brick, gravel or cinders thoroughly rolled and brought to a smooth surface with rammed gravel or cinders. On this frost vent a 2-in. layer of 1:5 mortar is laid and upon the foundation thus prepared the tile are laid to a true surface and grouted. The tiles are 2 in. thick, the lower three-fourths is composed of 1 part Portland cement and 4 parts of clean, sharp sand, thoroughly mixed and carefully rammed into the molds to a uniform depth. The upper one-fourth is composed of 1 part Portland cement and 2 parts of clean, sharp sand, placed immediately upon the lower part and thoroughly rammed to the proper thickness.

In the manufacture of the tile according to this specification, it has been found that 1 bbl. of cement will average 80 sq. ft. of tile, one bag averaging 20 sq. ft. or five 2 × 2 ft. tile. The sand required for the 2 × 2 ft. tile totals 0.66 cu. ft. or 0.165 cu. ft. of sand per sq. ft. of tile. The sand used has been screened, not washed, and by analysis the voids approximately equal the quantity of cement specified.

The cost of materials was as follows:

Material:	Cu. ft.	Sq. ft. of tile
Cement, $1.90 per bbl.	$0.475	$0.0237
Sand, 0.50 per cu. yd.	0.0185	0.0030
Total cost per sq. ft. for material	....	$0.0267

The labor cost, including curing and overhead follows:

Item	No.	Tile mnfd. sq. ft.	Cost per day
Foreman	1	....	$ 5.00
Tile makers	4	1600	12.00
Mixers	2	....	5.00
Laborers	4	....	9.00
Curing, superintendence, overhead, depreciation	..	....	9.00
			$40.00
Total cost per square foot for labor curing and overhead,			0.0250

The total cost of tile per square foot on racks in yard is therefore:

Material	$0.0267	
Labor, including curing and overhead	.0250	
Total	....	$0.0517

For the actual construction of sidewalk the following calculation is obtained. The tile are generally delivered on the street with a 5-ton motor truck averaging four truck loads per day. This has been found to be the most economical method of delivery. The average load consists of 320 sq. ft., weighing approximately 7,000 lbs. The laborers in the yard at the factory with the assistance of the driver, load the truck and the driver is assisted by the sidewalk crew in unloading the tile at their destination. It will be noted that an average of 1,280 sq. ft. of tile are delivered on the street during the 8-hour day. The cost has averaged approximately 1 ct. per square foot of tile for this delivery.

The construction of the walk as calculated on the average of construction shows that four men and one foreman average 100 ft. of 6 ft. walk per 8-hour day.

Cinders for the base have been obtained free at the gas plants and other places where considerable coal is consumed. The cinders have been delivered at the site of the construction in 3-yd. dump wagons and an average of four loads per day have been received. Sand for the concrete between the cinder base and the tile has generally been obtained near the place of construction. A team with driver is required part time with each crew to plow and assist in preparing the base, remove the surplus material, haul sand and move forward water tanks and form material incidental to the construction. For the total field operations to complete the walk, the following table gives an average of the costs involved:

AVERAGE CONSTRUCTION COST

Item	No.	Total cost	Total sq. ft.	Cost per sq. ft.
Delivering tile	1,280 sq. ft.	$12.80	1280	$0.0100
Cinders	12 cu. yd.	6.00	960	.0062
Concrete sand—Included in price of team.				
Cement	3.75 bbl.	7.12	600	.0118
Laborers	4	9.00	600	.0118
Foreman	1	5.00	600	.0083
Team	1 ½ time	3.00	600	.0050
Total cost per square foot for construction				$0.0563

For a tile constructed sidewalk, according to the specifications, we have a total estimated cost for the completed work as follows:

Cost of tile in stack at yard per square foot	$0.0517
Cost of delivering tile, cinders and constructing walk, per square foot	0.0563
Total cost per square foot	$0.1080

Table XXX gives the contract prices covering operations for the past four years on sidewalk work and incidentals connected with the construction from which considerable additional revenue has been received.

TABLE XXX.—CONTRACT PRICES FOR SIDEWALK CONSTRUCTION AND EXTRAS, 1916 to 1919, ST. PAUL

Item	1916	1917	1918 Dist. 1	1918 Dist. 2	1919 Dist. 1	1919 Dist. 2
Cement blks., new, per sq. ft.	$0.094	$0.108	$0.105	$0.12	$0.0975	$0.105
Cement blks., relay, per sq. ft.	0.05	0.06	0.05	0.07	0.05	0.06
Resetting curb, per lin. ft.	0.05	0.05	0.05	0.10	0.05	0.10
Rubble masonry laid in cement	4.25	4.50	4.50	4.50	4.50	4.75
Portland cement concrete	6.00	6.00	4.50	7.00	5.00	6.50
Brickwork, per thousand	15.00	15.00	14.00	15.00	16.50	....
Earthwork, per cu. yd.	0.50	0.60	0.60	0.70	0.75	0.75
Lumber, per 1000 ft. B. M.	35.00	37.00	40.00	50.00	40.00	40.00
Reinforcing iron and steel, lb.	0.10	0.12	0.11	0.12	0.10	0.12
Brick paving, including concrete foundation	2.35	2.40	2.40	2.75	2.60	2.75
Reinforced concrete 5 in. thick, per sq. ft., reinforcing steel extra	0.30	0.35	0.30	0.40	0.25	0.40
9-in. sewer pipe in place, per lin. ft.	List.	List.	0.37	List.	0.55	0.55
12-in. sewer pipe in place, per lin. ft	List.	List.	0.40	List.	0.70	0.70
15-in. sewer pipe in place, per lin. ft.	List.	List.	0.42	List.	0.80	0.80
Cement walk surfaced in place	0.15	0.16	0.14	0.20	0.15	0.20

The contracts for 1916, 1917 and district No. 2 in 1918 were executed by one contractor.

Cost of Grading and Constructing Sidewalks, Los Angeles, Cal.—E. E. Glass in Engineering and Contracting, April 4, 1917, gives the following:

The work, consisting of the improvement of the streets in a hilly suburban tract by grading and constructing about 7 miles of concrete walks, curbs and gutters, was done in Nov. and Dec., 1916. As the soil was a heavy, stiff clay, the contractor pushed the work with all possible speed in order to beat the winter rains and the excavation was practically complete and the concrete work half finished when the first rain fell in Dec. Thereafter some delay was experienced because of wet ground.

Grading.—Two elevating graders were employed for ordinary grading, one drawn by a gas tractor and the other by 16 mules (six pushing). A steam shovel was used in the heavier cuts and handled about 3,000 cu. yd. of hard-pan. As the cut became deeper and the clay harder, the shovel could not fill with less than three tries, so blasting had to be resorted to. The maximum cut was only 9 ft. Holes were sunk by two men on a churn drill and sprung at grade by a stick of 40 per cent dynamite. The spacing was about equal to the depth of hole and the average load was a half keg of black powder fired by an electric battery and a stick of dynamite. The best shots merely heaved the ground, but occasionally a hole would "blow up," and as the streets were in a residence district it was found necessary to lay old planks over the holes to prevent chunks of clay flying and damaging property.

The business-like handling of earth sales is worthy of notice. When the work was awarded, the contractor sent salesmen with blank contracts to the owners of property in the district. They received a commission and sold excess yardage for as much as 40 ct. per cu. yd. for filling lots. Any reasonable terms were considered, with the property as security. This appears to be a far better arrangement than the more common wasting of earth where the contractor does not get the price he wants and spot cash.

All hauling was done in 1½ cu. yd. dump wagons. An item which tended to increase the cost of the earth-work was the inability of the graders to work around power and telephone poles where light cut or fill made their removal unnecessary. This required plowing the cut between the pole line and property line and slipping the earth out into the street, where the grader picked it up.

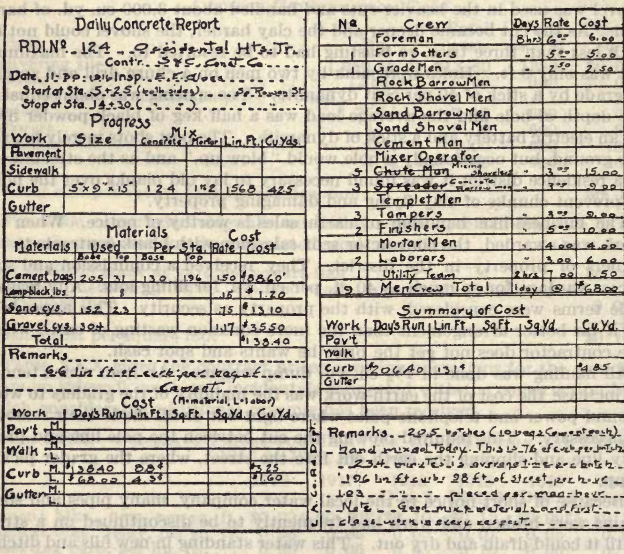
Because of short notice to the local water company, many pipes and some mains were broken and work had frequently to be discontinued on a street until it could drain and dry out. This water standing in new fills and ditches causes much inconvenience on a grading job and is easily avoided.

Concrete Work.—The curb, walk and gutter gangs began at the same point and followed in the order named, about a week apart.

The county's resident engineer, in charge of the work, had an inspector with each of the three gangs. Each inspector filled in the day's run of work in feet, size of crew and amount of cement used, on the progress report form shown in Fig. 15 which also gives a typical day's run of the curb outfit, hand-mixing. The resident engineer worked up the balance of the cost, from which the final cost of the job was accurately determined.

The greater portion of the curb work was made by hand mixing. The materials were turned three times dry and three times wet on a 3 ft. × 10 ft. sheet iron strips laid together to form a good mixing platform, readily moved along the street as the work progressed. Ten-bag batches were mixed, which ran about 75 lin. ft. of curb, depending upon the number of openings left for driveways and the amount of low grade (giving overdepth of curb). All concrete on the work was 1:2:4 and mortar was specified 1 part cement and 2. parts sand with 1 lb. of lamp black per barrel of cement used. On the curb finish, the contractor found it necessary to use more cement in the mortar to trowel smoothly.

Carey expansion joints were placed every 40 ft. in curb, walk and gutter and the facing cut through to expose the felt. The curb was 5 in. wide at top, 3 in. at base and 15 in. high, with ½ in. of mortar on top face and ¼ in. of mortar on 4 in. of back and 3 in. of the front face. The gutter line was 8 in. below top of curb on the greater part of the work, the gutter being 5 in. thick and 2 ft



Daily Concrete Report

R.D.I. No. 124 Occidental Hts. Tr.
Cont'r. S & S. Const. Co.
Date 11-30-1916 Insp. E. E. Aloes
Start at Sta. 5+25 (both sides) So. Rowan St.
Stop at Sta. 14+30 (" ")

Progress

Work	Size	Mix Concrete	Mix Mortar	Lin. Ft.	Cu. Yds.
Pavement					
Sidewalk					
Curb	5"×9"×15"	1 2 4	1 & 2	1568	42.5
Gutter					

Materials

Materials	Used Base	Used Top	Per Sta. Base	Per Sta. Top	Rate	Cost
Cement, bags	205	31	13.0	1.96	1.50	$88.60
Lamp-black, lbs		8			.15	$1.20
Sand, cys.	15.2	2.3			.75	$13.10
Gravel, cys.	30.4				1.17	$35.50
Total						$138.40

Remarks 6.6 lin. ft. of curb per bag of cement.

Cost (M=material, L=labor)

Work		Day's Run	Lin. Ft.	Sq. Ft.	Sq. Yd.	Cu. Yd.
Pav't	M.					
	L.					
Walk	M.					
	L.					
Curb	M.	$138.40	8.8¢			$3.25
	L.	$68.00	4.3¢			$1.60
Gutter	M.					
	L.					

No.	Crew	Days	Rate	Cost
1	Foreman	8 hrs	6.00	6.00
1	Form Setters	"	5.00	5.00
1	Grade Men	"	2.50	2.50
	Rock Barrow Men			
	Rock Shovel Men			
	Sand Barrow Men			
	Sand Shovel Men			
	Cement Man			
	Mixer Operator			
5	~~Chute Man~~ Mixing Shovelers	"	3.00	15.00
3	~~Spreader~~ Concrete Barrow men	"	3.00	9.00
	Templet Men			
3	Tampers	"	3.00	9.00
2	Finishers	"	5.00	10.00
1	Mortar Men	"	4.00	4.00
2	Laborers	"	3.00	6.00
1	Utility Team	2 hrs	7.00	1.50
19	Men Crew Total	1 day	@	$68.00

Summary of Cost

Work	Day's Run	Lin. Ft.	Sq. Ft.	Sq. Yd.	Cu. Yd.
Pav't					
Walk					
Curb	$206.40	13.1¢			$4.85
Gutter					

Remarks. 20.5 batches (10 bags cement each) hand mixed today. This is 76' of curb per batch. 23.4 minutes is average time per batch. 196 lin. ft. curb: 98 ft. of street per hour. 1.03 " " " placed per man-hour. Note: Good mix, materials and first-class work in every respect.

L. A. Co. Rd. Dep't.

FIG. 15.—Inspector's concrete report with typical day's run of curb crew.

wide, but Ditman street drains the district and here curbs were given 10 in. face and gutters were 5 in. thick by 3 in. wide. All gutters were floated rough and marked every 3 ft. to correspond with the curb marks.

The walk was built 4 in. wide with a 3 in. base of 1:2:4 concrete and a ½-in. top of 1:2 mortar as before described. A Chicago paving mixer was used and gave good results. In all the work both sides of the street were carried along together, the concrete being wheeled from the platform or mixer to the forms in barrows.

All cement work was promptly covered with earth which was kept moist for two weeks.

The cost of this work is given in Table XXXI, see Fig. 15, for unit costs of materials and labor.

TABLE XXXI.—ROAD DISTRICT IMPROVEMENT NO. 124, STREETS IN OCCIDENTAL HEIGHTS, LOS ANGELES COUNTY ROAD DEPARTMENT

Work done—Grading, cement sidewalks, curbs and gutters.
Total length, 4.2 miles.
Average haul, 6 miles.

Actual Cost to Contractor:		
Excavation, 38.563 cu. yd. at $0.279		$10,758.75
Concrete for culvert, furnishing, hauling and placing, 4 cu. yd. at $23.04		92.17
Reinforcing steel for culvert, furnishing, hauling and placing, 330 lb. at 5 cts		19.50
Sidewalk, 3½ in. by 4 ft., furnishing, hauling and placing, 141,050 sq. ft. at $0.07		10,402.64
Detail of Cost of Sidewalk:	Per sq. ft.	
Cement	$0.0244	
Gravel	.0147	
Sand	.0061	
Lamp black	.0009	
Exp. joints	.0004	
Water	.0002	
Grading	.0067	
Moving material	.0012	
Mixing and placing	.0140	
Covering and watering	.0041	
Repairs	.0011	
Total	$0.0740	
Gutter, 5″ × 2′ (17 % is 3′ wide), furnishing, hauling and placing, 79,383 sq. ft. at $0.080		6,365.28
Detail of Cost of Gutter:	Per sq. ft.	
Cement	$0.0264	
Gravel	.0159	
Sand	.0066	
Exp. joints	.0005	
Water	.0003	
Grading	.0099	
Moving materials	.0020	
Mixing and placing	.0141	
Covering and watering	.0019	
Repairs	.0020	
Total	$0.0800	
Curbs, 5″ × 9″ × 15″, furnishing, hauling and placing, 35,188 lin. ft. at. $0.211		7,416.33
Detail of Cost of Curb:	Per lin.ft.	
Cement	$0.0581	
Gravel	.0350	
Sand	.0145	
Lampblack	.0008	
Exp. joints	.0014	
Water	.0007	
Grading	.0320	
Moving material	.0051	
Mixing and placing	.0474	
Backfilling and watering	.0098	
Repairs	.0058	
Total	$0.2110	
Total cost of work		$35,054.67
Less 2,910 bb . cement at $1.47 furnished by county		4,277.70
Actual cost to contractor		$30,776.97

The above does not include interest, insurance or overhead expense.

One Course Monolithic vs. Two Course Concrete Sidewalks.—Maj. F. S. Besson, in Engineering and Contracting, May 4, 1921 gives the comparative advantages, costs, etc., of constructing both 1 and 2 course concrete sidewalks. In concluding his article Maj. Besson gives the following summary:

A 5 in. one course walk of gravel concrete, proportioned 1 bag of cement (one cu. ft.), 2¼ cu. ft. sand and 3⅜ cu. ft. gravel, presents all the advantages of a two course walk and none of its disadvantages. This is accomplished with (1) a saving of from 100 to 200 bags of cement per 1,000 sq. yd. of walk, (2) a labor saving of 6 men in an organization capable of approximating 350 to 400 sq. yd. of walk per day, (3) an increase, with a given type of concrete mixer, of from 10 to 12 per cent in daily yardage, and (4) a saving of the first cost and maintenance of a mortar mixer.

Output of Gang in Constructing One Course Concrete Sidewalks (Engineering and Contracting, Jan. 1, 1919).—The one-course type was decided upon for the subdivision of the American Steel & Wire Co. at Donora, Pa., where an extensive concrete housing development is being completed. Contract was let for approximately 25,000 sq. ft. of 5-ft. walk, 4½ in. thick. The work was handled in much the same way as one-course concrete road construction.

Of especial interest are the steel dividing plates used to separate concrete into 5-ft. slabs, as the plates must not extend above the sidewalk surface if the roller method of finishing is to be followed.

Where wooden side forms were used, 3/16-in. steel plates 5 ft. long by 4½ in. in depth were spaced at 5-ft. intervals. Near the top at each end of the plate a small hole was provided so that the plate could be removed with hooks. To prevent concrete from pushing these plates out of position, they were staked near the ends and at the center with steel pins.

On part of the work the forms were of steel. The type of dividing plate used with these patented forms had a projecting part in the shape of a hook on each end which fitted over the vertical web of the channel-shaped side form, the upper flange being cut through to make that possible. Only one stake on level ground, or two on grades, were needed with this type of plate.

Concrete was mixed in proportions of 1:2:3, using crushed blast furnace slag ranging in size from ¼ in. to 1½ in. as coarse aggregate. This gave particles larger than are ordinarily used in sidewalk construction, but little trouble was experienced from this cause when the concrete was finished with a heavy roller.

Care was taken to make adequate provision for expansion. Every 50 ft. a strip of prepared filler ½ in. in thickness was placed across the sidewalk, and where the walk abutted a street curb two thicknesses of filler were used. Between houses and walks a ½ in. joint was placed.

Concrete was deposited directly on the clay subgrade and struck off ½ in. high with a template. Following this, concrete was rolled longitudinally with a 10-in. roller 5 ft. 5 in. long, which weighed 2¼ lb. per lineal inch. Since this roller rested on the side forms after concrete had been compacted to the proper level, it was satisfactory although heavier than is used ordinarily. Immediately after rolling the surface was finished with wood floats, dividing plates were removed, joints grooved and the sidewalk edged.

The concreting crew was made up of 14 men, including the superintendent; five men were employed in the mixing crew, three wheeled concrete, two set forms and three did the finishing. Twenty-one hundred square feet was the largest day's work done, while 1,800 sq. ft. was a fair daily average. The mixer was a two-sack batch side dump machine. Usually it was moved four times daily.

Cost of Constructing a Wide Concrete Sidewalk, Harrisburg, Pa.—Joel D. Justin gives the following data in Engineering and Contracting, Sept. 1, 1915.

In connection with the construction of a series of reinforced concrete retaining walls along the river front, the City of Harrisburg completed, in 1915, a concrete sidewalk 10,600 ft. long and 12 ft. 3 ins. wide.

The sidewalk which was built by contract under rigid inspection, was constructed in alternate blocks 6 ft. 1½ ins. square and 6 ins. thick, with 1 part of cement, 2½ parts of sand and 4½ parts run of crushed limestone, maximum size 1 in. The mixture was made so dry that considerable heavy ramming was necessary to bring moisture to the surface. This concrete was then deposited in a block compartment and screeded and thoroughly tamped. The top coat mixed 1 part cement to 1½ part quartz sand, was mixed so dry that it is necessary to squeeze a ball of the mortar in the hand to bring moisture to the surface. The top coat is then spread over the concrete base and screeded and rammed into place, either with tampers or by striking heavily with the flat of the shovel. The surface is then finished off hard and smooth with floats and metal trowels.

It is essential that both concrete base and top coat should be placed fairly dry, as if either is wet, there is formed a minute layer of laitance between the base and the top coat. This causes a dividing plane, which frequently explains the peeling off of the top coat of sidewalk work as generally constructed.

The writer has placed over one hundred thousand square yards of top coated concrete in the manner here outlined, where weather conditions are exceptionally severe and none of it has come off. He is firmly convinced that the method secures a perfect bond between the concrete and the top coat. Blocks placed in this manner have been broken up and removed and it was found impossible to separate the top coat from the base, the fracture in every case occurring elsewhere.

The sidewalk was located at the foot of a bank varying in height from 12 to 15 ft. A two bag batch steam driven mixer of the Milwaukee Paver type was stationed on the bank and moved from place to place under its own steam as the work progressed. Set ups were from two to three thousand feet apart. Sand, stone and cement were delivered by team on an asphalt street within 20 to 75 ft. of the mixer. The cost of cement delivered on the job was $1.10 per barrel net, including deduction for lost and stolen bags. Crushed stone cost 90 cts. per ton delivered on the job and sand $1.30 per ton.

After mixing, the concrete was dumped through a chute into Koppel cars, running on a narrow gage track beside the sidewalk. From the cars, the concrete was dumped directly into place. The top coat was mixed on the sidewalk and transported in wheelbarrows to the points required.

Each block 6 ft. 1½ ins. square and 6 ins. thick contained 0.695 cu. yds., requiring 1.25 bbls. of cement, 0.822 bbls. of this being in the concrete base and 0.428 bbls. in the top coat. The average was thus 1.8 bbls. per cubic yard including the top coat.

An itemized statement of the organization and cost per unit is given in Table XXXII. The average output per 10-hour day was 100 blocks or 69.5 cu. yds. or 417 sq. yds.

It should be noted that no allowance has been made for overhead or depreciation. All other charges to the contractor are included.

TABLE XXXII

	Cost per day	Per cu. yd.	Per sq. yd.
Supplying Mixer—			
Cement, 1 man @ $1.50	$ 1.50	....	......
Stone, 6 men @ $1.50 per 10-hr. day	9.00	....	......
Sand, 2 men @ $1.50 per 10-hr. day	3.00	$0.194	$0.032
Mixer Running—			
1 engineer @ $2.50	2.50	....	......
1 fireman @ $2.00	2.00	0.065	0.011
Transporting Concrete—			
2 men on cars at mixer @ $1.50	3.00	....	......
3 men on train @ 1.50	4.50	....	......
1 horse @ 2.00	2.00	0.130	0.022
Placing and Ramming Concrete—			
4 men placing, ramming, screeding @ $1.50	6.00	0.086	0.014
Mixing Top Coat—			
5 men mixing @ 1.50	7.50	0.108	0.018
Transporting Top Coat—			
3 men wheeling @ $1.50	4.50	0.065	0.011
Placing and Screeding Top Coat—			
4 men @$1.75	7.00	0.101	0.017
Finishing Top Coat—			
1 man @ $3.00.			
1 man @ 2.00.			
1 man @ 2.00	7.00	0.101	0.017
Setting Templets—			
1 foreman @ $3.00	3.00	....	......
3 carpenters @ $2.00	6.00	....	......
2 helpers @ $1.75	3.50	0.180	0.030
Finished Grading—			
1 foreman @ $2.00	2.00	....	......
8 men @ $1.50	12.00	0.201	0.034
Total labor cost	$85.50	$1.23	$0.205
Coal for mixer @ $3.10 ton	0.78	0.011	0.009
Use of mixer, tracks and cars	......	.0444	0.024
Grand total (aside from overhead)	$87.28	$1.26	$0.210

	Per cu. yd.	Per sq yd.
Cost of Materials—		
1.4 tons stone @ 90 cts	$1.26	$0.210
.7 ton sand @ $1.50	.91	.152
1.8 bbls. cement @ $1.10	1.98	0.330
Cost materials	$4.15	$0.696
Total labor, mixer-coal	1.26	0.210
Total cost	$5.41	$0.902

6 sq. yds. = 1 cu. yd. (6 ins. thick).

Cost of Concrete Sidewalk in Chicago.—N. E. Murray gives the following in a paper before the Illinois Society of Engineers and Surveyors, Jan. 26–8, 1910, abstracted in Engineering and Contracting, Feb. 2, 1910.

The ordinary concrete sidewalk gang in Chicago is usually composed of six men paid as follows:

1 finisher 8 hours at 65 cts	$ 5.20
1 helper 8 hours at 47½ cts	3.80
4 laborers 8 hours at 37½ cts	12.00
Total	$21.00

Under favorable conditions this gang will construct 900 sq. ft. of walk per day. From information furnished me by several of the leading contractors, each employing on an average of six gangs of men, a gang of six men will average only 600 sq. ft. per day for an entire season. This figure will be used as a basis for computing the cost of labor in the following table:

Cinders (allow for 20 % shrinkage), 20.83 cu. yds. at 50 cts.	$10.42
Base 4¼ inches thick—Mix 1-2½-5:	
Cement, 9.77 bbls., at $1.20	$11.72
Sand, 3.47 cu. yds., at $1.75	6.07
Gravel, 6.85 cu. yds., at $1.50	10.28
Total	$28.07
Wearing coat ¾ in. thick—Mix 2-3.	
Cement, 5.56 bbls., at $1.20	$ 6.67
Sand, 1.17 cu. yds., at $1.75	2.04
Total	$ 8.71
Water at 1 mill per square foot	0.60
Labor, one gang one day	21.00
Use of tools, waste of material, etc., at 2 %	1.37
Supt. and office exp. at 5 %	3.51
Profit at 10 %	7.36
Total	$81.04

The average cost per foot when 600 sq. ft. per day are laid divided into unit cost per sq. ft. is as follows:

Cinders	$0.0174
Base:	
Cement	$0.0195
Sand	.0101
Gravel	.0171
Total	$0.0468
Top:	
Cement	$0.0111
Sand	.0034
Total	$0.0145
Water	$0.0010
Labor	0.0350
Tools, waste, etc., 2 %	0.0023
Supt., 5 %	0.0058
Profit, 10 %	0.0123
Total	$0.1351

In the above the cost of materials and water amounts to 7.97 cts. per sq. ft., which will remain constant, while the cost of labor, superintendent, etc., will vary according to the number of square feet laid per day per gang:

Av. sq. ft. per day.	700	800	900	1,000
Cost of labor, supt., etc	$0.1291	$0.1248	$0.1213	$0.1185

Cost of Cutting Edge of Concrete Walk.—H. R. Ferris gives, in Engineering and Contracting, Oct. 4, 1916, the following:

During the work on some street widening improvements, it was found necessary, in order to make room for a granite curb, to trim about 3 in. off the outside edge of a 4-in. concrete walk, and for a distance of 512 ft.

The work was done by an unusually good workman, using a medium hand hammer and ordinary cold chisels.

The cost follows:

Foreman marking and lining edge of walk, 2 hr. @ 62.5 cts.	$ 1.25
Laborer cutting edge of walk, 24 hr. @ 30 cts.	7.20
Removing old concrete—	
Labor, 4 hr.	1.20
Teams, 1 hr.	.65
	$10.30
Cost per lineal foot	2 cts.

Cost of Raising Sunken Concrete Walk.—H. R. Ferris gives the following note in Engineering and Contracting, Oct. 4, 1916.

In the course of some construction connected with street widening improvements, it was found necessary to raise to its original level 240 ft. of concrete walk which owing to defective earth foundation had sunk 5 or 6 in. on the outside edge. The walk was 12 ft. wide, 4 in. thick, with a mesh reinforcement, and although over 15 years old was still in perfect condition. It was possible that its settlement had been foreseen by the constructors, as 5-in. "I" beams had been placed cross-wise underneath it, at intervals of 8 ft.

In order to make room for a granite curb, the "I" beams which projected beyond the edge of the walk, were cut by hand with a hack-saw. The labor cost of cutting these I-beams was 48 ct. each. A concrete pier (see sketch) was placed under the outside edge of the walk after it had been raised to its original position. Twelve jacks were used for the work. The costs follow:

Labor—	
Foreman, 3 days @ $4	$12.00
Labor raising walk, 112 hr. @ 30 cts	33.60
Labor concreting, 56 hr. @ 30 cts	16.80
Labor cutting "I" beams (30), 48 hr. @ 30 cts	14.40
Labor on forms, reinforcement, 14 hr. @ 30 cts	4.20
	$81.00
Materials—	
Cement, 16 bbl. @ $2	$32.00
Sand, 6½ cu. yd. @ $1	6.50
Gravel, 13 cu. yd. @ $1.10	14.30
Hack saw (frame and blades)	3.50
Reinforcing steel, 500 lb. @ 3 cts	15.00
Renting jacks	6.00
	$77.30

Cost of Constructing Concrete Combined Curb and Gutter.—Fig. 16 shows the dimensions and mix used in constructing the combined curb and gutter

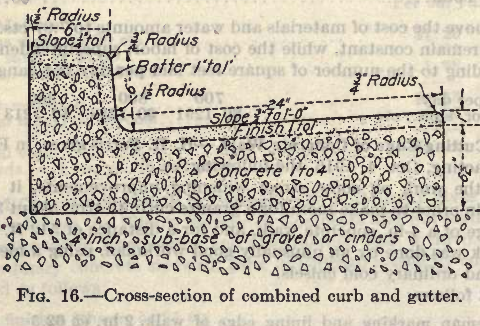


FIG. 16.—Cross-section of combined curb and gutter.

at Webb City, Mo. Costs for typical examples of this type of construction are given by E. W. Robinson in Engineering and Contracting, May 15, 1912, as follows:

The costs given have been compiled from the daily report blanks turned in each day by the city inspectors. It will be noticed that there is considerable variation in the cost of the different items for different jobs, though the totals agree pretty closely. There are several reasons for this. In the first place there was considerable difference in the efficiency of the men and methods employed. Also on this kind of work it is not always economical to have a gang organized so that each man does only one or two things, and such frequent switching of men is hard to follow in trying to keep the time on each operation. In some cases the foreman made a hand wherever the men got behind, in others he did no actual labor. Then the personal equation of the inspector entered in no small degree in the manner of the division of labor on the different items. However the totals give a fair average of the cost of this work in this city for the last two years.

(1) 6-In. Curb and Gutter, 2,959 Lin. Ft.

(Concrete mixed by hand. Good foreman and well organized gang. Includes setting forms, mixing and placing only. Public contract.)

	Cost per lin. ft.
Labor:	
1 foreman, 145½ hours at $0.333	$0.01637
1 finisher, 141½ hours at $0.555	0.02654
2 asst. finishers and mortar mixers, 72 hours at $0.25, 17 hours at $0.222	0.00736
1 mortar mixer, 48½ hours at $0.277	0.00453
3 form setters, 9 hours at $0.277, 100½ hours at $0.25, 147½ hours at $0.222	0.02040
4 concrete mixers, 714 hours at $0.22	0.05357
Total labor	$0.12877
Material:	
Cement, concrete and mortar, 1,445½ sacks at $0.35	$0.17097
Sand, mortar, 484.1 cu. ft. at $0.08	0.01309
Gravel, concrete, 338.4 cu. yds at $0.50	0.05717
Water, 1,838½ cu. ft. at $0.005	0.00311
Total material	$0.24434
Total for labor and material	$0.373

(2) 9-In. Curb and Gutter, 2,089.5 Lin. Ft.

(Concrete mixed by hand. Includes setting forms, mixing and placing only. Work interrupted by rain frequently. Foreman did no actual work. Public contract.)

	Cost per lin. ft.
Labor:	
1 foreman 115½ hours at $0.666	$0.03687
1 finisher, 115½ hours at $0.444	0.02454
1 mortar mixer, 115½ hours at $0.278	0.01535
2 form setters, 226 hours at $0.25	0.02704
5 concrete mixers, 544 hours at $0.222	0.05787
Total for labor	$0.16168
Material:	
Cement, mortar and concrete, 1,114½ sacks at $0.35	$0.18670
Sand, mortar, 361½ cu. ft. at $0.08	0.01384
Gravel, concrete, 240 cu. yds. at $0.50	0.05744
Water, 1,169 cu. ft. at $0.005	0.00280
Total for material	$0.26078
Total for labor and material	0.42247

(3) 9-In. Curb and Gutter, 1,279.2 Lin. Ft.

(Concrete mixed with Coltrin continuous mixer part of time, rest with Eclipse batch mixer. Includes sub-base, setting forms, mixing and placing only. Does not include water and gasoline. Good weather. Public contract. Good foreman, did no actual work.)

Labor:	Cost per lin. ft.
1 foreman, 63 hours at $0.666	$0.0328
2 finishers, 64 hours at $0.444, 40½ hours at $0.278	0.0309
2 form setters, 132 hours at $0.222	0.0233
1 mortar mixer, 62 hours at $0.222	0.0107
1 feeding mixer, 62 hours at $0.222	0.0107
2 off-bearing, 71 hours at $0.222, 5 hours at $0.278	0.0133
2 placing and tamping, 110½ hours at $0.222	0.0192
Total for labor	$0.1409
Material:	
Cement mortar and concrete, 626 sacks at $0.40	$0.1957
Sand, mortar, 217 cu. ft. at $0.08	0.0136
Gravel, concrete and sub-base, 132.3 cu. yds. at $0.50	0.0517
Total for material	$0.2610
Total for material and labor	$0.4019

(4) 9-In. Curb and Gutter, 2,900 Lin. Ft.

(Concrete mixed with Eclipse batch mixer. Includes sub-base, setting forms and mixing and placing, but not water or gasoline. Late fall of year and some work lost because of frost. Well organized gang.)

Labor:	Cost per lin. ft.
1 foreman, 99 hours at $0.666	$0.0228
2 finishers, 95 hours at $0.30, 14 hours at $0.50	0.0123
2 form setters, 198 hours at $0.2333	0.0159
2 mixing and placing mortar, 198 hours at $0.233	0.0159
5 mixer men, 464 hours at $0.222	0.0356
Total for labor	$0.1024
Material:	
Cement, mortar and concrete, 1,291 sacks at $0.40	$0.1767
Sand, mortar, 457½ cu. ft. at $0.07	0.0116
Gravel, concrete, 122 cu. yds. at $0.50	0.0210
Gravel, sub-base, 161.1 cu. yds at $0.50	0.0278
Total for material	$0.2371
Total for labor and material	$0.3395

(5) 4-Ft. Sidewalk, 436 Sq. Ft.

(Concrete mixed by hand. Includes setting forms, mixing and placing only. Foreman was also contractor and finisher. Private contract.)

Labor:	Cost per sq. ft.
1 foreman and finisher, 9 hours at $0.50	$0.0103
4 mixing and placing concrete, 24 hours at $0.222	0.0122
1 mixing and placing mortar, 7 hours at $0.222	0.0036
Total for labor	$0.0261
Material:	
Cement, mortar and concrete, 33 sacks at $0.35	$0.0265
Sand, mortar, 25 cu. ft. at $0.08	0.0046
Water, 6 bbls. at $0.10	0.0014
Gravel, concrete, 4 cu. yds. at $0.50	0.0046
Total for material	$0.0371
Total for material and labor	$0.0633

(6) 4-Ft. Sidewalk, 4,934 Sq. Ft.

(Concrete mixed by hand. Includes setting forms, mixing and placing only. Foreman did some finishing, but was attending to other business most of time. Otherwise gang was efficient. Lost 50 ft. of finish by rain. Public contract.)

Labor:	Cost per sq. ft.
1 foreman and finisher, 42 hours at $0.555	$0.0047
1 finisher, 17¼ hours at $0.444	0.0015
3 mixing and placing mortar, 107 hours at $0.222	0.0048
4 mixing concrete, 151¾ hours at $0.222	0.0068
2 placing concrete, 82 hours at $0.25	0.0042
2 setting forms, 58 hours at $0.222	0.0027
Total for labor	$0.0247
Material:	
Cement, concrete and mortar, 414 sacks at $0.40	$0.0336
Sand, mortar, 444 cu. ft. at $0.08	0.0072
Gravel, concrete, 49.6 cu. yds. at $0.50	0.0050
Water, 9 tanks at $0.50	0.0009
Total for material	$0.0467
Total for material and labor	$0.0714

(7) 4-Ft. Sidewalk, 12,504 Sq. Ft.

(Concrete mixed with Coltrin continuous mixer. Includes setting forms, mixing and placing only, but not gasoline. Efficient gang. Foreman was member of firm and helped at all times; 50 lin. ft. lost by rain. Public contract.)

Labor:	Cost per sq. ft.
1 foreman, 18 days at $5.00	$0.0072
2 finishers, 105¼ hours at $0.555, 45 hours at $0.333	0.0059
2 mixing and placing mortar, 262 hours at $0.222	0.0047
4 mixer men, 505½ hours at $0.222	0.0090
1 water boy, 94 hours at $0.111	0.0008
Total for labor	$0.0275
Material:	
Cement, concrete and mortar, 853 sacks at $0.40	$0.0273
Gravel, concrete, 113 cu. yds. at $0.50	0.0045
Sand, finish, 853 cu. ft. at $0.08	0.0053
Water, 152 bbls. at $0.10	0.0012
Total for material	$0.0384
Total for labor and material	$0.0659

(8) 4-Ft. Sidewalk, 9,566.7 Sq. Ft.

(Concrete mixed with a Coltrin continuous mixer. Includes setting forms, mixing and placing only. Does not include water and gasoline. Fairly efficient gang. Foreman did no actual work but was a hustler. Was also the contractor. Public contract.)

Labor:	Cost per sq. ft.
1 foreman, 54½ hours at $0.666	$0.0038
1 finisher, 63½ hours at $0.444	0.0030
2 mixing mortar, 104 hours at $0.222	0.0024
2 feeding mixer, 109 hours at $0.222	0.0025
2 wheeling mortar and concrete, 125 hours at $0.222	0.0029
2 placing concrete and mortar, 119 hours at $0.222	0.0028
Total for labor	$0.0174
Material:	
Cement, concrete and mortar, 748 sacks at $0.40	$0.0313
Sand, mortar, 467 cu. ft. at $0.08	0.0039
Gravel, concrete, 97 cu. yds. at $0.50	0.0051
Total for material	$0.0403
Total for labor and material	$0.0577

Cost of Laying Granite Curb.—Engineering and Contracting, June 5, 1918, gives the following:

Granite for the 5108 ft. of curb was delivered on the work, in blocks from 5 to 8 ft. long, of the dimensions shown on the sketch. The stones were bedded in 1:3:5 concrete as required by the specifications, laid to a true line and grade, and joints exceeding ¼ in. were not permitted.

A good working foreman, with an indifferent Italian crew, performed the work. Stones were placed entirely by hand, with the aid of crow-bars, jacks, etc. The contractor thinks it probable that considerable economy might have been effected by using a small portable derrick.

The costs follow:

	Per lin. ft.
Curb, setter, 307 hours at 50 cts	$0.030
Helper, 307 hours at 40 cts	.024
Labor, 1,850 hours at 30 cts	.108
Total	$0.162

A snatch team was used at odd times for moving around stones which had not been conveniently distributed. This cost is not included in the figures given above.

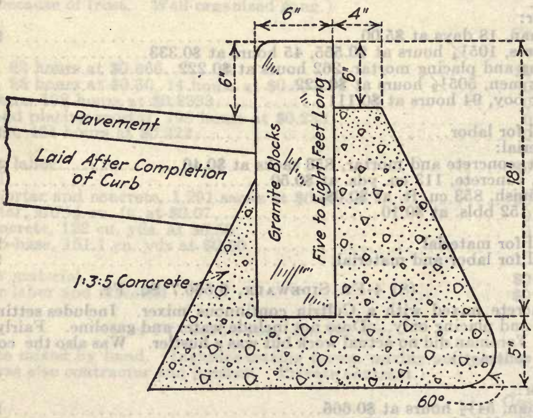


FIG. 17.—Sketch showing dimensions of granite curb.

Labor Costs of Laying Curved Granite Curbs at Street Intersections.—H. R. Ferris gives the following data in Engineering and Contracting, Jan. 3, 1917.

The costs cover the labor of laying 44 returns (630 lin. ft.) of curved granite curb at 11 street intersections. The stones were 20 in. deep, 6 in. wide at top and dressed for 5 in. on the face. At the bottom they were generally 7 or 8 in. wide. Each piece came in lengths varying from 4 to 7 ft. and were conveniently delivered within a few feet of their final location. The bottom 12 in. of the curb were imbedded in 1:3:6 concrete.

The work was done by an energetic and competent curb-setter and helper who handled their part of the work well. The common labor, which included the excavation of the trench, moving stones, mixing concrete, etc., was very inefficient, however, and probably 35 per cent of this cost could have been saved with first class laborers.

The curbs were laid under strict inspection. No joints over ¼ in. were allowed, and the bottom of all curbs had a true setting bed in order to "secure a uniform depth throughout." The workmen were required to set the stones so that they would be "free of depressions and wind, and true to line and grade." The stones were set to a 9-ft. radius.

The labor costs follow:

Cost of Laying 630 Lin. Ft. Of Curved Granite Curb

Curb setter, 84 hours @ 40c	$ 33.60
Helper, 56 hours @ 35c	19.60
Labor, 342 hours @ 25c	85.50
	$138.70
Total cost per lin. ft. of labor	22 cts.

Cost of a Cobble Lined Gutter, California.—E. Earl Glass gives the following in Engineering and Contracting, June 6, 1917.

To prevent cutting by storm water, the Los Angeles County Road Department recently constructed a cobble lined gutter on each side of a steep hillside road. The adjoining property owners furnished the cobbles and gravel, which they hauled from a nearby stream bed.

The gutter (3 ft. wide and 7 ins. deep at center) was roughed out with plow and slips and shaped with shovels. The soil being a very sandy silt furnished an excellent bed for the stones. Excepting the team work on rough grading, all the work was done by three laborers with part of the time of a road foreman.

The best stones for this work are hard, clean, stream cobbles, about 6-in. × 10-in. faces and 4 or 5 in. thick. Cobbles are often laid vertically or at a slight angle as on street pavements, but we laid this work flat, thus effecting a great saving in time and material, and getting practically the same results.

After 400 ft. of gutter had been laid, one of the men would go back and wet the gutter until water showed between the stones. He then tamped every stone with a sledge. He mixed half-bag batches of coarse mortar (1:3:5) in a mortar box and shoveled the soupy grout onto the wet stones. Another laborer swept the mortar along with a street broom, filling all voids between the stones with the concrete and leaving the gutter section smooth but showing all rock faces. As soon as the mortar was sufficiently set, an inch depth of earth was spread over the finished gutter and kept damp for a week.

At all driveways and in front of residences where a deep, open gutter would be objectionable, the property owners provided 14-in. concrete pipe which were laid in shallow trenches with open joints. The gutter was flared to connect with these pipe culverts, providing substantial and artistic head walls, with generous capacity for entry and delivery of a full stream of storm water.

The cost of the improvement was as follows:

	Pipe	Gutter	Total
Length, ft.	224	4,656	4,880
Excavating and backfilling	$ 16.50	$218.75	$235.25
224 lin. ft. of 14-in. concrete irrigation pipe @ 33 ct. delivered	74.00	....	74.00
30 tons (25 cu. yd.) of bank gravel for grouting	....	8.00	8.00
367 tons of clean, granite cobbles for paving gutter	....	103.00	103.00
Laying stone for pipe end walls and paving gutter	17.50	243.50	261.00
Grouting end walls and gutter	4.50	60.70	65.20
Cement for end walls and gutter, 28½ bbl. @ $2.00	3.50	53.50	57.00
Supervision	18.00	87.00	105.00
Total	$134.00	$774.45	$908.45
Total cost per lin. ft.	$ 0.60	$ 0.166	$ 0.186
Total cost per sq. ft. of paved surface	....	$ 0.04¾	....

Note—Labor, $2.50 per 8-hour day.

Twenty-three yards of 1:3:5 concrete were used in grouting, which is a rate of 0.14 cu. yd. per 100 sq. ft. of cobble-gutter surface. Labor only for laying and grouting (no grading) was $6.60 per 100 lin. ft., or the three men finish 114 lin. ft. per day, exclusive of excavation.

CHAPTER XVI

HIGHWAY BRIDGES AND CULVERTS

This chapter contains costs and other economic data relative to constructing highway bridges. In the following chapter other data will be found which may also prove of value in connection with highway bridge construction. Many data on this subject are also given in the voluminous section on bridges in Gillette's "Handbook of Cost Data."

Economic Highway Bridges and Culverts.—The following is taken from an abstract, published in Engineering and Contracting, July 28, 1920, of a paper presented at the Canadian Good Roads Convention at Winnipeg, June, 1920, by M. A. Lyons.

In selecting the type of structure three factors will influence this choice, viz., economy, service and appearance, and of these the first two will generally, but not always rightly, be the deciding factors. It is impossible to estimate the value of the æsthetic in design, and, as this value cannot be expressed in concrete symbols, it is frequently not understood, and, consequently, beauty of appearance is not given full value in deciding on the type of structure. It is a question as to how much additional money should be spent in order to achieve a pleasing appearance. The cost of a bridge is, however, soon forgotten, but an unsightly bridge cannot be forgotten, for it remains as a constant unpleasant jar on the senses.

Comparative Costs of Timber, Steel and Concrete Bridges.—In selecting the most economical type of bridge, first-cost upkeep and value of non-interruption of traffic must be considered. The timber structure is in about every case the cheapest in first cost, but in the long run it does not generally prove to be as cheap as steel or concrete. A wooden pile bridge, if suitable for the site, is no doubt the cheapest bridge in direct cost.

For example, a 50-ft. pile bridge will cost today about $1,500. Allowing 6 per cent interest, a yearly payment of $270 would be required to keep this bridge in condition, made up as follows: Flooring to be renewed every 3 years, first cost $270, yearly payment for 3 years $101; stringers to be renewed every 6 years, first cost $270, yearly payment $55; remainder of bridge to last 12 years, first cost $960, yearly payment $114; total yearly cost $270. Indirect costs, such as delay to traffic during repairs, loss of traffic through neglect of repairs, liability to accident or fire may run the total cost far beyond the direct costs. At best, the pile bridge is very unsightly and only to be considered where first costs are of prime importance, as they sometimes are.

In many cases stream conditions are such that it is not permissible to have piles in the stream bed and a clear opening of long span is required. The type of structure may then be a choice between a wooden span, a steel span or a concrete span. Unless the wooden span is to be placed on piles, which, in many cases, is not feasible, the cost of the substructure for the three types will be about the same, so that it will only be necessary to compare the relative costs of the superstructure. Again selecting a 50-ft. span for comparison, and assuming wooden flooring to be renewed every three years, wooden stringers to be renewed every six years, painting wood and steel to be carried out every four years, the life of concrete and steel to be over 30 years and the life of a wooden truss to be over 15 years, we have the following relative costs:

FIRST COSTS

Wooden Truss—	
12,400 ft. B. M. timber at $100 per M	$1,240
3,000 lb. steel at 15 cts. per lb	450
Painting	250
	$1,940
Steel Bridge—	
17.6 tons steel at $220	$2,772
4,600 ft. B. M. timber at $80 per M	368
	$3,140
Concrete Bowstring—	
68 cu. yd. concrete at $35 per cu. yd	$2,380
11,600 lb. steel at 10 cts. per lb	1,160
1,850 sq. ft. mesh at 20 cts. per sq. ft	370
1,000 lb. structural steel (bearings, etc.), 20 cts. per lb	200
Crosby clips and handrail	200
	$4,310

YEARLY COSTS

Wooden Truss—	
Flooring 2,800 ft. B. M. at $80, cost $224, yearly payment based on 3-year life	$ 84
Stringers, 3,200 ft. B. M. at $80, cost $256, yearly payment based on 6-year life	54
Remainder of bridge $1,210, yearly payment based on 15-year life	125
Yearly cost of painting every 4 years	72
Total yearly cost	$ 335
Steel Truss—	
Timber, 4,670 ft. B. M. at $80, cost $374, yearly payment based on 3-year life	$ 140
Yearly payment on steel truss for 30 years (cost $2,772)	201
Yearly cost of painting every four years	36
Total	$ 377
Concrete Bridge—	
Yearly payments on concrete bridge for 30 years (cost $4,310)	$ 311

It thus appears that the concrete superstructure, for spans of this length at least, is cheaper than either wood or steel. It must also be noted, in the case of steel and concrete bridges, that at the end of 30 years the bridge is paid for and the yearly payments cease (except for the repairs on the steel bridge), while in the case of the wooden bridge the yearly payments still go on.

Every Bridge a Problem in Itself.—For bridges of any size it is impossible to make any general statement that one class of bridge is cheaper than another, as every bridge is a problem in itself, and the foregoing is given as an example of a method of obtaining relative costs. The question of the nature of the foundations, cross-section of the stream-bed, condition of stream flow, waterway required, availability of materials, relative cost of materials, relative costs and availability of labor, relative cost of substructure to the superstructure, ice conditions and economical and suitable length of span must be taken into account when deciding which is the economical bridge.

Wooden bridges are confined chiefly to two types, the pile trestle and the Howe truss. For steel bridges of clear span of 30 ft. or under, simple stringer spans are cheapest; from 30 ft. to about 45 or 50 ft., plate girders; from 50 ft. to 80 or 90 ft., low or pony trusses; 400 or 500 ft., trusses with subdivided panels; beyond this, cantilever or suspension bridges, with steel arches, coming in any place in the list.

Every concrete bridge is a study in itself. In Manitoba there have been constructed, or are under way, slab and girder bridges up to 30-ft. span, through girders up to 50-ft. span, barrel arches up to 100-ft. span, open-spandrel arches up to 60-ft. span, through arch or rainbow type up to 90-ft. span and bowstrings up to 90-ft. span. These are, however, only given as an example of different types of concrete bridges.

Culverts, Types and Costs.—Coming to the small but important culverts, there are, in general, four types in common use: First, wooden culverts; second, steel or iron culverts; third, concrete pipes; and fourth, concrete culverts cast in place. The wooden culvert is undoubtedly the cheapest, but the objection to this is that it is out of commission or unsafe about most of the time. In point of cost, concrete pipe culverts come next. These, however, must be placed where no water will freeze in or around them, and they must have a good, solid bed. Considerable saving has been effected in Manitoba by the use of concrete pipe, and the results have been quite satisfactory. The cost of manufacture last year ran about as follows:

	Per lin. ft.
10-in. diameter	36 cts.
12-in. diameter	45 cts.
15-in. diameter	50 cts.
18-in. diameter	83 cts.
24-in. diameter	$1.22
30-in. diameter	1.75

The breakage in handling ran about 1 per cent.

Corrugated steel or iron pipes have been used extensively where lack of suitable materials or labor prevent the making of concrete pipes. These can be laid in places where it would not be suitable to lay concrete pipes. We have also used semi-circular reinforced culverts cast in place with success. These cost about the same as the corrugated iron pipes. We seldom use pipe culverts of over 30-in. or 36-in. diameter. Above that we advocate reinforced concrete box culverts.

Diagrams for Estimating Materials Required for Standard Steel and Concrete Spans of the Illinois Highway Department.—The following is given by G. F. Burch in Illinois Highways, June, 1915, abstracted in Engineering Record, July 7, 1915.

These diagrams give the weight of steel and the amount of concrete in steel truss spans from 50 to 160 ft. long, with a 4-in. concrete floor, in reinforced-concrete girder spans from 30 to 60 ft. long, and in reinforced-concrete slabs from 5 to 30 ft. long. In addition curves are given for the amount of concrete in the abutments, both plain and reinforced.

Material in Superstructures.—The steel trusses are of the ordinary Pratt truss type with parallel chords and riveted connections. The design provides for a 4-in. concrete floor, with a wearing surface assumed to weigh not less than 50 lb. per square foot. On account of the weight and rigidity of the concrete floor no allowance is made for impact. Floor systems are designed to carry a 15-ton traction engine in addition to the dead load. Trusses are designed to carry a uniform load of 100 lb. per square foot of road surface for spans from 50 to 150 ft., and a uniform load of 85 lb. for spans exceeding 150 ft. long. The usual A. R. E. A. unit stresses are used in the design. Pony trusses are used for spans of from 50 to 85 ft., and through trusses for spans of from 90 to 160 ft.

Reinforced-concrete through girders are used for spans of from 30 to 60 ft. This type of structure is designed to carry either a uniform load of 125 lb. per square foot, or an engine load of 24 tons.

Plain Concrete Abutments.—In preparing curves to show the quantities in abutments it was found that there were many variables which might be con-

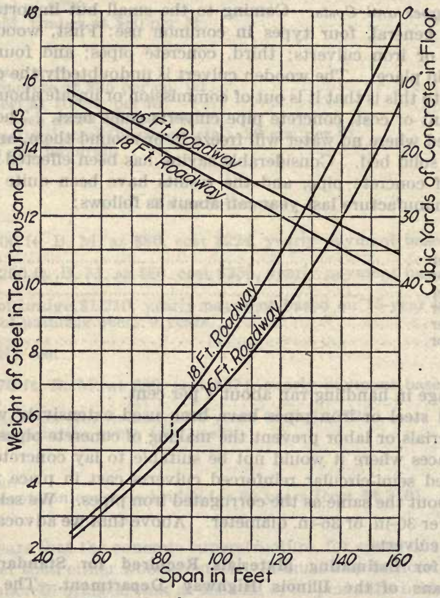


FIG. 1.—Steel truss superstructures.

sidered, but which if used would produce such complex formulas as to make the curves of little use in the field. It was found that curves giving reliable results might be obtained by plotting the cubic yards of concrete in two abutments against a formula which represented a measure of the quantities desired. The variables in this formula are H, height of abutment from bottom of foundation to top of roadway; R, clear width of roadway on superstructure, and W, length of average wing wall. For plain concrete abutments the best results were obtained by using the term $H^2 (R + 2W)$.

Plain concrete abutments for steel bridges are designed with a footing width of one-third of the height over all, and the thickness of the footing is usually from 18 to 24 in. The width of the base of the abutment and wing walls at the top of the footing is made approximately one-quarter of the height of the walls. The back of the abutment wall is vertical and the face of the wall is battered to a top width of from 30 to 38 in. The wing walls are battered on both sides and have a top width of 12 in. Fig. 4 shows the curves from which the yardage of plain concrete abutments for steel bridges may be obtained. When field measurements are made to determine the necessary height of abutments, and the width of roadway is decided upon, it is easy to estimate the length of wing walls which will be required. These figures are then used in the formula and the yardage of concrete is read directly from the curve.

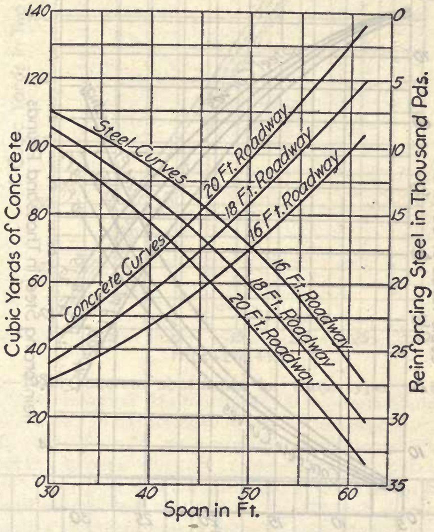


FIG. 2.—Reinforced concrete through girder superstructures.

The design of plain concrete abutments for girder bridges is similar to the design for steel bridges, except that the wing walls are battered on the face side only, and the top width of the abutment wall is 18 in. Plain concrete abutments for slab bridges differ slightly from the preceding design. The width of footing on the abutment wall is limited only by the safe bearing capacity of the soil, with a minimum of 3 ft. This width may sometimes be less than one-third.

Curves for Estimating Steel Bridge Quantities.—Engineering and Contracting, April 25, 1917, abstracts the curves shown as Figs. 5 and 6 from a Bridge Manual prepared under the direction of John H. Lewis, State Engineer of Oregon, for the State Highway Commission. They are intended for handy reference, to determine within reasonable limits the approximate quantities or weights of the materials which enter into the construction of the types of bridges for which the curves were prepared.

The diagrams are based on through Pratt bridges, designed according to the standards of the Oregon State Highway Department for the loadings given.

They are in no way intended as a substitute for careful estimating when the question of any crossing enters the contract and construction stage. The final estimates should always be made up on accurate plans and details worked out for the particular bridge in question to cover any special conditions.

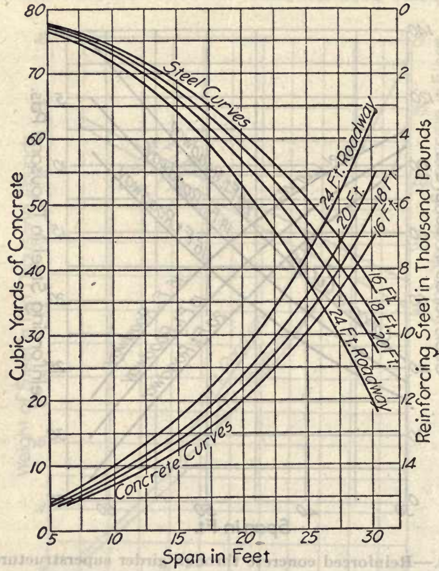


FIG. 3.—Reinforced concrete slab superstructures.

Men in the field, however, are often called upon to prepare an estimate on short notice upon which definite construction programs may be authorized without further delay. After the quantities of materials are obtained, prices and labor costs can be judged in the field on the basis of local conditions, perhaps better than anywhere else, and the rough estimate be made up in a short time.

The curves give the weight of steel in both medium and heavy traffic bridges of spans ranging from 60 to 260 ft.

The bridges are of the pony or low truss type, from 60 to 90 ft., and through Pratt trusses from 100 to 260 ft.

Roadways are taken at 16 ft.

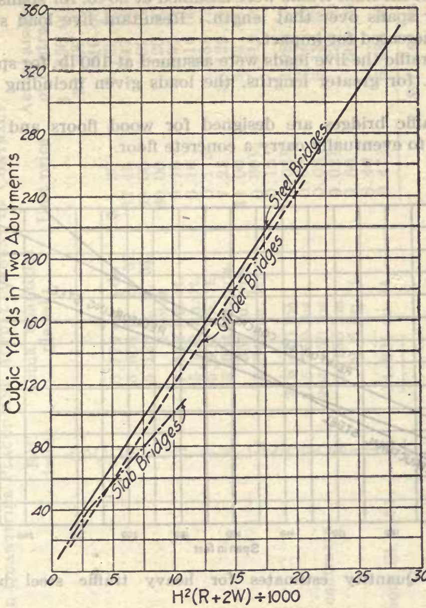


FIG. 4.—Plain concrete abutments for three types of bridges.

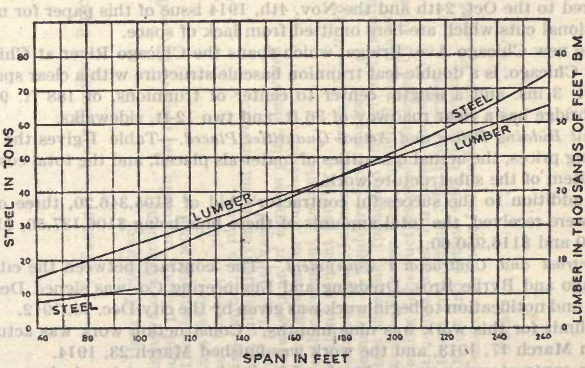


FIG. 5.—Quantity estimates for medium traffic steel bridges.

Live loads for medium traffic were assumed at 60 lb. for spans up to 150 ft., and 50 lb. for spans over that length. Resultant live load stresses in the trusses were increased for impact.

For heavy traffic the live loads were assumed at 100 lb. for spans up to 150 ft., and 75 lb. for greater lengths, the loads given including provision for impact.

Medium traffic bridges are designed for wood floors and joists: heavy traffic bridges to eventually carry a concrete floor.

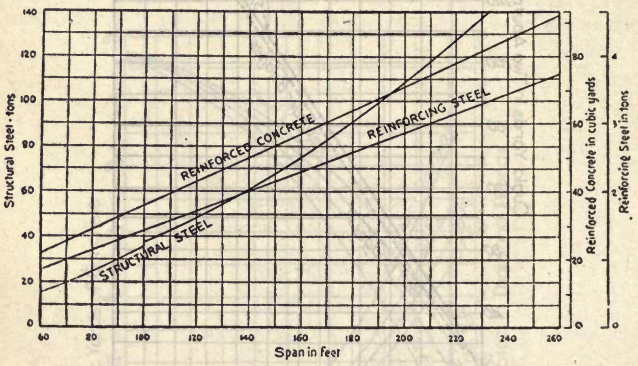


Fig. 6.—Quantity estimates for heavy traffic steel bridges.

Costs of Substructure of the Double-Leaf Trunnion Bascule Bridge at Chicago Ave., Chicago, Ill.—Carl O. Johnson gives the following detailed labor costs in Engineering and Contracting, Nov. 4, 1914. The reader is referred to the Oct. 24th and the Nov. 4th, 1914 issue of this paper for many additional cuts which are here omitted from lack of space.

The new Chicago Ave. Bridge, which spans the Chicago River at Chicago Ave., Chicago, is a double-leaf trunnion bascule structure with a clear span of 161 ft. 3 ins. and a length, center to center of trunnions, of 188 ft. 9 ins. The bridge has a clear roadway of 36 ft. and two 12-ft. sidewalks.

Unit Bidding Prices and Actual Quantities Placed.—Table I gives the unit bidding prices, the actual quantities of materials placed, and the total costs of each item of the substructure work.

In addition to the successful contractor's bid of $105,346.20, three other bids were received, the total amounts of these bids being $106,137.50, $107,-100.00 and $116,950.00.

Contract and Contractor's Equipment.—The contract between the city of Chicago and Byrne Bros. Dredging and Engineering Co. was signed Dec. 2, 1912, and notification to begin work was given by the city Dec. 13, 1912. The time limit for this work was nine months. Construction work was actually begun March 17, 1913, and the work was finished March 23, 1914.

The contractor was required to furnish all labor, material and plant necessary for the construction work, and was made responsible for all damages due

TABLE I.—UNIT BIDDING PRICES, ACTUAL QUANTITIES PLACED AND ACTUAL AMOUNT OF CONTRACT

Item of contract	Ref. letter	Actual quantities placed	Unit price	Actual amount of contract
Remove obstructions	A	....	....	$ 650.00
Build, protect, maintain and remove two cofferdams	B	....	....	22,300.00
Miscellaneous work	C	....	....	910.00
Excavation	D	6,774 cu. yds.	$ 1.29	8,738.46
Oak timber, in place	E	5,564 ft. B. M.	62.40	347.19
Pine timber, in place	F	5,128 ft. B. M.	39.00	199.99
Test piles, delivered and driven	G	4 piles	30.00	120.00
Oak piles, delivered	H	7,182 lin. ft.	0.18	1,292.76
Norway pine or cypress piles, delivered	I	5,100 lin. ft.	0.16	816.00
Driving piles for foundation	J	9,902 lin. ft.	0.115	1,138.73
Portland cement concrete	K	3,604 cu. yds.	7.25	26,129.00
Portland cement mortar	L	357 cu. yds.	11.00	3,927.00
Concrete shaft foundation, from El. —20 to El. —45	M	18,648 cu. ft.	0.39½	7,319.34
Removal of boulders from shafts	N	....	0.12	....
Steel sheeting, furnished and driven in shafts	O	279.470 lbs.	0.02½	6,986.75
Steel reinforcing bars, furnished and placed	P	145,710 lbs.	0.02	2,914.20
Setting substructure steel, furnished by superstructure contractor	Q	204,550 lbs.	0.03	6,136.50
Structural steel, furnished and set	R	9,136 lbs.	0.02½	228.40
Divert and extend 5-ft. brick sewer	S	69.6 lin. ft.	9.60	668.16
Divert and extend 4-ft. brick sewer	T	....	8.40	....
Concrete cylinder foundation, from El. —45 to rock, about El. —81.	U	14,601 cu. ft.	0.47½	6,935.48
Total	..	....	....	$97,757.96

to the construction of the substructure. The construction plant consisted of the following equipment:

One 6-cu. yd. "Marion" dipper dredge.
Two dump scows, 500-cu. yd. capacity each.
Two dump scows, 250-cu. yds. capacity each.
One derrick scow equipped with a 12-in. sand pump.
Two deck scows.
One floating pile driver.
One shore pile driver.
One stiff-leg derrick with 40-ft. wood mast and 80-ft. boom.
One stiff-leg derrick with 40-ft. steel mast and 90-ft. boom.
One 22-HP. hoisting engine.
One 30-HP. hoisting engine.
One 80-HP. locomotive firebox boiler.
One ½-in. cu. yd. concrete mixer.
Three 8-in. centrifugal pumps.
One 6-in. submerged centrifugal pump.
One 4-in. piston pump.

Rates of Wage and Division of Labor.—The following rates of wages were paid the rates being regulated principally by agreement with the labor unions:

Superintendent, $200 per month.
Timekeepers, from $1.50 to $3.75 per day; average rate, 35.9 cts. per hour.
Watchman, $2.50 per day.
Hoisting engineers, 75 to 80 cts. per hour; average rate, 76.2 cts. per hour.
Firemen, 46 cts. per hour.
Winchmen, 52½ cts. per hour.
Signalmen, from 40 to 50 cts. per hour; average rate, 45½ cts. per hour.
Carpenter foremen, 75 cts. per hour.
Carpenters, 65 cts. per hour.
Carpenters' helpers, 48 cts. per hour.
Labor foremen, from $4.50 to $7.00 per day; average rate, 58.2 cts. per hour.
Laborers, from 25 to 60 cts. per hour; average rate, 44.2 cts. per hour.
Iron worker foreman, $1.14 per hour.
Iron worker straw boss, 93¾ cts. per hour.
Iron workers, 68 cts. per hour.
Machinists, 65 cts. per hour.
Sewer brick layers, $11.00 per 8-hour day.
Pile driver crew, 10 men at 8 hours each, $43.76 per day (ordinary work).
Pile driver crew, 10 men at 8 hours each, $53.08 per day (driving steel sheeting)
Dredge crew, 7 men at 12 hours each, $33.00 per day.
Dredge crew, 10 men at 12 hours each, $38.46 per day.
Derrick scow engineer, 75 cts. per hour.
Derrick scow fireman, 30 cts. per hour.

A day, or shift, was 8 hours. The superintendent, timekeepers, and labor foremen worked 8 to 12-hour shifts. The average rate of wage for all classes of labor for the entire job was 53 cts. per hour.

Table II gives the division of labor on the work, classified both as to time and cost.

TABLE II.—DIVISION OF LABOR ON JOB

Kind of labor.	Percentage of total hours worked	Percentage of total cost of work
Superintendent, timekeeper, watchman, etc.	8.5	8.2
Engineers and firemen	12.4	15.7
Carpenters	10.6	13.2
Laborers	50.5	43.4
Iron workers	0.8	1.2
Machinists	0.1	0.1
Bricklayers	0.1	0.2
Pile driver crew	14.4	16.2
Dredge crew	2.4	1.7
Derrick scow crew	0.2	0.1
Total labor	100.0	100.0

Time and Cost Data for Various Labor Items.—In all the cost data given in this article, only *actual job labor costs* have been considered. No charge has been made for tug service, plant rental or depreciation, interest, or central office overhead charges, etc.

Tables III to IX, inclusive, contain accounts which were prorated among the contract items as shown. These tabular data give essential information on the cost and the time required to complete various parts of the work.

The average rate for the work indicated in Table III was 54 cts. per hour. The items given in Table III were prorated among all items where the pile driver crew was used according to the number of hours worked, as follows:

Item	Total hours	Total cost
Cofferdams	875	$ 474.00
Steel sheeting for concrete caissons	454	245.00
Miscellaneous	41	22.30
Pine timber	41	22.30
Oak timber	11	4.66
Test piles	11	4.55
Pile driving for foundation	289	156.00
Removal	247	137.00
To Table VIII	82	44.60
To Table IX	11	4.55
Total	2,062	$1,114.86

TABLE III.—PILE DRIVING EQUIPMENT

Item	Total hours	Total cost
Rigging floating pile driver No. 1	60	$ 32.86
Unloading and erecting shore pile driver No. 2	193	109.37
Rigging and erecting shore pile driver No. 3	730	360.89
Removing wrecked pile driver	164	90.98
Rebuilding shore pile driver	535.5	313.15
Removing steam hammer for another job	11.5	7.51
Wrecking old pile driver	112	56.86
Repairing pile driver scow	216	121.36
Storing pile driver	40	21.88
Total	2,062	$1,114.86

Unloading the steel cofferdam sheeting, the steel caisson sheeting and the reinforcing bars for the concrete work, hauling this material from the cars to the scow, towing the same about 1,500 ft., and unloading the material on the docks required 344 hours, at a cost of $171.50, the average rate of wage for this work being 50 cts. per hour. These items were prorated according to the amount of steel used for the various parts of the work as given in Table IV.

TABLE IV.—HANDLING STEEL

Item	Total hours	Total cost
Cofferdams	189	$ 94.41
Steel caisson sheeting	100	49.70
Reinforcing bars	55	27.40
Total	344	$171.51

Unloading coal for the plant on the west side of the Chicago River required 64½ hours, at a total cost of $28.57, the average rate of wage being 45 cts. per hour. This item was prorated as given in Table V.

TABLE V.—HANDLING COAL

Item	Total hours	Total cost
Pumping water from cofferdam	58	$25.71
Excavation	6½	2.86
Total	64½	$28.57

The cost and the time required to sort the old lumber used in the cofferdams are given in Table VI. The average rate of wage for this work was 47 cts. per hour, and the work was prorated 50 per cent to each cofferdam.

TABLE VI.—SORTING LUMBER

Item	Total hours	Total cost
Sorting lumber	281½	$131.42

The time and cost data on the labor which may be classified as superintendence is given in Table VII. This item includes the work of the superintendent, timekeepers, watchman and the unclassified time of the carpenter and labor foremen. It amounts to 12.1 per cent of the net pay roll, the average rate of wage being 53 cts. per hour.

TABLE VII.—SUPERINTENDENCE

Item	Total hours	Total cost
Superintendence	9,612	$5,010.01

Table VIII gives the cost and the number of hours worked on items pertaining to the work of the derricks.

TABLE VIII.—WORK PERTAINING TO DERRICKS

Item	Total hours	Tota cost
Clearing space for west plant	47	$ 18.80
Driving five 28-ft. piles for derrick foundation	85	46.50
Framing west derrick, 40-ft. mast, 80-ft. boom	40	26.00
Rigging and erecting west derrick	195½	106.91
Housing boilers	371½	189.84
Wrecking west derrick and plant	114	57.82
Cleaning up site of plant	30	12.00
Prorated amount from Table III	55	29.74
Total (average rate of wage, 52 cts. per hour)	938	$ 487.61
Driving three 45-ft. and two 30-ft. piles for foundation of east derrick	40	$ 21.88
Cutting and framing bent to above piles	12	7.80
Building crib for foundation of derrick sill	36	14.40
Rigging and erecting east derrick, 40-ft. mast. 90-ft. boom	291	153.91
General work on east plant	1,094½	628.49
Prorated amount from Table III	27	14.86
Total (average rate of wage, 56 cts. per hour)	1,500½	$ 841.34
Unloading east and west plants	74	$ 33.35
General work on east and west plants	154	92.92
Total (average rate of wage, 55 cts. per hour)	226	$ 126.27
Grand total	2,666½	$1,455.22

As the items given in Table VIII were charged principally to the derrick plant, they were prorated among the contract items according to the "derrick engineer" hours charged against these items, as follows:

Item	Total hours	Total cost
Cofferdams	320	$ 174.57
Miscellaneous	160	87.34
Excavation	480	260.12
Concrete	586½	320.04
Mortar	134	73.78
Caissons above El. —45	320	174.57
Caissons below El. —45	533	291.02
Setting substructure steel	133	73.78
Total	2,666½	$1,455.22

The cost and the time charged to the concrete plant are given in Table IX.

TABLE IX.—CONCRETE PLANT

Item	Total hours	Total cost
Loading and unloading sand scow	357½	$ 151.00
Placing protection over east pit floor	8	3.60
Cleaning rubbish and concrete from east pit floor	144	73.40
Clearing space for east concrete mixing plant	20	8.15
Erecting east concrete mixer and 85½-ft. tower for same, using 4,454 ft. B. M. lumber	965	549.89
Handling concrete chutes	270	139.53
Removing east concrete mixing plant	100	50.00
Removing east concrete tower	62	32.55
Prorated amount from Table III	11	4.55
Unloading stone scows	332	144.98
Clearing storage space for sand and stone on west side of river	37	14.80
Setting west concrete mixer and running water pipe line	72½	43.24
Resetting concrete mixer in second position	138	70.08
Resetting concrete mixer in third position	141	74.22
Changing concrete chute to west side	93	45.20
Removing west concrete mixing plant	25	10.00
Building and removing platform for stone storage on west side	332	144.98
Unloading stone from canal boats on west side	373	191.50
Clearing rubbish and concrete from west pit, etc	438½	207.33
General repairs to concrete plant	270½	122.72
Miscellaneous, moving of cement	153	69.19
Total (average rate of wage, 50 cts. per hour)	4,182	$2,117.03

The items given in Table IX were charged against "concrete" items, as follows:

Item	Total hours	Total cost
Concrete	3,027.35	$1,532.44
Mortar	243.33	123.10
Concrete caisson foundations between El.—20 and El.—45	501.97	254.25
Concrete caisson foundations below El. —45	409.35	207.24

Discussion of Construction and Cost Data and Unit Costs.—A description of the work done under each subdivision of the contract, together with a discussion of the cost data will now be given. Each item is referred to by the reference letter given in the specifications and shown in Table I.

"*A*"—*Removal of Obstructions*.—This item included all work done in removing obstructions which interfered with the construction of the substructure. The work consisted principally of removing a rubble masonry pier containing 103 cu. yds., timber and pile approaches, parts of brick sewers, and concrete walks. The lump sum bid for this work was $650. The construction plant used consisted of a pile driver, a derrick scow and a deck scow. The actual labor costs for this work were divided as follows:

Item	Total hours	Total cost
Removal of timbers, piles, etc	1,733	$ 831.38
Removal of stone, brick, concrete	748	282.05
Prorated charge	247	137.00
Total	2,728	$1,250.43
Superintendence, etc., 12.1 per cent	330.1	151.30
Grand total	3,058.1	$1,401.73

Average labor cost, 46 cts. per hour.

"B"—Cofferdams.—The cofferdams, which were of the single-wall type, were built of steel and wooden sheeting, and entirely enclosed the main piers and small walls. The lump sum for building, maintaining, protecting and removing the two cofferdams was $22,300.

The west cofferdam had maximum dimensions of 86.7 ft. by 55.3 ft., enclosing an area of 4,424 sq. ft. The maximum depth of water outside of this dam was 19.9 ft.

The east cofferdam had maximum dimensions of 91.9 ft. by 56.3 ft., inclosing an area of 4,655 sq. ft. The maximum depth of water outside of this dam was 20.9 ft.

The excavation (all soft clay) was carried down to a general elevation of −20.0 (the river being at elevation about +0.8), from which depth four caissons were sunk to bed rock, which lies at an average elevation of −81.1. The sites of the cofferdams were first cleared with dipper dredges, the west cofferdam being dredged from an original *average* depth of 2.3 ft. to an *average* depth of 10.7 ft., and the east cofferdam, from an *average* depth of 4.3 ft. to an *average* depth of 11.7 ft. The excavated material was dumped into scows and towed to dumping grounds in Lake Michigan. The only dredging paid for consisted of that enclosed by the cofferdams, although considerable dredging was done outside of the cofferdam walls. After the site was cleared the foundation piles and the cofferdam sheeting were driven. "Lackawanna" arched web sheeting, weighing 35 lbs. per square foot and having a length of 40 ft., was used in the river and also up to a point about 10 ft. inland where it connected with 6 × 12-in. × 28-ft. "Wakefield" sheet piling. At the east side of the river the steel sheeting was extended along a nine-story reinforced concrete building and a one-story freight house where their foundations appeared to be in danger.

Six brace piles were also driven in each cofferdam to support temporarily the system of bracing. The waling timbers were of 12 × 12-in. pine and were suspended by cables which passed through holes in the top of the steel sheeting. A 12 × 12-in. post was set on top of the upper tier of waling and bolted to the steel sheeting, the cables and posts preventing any movement of the waling due to the changing elevation of the water level within the cofferdam. The remaining timbers were either 12 × 12-in. pine or waste pieces of piles. Where timbers butted against waling pieces a 4 × 12-in. × 3 ft. oak block was used. Corner braces were used in the cofferdam pockets over the caissons. Four sets of bracing were placed in each dam—at elevations +0.5, −6.0. −10.0 and −14.0, the bottom of the main excavation being at elevation −20.0. The tiers of bracing were separated by 12 × 12-in. posts and were tied together with double ¾-in. tie rods. They were also bolted to the brace piles where convenient.

One 12-in. and three 8-in. centrifugal pumps were required to pump the first 6 ft. of water from the west cofferdam, this pumping requiring about two hours. From this level a 6-in., or an 8-in. pump, operated from time to time, was sufficient to remove the water from the cofferdam. When the pumping began, fine ashes were distributed along the outside of the steel sheeting, which proved very effective in stopping leaks. No other means were employed to make the sheeting watertight.

At the completion of the work all the material composing the cofferdams and bracing was recovered except the "Wakefield" sheeting and 43 pieces of the "Lackawanna" steel sheeting.

The high cost of pumping given in Table X was due to the fact that it was necessary to pump part of the time both day and night, which necessitated the employment of hoisting engineers as pumping engineers for 24 hours each day.

Tables X and XI give cost data, for the west and east cofferdams, on the driving of wood and steel sheet piling, the pumping of water from the cofferdams, the bracing of the cofferdams, and removing them.

Table XII gives a summary of the labor costs of constructing and removing the two cofferdams.

TABLE X.—FORCE ACCOUNT AND LABOR COST DATA FOR WEST COFFERDAM

Item	Total hours	Rate, cts. per hr.	Total cost	Remarks
Driving Wood Piles and Wood Sheeting				
Sorting old piles and lumber	140.8	..	$ 65.71	
Driving 11 22-ft. piles at back and side of dam.	200	..	109.40	Rate, 4.4 piles per 8-hr. day.
Driving 6 30-ft. brace piles	25	..	13.67	Rate, 19.2 piles per 8-hr. day.
Driving and chaining 2 12-pile clumps, 45-ft. piles, and 2 protection piles	85	..	46.37	Rate, 26.0 piles per 8-hr. day.
Building 7 6×12-in. ×28 ft. Wakefield sheeting corners	43	..	25.95	
Driving 127 6×12-in. × 28-ft. Wakefield sheeting with shore driver	451	..	244.35	Rate 22½ sheets per 8-hr. day.
Prorated charge	136	..	73.00	
Total	1,080.8	54	$ 578.45	
Superintendence, etc., 12.1 per cent	130.7	..	69.99	
Grand total	1,211.5	54	$ 648.44	
Driving Steel Sheeting				
Preliminary handling of steel sheeting	55	..	$ 27.67	
Loading steel sheeting from dock to scow	80	..	53.08	
Driving steel sheeting, 138 pieces 40-ft. long and 3 pieces 25-ft. long =115.13 tons	617	..	404.72	Rate, 18.3 pieces per 8-hr. day.
Prorated charge	132	..	71.00	
Total	884	63	$ 556.47	Cost, 7.2 hrs. per ton = $4.83, or $3.94 per sheet; av. sheets per day =13.
Superintendence, etc., 12.1 per cent	107	..	67.34	
Grand total	991	63	$ 623.81	Cost, 8.6 hrs. per ton = $5.40, or $4.44 each; av. sheets per 8-hr. day =11½.

TABLE X.—(*Continued*)

Pumping Water from Cofferdam				
Installing pumps and pumping water	5,433.5	..	$3,222.30	
Handling coal for pumps	58	..	25.71	
Placing ashes to waterproof sheeting	1,096.5	..	447.41	
Plugging extraordinary leaks in dam	192.5	..	111.33	
Tending boiler plant for pumping	449	..	284.58	
Total	7,229.5	57	$4,091.33	
Superintendence, etc., 12.1 per cent	874.8	..	495.05	
Grand total	8,104.3	57	$4,586.38	
Bracing Cofferdam				
Unloading timber from scow to cofferdam	58	..	$ 32.33	
Placing first set of bracing	230¾	..	149.24	
Placing second set of bracing	430¾	..	246.08	
Placing third set of bracing	313	..	195.81	
Placing fourth set of bracing	313	..	195.28	
Prorated charge	14	..	7.60	
Total (timber used = 58,526 ft. B. M., of which 44,776 ft. B. M. was 12 × 12-in. waling and bracing. Area of cofferdam = 4,424 sq. ft.)	1,359½	61	$ 826.34	58,526 ft. B. M. at 23.2 hrs. per M = $14.20, or 44,776 ft. B. M. at 28½ hrs. per M = $17.40. 100 sq. ft. area in 31 hrs. = $18.70.
Superintendence, etc., 12.1 per cent	164½	..	99.99	
Grand total	1,525	61	$ 926.33	58,526 ft. B. M. at 26 hrs. per M = $15.90, or 44,776 ft. B. M. at 32 hrs. per M = $19.40. 100 sq. ft. area in 35 hrs. = $21.00.
Removing Cofferdam				
Removing braces of cofferdam	209	..	$ 108.15	
Removing pit timbers	301	..	146.84	
Pulling 141 pieces steel sheeting = 115.13 tons	800	..	521.48	Pulled, 14.1 pieces per 8-hr. day = $3.70 each, or $4.53 per ton.
Prorated charge	146	..	79.30	
Total	1,456	59	$ 855.77	
Superintendence, etc., 12.1 per cent	176.2	..	103.55	
Grand total	1,632.2	59	$ 959.32	

TABLE XI.—FORCE ACCOUNT AND LABOR COST DATA FOR EAST COFFERDAM

Driving Wood Piles and Wood Sheeting

Item	Total hours	Rate, cts. per hr.	Total cost	Remarks
Handling Wakefield sheeting	12	..	$ 4.80	
Driving 101 pieces Wakefield sheeting, 6 × 12-in. × 28-ft.	375	..	204.80	Rate, 21½ pieces per 8-hr. day.
Driving 10 20-ft. piles at back wall	60	..	32.82	Rate, 13 piles per 8-hr. day.
Driving and chaining 2 12-pile clumps of 45-ft. piles and 4 protection piles	130	..	71.11	Rate, 17 piles per 8-hr. day.
Driving 9 brace piles	30	..	16.41	Rate, 24 piles per 8-hr. day.
Sorting old piles and lumber	140.75	..	65.71	
Prorated charge	108	..	59.00	
Total	855.75	53	$ 454.65	
Superintendence, etc., 12.1 per cent	103.55	..	55.01	
Grand total	959.3	53	$ 509.66	
Driving Steel Sheeting				
Loading steel sheeting from dock to scow	258	..	$ 171.08	
Driving 179 pieces of steel sheeting 40-ft. long and 3 pieces 25-ft. long = 149.73 tons	695	..	461.13	Rate, 21 pieces per 8-hr. day.
Prorated charge	172	..	93.50	
Total	1,125	63	$ 725.70	Rate 13 pieces per 8-hr. day = $4.00 each. 7½ hrs. per ton = $4.86 per ton.
Superintendence, etc., 12.1 per cent	136.1	..	87.81	
Grand total	1,261.1	63	$ 813.51	Rate, 11½ pieces per 8-hr. day = $4.48 each. 8½ hrs. per ton = $5.40 per ton.
Pumping Water From Cofferdam				
Installing pumps and pumping water	4,366	..	$2,623.56	
Handling coal for pumps	34	..	18.15	
Placing ashes for waterproofing sheeting	467	..	191.47	
Plugging extraordinary leaks in dam	48	..	27.86	
Puddling parts of cofferdam	182.5	..	83.13	
Prorated charge	52	..	28.00	
Total	5,149.5	57	$2,972.17	
Superintendence, etc., 12.1 per cent	623.1	..	306.03	
Grand total	5,772.6	57	$3,278.20	

TABLE XI.—(*Continued*)

		Bracing Cofferdam		
Unloading timber from scow	105	..	$ 55.57	
Waling and mud sills for back wall	45	..	24.16	
Placing first set of bracing	322	..	209.30	
Placing second set of bracing	467.5	..	290.23	
Placing third set of bracing	270	..	170.65	
Placing fourth set of bracing	339.5	..	213.26	
Prorated charge	19	..	10.50	
Total (lumber used, 62,845 ft. B. M., of which 50,646 ft. B. M. was 12 × 12-in. waling and bracing. Area of cofferdam = 4,655 sq. ft.)	1,568	62	$ 973.67	62,845 ft. B. M. at 24½ hrs. per M. = $15.50. 50,646 ft. B. M. at 31 hrs. per M. = $19.60. 100 sq. ft. area in 33.2 hrs. = $21.00.
Superintendence, etc., 12.1 cent	189.7	..	117.81	
Grand total	1,757.7	62	$1,091.48	62,845 ft. B. M. at 28 hrs. per M. = $17.70. 50,646 ft. B. M. at 34.7 hrs. per M. = $21.50. 100 sq. ft. area in 37.7 hrs. = $23.40.
		Removing Cofferdam		
Removing bracing of cofferdam	401	..	$ 233.66	
Removing timbers from pit	139	..	67.85	
Sawing off back line of Wakefield sheeting	38	..	15.20	
Burning off 43 pieces steel sheeting at ground	32	..	16.66	Burn about 7 per hr. The 32 hrs. includes helpers' time.
Pulling 138 pieces steel sheeting = 113½ tons	558	..	357.23	Rate 20 pieces per 8-hr. day. $2.59 each = $3.14 per ton.
Prorated charge	96	..	52.10	
Total	1,264	59	$ 742.70	
Superintendence, etc., 12.1 per cent	152.9	..	89.87	
Grand total	1,416.9	59	$ 832.57	

TABLE XII.—SUMMARY OF LABOR COSTS OF EAST AND WEST COFFERDAMS

	West dam		East dam		Both dams	
Item	Total cost	Per cent of total	Total cost	Per cent of total	Total cost	Per cent of total
Driving piles and sheeting for cofferdam	$1,272.25	16.4	$1,323.17	20.3	$ 2,595.42	18
Pumping water from cofferdam	4,586.38	59.2	3,278.20	50.2	7,864.58	55.4
Bracing cofferdam	926.33	11.95	1,091.48	16.7	2,017.81	14
Removing cofferdam	959.32	12.45	832.57	12.8	1,791.89	12.6
Total	$7,744.28	100	$6,525.42	100	$14,269.70	100

"*C*"—*Miscellaneous Work.*—The miscellaneous work included the following items: Making preliminary borings; furnishing scows and other supports for steel tapes during the taking of measurements across the river; making temporary sewer diversions; building and removing shed for storage of cement; protecting, supporting, maintaining, and restoring adjacent buildings affected by the construction of the cofferdams and substructure (no work required as buildings were not damaged); providing office space and temporary telephone service during construction. The lump sum bid for this work was $910. The borings were made by the city. One of the offices given below was 12 × 20 × 10 ft. high and the other, 10 × 20 × 9 ft. high.

The actual labor cost for this work was divided as follows:

Item	Total hours	Total cost
Twice diverting 5-ft. east sewer into 140-ft. wooden flume	1,522.8	$ 759.32
Diverting 4-ft. west sewer into 146-ft. wooden flume	427.1	186.59
Constructing two offices, 3,100 ft. B. M. lumber used	170.39	102.91
Miscellaneous work	973.59	439.49
Total (average wage rate, 48 cts. per hour)	3,093.88	$1,488.31

"*D*"—*Excavation.*—The price bid for excavating the site of the piers, tail pits and abutments, including the necessary back-fill, was $1.29 per cubic yard.

The excavation naturally divides itself into three classes: that removed by dredging; the excavation outside of the cofferdams; and the excavation within the cofferdams. Before excavation was commenced soundings were taken so that the river bottom at the bridge site could be accurately plotted. The sites of the cofferdams were then dredged and the dams constructed. Later, another set of soundings was taken, and the actual quantity of material removed from the cofferdams by dredging was computed to be 2,651.5 cu. yds., which was about 39 per cent of the total excavation. The material within the cofferdams was soft, blue clay and this was excavated by hand, the material being handled in buckets by derricks into dump scows and towed to the dumping grounds in Lake Michigan. The excavation outside of the cofferdams, principally at the site of the abutments, was also clay. The labor of cutting off the foundation piles was included in that classified under excavation. The total and unit labor costs of excavation are given in Table XIII.

TABLE XIII.—LABOR COST OF EXCAVATION

Item	Total hours	Rate, cts. per hr.	Total cost
Dredging Within Cofferdams			
Dredging, 2,651.5 cu. yds..................	2,168	..	$ 712.43
Prorated charge..........................	95	..	37.31
Total..................................	2,263	33	$ 749.74
Cost per cu. yd. (0.815 hrs.) = $0.268			
Superintendence, etc., 12.1 per cent......	273.8	..	90.72
Grand total............................	2,536.8	33	$ 840.46
Cost per cu. yd. (0.96 hrs.) = $0.32			
Excavation Outside of Cofferdams			
Excavation for east and west abutments, 1,389.7 cu. yds..........................	1,660	48	$ 800.03
Prorated charge..........................	75	..	42.00
Cost per cu. yd. (1.2 hrs.) = $0.58			
Total..................................	1,735	..	$ 842.03
Superintendence, etc., 12.1 per cent	209.9	..	101.89
Grand total............................	1,944.9	48	$ 943.92
Cost per cu. yd. (1.4 hrs.) = $0.68			
Excavation Outside of Cofferdams			
Excavation, 2,949 cu. yds................	6,258	..	$3,136.53
Prorated charge..........................	280	..	166.31
Total..................................	6,538	51	$3,302.84
Cost per cu. yd. (2.2) hrs. = $1.065			
Superintendence, etc., 12.1 per cent.......	791.1	..	399.64
Grand total............................	7,329.1	51	$3,702.48
Cost per cu. yd. (2.5 hrs.) = $1.25			
Back-fill			
Back-fill................................	667	43	$ 289.55
Prorated charge..........................	30	..	14.50
Total..................................	697	..	$ 304.05
Superintendence, etc., 12.1 per cent.......	84.3	..	36.67
Grand total............................	781.3	43	$ 340.72
Grand total, all items, 6,990.2 cu. yds...	12,592.1	46	$5,826.58
Cost per cu. yd. (1.8 hrs.) = $0.83			

"*E"—Oak Timber in Place.*—The price bid for the oak timber used in constructing docks and pier protection, bumping timbers in tail pits and permanent sheet piling, including all labor, timber, tools, bolts, nuts, washers, spikes and other appurtenances, was $62.40 per M. ft. B. M. in place. The quantity of oak lumber placed was 5,564 ft. B. M.

TABLE XIV.—LABOR COST OF PLACING OAK TIMBER

Item	Total hours	Rate, cts. per hr.	Total cost	Per 1,000 ft. B. M. Hours	Per 1,000 ft. B. M. Cost
Placing 5,564 ft. B. M. oak.......	375	63	$236.17	68	$42.50
Prorated charge................	11	..	4.66	..	......
Total..........................	386	..	$240.83	69	$43.00
Superintendence, etc., 12.1 per cent..........................	46.7	..	29.14	..	......
Grand total....................	432.7	63	$269.97	78	$48.50

The high cost of this work, given in Table XIV, is mainly due to the small quantity of timber used and to the large amount of cutting and fitting required. The excavation required for a part of the sheeting also increased the cost considerably.

"F"—Pine Timber in Place.—The price bid for the pine timber used in constructing docks, pier protections, etc., including all labor, timber, tools, bolts, nuts, washers, spikes and appurtenances, was $39.00 per M. ft. B. M. The amount of pine timber placed was 5,128 ft. B. M

The high cost of placing this timber, given in Table XV, was due to the same causes as were given for placing the oak timber.

TABLE XV.—LABOR COST OF PLACING PINE TIMBER

Item	Total hours	Rate, cts. per hr.	Total cost	Per 1,000 ft. B. M. Hours	Per 1,000 ft. B. M. Cost
Placing 5,128 ft. B. M. pine......	496	57	$284.48	97	$55.50
Prorated charge................	41	..	22.30	....	......
Total......................	537	..	$306.78	105	$60.00
Superintendence, etc., 12.1 per cent......................	65	..	37.12	....	......
Grand total.................	602	57	$343.90	117	$67.00

"G"—Test Piles.—The price bid for furnishing and driving four 60-ft. test piles was $120. These piles were located so as to be used later as protection and foundation piles. The plant used was one pile driver. The actual labor cost for this work was divided as follows:

Item	Total hours	Total cost
For driving four 60-ft. test piles (cost per foot, 11½ cts.; rate per 8-hour day, 6.4 piles)........................	50	$27.35
Prorated charge....................................	11	4.55
Total..	61	$31.90
Superintendence, etc., 12.1 per cent..................	7.38	3.86
Grand total....................................	68.38	$35.76

Average labor cost, 52 ct. per hour; rate per 8-hour day, 4.7 piles.

"H" and "I"—Furnishing Oak and Norway Pine Piles.—The piles under the abutments were only about 25 ft. long, this short length being used so as not to interfere with the future subway construction at this location. The remaining foundation and protection piles were about 45 ft. long. The cost of these piles delivered was as follows:

Oak piles, 7,182 lin. ft. at 18 cts......................	$1,292.76
Norway pine piles, 5,100 lin. ft. at 16 cts..............	816.00
Total..	$2,108.76

"J"—Driving Piles.—The bidding price below cut-off for driving piles in foundations, piers, pier protections, abutments, outside walls and dock lines was 11½ cts. per linear foot. There were 320 piles, 9,902 lin. ft., actually used, the bidding price for this item being $1,138.73.

The actual labor cost of driving these piles was divided as follows:

Item	Total hours	Total cost
Driving piles (320 piles, 9,902 lin. ft., below cut-off)....	1,466	$ 799.90
Prorated charge..................................	266	144.00
Total..	1,732	$ 943.90
Superintendence, etc., 12.1 per cent..................	209.45	114.21
Grand total..	1,940.45	$1,058.11

Cost (exclusive of prorated charge and superintendence), 8 cts. per linear foot below cut-off; rate, 17.4 piles per 8-hour day.

Cost (including prorated charge and superintendence), 11 cts. per linear foot below cut-off; rate, 13 piles per 8-hour day.

"K"—Concrete in Tail Pits, Outside Walls, Sewers, Abutments and Footings.—The price bid for the concrete in the piers, tail pits, outside walls, sewers and sewer outlets, abutments, footings, etc., including all labor, materials, forms, etc., was $7.25 per cubic yard. This concrete work did not include that in the caissons, which was let under a separate item. The quantity of concrete placed was 3,604 cu. yds.

The concrete used for this work and also for the caissons was a 1:3:5 mix. Part of the sand used was bank torpedo, hauled in by cars and teamed to the site; the remainder was Lake Michigan torpedo sand, brought to the site by a sand sucker and unloaded by two clam-shell buckets onto a moving belt attached to a 60-ft. boom. By this arrangement the sand was placed practically where it was wanted. The crushed stone used was brought in by teams and boats; that delivered in boats being loaded on skips at the quarry and unloaded at the site by a derrick.

The mixer on the west side of the river was set on top of the approach and the concrete chuted into place. The materials were measured in wheelbarrows, a batch being about ¼ cu. yd. The capacity of the mixer was ½ cu. yd. Most of the chutes were built of 2 × 12-in. plank and were unlined. At the east side of the river an 85-ft wooden tower was used. The sand was delivered by boat. The tower was 4 ft. 9 ins. by 6 ft. 3 ins., and was built of 6 × 6-in. posts and 2 × 6-in. braces. The main distributing chute was set at an angle of about 30° with the horizontal. The same mixer was used as for the west side.

The forms were built of 2 × 8-in. planks and 4 × 6-in. studs placed about 3 ft. apart. The forms on the inside of the pit and on the outside above the water line were *D* and *M* lumber.

Table XVI gives the labor costs for the concrete work under item "K."

"L"—Cement Mortar for Facing and Waterproofing.—The price bid for furnishing and placing the Portland cement mortar used for facing and for waterproofing the courses in the tail pits was $11.00 per cubic yard. The quantity of mortar placed was 357 cu. yds.

The mortar used for this work was a 1:2 mix. A 6-in. horizontal mortar course was placed at elevation −18, or about in the center of the tail pit floor, and extended from this course on the outside of the tail pit walls to elevation −2, where the thickness was reduced to 4 ins. From elevation +2 to the tops of these walls the thickness of the mortar course was 2 ins. The inside of the pit had a 3-in. mortar finish on the floor and a 2-in. course on the sides. The small walls on the outside of the main piers were merely spaded, as were the abutments.

TABLE XVI.—LABOR COSTS OF CONCRETE UNDER ITEM "K"

Item	Total hrs.	Rate, cts. per hr.	Total cost	Unit-costs Per cu. yd. Hrs.	Cost
	Mixing and Placing Concrete, 3,604 Cu. Yds.				
Labor	7,228.5	46	$3,343.71	2.00	$0.93
Prorated charge	570.5	..	258.00	....	.....
Total	7,799	46	$3,601.71	2.16	$1.00
Supt., etc., 12.1 %	943.7	..	435.81	....	.....
Grand total	8,742.7	46	$4,037.52	2.44	$1.20
	Building Forms, 38,340 sq. ft.*				
Labor	3,929	60	$2,337.49	1.09	$0.65
Prorated charge	303	..	186.00	....	.....
Total	4,232	60	$2,523.49	1.17	$0.70
Supt., etc., 12.1 %	512.1	..	305.34	....	.....
Grand total (38,340 sq. ft., 3,604 cu. yds.)	4,744.1	60	$2,828.83	1.32	$0.73
	Stripping Forms				
Labor	1,004.5	50	$ 505.28	0.28	$0.14
Prorated charge	77.3	..	39.06	....	.....
Total	1,081.8	50	$ 544.34	0.30	$0.15
Supt., etc., 12.1 per cent	130.9	..	65.87	....	.....
Grand total	1,212.7	50	$ 610.21	0.34	$0.17
Grand total, all items	14,699.5	51	$7,476.56	2.9	$2.10

* The unit costs per sq. ft. of forms were about one tenth of the cost per cu. yd. being $0.061, 0.066 and 0.075.

The same plant was used for this work as for the concrete work. The mortar was held in place by 1-ft. mortar boards. These boards were set up against the forms, and the concrete was placed up to their tops. The mortar was then placed in the space between the forms and the mortar boards. The boards were then raised, and the operation was repeated. The concrete was thus placed in 1-ft. horizontal layers and the mortar placed against the concrete while the latter was still green.

Table XVII gives the labor costs of mixing and placing the mortar courses.

TABLE XVII.—LABOR COSTS OF MIXING AND PLACING MORTAR COURSES

Item	Total hrs.	Rate, cts. per hr.	Total cost	Per cu. yd. Hrs.	Cost
Mixing and placing mortar, 357 cu. yds.	1,612	44	$ 706.92	4.5	$1.98
Prorated charge	411.6	..	212.40	...	.....
Total	2,023.6	45	$ 919.32	...	.....
Superintendence, etc., 12.1 per cent	244.9	..	111.24	...	.....
Grand total	2,268.5	45	$1,030.56	6.3	$2.90

"M"—Concrete Shaft Foundations from Elevation −20 *to Elevation* −45. The price bid for completed concrete shaft foundations below elevation −20 and above elevation −45 was 39¼ cts. per cubic foot (net volume). This price included cost of excavation, removal of water, removal of boulders of less than 20 cu. ft. each, and furnishing of all labor, materials, tools, ma-

chinery, etc., necessary to do the work (except steel sheeting and reinforcing bars). The quantity of concrete placed was 18,648 cu. ft., making the price bid for this item $7,319.34.

The concrete caisson foundations were divided into two parts, the rectangular portion from elevation −20 to elevation −45 and the circular portion from elevation −45 to bed rock. The upper was already lined with steel sheeting; therefore it was only necessary to place the bracing, which consisted of 6 × 12-in. and 12 × 12-in. pine spaced about 5 ft. apart, as the excavation proceeded. The material encountered, down to elevation −45 was blue clay and could be removed with shovels. It was first hoisted by means of tripods and windlasses and later with the derrick, the latter being more economical. The waste material was towed in dump scow to Lake Michigan for disposal. The price bid, 39¼ cts. per cubic foot, included the concrete work. The concrete plant is described under item "K."

Table XVIII gives the labor costs for the concrete shaft foundations between elevation −20 and elevation −45.

TABLE XVIII.—LABOR COSTS OF CONCRETE SHAFTS BETWEEN ELEVATIONS −20 AND −45

Item	Total hrs.	Rate, cts. per hr.	Total cost	Per cu. yd.* Hrs.	Per cu. yd.* Cost
Preliminary Work and Excavation					
Loading and unloading from scow the lumber for bracing.	32	....	$ 16.88	....	.....
Excavating and bracing caissons from El. −20 to El. −45............	2,470.5	50	1,244.28	3.58	$1.80
Prorated charge................	320	....	174.57	....	.....
Total..........................	2,822.5	51	$1,435.73	4.1	$2.08
Superintendence, etc., 12.1 per cent	341.5	....	173.72	....	.....
Grand total....................	3,164.0	51	$1,609.45	4.6	$2.32
Concreting between Elevation −20 and Elevation −45					
Concreting of upper part of caisson.	1,392.3	47	$ 649.41	2.0	$0.94
Prorated charge................	60.1	....	26.90	....	.....
Total..........................	1,452.4	47	$ 676.31	....	.....
Superintendence, etc., 12.1 per cent.	175.7	....	81.83	....	.....
Grand total....................	1,628.1	47	$ 758.14	2.36	$1.10
Grand total, excavating and concreting....................	4,792.1	49.5	$2,367.59	6.96	$3.43

* Per cubic foot; 0.258 hrs.; $0.127.

"*O*"—*Steel Sheeting for Concrete Shafts.*—The price bid for the steel sheeting used for the shaft foundations, including furnishing of same, driving and leaving in place was 2.5 cts. per pound. It was specified that the sheeting must weigh at least 35 lbs. per square foot. The length of the steel sheeting was 25 ft. its top being at elevation −20.5 and its bottom at elevation −45.5. "Lackawanna" arched web sheeting, weighing 35 lbs. per square foot was used. The size and shape of the top portions of the sub-foundation piers were changed to 10.5 ft. square for the river caissons and 8 ft. 2 ins. by 9 ft. 4 ins. for the anchor pier shafts, to accommodate the sheeting and at the same time give the same area as called for in the original plans. The sheeting was all driven with a floating pile driver, before the cofferdams were closed, so as not to blockade the river. The method of procedure was as follows:

A corner sheet was first placed. This sheet was then plumbed very carefully in one direction with a transit and in the other by a hand level. It was driven into the mud far enough so that its top was just above the water. The remaining sheets on this side of the shaft were then placed, particular attention being given to the other corner to insure its being vertical. The two adjacent sides of the caissons were set simultaneously, care being taken to keep the correct distance between them. The opposite wall was then set. (It should be noted that the sheets were merely set in place in the mud, all their tops being above water.) The sheeting was then driven by using another 25-ft. steel sheet as a follower. Two steel lugs were bolted to the sides of the follower at the bottom, to keep it in place on the first sheet. The "Worthington" steam hammer used for this work was an additional help in keeping the follower in place. A total of 264 pieces, weighing 139.74 tons, was used. Table XIX gives the labor cost for this work.

TABLE XIX.—LABOR COST OF DRIVING STEEL SHEETING FOR SHAFTS

Item	Total hrs.	Rate, cts. per hr.	Total cost
Preliminary handling of sheeting	125	..	$ 66.89
Placing lugs on followers	50.5	...	21.14
Total	175.5	50	$ 88.03
Superintendence, etc., 12.1 per cent	21.2	..	10.65
Grand total	196.7	50	$ 98.68
Driving Steel sheeting			
Driving steel sheeting	2,560.5	..	$1,675.08*
Prorated charge	454	..	245.00
Total	3,014.5	64	$1,920.08
Superintendence, etc., 12.1 per cent	364.8	..	232.33
Grand total	3,379.3	64	$2,152.41†
Grand total, preliminary and driving	3,576	63	$2,251.09‡

* Av. 8.2 pieces per 8-hr. day; 18.3 hrs. per ton; $11.99 per ton.
† 24.2 hrs. per ton, or $15.50 per ton.
‡ Av. 5.6 pieces per 8-hr. day; 26.9 hrs. per ton; $16.80 per ton.

"P"—Reinforcing Bars for Concrete.—The price bid for furnishing and placing the steel reinforcement in the concrete cylinders, shafts, foundations, piers, pit constructions, outside walls, and abutments was 2 cts. The amount placed was 72.85 tons.

The labor costs of this work are given in Table XX.

TABLE XX.—LABOR COSTS OF PLACING REINFORCING BARS

Item	Total hrs.	Rate, cts. per hr.	Total cost	—Per ton— Hrs.	Cost
Unloading, sorting and miscellaneous handling of bars	160	..	$ 78.53	.....	.....
Placing bars, 72.85 tons	927.5	..	437.68	.....	.....
Total	1,087.5	47	$516.21	14.9	$7.07
Superintendence, etc., 12.1 per cent	131.6	..	62.46	.....	.....
Grand total	1,219.1	47	$578.67	16.8	$7.95

"*Q*"—*Handling and Setting Substructure Steel.*—The price bid for handling and setting substructure steel (furnished by contractor for the superstructure) was 3 cts. per pound. The amount of steel set was 102.27 tons.

The steel set consisted principally of four "knocked down" trusses spanning the caissons, two anchor columns, one floorbeam connecting these columns, and four large anchor bolts for each side of the river. The cofferdam bracing was designed so as to avoid interfering with the erection of these substructure trusses. The pieces were all handled by the derrick, being fastened together with turned bolts. These trusses were set in place before any part of the main piers was concreted. When the concrete reached the proper height the anchor columns and floorbeam were set, particular care being taken to set them accurately.

Table XXI gives the labor costs of handling and setting the substructure steel.

TABLE XXI.—LABOR COSTS OF PLACING SUBSTRUCTURE STEEL

Item	Total hrs.	Rate, cts. per hr.	Total cost	—Per ton— Hrs.	Cost
Handling steel from cars to site	177	..	$ 93.76	1.7	$ 0.92
Bolting and erecting	1,154	..	803.83	11.3	7.90
Total	1,331	..	$ 897.59	13.0	$ 8.80
Prorated charge	133	..	73.78	....	......
Total	1,464	..	$ 971.37	....	......
Superintendence, etc., 12.1 per cent	177.1	..	117.54	....	......
Grand total	1,641.1	67	$1,088.91	16.0	$10.65

Note.—Derrick and derrick scow were used about 10 days each.

"*R*"—*Furnishing and Erecting Structural Steel.*—The price bid for furnishing and erecting structural steel was 2.5 cts. per pound. The quantity placed was 9,136 lbs.

This steel was principally chains for the pile clumps, and the work was so closely allied to the pile driving that its labor cost was merged with the cost of pile driving.

"*S*"—*Diverting and Extending Sewer.*—The price bid for diverting and extending the 5-ft. sewer (two-ring brick construction), including excavation, was $9.60 per linear foot.

As the sewers on each side of the river were located in the center of the street, it was necessary to make a temporary diversion to the side while construction was being carried on. The above price, $9.60 per linear foot, included the connection from the original sewers to the new outlets. The cost of the temporary diversion was included in item "C." On the west side of the river 50.1 ft. of new sewer were built, and on the east side 19.5 ft. were constructed. Practically all of this construction was on a curve and through a 15-ft. cut. The cost of this work is given in Table XXII.

TABLE XXII.—LABOR COST OF CONSTRUCTING 5-FT. SEWER

Item	Total hrs.	Rate, cts. per hr.	Total cost	Per linear ft. Hrs.	Cost
Excavating in clay, bracing trench, pumping, laying 2-ring, 5-ft. sewer, and backfilling	1,498	52.5	$787.41	22	$11.31
Superintendence, etc., 12.1 per cent	181.3	....	95.28	..	......
Total	1,679.3	52.5	$882.69	24	$12.70

"U"—Concrete Shafts Below Elevation −45.—The price bid for completed concrete shafts below elevation −45 was 47½ cts. per cubic foot. This price included the cost of excavation, removal of water, removal of boulders of less than 20 cu. ft. each, furnishing and placing all lagging and iron or steel rings, and all equipment for doing this work. This price did not include reinforcing bars. The total quantity of concrete placed was 14,601 cu. ft., the concrete being a 1:3:5 mix.

The part included in this item is the circular portion of the shaft foundation, the river pier and the anchor pier cylinders being 8 ft. and 7 ft. in diameter, respectively. These diameters were adhered to as closely as possible. The material down to elevation −60 could be removed with shovels; but from this elevation to bed-rock, at an average elevation of −81, it first had to be loosened with grubs. The clay overlying the rock was impregnated with gravel and small boulders, and directly above the rock there was a thin layer black sand, slightly water-bearing. The excavated material was disposed of in the same manner as in the upper part of the shaft, tripods and windlasses being first tried only to be discarded for the derrick, which hoisted the material from the four caissons. The lagging used was 3 × 6-in. tongue-and-groove lumber, in 3-ft. and 6-ft. lengths. The lagging was held in place by ¾-in. by 4 and 5-in. iron rings spaced about 3 ft. apart.

Table XXIII gives the labor costs for constructing the concrete shaft foundations below elevation −45.

TABLE XXIII.—LABOR COSTS OF CONCRETE SHAFTS BELOW ELEVATION −45

Item	Total hrs.	Rate, cts. per hr.	Total cost	Per cu. yd.* Hrs.	Per cu. yd.* Cost
Excavation					
Setting windlasses and building material platforms	483	..	$ 200.31	.....	.....
Excavating caissons from El. −45 to rock	5,250	50	2,644.10	9.7	$4.90
Prorated charge	533	..	291.02	.....	.....
Total	6,266	50	$3,135.43	11.6	$5.80
Superintendence, etc., 12.1 per cent	758.2	..	379.39	.....	.....
Grand total	7,024.2	50	$3,514.82	13.0	$6.50
Concreting					
Concrete shafts below El. −45	1,168.4	47	$ 544.37	2.16	$1.00
Prorated charge	408	..	206.62	.....	.....
Total	1,576.4	48	$ 750.99	2.92	$1.38
Superintendence, etc., 12.1 per cent	190.7	..	90.87	.....	.....
Grand total	1,767.1	47	$ 841.86	3.27	$1.55
Grand total, excavating and concreting	8,791.3	50	$4,356.68	16.27	$8.05

* Per cubic foot; 0.6 hrs.; $0.30.

Cost of Abutment Masonry and Slope Paving for Highway Bridge Foundations Illinois and Mississippi Canal.—The following matter, compiled from data collected by Fred W. Honens, U. S. Engineer's Office, Kansas City, Mo., is given in Engineering and Contracting, April 20, 1910.

To carry highways across the Illinois & Mississippi Canal required 67 bridges. Except for one swing bridge, three lift bridges and two special bridges at locks, these bridges are fixed truss bridges on concrete abutments. Three types of structure were employed.

1. On the eastern section generally the abutments were U shaped and the superstructures were pony Warren trusses of 100-ft. spans and 14-ft. clear roadway.

2. On the western section generally the abutments were wing abutments and the superstructures were 110-ft. Pratt trusses. The wing abutments were 23 ft. long and 16 ft. high, with 18-ft. wings at an angle of 30°.

3. On the feeder canal a three-span structure carried on straight abutments and two-tower piers was employed. The main 75-ft. spans were pony Pratt trusses and the two approaches were stringer spans of 21 ft.

On the main canal the bridges had a clearance of 17 ft. over the water. On the feeder canal the clearance was reduced to 12 ft. The following data relate to the structures used on the western section of the main canal.

The wing abutments contain for each bridge (two abutments) 190 cu. yds. of natural cement concrete in the footings and 248 cu. yds. of Portland cement concrete in the abutments proper. The parapets are oak timbers 12 ins. wide and 22 ft. long. The slopes of the canal in front of each abutment for a distance of from 60 to 120 ft. are paved with hand laid rubble for the first bridges built and with concrete about 10 ins. thick for the bridges built later.

The steel superstructures were designed to carry a live load of 100 lbs. per sq. ft. or an engine load of 8 tons on axles 7 ft. c. to c. The trusses are 110-ft. spans, 20 ft. high and spaced 19 ft. 1 in. c. to c., having a clearance of 16½ ft. between guards. These guards are 6 × 8 in. pine raised 3 ins. above the floor and having on the wearing side 3 × 3 × ¼-in. angles.

The embankment approaches are 21 ft. wide on top, with side slopes of 1 on 1½ and with grades running from 3 to 6 per cent. The roadways are surfaced with gravel or crushed rock and have board railings extending from bridges to foot of slope.

The costs given here relate to the substructure, that is, the concrete abutments and footings and the adjacent slope paving. The forms for the abutments were simple, consisting of opposite posts tied through the walls at bottom and mid height with bolts and at the top above the wall with 3 × 12-in. plank with short knee braces. The concrete was mixed in a Smith mixer charged by one-horse dump carts and was hauled to the work in cars and hoisted by horse elevator and dumped into the forms.

The following is the detailed cost of the substructure for highway bridge No. 34. Excavation and back fill cost as follows:

	Total	Per cu. yd.
Excavation (576.6 cu. yds.):		
Labor	$ 151.52	......
Stakes	3.00	......
Total	$ 154.52	$0.268
Back fill (256.4 cu. yds.):		
Labor	$ 55.88	$0.220

There were 190 cu. yds. of natural cement concrete in the footings which cost as follows:

	Total	Per cu. yd.
Concrete Materials:		
Cement	$ 208.80	$1.099
Crushed stone	289.02	1.521
Sand	113.00	0.594
Total	$ 610.82	$3.214

Receiving Concrete Materials:		
Hauling cement	$ 23.50	$0.214
Unloading cement	2.65	0.014
Hauling crushed stone	94.98	0.499
Freight on gravel	7.50	0.039
Total	$ 128.58	$0.676
Labor mixing and placing	218.39	1.149
Grand total	$ 955.79	$5.039
Form Materials:		
Lumber	$ 28.50	$0.150
Stakes	3.00	0.016
Hardware	1.65	0.008
Total	$ 33.15	$0.174
Form Labor:		
Hauling and unloading lumber	$ 3.70	$0.019
Labor constructing	17.16	0.090
Labor wrecking	2.00	0.011
Total	$ 22.86	$0.120
Grand total	56.01	0.294
Miscellaneous:		
Labor receiving materials	$ 15.48	$0.081
Miscellaneous labor	8.72	0.046
Total	$ 24.20	$0.127
Grand total	1,038.00	5.460

The cost of 248 cu. yds. of Portland cement concrete in the abutments proper was as follows:

	Total	Per cu. yd.
Concrete Materials:		
Cement	$ 496.32	$2.001
Crushed stone	378.00	1.524
Sand	135.52	0.546
Total	$1,009.84	$4.071
Receiving Concrete Materials:		
Hauling cement	$ 23.87	$0.096
Unloading cement	3.40	0.013
Testing cement	29.50	0.118
Hauling crushed stone	114.78	0.462
Freight on gravel	9.50	0.038
Total	$ 181.05	$0.727
Concrete labor	265.67	1.071
Running mixer labor	22.00	0.081
Total	$ 287.67	$1.152
Grand total	$1,478.56	$5,952
Form Materials:		
Lumber	$ 59.50	$0.239
Hardware	11.35	0.045
Total	$ 70.58	$0.284
Form Labor:		
Hauling and unloading lumber	$ 50.82	$0.205
Labor constructing	119.86	0.483
Labor wrecking	15.75	0.063
Total	$ 186.43	$0.751
Grand total, forms	257.28	1.035

Miscellaneous:		
Labor receiving materials	$ 19.39	$0.078
Miscellaneous labor	15.42	0.062
Coal	19.19	0.076
Total	$54.00	$0.216
Grand total	$1,789.84	$7.217

The cost of 313 sq. yds. of rubble stone paving was as follows:

Item	Total	Per sq. yd.
Rubble stone	$406.78	$1.299
Hauling rubble stone	83.44	0.266
Labor paving	180.32	0.576
Labor receiving material	13.94	0.044
Miscellaneous labor	7.86	0.025
Total	$692.34	$2.210

The following expenses were charged against the whole work:

Engineering and inspection	$153.43
Traveling	4.08
Chicago office expenses	69.84
Total	$227.35

The grand total cost of the whole work was $3,957.93.

The work described was done by day labor and the wages paid were about as follows:

Carpenters, per day	$2.50
Laborers, per day	1.75
Teamsters with team	3.00

An 8-hour day was worked.

In Table XXIV are given the masonry and slope paving costs of 20 other bridges of the same type as that described.

TABLE XXIV.

	National cement, concrete		Portland cement, concrete		Slope paving	
No. of bridge	No. cu. yds.	Per cu. yd.	No. cu. yds.	Per cu. yd.	No. sq. yds.	Per sq. yd.
17A	200	$7.10	248	$8.97	...	....
18A	200	6.20	248	8.64	...	....
20	234	5.99	248	8.24	...	....
21	252	6.54	248	8.73	340	$2.04
22	304	6.39	248	8.86	...	....
23	200	5.38	248	7.52	340	1.95
24	156	6.31	248	7.93	340	1.82
25	190	5.85	248	7.59	340	2.39
26	201	5.66	248	8.21	340	2.32
27	156	6.05	248	7.71	348	1.94
28	190	5.41	248	7.94	343	1.92
29	156	5.93	248	7.39	339	1.94
30	156	5.89	248	8.21	339	1.92
31	190	5.18	248	7.40	313	1.94
32	190	5.62	248	7.83	313	2.28
33	200	5.90	248	8.12	313	2.20
35	190	5.11	248	6.96	304	2.31
37	190	4.98	248	7.21	345	1.91
38	133	6.32	248	7.07	276	2.63
39	...	....	248	7.05	270	2.36

Cost of Dismantling an Old Highway Bridge and Erecting New Truss and Girder Spans.—George Harper gives the following data in Engineering and Contracting, Dec. 24, 1913.

The following data apply to the dismantling of an old highway steel truss bridge, with roadway and sidewalks, and to the erection in its place of a new structure with a 60-ft. roadway and an 8-ft. sidewalk. The new bridge consists of a deck truss span over the Mahoning River and two through girder spans over six railroad tracks of three different trunk lines, at Youngstown, Ohio. The work was done in 1910.

The span across the river has a length of about 180 ft. and that across the railroad tracks has a length of about 84 ft. The old structure was used by the sub-contractor as falsework during the erection of the new bridge; and as it was taken down after the completion of the connection, its weight is included in the tonnage given in Table I, being about 35 per cent of the total for this span. The dismantling and removal of it cost about 35 per cent of the total cost shown in the table for the river span.

The sub-contractor for the work was a first-class bridgeman, who took personal charge of the work and who had gathered an efficient crew of skilled men. He was, however, subjected to many delays, which were due to no fault of his and which served seriously to hinder the progress of the work.

The weight of steel in the two girder spans over the railroad tracks is about 198 tons. The erection cost for these spans is higher than that for the river span, as it was necessary to use a Lucius erector to set them. One span was set in about five minutes and the other in about eight minutes, without any delay to traffic.

The total erection cost of $8,136, shown in Table XXV, was within three per cent of the actual erection and other costs to the sub-contractor. The painting of the structure, the railing, roadway paving, and the cement sidewalks were let under separate contracts. The data shown in the table are only for the dismantling of the old highway bridge, the erection of the new structure, and the placing and riveting of the buckle plates for the roadway. The best type of hoisting engines and general apparatus were used on this work. The dismantling of the old structure was hindered somewhat and the cost of the

TABLE XXV.—DATA ON DISMANTLING OLD TRUSS BRIDGE AND ERECTING NEW SPANS

	Time, days	Rate per day	Labor cost	Total* cost	Cost per ton (560 tons†)	Erection cost per ton on girder spans (198 tons)
River span						
Foreman	77½	$ 6.00	$ 465	$ 535	$ 0.96	.....
Bridgemen and laborers	890	4.50	4,005	4,606	8.22	.....
Stationary engineers	68	4.50	306	352	0.63	.....
Watchmen	51	2.50	128	147	0.26	.....
Total	.....	.....	.....	$5,640	$10.07	.....
Spans Over Railroad Tracks						
Foreman	35	$ 6.00	$ 210	$ 242	.....	$ 1.22
Bridgemen and laborers	273	4.50	1,229	1,413	.....	7.14
Engineers	7	4.50	31	36	.....	0.18
Watchmen	19	2.50	48	55	.....	0.28
Lucius erector	3	250.00	750	750	.....	3.78
Total	.....	.....	.....	$2,496	.....	$12.60
Grand total	.....	.....	.....	8,136	.....	.....

* Total cost is made up of labor cost plus 15 per cent to cover plant cost.
† The 560 tons consisted of 374 tons of new steel erected and 186 tons of old steel taken down and used as falsework.

work was increased due to the difficulty of removing the old piers, which were in bad condition. The time required, the rate of wage, and the cost of the work, exclusive of materials, are shown in Table XXV.

The work on the river span was done during May and August and that on the span over the railroad tracks during October and November, 1910.

Cost of Erecting the St. Paul, Neb., State Aid Bridge.—Geo. K. Leonard gives the following data in Engineering and Contracting, Feb. 28, 1917.

The contract for this bridge was let in September, 1915. It is located one mile from the town of St. Paul, Neb., and extends over the Middle Loup River. The right of way adjoins that of the Union Pacific R. R. and the same length of spans was used so that the piers in the two bridges would fall in the same line. The entire bed of the river at this point is composed of fine sand with

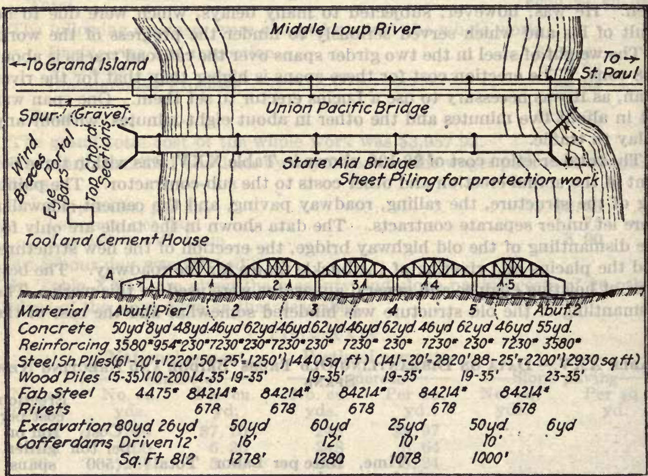


FIG. 7.—General layout of St. Paul, Neb., state aid bridge and material quantities involved.

some gravel too deep to excavate economically for concrete. During the summer the river is practically dry with the exception of one channel under Span No. 5. The general layout of the structure is shown in Fig. 1. The material quantities also are shown in this cut.

The superstructure is composed of five 8-panel 145-ft. pin-connected curved chord trusses and one 20-ft. I-beam span, all with a 16-ft. roadway, carrying a 6-in. concrete floor. It was designed to carry a live load of 75 lb. per square foot, or a 15-ton traction engine.

The substructure includes five mass concrete piers and two reinforced concrete abutments resting on 35-ft. cypress piles. A row of 7-in. Lackawanna steel sheet piling 20 ft. long is driven under the whole length of each abutment and adjoining these on Abutment No. 2 additional piling are driven for protecting the approach. The concrete extends to a depth of 3 ft. below the low water level and the piles are embedded in the footings 2 ft.

At the start of the work the contractor made arrangements with the Union Pacific R. R. for the construction of a spur to the end of the highway bridge. All material with the exception of the form lumber, which was hauled from St. Paul, was delivered to the bridge site on this spur. The cost of the spur was charged to the various materials according to their tonnage as follows:

Material	Amount	Tonnage	Amount charged
Steel Sheet piles	7,490 lin. ft.	47.00	$ 15.32
Wood piles	4,330 lin. ft.	64.95	21.25
Falsework piles	4,315 lin. ft.	64.73	21.20
Cement	977 bbls.	195.40	64.00
Gravel		1,096.00	358.60
Reinforcing steel		22.71	7.43
Fabricated steel		212.77	69.60
Coal		166.20	54.40
Plant		25.00	8.20
Total tonnage		1,894.76	
Total cost spur			$620.00

Total cost spur ton of material 32.7 cts.

These amounts which are charged to the material from the spur will hereafter be charged to hauling, since the spur did away with the hauling costs.

Labor Organization.—The labor organization was as follows:

	Per hour, cents
Pile driving:	
1 foreman	40
1 engineer	40
1 niggerhead man	35
1 fireman	30
1 jet man	30
3 laborers	30
Concrete:	
1 mixer man	35
5 cart pushers	30
2 tampers	35
1 cement man	30
4 gravel wheelers	25
Steel erection:	
1 foreman	40
1 engineer	40
1 niggerhead man	35
1 fireman	30
2 laborers	40
2 laborers	35
4 laborers	30
Riveting (two gangs):	
1 foreman	42½
1 compressor man	35
1 fireman	30
2 rivet heaters	42½
1 gun man	42½
1 gun man	40
2 buckers	35
2 rivet catchers	35
2 fitting-up men	35
1 supply man	25
General foreman	45
Night watchman	20
Water boy	15

Plant.—Piles were driven and a platform built from the spur to the end of the bridge. On this the plant was erected and part of the material unloaded. For the pile driving a traveler carrying a stiff-leg derrick and a steam hoisting engine, operating a 1,600-lb. hammer in swinging leads, was used. A small jet pump assisted greatly in all the pile driving.

The cofferdam at Pier No. 1 was first driven, using the sheet piling, which were afterward driven under the abutments. The excavation was done with an orange-peel after which the wood piles were driven. Next the falsework of Span No. 1 was driven, the floor beams being placed on each successive bent and enough joists to carry the traveler bolted to the beams. The work progressed in like manner across the bridge.

Concreting followed the pile driving and after the footings were poured the traveler returned and pulled the cofferdam.

In Abutment No. 2 the sheet piling served for both cofferdam, and forms around the face and wood forms had to be sunk around the rear. Abutment No. 1 was finished last.

At the start a ¼-yd. mixer was used, being run by a gas engine. Later a steam engine and boiler were used. In mixing for Piers Nos. 1 and 2 the mixer was set over the forms, but it was then moved to the end of the bridge and the rest of the concrete was mixed there and hauled to the forms in Koppel cars.

The cost of the plant and its distribution is as follows:

Making working platform	$ 85.00
Making tool and cement house	30.00
Unloading and erecting derrick	88.00
Erecting and moving concrete plant	164.90
Repairs on derrick	194.89
Wrecking and loading out plant	178.75
Hauling	8.20
Total	$749.74

This was charged to the various branches of the work according to the time spent on same. If the unit costs are desired without the plant included it is very easily found.

Following is the distribution of the plant cost to the various branches:

Kind of work		Repairs	Total charged
Driving falsework	$ 53.52	$ 27.35	$ 80.87
Driving sheet piling	12.05	....	12.05
Driving wood piling	165.56	80.47	246.03
Driving cofferdam piling	74.00	78.32	152.32
Steel erection	84.82	8.75	93.57
Concreting	164.90	....	164.90
Totaling	$554.85	$194.89	$749.74

Coal:	Cost per ton	Total cost
166.2 tons	$6.43	$1,068.66
Unloading	.185	30.74
Hauling	3.27	54.40
Total	$6.942	$1,153.80

Construction Costs

SUPERSTRUCTURE

Falsework:	
Labor driving	$ 711.55
Labor removing	112.15
Coal (18 tons)	125.00
Plant	80.87
Total	$1,029.57
Cost per span	205.91
Cost per lin. ft. bridge	1.42
Cost per ton steel	4.90

These units include laying floor beams and enough joists to carry the traveler.

Erecting (excluding approach):	
Labor erecting	$ 936.85
Coal (28 tons)	194.20
Plant	93.57
Total	$1,224.62
Cost per span	244.92
Cost per lin. ft. bridge	1.69
Cost per ton steel	5.83
Labor erecting approach	5.40
Cost per ton	2.61

Riveting:

Labor riveting	$ 936.85
Setting compressor	88.88
Coal (16 tons)	111.00
Total	$1,136.73
Cost per span	227.34
Cost per ton steel	5.41
Cost per rivet	.330

Painting (one coat):

Labor painting	$ 233.96
Cost per span	46.79
Cost per ton steel	1.12

Falsework piles:

1,875 lin. ft. at 15 ct.	$ 281.25
140 lin. ft. at 15½ ct.	21.70
2,300 lin. ft. at 13½ ct.	310.50
Totaling 4,315 lin. ft.	$ 613.45
Hauling	21.20
Total	$ 634.65
Cost per span	126.94
Cost per lin. ft. bridge	.88
Cost per ton steel	2.98

Fabricated steel:	Cost per ton		Total cost	
Hauling	$ 0.327		$ 69.60	
Unloading	.623		131.97	
Total		$ 0.950		$ 201.57
161 ton trusses (est.)	$55.00		$8,855.00	
49.7 ton joist (est.)	39.00		1,938.30	
210.7 tons ft. (est.)	12.00		2,528.40	
Average		59.50		13,421.70
Total		$60.45		$13,623.27
Total per span				2,724.66
2.07 tons approach at $51.00				105.57

Paint (one coat):

110 gal. at $1.00	$110.00
Cost per span	22.00
Cost per ton steel	.518
Paint per ton	.518

Summary Superstructure

	Labor		Material		Total	
	Span	Ton	Span	Ton	Span	Ton
Falsework	$205.91	$ 4.90	$ 126.94	$ 2.98	$ 332.85	$ 7.88
Steel	244.92	5.83	2,724.66	60.45	2,969.58	66.28
Riveting	227.34	5.41	....	......	227.34	5.41
Painting	46.79	1.12	22.00	.52	68.79	1.64
Total	$724.96	$17.26	$2,873.60	$63.95	$3,598.56	$81.21
Total cost of five spans					$17,992.80	
Total cost of approach					110.91	
Total cost of superstructure					18,103.71	

SUBSTRUCTURE

Wood piles (top of piles driven 12 in. below low water):

	Per lin. ft.	Per pile	Total
Labor pointing and carrying to position	$0.0313	$ 1.059	$ 135.61
Labor driving	.1159	3.925	502.31
Coal (56 tons)	.0897	3.035	388.50
Plant	.0569	1.908	246.03
Hauling	.0049	.166	21.25
Total	$0.2987	$10.093	$1,293.70
4,330 lin. ft. piling	.155	5.42	671.15
Total cost piling	$0.4537	$15.513	$1,964.85

Steel sheet piles (top of piles driven to water line):

	Per sq. ft.	Per lin. ft.	Per pile	Total
Labor carrying to position	$0.01762	$0.01014	$0.244	$ 75.95
Labor driving	.0835	.048	1.059	359.55
Coal (4 tons)	.00644	.00371	.082	27.76
Plant	.0028	.00161	.035	12.05
Hauling	.00356	.00204	.045	15.32
Total	$0.11392	$0.06550	$1.445	$ 490.63
Piling	.4618	.27	5.93	2,018.15
Total cost piling	$0.57572	$0.33550	$7.375	$2,508.78

Lumber:	
31.5 M ft. B. M	$861.55
Cost per yard concrete	1.35
Forms:	
Abutments—	
Labor placing	$333.99
Labor removing	36.90
Total	$370.89
Cost per yard concrete	3.53
Piers (including placing small amount of steel)—	
Labor placing	$279.74
Labor removing	55.00
Total	$334.74
Cost per yard concrete	1.13
Floor—	
Labor placing	$290.70
Labor removing	113.20
Total	$403.90
Cost per yard concrete	1.70

Cement:

	Per bbl.	Total cost
977 barrels	$1.80	$ 1,758.60
Unloading	.062	$ 60.37
Hauling	.065	64.00
Total	$1.927	$ 1,882.97
Barrels per yard (foundation)		1.45
Cost per yard concrete		$2.80
Barrels per yard (floor)		1.65
Cost per yard concrete		$3.18

Gravel:

	Per ton	Total cost
1,096 tons	$1.21	$1,327.02
Unloading	.157	171.53
Hauling	.327	358.60
Total	$1.694	$1,857.15
Tons per yard concrete		1.715
Cost per yard concrete		$2.90

Concrete:	
Plant	$ 164.90
Cost per yard concrete	.26
Foundations—	
Labor placing	$ 715.42
Coal (10 tons)	69.40
Gasoline (250 gal.)	53.13
Total	$ 837.95
Cost per yard concrete	2.09
Floor—	
Labor placing	$ 484.80
Coal (9.7 tons)	67.30
Total	$ 552.10
Cost per yard concrete	2.32
Cofferdams (5 piers only):	
Preparing site	$ 32.40
Driving piles	241.11
Pulling piles	575.22
Excavating	160.32
Plant	152.32
Coal (24.5 tons)	170.03
Total	$1,331.40
Cost per yard concrete	4.50

SUMMARY CONCRETE

	Abutments		Piers		Floor	
	Total	Per yd.	Total	Per yd.	Total	Per yd.
Lumber	$ 141.35	$ 1.35	$ 399.10	$ 1.35	$ 321.10	$ 1.35
Forms	370.89	3.53	334.74	1.13	403.90	1.70
Cement	294.00	2.80	829.80	2.80	759.17	3.18
Gravel	304.50	2.90	858.40	2.90	694.25	2.90
Mixing	246.55	2.35	694.90	2.35	613.50	2.58
Cofferdams	......	.....	1,331.40	4.50	....	.....
Total	$1,357.29	$12.93	$4,448.34	$15.03	$2,791.92	$11.71
Total charged to concrete						$8,597.55

REINFORCING

	Per ton	Total cost
45,410 lb.	$60.00	$ 1,362.30
Unloading	.382	8.67
Hauling	.327	7.43
Total	$60,709	$ 1,378.40
Placing in abutments		19.28
Cost per ton		8.55
Placing in floor		90.60
Cost per ton		6.74

SUMMARY SUBSTRUCTURE

Wood piles	$ 1,964.85
Steel sheet piles	2,508.78
Concrete	8,597.55
Reinforcing	1,488.28
Total	$14,559.46

TOTAL COST OF BRIDGE

Superstructure	$18,103.71
Substructure	14,559.46
Miscellaneous material	535.00
General foreman	810.00
Night watchman	260.00
Water boy	47.75
Total	$34,315.92

Cost of a Steel Highway Bridge in Texas.—William C. Davidson gives the following costs in Engineering and Contracting, Oct. 25, 1916.

The bridge was built in McLennan County, Texas, about 10 miles from Waco. It spans Aquilla Creek, one of the larger tributary streams of the Brazos River. The structure has a total length of 273 ft., consisting of 120 ft. of main span and 153 ft of timber trestle approaches.

The work was handled under direct supervision of the county engineer. An experienced steel bridge foreman was employed to superintend the construction work, which was in direct charge of the writer as assistant engineer. Foundation excavation was commenced about July 1, 1915, and two months later the road and bridge were opened to traffic. To obtain a more direct alignment the site of the new bridge was moved several feet upstream from the site of the old structure.

Labor for handling the work was obtained locally with the exception of a form-builder who was obtained from Waco. Common labor was obtained at $1.50 to $1.75 per day of eight hours each. The form builder was paid at the rate of $3 per day. Practically all the hauling was done under contract. Miscellaneous teaming was paid for at the rate of $0.40 per hour. The foreman was employed at $4 per day straight time, no overtime being allowed for more than an eight-hour day. Laborers were paid overtime for all work exceeding eight hours per day. It was necessary to haul a part of the material, such as form lumber, tools, equipment for camp outfit and other miscellaneous supplies, from Waco. This teaming was done by one of the county maintenance outfits, at a cost of $3 per day.

The nearest railroad spur was situated a distance of five miles from the site of the bridge. Cement, structural steel, bridge lumber, piling and wood preserver for treating certain portions of the wood work, were shipped to this point. The hauling of this material to the site was contracted to a local teamster at the following prices: Cement, 6⅔ ct. per sack; bridge lumber, 25 ct. per 100 ft. B. M.; structural steel, $1 per ton. The piling and wood preserver were hauled to the site at a cost of $0.40 per hour for man and team. Gravel for the pile footings and concrete piers was also hauled under contract, from local pits situated two and five miles from the site, respectively. From the pit located two miles distant, 130 cu. yd. were obtained at a cost of $0.50 per yard for the hauling and $0.10 per yard for the gravel. Added to the above cost was that of stripping the pit which amounted to $0.11 per yard, making a total cost per yard at the site of $0.71. Owing to the fact that the above pit would not supply sufficient gravel to construct the piers and footings, it became necessary to haul 39½ cu. yd. from another local pit situated five miles from the site. This gravel was contracted at $1.15 per cubic yard for loading and hauling and $0.10 per cubic yard for the gravel, making a total cost at the site of $1.25 per cubic yard. No stripping was necessary at this pit. Tickets were issued to the teamsters by the foreman for each load of gravel as it was received at the site, and payment was made upon the basis of these tickets, The invoices of the material companies were taken as the basis of payment for the haul of cement, steel and lumber.

The concrete used in the construction of the piers was mixed in the proportion of one part of cement to six parts of pit run gravel. A form finish was given the outer surface of the piers. Vertical and horizontal reinforcing rods were used as shown on the pier detail. The steel was designed for what was designated in the standard specifications as a "Class B Loading." This consisted of a load of 80 lb. per square foot of total floor surface, being the equivalent of a 10-ton traction engine having axles 8 ft. on centers and a 6-ft. gage, two-thirds of the load to be carried on the rear axles and distributed over 12 ft. in width.

The following is an itemized statement of the cost of the bridge, including all material and labor:

Material:	
Structural steel, f. o. b. cars at factory, 42,770 lb. @ \$3.14 per 100 lb.	\$1,325.87
Freight on steel, 42,770 lb. @ 55c per 100 lb.	235.24
Bridge lumber, 25,335 ft. B. M.	426.56
Cement, 425 sacks @ 32c per sack net	178.50
Reinforcing steel, 4,455 lb. @ \$2.75 per 100 lb.	122.51
Form lumber, 3,900 ft. B. M.	104.39
Piling, 454 lin. ft. @ 7½c per foot	34.05
Nails, 2 kegs 60d and 1 keg 6d	7.85
2 rolls, No. 9 wire for forms	4.90
Gravel, 169½ cu. yd. @ 10c	16.95
Paint, 14 gal. @ \$1.95	27.30
Linseed oil, 4 gal. @ 85c	3.40
Machine bolts	19.64
Misc. tools and hardware	29.98
Paint brushes	1.15
Wood preserver	5.00
Total	\$2,643.29
Labor:	
Clearing of bridge site	\$ 8.90
Foundation excavation	57.35
Mixing and placing concrete	78.40
Building of forms	165.05
Removal of forms	16.75
Hauling form lumber	12.00
Hauling cement, 425 sacks @ 6⅔c	28.33
Hauling gravel, 169½ cu. yd. (130 cu. yd. @ 50c, 39½ cu. yd. @ \$1.15)	110.43
Hauling reinforcing steel	8.00
Extra cutting of steel	.75
Hauling bridge lumber	65.42
Erection of steel, including decking of main span and approaches	207.20
Construction and removal of false work	51.50
Building approaches (not decking)	42.55
Painting steel span (one coat)	14.90
Rent on storage house	3.00
Miscellaneous hauling:	
Moving concrete mixer from R. R. to site	2.00
Stripping gravel pits	14.80
Hauling cement from storage house to site	3.60
Hauling piling from R. R. to site	8.00
Unloading piling at R. R.	4.80
Unloading bridge lumber at R. R.	3.75
Moving lumber at bridge	.40
Foreman's time (60 days @ \$4.00 per day)	240.00
Structural steel workman (connecting span)	25.00
Total	\$1,172.68
Cost of material	2,643.29
Grand total cost, material and labor	\$3,815.97

Unit Costs.—On the basis of the foregoing cost data, unit costs on the several items of material have been computed. The foundation excavation was entirely pick and shovel work and consisted of alluvial deposits and a firm clay. The depth of the excavation was 12 ft. and a double handling of material was required near the bottom of the piers. There was a total of 85.7 cu. yd. of material taken from both piers, at a total cost of \$57.35 or a unit cost of $0.67. Mixing and placing of concrete cost $78.30. The total cubic yardage of concrete in the piers and pile footings amounted to 125.7, from which is deduced a cost of $0.62 per cubic yard. Water used in mixing the concrete was obtained from the creek at the site by means of a hand pump. It was pumped into barrels to an elavation of about 20 ft. above the creek, from which it was conveyed by means of buckets to the mixer. The piers were poured to an elevation slightly above the ground, then the approaches were built and the mixer placed upon them, from which the remainder was poured without difficulty.

The piers being of rather unusual design, involved expensive form work from the standpoint of labor, the total cost being $165.05, or a unit cost per yard of concrete, of $1.33. The lumber, wire, nails, removal of forms and the hauling of form lumber amounted to $140.79, with a resultant unit cost for material of $1.12 per cubic yard. Therefore the total unit cost for forms was $2.45 per cubic yard, which is somewhat higher than is to be expected for form work on piers.

The total cost of the cement at the site, including first cost, hauling and storage, was $215.43, from which it is estimated that the cost for cement per cubic yard of concrete amounts to $1.70. The concrete gravel cost at the site $142.18, including first cost, hauling and stripping of pits. This results in a unit cost of $1.13 per cubic yard. The cost of water for the concrete was included in the item "mixing and placing" and the cost of placing reinforcing steel was not separated from that of building forms. From the foregoing a summary of cost per cubic yard of concrete is as follows:

Cement	$1.70
Gravel	1.13
Forms	2.45
Mixing and placing	.62
Supplies for mixer	.02
Foreman	.38
Total	$6.30

The bridge was erected at a total cost for labor on superstructure and false work of $258.50, which cost included the erection of steel and the decking of main span and approaches. A cost of $0.95 per linear foot of bridge is deduced from the foregoing. It required material amounting to $31.85 to paint the steel work, with a corresponding cost per ton of steel of $1.49. Labor required amounted to $14.90 or a cost per ton of steel of $0.70. The total cost, therefore, per ton of steel for labor and material was $2.19.

Unit Costs of Constructing Plate-Girder Bridges with Concrete Substructures in Chicago.—The following data are taken from an article in Engineering News, Aug. 27, 1914, by Harry J. McDargh.

In erecting seven plate girder bridges on west fork of the North Branch of the Chicago River the work was carried out by the use of day labor. The field organization consisted of an engineer (Mr. McDargh) acting as general superintendent; an instrument man as time-keeper and material clerk; a foreman of carpenters, cement mixers and laborers and in charge of substructure construction, and a foreman of bridge and structural-iron workers in charge of erection of the superstructure. The rates of wages (union scale) were as follows:

Foremen	80 cts. per hour.
Engineman (for hoisting)	72½ cts. per hour.
Carpenters	65 cts. per hour.
Laborers	40 cts. per hour.

Material costs under contracts made by the city were as follows:

Material:	Cost
Cement	$ 1.20 per bbl. net.
Torpedo sand	1.70 per cu. yd.
Stone and gravel	1.65 per cu. yd.
Lumber (average)	$29.00 per M. ft. B. M.
Superstructure steel	2.61 cts. per lb.

The plant consisted of a 10-ton stiff-leg derrick with a 42-ft. boom, a 16-hp. steam-hoisting engine, four 1-yd. self-dumping steel buckets, a steam pump, a gasoline-driven concrete mixer of 8-ft. batch capacity, and the other necessary smaller equipment.

The superstructure design is shown in Fig. 8. The main girders are 75 ft. 8 in. long, with the floor system designed to carry the heaviest city traffic. The roadway is 24 ft. between curbs, paved with 4-in. creosoted-wood blocks on 2-in. creosoted subplanking laid tight on 4 × 6-in. creosoted sleepers spaced 9 in. c. to c. The two 8-ft. walks are of reinforced-concrete flat-slab construction. The sidewalk railing on the bridge is of ornamental iron construction, and joins the concrete parapet walls carried on the wing walls of the substructure.

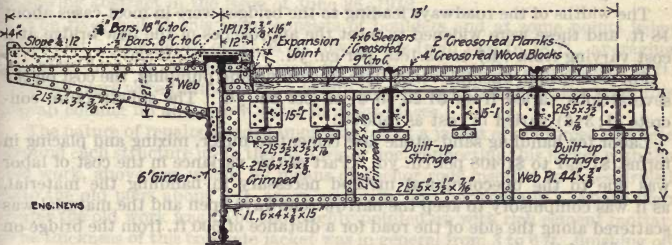


FIG. 8.—Half cross-section of plate-girder bridges over the west fork of the North Branch of the Chicago River.

The wing walls of the substructure end in a circular return and come to within 2 ft. of the property line. All streets are 66 ft. wide. The esthetic treatment of both the substructure and superstructure was recommended by the Chicago Plan Commission, and the resulting structure is quite effective in appearance. Excavation for the substructure was made through loam. gravel and stiff blue clay to a depth of at least 8½ ft. below low water to allow for a possible future dredging of this stream.

The average depth of excavation was 26 ft. below the curb grade, and each pit was sheathed tight to blue clay, due to the water-bearing gravel and the proximity to the river. No extraordinary conditions were encountered. Excavation of the blue clay was laborious, however, as it could only be loosened in small chunks by the use of mattocks. Keeping the clay water-soaked was found advisable.

Cost and Progress of Work.—The substructures at N. 40th Ave. and N. 48th Ave. were started during the fall of 1912, but all work was suspended before the end of the year. Work was again started May 9, 1913, and three other substructures (at Central Park Ave., Kedzie Ave. and 56th Ave.) were completed during the year. The substructure at Forest Glen Ave. was 90 per cent completed on Dec. 31, and was entirely completed Jan. 29, 1914.

The superstructure steel for N. 40th Ave. was delivered on the site July 2, the erection completed Aug. 12 and the roadway opened to traffic Sept 1. Erection of 48th Ave. superstructure was started July 31, completed Sept. 3, and the roadway opened to traffic on Oct. 1.

The next superstructure steel arrived Oct. 21, and was erected at Central Park Ave. and this bridge opened to traffic on Dec. 20.

The steel for the Kedzie Ave. superstructure arrived on Dec. 4, erection was completed Dec. 27, and the roadway opened to traffic Feb. 14, 1914. Erection of the superstructure at 56th Ave. was started Dec. 29, completed Jan. 28, and the roadway opened to traffic Feb. 26. At Forest Glen Ave. the delivery of the steel was started Feb. 9, but was tied up until Feb. 20 by a strike on the company furnishing the material. Erection was completed Mar. 12, and the roadway opened to traffic on Apr. 7, 1914.

The erection of the steelwork was done without the aid of power machinery and all riveting was by hand. The cost varied from 0.75 to 0.77c. per lb.

The creosoted wood-block pavement with sub-planking and sleepers cost for material $4 per sq. yd.; the labor for placing averaged 81½c per sq. yd. for roadways without car tracks and $1.40 on the roadway with car tracks.

The widths of the roadways leading to the bridges were in most cases about 18 ft. and these were widened to meet the approaches of the new bridge at a cost varying from 74.7 to 95.1cts. per cu. yd.

For excavation, backfill, coffer-dam, sheathing and pumping, the cost on the several jobs varied from $1.23 to $1.55 per cu. yd. The substructure concrete (1:3:6) varied in cost as follows:

Labor for handling sand, stone and cement to mixer, mixing and placing in forms, $1.291 to $1.408 per cu. yd. Part of this variance in the cost of labor was due to the uneconomical method necessary in handling the material, as it was compulsory to keep the narrow roadways open and the material was scattered along the side of the road for a distance of 600 ft. from the bridge on each side of the river.

Material cost $3.778 to $4.558 per cu. yd. of concrete. This variance was due to difference in length of haul for delivery.

Forms, including labor and material, cost $1.580 to $1.986 per cu. yd. of concrete.

Cost of Moving Small Highway Bridge in Chicago.—In replacing a bridge at Kedzie Ave. over the west fork of the North Branch of the Chicago River in 1914, it was decided that the bridge could be moved to Foster Ave., an unimportant thoroughfare, and that it would serve 10 yrs. or more at this, its third place of usefulness. Harry J. McDargh in Engineering News, Aug. 27, 1914 gives the cost of moving the bridge as follows:

The old structure was a wrought-iron through-truss bridge, 63 ft. long and 36 ft. wide over all and weighed 35 tons. The truss while being "house moved" was carried on two sets of 12 × 12-in. timbers 6 ft. c. to c., placed symmetrically to the center of the bridge. Using wood rollers on a timber runway and a crab, the truss was moved 4,300 ft. and set upon bents for $383.50. The rates of wages (union scale) were as follows:

Foreman	80 cts. per hour
Carpenters	65 cts. per hour
Laborers	40 cts. per hour

Cost of 105-Ft. Strauss Bascule Bridge over the Sabine Neches Canal at Port Arthur, Texas.—According to Engineering Record, Aug. 19, 1916, this bridge was completed by the contractor in 1913 at a cost of $35,000, the steel being fabricated at Beaver Falls, Pa.

The main span of the bridge is 105 ft. center to center of channel piers; six-panel through riveted Warren trusses, 24 ft. apart on centers, provide a 21-ft. clear roadway and two 6-ft. clear sidewalks are carried on cantilever brackets. The roadway has 3-in. wooden planking supported on steel stringers and provides for a double-track electric street railway.

Cost of Jacketing with Concrete the Underwater Portions of a Bridge Substructure.—Three masonry piers and an abutment founded on stone-filled cribs were repaired in 1911 by building jackets of concrete around the underwater portions. The old piers had been in use some 65 years. The portions above low water were of squared granite laid in mortar probably of lime or a mixture of lime and natural cement. Below low water the piers were closely framed hewn pine cribs filled with field stone and were well preserved. The strengthening work was considered necessary to fit the piers to carry a steel superstructure being built to replace the original wood spans. The conditions encountered in this work and the method and cost of doing the work are described by E. E. Greenwood, engineer in charge, in the Proceedings, Maine Society of Civil Engineers, from which Engineering and Contracting, gives the following abstract in the issue of June 26, 1912.

The river bed at this point consists of boulders and at some points ledge crops out. The depth of water at low tide is from two to 18 ft., averaging about 12 or 14 ft. at the piers, and the ordinary rise of the tide is about 16 ft. The old piers were protected by a heavy riprap deposited about the base, this riprap coming up above low water in a few places.

The nature of repairs decided upon was to put a jacket of reinforced concrete around each structure up to the high water line, connecting this jacket with the old work, above low water, by means of anchor rods inserted in holes drilled into the old piers about 3 ft. apart vertically and horizontally. Above high water the old work was to be thoroughly pointed up with rich cement mortar. The thickness of this concrete jacket was in general from 3 to 6 ft., finishing off at the top two and one-half feet thick.

On account of the uncertainty of what we should have to contend with as the work should progress it was thought impracticable to make specifications under which a contractor could be expected to make a reasonable bid on the work, either by unit prices or a lump sum. It was therefore decided to do the work by the day under the supervision of a competent foreman.

The first step was to remove a large part of the old riprap about the piers and prepare a foundation for the concrete jacket. As a cofferdam of sufficient depth was impracticable it was decided to do this work with divers. Therefore two divers' outfits were organized and set to work, and the old riprap and debris were removed to such a depth as to secure a suitable foundation.

It was found that the old riprap was so closely packed that it was not necessary to go down to the old river bed in most places. The depth was generally from 3 to 10 ft. below low water, with some points deeper.

Our next step was to devise the most practicable method of building a form for the concrete, and it was decided to build a timber crib 8 ft. wide entirely around the pier, leaving the space between the crib and pier to correspond with the required thickness of concrete, which was generally about 6 ft. below low water.

This crib was built of 8 × 8-in. hemlock timber and divided into checks about 8 ft. square, each alternate check being floored over to contain rocks for sinking it. The crib was built up to 2 or 3 ft. above water at low tide, thus giving something on which to work while the tide was out to build the forms in the ordinary manner above that height. After the crib was grounded all the checks were filled with field stone and a quantity of the larger sized stones was deposited outside the crib as an extra precaution against scour. The inner side of the crib was then lined with vertical matched spruce plank driven as much as possible in the bed and all holes at the bottom thoroughly chinked by divers, thus giving an almost water-tight form for the concrete. The concrete was then deposited in the water, partly by means of the bottom dump bucket and partly by means of the flexible chute method, always endeavoring to deposit the mixture with the least possible wash. After reaching the height of low water the work was mostly done by working a few hours at a time while the tide was out. The concrete in general was a 1:2:4 mixture of Portland cement, sand and crushed rock. In the abutment where the work was all above water a 1:3:6 mixture was used. This piece constituted about one-sixth of the entire job. A Smith mixer of 1 cu. yd. capacity was used on all of the work.

The cement was delivered on the work by the local dealers for $1.73 per barrel. Sand was delivered for $1.50 per load of about 1¼ cu. yds. or at about $1.20 per cubic yard. Crushed rock cost delivered on the work $2.25 per cubic yard. Labor cost $2 per day of nine hours. Hemlock lumber cost $18 per thousand and spruce lumber $22 per thousand delivered.

An accurate account was kept of the total cost but the exact division between the different classes as given below is something of an estimate but is believed to be quite near the facts. The total amount of concrete built assuming that 5 per cent of the total entered the cavities of the old work was 2,190 cu. yds.

Lumber for crib work and forms cost	$ 1,922
Tools bought and hired	800
Field stone for filling cribs	356
Teaming	112
Cement	4,249
Sand	1,059
Crushed rock	3,582
Liability insurance	125
Coal	112
Incidentals and office expenses	575
Labor on cribs, forms and concrete	5,337
Preparing foundations under water	5,100
Making anchor connections with old work	400
Iron for reinforcing and for protecting corners	490
Pointing up old work above concrete jacket	300
Riprapping outside of cribs	200
Engineering	1,350
Total	$26,069
Less estimated salvage on tools and lumber	500
Net cost	$25,569

This gives a cost of $11.68 per cubic yard for the whole job. But if we omit the last six items above mentioned as not usually chargeable to the yard price of concrete, we have $8.32 as the net yard price which includes the cost of all crib work and forms.

The work was done between July 5 and October 13 and was under the direct supervision of Joseph Mullen.

Cost of Forms for Concrete Bridges and Culverts.—The following is taken from Engineering and Contracting, March 26, 1919.

It has been found in bridge and culvert work in Kentucky that a fair approximation of the cost of forms for the different classes of reinforced concrete superstructures or culverts in state work may be estimated per cubic yard of concrete (if the forms are not to be used the second time) by allowing 100 ft. B.M. of lumber per cubic yard and four hours' time each for the carpenter and helper for the erection; and for the substructures of slabs or girder bridges, 2½ hours' carpenter's time and 2½ hours' helper's time for the plain concrete. These figures were given by Charles D. Snead, Bridge Engineer of the State Department of Public Roads, in an address at the Kentucky

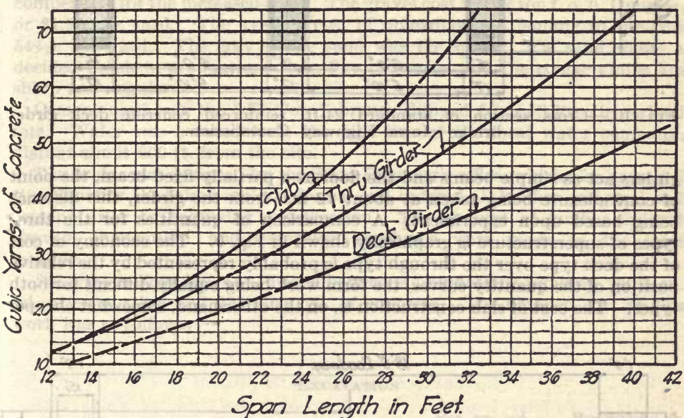


FIG. 9.—Quantities of concrete in three standard types of reinforced concrete superstructures—Iowa Highway Commission.

Road School, and are based upon actual work done with the ordinary type of labor available in the state. Where the forms are used twice it has been found that it requires about one-half the time, estimated for buildings, to re-erect them.

Relative Economy of Slab, Through Girder and Deck Girder Types of Concrete Bridges.—The following matter is taken from an abstract, published in Engineering and Contracting, March 24, 1915 of a paper by C. B. McCullough, presented at the 11th Annual convention of the American Concrete Institute at Philadelphia, Pa.

The slab type of superstructure consists of a simple beam or slab, reinforced for main and diagonal tension by longitudinal rods, and for lateral distribution, shrinkage and temperature stresses by transverse rods.

The deck girder type (see Fig. 10) depends for its economy on the fact that the carrying capacity of a beam varies as the square of the depth but only as the first power of the width. Thus the use of deep narrow girders operates to reduce the amount of material and consequently cuts down the cost. The stresses arising in the superstructure are transmitted into the girders by means of a thin doubly reinforced floor, which acts as a beam partially fixed and partially continuous. The girders themselves are reinforced for main and diagonal tension both by bent up rods and by stirrups.

In the through type of girder construction (see Fig. 11) two main side girders support the floor, which is hung or suspended between them. The main

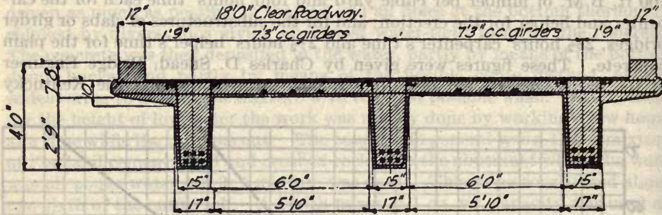


Fig. 10.—Cross section of standard 24-ft. reinforced concrete deck girder bridge—Iowa Highway Commission.

girders act as simple beams and the floor as a partially fixed beam, the point of contraflexure being taken at about 12 ins. from the girder, this distance being based upon experiment. A comparison of quantities for the three types of superstructure is graphically shown in Fig. 9. The economy of cost of the deck type over the through type is probably represented by the relative position of the quantity curves, the form work being equally difficult for both types. The cost of slab construction is, on the other hand, somewhat cheaper

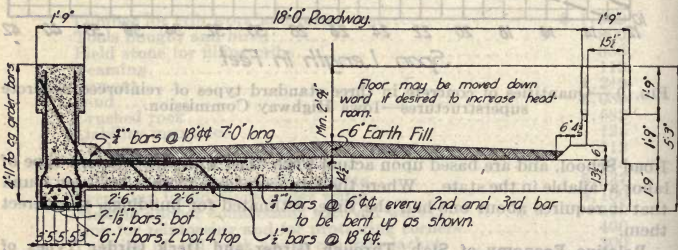


Fig. 11.—Cross section of standard 30-ft. reinforced concrete through girder bridge—Iowa Highway Commission.

than the quantitites would indicate, on account of the simple form work, and this type of construction is probably the economical one for spans below 20 or 22 ft. The economy of the through girder and the slab over the deck type is one of headroom rather than of cost.

Cost of 113-Ft. Reinforced Concrete Girder Bridge Near Douglas, Ariz.—During 1915–1916 the State Highway Department of Arizona constructed a 113-ft. concrete bridge over the Whitewater River near Douglas, Ariz. The structure was of the through girder type, and consisted of two spans 37 ft. 6 in. each and one span 38 ft. It replaced a 90-ft. frame bridge. Very complete cost data on the work are given in the recently issued annual report of Lamar Cobb, State Engineer, from which the matter that follows is given in Engineering and Contracting, Dec. 27, 1916.

The bridge was constructed by day labor under the direction of J. C. Ryan, Division Engineer of the State Highway Department. Laborers were paid $3 per 8-hour day and carpenters $4 per day. Teams and drivers were hired for $5 per day.

Gravel was secured from the Fairbanks beds. A few cars of screened sand were bought, but most of it was run-of-bank gravel and was screened on the ground. This gravel shows a very low voidage content.

Although this gravel was expensive, the superior results secured from it on account of its low voidage content, and general good qualities for mixing, compensate for the increased cost. The gravel cost $1 per ton f. o. b. Douglas, or $1.39 per yard. The average cost of unloading and hauling to site was 54½c per yard. The cost of the sand was the same. The sand shows a decided break in graduations from fine to coarse, and the coarse grains are sharp and angular.

Cement used was the "El Toro" brand, shipped from El Paso in carload lots. Water was secured from the pipe line of the local water company, distant about 600 ft. from the site.

The bridge was designed by the State Engineer's office, which also prepared the plans for the falsework and forms, and ordered all lumber and steel and cement prior to beginning construction. The amount of lumber ordered proved inadequate and extensive purchases were made in the local market.

Subaqueous Foundations.—The subaqueous foundations required 236.5 cu. yd. of excavation and 223.7 cu. yd. of concrete. The detailed cost of this work was as follows:

EXCAVATION

	Total	Per cu. yd. excavation (236.5 cu. yd.)	Per cu. yd. concrete (223.7 cu. yd.)
Foreman	$ 200	$0.85	$0.90
Laborers	649	2.74	2.91
Drivers	51	.21	.23
Teams	24	.10	.11
Miscellaneous	153	.65	.68
Tools	71	.30	.32
Total	1,148	$4.85	$5.15
Pumping—			
Foreman	$ 28	$0.118	$0.125
Laborers	200	.85	.90
Fuel	29	.121	.129
Miscellaneous	48	.200	.214
Tools	148	.605	.660
Total	$ 453	$1.914	$2.028
Less chargeable to concreting	18	.077	.083
Net total	$ 434	$1.837	$1.945

Shoring

Sheet piles driven, 340; average length, 10 ft. Cost per lin. ft., 3,380 lin. ft. at 20¾ cts. Board feet driven, 8.88 M. ft. at $78.60. Cost per lin. ft. labor only, 14.6 cts.

	Total	Per M ft., B. M.	Per cu. yd. excavation (236.5 cu. yd.)	Per cu. yd. concrete (223.7 cu. yd.)
Foreman	$ 45	$ 5.05	$0.19	$0.20
Carpenters	8	.87	.033	.035
Laborers	182	20.35	.773	.820
Lumber	255	28.80	1.085	1.146
Nails	4	.42	.002	.003
Miscellaneous	114	12.80	.480	.507
Tools	63	7.07	.265	.281
Teams and drivers	29	3.24	.122	.128
Total	$698	$78.60	$2.95	$3.12

Piling

Excavation, 69.9 cu. yd. at $1.45. Concrete, 7.10 cu. yd. at $1.41. Number piles driven, 17; length, 8 ft.; cost per lin. ft.; $0.7362. Penetration, 5 ft.; cost per ft. penetration, $1.145. Board feet driven, 0.896 M. B. ft. Cost per M. B. ft., $111.50. Lumber per lin. ft., $0.2275. Lumber per M. B. ft., $34.40. Cost driving only, per lin. ft., $0.5075. Cost driving only, per M. B. ft., $77.00.

	Total	Per cu. yd. concrete (223.7 cu. yd.)
Foreman	$ 4.00	$0.017
Laborers	29.00	.129
Teams	8.00	.034
Drivers	8.00	.034
Tools	17.00	.074
Miscellaneous	5.00	.022
Total labor	$ 69.16	$0.310
Lumber	30.85	.138
Total	$100.01	$0.448

Concreting Materials to Mixer

Yardage, loose material, not including slag: 143 cu. yd.

		Total	Cost per yd. of loose material	
Foreman	$8.63		......	......
Miscellaneous	3.68	$12.00	$0.086	$0.055
Laborers		65.00	.449	.289
Tools		3.00	.018	.012
Total		$80.00	$0.553	$0.356

Concreting Mixing—Operation

	Total	Per cu. yd. concrete (223.7 cu. yd.)
Foreman	$ 6.00	$0.024
Laborers	45.00	.202
Miscellaneous	158.00	.708
Repairs	57.00	.253
Tools	33.00	.147
Fuel, 22 gal. at 17 cts	4.00	.017
Water, 20,715 gal. at $1.42 per M. gal.	29.00	.132
Total	$332.00	$1.483

Concreting Mixing—Materials

Number sacks cement per yard concrete, 3.43 sacks; net cost per sack cement, \$0.75; cu. yd. sand per yard concrete, \$0.412 cu. yd.; cu. yd. sand per yard concrete, \$0.412 cu. yd.; cost per yard of sand, \$2.135; cu. yd. slag per yard concrete, \$0.613 cu. yd.; cost per yard of slag, \$1.105; cu. yd. gravel per yard concrete, \$0.232 cu. yd.; cost per yard of gravel, \$2.100; per cent of slag to total concrete, 61.25 per cent; average gallons water per yard concrete, 90½ gal.; cement, \$648.76—767 sacks; less sacks returned, \$72.05.

	Total	Per cu. yd. concrete (223.7 cu. yd.)
Net cost of cement	\$ 577.00	\$2.58
Sand, 91.9 cu. yd. at \$2.135	196.00	.878
Slag, 136.9 cu. yd. at \$1.105	151.00	.676
Gravel, 52.0 cu. yd. at \$2.10	109.00	.488
Total	\$1,033.00	\$4.622

Concreting Forms

Foreman	\$9.37		
Miscellaneous	4.58	\$ 14.00	\$0.062
Laborers		86.00	.385
Tools		9.00	.039
Total		\$109.00	\$0.486

Concreting—Placing

Foreman	\$3.61		
Miscellaneous	1.46	\$ 5.00	\$0.023
Laborers		26.00	.119
Tools		4.00	.019
Total		\$ 35.00	\$0.161
Add cost of pumping		18.00	.081
Grand total placing		\$ 54.00	\$0.242

Summary

Total subaqueous excavation, \$2,280.90—cost per yard excavation, \$9.637 per cu. yd.; concrete, \$10.215; total subaqueous concrete, \$1,607.53—cost per yard concrete, \$7.183; total subaqueous piling, \$100.01—cost per M. ft., \$111.50; lin. ft., \$0.77; yard concrete, \$0.448; grand total subaqueous foundations, \$3,988—cost per yard concrete, \$17.846.

Subaqueous Foundations: Comparisons of Cost—Excavation

The following figures are for costs per yard excavation:

	East abutment	West abutment	Pier No. 1	Pier No. 2
Excavation	\$1.65	\$ 8.00	\$4.71	\$2.90
Pumping	.76	3.03	1.46	1.54
Shoring	3.57	2.89	2.93	2.68
Piling	....	1.45	....	....
Total	\$5.98	\$15.37	\$9.10	\$7.12

SUBAQUEOUS FOUNDATIONS: COMPARISONS OF COSTS—CONCRETE

The following figures are for costs per yard concrete:

	East abutment	West abutment	Pier No. 1	Pier No. 2
Excavation	$ 1.375	$ 7.75	$ 5.50	$ 3.48
Pumping	.63	2.90	1.77	1.845
Shoring	2.965	2.77	3.49	3.205
Piling	....	1.41	....	....
Total excavation	$ 4.97	$14.83	$10.76	$ 8.53
To mixer	.324	.339	.42	.31
Mixing operations	1.855	1.346	1.475	1.42
Mixing materials	5.05	4.36	4.56	4.81
To forms	.143	.329	.86	.42
Placing	.138	.478	.055	.24
Total concreting	$ 7.52	$ 6.852	$ 7.37	$ 7.20
Grand total	$12.48	$21.682	$18.13	$15.73

Superaqueous Foundations.—The original design, which called for reinforced concrete walls and columns resting on 24-in. footings at the bottom of the subaqueous excavation, was not followed in the construction. The successful placing of the reinforcing and concrete as in the original design would have required a water-tight sheet-piling, and a concrete seal at the bottom, and a type of sheeting that would stand without bracing. Sheet-steel piling would have served this purpose, but was not obtainable, so the original design was abandoned. Instead, that part of the foundations that were below water level were cast in mass-concrete, and that part of the foundations that were above the water level were put in according to the plans. This required that the reinforcing steel be cut to new lengths. The East abutment did not extend to sufficient depth to establish a firm foundation, and an extra subfooting was put under it, although the plans did not call for that depth. The only difficulty experienced in pouring this part of the foundation was that the forms for the columns were not strong enough to stand the weight of the concrete, and they bulged in spite of all that could be done to tie and brace them in place. The columns were on a skew, and the concentration of pressure on the sharp angles overcame the pressure on the flat angles, so that the columns deformed along the sharp angles. One column skewed so badly it was torn down and replaced, while all of them showed more or less deformation on the sharp angles. It is thought that if a heavy piece of timber had been placed along the sharp angles, and tied in securely, the trouble might have been prevented, but no provision had been made for such timber in the plans of the forms. The parapet placed on the abutments as a continuation of the curb on the girders did not allow sufficient play to take care of the expansion and cracks have developed in the parapet, especially on the east end.

The superaqueous foundations required 810 cu. yd. of excavation and the placing of 87 cu. yd. of concrete.

The yardage as to excavation, represents the dry excavation for the abutments. The excavation on the west end was through clay, while on the east end it was through hard gravel, requiring blasting to loosen it. Both excavations, after loosening, were taken out with scrapers. The yardage as to concrete is for the two abutments only.

	Total	Per cu. yd. excavation	Per cu. yd. concrete
Foreman	$ 53.00	$0.066	$0.613
Laborers	239.00	.295	2.740
Drivers	92.00	.114	1.059
Teams	92.00	.114	1.059
Explosive	14.00	.017	.161
Miscellaneous	62.00	.077	.715
Tools	37.00	.045	.426
Total	$589.00	$0.7280	$6.773

Forms—Framing and Erecting

Yardage, concrete, 120 cu. yd., based on total concrete in superaqueous foundations; board ft. framed, 4,720 M. B. ft. at $81; square feet covered, 2,488 sq. ft. at $0.1535; board feet actually used, 2,360 M. B. ft., $162; cost of lumber actually used, 2,360 M. B. ft. at $28.40; ratio feet framed to feet used, 2:1; labor cost only, per sq. ft., $0.03; per M. B. ft., $78.90, framed.

	Total	Per cu. yd. concrete
Foreman	$ 20.00	$0.1709
Carpenters	91.00	.7625
Laborers	88.00	.7310
Miscellaneous	104.00	.8640
Tools	3.00	.0228
Total labor	$306.00	$2.5512
Lumber	67.00	.5580
Nails	9.00	.0760
Total materials	$ 76.00	$0.6340
Total labor and materials	$382.00	$3.1852

Forms—Stripping

Cost per M. B. ft., framed, $14.00; cost per square foot, $0.0265

	Total	Per cu. yd. concrete
Foreman	$ 11.00	$0.0887
Carpenters	4.00	.0334
Laborers	48.00	.3965
Miscellaneous	3.00	.0267
Tools	1.00	.0081
Total	$ 66.00	$0.5534

Total Forms: Framing and Erecting and Stripping

Total cost, $449; cost per cu. yd. concrete, $3.7386; cost per M. B. ft., $95; cost per square foot, $0.18; cost for labor only, per M. B. ft., $78.80 framed; cost for lumber only, per M. B. ft., $16.20 framed, net cost; per sq. foot, $0.035 (net cost of lumber); actual B. ft. lumber used, 2.360 M. B. ft.; first cost of lumber used, $93.05 per M. B. ft., $39.40; less credits for scrap recovered, $26 per M. B. ft., $11; net cost of lumber, $67.05 per M. B. ft., $28.40; ratio first cost to credits, 1:0.279.

Concreting: To Mixer

Yardage, concrete, 120.0 cu. yd. at $0.5689; loose materials, 130.4 cu. yd. at $0.5225.

		Total	Per cu. yd. concrete
Foreman	$7.47	....	....
Miscellaneous	3.22	$ 11.00	$0.0892
Laborers		55.00	.4580
Tools		3.00	.0217
Total		$ 69.00	$0.5689

Concreting: Mixing—Operation

	Total	
Foreman	$ 4.00	$0.0295
Laborers	24.00	.1990
Miscellaneous	108.00	.8980
Repairs	38.00	.3125
Tools	20.00	.1656
Fuel, 14½ gal. at $0.169	2.00	.0205
Water, 13,435 gal. at $1.308 M	17.00	.1463
Total	$210.00	$1.7714

Concreting—Mixing Materials

Number sacks cement per yard concrete, 4 sacks; net cost per sack cement, $0.74; cu. yd. sand per yard concrete—0.37 cu. yd.; cost of sand per yard sand, $2.18; cu. yd. gravel per yard concrete, 0.72 cu. yd. cost of gravel per yard gravel, $2.145; average gal. water per yard concrete, 120 gal.; cement, 478 sacks at $0.833, $398.67; less credit for sacks returned, $44.95.

	Total	Per cu. yd. concrete
Net cost of cement at $0.74	$354.00	$2.945
Sand, 44.3 cu. yd. at $2.18	97.00	.806
Gravel, 86.1 cu. yd. at $2.145	184.00	1.535
Total	$635.00	$5.286

Concreting Forms

Foreman	$7.98	....	....
Miscellaneous	3.02	$ 11.00	$0.0916
Laborers		39.00	.3220
Tools		4.00	.0346
Total		$ 54.00	$0.4482

Concreting—Placing

Foreman	$3.22	....	....
Miscellaneous	1.29	$ 5.00	$0.0375
Laborers		$ 25.00	.2055
Tools		....	.0015
Total		$ 30.00	$0.2445

Reinforcing—Bending

Yardage, concrete, 120.0 cu. yd.; pounds steel bent, 13,141 lb.

		Per cu. yd.	Per lb.
Foreman	$ 5.00	$0.0427	$0.00039
Laborers	28.00	.2330	.00212
Tools	5.00	.0405	.00037
Totals	$38.00	$0.3162	$0.00288

Reinforcing—Placing

Foreman	$ 33.00	$0.278	$0.00254
Laborers	43.00	.358	.00327
Tools	1.00	.001	.00006
Miscellaneous	24.00	.209	.00185
Total labor	$101.00	$0.846	$0.00772
Steel	297.00	2.475	.02260
Total	$398.00	$3.321	$0.03032
Add cost of bending	38.00	.3162	.00288
Total cost of reinforcement	$436.00	$3.6372	$0.03320

Summary

		Per yard concrete
Total excavation	$ 589.44	$ 4.92
Total forms	448.86	3.74
Total concreting	996.09	8.32
Total reinforcing	436.19	3.63
Grand total	$2,470.58	$20.61

Recapitulation—Substructure

Account	Cost	Pctg. of total cost of bridge	Cu. yd.	Cost per yard
Subaqueous foundations	$3,988.44	33.25	223.7	$17.85
Superaqueous foundations	2,470.58	20.55	120.0	20.61
Total substructure	$6,459.02	53.80	343.7	$18.80

Cost per yard subaqueous concrete, $17.85; cost per yard superaqueous concrete, neglecting reinforcements, $16.98. Average mix used in subaqueous concrete: 1 part cement, 3.2 parts sand, 4.8 parts gravel, 1.8 slag. Average mix used in superaqueous concrete: 1 part cement, 2 parts sand, 4 parts gravel.

SUPERSTRUCTURE

Falsework.—The original plans for falsework did not allow of any adjustment between the posts and caps, and it was necessary to make hard-wood wedges, and purchase additional timbers to serve as bottom caps. Twenty piles were also driven over the channel of the creek.

Girder Forms.—The failure of the girder forms to stand up under the strain of the pouring of the concrete caused the resulting girder to have a decidedly wavy appearance. The cause of this lay in the fact that the inside forms had no direct support, but relied on the outside forms to prevent any motion of the inside forms without a corresponding movement of the outside forms, but did not prevent both forms from moving laterally together. Not sufficient lumber was provided to prevent such lateral movement and when the concrete was poured, and the short legs under the inside forms were of necessity removed, the whole girder warped as a result of the unsupported weight on the inside. On the second and third spans, the brackets were left off the cross-pieces since they served no useful purpose. On these spans, the inside forms dropped, as on the first, but without pulling the outside forms so badly out of place. If it had been possible to pour the floor first, and then set the girder forms on the floor, this trouble might have been prevented, but the nature of the reinforcement did not allow casting the floor and curb-line separately from the girders, and that method was impracticable. If sufficient timbers had been provided to allow hanging both the girder forms from cross-timbers supported on posts resting on the falsework, it would again have been possible to avoid the trouble, but such timbers were not available.

An effort was made to put the forms up in sections, in order to save expense, but this plan failed because of the recessed corners at the top and bottom of the inside panels where the panels joined the coping and the curb. The forms caught in these recesses and prevented swinging the forms away after pouring. Because of this, each inside post had to be torn down before the panels could be moved. The same applies to the outside posts, but in a lesser degree, since the outside posts were of one piece, while the inside posts were in three pieces.

Concreting.—The first span was poured by dumping the buggies into a chute and shoveling from the chute to the forms, in an effort to save the forms from vibration as much as possible. Since this did not seem to have any effect, the rest of the bridge was poured by constructing a trestle work level with the tops of the forms and dumping directly into the forms.

Reinforcing.—The reinforcing presented some difficulty on account of its complexity, which ran up the cost of placing. The bars were spaced by small concrete bricks, and every effort was made to conform to the cross-section shown on the plans. In bending, the only trouble encountered was in the stirrups. The Bates Tyer used worked in a satisfactory manner, but the ties furnished were too light for the heavy steel, and broke easily under strain.

Forms—Framing and Erecting

Yardage concrete, 171 cu. yd.; board feet framed, 10.221 M. B. ft.; actual board feet used, 7.679 M. B. ft., $27.65; square feet covered, 5,330 sq. ft.; total cost per M. B. ft. actually used, $110; labor cost only per M. B. ft. actually used, $80; ratio feet framed to feet used, 1.34:1.

	Total	Per cu. yd. concrete	Per M. B. ft. framed	Per sq. ft.
Foreman	$ 65.00	$0.382	$ 6.47	$0.0123
Carpenters	184.00	1.078	18.00	.0346
Laborers	281.00	1.645	27.50	.0528
Miscellaneous	74.00	.432	7.30	.0139
Tools	9.00	.049	.84	.0016
Total labor	$614.00	$3,587	$60.11	$0.1152
Lumber	212.00	1.250	20.75	.0399
Nails	20.00	.110	1.92	.0037
Total forms	$845.56	$4.947	$82.78	$0.1588

Forms—Stripping

Cost of stripping per M. B. ft. framed, $10.51; cost of stripping per square foot, $0.02014.

Foreman	$ 14.00	$0.0805	$ 1.345	$0.00258
Carpenters	7.00	.0408	.685	.00131
Laborers	79.00	.4610	7.725	.01480
Miscellaneous	4.00	.0239	.400	.00077
Tools	3.40	.0212	.355	.00068
Total	$107.00	$0.6274	$10.510	$0.02014

Total Forms—Framing, Erecting and Stripping

Total cost, $952.99; cost per cu. yd. concrete, $5.5744; cost per M. B. ft. framed, $93.29; cost per square foot covered, $0.17894; cost of labor only, per M. B. ft. framed, $70.50; materials per square foot, $0.1350; cost of materials only, per M. B. ft. framed, $22.79; per square foot, $0.04394; first cost of lumber used, $300.10; per M. B. ft., $39.05; less credits for scrap recovered, $88; per M. B. ft., $11.40; net cost of lumber, $212.10 per M. B. ft., $27.65; ratio first cost to credits, 1:0.292.

The above costs are for the costs of framing both the girder, forms and the floor. Complete figures as to cost of the floor were not kept, but an estimate, based on the labor distribution for the first span shows the following costs per square foot:

Floor, 2,500 sq. ft. at $0.07	$175.00
Girders, 2,830 sq. ft. at $0.2330	671.00

From which:

Cost of laying floor, per sq. ft.	$ 0.0700
Cost of forms for plain surfaces	.1535
Cost of forms for paneled surfaces	.2330

These figures are for framing and erecting only, and do not include cost of stripping.

FALSEWORK: FRAMING AND ERECTING: BENTS

Yardage, concrete, 171 cu. yd.; board feet framed, 12.919 M. B. ft.; board feet actually used, 8.902 M. B. ft.

	Total	Per cu. yd. concrete	Per M. B. ft. framed
Foreman	$ 13.00	$0.0760	$ 1.0075
Carpenters	37.00	.2160	2.8650
Laborers	74.00	.4320	5.7300
Miscellaneous	17.00	.0977	1,2800
Tools	2.00	.0108	.1348
Total labor	$142.00	$0.8325	$11.0173
Lumber	260.00	1,5150	20.10
Nails	19.00	.1150	1.46
Total bents, F. and E	$421.00	$2.4625	$32.5773

FALSEWORK: BENTS: STRIPPING

Cost of stripping per M. B. ft. framed, $4.2470; cost of stripping per cubic yard, $0.3207.

	Total	Per cu. yd. concrete	Per M. B. ft. framed
Foreman	8.00	$0.0480	$ .6350
Carpenters	8.00	.0467	.6200
Laborers	37.00	.2145	2.8400
Tools	....	.0028	.0360
Miscellaneous	2.00	.0087	.1160
Total	$ 55.00	$0.3207	$ 4.2470

FALSEWORK: PILES: DRIVING

Board feet driven, 1,280 B. ft.; linear feet driven, 320 lin. ft.

	Total	Per cu. yd. concrete	Per M. B. ft.	Per lin. ft.
Foreman	$ 9.00	$0.0543	$ 7.28	$0.0290
Carpenters	9.00	.0555	7.43	.0297
Laborers	56.00	.3300	44.10	.1765
Miscellaneous	12.00	.0690	9.25	.0370
Tools	36.00	.2125	28.40	.1135
Teams	9.00	.0512	6.84	.0274
Drivers	9.00	.0512	6.84	.0274
Total labor	$141.00	$0.8237	$110.14	$0.4405
Lumber	44.00	.2580	34.45	.1380
Nails (drift pins)	5.00	.0295	3.95	.0155
Total piling	$190.15	$1.1112	$148.54	$0.5940

TOTAL FALSEWORK, FRAMING AND ERECTING, STRIPPING AND PILING—

Total cost, $665.66; cost per cu. yd. concrete, $3.8944; cost per M. B. ft. framed and driven, $57.88; board feet framed and driven, per M. B. ft., 11.5; cost of labor only, per M. B. ft., $29.40; per yard, $1.98; cost of materials only, per M. B. ft., $28.48; per yard, $1.9144; first cost of lumber used, $394.99; per M. B. ft., $38.99; less credits for scrap recovered, $91.27; per M. B. ft., $8.975; net cost of lumber, $303.72; per M. B. ft., $29.925; number of piles driven, 20; length, 16 ft.; size, 8 × 8.

REINFORCING: BENDING

Yardage, concrete, 171.0 cu. yd.; pounds steel bent, 30,947 lb.

	Total	Per cu. yd. concrete	Per lb.
Foreman	$ 21.00	$0.1235	$0.00068
Laborers	152.00	.8900	.00492
Tools	26.00	.1530	.00085
Miscellaneous	11.00	.0642	.00035
Total	$211.00	$1.2307	$0.00680

Reinforcing: Placing

Yardage, concrete, 171.0 cu. yd.; pounds steel placed, 30,947 lb.

	Total	Per cu. yd. concrete	Per lb.
Foreman	$ 27.00	$0.1595	$0.00089
Laborers	$ 195.00	1.1385	.00630
Tools	19.00	.1085	.00060
Miscellaneous	79.00	.4630	.00256
Total labor	$ 320.00	$1.8695	$0.01035
Steel	875.00	5.1105	.02825
Total placing	$1,195.00	$6,9800	$0.03860
Add cost of bending	211.00	1.2307	.00680
Total cost of reinforcement	$1,404.00	$8.2107	$0.04540

Concreting: to Mixer

Yardage, concrete, 171.0 cu. yd.; loose materials, 235.5 cu. yd. at $0.6280.

	Total	Per cu. yd. concrete
Foreman	$ 23.00	$0.1345
Laborers	117.00	.6820
Tools	63.00	.3690
Total	$203.00	$0.8675

Concreting: Mixing Operation

	Total	Per cu. yd. concrete
Foreman	$ 6.00	$0.0363
Laborers	45.00	.2665
Water, 22,900 gal. at $1.41 per M	32.00	.1900
Fuel, 6 gal. oil at $0.80	5.00	.0281
80 gal. gas at $0.188	15.00	.0879
Repairs	62.00	.3640
Miscellaneous	97.00	.5670
Tools	63.00	.3690
Total	$326.00	$1.9088

Concreting: Mixing Materials

Yardage, concrete, 171.0 cu. yd.; number sacks cement to one yard concrete, 5.14 sacks.

The number of sacks to one yard of concrete is more than usual. This is due to the fact that the floor on the first span was resurfaced, being improperly placed first running.

Net cost per sack cement		$0.7775
Number sacks used		880
Cu. yd. sand per yard concrete		0.4825
Cost of sand per yard sand		$2.415
Cu. yd. gravel per yard concrete		0.8950
Cost of gravel per yard gravel		$2.410
Average gal. water per yard concrete		134
Cement, 880 sacks at $0.8750	$769.83	
Less credit for sacks returned	85.29	

	Total	Per cu. yd. concrete
Net cost of cement at $0.7775	$ 685.00	$4.00
Sand, 82.5 cu. yd. at $2.415	199.00	1.165
Gravel, 153 cu. yd. at $2.41	369.00	2.160
Total	$1,253.00	$7.325

Concreting: to Forms

	Total	Per cu. yd. concrete
Foreman	$ 18.00	$0.1081
Laborers	90.00	.5275
Tools	14.00	.0808
Total	$122.00	$0.7164

Average length of haul, 60 ft. Cost per foot per yard, $0.01194.

CONCRETING: PLACING

Foreman	$ 18.00	$0.1047
Laborers	90.00	.5230
Tools	2.00	.0182
Total	$110.00	$0.6459

CONCRETING—MISCELLANEOUS

	Total	Per cu. yd. concrete
Finishing: Cost of labor only	$ 68.17	$0.3990

The surface was never completely finished with carborundum brick, as was originally intended, hence costs per square foot of area is not available.

	Total	Per cu. yd. concrete
Expansion joints—Labor only	$ 10.00	$ .0615
Plates and rockers	65.00	.3820
Asphaltum, 40 gal. at 50 cts	20.00	.1170
Tar paper, four rolls	9.00	.0526
Proportion miscellaneous and office	4.00	.0283
	$110.0	$0.6414

RECAPITULATION: SUPERSTRUCTURE

	Total	Per cu. yd. concrete
Forms	$ 953.00	$ 5.5744
Falsework	666.00	3.8944
Reinforcement	1,405.00	8.2107
Concreting	2,137.00	12.5040
Total	$5,161.00	$30.1835

Costs of the McKinley Ford Bridge, La Salle County, Illinois.—The following data are from a detailed account of the construction of this bridge published in Engineering and Contracting, Feb. 24, 1915.

The McKinley Ford Bridge is located in Sarena township, La Salle county, Illinois. It consists of two 50-ft. reinforced concrete through girder spans on a concrete pier and abutments. The clear width of roadway is 16 ft., and the height of the pier and abutments, from bottom of footing to bridge seat, is 16 ft. 11 ins. The bridge was designed under the "General Specifications for Bridge Work" of the Illinois State Highway Department. It is a standard type, and was built during the latter part of 1913, at an actual cost of $3,893.

Pier.—The center pier has a thickness of 3 ft. and a width of 23 ft. 1 in., under coping; a thickness of 4 ft. 2 ins.; and a width of 24 ft. 3 ins. at the base; and a height, from bridge seat to bottom of footing of 16 ft. 11 ins. The coping has a width of 3 ft. 8 ins., a length of 23 ft. 9 ins., and a thickness of 15 ins. The footing has a width of 8 ft., a length of 25 ft., and a thickness of 2 ft., and it is reinforced with a layer of ½-in. square bars, spaced 12 ins. on centers. At the top, near each end of the pier, there is a recess 20 × 25 ins. × 15 ins. deep for the cast iron rockers. A concrete mixture consisting of 1 part cement, 3 parts sand, and 5 parts gravel was used. The pier extends 4 ft. 6 ins. below the bed of the stream.

Abutments.—The concrete abutments, which have a height, from bridge seat to bottom of footings, of 16 ft. 11 ins., are reinforced and are of the wing-wall type, the wing-walls being of the cantilever type. The abutments have a thickness of 12 ins., with vertical faces, this thickness being increased to 18 ins. under the girders. The footings have a width of 4 ft. 6 ins., a thickness of 20 ins., and extend to the same depth as the pier.

The wing-walls have a top thickness of 12 ins., and a bottom thickness of 18 ins. Their footings have a width of 6 ft. 3 ins. and a thickness of 20 ins. A concrete mixture consisting of 1 part cement, 2½ parts sand, and 4 parts gravel was used for the abutments and wing-walls.

Girders.—The girders have a depth of 5 ft. 6 ins., a thickness of top flange of 26 ins., and of web of 23 ins., and are paneled as shown in Fig. 1. They are spaced 18 ft. 2 ins. on centers. All exposed edges of the girders are beveled with a ¾-in. triangular molding, and all edges of panels have a 45° bevel. The girders are heavily reinforced, the main reinforcing bars being arranged in four rows, spaced 5 ins. on centers. The concrete mixture for the girders and floor system consists of 1 part cement, 2½ parts sand, and 4 parts gravel.

Floor System.—The bottom of the reinforced concrete floor slab is flush with the bottoms of the girders, while the top is crowned to conform with the finished roadway. The thickness of the floor slab at the crown is 13 ins., and at the curb 10 ins. Drainage of the roadway is secured by placing 3-in. tile drains through the slab and near the curb on 8-ft. centers. The wearing surface (which is not included in this contract) consists of a 6-in. layer of macadam.

Cast Iron Rockers.—Cast iron rockers are used under the ends of the girders which rest on the center pier; they are not used under the abutment ends of the girders. These segmental rockers have a thickness of 3½ ins., a depth of 14 ins., and a length of 2 ft., the top and bottom surfaces of which are turned to a diameter of 7 ins.

Steel bearing plates, 9 ins. wide, 1 in. thick and 2 ft. long, are placed at both the top and bottom of the rockers.

Expansion Joint.—A ¼-in. tar paper expansion joint is provided between the two girder spans. Tar paper is also placed on the top of the piers between the rockers and the edges of the piers. The space around the rockers is filled with asphalt.

SUMMARY OF MATERIALS REQUIRED

Reinforcing steel:	Lbs.
In pier	160
In abutments	6,360
In superstructure	36,080
Total	42,600
8 steel bearing plates	490
4 cast iron rockers	1,190
Concrete:	Cu. yds.
Class B, in pier	60.4
Class A, in abutments	103.8
Class A, in superstructure	140.4
Total Class B	60.4
Total Class A	244.2
Total concrete in bridge	304.6

As actually constructed there were used in the construction of this bridge 308.3 cu. yds. of concrete, the extra 3.7 cu. yds. being placed in the substructure. Square twisted bars were used for reinforcement.

Construction Features.—Construction work was started Sept. 13, 1913, and the bridge was completed Nov. 28, 1913. The bridge is located about four miles from the railroad station, and the materials, with the exception of the sand and gravel, were hauled that distance. The sand was removed from the creek and was transported in wheelbarrows a distance of 150 ft. The gravel was also obtained near the site, being hauled about 400 ft. About 125 cu. yds.

of the total of 187.4 cu. yds. of gravel required were screened. The prices of the materials are given under "Cost Data."

The pier was located in the bed of the stream, and the abutments, one on each bank. About 500 ft. B. M. of sheet piling were required for the coffer-dam of the center pier. Of the 240 cu. yds. of excavation required, about 108 cu yds. were classified as dry excavation and 132 cu. yds. as wet excavation. Foremen were paid 65 cts. per hour and workmen 25 cts. per hour. The rate of pay for teams was 45 cts. per hour.

Cost Data.—The data in Table XXVI give the quantities of materials used, the unit prices, the cost of each item, and the total actual cost of the bridge to the contractor.

TABLE XXVI.—QUANTITIES OF MATERIALS, UNIT PRICES AND TOTAL COSTS

Cement, 416 bbls. at $1.25		$ 520.00
Hauling cement 4 miles		65.84
Sand, in place, 117.2 cu. yds. at 30 cts		35.16
Hauling sand 150 ft. in wheelbarrows from creek		98.40
Gravel, in place, 187.4 cu. yds. at 30 cts		56.22
Screening 125 cu. yds. of gravel		78.20
Hauling gravel 400 ft		187.18
Form lumber, 6,000 ft. B. M. at $22.67		136.00
Falsework lumber, 3,000 ft. B. M. at $15		45.00
Wire, nails, etc., 240 lbs. at 5 cts		12.00
Hauling form lumber 4 miles		15.00
Hauling falsework lumber 4 miles		7.00
Reinforcing steel, 42,600 lbs		816.80
Hauling steel 4 miles		32.00
Rockers and plates, 1,680 lbs. at 2 cts		33.60
Asphalt, 50 gals. at 15 cts		7.50
Hauling rockers and asphalt at $4.50 per day		3.50
Sheet piling, 500 ft. B. M. at $20		10.00
Cost of driving sheet piling		8.00
Cost of removing sheet piling		5.00
Labor on 108 cu. yds. dry excavation:		
Foreman, 40 hrs. at 65 cts	$ 26.00	
Laborers, 344 hrs. at 25 cts	86.00	112.00
Labor on 132 cu. yds. wet excavation:		
Foreman, 130 hrs. at 65 cts	$ 84.50	
Laborers, 1,272 hrs. at 25 cts	318.00	402.50
Cost of pumping during excavation:		
Foreman, 9 hrs. at 65 cts	$ 5.85	
Laborers, 104 hrs. at 25 cts	26.00	31.85
Cost of pumping during concreting:		
Foreman, 4 hrs. at 65 cts	$ 2.60	
Laborers, 34 hrs. at 25 cts	8.50	11.10
Labor, building forms:		
Foreman, 115 hrs. at 65 cts	$ 74.75	
Laborers, 1,146 hrs. at 25 cts	286.50	361.25
Labor, building falsework:		
Foreman, 35 hrs. at 65 cts	$ 22.75	
Laborers, 350.5 hrs. at 25 cts	87.63	110.38
Labor, bending and placing steel:		
Foreman, 36 hrs. at 65 cts	$ 23.40	
Laborers, 361 hrs. at 25 cts	90.25	113.65
Labor, mixing and placing concrete:		
Foreman, 115 hrs. at 65 cts	$ 74.75	
Laborers, 1,142 hrs. at 25 cts	285.50	360.25
Labor, removing forms:		
Foreman, 20 hrs. at 65 cts	$ 13.00	
Laborers, 231 hrs. at 25 cts	57.75	70.75
Traveling expenses of men from Chicago and back		100.00
Gasoline, oil and incidentals		97.00
Total		$3,943.13
Salvage on lumber and falsework		50.00
Total net cost to contractor		$3,893.13

Table XXVII gives the unit costs of the various items of the bridge. There were 308.3 cu. yds. of concrete and 42,600 lbs. of steel placed. There were used on this work 416 bbls. of cement, 117.2 cu. yds. of sand, and 187.4 cu. yds. of gravel. The costs given do not include the cost of removing the old bridge.

The cost of the excavation per cubic yard of substructure concrete was $5.435, and the cost of the falsework per cubic yard of superstructure concrete was $1.278.

TABLE XXVII.—UNIT COSTS OF VARIOUS ITEMS

Item	Cost per cu. yd. of concrete
Cement	$ 1.971
Sand	0.448
Gravel	1.125
Labor on forms	1.525
Form materials	0.315
Labor on falsework	0.421
Falsework materials	0.161
Steel, in place	3.241
Mixing and placing concrete	1.379
Excavation	1.897
Miscellaneous, not included in above	0.145
Total	$12.628

Cost of Concrete Viaduct at Fort Worth, Texas.—The viaduct which carries an extension of North Samuels Ave. across the Trinity River in Fort Worth, Texas consists of nine spans of 50 ft.

The following data are given in a description of the methods and costs of constructing this viaduct by E. W. Robinson, published in Engineering and Contracting, April 29, 1914.

Contractor's Equipment.—The plant used on the job consisted of both new and second-hand machinery, which invoiced at the beginning of the job at $4,852. It consisted of the following: One 5-ton "A"-frame derrick car with a 60-ft. boom, operated by a 7 × 10-in. D. C. D. D. hoisting engine; a concrete chuting plant with an 18-cu. ft. bucket and 121 ft. of steel chutes; a single-drum mine hoist; a 9-cu. ft. gasoline-driven mixer with a self-loader; a 3-cu. ft. gasoline-driven mixer; 25 ft. of swinging leads and a 2,500-lb. drop-hammer which was operated from the boom of the derrick; two 1-cu. yd. turn-over dirt buckets and a 1-cu. yd. clam-shell bucket; and two pumps, one steam-driven and the other gasoline-driven. The small mixer was used to mix the concrete used in the railing at the opposite end of the bridge from the main plant, which made it unnecessary to operate the main plant for the small amounts of concrete required for that work. The chuting plant was moved twice, the second move being back to the first location.

In addition to the above mentioned equipment there were the usual petty tools and supplies for a job of this kind, on which depreciation is not far from 100 per cent. The total amount expended for petty tools and repairs for this job was $1,642, and these tools will likely invoice at about $200, showing a depreciation of 87 per cent, which is 5.9 per cent of the pay roll.

Materials and Proportions.—The concrete for the substructure was mixed in the proportions of 1:2½:5, and for the superstructure, in the proportions of 1:2:4. The top ½ in. of the sidewalks was surfaced with a 1:1 cement mortar, which was floated and troweled to a smooth finish. The sand was bank sand from local pits. It was delivered on the job for $1.20 per cubic yard. The stone used was crushed limestone from a nearby town. It was required to pass a 1-in. ring for the 1:2:4 concrete, and to pass a 2-in. ring for the 1 : 2½ : 5 concrete. The stone cost $1.26 per long ton of 2,240 lbs. f. o. b. cars at a team track located about ¼ mile from the work. It was unloaded by contract for $0.25 per long ton. One-man stone cost practically the same on the job as the crushed stone. About 250 tons of this were used in the abutments and pier shafts, but little saving was effected by its use, owing to the high cost of placing it, as the yardage in each place did not warrant much outlay for hoisting, etc.

Mixing and Placing.—All of the concrete, except a small yardage in a part of the railing, was mixed and placed through the central plant at the tower. The whole superstructure between curbs for one span was poured in one continuous operation, the sidewalk stringer, the curb stringer and the sidewalk slab being poured a few days later. The reason for this was because of the difficulty of supporting the side forms for the curb stringers to line and grade while the concrete on the roadway slab was still green.

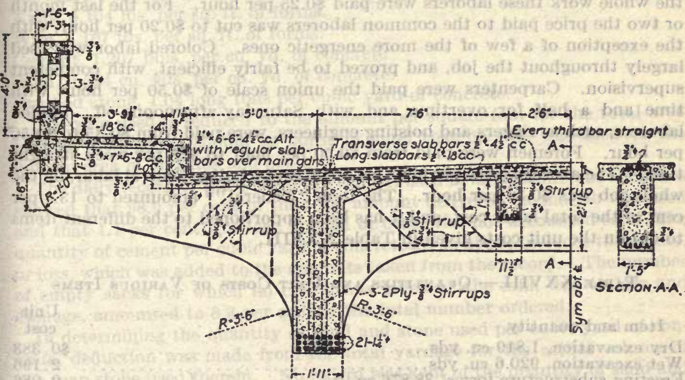


FIG. 12.—Cross-section of roadway—Fort Worth Viaduct.

The main towers, which were approximately 110 ft. high, were so designed that the concrete would reach all points on a grade of not less than 1 in 4. However, the arrangement was not always followed as intended, and occasionally this slope was flattened. The maximum distance which the concrete was chuted was 250 ft., and no trouble was experienced except when a dry batch was run through, which caused the following batch to spill over the sides of the chutes.

The stone and sand were dumped as near as possible to the mixer, and were conveyed from the piles to the hopper of the self-loader in wheelbarrows. Although at times of short duration the concrete was properly mixed and deposited at the rate of 30 or 35 cu. yds. per hour this rate could not be maintained for any great length of time. A good average for the whole day's run was 20 cu. yds. per hour. A high-speed mine hoist was used for raising the bucket in the tower, and there were no delays from that source. The typical organization of the concrete gang for a day's run was 3 men on the sand, 6 men on the stone, 2 men bringing and emptying the cement into the mixer, 1 man each to run the mixer and hoister, and 4 men on top placing and working the concrete around the reinforcement and shifting the chutes. However, the above organization would vary according to the location and condition of the stone and sand piles.

Cost Data.—The general foreman, or timekeeper, was required to make out daily reports showing the number of hours spent each day on each item of work, together with the wage rate. These reports were filed in the office, together with the progress charts and photographs, and constitute a complete record of the progress of the work as well as furnishing a method of determining the cost of the various classes of work done. The man who made out these reports was required to make the totals check with the total time turned in for the pay-roll. In this way the total cost of labor is absolutely correct, although the different items may be in error to some extent.

Eight hours constituted a day's work except in an emergency. For the first week or two common laborers were paid $1.75 per day, but for practically the whole work these laborers were paid $0.25 per hour. For the last month or two the price paid to the common laborers was cut to $0.20 per hour, with the exception of a few of the more energetic ones. Colored labor was used largely throughout the job, and proved to be fairly efficient, with competent supervision. Carpenters were paid the union scale of $0.50 per hour, with time and a half for overtime and with Saturday afternoons off. Skilled laborers, such as riggers and hoisting engineers, were paid from $0.35 to $0.50 per hour. Foremen were paid from $0.50 per hour to $25 per week straight time. The average price per hour for all labor, including general labor, on the whole job was $0.34 per hour. The item "General"* amounted to 13.4 per cent of the total labor cost, and it has been apportioned to the different items to obtain the unit costs given in Table XXVIII.

TABLE XXVIII.— QUANTITIES AND UNIT COSTS OF VARIOUS ITEMS

Item and quantity	Unit cost
Dry excavation, 1,819 cu. yds.	$0.383
Wet excavation, 920.6 cu. yds.	2.196
Erecting substructure forms, 38,876 sq. ft.	0.086
Erecting substructure forms, 3,413.6 cu. yds.	0.971
Wrecking substructure forms, 38,876 sq. ft.	0.017
Wrecking substructure forms, 3,413.6 cu. yds.	0.190
Erecting superstructure forms, 44,460 sq. ft.	0.149
Erecting superstructure forms, 1,237.2 cu. yds.	5.346
Wrecking superstructure forms, 44,460 sq. ft.	0.025
Wrecking superstructure forms, 1,237.2 cu. yds.	0.928
Bending and placing reinforcing steel, 123.9 tons	13.42
Driving foundation piles, 200	2.995
Preparing concrete plant, 4,650.8 cu. yds.	0.302
Mixing and placing concrete, 4,650.8 cu. yds.	0.823
Railing, complete, 906 lin. ft.	1.395
Railing, complete, 76.9 cu. yds.	16.44
Placing rip-rap, 690 cu. yds.	0.129

* The item "General" is intended to cover all labor which is general in its nature and cannot be charged to any particular class of work, such as that of the superintendent, general foreman, night watchman, and water boy. This cost is kept as a separate item, and is distributed to all other items in proportion to their total costs.

Miscellaneous Data.—The following quantities of lumber were delivered and used on the job:

Size	Ft. B. M.
1-in.	60,161
2-in. and 3-in.	98,848
4 × 4-in. to 8 × 12-in.	37,840
Miscellaneous and second-hand	20,800
Total, various sizes	217,649

Of this amount between 7,000 and 8,000 ft. B. M. of the 1-in. lumber had a salvage value of from one-half to two-thirds its cost price. There was also about the same amount of 2-in. and 3-in. lumber which could be used again or sold as second-hand lumber. Practically all of the large timbers were in good shape at the end of the job, but in the smaller sizes the loss approximated 50 per cent or more.

The quantities of materials given below are reduced to the amounts used per cubic yard of concrete or per square foot of forms, as the case may be:

Nails, 0.104 lbs. per sq. ft. of forms.
Wire, 0.107 lbs. per sq. ft. of forms.
Cement, 1.207 bbls. per cu. yd. of concrete
Sand, 0.504 cu. yds. per cu. yd. of concrete.
Crushed stone, 1.04 long tons per cubic yard of concrete.

The wire used is reduced to the amount per square foot for the total area formed, although it should be borne in mind that no wire was used on the bottom area of all slabs and beams.

The daily record of the quantity of cement used in all the different members showed that 98.9 per cent of the total amount delivered on the job was used and that 1.1 per cent was lost, wasted or otherwise not accounted for. The quantity of cement per cubic yard of concrete given above includes this waste, or loss, which was added to the amounts taken from the record. The number of empty sacks for which no credit was given at the mill, due to loss and damage, amounted to 8.3 per cent of the total number ordered.

In determining the quantity of sand and stone used per cubic yard of concrete, deduction was made from the total yardage for the actual volume of one-man stone used therein. No record was kept of the quantity of sand and stone used in the separate members.

Construction was started the latter part of May, 1913, and the work was completed in January, 1914.

The total bidding price of the viaduct was $54,339.63, but owing to increases in the quantities over the engineer's estimate, due to changes in the plans, the final contract price was $57,303.48. Although all of the work never ceased, except during the very heaviest rains, the whole progress was delayed several weeks on account of high water. Some material was lost by floods during September and December. Fortunately, each time the water rose to an unusual height it happened that there were no newly poured spans on the falsework in the channel.

(The cost per sq. ft. was about $3.07, based upon the contract price of $54,339.63 and the total area of the viaduct.)

Cost of Main Street Concrete Viaduct, Fort Worth, Texas.—The contract cost of the Main Street Viaduct, Fort Worth, Tex., given in Engineering and Contracting, March 10, 1915 in an abstract of a paper by S. W. Bowen in Proceedings A. S. C. E., Vol. XL, follows:

The viaduct has a 54-ft. clear roadway and two 8-ft. sidewalks. The general dimensions and type of construction are shown in Fig. 13.

Because of the sudden, large and rapid rises to which the Trinity River is subject it was thought advisable to use, at least for the arch spans, a method of construction that would not require falsework in the stream.

After a careful consideration of various types, it was decided to use, for the main spans of the viaduct, three-hinged, ribbed arches, with structural steel reinforcement designed to support the weight of the forms and the plastic concrete of the ribs and braces during construction. For the approach spans and for the river spans of the smaller viaducts girder spans were adopted.

The three-hinged arch was selected because it would not be strained by unequal settlement, because the stresses are statically determinate, and

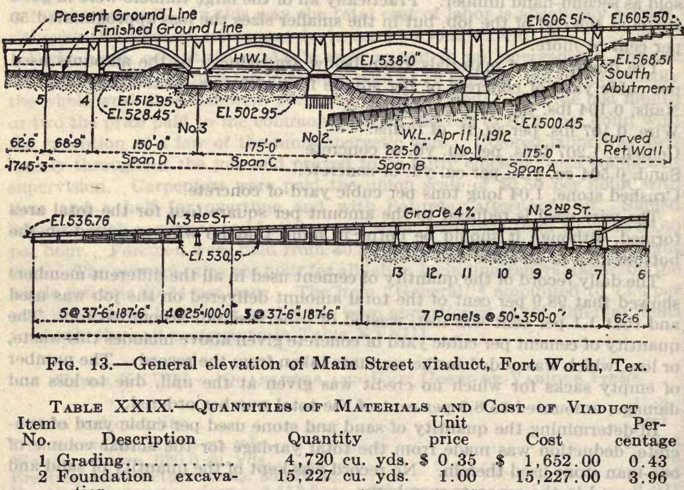


FIG. 13.—General elevation of Main Street viaduct, Fort Worth, Tex.

TABLE XXIX.—QUANTITIES OF MATERIALS AND COST OF VIADUCT

Item No.	Description	Quantity	Unit price	Cost	Percentage
1	Grading............	4,720 cu. yds.	$ 0.35	$ 1,652.00	0.43
2	Foundation excavation...............	15,227 cu. yds.	1.00	15,227.00	3.96
3	Rock excavation.....	444 cu. yds.	2.00	888.00	0.23
4	(a) Concrete No. 1 (1:2:4)...........	10,611 cu. yds.	10.25	108,762.75	28.16
	(b) Concrete No. 2 (1:2½:5)...........	14,880 cu. yds.	6.85	101,928.00	26.40
	(c) Concrete No. 3 (1:3:6)...........	438 cu. yds.	6.25	2,737.50	0.71
5	Railings...........	3,875 lin. ft.	2.00	7,750.00	2.01
6	Structural steelwork.	1,537,400 lbs.	0.05	76,870.00	19.90
7	Steel reinforcing bars.	1,375,150 lbs.	0.035	48,130.25	12.46
8	Steel castings........	205,460 lbs.	0.07	14,382.20	3.72
9	Iron castings........	11,173 lbs.	0.04	446.92	0.11
10	Anchor-bolts and T. P. casings.........	21,311 lbs.	0.06	1,278.66	0.33
11	Steel dowels.........	98	3.00	294.00	0.08
13	Rip-rap............	836 cu. yds.	1.50	1,254.00	0.32
14	Manholes..........	2	50.00	100.00	0.03
15	Removing old bridge.	....	......	2,500.00	0.65
17	Timber piles........	194	10.00	1,940.00	0.50
	Total..........................		....	$386,141.28	100.00

because the temperature stresses are eliminated. Ribbed construction was adopted as being light and best adapted to the use of hinges, and also because no waterproofing would be required. Structural reinforcement for the ribs and braces was used in order to dispense with falsework, as far as possible.

The cost of the viaduct, per linear foot, was $244.60; the cost, per square foot of horizontal projection, was $3.66; the cost, per square foot of vertical projection, was $6.34; and the cost, per cubic foot of volume, between finished ground line and crown of roadway, was $0.091. The total estimated cost of the viaduct, including paving, lighting and engineers' fees, was $428,882.

The cost per square foot of vertical projection is based on the area of the projection of the viaduct between the finished ground line and the top of the roadway. For the horizontal projection, the extreme width over the copings or stringer moldings was taken. In computing the cost per cubic foot the volume included between vertical planes through the copings and between the finished ground line and the top of the roadway was taken. The total cost on which the above unit costs are based is the cost of the structure based on the contractor's unit prices and the quantities as given in the table, to which has been added the cost of the paving, lighting, and engineers' fees.

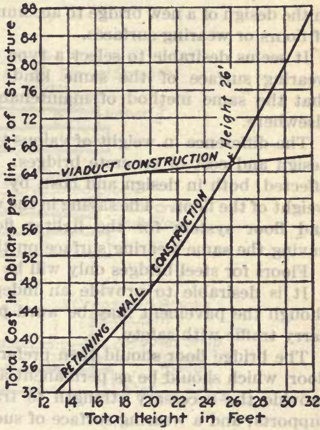


FIG. 13A.—Economic height-limit of retaining wall.

Economic Height-Limit of Retaining Wall as Compared with Viaduct Construction for Hill Side Road.—In constructing the side-hill road called Beardsley St., in Kansas City, comparative cost studies were made to determine at what height (from foundation to grade) viaduct construction would be more economical than retaining walls with fills.

The following cut reproduced from Engineering News-Record, June 13, 1918, shows the general method used. The solution in this particular case gave the economic height-limit of the retaining wall construction as 26 ft. In applying this method to other conditions it would be, of course, necessary to make a new diagram plotted from estimates for those conditions.

Cost of Steel Highway Bridges and Floors.—The following data, given in Engineering and Contracting, Jan. 1, 1915, are taken from a paper by Clifford Older (Bridge Engineer, Illinois Highway Commission) presented at the annual convention of the American Road Builders' Association in Chicago, Dec. 14–18, 1914.

Maintenance of Bridge Floors.—Definite statistics in regard to the number and length of highway bridges for any considerable mileage of highways are difficult to obtain and are not at present available. In some states, however, we are able to ascertain the amount of the total expenditure for bridge work of all kinds. Available information of this kind seems to indicate that approximately one-half of the funds raised for ordinary road and bridge purposes are expended in the renewal and maintenance of bridges.

It is evident, therefore, that if maintenance expenditures are to be reduced to the minimum highway bridges and bridge floors should receive careful consideration.

Judging from conditions in Illinois it is probable that at least 90 per cent of all existing highway bridges are provided with nothing better than plank floors, and that the maintenance of these floors costs approximately 15 per cent of the total expenditure for road and bridge maintenance, or about $10 per mile of road per annum.

Floors for New Bridges.—It is a simple matter to provide sufficient strength in the design of a new bridge to accommodate any of the various modern types of floors or wearing surfaces.

It seems desirable to select a type of floor which will permit the use of a wearing surface of the same kind as that on the adjacent highway, so that the same method of maintenance may be used on the bridge floor as elsewhere.

The difference in weight of vaious types of floors has but little effect on the design and cost of concrete bridges. Steel bridges, however, are materially affected, both in design and cost, by a comparatively small variation in the weight of the floor. The saving in the weight and cost of the steel in the trusses and floor system for the lighter floors may out-weigh the advantage of having the same wearing surface on the bridge as elsewhere on the highway.

Floors for steel bridges only will be considered in this discussion.

It is desirable to provide an independent wearing surface so that even though the pavement may be worn practically through, the bridge will still carry traffic with safety.

The bridge floor should then preferably consist of two elements: The sub-floor, which should be as permanent as the bridge superstructure, and should provide the necessary strength to transmit the highway loads to the floor supports; and a wearing surface of such character as to permit of economical maintenance.

In considering construction materials for both of these elements the matter of weight increases in importance with the length of span. For sub-floors of the more permanent type buckle-plates with concrete covering, reinforced concrete, and creosoted plank cover the field. For wearing surfaces, brick, concrete, creosoted blocks, macadam gravel, mixtures of bituminous materials with sand, gravel or stone, plank, ordinary soil, and practically all other varieties of surfacing materials have been used.

In comparing costs it is necessary to consider, not only the cost of the floor and its maintenance, but also the effect of the weight of floor selected on the design and cost of the remainder of the bridge.

Classification of Floors.—For the purpose of considering the effect of the weight of the floor on the design of the superstructure the various types of floors are herein grouped in four classes, as follows:

Class A Floors.—Floors which weigh approximately 100 lbs. per square foot of roadway surface are included in Class A. Floors consisting of a reinforced concrete sub-floor, assumed to weigh 50 lbs. per square foot, on which is placed a wearing surface of concrete, brick, macadam or gravel, are of this class. The wearing surface is assumed also to weigh 50 lbs. per square foot of roadway surface.

Class B Floors.—Floors which weigh approximately 65 lbs. per square foot of roadway surface are included in Class B. Floors consisting of a concrete sub-floor, with a creosoted block wearing surface, and floors consisting of creosoted plank sub-floors with a brick wearing surface, are of this class.

Class C Floors.—Floors which weigh approximately 32 lbs. per square foot are included in Class C. Floors consisting of a creosoted plank sub-floor, with a creosoted block wearing surface, are included in this class.

Class D Floors.—Floors which weigh approximately 26 lbs. per square foot are included in Class D. Floors consisting of a creosoted plank sub-floor, with a wearing surface about ¾ in. thick and composed of a mixture of gravel and bituminous material, are of this class.

Buckle-plate floors are not considered, as they weigh as much and cost more than concrete sub-floors.

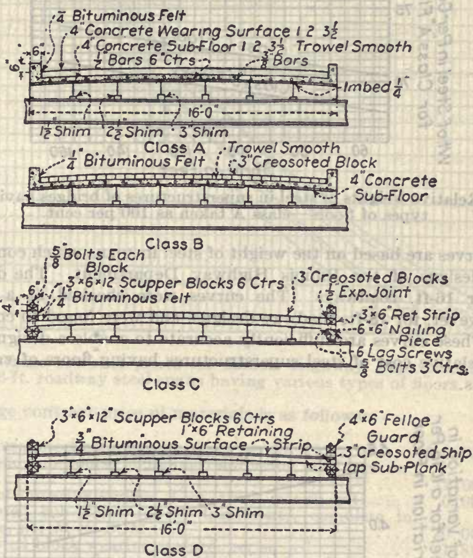


FIG. 14.—Standard types of bridge floors, Illinois Highway Department.

Standard Types of Floors.—Figure 14 shows standard designs used by the Illinois Highway Department for the floors above mentioned.

The creosoted plank sub-floors (Class C and Class D) are crowned by bending the plank over the stringers and anchoring the ends to the nailers by means of lag-screws.

The creosoted blocks (Class B and Class C) are laid on a ¼-in. bituminous felt cushion, which is coated with asphalt immediately before laying the blocks.

Ship-lap sub-plank are used for floors having a bituminous gravel wearing surface. The use of this form of sub-plank has been found to be the cheapest and most effective method of preventing the leakage of the bituminous material.

Explanation of Curves.—The curves shown in Fig. 15 give the weight of the structural steel in bridge superstructures as a percentage of the weight of the steel in superstructures having Class A floors, that is, the weight of superstructure steel in bridges having floors weighing 100 lbs. per square foot is taken as 100 per cent and the weight of steel required for the lighter floors is expressed as a percentage of this weight.

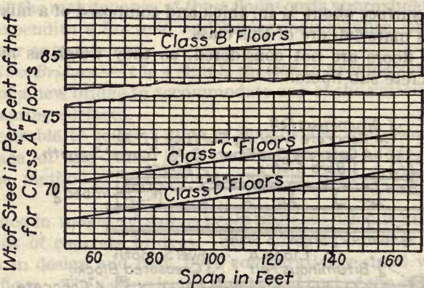


FIG. 15.—Relative weights of steel in superstructures of bridges having different types of floors—class A taken as 100 per cent.

These curves are based on the weight of steel in spans which conform to the standard designs of the Illinois Highway Department. The designs used provide for 16-ft. roadways. The curves were checked at a number of points, however, for 18-ft. roadway designs, and were found to conform very closely. These curves are sufficiently accurate to enable a designer to determine the relative cost of steel superstructures having floors of various types and weights.

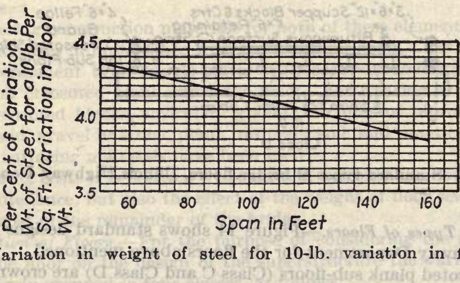


FIG. 16.—Variation in weight of steel for 10-lb. variation in floor weight.

The curve shown in Fig. 16 is based on the curves of Fig. 15, and it shows the average per cent variation in weight of steel for a variation of 10 lbs. per square foot in the weight of the floor.

Figure 17 shows the average contract prices for the Illinois Highway Department standard 15-ft. roadway steel spans with floors complete. For spans up to 80 ft., inclusive, riveted pony trusses are used, and for spans from 90 to 160 ft., riveted Pratt trusses are used. This range of span length covers at least 90 per cent of the highway bridges in Illinois.

"A."—Sub-floor concrete, surface concrete.
"B."—Sub-floor concrete, surface blocks.
"C."—Sub-floor plank, surface blocks.
"D."—Sub-floor plank, surface bituminous.
"D_1."—Sub-floor plank, surface bituminous—includes capitalized maintenance.
"E."—Untreated plank floor—includes capitalized maintenance.

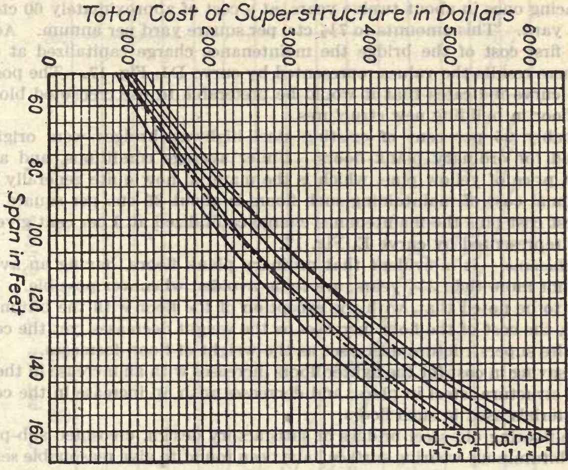


FIG. 17.—Average contract prices for Illinois Highway Department standard 16-ft. roadway steel spans having various types of floors.

The average contract price of materials is as follows:

Structural steel complete in place, per lb.	$ 0.03½
Concrete sub-floors, including reinforcing steel, per cu. yd.	12.00
Concrete wearing surface, 4 ins. thick, per sq. yd.	0.90
Creosoted sub-plank (12-lb. treatment), complete in place, per M ft. B. M.	70.00
Creosoted block wearing surface, per sq. yd.	1.80
Bituminous gravel wearing surface, per sq. yd.	0.60

The average cost of sub-floor and wearing surface per linear foot of 16-ft. wide roadway (1.78 sq. yds. including curbs) is as follows:

	Per lin. ft. of bridge
Concrete sub-floor with concrete wearing surface (wt. 100 lbs. per sq. ft.)	$4.25
Concrete sub-floor with creosoted block wearing surface (wt. 65 lbs. per sq. ft.	5.80
Creosoted plank sub-floor with creosoted block wearing surface (wt. 32 lbs. per sq. ft.)	7.30
Creosoted plank sub-floor with bituminous gravel wearing surface (wt. 26 lbs. per sq. ft.)	5.15

It seems probable that under average conditions the length of life of the floors represented by the upper three full-line curves of Fig. 17 may equal that of the remainder of the superstructure and that the cost of maintenance for this period would be small.

The experience of the Illinois Highway Department seems to indicate that, under average conditions, the bituminous wearing surface requires a light treatment of oil and stone chips or screened gravel at intervals of about four years, at a cost of about 10 cts. per square yard, and a probable complete resurfacing once in about twelve years, at a cost of approximately 60 cts. per square yard. This amounts to 7½ cts. per square yard per annum. Adding to the first cost of the bridge the maintenance charge capitalized at 6 per cent there results the values represented by curve D1, Fig. 17. The position of this curve indicates that it would be preferable to use creosoted block or other floor in building new structures.

Probably 95 per cent of existing steel highway bridges were originally designed for ordinary plank floors. Under average conditions, and at the present price of yellow pine, which is the material now quite generally used, the annual cost of maintaining such floors is about 35 cts. per square yard. The first cost plus the maintenance charge capitalized at 6 per cent gives the results represented by curve E, Fig. 17.

Conclusions.—It is evident that ordinary plank floors, having an average life of not more than 3½ years, are to be avoided whenever possible.

It is to be noted that, with the exception of the floor with the bituminous surface, the cost of the floor increases as the weight decreases, yet the cost of the entire superstructure decreases as the weight of floor decreases.

The saving in cost for the lighter floors increases with an increase in the unit cost of structural steel in place, and decreases with an increase in the cost of the materials used in such floors.

In re-flooring old steel bridges of satisfactory design, creosoted sub-planks with a bituminous wearing surface have been found to give reasonable service. The weight is somewhat greater than that of a plank floor, but the effect of the added weight is probably offset by the reduction of impact, due to the comparatively smooth and yielding surface.

The cost of maintaining the bituminous surface is only about 20 per cent of that of an ordinary plank floor.

There seems to be no place in the economic design of new highway bridges for floors consisting of a creosoted plank sub-floor with a brick wearing surface, as the life of such a floor could hardly be greater than that of Class C, Fig. 14, while the cost of the complete superstructure would be greater than that represented by curves B and C, Fig. 17.

The floors listed under Class A seem hardly to be justifiable, except for short spans, unless other considerations outweigh first cost.

Economic Panel Length for Bridge Floors of Concrete Slabs on Steel Beams.—William Snaith gives the following data in an article "Standard Bridge Floors of Concrete Slabs on Steel Beams" published in Engineering News-Record, July 12, 1917.

The floor systems investigated have been designed to meet the usual standard specifications as to construction. The dead-load D is taken to include the weight of the concrete slab, the supporting steel and two hand-rails each weighing 200 lb. per lin. ft. The live-load L is either a 15-ton road roller or a uniform load of 100 lb. per sq. ft., whichever gives the greatest stresses. The roller is assumed to consist of two back wheels with 20-in. face and 5-ft. center to center and of one front wheel with 40-in. face, the axles being 10 ft. center to center and the load on each of the three wheels being 10,000 pounds.

The effect of impact is calculated from the formula:

$$Impact = \frac{L_2}{2(D + L)}$$

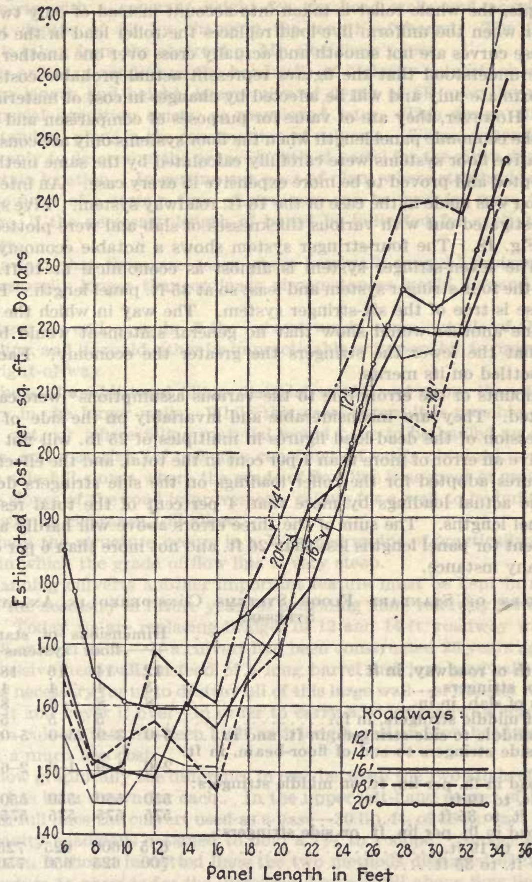


FIG. 18.—Estimated costs of floors per square foot, including floor-beams, stringers, slab and curb.

This impact formula will give uniformly better results than a straight percentage of the live-load or a formula based only on live-load and panel length.

Average prices for steel beams in place in bridge floors and for concrete in place were assumed, and the total cost of one bay (slab, curb, stringers and floorbeam) was calculated. These values were divided by the area of floor supported (nominal width multiplied by panel length), and the results were expressed in curves, Fig. 18.

Owing to the use of commercial sizes and abrupt changes in loading, when, for example, the whole roller is taken into account instead of only two back wheels, or when the uniform live-load replaces the roller load in the calculations, these curves are not smooth and actually cross over one another. It is not to be understood that the figures represent actual probable costs; they are approximate only and will be affected by changes in cost of materials and locality. However, they are of value for purposes of comparison and clearly indicate the economic panel length when the floor systems only are considered.

Alternative floor systems were carefully calculated by the same methods as those adopted and proved to be more expensive in every case. An interesting comparison was made in the case of the 16-ft. roadway system. Five systems were investigated out with various thicknesses of slab and were plotted similarly to Fig. 18. The four-stringer system shows a notable economy at all spans. The seven-stringer system is almost as economical at 10-ft. panel length as the four-stringer system and least so at 35-ft. panel length. Exactly the reverse is true of the six-stringer system. The way in which the curves crossed one another would show that no general statement would be warranted that the fewer the stringers the greater the economy. Each case must be settled on its merits.

The amounts of the errors due to the various assumptions* were carefully investigated. They are inconsiderable and invariably on the side of safety The expression of the dead-load figures in multiples of 25 lb. will not in any case involve an error of more than 1 per cent in the total, and the effect of the round figures adopted for the roller loadings on the side stringers does not exceed the actual loadings by more than 4 per cent of the total results at 35-ft. panel lengths. The sum of the three errors above will hardly amount to 4 per cent for panel lengths less than 20 ft. and not more than 6 per cent at 35 ft. in any instance.

PARTICULARS OF STANDARD FLOOR SYSTEMS CONSIDERED IN ANALYSIS OF STRESSES

	Dimensions of standard floor systems				
Clear width of roadway, in ft.	12	14	16	18	20
Number of stringers	3	4	4	4	5
Thickness of slab, in in.	8	8	8	8	8
Spacing of middle stringers, in ft.	...	5	5	5	5
Distance middle to side stringers, in ft. and in.	5–0	3–9	5–0	5–0	4–6
Distance side stringers to end of floor-beam, in ft. and in.	2–0	1–9	1–6	2–6	1–6
Dead-load in lb. per lin. ft. on middle stringers:					
Panels 6 ft. to 19 ft.	550	550	550	550	550
Panels 20 ft. to 35 ft.	575	575	575	575	575
Dead-load in lb. per lin. ft. on side stringers:					
Panels 6 ft. to 19 ft.	675	600	625	725	600
Panels 20 ft. to 35 ft.	700	625	650	750	625

* The assumptions were as follows:
1. Max. bending moment equals the sum of the Max. L.L. and D.L. moments.
2. D.L. per lin. ft. per stringer taken in round numbers to nearest multiple of 25 above the actual.
3. L.L. from the roller on side stringers taken in even thousands of pounds.
4. Wt. of each wheel acts at a point (in stringer and floor beam calculations).
5. In stringer calculations the slab is assumed not to be continuous.
6. Length of floor beam (between center line of trusses) is assumed to be 2 ft. greater than width of roadway.

The Economic Design of Culverts for Various Depths of Fill.—In a paper before the Ohio Engineering Society, an abstract of which is published in Engineering and Contracting, March 31, 1915, P. K. Sheidler of the Ohio Highway Department points out the advantages of using a standard design for culverts with a constant height for the head walls and providing for different depths of fill by changing the length of barrel. The following matter is taken from the abstract of Mr. Sheidler's paper.

Under ordinary conditions the headwalls of highway culverts should have the same length and height, irrespective of depth of fill over them—unless some special condition exists, as mentioned later. This design allows the use of standard plans in the construction of culverts To use a standard plan one has only to determine the proper length of barrel for the given depth of fill at a certain location. In getting out a set of plans where standards are used, one blue print of a certain type of structure can be used for more than one structure, if the necessary length of barrel be indicated for each particular structure.

It is a fact that there are cases where headwalls must be designed higher and necessarily longer than ordinary circumstances would demand. These are:

1. Where the end or ends of the culvert would come outside of the right-of-way line, and it would either be impracticable or impossible to procure additional right-of-way.

2. Where the additional filling material would cost more than the extra masonry in the larger walls. While this case is rare it is possible—such as in rock cut, or where filling material would have to be hauled an excessive distance, and materials for masonry construction easily obtained.

3. On side hill slopes where the grade of flow line is as great or greater than the side slopes of the road improvement, calling for a wall to be built as close to roadway as clearanee will allow.

4. Where the structure occurs in a V-shaped ravine of practically constant width, in which the grade of flow line is very steep.

In planning culverts another important feature must be kept in mind. I refer to the necessity in future years of providing more roadway for increased traffic. Today we are replacing bridges of 12 and 14-ft. roadway with those of 16, 18 or even 24 ft. If a culvert had been constructed 25 years ago with a high, massive headwall, instead of a long barrel and low headwall, today it becomes necessary for us to destroy all of this large wall—or at least to remove part of it and cover it over—in order to carry a wider roadway across. Extending a culvert that has been built with long barrel and low headwall can be done at a much less cost.

To show graphically the difference in cost between the two kinds of designs, a curve has been drawn for each. In the upper left-hand corner of Fig. 19 is shown in full lines the culvert used as a base—30 lin. ft. of 18-in. cast iron pipe with gravity headwalls designed to hold a 1½ to 1 slope. Superimposed on this section is shown in dotted lines the two methods discussed of increasing the structure to provide for the increased depth of fill above flow line.

Two tables were computed to obtain data for plotting the curves and are also shown. The table marked "A" gives total costs of culverts whose barrels are kept a constant length of 30 ft. and whose headwalls are raised and lengthened for different depths of fill varying by 1 ft.

Table "B" shows the cost of culverts whose headwalls are kept of constant dimension, and whose barrels vary in length to fit the road section.

TABLE A.—ESTIMATED QUANTITIES AND COSTS OF CULVERTS WITH HIGH HEAD WALLS

H = height above flow line	L = length of head wall	W = width of bottom	Concrete, cu. yds.	C. I. pipe, lin. ft.	Hand rail, lin. ft.	Cost of head wall	Cost of barrel	Cost of hand rail	Total cost
3	5′–0″	1′–9″	2.6	30	..	$ 20.80	$60.00	......	$ 80.80
4	8′–0″	2′–2″	5.8	30	..	46.40	60.00	......	106.40
5	11′–0″	2′–6″	10.4	30	20	83.20	60.00	$20.00	163.20
6	14′–0″	2′–9″	16.3	30	26	130.40	60.00	26.00	216.40
7	17′–0″	3′–2″	24.7	30	32	197.60	60.00	32.00	289.60
8	20′–0″	3′–6″	34.9	30	38	279.20	60.00	38.00	377.20
9	23′–0″	3′–9″	46.4	30	44	371.20	60.00	44.00	475.20
10	26′–0″	4′–2″	62.2	20	50	497.60	60.00	50.00	607.60
11	29′–0″	4′–6″	79.8	30	56	638.40	60.00	56.00	754.40
12	32′–0″	5′–0″	103.0	30	62	824.00	60.00	62.00	946.00

TABLE B.—ESTIMATED QUANTITIES AND COSTS OF CULVERTS WITH LOW HEAD WALLS

H = height above flow line	L = length of head wall	W = width of bottom	Concrete, cu. yds.	C. I. pipe, lin. ft.	Fill, cu. yds.	Cost of head walls	Cost of barrel	Cost of fill	Total cost
3	5′–0″	1′–9″	2.6	30	...	$ 20.80	$ 60.00	.....	80.80
4	5′–0″	1′–9″	2.6	33	...	20.80	66.00	.....	86.80
5	5′–0″	1′–9″	2.6	36	5	20.80	72.00	$ 2.00	94.80
6	5′–0″	1′–9″	2.6	39	10	20.80	78.00	4.00	102.80
7	5′–0″	1′–9″	2.6	42	25	20.80	84.00	10.00	114.80
8	5′–0″	1′–9″	2.6	45	45	20.80	90.00	18.00	128.80
9	5′–0″	1′–9″	2.6	48	60	20.80	96.00	24.00	140.80
10	5′–0″	1′–9″	2.6	51	100	20.80	102.00	40.00	162.80
11	5′–0″	1′–9″	2.6	54	125	20.80	108.00	50.00	178.80
12	5′–0″	1′–9″	2.6	57	175	20.80	114.00	70.00	204.80

The curve "C" was plotted to show the cost of fill that would be necessary to cover the barrel of the long culverts and to occupy the space taken up by the high headwalls, if they were to be removed. The area between the curves "B" and "C" represents this cost—the ordinates being plotted from the curve "B."

The sudden jump in the upper curve is caused by adding the cost of handrail to this type of culvert at the point where top of the wall is five feet above flow line in order to comply with the state law governing this. The assumed prices used are:

Concrete, cu. yd.	$8.00
18-in. cast iron pipe, lin. ft.	2.00
Handrail, lin. ft.	1.00
Earth fill, cu. yd.	.40

In order to show a specific example from these tables, we have selected the two types of culverts that would be necessary for a fill of ten feet above the flow line—the two types are superimposed to make the comparison more striking. This is shown in Fig. 19. The cost of the culvert with the high walls is $607.60, while that of the other is only $162.80, representing a saving of $444.80.

Cost of Concrete Arch and Pipe Culverts, Using Collapsible Steel Forms, Menominee County, Mich.—In extending the Bay Shore Road in 1911 a number of culverts were required. The costs of these culverts as built by force account are given in an article by K. I. Sawyer in Engineering and Contracting, March 13, 1912, from which paper the following data are taken.

Three sizes of concrete culverts were adopted for use on this road, standard sizes being used in batteries when necessary capacity required. The sizes adopted were 24 in. round tile and 48 and 96 in. diameter full arch culverts.

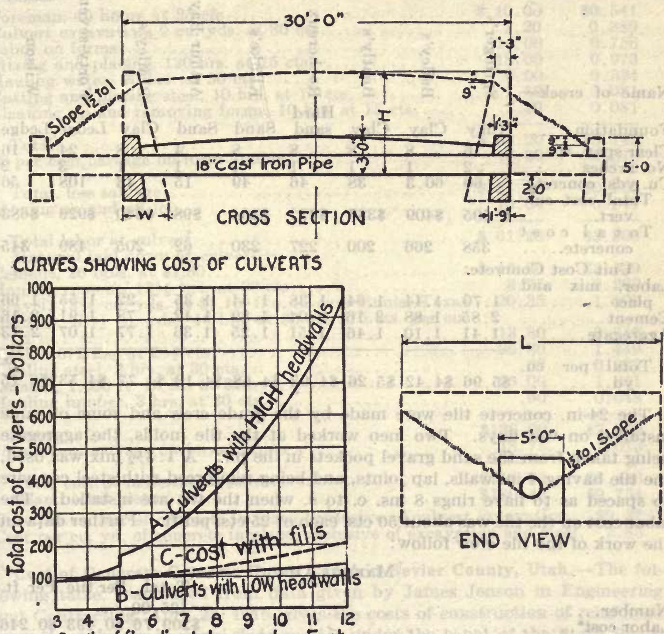


FIG. 19.—Curves showing the difference in cost under various depths of fill of a typical road culvert.

The so-styled culvert crew put in all the 4 and 8 ft. arches on this road and two arches on No. 1 road this season. The crew was equipped with Blaw collapsible steel centering, lumber and miscellaneous tools. The crew lived in tents, taking its own cook with it, and moved from creek to creek. All culverts are designed for 25 ton engine, live load; they are of monolithic pattern and without reinforcement. This latter requirement was not to the satisfaction of the engineer, but was necessary on account of local sentiment. The crew was inexperienced when started and the engineer lived practically on the job for the first two structures. Better success was had, however, than a year previous, when a culvert was installed by a crew of experienced sidewalk and street concrete workers.

Costs and data on culverts are given in Table XXX. The schedule of wages of this culvert crew was:

Foreman, 30 cts. per hour.
Teams, 45 cts. per hour
Labor, 20 cts. per hour.

TABLE XXX.—MASS CONCRETE CULVERTS—NO REINFORCEMENT

Name of creek—	Springer's	Bailey's	Beatly's	Rochereux	Klinke's	Arthur Bay	Brailey's	Forty-seven	Wilson
Foundation......	Clay	Clay	Clay	Hard sand	Sand	Sand	Clay	Ledge	Ledge
Clear span, ft ...	16	8	8	8	8	4	8	24	16
No. arches	2	1	1	1	1	1	1	3	2
Cu. yds. concrete.	60	60.3	38	46	49	15	43	108	56
Total cost culvert.	$ 505	$409	$387	$372	$364	$98	$340	$929	$683
Total cost concrete.....	358	266	200	227	230	62	205	489	345
Unit Cost Concrete:									
Labor, mix and place	1.70	1.44	1.64	1.38	1.54	1.35	1.22	1.55	1.66
Cement.........	2.85	1.88	2.16	2.04	1.89	1.42	1.78	1.91	2.16
Aggregate.......	1.41	1.10	1.46	1.51	1.25	1.36	1.77	1.07	2.13
Total per cu. yd..........	$5.96	$4.42	$5.26	$4.93	$4.68	$4.13	$4.77	$4.53	$6.15

The 24-in. concrete tile were made by the grade crew and some of same installed on wet days. Two men worked at the tile molds, the aggregate being taken from the sand gravel pockets in the pit. A 1:3½ mix was used, the tile having 4-in. walls, lap joints, and being reinforced with steel car wire so spaced as to have rings 8 ins. c. to c. when the tile are installed. The labor cost on the tile was about 50 cts. each or 25 cts. per ft. Further data on the work of the tile crew follow:

MAKING TILE

	Total	Per tile	Per ft.
Number..	425.00		
Labor cost*..	$209.76	$0.493	$0.246
Cement cost..	170.50	0.401	0.201
Total cost..	$380.26	$0.894	$0.447

INSTALLING TILE

	Total	Per tile	Per ft.
Number..	214	....	.....
Cost*..	$331.56	$1.55	$0.775

*Labor rates were the same as for the culvert crew.

Cost of a 4 × 5-Ft. Reinforced Concrete Box Culvert.—The following cost data on the construction of a 4 × 5-ft. concrete box culvert, 26 ft. long, given in Engineering and Contracting, Dec. 4, 1912, are taken from a bulletin on culverts and small bridges issued by the North Carolina Geological and Economic Survey. The culvert was constructed by a regular county concrete gang, composed of a foreman, seven men and two teams and drivers. It was completed in four days of 10 hours each. The excavation was light, but the soil was of a hard, black nature that was hard trimming. Water for mixing had to be hauled two miles. Sand gravel was used for aggregate in the concrete. The gravel contained a slight excess of sand. Mixing was done by hand with negro labor. Twisted square steel bars were used for reinforcing. The quantities were as follows: 14½ cu. yds. of 1:3:5 concrete; 4 cu. yds. of 1:2½:4 concrete; 432 lbs. of ¾-in. steel; 640 lbs. of ½-in. steel; and 1,000 ft. B. M. of lumber. The cost of the culvert was as follows:

	Total	Per cu. yd. concrete
Labor—		
Foreman, 40 hours at 25 cts.	$ 10.00	$0.541
Culvert excavation, 9 cu. yds. at 80 cts.	7.20	0.389
Labor on forms	14.00	0.756
Mixing and placing, 120 hrs. at 15 cts.	18.00	0.973
Hauling water, 20 hrs. at 30 cts.	6.00	0.324
Cutting and placing steel, 10 hrs. at 15 cts.	1.50	0.081
Cleaning up and removing forms, 10 hrs. at 15 cts.	1.50	0.081
Total	$ 58.20	$3.145
50 per cent salvage on form lumber	7.00	0.378
Total, less salvage	$ 51.20	$2.767
Moving on and off job	10.00	0.541
Total labor at culvert	$ 61.20	$3.308
Material laid down at culvert—		
Cement, 26 bbls. at $1.80	$ 46.80	$2.529
Hauling cement, 12½ hrs. at 30 cts.	3.75	0.203
Gravel, 18½ cu. yds. at $1.10, f. o. b. cars Ennis, Texas	20.35	1.100
Hauling, 18½ cu. yds., 46 hrs. at 30 cts. (75 cts. per cu. yd.)	13.80	0.746
Steel, 1,072 lbs. at 2½ cts.	26.80	1.449
Hauling steel, 2 hrs. at 30 cts.	.60	0.032
Lumber, 1,000 ft. B. M. at $25	25.00	1.351
Hauling lumber, 3 hrs. at 30 cts.	.90	0.048
Total	$138.00	$7.459
75 per cent salvage on form lumber	18.75	1.013
Total cost of material on job	$119.25	$6.446
Grand total cost of job	$180.45	$9.754
Cost per cu. yd. of concrete in place, exclusive of culvert excavation		$9.37
Cost per cu. yd. of concrete in place, exclusive of excavation and steel		7.85

Cost of Concrete Culverts Under Canal in Sevier County, Utah.—The following table, rearranged from data given by James Jenson in Engineering and Contracting, April 23, 1913, gives the costs of construction of reinforced concrete culverts to carry flood waters under the canal of the State Board of Land Commissioners, in Sevier county, Utah. The length of canal along which these culverts were distributed is ten miles. No two culverts were constructed from the same setting. On account of the comparatively small units in which this work had to be done, and the ruggedness of the country with reference to the moving of machinery and mixers, all concrete was mixed by hand. Sand and gravel for these structures was hauled by team an average distance of three miles, and constitutes the sole cost in column headed "Sand and Gravel." Water for mixing and camp purposes was also hauled by team a distance of two to three miles, and is included in the column headed "Haulage and Moving," which column also includes the cost of hauling cement, reinforcing steel, and form material from the railroad station, a distance averaging about eight miles. This column also includes the cost of moving apparatus and mixing boards from one setting to another; also moving the construction camp three different times.

The column headed "Hand Excavation" represents the cost of digging the trenches for the footing walls, and leveling the main trench for the culvert after it had been cut down practically to grade by team and scraper work.

The column headed "Form Material" is obtained from taking the total cost of all form material, including timber, wire, nails, etc., and dividing it up in proportion to the number of cubic yards of concrete in each structure. No deductions have been made from these averages on account of any salvage value of form material still on hand.

Two mixing gangs were used, each provided with its own accompaniment of apparatus and teams for hauling purposes. The work was done during the months of February, March and April, 1912, under extremely adverse weather conditions. During the major portion of this time all green concrete had to be covered up to keep it from freezing. No account was kept of this, but is included in the column headed "Mixing and Placing Concrete."

TABLE XXXI.—COST PER CU. YD. OF CULVERT CONSTRUCTION

TUBULAR CULVERTS

No.	C	18	3	7	1
Diam. ins.	18	18	18	18	24
Length, ft	49	49	52	68	30
Sacks of cement used	49	50	65	...	90
Lbs. of reinforcement used	200	180	200	217	272
Total concrete, cu. yds	9.8	10	13	13.6	18
Cost per cu. yd.:					
Cement	$ 3.102	$ 3.200	$ 3.200	$ 3.210	$ 3.200
Reinforcement at 3 cts. per lb.	0.612	0.540	0.461	0.479	0.453
Sand and gravel	2.857	1.960	1.723	1.815	1.400
Mixing and placing concrete	2.929	2.507	2.962	1.822	2.756
Total concrete	$ 9.500	$ 8.207	$ 8.346	$ 6.326	$ 7.809
Form material	2.022	2.023	2.023	2.022	2.023
Building and moving forms	0.535	0.512	0.404	0.354	0.458
Total forms	$ 2.557	$ 2.535	$ 2.427	$ 2.376	$ 2.481
Haulage and moving	1.523	1.333	1.333	1.333	1.333
Hand excavation	0.447	0.447	0.447	0.445	0.447
Grand total	$14.027	$12.522	$12.553	$10.480	$12.080

BOX CULVERTS

No.	B	24	9	10	21
Dimensions, ft	2 × 2	2 × 2	3 × 3	3 × 3	3 × 3
Length, ft	47.5	48	48	48	47.5
Sacks of cement used	66	69	130	138	141
Lbs. of reinforcement used	335	335	1,369	1,369	1,369
Total concrete, cu. yds	13.2	13.8	20.6	27.6	28.2
Cost per cu. yd.:					
Cement	$ 3.200	$ 3.200	$ 4.039	$ 3.200	$ 3.200
Reinforcement at 3 cts. per lb.	0.761	0.728	1.993	1.489	1.456
Sand and gravel	2.121	2.434	0.679	0.820	1.192
Mixing and placing concrete	2.683	2.283	2.961	2.075	2.406
Total concrete	$ 8.765	$ 8.645	$ 9.672	$ 7.584	$ 8.254
Form material	$ 2.022	$ 2.022	2.022	2.023	2.023
Building and moving forms	0.719	0.681	0.582	0.407	0.412
Total forms	$ 2.741	$ 2.703	$ 2.604	$ 2.430	$ 2.435
Haulage and moving	1.333	1.333	1.333	1.333	1.333
Hand excavation	0.447	0.447	0.447	0.447	0.447
Grand total	$13.286	$13.128	$14.056	$11.794	$12.469

BOX CULVERTS (cont'd)

No.	16	6	13	20	23
Dimensions, ft.	3 × 4	4 × 4	4 × 4	4 × 4	4 × 4
Length, ft.	46	47	49	50.5	48
Sacks of cement used	144	146	163	167	179
Lbs. of reinforcement, used	1,490	1,617	1,617	1,626	1,617
Total concrete, cu. yds.	28.8	29.2	32.6	33.4	35.8
Cost per cu. yd.:					
Cement	$ 3.200	$ 3.200	$ 3.200	$ 3.200	$ 3.200
Reinforcement at 3 cts. per lb.	1.552	1.661	1.488	1.460	1.355
Sand and gravel	0.833	1.151	1.032	1.089	1.173
Mixing and placing concrete	2.317	2.231	2.496	1.997	2.162
Total concrete	$ 7.902	$ 8.243	$ 8.216	$ 7.746	$ 7.890
Form material	2.023	2.022	2.022	2.023	2.023
Building and moving forms	0.455	0.613	0.552	0.392	0.503
Total forms	$ 2.478	$ 2.635	$ 2.574	$ 2.415	$ 2.526
Haulage and moving	1.333	1.333	1.333	1.333	1.333
Hand excavation	0.447	0.447	0.447	0.447	0.447
Grand total	$12.160	$12.658	$12.570	$11.943	$12.196

ARCH CULVERTS

No.	22	8	12	11	5
Dimensions, ins.	14 × 14	14 × 14	14 × 14	14 × 14	14 × 14
Length, ft.	48	52	60	66	52
Sacks of cement used	50	52	56	62	65
Lds. of reinforcement used	183	182	248	272	200
Total concrete cu. yds.	10	10.4	11.2	12.4	13
Cost per cu. yd.:					
Cement	$ 3.200	$ 3.200	$ 3.200	$ 3.200	$ 3.200
Reinforcement at 3 cts. per lb.	0.549	0.526	0.664	0.658	0.461
Sand and gravel	2.240	1.076	1.250	1.353	1.713
Mixing and placing concrete	2.080	4.985	3.062	2.879	3.236
Total concrete	$ 8.069	$ 9.787	$ 8.176	$ 8.040	$ 8.610
Form material	2.023	2.023	2.022	2.022	2.023
Building and moving forms	0.825	0.793	0.602	0.484	0.635
Total forms	$ 2.848	$ 2.816	$ 2.624	$ 2.506	$ 2.658
Haulage and moving	1.333	1.336	1.333	1.333	1.333
Hand excavation	0.447	0.447	0.447	0.448	0.450
Grand total	$12.697	$14.39	$12.584	$12.327	$13.051

The chief item of interest as shown by these cost data, aside from the general value for comparison with other structures of a similar nature and built under like conditions, is the inverse proportion of the labor costs to the size of the unit constructed, which emphasizes the importance of knowing not only total yardage of concrete to be installed, but also its distribution in various units, and the variation of size in these units.

Wages per day paid were as follows: Teams with driver, $4; foreman, $4; laborers, $2.25.

SUMMARY

A total of 3,093 sacks of cement and 22,640 lbs. of reinforcement was used in the 28 culverts, and an automatic spill, waste gate and waste valve. Total concrete, 613.1 cu. yds.

Item	Total	Av. per cu. yd.
Cement	$1,979.06	$ 3.23
Reinforcement at 3 cts. per lb.	679.20	1.11
Sand and gravel	810.51	1.32
Mixing and placing concrete	1,566.20	2.55
Total concrete	$5,034.97	$ 8.21
Form material	1,240.17	2.02
Building and moving forms	270.53	0.51
Total forms	$1,510.70	$ 2.53
Haulage and moving	748.43	1.22
Hand excavation	274.21	0.44
Grand total	$7,568.31	$12.40

Construction Cost of 5-ft. Combination Corrugated Pipe and Concrete Culvert.—The following data are taken from an article in Engineering and Contracting, Jan. 1, 1913, by John N. Eddy.

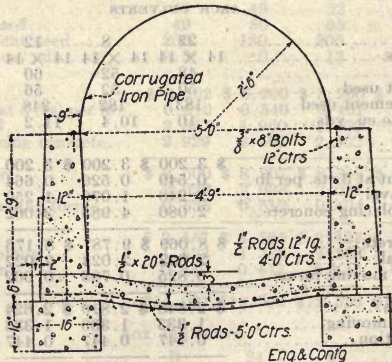


FIG. 20.—Combination corrugated pipe arch and reinforced concrete invert culvert.

Fig. 20 represents a section of a 40-ft. combination iron pipe and concrete culvert built by force account for the City of Billings, Mont. in the summer of 1912. This design assumes the use of a half-section of corrugated pipe for the arch only, which rests on side walls of concrete as shown. While it was found that the concrete portion cost approximately the same as a half-section of pipe, it was possible to secure slightly greater culvert area. The plan was adopted primarily as an experiment, and seems to have possibilities worthy of consideration. The figure showing the details of this design is self-explanatory.

In constructing the combination culvert, the side wall footings were placed first, after which the reinforced concrete floor was laid on a gravel base. Wall forms were then built and concrete poured. The setting and bolting of the iron arch completed the work with the exception of the end walls, which were then built. The cost of this culvert was as follows:

20 lin. ft. of 60-in. No-co-ro culvert pipe, at $5.44 per lin. ft.	$108.80
Cement, 62 bbls., at $2.10, net	130.20
Gravel, 37.5 cu. yds., at $1.25 per cu. yd	46.90
Lumber, 1,024 ft. B. M	28.70
Reinforcement, 183 lbs., at 5 cts. per lb	9.15
Backfilling, 248.5 cu. yds., at 17 cts. per cu. yd	42.25
Foreman, $4 per day of 8 hrs. Labor, $3 per day of 8 hrs.	401.30
Miscellaneous (hardware, power and wiring for pump, drayage, etc.)	27.00
Total cost	$794.30

Cost of Reinforced Concrete and Vitrified Pipe Culvert.—F. M. Balsey gives the following in Engineering News-Record, June 13, 1918.

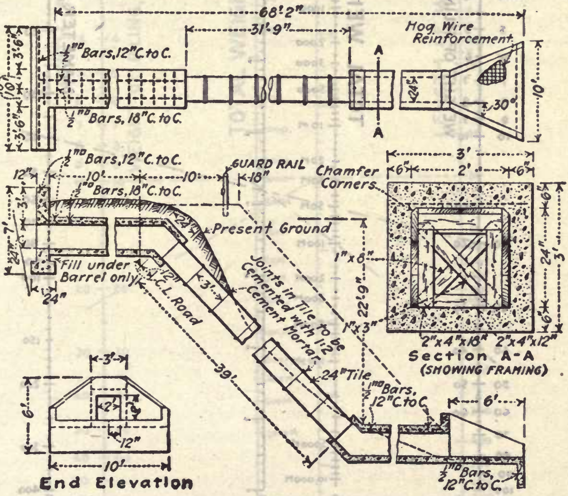


FIG. 21.—Special culvert for roads built in rolling country.

Drop-inlet culverts to convey water from the upper ditch to a point of discharge very much lower on the other side of the road are often necessary on highway work in rolling country. The design shown in Fig. 21, was worked up to meet a condition where the point of discharge was 24 ft. lower than the flow line of the upper ditch.

If a conventional drop-inlet culvert had been installed at this point it would have necessitated the excavation of a well at least 22 ft. deep and the driving of a tunnel from the bottom of this well to the point of discharge. Another alternative would, of course, have been to cut through the entire bank. In either case the excavation would have been difficult and expensive. The special design is considerably cheaper and in other ways much to be preferred.

Reference to the drawing will show that the ditch was cut to a slope of about 1½ to 1, and of a width to take the 24-in. sewer pipe which was used in place of concrete because no economical method could be devised by which the concrete could be poured on so steep a slope. Tile of this size could not be found

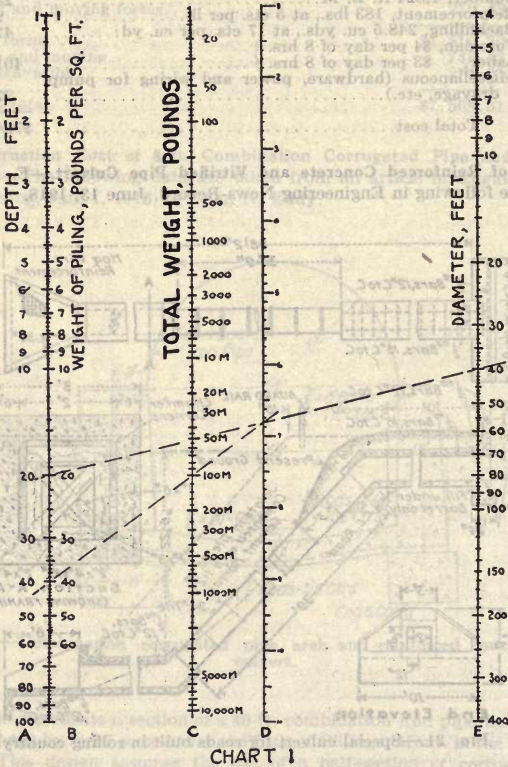


FIG. 22.—Chart for determining weight of steel sheeting required for circular cofferdams.

in stock in the neighborhood, and the necessity for ordering it specially added somewhat to the cost of the work, which was $227.61, distributed as follows:

Reinforced concrete, 10 cu. yd. at $11	$110.00
24-in. sewer pipe, 39 lin. ft.	52.71
Freight on pipe	31.40
Labor installing pipe	15.31
Contractor's fee, at 15 %	15.34

A total of 146 lb. of steel was required for the reinforcement exclusive of the "hog-wire" used in the apron. A complete bill of material follows:

Steel,
2½ in. sq. bars 16 ft. long
22½ in. sq. bars 2½ ft. long
6½ in. sq. bars 9½ ft. long
3½ in. sq. bars 14 ft. long
Cement, 15.5 bbl.
Sand, 4.3 cu. yd.
Stone, 8.6 cu. yd.

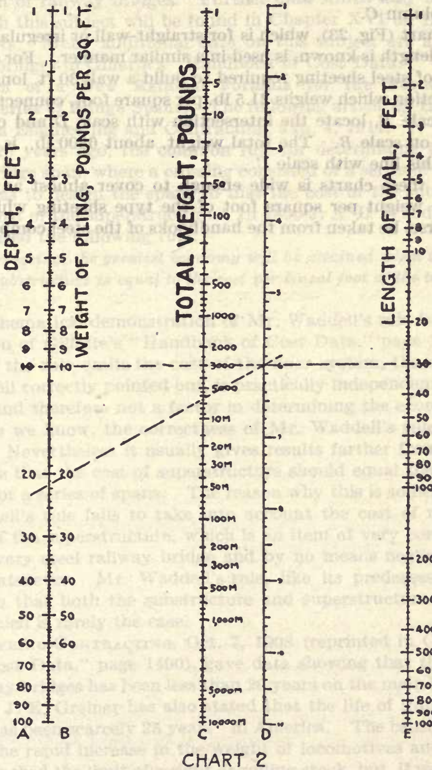


FIG. 23.—Chart for determining weight of steel sheeting required for straight-wall or irregular cofferdams.

The design can easily be modified in dimension or in slope of barrel to fit almost any condition found in the field. In many cases it will be found that considerable saving will result.

Weight of Steel Sheeting for Round or Box Cofferdams.—In Engineering Record, Oct. 7, 1916, N. G. Near gives the following nomographic charts which save considerable time in calculating the quantity of steel sheeting required for a given wall or cofferdam, especially in the case of a circular structure. Chart No. 1 (Fig. 22) is for computing the weight of such cofferdams, and its use may be illustrated by supposing that it is desired to find the weight of steel sheet piling required to construct a cofferdam 40 ft. in diameter and 20 ft. deep, assuming that a section weighing 40 lb. to the square foot is used. To solve this problem, connect 20 on scale *A* with 40 on scale *E* and locate the intersection with scale *D*. Connect the point thus found with 40 on column *B*. The weight, 100,000 lb., is then read at the intersection of this last line with column *C*.

The second chart (Fig. 23), which is for straight-wall or irregular structures where the total length is known, is used in a similar manner. For example, to find the weight of steel sheeting required to build a wall 30 ft. long and 10 ft. deep, using a section which weighs 21.5 lb. per square foot, connect 10 on scale *A* with 30 on scale *E*, locate the intersection with scale *D* and connect this point with 21.5 on scale *B*. The total weight, about 6500 lb., is read at the intersection of this line with scale *C*.

The range of these charts is wide enough to cover almost any sheet-pile structure. The weight per square foot of the type sheeting which is to be used can, of course, be taken from the handbooks of the steel companies which make piling.

CHAPTER XVII

RAILWAY BRIDGES

This chapter is made up of cost and other economic data relative to the construction of railway bridges. Further data which may be useful in connection with this subject will be found in Chapter XVI on Highway Bridges and Culverts. Many additional data on this subject are also given in the section on bridges in Gillette's "Handbook of Cost Data."

Deduction of a New Rational Formula for the Economic Length of Each of a Series of Bridge Spans.—The following article by H. P. Gillette was published in Engineering and Contracting, Jan. 4, 1911.

Up till 20 years ago, the common rule for determining the approximate length of bridge span, where a crossing consisted of a series of spans supported by piers, was to design the spans so that the cost of the substructure would equal the cost of the superstructure. In 1890 J. A. L. Waddell, M. Am. Soc. C. E., deduced the following rule:

For any crossing, the greatest economy will be attained when the cost per lineal foot of the substructure is equal to the cost per lineal foot of the trusses and lateral system.

The mathematical demonstration of Mr. Waddell's rule is reprinted in the 1910 edition of Gillette's "Handbook of Cost Data," page 1489. It will be noted that the rule omits the cost of the floor system, the cost of which, as Mr. Waddell correctly pointed out, is practically independent of the length of the span, and therefore not a factor in determining the economic span.

So far as we know, the correctness of Mr. Waddell's rule has never been disputed. Nevertheless it usually gives results farther from the truth than the old rule that the cost of superstructure should equal the cost of the substructure for a series of spans. The reason why this is so lies in the fact that Mr. Waddell's rule fails to take into account the cost of maintenance and renewals of the superstructure, which is an item of very considerable importance in every steel railway bridge and by no means negligible in any steel bridge whatsoever. Mr. Waddell's rule, like its predecessor, involves the assumption that both the substructure and superstructure are equally permanent which is rarely the case.

Engineering-Contracting, Oct. 7, 1908 (reprinted in Gillette's "Handbook of Cost Data," page 1490), gave data showing that the average life of steel railway bridges has been less than 20 years on the main lines of American railways. J. E. Greiner has also stated that the life of iron or steel railway bridges "has been scarcely 25 years" in America. The cause of this short life has been the rapid increase in the weight of locomotives and cars. Perhaps we have reached the limit of weight or rolling stock, but, if we are to judge the future by the past, we certainly have not reached the limit; and, if we have not, the life of steel bridges built today will probably be little if any greater than was the life of steel bridges built 20 years ago—at the time that Mr. Waddell deduced the rule above quoted.

Our object is to present a rational formula for determining the economic pan of each of a series of bridges, taking into consideration not only first cost but maintenance and depreciation. We shall show that, when these important factors are considered, a correct rule (= equation 17 deduced below) to be applied is as follows:

For the economic span, where a series of spans rest on piers, the length of span must be such that the first cost plus the capitalized cost of annual maintenance and depreciation of the longitudinal trusses (or girders) and the lateral system must equal the first cost plus the capitalized cost of annual maintenance and depreciation of the piers and other substructure.

We shall also deduce a general formula (eq. 16) that will give the economic length of span, for any class of bridge, upon substitution of proper values for the constants.

Proceeding now to the demonstration the following symbols will be used:

L = length, in feet, of span.
K = cost, in dollars, of each pier.
S = cost of substructure, in dollars, per lineal foot of bridge.
T = cost of trusses, in dollars, per lineal foot of bridge.
y = cost of entire bridge (piers and superstructure) per lineal foot.
p = price, in dollars, per pound of steel trusses in place.
w = weight of steel, in pounds, per lineal foot of entire superstructure.
C = a constant in the straight line formula for bridge weight ($w = CL + F$), the value of C depending on the type of bridge and the loading.
F = weight of steel floor system, in pounds, per lineal foot of bridge.
M = capitalized cost of annual repairs and renewals of steel trusses, expressed as a percentage of the first cost of the trusses.
N = capitalized cost of annual repairs and renewals of the pier, expressed as a percentage of the first cost of the pier.
B = width, in feet, of floor of a highway bridge.

The weight per lineal foot of a steel bridge, whether plate girder or truss bridge, may be expressed by the following general formula:

$$w = CL + F \qquad (1)$$

Hence the cost of the steel per lineal foot of bridge is

$$I = wp = pCL + pF \qquad (2)$$

When the cost of a pier is not affected by increasing or decreasing the length of bridge span, as is usually the case, then

$$S = \frac{K}{L} \qquad (3)$$

But

$$y = I + S \qquad (4)$$

$$y = pCL + pF + \frac{K}{L} \qquad (5)$$

To determine the minimum value of y (= cost per lineal foot of entire bridge), differentiate eq. (5), remembering that L and y are the only variables.

$$dy = pCdL - \frac{KdL}{L^2} \qquad (6)$$

Placing the first differential coefficient $\frac{dy}{dL} = 0$, we have

$$pC = \frac{K}{L^2} \qquad (7)$$

Substituting for $\frac{K}{L}$ its value in eq. (3), we have

$$pC = \frac{S}{L} \qquad (8)$$

$$pCL = S \qquad (9)$$

But pCL is the cost of the trusses per lineal foot of bridge, hence

$$T = pCL \qquad (10)$$

$$T = S \qquad (11)$$

Hence, for the economic span, the cost of the trusses per lineal foot of bridge must equal the cost of the pier per lineal foot of bridge, provided there is no annual expense for maintenance and depreciation.

If eq. (7) be solved for L, we have

$$L = \sqrt{\frac{K}{pC}} \qquad (12)$$

If eq. (7) be solved for K, we have

$$K = pCL^2 \qquad (13)$$

Equation (12) is to be used only where there is no annual expense for repairs or renewals of either substructure or superstructure, which is rarely the case.

If a steel bridge has a life of 20 years, and if money is worth 5 per cent per annum to the investor, a sinking fund table shows that \$3 must be put in the fund annually to amount to \$100 at the end of 20 years. This \$3 is the annual cost of renewals. Capitalizing it at 5 per cent, we have \$3 ÷ 0.05 = \$60, which is the capitalized cost of renewals on every \$100 of first cost of bridge steel in place. Hence the value of M in this case is 60 per cent, or 0.60. In other words the total cost of the steel per pound is $p + Mp$, or $(1 + M)p$, or $1.6p$ in this case, if we include not only the first cost but the capitalized cost of renewal.

In addition there is the annual cost of painting the steel. If it costs \$2 a ton to scrape and paint the steel, and if this is done every 5 years, we have \$0.40 as the annual cost of painting, which capitalized at 5 per cent is \$8 per ton. If steel costs \$80 per ton in place, the capitalized cost of painting the steel is 10 per cent, or 0.10, of its first cost. This 0.10 also is a part of M, hence the total value of M in this case is $0.6 + 0.1 = 0.7$. Hence in this case the entire cost of the steel per pound is its first cost plus its capitalized cost of renewal and painting, or $1.7p$. Therefore, if the steel in a bridge has a limited life, we must substitute for p, in eqs. (9) and (12) its entire cost, namely $1.7p$ in the particular case just discussed, or $(1 + M)p$ in any case. This gives us, instead of eqs. (9) and (12),

$$(1 + M)pCL = S, \text{ or } (1 + M)T = S \qquad (14)$$

$$L = \sqrt{\frac{K}{(1 + M)pC}} \qquad (15)$$

Assuming money to be worth 5 per cent per year, we can readily derive the capitalized cost of steel renewals for any given life of steel bridge, by the method above indicated, and adding 0.10, or 10 per cent, as the capitalized cost of painting, we have the total value of M as in Table I.

TABLE I

Life in years	Value of M
20	0.60
25	0.52
30	0.40
35	0.32
40	0.27
50	0.20

Values of C may be derived from formulas giving the weight of steel per lineal foot of bridge. Using the formulas given on pages 1471, 1474 and 1478 of Gillette's "Handbook of Cost Data," 2nd edition, we have Table II.

TABLE II

C = 7, for single track railway truss bridges, Cooper's E-50 loading.
C = 12, for plate girder bridges, ditto.
C = 1½, for single track electric railway truss bridges, loaded with 30-ton cars, or 2,000 lbs. per lin. ft.
C = 5, for plate girder bridges, ditto.

$C = \frac{B}{11.3} = 0.09\ B$, for highway riveted steel truss bridges, with sidewalks, wooden floor system, loaded 80 lbs. per sq. ft., with sidewalks (B being width in feet of floor, including width of sidewalk).

$C = \frac{B}{9.5} = 0.11\ B$, for ditto without sidewalks.

$C = \frac{B}{4.25} = 0.24\ B$, for through plate girders, ditto.

$C = \frac{B}{5} = 0.20\ B$, for deck plate girders, ditto.

$C = \frac{B}{4} = 0.25$, for truss highway bridge with solid floors (assumed dead weight being 150 lbs. per sq. ft. of floor).

$C = \frac{B}{2.4} = 0.42\ B$, for through plate girders, ditto.

$C = \frac{B}{2.6} = 0.38$ for deck plate girders, ditto.

There are some rivers and river beds of a character that necessitate considerable expenditures for riprap and other pier protection at frequent intervals. In such cases, the annual cost of pier protection should be capitalized and added to the first cost. Thus, if \$50 is the average annual expenditure for pier protection and maintenance, we have \$50 ÷ 5 per cent = \$1,000, which is the capitalized cost of pier maintenance. If the first cost of the pier is \$2,500, this \$1,000 is 40 per cent, or 0.40, of the first cost. Hence $N = 0.4$, and in eq. (15) we must substitute $(1 + N)K$ for the value of K there given, if we are to take into consideration the capitalized maintenance cost of the pier as well as its first cost. Then we have

$$L = \sqrt{\frac{(1 + N)K}{(1 + M)pC}} \qquad (16)$$

In like manner, eq. (14) becomes

$$(1 + M)T = (1 + N)S \qquad (17)$$

Eq. (17) is the rule printed above in italics.

EXAMPLES

Example I.—Assume a first cost for a bridge pier of \$2,500, a first cost of \$0.04 per lb. for steel in place, a life of 30 years for the steel, of a single track railway truss bridge, Cooper E-50 loading. What is the economic span when there are a series of spans?

In eq. (15) substitute the above values, and we have

$$L = \sqrt{\frac{K}{(1+M)pC}} = \sqrt{\frac{2{,}500}{(1+M)\times 0.04C}} \quad \text{(16)}$$

Table I gives $M = 0.4$ for a life of 30 years.

Table II gives $C = 7$ for a truss railway bridge.

Therefore,

$$L = \sqrt{\frac{2{,}500}{1.4 \times 0.04 \times 7}} = 80 \text{ ft.} \quad \text{(17)}$$

Hence the economic span is 80 ft.

Example II.—Assume a solid floor highway truss bridge with floor width (B) of 24 ft., a cost of each pier of \$3,600, a first cost of \$0.04 per lb. for steel in place, a life of 40 years for the steel. What is the economic span?

$$L = \sqrt{\frac{K}{(1+M)pC}} = \sqrt{\frac{3{,}600}{(1+0.27)\times 0.04 \times 6}} = 109 \quad \text{(16)}$$

Hence the economic span is 109 ft.

Example III.—A series of railway truss bridge spans consists of 150 ft. spans; the loading is Cooper E-50; steel costs 4 cts. per lb. in place. What should be the cost of each pier to justify such a span, even assuming that the steel requires no repairs and renewals?

Eq. (13) gives the desired value for K, hence

$$K = pCL^2 = 0.04 \times 7 \times 150 \times 150 = \$5{,}300 \quad \text{(17)}$$

A concrete pier containing 200 cu. yds. and costing \$12.50 per cu. yd. including cost of cofferdam, excavation and foundation piles, costs \$2,500. Such a \$2,500 pier is fairly typical, and railway spans of 150 ft. may be frequently seen on piers of no greater size and cost, showing that a much shorter span than 150 ft. should have been used. In fact, as was shown in Example I, a span of 80 ft. is the economic where piers cost \$2,500 each, and where the life of the steel bridge is 30 years, money being worth 5 per cent.

Discussion.—It will be noted that Mr. Waddell's rule (eq. 11), or its equivalent as given in eq. (12), results in a considerably longer span than is obtained by the use of the correct rule (eq. 17), or its equivalent as given in eq. (16).

A study of eq. (16) or (17) shows that an engineer should make the surveys for and designs of the piers of a bridge crossing, and should carefully estimate the cost of piers before attacking the problem of designing the span. The size and cost of a pier are usually not materially affected by the cost of the span, whereas the length and cost of the span are functions of the cost of the pier. Many bridge engineers have attacked such problems wrong end to, selecting span lengths in advance of determining the probable cost of piers. Witness to this may be had by studying published costs of bridge crossings, as well as by even cursory examination of many crossings.

Rules for Designing Bridge Spans, the Cost of Whose Supports Varies with the Span Length.—In the deduction of the preceding formulas it has been assumed that the cost of each pier, K, was not affected by the length of the span. This usually holds true of piers in rivers, for their cross-section is designed to resist the thrust and impact of ice, logs, boats, etc., and is, therefore, far in excess of a cross-section required merely to support the bridge spans and their loads. But when a bridge is built over the land, or in still water where boats do not ply, or wherever the piers (or their equivalent) are given a cross-section sufficient merely to support the load, the preceding formulas can not be used without modification.

When a pier becomes merely a supporting column, its cross-section varies directly with the load. Hence doubling the span doubles the load on the column, and therefore doubles its area of cross-section and approximately doubles its cost. In brief, the total cost of columns is practically a constant for any given length of crossing, regardless of the lengths of individual spans. Such columns are like the floor system in that their cost per lineal foot of bridge is unaffected by changes in the span lengths. Hence, the formulas above given can be applied to a series of spans supported by columns, only upon condition that the cost of the columns be entirely ignored. In the case of an elevated railway, for example, K (in the above formulas), becomes merely the cost of the foundations, or, more correctly, the cost of that part of the foundation not appreciably affected by the load upon the column. The same holds true of viaducts.

A study of the detailed cost of a number of steel viaducts, given in Gillette's "Handbook of Cost Data," page 1620 et seq., shows that several viaducts approximate closely to eq. (17), but that many of them fall wide of the economic mark, so wide, in fact, that it is quite clear that the designers made little or no advance study of the cost of the foundation and pedestals.

Cost of elevated railways, in the same book, page 1376 et seq., show similar errors of economic design, if no account is taken of the fact that close spacing of columns on city streets is often prohibitory, because of damage, or alleged damage, to property. This last factor, however, is one that frequently operates to produce longer spans of elevated railway girders than would otherwise be economically permissible.

It is evident that in applying eq. (17), the designer must bear in mind that no part of the cost of the substructure which is a function of the load of the span and its live load should be regarded as being a part of K. When this provision is held clearly in mind, eq. (17) furnishes a correct solution not only for bridge spans on masonry piers, but for viaducts and elevated railways.

Deduction of a Formula for the Most Economic Span of Timber Trestles.—The following is an article by H. P. Gillette in Engineering and Contracting, April 17, 1912.

The calculation for timber trestle spans differs mainly from that for steel spans in that the masonry piers for steel spans have a much longer life than that of the steel spans, whereas the bents of a trestle usually have a life that is the same as that of the stringers or beams. The economic effect of a life of masonry piers that is longer than the life of the supported steel spans is fully discussed in the preceding pages. In the same article it is shown that the cost of the floor system does not enter as a factor in the problem of most economic steel span. Similarly, of course, the cost of the "deck" of a railway trestle or the cost of the floor plank of a highway trestle does not enter the problem before us.

Let

C = total cost (in dollars) of beams or stringers in a span.

c = cost of beams per lin. ft. of trestle.

K = total cost of a bent.

k = cost of bents per lin. ft. of trestle.

y = combined cost of beams and bents per lin. ft. of trestle.

W = total safe load (dead and live) in lbs. at center of a span

F = constant for any given kind of timber = 70 for southern yellow pine.

b = aggregate breadth, in inches, of beams in a span.

d = depth of beam, in inches.

L = length of span, in feet.

M = number of 1,000 ft. B. M. of beams in a span.

p = price (in place) per M. of timber in beams, in dollars.

(1) $C = pM.$

(2) $c = \dfrac{pM}{L}.$

(3) $k = \dfrac{K}{L}.$

(4) $y = c + k = \dfrac{pM}{L} + \dfrac{K}{L}.$

(5) $W = \dfrac{Fbd^2}{L}.$ (See theoretical mechanics.)

(6) $bd = \dfrac{WL}{Fd}.$

(7) $M = \dfrac{bdL}{12{,}000}.$

(8) $bd = \dfrac{12{,}000M}{L}.$

Combining (6) and (8)

(9) $\dfrac{WL}{Fd} = \dfrac{12{,}000M}{L}.$

(10) $M = \dfrac{WL^2}{12{,}000Fd}.$

Substituting in (4).

(11) $y = \dfrac{pWL}{12{,}000Fd} + \dfrac{K}{L}.$

To solve for a minimum unit cost (y), differentiate and place the first differential coefficient equal to zero.

(12) $dy = \dfrac{pWdL}{12{,}000Fd} - \dfrac{KdL}{L^2}.$

(13) $\dfrac{dy}{dL} = \dfrac{pW}{12{,}000Fd} - \dfrac{K}{L^2} = 0.$

(14) $K = \dfrac{pWL^2}{12{,}000Fd}.$

Substituting value of M (see eq. 10) in eq. (14).

(15) $K = pM$.

But by eq. (1), $pM = C$, hence

(16) $K = C$.

Hence the most economic trestle span is secured when the cost of a single bent equals the cost of all the beams or stringers in a single span.

To arrive at a formula that will give the length of the most economic span directly, solve for L in e. (14). Then:

$$(17)\ L^2 = \frac{12{,}000KFd}{pW}.$$

$$(18)\ L = \sqrt{\frac{12{,}000KFd}{pW}} = 110\sqrt{\frac{KFd}{pW}}.$$

nearly. Equation (18) is the desired formula by which to determine the most economic span for a timber trestle.

It will be observed that the first step in solving for L in eq. (18) is the determination of the cost (K) of a bent. It will also be noted that K is assumed not to be affected by the length of the spans between bents, which is essentially true in all ordinary railway and wagon trestles, for the posts are commonly made of some standard cross-section (as 12 × 12 ins.) regardless of the height of the bents, and so large a factor of safety is used for the posts that the number of posts in a bent is not altered by ordinary changes in the spacing of the bents; that is, in the span of the beams. If, however, change is made in the amount of timber in the bents because of increased live load per bent due to longer spans, then, although there is an increase of material in the posts per bent, there is no increase in the total material of all the posts in the whole trestle. In other words, changes in the amount of material in posts of a bent resulting from increased spans cause no change in the material in all the posts per lin. ft. of bridge; hence we must confine our attention, in solving for K, to such costs of a bent as remain unaffected by changes in spacing of bents.

For any given type of trestle and loading, the cost per bent (K) is mainly a function of the height of the bent and the price of timber in place. Hence the economic span L varies approximately as the square root of the height of average bent in the trestle. This is a point that is seldom given enough consideration by designers of trestles.

The ordinary limitations as to commercial length (L) and depths (d) of timber beams do not permit any great refinement in solving for the most economic span in trestles. But on the Pacific coast, where very long and large timbers are available at low cost, trestle designers can use eq. (18) to great advantage. The writer has seen any number of wagon road and railway trestles on the Pacific coast that were uneconomically designed, apparently because "standard designs" worked out for eastern conditions had been adopted. Highway trestles with bents spaced 16 ft. apart are far from being economic in a country where timbers 30 ft. long are available and cheap; yet a 16 ft. spacing of bents is often used for wagon road trestles, merely because it is "standard." Standard designs are money savers when standard conditions exist, but otherwise standard designs are frequently causes of great waste of money.

Equation (18) makes it evident that before the spacing of bents is decided upon, the average height of bents should be determined. It also shows that the unit price (p) of timber is an important factor when the unit price of timber in the beams exceeds that in the bents, as often happens where very long beams are required.

The safe center load (W) should of course include the load of the beams and deck, and this is readily allowed for by remembering that a uniformly distributed load is equal in effect to half as great a center load on a beam.

Equation (18) contains the element d, or depth of beam; d is usually made as great as possible, having regard to commercial sizes of timber and the effect of d upon the unit price of timber (p). In any given market the relation

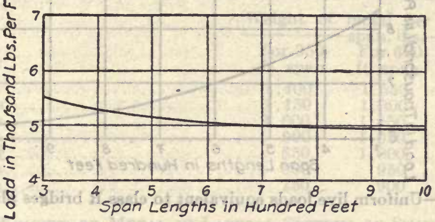


FIG. 1.—Uniform live load equivalent to class R bridges.

of p to d (the depth) and L (the length) of beams can be determined and expressed in the form of an equation, so that the value of p thus determined can be substituted in eq. (18), thus permitting a direct solution of the problem without resorting to the clumsier method of successive approximations.

A Comparison of Carbon Steel and High-alloy Steels for Bridges.—The following data on "High-alloy Steels for Bridges," abstracted and rearranged from a paper by J. A. L. Waddell, in Proceedings, American Society of Civil Engineers, Vol. XL, p 669, and from the discussion of this paper on p. 1613 of

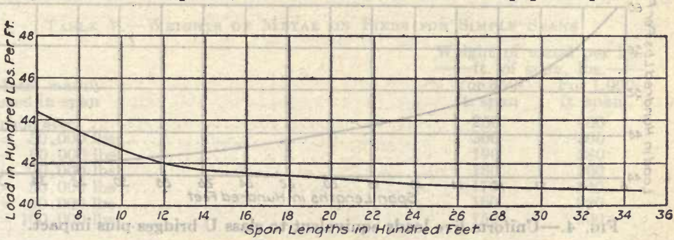


FIG. 2.—Uniform live load equivalent to class U bridges.

the Proceedings, were published in Engineering and Contracting, June 17, 1914.

A condition which at present militates seriously against the use of nickel steel in bridge building is that the manufacturers ask for it an additional price of about 2 cts. per pound, as compared with ordinary carbon steel, although but little more than one-half that would be a sufficient excess price. As the future development of America will necessitate the construction of many long-span bridges it is almost a necessity that there be found an alloy of steel of great strength, high elastic limit, workable under all necessary manipulations in the shops, and of moderate cost. It is realized that the discovery of such an alloy will require much study and exhaustive experiments, but the saving in cost of a single large bridge might easily exceed the entire expenditure for such experiments.

The basis of the following investigation is a mass of diagrammed and tabulated data on the weights of metal in simple spans and cantilever bridges of carbon steel, up to a limit of 600-ft spans for the former and 1,800-ft. main openings for the latter, accumulated by the writer and his firm during the last

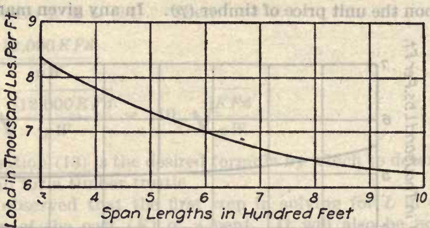


Fig. 3.—Uniform live loads equivalent to class R bridges plus impact.

25 years, together with the weights of nickel-steel bridges and of mixed nickel-steel and carbon-steel bridges computed by the writer in the preparation of a previous paper on "Nickel-Steel for Bridges." As the weights of metal per linear foot in simple truss bridges were limited to lengths of 600 ft. in the former paper they have here been extended to 1,000 ft. by making actual calculations of stresses, sections, and weights of metal for several long spans, using the various kinds of steel assumed. The weights for bridges of carbon steel are based on the standard specifications given in the writer's "De Pontibus." They are quite accurate up to the limits of 1,000 ft. for

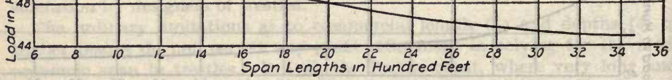


Fig. 4.—Uniform live loads equivalent to class U bridges plus impact.

simple spans and 1,800 for the main openings of cantilever bridges. Figs. 1 and 2 give the equivalent uniform live load per linear foot of single track assumed in computing the weights of trusses. The impact percentages were obtained from the writer's formula.

$I = \dfrac{40,000}{L + 500}$, where I is the percentage of impact, and L is the loaded length, in feet, required to give the maximum stress. Figs. 3 and 4 give a combination of the equivalent uniform live loads and the impact loads. The loads obtained from these curves added to the dead loads give the total loads per linear foot used for the bridges.

Tables III to VIII, inclusive, give the approximate weights of metal, in pounds per linear foot of span, for the floor system, lateral system and on piers for simple and cantilever bridges, for various spans and elastic limits, *E*. From these tables and the diagrams shown in Figs. 5 and 6 (which will be explained later) there can be determined the weights for the trusses.

(The author develops reduction formulas for determining the weights of floor systems, lateral systems and on piers of alloy-steel bridges from the known weights of carbon-steel bridges, but we have omitted these in our abstract.)

TABLE III.—WEIGHTS OF METAL IN FLOOR SYSTEMS OF SIMPLE SPANS

Metal mainly used in span	Weight of metal per lin. ft. of span, lbs. For 350-ft. span	For 600-ft. span	For 1,000-ft. span
Carbon steel	1,400	1,550	2,000
E = 50,000 lbs.	1,150	1,300	1,750
E = 60,000 lbs.	1,000	1,150	1,600
E = 70,000 lbs.	900	1,050	1,500
E = 80,000 lbs.	850	1,000	1,400
E = 90,000 lbs.	800	950	1,300
E = 100,000 lbs.	750	900	1,200

TABLE IV.—WEIGHTS OF METAL IN LATERAL SYSTEMS OF SIMPLE SPANS

Metal mainly used in span	Weight of metal per lin. ft. of span, lbs. For 350-ft. span	For 600-ft. span	For 1,000-ft. span
Carbon steel	450	600	1,200
E = 50,000 lbs.	450	600	1,150
E = 60,000 lbs.	450	600	1,100
E = 70,000 lbs.	450	600	1,050
E = 80,000 lbs.	450	600	1,000
E = 90,000 lbs.	450	600	950
E = 100,000 lbs.	450	600	900

TABLE V.—WEIGHTS OF METAL ON PIERS FOR SIMPLE SPANS

Metal mainly used in span	Weight of metal per lin. ft. of span, lbs. For 350-ft. span	For 1,000-ft. span
Carbon steel	250	400
E = 50,000 lbs.	200	300
E = 60,000 lbs.	190	280
E = 70,000 lbs.	180	260
E = 80,000 lbs.	170	240
E = 90,000 lbs.	160	220
E = 100,000 lbs.	150	200

TABLE VI.—WEIGHTS OF METAL IN FLOOR SYSTEMS OF CANTILEVER BRIDGES

Metal mainly used in span	Weight of metal per lin. ft. of span, lbs. 600-ft. span	1,200-ft. span	1,800-ft. span	2,400-ft. span	3,000-ft. span	3,600-ft. span
Carbon steel	1,600	1,800	2,000	.....	.....	.....
E = 50,000 lbs.	1,200	1,450	1,650	2,400	.....	.....
E = 60,000 lbs.	1,000	1,200	1,400	2,100	.....	.....
E = 70,000 lbs.	950	1,150	1,300	1,850	.....	.....
E = 80,000 lbs.	900	1,050	1,200	1,700	2,200	.....
E = 90,000 lbs.	850	950	1,100	1,600	2,000	.....
E = 100,000 lbs.	800	900	1,000	1,500	1,900	2,400

TABLE VII.—WEIGHTS OF METAL IN LATERAL SYSTEMS OF CANTILEVER BRIDGES

Metal mainly used in span	Weight of metal per lin. ft. of span lbs. 600-ft. span	1,200-ft. span	1,800-ft. span	2,400-ft. span	3,000-ft. span	3,600-ft. span
Carbon steel	800	1,100	1,400	.....	....	.....
E = 50,000 lbs.	800	1,050	1,300	1,800	.....	.....
E = 60,000 lbs.	800	1,000	1,200	1,600	.....	.....
E = 70,000 lbs.	800	1,000	1,200	1,600	2,000	.....
E = 80,000 lbs.	800	1,000	1,200	1,600	2,000	.....
E = 90,000 lbs.	800	1,000	1,200	1,600	2,000	2,400
E = 100,000 lbs.	800	1,000	1,200	1,600	2,000	2,400

TABLE VIII.—WEIGHTS OF METAL ON PIERS FOR CANTILEVER BRIDGES

Metal mainly used in span	Weight of metal per lin. ft. of span, lbs. 600-ft. span	1,200-ft. span	1,800-ft. span	2,400-ft. span	3,000-ft. span	3600-ft. span
Carbon steel	700	1,100	2,100	.....	.....	.....
E = 50,000 lbs.	600	900	1,700	.....	.....	.....
E = 60,000 lbs.	580	860	1,600	2,200	.....	.....
E = 70,000 lbs.	560	820	1,500	2,100	3,500	.....
E = 80,000 lbs.	540	780	1,400	2,000	3,200	.....
E = 90,000 lbs.	520	740	1,300	1,900	2,900	3,900
E = 100,000 lbs.	500	700	1,200	1,800	2,600	3,600

The weight in pounds per linear foot of the trusses of simple carbon steel spans may be expressed by the formula,

$$T = K + T_1 + C_c + C_w,$$

where K is the part of the total truss weight per linear foot which is independent of the quality of the metal and of the stresses; T_1 is the weight of the main portions of the tension members and of their details which are directly affected by the stresses; C_c is the weight of the main portions of the compression chords and inclined end posts and their details which are directly affected by the stresses; and C_w is that of the main portions of the compression web members which are directly affected by the stresses. From experience in designing large bridges it may be stated that, as an average, $K = 0.2T$; $T_1 = 0.3T$; $C_c = 0.3T$; and $C_w = 0.2T$.

It is well known that in trusses with parallel chords and of economic depths the weight of the chords is equal to the weight of the web; but in trusses with polygonal chords, having center depths less than the theoretically economic ones, as do those of all long-span bridges, the weight of the chords is much greater than that of the web. As a general average for long spans the ratio of weight of chords to that of webs is about 6 to 4.

Fig. 5 gives the total weight of metal per linear foot of span in simple-truss bridges for "Class R" live load, for carbon steel and for alloy steels having various elastic limits. An inspection of these curves shows the great saving in weight of metal which may be obtained by using alloy steels instead of carbon steel. This difference is most apparent between the weights for alloy steel having an elastic limit of 50,000 lbs. (the nickel steel which the manufacturers are willing to furnish) and that having an elastic limit of 60,000 lbs. The gradual reduction in the saving of metal with the increase of elastic limit is strikingly noticeable; and the conclusion may be drawn that, unless the extremely high-alloy steels can be obtained with only a moderate increase in cost, there will be no economy in using them for simple-span bridges.

Fig. 6 gives the average total weights of metal per linear foot of span for

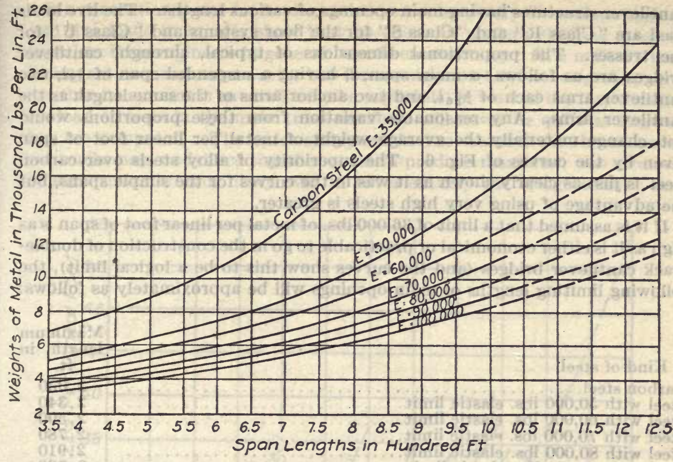


Fig. 5.—Total weights of metal per linear foot of span for double-track, simple-span bridges of carbon steel and alloy steels of various elastic limits.

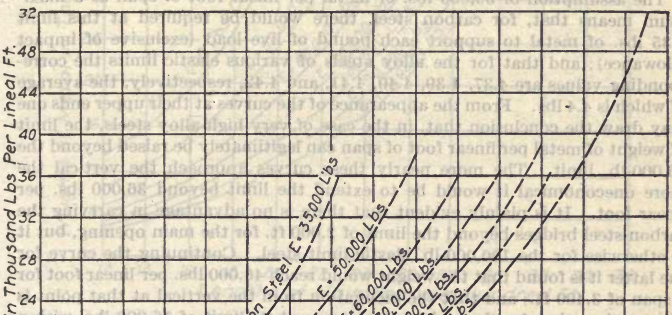


Fig. 6.—Total weights of metal per linear foot of span for double-track, cantilever bridges of carbon steel and alloy steels of various elastic limits.

cantilever structures having main openings of various lengths. The live loads used are "Class R" and "Class S" for the floor systems and "Class U" for the trusses. The proportional dimensions of typical, through, cantilever bridges are as follows: a main span, l, having a suspended span of $\frac{3}{8}l$, two cantilever arms each of $\frac{5}{16}l$, and two anchor arms of the same length as the cantilever arms. Any reasonable variation from these proportions would not change materially the average weight of metal per linear foot of span given by the curves of Fig. 6. The superiority of alloy steels over carbon steel is just as clearly shown as it was in the curves for the simple spans, but the advantage of using very high steels is greater.

If it is assumed that a limit of 36,000 lbs. of metal per linear foot of span is as high as it is either economical or practicable to go in the construction of double-track cantilever bridges (and the curves show this to be a logical limit), the following limiting lengths of main openings will be approximately as follows:

Kind of steel	Maximum length, in ft.
Carbon steel	2,030
Steel with 50,000 lbs. elastic limit	2,340
Steel with 60,000 lbs. elastic limit	2,590
Steel with 70,000 lbs. elastic limit	2,780
Steel with 80,000 lbs. elastic limit	2,910
Steel with 90,000 lbs. elastic limit	3,030
Steel with 100,000 lbs. elastic limit	3,140

The assumption of 36,000 lbs. of metal per linear foot of span as a maximum means that, for carbon steel, there would be required at this limit 4.35 lbs. of metal to support each pound of live load (exclusive of impact allowance); and that for the alloy steels of various elastic limits the corresponding values are 4.37, 4.39, 4.40, 4.41, and 4.42, respectively, the average of which is 4.4 lbs. From the appearance of the curves at their upper ends one may draw the conclusion that, in the case of very high-alloy steels, the limit of weight of metal per linear foot of span can legitimately be raised beyond the 36,000-lb. limit. The more nearly these curves approach the vertical the more uneconomical it would be to extend the limit beyond 36,000 lbs. per linear foot. It is plainly evident that there is no advantage in carrying the carbon-steel bridges beyond the limit of 2,000 ft. for the main opening, but it is otherwise for the 100,000-lb. elastic limit steel. Continuing the curve for the latter it is found that the weight would reach 46,000 lbs. per linear foot for a span of 3,400 ft.; and that the inclination from the vertical at that point is greater than that for the carbon-steel curve at its limit of 36,000 lbs. with a main opening of 2,030 ft. Perhaps therefore it would be more correct to assume the extreme economic limit of main opening to be 3,400 ft. or even 3,500 ft. For this last length the average weight of metal per linear foot of bridge shown by the 100,000-lb. elastic limit curve would be 52,000 lbs, which means that it would require 6.38 lbs. of metal to support each pound of live load, exclusive of the effect of impact. Although this is an excessive quantity, it is nevertheless conceivable that conditions might exist which would render it advisable to adopt this extreme limit of main opening, although at such a length a suspension bridge would undoubtedly be cheaper. If it is admitted (as is maintained by some bridge engineers) that the impact of the live load on the main members of long-span trusses is immaterial, the practical limit of length of the main opening will be somewhat increased. Moreover, such a contention is not far from correct, as the latest experiments on impact from live loads in bridges show that its effect on moderately long spans is much less than engineers in general have been assuming. It is unlikely that the impact ever reduces to zero, but for openings of 1,200 ft. or greater it is true that its amount is so small as to be negligible, in view of the fact that the live load stresses in the main truss members will never be quite as large as they are computed. The latter statement is true, because (a) the trains on two tracks never advance together so as to produce maximum web stresses; (b) such trains are not likely ever to cover entirely the bridge or even any

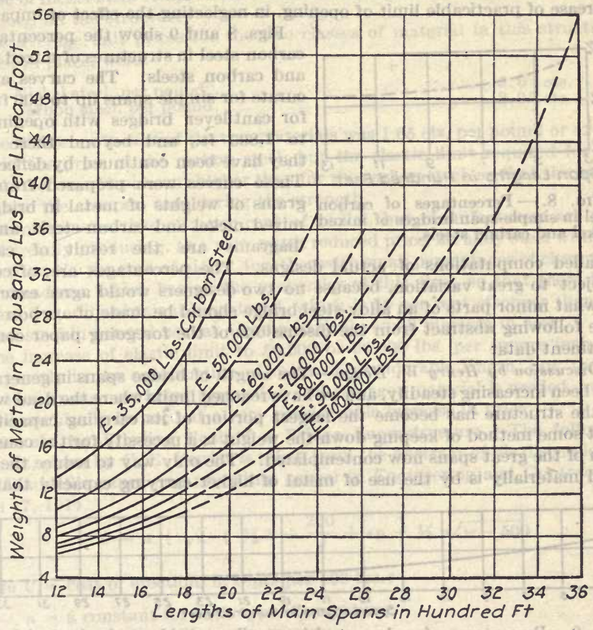


FIG. 7.—Total weights of metal per linear foot of span for double-track, cantilever bridges of carbon steel and alloy steels of various elastic limits when impacts are assumed as zero.

individual part of it, except, perhaps, the central span; and (c) it is improbable that any load of cars—unless they are ore or coal cars—will ever be uniformly full or loaded to the assumed limit.

Fig. 7 shows the curves of weights for cantilever bridges of the same type and loading as those used in preparing the curves in Fig. 8 except that the impact on main members of trusses is assumed to be zero. These curves begin at main openings of 1,200 ft. and extend to the greatest practicable limiting lengths of such openings. A comparison of the curves of Figs. 6 and 7 shows that by neglecting impact on trusses there is an average saving of about 700 lbs. of metal per linear foot of span, for all spans and all kinds of steels. With a few exceptions this difference is comparatively uniform for all the curves, over their entire lengths.

Under the assumption that the limit of weight of metal is 36,000 lbs. per linear foot the greatest practicable span lengths have been increased on the average only about 20 ft. by neglecting impact on trusses. By comparing the extensions of the curves for steel having an elastic limit of 100,000 lbs. it is found that, for an assumed limit of 52,000 lbs. of metal per linear foot of span, the extreme practicable length of main opening has been increased only 25 ft. These comparisons indicate that there is little gain, either in economy or increase of practicable limit of opening, in neglecting the effect of impact.

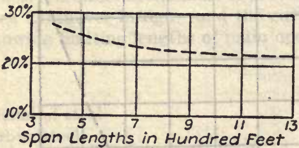


FIG. 8. — Percentages of carbon steel in simple-span bridges of mixed nickel and carbon steels.

Figs. 8 and 9 show the percentages of carbon steel in structures of mixed nickel and carbon steels. The curves are accurate for simple spans up to 600 ft. and for cantilever bridges with openings up to 1,800 ft., and beyond these limits they have been continued by deflections. These curves were prepared from diagrams of weights of metal in bridges of mixed nickel and carbon steels, and the diagrams are the result of careful, detailed computations of actual designs. The percentages are, of course, subject to great variation, because no two designers would agree exactly as to what minor parts of an alloy-steel bridge should be made of carbon steel. The following abstract from the discussions of the foregoing paper contains pertinent data:

Discussion by Henry W. Hodge.—The length of bridge spans in general use has been increasing steadily, and we have reached limits where the dead weight of the structure has become the largest portion of its carrying capacity, so that some method of keeping down the weight is a necessity for the construction of the great spans now contemplated. The only way to reduce the dead load materially is by the use of metal of higher carrying capacity than our

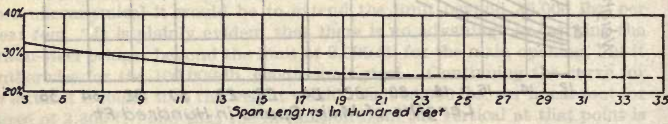


FIG. 9.—Percentages of carbon steel in cantilever bridges of mixed nickel and carbon steels.

present materials, and an important step has been made in this direction by the use of nickel steel, which has 50 per cent greater carrying capacity than the carbon steel in general use.

The trusses of the three 668-ft. spans of the St. Louis Municipal Bridge were designed for nickel steel throughout, except certain minor sub-members. Nickel-steel eye-bars and carbon-steel compression members were also used, the floor system and bracing being of carbon steel in each case.

The weights of each span were:

With complete nickel-steel trusses, lbs.	9,200,000
With nickel-steel bars, and the rest of carbon steel, lbs.	10,900,000

As the dead load of railways, tracks, etc., was 5,500 lbs. per linear foot, the total average dead load was:

With nickel-steel trusses, lbs. per linear foot	19,300
With nickel-steel bars, and the rest of carbon steel, lbs. per linear foot	21,800

Thus, the nickel-steel compression members in the trusses made a difference in weight of 2,500 lbs. per linear foot, or 13 per cent.

The average live load on the two decks was 16,600 lbs. per linear foot, thus the use of nickel-steel compression members made a saving of 7 per cent in the total load on the structure.

The average unit prices for the two classes of material in this structure, erected in place, were:

Nickel steel, per pound	5.6 cts.
Carbon steel, per pound	3.95 cts.

The difference in cost of the two materials was 1.65 cts. per pound or 42 per cent of the price of the carbon steel; but the elastic limit required for the nickel steel was 50 per cent higher than for the carbon steel, so that the nickel steel was the cheaper, considering the strength.

The nickel steel had 3¼ per cent of nickel, but manufacturers are now commercially producing, at a very much reduced price, an alloy steel with not more than 1½ per cent of nickel, together with small percentages of chromium and vanadium, which has all the properties of this steel, so that there is at present a readily obtainable material, which is 50 per cent stronger than the carbon steel in general use, at a comparatively small increase in cost.

The increase of elastic limit to 50,000 or 60,000 lbs. per square inch will help greatly in the construction of spans of considerable length; but, for the very long spans now being planned, a still stronger material is needed, and it can economically be used at a very considerable increase in price.

Formula for Erection Cost of a Bridge Superstructure.—The following formula, given by C. E. Fowler is taken from the abstract of his discussion of Mr. Waddell's paper (see preceding pages) in Engineering and Contracting, June 17, 1914.

$$C = a + \sqrt{l} + \tfrac{3}{4} h + \frac{200}{d} + sp - \tfrac{1}{5}\sqrt{w - 500}$$

where C = cost of erection, in cents per 100 lbs.;

a = a constant for each type of structure;
= 15 cts. for railway pin trusses;
= 25 cts. for railway riveted trusses;
= 20 cts. for railway girders;
= 20 cts. for highway pin trusses;
= 30 cts. for highway riveted trusses;
= 15 cts. for highway girders;
l = span length, in feet;
h = height of falsework, in feet;
d = daytime temperature, average, in degrees Fahrenheit.
p = number of coats of paint;
w = weight in lbs. per lin. ft.

Taking the case of a riveted railway span 225 ft. long, height of falsework 48 ft., average temperature 40°, 2 coats of paint, and weighing 2,100 lbs. per linear foot, we find the probable erection cost to be 83 cts. per 100 lbs., or $16.60 per ton.

A railway pin span of 144 ft., height of falsework 36 ft., average temperature 50°, 2 coats of paint, and weighing 1,400 lbs. per linear foot, would have an erection cost of 62 cts. per 100 lbs., or $12.40 per. ton.

These two examples show what an influence a change in any one of the factors will have on the unit erection cost. The formula was deduced to fit certain conditions, which to a large extent were due to the personal equations of the designer and the erector; and, with plans prepared by some designers, the cost of erection would exceed very greatly the values found from the formula, it being only too common on the part of many designers to forget that structures must be erected at a reasonable cost, and still others seem to forget the process of erection entirely. Many erection costs, of course, will exceed greatly what they should, due to unforeseen causes.

Cost of Concrete Abutments and Pedestals on Track Elevation Work.—Charles G. Huestis gives the following data in Engineering and Contracting, Feb. 21, 1912.

At the point where the following described work took place two streets intersect at the exact place crossed by four tracks of the railroad proposed to be elevated. On one of these streets are two tracks of a very busy street car line and steam tracks on both streets. On account of heavy traffic the railroad company was obliged to use at least two of its tracks during construction and at least one of the trolley tracks had to be kept in service. Team traffic also had to be maintained on at least one side of the street. Overhead along the railroad line were twenty or more telegraph and telephone wires and along the streets were electric light wires and trolley wires.

The masonry consisted of a heavy concrete abutment on each side of the street and 23 pedestals in the street. It was impossible to find place in the street for machinery so that all the working room allowed was the space of two tracks and outside the outer track about 20 ft. in width and back as far as required.

The railroad company abandoned two of its tracks, and the stub end on each side of the street was allowed the contractor for construction sidings. A stiff-leg derrick with a 40-ft. boom was set up, with one leg parallel to the face of the abutment and in such a position that the boom would reach pedestals in the center of the street. One track of the street railway company with its trolley wire was taken out of service and by working a low boom the derrick was able to avoid other wires almost entirely. The stiff-leg parallel to the abutment necessarily crossed the siding track but was high enough to allow cars to move under it so that excavated material from the pedestal pits might be loaded by derrick and taken away by the railroad company.

A ½-cu. yd. Smith mixer was set up near the end of the siding and far enough ahead of the derrick to allow the boom to reach the mixer when very high. When the siding was not in use for cars to remove excavated material the cars containing materials for concrete were placed alongside and back of the mixer and derrick. Plank staging was built alongside the cars and to the mixer, so that wheelbarrows might be loaded over the sides of cars and wheeled to the mixer. The excavated material as well as the concrete were handled in 1-cu. yd. dump buckets by the derrick. When several pedestals had been built the excavated material from others was used as backfilling for the ones completed.

The derrick was first erected near the face of the abutment and when the pedestals in the street were completed it was necessary to move the entire rig, derrick and mixer, backward about 40 ft. in order to build the abutment. This was accomplished by drawing the engine on rollers by its own power, and sliding the derrick on plank, still erect, using the engine for power.

Exactly the same method was followed on the opposite side of the street, two derricks and two mixers being used on the entire work.

Excavation.—The excavation for the abutments was about 16 ft. in depth and for the pedestals from 16 to 22 ft. The material, beside the street paving and sidewalk on top, was about 5 ft. of clay and the remainder gravel, all perfectly dry. Excavaton, as covered by the contract, was measured only to the foundation lines of the concrete footings though as a matter of fact much more was necessarily excavated in deep pits. The entire payroll for excavating, sheathing and bracing, backfilling to original ground or loading on cars was the sum of $2,292.58 for 2,832 cu. yds., engineer's measurement. (This gives a unit cost of slightly over 80 cts. per cubic yard.—Editors.)

Concrete.—The concrete materials were crushed stone and gravel taken from cars direct as described above. Water was piped to the mixers from a nearby hydrant, and cement was carried from box cars back of gravel and stone cars. The cost of unloading materials as described and wheeling them to the mixer, together with mixing and placing them and the finishing of the face after the forms were removed, was as follows for a total of 1,598 cu. yds.:

46½	hrs. foreman at 40 cts.	$ 18.60
20	hrs. foreman at 37 cts.	7.40
52	hrs. foreman at 38½ cts.	20.02
138	hrs. foreman at 32½ cts.	44.85
144	hrs. hoist runner at 30 cts.	43.20
3	hrs. carpenter at 27½ cts.	.73
54½	hrs. straw boss at 25 cts.	13.63
2,186½	hrs. labor at 20 cts.	437.30
781	hrs. labor at 17½ cts.	136.67
51	hrs. labor at 15 cts.	7.65
	Total	$730.05

(This total gives a cost per cubic yard of concrete of 45.7 cts., say 46 cts.—Editors.)

Forms.—The concrete forms were extremely easy to build and set. There were no sloping wings and nothing but straight work except that one end of each abutment was turned at an angle of about 30°. The other ends of the abutments were left for future extension. There were three expansion joints in one abutment and two in the other, where a full stop in each case was made and key ways put in for bonding. It took 30,500 ft. B. M. of lumber to form the neat work of abutments and the formed part of pedestals, if all had been formed at once. Two-inch yellow pine boards were used and 4 × 6-in. yellow pine for uprights. The total payroll for building forms, oiling with paraffine oil, removing forms and cleaning lumber was as follows:

23½	hrs. foreman at 40 cts.	$ 9.40
58½	hrs. foreman at 38½ cts.	22.52
7	hrs. foreman at 37 cts.	2.59
18	hrs. foreman at 32½ cts.	5.85
56	hrs. hoist engineer at 30 cts.	16.80
451½	hrs. carpenters at 27½ cts.	124.16
479½	hrs. carpenters at 25 cts.	119.88
69½	hrs. carpenters at 22½ cts.	15.63
463½	hrs. labor at 20 cts.	92.70
25½	hrs. labor at 17½ cts.	4.46
4	hrs. labor at 17½ cts.	.60
	Total	$ 414.59

(On a basis of 1,598 cu. yds. of concrete the cost of forms per cubic yard was 25.9 cts. or say 26 cts. As a matter of fact not all of the concrete work required built forming, so that this unit cost is indicative only —Editors.)

Rigging.—The total payroll for setting up and taking down, together with moving each plant once as described above, also the building and moving of stagings alongside of cars, for two derricks and two mixers, was as follows:

40 hrs. foreman at 38½ cts.	$ 15.40
31 hrs. foreman at 40 cts.	12.40
119 hrs. rigger at 32½ cts.	38.68
57 hrs. hoist engineer at 30 cts.	17.10
45½ hrs. carpenter at 27½ cts.	12.43
157½ hrs. carpenter at 25 cts.	39.38
41 hrs. carpenter at 22½ cts.	9.23
3 hrs. carpenter at 23 cts.	.69
479½ hrs. labor at 20 cts.	95.90
149½ hrs. labor at 17½ cts.	26.16
30½ hrs. labor at 15 cts.	4.57
Total	$271.94

The payroll for setting up one derrick only, unloading and setting one mixer, together with building platform and stagings once only, was as follows:

8 hrs. foreman at 40 cts.	$ 3.20
10 hrs. foreman at 38½ cts.	3.85
30 hrs. rigger at 32½ cts.	9.75
20 hrs. hoist engineer at 30 cts.	6.00
100 hrs. carpenter at 25 cts.	25.00
3 hrs. carpenter at 23 cts.	.69
30 hrs. carpenter at 22½ cts.	6.75
29 hrs. labor at 20 cts.	5.80
35 hrs. labor at 17½ cts.	6.12
Total	$67.16

The other items of payroll not mentioned in the above were as follows:

Building and repairing tool house	$ 28.71
Loading and unloading tools and lumber	133.87
Night watch, Sunday watch and other general expense	158.97
Repairs to machinery	12.66
Total	$334.21

Total payroll for the work $4,043.36.

The ledger accounts for this work show other expenses as follows:

Premium on bond	$ 20.00
Liability insurance	98.72
General and sundry expenses	48.65
Office and timekeeper	275.00
Materials for repairs	11.29
Small tools	34.49
Lumber for foundations	274.04
Form lumber	267.70
Wire and nails for forms	40.20
Paraffine oil for forms	3.70
Oil waste, etc	37.70
47.04 tons of coal	141.13
Water, lump sum	75.00
Paid railroad company for unloading cars of excavated material	76.80
Total ledger accounts	$1,404.42

The coal consumption amounted to about ⅓ ton per day per boiler. Only 20 h.p. upright boilers were used.

Fig. 10 shows the character of the masonry. In constructing the abutment 2 × 2-in. molding was used to bevel top and bottom edges of the coping and to mark expansion joints. There were eleven square pedestals of the dimensions shown; ten pedestals 18 ins. less in height and 9 × 8 ft. on the bottom, and two pedestals irregular in shape on account of being set close to the sidewalk. These were five courses in height.

Labor Cost of Piers and Abutments for Viaduct of the Fort Dodge, Des Moines & Southern (Electric) Ry.—In Engineering and Contracting, March 19, 1913, C. J. Steigleder describes the methods of constructing the piers and abutments for the steel deck plate girder viaduct, 784 ft. long and 156 high, which replaced a wooden trestle. The following data are taken from Mr. Steigleder's article.

Fig. 11 shows the general arrangement of the work.

Specifications called for a concrete mixture of 1:3:6, except for the coping course. The coping course was considered the top foot of the pedestal and was made of 1:2:4 concrete. The stone used with the 1:3:6 measure was from 1 to 2 ins. in the largest dimensions, and for the 1:2:4 mixture not more

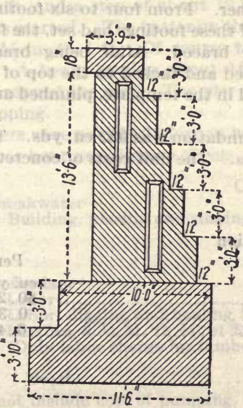


FIG. 10.—Section of concrete abutment.

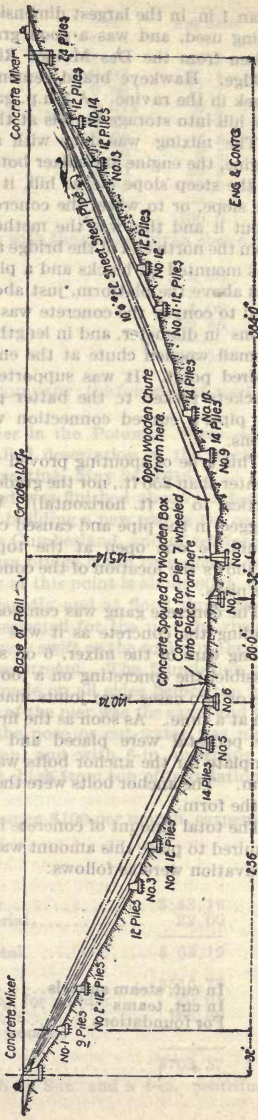


FIG. 11.—Diagram showing arrangement of chutes for concreting viaduct piers.

than 1 in. in the largest dimensions. All stone was screened, no crusher run being used, and was a good grade of limestone rock. The sand used was taken from the Des Moines River, about five miles above the site of the bridge. Hawkeye brand cement was used, and water was secured from a creek in the ravine. A 7-h.p. gasoline pump was used to force the water up the hill into storage barrels at the mixer.

The mixing was done with a Ransom mixer, driven by a 6-h.p. Stover engine, the engine and mixer both being mounted on the same frame. Owing to the steep slope of the hill, it was impracticable to move the mixer down the slope, or to wheel the concrete to place. The most efficient way was to spout it and this was the method used One-half of the piers were poured from the north end of the bridge and the other half from the south. The mixer was mounted on blocks and a platform built up around it so that the hopper was above the platform, just about the height of a wheelbarrow The chute used to convey the concrete was made of No. 23 sheet steel, circular in form, 10 ins in diameter, and in lengths of 10 and 12 ft. The pipe was attached to a small wooden chute at the end of the hopper, and from here run to any desired point. It was supported at joints by wooden cross-frames, or by brackets tacked tc the batter posts on the existing bridge. At the end of the pipe, a curved connection was used to turn the concrete down into the forms.

This type of spouting proved very satisfactory where the distance was not greater than 250 ft., nor the grade less than 24° with the horizontal (about 1 ft. vertical to 2.3 ft. horizontal). When on a less grade than this, the concrete clogged in the pipe and caused considerable trouble. A better type of chute would be one open at the top so as to give access to the concrete. Fig. 11 shows the location of the concrete mixer and how the piping was carried to the piers.

The concrete gang was composed of 12 men and a foreman; 2 were used in spading the concrete as it was placed, 1 on water and dumping cement, 1 taking care of the mixer, 6 on sand and rock, and 2 carpenters. As far as possible, the concreting on a footing or pedestal was continuous, and only in one or two cases were joints made in either. From four to six footings were run at a time. As soon as the first two of these footings had set, the forms for the pedestal were placed and securely braced. After being braced, the template for the anchor bolts was centered and tacked to the top of the pier form. The anchor bolts were then placed in the template, plumbed and wired to the form.

The total amount of concrete in the foundation was 932 cu. yds. The time required to place this amount was 40 days. The unit costs of concrete and of excavation were as follows:

Excavation

	Per cu. yd.
In cut, steam shovels	$0.22
In cut, teams	0.36
For foundations	0.48

Concrete

	Per cu. yd.	Per cent
Cement	$1.16	21.3
Rock	0.93	17.1
Sand	0.80	14.7
Water	0.014	0.3
Lumber	0.40	7.3
Pipe for spouting	0.25	4.6
Train service	0.19	3.5
Labor*	1.65	30.3
Incidentals	0.05	0.9
Total	$5.44	100.0

* The average daily output was 23.3 cu. yds.; with the gang as given above, the rates of pay would be about as follows:

1 Foreman	$ 5.00
2 Carpenters @ $4.00	8.00
1 Engineman	3.00
9 Laborers @ $2.50	22.50
	$38.50

The excavation was done by the railroad company; the foundation work by contract.

Cost of Cofferdam for a Small Bridge Pier in the Potomac River.—The following data are taken from a more detailed description of the work by Elliott Vandevater in Engineering and Contracting, May 24, 1916.

The work was begun in October, 1910, and was finished about the last of December of the same year. It consisted of building a new pier in the center of the Potomac River about ten miles above Cumberland, and of reinforcing the old stone abutments, so that the old truss bridge could be replaced with plate girders of one-half the span. The river at this point is about 80 ft. wide in times of ordinary flow but it rises very rapidly and at flood times covers more than twice this width. At the point selected for the pier the river is about 8 ft. deep normally and the current is very swift as the rocks on the east bank throw the current to the center of the stream. The foundation was 30 × 14 ft. and a step of about 18 in. was made on all sides before the neat work was started. The batter on three sides of the pier was the same and was about 1½ in. to 1 ft. Of course that on the nose or cut-water was much greater. A heavy coping about 1½ ft. deep, and with 6-in. overhang all around, capped the pier. The pier was 20 ft. high from top of foundation to top of coping.

Laborers were paid $1.75 for ten hours, foremen $100 per month, carpenters 35 cts. per hour and firemen 25 cts. per hour.

Costs*

Breakwater—	
Building, placing and sinking—Labor	$ 43.19
Material	22.00
Total	$ 65.19
Cofferdam—	
Labor	$516.76
Labor, digging and hauling 55 yd. clay for puddle	20.01
Lumber, 8.34 M. B. M. at $20	166.80
(Only labor charge for lumber cut in woods.)	
Total	$703.57

* Do not include cost of pumping, for which an 8-in. and a 4-in. centrifugal pump were used.

Trestle for Unloading Materials—	
Labor	$ 45.83
Lumber, .5 M. B. M	10.00
Total	$ 55.83
Concrete Trestle—	
Labor	$ 75.62
Material, 2 M. B. M. at $20	40.00
Total	$115.62
Excavating Cofferdam—	
Labor	$196.97
Coal, oil, etc	15.00
Total	$211.97
Two Mixing Boards, 10 × 14 Ft.—	
Labor	$ 7.71
Material	12.00
Total	$ 19.71

Unloading stone cost 12 cts. per ton.
Unloading sand cost 3 cts. per ton.
Unloading 15,000 bd. ft. lumber cost 65 cts. per 1,000 ft. B. M.
Unloading cement (carried about 50 ft.) cost 2.5 cts. per bbl.
Mixing, hauling and placing concrete cost $1.05 per cu. yd.
Forms, including material, building, erecting and stripping, cost $1.74 per cu. yd.

The breakwater consisted of a V-shaped crib which was sunk about 10 ft. above the nose of the location of the foundation and was so placed to make it possible to examine the bottom of the river at the pier site.

The cofferdam consisted of a crib 3 ft. wide and with dimensions about 2 ft. larger than those of the foundations. The crib was built out of 6 × 6-in. timber with cross pieces of the same size about 4 ft. apart. On top of the bottom course of 6 × 6-in. timbers a 2-in. flooring was laid to hold the stone used in sinking the crib. Sheet piles of 2-in. lumber were driven on the outside and inside of the crib and the bottoms were cut to conform as closely as possible to the rock underlying the river bed. It was found necessary to drive an additional row of sheet piles 4 ft. outside of the crib and fill the space between the crib and this outer row of piles with clay.

The railroad approached the bridge from the east on a 15-ft. fill about 100 ft. long. A switch for unloading materials had been put in at the end of the fill. A one-legged trestle was built on the side of the fill and the track from the siding extended out on it, so that cars could be run out there and dumped by gravity. The bents were 7 ft. apart, the caps 10 × 10 in. and the stringers were two pieces of 6 × 6 in. laid symmetrically with respect to the rail. The legs and battered braces were cut in the adjoining woods and were at least 8 in. in diameter and not over 7 ft. long. The cement was unloaded on a level with the switch and stored in a tent. From here it was dropped through a chute directly onto the mixing board. Two mixing boards were placed together. Five men were kept mixing, four turning and one attending to cement and water. After mixing a batch on one board they changed to the other while four men loaded the mixed batch into a car and hauled it out to the foundation and dumped it. One man was kept busy loading wheelbarrows with stone and sand. As the distance was very short the mixing gang wheeled the material onto the board, dumped it and returned the wheelbarrows to place. This was found to work very satisfactorily, as the mixing gang mixed the concrete a little faster than it could be hauled away. When they had both boards full the mixing gang was put to work getting out cement until the hauling gang had caught up with them.

The concrete was deposited in the forms, built inside of the crib, from a light track supported by a trestle hanging from the bottom chords of the existing bridge.

Erection Costs for a Double-track Railway Bridge.—In Engineering News, Feb. 20, 1913, M. A. O. Stilson gives the erection costs of a bridge consisting of three double-track through spans, each 154 ft. 6 in. long c. to c. The trusses are of lattice type. The piers are square to the track and trusses.

There were in place two old spans (single-track), which were taken out as the work progressed. For cutting apart they were blocked up on the falsework put in for the new spans. The grade of the new track was that of the old, the pier height above high-water allowing for the extra depth of the new floor-beams. The use of a derrick car enabled this work to go forward while the first new span was erected.

An overhead traveler (see Fig. 12) was used for the erection. It was assembled and raised from the old truss. The raising of a traveler becomes a simple and rapid task when old spans are in place to erect from, as the assembling can be in a position not far from the vertical, letting the upper frame of the traveler rest on the top chord of the old spans and finally pulling the small distance to a perpendicular with tackle just prior to joining the bents of the traveler. The traveler could also be raised from the flat floor of the falsework, by means of a jack-frame erected at the foot of the traveler legs. This takes nearly twice the time of the other method, and costs (a gang of 12 men can have a traveler framed and ready for use in three days with the help of a hoisting engine) about $300.

The piers of the new three-span bridge were so located that the masonry could be all completed, with the exception of a few bridge-seat stones to carry track stringers, before the arrival of the bridge steel, thus allowing the new shoes to be placed at once. A temporary trestle at the upstream side of the main line cared for the train movement, allowing the erection to proceed undisturbed by the traffic. Therefore, the falsework had to be proportioned for the trusses alone.

The height of the piers above mean low water was about 27 ft. The river bottom was a well washed gravel, into which a pile could be driven to a penetration of 5 ft. only with difficulty.

The sequence of operations in the erection of the bridge was as follows: (1) Ship equipment and materials to bridge site; (2) unload; (3) place hoister and compressor and house them; (4) put in falsework; (5) erect traveler and wreck old spans; (6) place and block floor-system and bottom chord, cambered; (7) erect web-members; (8) place end posts; (9) place top chord; (10) place bottom and top laterals, with portals and other small members, or release traveler to second span; (11) rivet up; (12) strike falsework and traveler; (13) load material and equipment.

Cost of Shipment.—The cost of shipment of equipment and material to the bridge site is an item varying in each case, and also depending on the terms of the contract with the company owning the bridge. If a railway company, the contract may include transportation and work-train service during erection, though these items are properly a part of the cost, no matter by whom paid. It is not unusual, however, for a charge of $25 per day to be incurred for a locomotive, flat-cars and crew, especially where the bridge members have had to be unloaded at a distance. The economy effected through the use of a derrick car capable of propelling itself and loaded flat-cars thus becomes apparent.

Cost of Unloading.—The unloading of the material and bridge members at the site or some adjacent point, while variable, will generally be covered by the expense of a derrick and hoister, its erection and a possible shift, if the ground available makes this necessary. In the present case the material for the three spans was unloaded in about three weeks, including delays, by a gang of eight men, one engineer and one foreman, about $200 per week for labor cost.

Hoist.—Placing the hoister, compressor and their boilers is comparatively a small item unless considerable falsework be necessary for support. In this case three bents of six piles each, capped and braced, with plank floor, were placed, and the power set, by 12 men and one foreman in four days, costing $200.

Falsework.—The erection of the falsework, consisting of pile bents, capped and braced, floored with timbers parallel with the bridge and some plank, can go forward during the same period. The equipment of scow, pile hammer and hoister engine was able to drive 15 bents of 10 piles each (150 piles) in four days. The piles were delivered into the water above; they were of 25 to 27 ft. lengths, and were driven to a penetration of 5 ft. This gang consisted of one foreman, one engineer and four men, a labor cost of about $23 per day, according to rate of wages paid. The cost was, therefore, $92, or practically 62cts. per pile in place. The piles cost 10c. per lin. ft. delivered above the work, or $2.50 to $2.70 apiece, making $482 the total cost of piles in place. (This figuring assumes that the equipment can leave the work in good condition, so as to be available at full value for other work.) Cutting off the piles, capping, boring and bracing, was completed in eight days by a gang consisting of one foreman and eight carpenters, at a cost for labor of $23.50 per day, or $188 total. This includes placing the timbers to carry the trusses, drifting them in place, and laying floor-plank and traveler track.

The labor cost of one span of falsework in place is thus $280. The cost of piling is $390, and of timber as follows:

30 caps 12 × 12 in. × 25 ft.	9,000 ft. B. M.	
12 saddles 12 × 12 in. × 8 ft.	1,152	
50 stringers 12 × 12 in. × 25 ft.	15,000	
120 braces 3 × 12 in. × 30 ft.	10,800	
80 blocks 8 × 8 in. × 8 ft.	3,411	
240 plank 2 × 12 in. × 12 ft.	5,760	
Cost:		
40 M at $30	$1200	
6 M at 25	150	
		$1350
Total Cost of Falsework:		
Lumber	$1350	
Piles	390	
Labor	280	
	$2020	

This gives $2020 cost of falsework of one span in place ready for setting steel. In the three-span bridge in question, the riveting of Span No. 1 was completed early enough to release the falsework for use under Span No. 3, except for piling.

Traveler.—The traveler, as shown in Fig. 12 consisted of two bents suitably braced, supporting four timbers 12 × 16 in. by 30 ft., two over each truss, to carry the blocks of the main falls and smaller tackles. The erection of the traveler has been stated to cost about $150. It followed the placing of the falsework, using the old spans to erect from. The cost of the traveler itself was as follows:

1 foreman, $4	4	
6 carpenters, $3	$ 18	
4 days at	$22	$ 88
4 legs 12 × 12 in. × 48 ft	2,304 ft. B. M.	
4 batters 12 × 12 in. × 40 ft	1,920	
2 bott. chords 12 × 12 in. × 36 ft	862	
4 top chords 12 × 12 in. × 30 ft	1,440	
4 top timbers 12 × 16 in. × 30 ft	1,920	
16 braces 3 × 12 in. × 20 ft	960	
24 braces 3 × 12 in. × 12 ft	864	
4 diagonals 3 × 12 in. × 36 ft	432	
4 sills 8 × 16 in. × 30 ft	1,280	
12 doz. ¾-in. bolts, etc., at 60 lb	.05,	$36
4 flanged wheels, at 100 lb	.03,	12
4 sets axles, bearings, etc., at 40 lb	.03,	5
Cost of traveler:		
Lumber, 10 M at $35	$350	
Lumber, 3 M. at $25	75	
Hardware	54	
Labor	88	
		$567

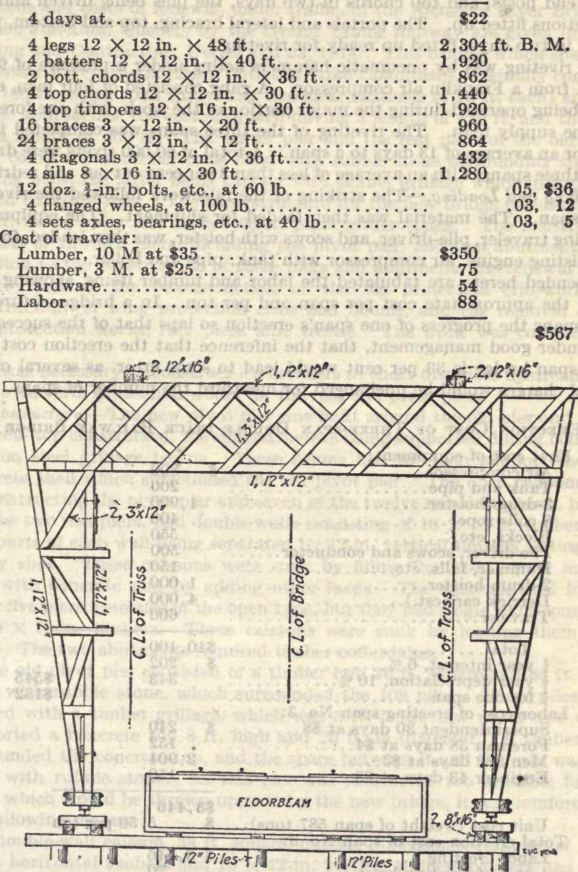


FIG. 12.—Sketch of bent of wooden traveler.

Removing Old Spans.—The wrecking of the two old spans occupied one foreman with 12 men two weeks, the pieces of the members being taken away by the derrick car.

Erecting New Trusses.—The floor-system of one span, including bottom chords, was put in place, blocked up, and bolted, by a gang consisting of two foremen, 18 men and one engineer in five days, assisted by a derrick car with one engineer, one foreman and eight men, who brought the bridge members from the storage yard in proper order.

The truss members and hanger posts were placed in two days, and the shoes, end posts, and top chords in two days, the pins being driven and the connections fitted up. The portals and lateral bracing, top and bottom, were placed in two days, fitted up ready for riveting.

The riveting was by pneumatic hammers acting under a pressure of 90 to 100 lb. from a Franklin air compressor. A gang consisted of four men, eight gangs being operated during the major portion of the work, with one foreman and one supply man. The riveting of the three spans was completed in 39 days, or an average of 13 days to a span. A total of 60,000 rivets were driven in the three spans, with an average of less than 3 per cent cut out and redriven.

Striking and Loading.—The striking of the falsework followed the riveting of its span. The material was then loaded for shipment. The equipment, including traveler, pile-driver, and scows with hoister, was then loaded, freeing the hoisting engine, air compressor with tank, pipe and boiler.

Appended hereto are tabulated the labor and lumber items, showing at a glance the approximate cost per span and per ton. In a bridge of three or more spans the progress of one span's erection so laps that of the succeeding one, under good management, that the inference that the erection cost of a single-span bridge is 33 per cent would lead to some error, as several of the general charges would be unchanged for one-third the number of spans.

Erection Cost of Three-span Double-track Railway Bridge

First cost of equipment:		
Air compressor	$ 800	
Tank and pipe	200	
3-drum hoister	1,900	
8 coils rope	400	
Blocks, etc.	550	
Pile driver, scows and conductor	500	
Hammer, falls, etc.	150	
2-drum hoister	1,000	
Derrick car (est.)	4,000	
Traveler	600	
Total	$10,100	
$\frac{1}{3}$ year interest, 6 %	$ 202	
$\frac{1}{3}$ year depreciation, 10 %	343	$545
$\frac{1}{3}$ for one span		$182
Labor cost of erecting span No. 3:		
Superintendent 30 days at $8	$ 240	
Foreman 38 days at $4	152	
Men 832 days at $3	2,904	
Engineer 43 days at $3	150	
	$3,446	
Unit cost (weight of span 587 tons)	$ 5.50 per ton	
Total erection cost of span No. 3:		
Labor erecting	$ 3,446	
$\frac{1}{3}$ cost of erecting hoist	70	
$\frac{1}{3}$ cost of erecting traveler	50	
$\frac{1}{3}$ cost unloading material, etc.	200	
$\frac{1}{3}$ interest and depreciation	182	
Total erection cost for 587 tons	$ 3,948	
	6.72 per ton	

The assumption has been made that an equipment such as has been described was in the hands of the erection company. But since it would be proper to add a charge not only for depreciation, but for interest on the invested funds, a value on which to base such is also given, the items of which are mostly estimated, although some are actual costs.

Costs of the Richelieu River Bridge, Lacolle Junction, Quebec.—The methods and costs of renewal, under traffic, of the Richelieu River Bridge at Lacolle Junction, Quebec, by the Grand Trunk Railway are given in Engineering and Contracting, Dec. 9 and 23, 1914. This bridge, which spans the Richelieu River, the northern outlet of Lake Champlain, originally consisted of a 180-ft. swing span (providing two clear channels of 73 ft. each) and pile trestle approaches, the east approach having a length of 350 ft. and the west one a length of 500 ft. The center pier and the rest piers of the old swing span consisted of timber cribs filled with rubble stone surrounding the supporting piles, the latter being capped with timber grillage which in turn supported concrete tops. The superstructure for the new bridge consists of one 250-ft. swing span and twelve 60-ft. plate girder spans. The substructure consists of thirteen piers, including the pivot pier, and two abutments. In addition to the construction of these piers and abutments the renewal of the bridge required the reconstruction of the old protection crib-work, the construction of wing protection cribs and booms, and the removal of the old protection works, rest piers and trestle. The work was completed in 1913.

It was necessary to construct ice breakers at short distances upstream, and to provide crib protection works for the rest and pivot piers.

Substructure.—The new pivot pier was built around the old pier and a new concrete top constructed, the superstructure being supported during construction on steel grillage beams. These beams had for their support the new concrete shell which surrounded the old pivot pier. The open caissons used in constructing the pivot pier and seven of the twelve remaining piers, including the two rest piers, had double walls consisting of 10 × 10-in. timbers, the two parts of each wall being separated by 12-in. vertical timbers resting on a heavy shoe. These caissons were sunk by filling the 12-in. space in each wall with concrete and by adding other loads. The caissons used for the other five piers were also of the open type, but they had single walls consisting of 10 × 10-in. timbers. These caissons were sunk by loading them with rails. The two abutments required timber cofferdams.

The old pivot pier consisted of a timber crib 26 ft. square and 33 ft. high, filled with rubble stone, which surrounded the 108 piles. These piles were capped with a timber grillage, which was 3 ft. below low water and which supported a concrete top 8 ft. high and 20 ft. in diameter. A timber wall surrounded the concrete top, and the space between it and the crib was also filled with rubble stone. As this pier was considered too unstable for the loads which would be thrown upon it by the new bridge, it was reinforced in the following manner:

A double-wall caisson, 38 ft. square, outside dimensions, built up of 10 × 10-in. horizontal timbers and 12 × 12-in. vertical timbers between the walls at intervals, was sunk around the old pier, leaving a 3-ft. space between it and the old crib. After this space was filled up to approximately 6 ft. below low water with plain concrete, reinforced concrete walls were carried up to the required level to receive the eleven 26-in., 166-lb. I-beams, on which the swing span was erected and operated during the completion of the piers.

Fig. 13 gives a half section showing the caisson and the old pivot pier before alteration, and a half section of the complete pivot pier.

It was originally intended to remove the rubble stone filling from the old crib one pocket at a time, but this was found to be impracticable owing to the existence of fissures in the slate-rock foundation, which made unwatering impossible. The stone was, however, taken out to a level 2 ft. below the old timber grillage. The old piles, the timber grillage and the concrete top were left in place, except the upper 18 ins. of the latter, which were removed by blasting. Instead of unwatering the pier, water was pumped into it until a 3-ft. head was produced, this head being utilized in forcing a 1:2 grout into the voids of the rubble stone. After the voids were filled the water was

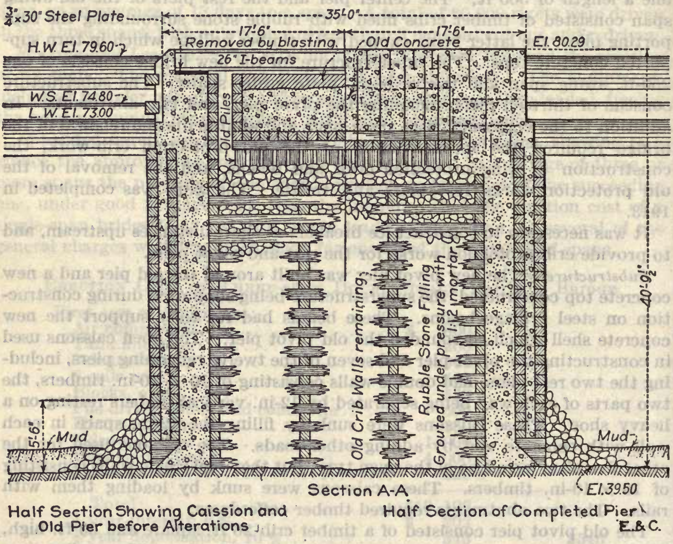


FIG. 13.—Half section of old pivot pier and half section of completed pivot pier of Richelieu River Bridge.

pumped out, and the concrete work was completed in the dry, grillage beams being embedded in the coping to distribute the loads from the swing span.

Seven of the intermediate piers (Nos. 4, 5, 6, 7, 9, 10 and 11) have caisson foundations, which are of similar construction to that used for the pivot pier and which differ only in shape. These piers are pointed, both on the upstream and downstream ends. Fig. 14 (a) shows a half cross section and a half end elevation of a typical intermediate pier and caisson in which the double-wall type of caisson was used; Fig. 14 (b) shows a side elevation of the pier and caisson; and Fig. 14 (c) shows a plan of the caisson. Above elevation 70 (the top of the permanent caisson) the construction for all of these piers is alike.

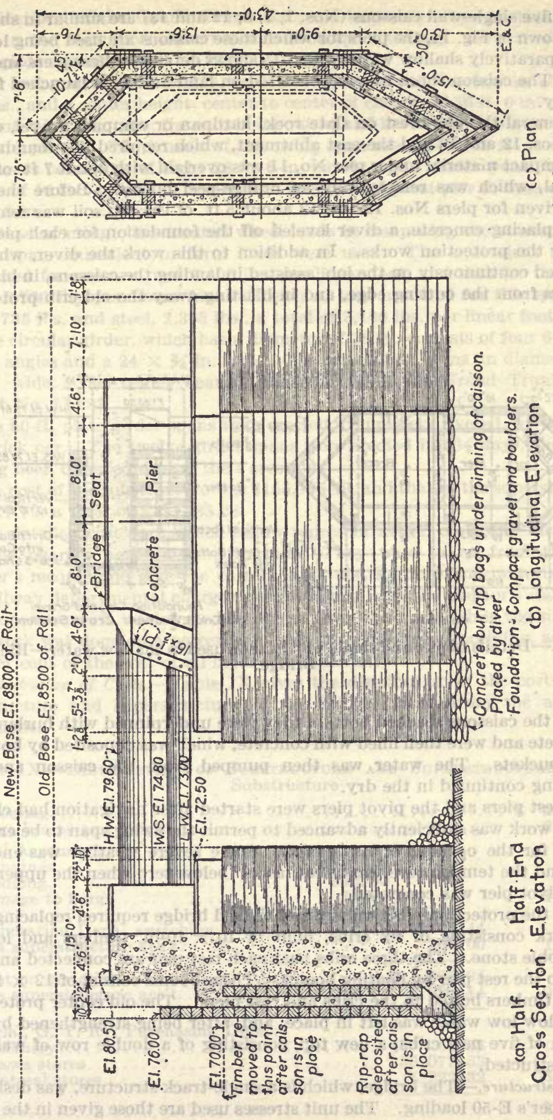


FIG. 14.—Details of typical intermediate pier and double-wall caisson of Richelieu River Bridge.

The five single-wall caissons (Nos. 1, 2, 3, 12 and 13) are similar in shape to that shown in Fig. 14, the piers for which these caissons are used being located in comparatively shallow water. Fig. 15 shows details of these piers and caissons. The caisson shoes were constructed on land and were launched from a skidway.

In general the piers rest on slate rock, hardpan or compact gravel, except piers Nos. 12 and 13 and the east abutment, which required pile foundations. The compact material under pier No. 11 was overlaid with about 7 ft. of loose material, which was removed by an orange-peel bucket. Before the piles were driven for piers Nos. 12 and 13 about 5 ft. of the top soil was removed. Before placing concrete, a diver leveled off the foundation for each pier and also for the protection works. In addition to this work the diver, who was employed continuously on the job, assisted in landing the caissons, in blasting boulders from the cutting edge, and in blasting away the old crib protection works.

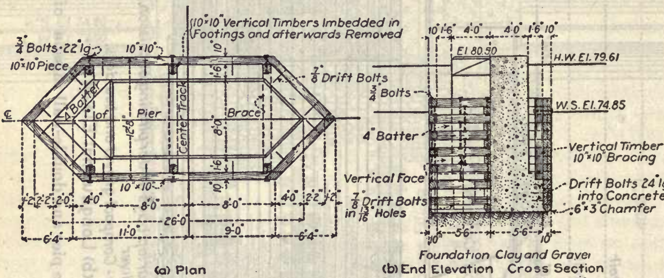


FIG. 15.—Details of pier and single wall caisson used in shallow water—Richelieu Bridge.

After the caissons reached bottom they were underpinned with burlap bags of concrete and were then filled with concrete, which was deposited by bottom-dump buckets. The water was then pumped from the caisson and the concreting continued in the dry.

The rest piers and the pivot piers were started after navigation had closed, and the work was sufficiently advanced to permit the swing span to be erected in time for the opening of navigation. Some severe weather was encountered, and the temperature was as low as 28° below zero when the upper part of the pivot pier was concreted.

All of the protection piles and cribs of the old bridge required replacing, the new work consisting of six cribs, built of 10 × 10-in. timbers and loaded with rubble stone. The three cribs near each rest pier are connected and are joined to the rest pier by floating booms. These booms consist of 12 × 12-in. vertical timbers bolted to the cribs and rest piers. The old center protection work below low water was left in place, and, after being strengthened by the addition of five new cribs, a new top, consisting of a double row of walings, was constructed.

Superstructure.—The bridge, which is a single-track structure, was designed for Cooper's E-50 loading. The unit stresses used are those given in the 1910 specifications of the Grand Trunk Ry., the impact allowances being those given in the Dominion Government's 1908 specifications. The twelve deck plate girder spans possess no unusual features.

The swing span has a length, center to center of end floorbeams, of 244 ft. 7½ ins., and a center height, center to center of chords, of 36 ft. 0 in. It is of the center-bearing type, the ends being raised and lowered by wedges operated by hand power. The trusses of the swing span are spaced 18 ft. on centers, each truss consisting of eight 28-ft. 6-in. panels and a center panel having a length of 16 ft. 7½ ins. The distance from top of pivot pier to base of rail is 11 ft. 0 in.

Instead of using concentrated wheel loads in computing the stresses in the swing span equivalent uniform loads were used. The equivalent uniform load used for one arm was 6,400 lbs. per linear foot, and that for the entire span, 5,700 lbs. per linear foot. The dead load assumed for this span was: floor, 735 lbs. and steel, 2,365 lbs., a total of 3,100 lbs. per linear foot.

The circular girder, which has a diameter of 18 ft., consists of four 6 × 4 × ⅝-in. angles and a 24 × ¾-in. web. The wheels are 12 ins. in diameter and 8 ins. wide. The center bearing steel casting is the Grand Trunk Ry.'s patent No. 11,283.

The 60-ft. plate girder spans were erected, completely riveted, by means of a derrick car. The twelve girder spans were erected in 5½ days, the traffic having been diverted during their erection.

The cost of the substructure was $155,955.49, and that of the superstructure $77,877.79, a total of $233,833.28.

The detailed cost data which follow represent actual costs and include all possible charges against the structure. They were taken from the contractor's records and give the correct labor distributions and material costs. All railway departmental charges were obtained from the auditor's statement. The superstructure was erected by the railway company, while the substructure work was done on a percentage basis, the contractor receiving, as profit, 6½ per cent of the cost of all labor and materials.

Distribution of Costs.—Table IX gives the distribution of the costs of the substructure and superstructure of the bridge, taken from the auditor's statement.

TABLE IX.—DISTRIBUTION OF SUBSTRUCTURE AND SUPERSTRUCTURE COSTS

Substructure

Engineering			$ 2,705.85
Grillage beams and freight			2,460.59
Special Accounts:			
Soundings	$ 81.00		
Dredging	845.00		
Damage to barge	75.00		1,001.00
Transporation Dept., switching		$ 1,773.44	
Less superstructure acc't		200.00	1,573.44
Freight on material		$11,395.95	
Less superstructure acc't		1,680.44	9,715.51
Material, G. T. Ry. Purchasing Dept.:			
Stationery		$ 67.58	
Ottawa stores		55,077.53	
Montreal stores		1,222.32	56,367.43
Fuel			2,159.40

TABLE IX.—(*Continued*)

J. S. Metcalfe Co.:			
Percentage		$ 9,263.09	
Less superstructure acc't		74.29	9,188.80
Expenditure—Supt., $2,635.12; mat., $1,100.66		$ 3,735.78	
Less superstructure acc't—Sup't		50.00	3,685.78
Labor		$66,063.95	
Less superstructure acc't		1,143.07	64,920.88
B. & B. Dept.:		$ 8,159.32	
Less superstructure acc't		6,312.12	*1,847.20
Motive Power Dept. for B. & B.:			
Driving piles			329.61
Total substructure			$155,955.49
* Material, $1,200.00; labor, $647.20.			
Total Material:			
Stores Department			$ 56,367.43
J. S. Metcalfe Co			1,100.66
B. & B. Department			1,200.00
Total			$ 58,668.09
Total Labor:			
Labor			$ 64,920.88
Superintendence			2,585.12
Sounding			81.00
B. & B. Dept			647.20
Total			$ 68,234.20
Superstructure			
Engineering			$ 609.53
Dominion Bridge Co			70,201.92
Motive Power Dept.—Power house			102.77
B. & B. Dept.:			
Removing ties and painting girders		$ 512.12	
Bridge floor		5,050.00	
Placing runouts, temporary trestle spur and removing old deck during erecting of steel		750.00	6,312.12
Transportation charges, switching			200.00
J. S. Metcalfe Co.:			
Operating bridge during const.:			
Labor		$ 1,143.07	
Superintendence		50.00	
Percentage		74.29	1,267.36
Road Department			229.82
Freight on old and new steel			1,680.44
Total			$ 80,603.96
Credit:			
Scrap steel		$ 265.58	
Grillage beams	$2,387.59		
Freight	73.00	2,460.59	
			2,726.17
Total—Superstructure			$ 77,877.79

Scale of Wages.—The prices paid for the various classes of labor were as follows:

	Cts. per hr.
Common laborers	22½
Handymen	25
Carpenters	35 to 40
Labor foreman	35
Carpenter foreman	40
General foreman	60
	Per day
Superintendent	$8.00
Driver*	6.50
Helper*	4.50

* Furnished by railway company.

Material Prices.—The following data give the materials used, where they were obtained, and the prices paid for them:

Sand, f. o. b. Swanton, Vt., 32 cts. per ton, duty free.
Crushed stone, f. o. b. Chazy, N. Y., 75 cts. per ton, duty 17½ per cent.
Rubble stone, f. o. b. Chazy, N. Y., 60 cts. per ton, duty free.
Rubble stone, f. o. b. bridge site, by barge from Isle La Motte, Vt., 85 cts. per ton, duty free.
Cement, f. o. b. Belleville, Ont., (Canadian brand), net $1.25 per barrel.
Lumber, McAuliffe-Davis Lumber Co., Chicago:
  2 × 4-in. × 10 to 14-ft. hemlock at $15 per M.
  2 × 6-in. × 10 to 14-ft. hemlock at $15 per M.
  2 × 8-in. × 10 to 14-ft. hemlock at $15 per M.
  1 × 6 to 8-in. × 10 to 18-ft. hemlock at $15 per M.
  1 × 6-in. × 12 to 16-ft. pine form lumber at $19.50 per M.
Lumber, E. Hines Lumber Co., Chicago:
  12 × 12-in. × 26-ft. l. l. y. p. at $28.50 per M
  12 × 12-in. × 18-ft. l. l. y. p. at $26.50 per M.
  12 × 12-in. × 22 to 24-ft. l. l. y. p. at $27.50 per M.
  10 × 10-in. × 22-ft. l. l. y. p. at $25.50 per M.
  10 × 14-in. × 14 to 25-ft. l. l. y. p. at $34.00 per M.
Lumber, John Harrison & Sons, Owen Sound, Canada:
  10 × 10-in. × 10 to 20-ft. hemlock at $20 per M.
  12 × 12-in. × 10 to 20-ft. hemlock at $20 per M.
Lumber, A. J. Martin, Sherbrooke, Canada:
  10 × 10-in. × 14-ft. hemlock at $18 per M.
  10 × 10-in. × 20-ft. hemlock at $20 per M.
  10 × 10-in. × 22-ft. hemlock at $22 per M.
Lumber, Marsh & Bingham, Chicago:
  10 × 10-in. × 10 to 14-ft., l. l. y. p., at $28 per M.
  10 × 10-in. × 16 to 20-ft., l. l. y. p., at $32 per M.
  12 × 12-in. × 10 to 14-ft., l. l. y. p., at $30 per M.
  12 × 12-in. × 16 to 20-ft., l. l. y. p., at $31 per M.
  12 × 12-in. × 26-ft., l. l. y. p., at $33 per M.
Lumber, W. H. Bromley, Canada:
  12 × 12-in. × 12 to 20-ft. red pine, at $25 per M.
Lumber, Colonial Lumber Co., Canada:
  12 × 12-in. × 12 to 20-ft. red pine, at $25 per M.
Lumber, Long Lumber Co., Hamilton, Ontario:
  10 × 10-in. × 12 to 18-ft. hemlock, at $16 per M.
  12 × 12-in. × 16 to 18-ft. hemlock, at $20 per M.
Lumber, R. Laidlaw & Co., Canada:
  12 × 12-in. × 16-ft. Georgia pine, at $35 per M.
  12 × 12-in. × 18-ft. Georgia pine, at $37 per M.
Lumber, W. B. Crane & Co., Chicago:
  12 × 14-in. × 14 to 16-ft. white oak, at $38 per M.

Prices of Miscellaneous Materials.—The following prices were paid for the miscellaneous materials listed in the accompanying table:

Reinforcing steel, per 100 lbs	$ 1.45
Drifts, sheared points without head, per 100 lbs	1.90
Ship spikes, per 100 lbs	2.90
Anchor straps, each	4.80
Machine bolts:	
7/8 × 15-in., per 100	29.40
7/8 × 24-in., per 100	42.00
1/2 × 15-in., per 100	10.62
Nose plates, each	7.15
1 10-in. sheave block	14.00
1 10-in. sheave snatch block	7.50
1 8-in. triple wood block	1.95
Steam hose, per lin. ft	.93
Suction hose, per lin. ft	1.33
1 3-ton M. J. duplex block	72.00
1 1-ton M. J. differential block	7.00
1 3-ton Harrington block	67.50
Dynamite, f. o. b. factory, per lb	.19
Amazon 3-ply roofing paper, per square	2.25
1 motor boat, 18-HP	600.00

Equipment Furnished by Substructure Contractor.—The accompanying table gives the equipment, and its value, furnished by the J. S. Metcalfe Co., the substructure contractor:

6 Hudson, V-shaped, 1-cu. yd. cars	$ 390
Track	40
1 No. 3 Gould trench pump	25
1 1/2-cu. yd. Cube mixer	1,600
1 1/2-cu. yd. Smith mixer (old)	400
1 Pulsometer pump	100
1 Emerson Jr. B. pump	120
1 No. 2 Emerson steam pump	368
2 No. 2 Wood electric drills	250
Motor and fittings	600
2 locomotive boilers	800
1 vertical boiler	300
12 wheelbarrows	45
Total	$5,038

Work Done by Bridge and Building Department.—The data given in Table X refer to materials furnished and work done by the Bridge and Building Department of the Grand Trunk Ry.

TABLE X.—COST DATA ON WORK DONE BY BRIDGE AND BUILDING DEPARTMENT

Piles and Pile Driving	
117 40-ft. piles (4,670 lin. ft. at 15 cts. per ft.)	$ 700.00
Motive Power Department	329.61
14½ days' pile driving at $8 per day, labor $16	232.00
*Labor, cutting piles—east abutment	20.00
Labor, cutting piles by driver, average about 8 piles per day at $17 per day; total, 62 piles in 8 days	136.00
Freight	80.00
Overhead charges	79.00
Total cost (per ft., 33.8 cts.)	$1,576.61
Supporting Track by Bridge Dept.	
Labor	$ 415.20
Material	500.00
Freight	120.00
Overhead charges	71.00
Total	$1,106.20

TABLE X.—(*Continued*)

Work Done by J. S. Metcalfe Co. as Part of B. & B. Dept.'s Work
This work consisted of changing trestle bents, supporting track and removing old trestle piles.

Labor	$1,411.57
Material	200.00
Transportation	23.44
Freight	70.00
Overhead charges	159.00
Total	*$1,864.01

*$1,864.01 − $20.00 = $1,844.01.

Table XI gives cost data on work done by the diver, such as cutting off piles and excavation for caissons and protection cribs.

TABLE XI.—COST DATA ON WORK DONE BY DIVER

Cutting off piles in foundation:	
Labor	$ 100.00
Material	20.00
Freight	2.75
Overhead charges	13.25
Total	$ 136.00
Cutting of old trestle piles inside and outside of caissons:	
Labor	$ 100.00
Material	20.00
Freight	2.76
Overhead charges	13.75
Total	$ 136.51
Excavation by diver:	
This account was for excavation work for caissons (area, 6,400 sq. ft.; cost, $1,975), and for protection cribs (area, 2,000 sq. ft.; cost, $851).	
Labor	$2,400.00
Material	130.00
Freight	10.00
Overhead charges	286.00
*Total	$2,826.00
*Cost per square foot (8,400 sq. ft.) =	34 cts.
Grand total	$3,098.51

Data on Open Timber Caissons.—Table XII* gives the quantity of timber required for the caissons of the piers and abutments, the various labor and material costs, the cost of miscellaneous items and the total and unit cost. The contractor's percentage and the engineering costs are not included (for contractor's percentage of the total cost of each pier and abutment see Table XV). The overhead charges given include: construction buildings, timekeeper, tool boys, watchman, shoveling snow, superintendence, general expense, equipment, labor and material.

Concrete Work.—Table XIII* gives the quantity of concrete placed in the piers, the various labor and material costs for piers and abutments, the cost of miscellaneous items, the total cost of the concrete in piers and abutments, and its unit cost. The contractor's percentage and the engineering costs are not included. (For contractor's percentage of the total cost of each pier and abutment see Table XV.) The overhead charges given in Table XIII include: construction buildings, shoveling snow, timekeeper, tool boys, watchman, superintendence and general expenses. The concrete was deposited under water by bucket, the average depth of water being about two-thirds of the height of the pier. In connection with the concrete work the pumping account amounted to $1,676.92, divided as follows: labor, $797.92; fuel, $530; miscellaneous material, $200; and overhead charges, $149; this amounts to 31.2 cts. per cubic yard of concrete in the piers and abutments.

* Tables XII and XIII have been greatly reduced from those given in article in which the details are given separately for each pier and abutment.

Crib Protection Works, Booms and Waling.—Table XIV gives the quantities of materials used in the cribs, booms and waling, the labor and material costs of various items, the cost of miscellaneous items, the total costs of the cribs. booms and waling, and their unit costs. The engineering costs are not included, The cribs were filled with stone from barges, the rip-rap being unloaded from trains. The total cost of the wing cribs and booms was $15,594, and that of removing the old protection work $1,190.98 (for details see Table XVI).

Summary of Pier Costs.—Table XV gives a summary of the cost of the various items of each pier and abutment, the total cost of each pier, and the total cost of all piers and abutments. The engineering costs are not included. Cofferdams were constructed for the two abutments and for pier No. 1. The cofferdam used for pier No. 1 consisted of 2-in. sheeting driven flush with the outside of the caisson and banked with clay on the outside. The cost given for this cofferdam, $306.98, includes the cost of excavating for the pier and that of puddling. The excavation work for the two abutments (cost, $300) was done by ordinary labor; that for pier No. 11 (cost, $600) was done by a dredge; and that for the remaining piers (cost, $1,975), by divers. The cost given for the caisson of the west abutment ($448) was for rip-rap only. The distance from the top of masonry to the base of rail is 8 ft. 6 ins.

The itemized costs of the pivot pier (No. 8) are shown in Table XV. These costs do not include engineering nor removal of old pier, the costs of which were $416 and $900, respectively. If these items are included, the total cost of the pivot pier is $24,517.96. The total cost of the concrete work for this pier was $11,827.45, which was divided as follows:

12-in. wall, 140 cu. yds. at $9.00	$ 1,260.00
Encasing walls and concrete burlap bags, 650 cu. yds. at $8.46	5,500.00
Rubble grouting, 450 cu. yds. = 150 cu. yds. grout at $12.00	1,800.00
Pier top, 360 cu. yds. at $8.22	2,969.45
Forms	298.00
Total	$11,827.45

The estimated cost of the pivot pier, including its proportion of the general charges, freight, interest and depreciation of plant, contingencies, engineering and superintendence, was $31,250. The difference between this and the actual cost of about $24,500 is due mainly to: (a) Grouting the rubble filling instead of removing it and replacing with concrete (approximate saving, $3,500); (b) lower cost of concrete than estimated (approximate saving, $2,500); and (c) lower cost of caisson (approximate saving, $750).

Table XVI gives a general summary of the costs of the bridge, the tabulation being made in such manner as to show the costs of labor and superintendence, material, transportation, fuel, freight, overhead charges and totals for each item of the work. It will be noted that the cost of labor and superintendence was about $9,600 in excess of that of materials.

In Fig. 16 the heights of the piers have been platted as ordinates and their total costs as abscissas. Excluding the rest piers, which are special cases, it is seen that the height-cost curve is practically a straight line.

Unit Costs.—The following unit costs include, in addition to the items noted, train service and freight, but do not include contractor's percentage nor engineering charges:

Timber in Caissons.—The average cost of the timber in the caissons, framed, erected and in place, including materials, tools, equipment and labor, was $69.02 per M ft. B. M.

Timber in Protection Crib Work.—The average cost of the timber in the crib protection work framed, erected and in place, including materials, tools, equipment and labor, was $60.87 per M ft. B. M. The prices of the various kinds of timber, per M ft. B. M., were: hemlock and spruce, $20; red pine, $25; long leaf yellow pine, $26 to $34.

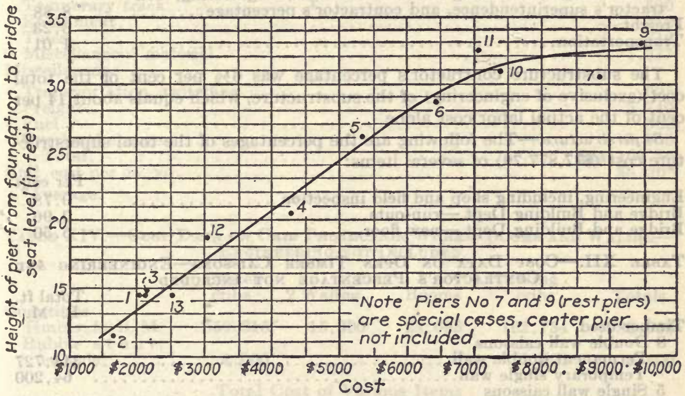


FIG. 16.—Curve showing relation between height and cost of intermediate piers of Richelieu River Bridge.

Concrete.—The average cost of the concrete, including materials, equipment, tools and labor, was $8.20 per cubic yard. The prices of the materials were: crushed stone, $1.10 per cubic yard ($0.75 per ton); sand, $0.32 per cubic yard; and cement, $1.25 per barrel, net.

Excavation.—The cost of the excavation, including equipment and labor, for the three classes of work as follows:

By diver, preparing bottom, 8,400 sq. ft., $0.34 per square foot.

By orange-peel bucket, 200 cu. yds., $4.22 per cubic yaid.

By ordinary labor, 200 cu. yds., $1.50 per cubic yard.

Rip-rap.—The cost of the 1,300 cu. yds. of rip-rap, including equipment and labor, was $2.25 per cubic yard.

Stone Filling.—The 5,400 cu. yds. of stone filling, including equipment and labor, cost $1.69 per cubic yard.

Piles.—The 40-ft. hardwood piles cost, in place, $13.48 each, or $0.34 per linear foot. This cost includes material, equipment, driving, cutting off and all other labor.

Superstructure.—The weight of the 250-ft. swing span was 737,062 lbs., and its cost, erected, was 5.34 cts. per pound.

The weight of the twelve 60-ft. deck plate girders was 710,370 lbs., and their cost, erected, was 3.27 cts. per pound.

The power plant and machinery cost $5,167.

PERCENTAGES OF TOTAL COST OF VARIOUS ITEMS

Substructure.—The following are the percentages of the total substructure cost ($155,955.49) of some of the principal items:

	Per cent
Engineering, including preliminary surveys, plans and field inspection	1.73
Bridge and Building Dept., including changing of trestle bents, re-supporting track, etc	1.90
Soundings	0.23
Contractor's superintendent	1.66
General charges, including overhead charges, engineering, contractor's superintendence, and contractor's percentage	8.88
Freight	6.23
Transportation	1.01

The substructure contractor's percentage was 6½ per cent of the total cost (exclusive of engineering) of the substructure, which equals about 14 per cent of the actual labor cost alone.

Superstructure.—The following are the percentages of the total superstructure cost ($77,877.79) of several items:

	Per cent
Engineering, including shop and field inspection	0.78
Bridge and Building Dept.—run-outs	0.96
Bridge and Building Dept.—new floor	6.50

TABLE XII.—COST DATA ON OPEN TIMBER CAISSONS—ENGINEERING AND CONTRACTOR'S PERCENTAGE NOT INCLUDED

	Total ft. B. M.
Timber used	
8 Double wall caissons	
Permanent double wall	344,727
Temporary single wall	64,200
5 Single wall caissons	
Permanent single wall	28,760
Temporary single wall	18,400

COSTS

	Total
Labor	
Framing	$13,881
Tearing down, single wall	459
Rip-rap	724
Unloading material	460
Material	
Timber	7,690
Tools	623
Rip-rap	1,127
Iron	1,075
General	382
Miscellaneous	
Fuel	229
Freight	1,250
Transportation	545
Overhead charges	3,033
Total	$31,478
Average unit cost per M. ft. B. M.	$69.02*

* This varied from a minimum of $56 to a maximum of $81.

TABLE XIII.—COST DATA ON CONCRETE WORK—ENGINEERING AND CONTRACTOR'S PERCENTAGE NOT INCLUDED

	Cu. yds.
Quantity	
In 13 piers and 2 abutments exclusive of 12-in. walls	4,862
Between caisson walls (8 double wall caissons)	519
Total	5,381
Costs	
Labor	
Mixing and placing, excluding 12-in. walls	$ 6,884.45
Mixing and placing between 12-in. walls	1,310
Unloading material	2,878.11
Forms	2,941
Temporary tracks	720
Equipment	882
Material	
Cement sand and crushed stone	15,048
Forms	550
Temporary track	580
Equipment	442
Tools	316
Miscellaneous material	1,337
Miscellaneous	
Transportation, switching	625
Freight	5,740
Fuel	800
Overhead charges	3,056
Total	$44,109.56
Unit cost per cu. yd	$8.20*

*Average.

TABLE XIV.—COST DATA ON CRIB PROTECTION WORKS, BOOMS AND WALING—ENGINEERING NOT INCLUDED

	Center cribs	2 Waling	Booms	Wing cribs	Totals
Quantities					
Timber, ft. B. M.	550.316	15,300	24,696	192,734	783,046
Rubble stone, cu. yds.	4,000	......	......	1,400	5,400
Total Cost of Various Items					
Labor					
Unloading material	$ 380	$ 20	$ 30	$ 200	$ 630
Framing	7,085.00	793.72	1,223.00	3,595.00	12,696.72
Excavation by diver	505			346	851
Filling cribs	1,737.15	....	....	806.00	2,543.15
Rip-rap	135.09	....	....	101.00	236.09
Material					
Timber	11,080	495	705	4,260	16,540
Iron	1,000	55	35	490	1,580
Rubble stone	3,500	....	....	1,213	4,713
Tools	250	35	40	100	425
Miscellaneous					
Transportation	200	14	16	100	330
Freight	1,310	80	120	690	2,200
Fuel	140	....	....	60	200
Overhead charges	3,106	169	248	1,216	4,739
Total cost	30,428.24	1,661.72	2,417.00	13,177.00	47,683.96
Unit cost per M. ft. B. M.	55.30	108.45	97.87	68.37	60.87
Contractor's percentage			$ 3,097.00		
Grand total cost			$50,780.96	$64.85	

TABLE XV.—SUMMARY OF COSTS OF PIERS AND ABUTMENTS OF RICHELIEU RIVER BRIDGE

Pier No.	West abutment	1	2	3	4	5	6	7
Height from foundation to seat, ft.	14.5	14.5	11.5	14.5	20.5	26.0	28.5	30.5
Piles	....	....	....	....	....	....	....	....
Excavation	$ 150.00	....	$ 140.00	$ 140.00	$ 150.00	$ 150.00	$ 150.00	$ 190.00
Caisson	448.00	$ 598.00	537.00	665.00	1,665.00	2,287.00	3,104.00	3,321.00
Pumping	50.00	90.00	90.00	90.00	125.00	125.00	125.00	150.00
Concrete and forms	2,275.11	914.00	770.00	1,093.00	2,096.00	2,446.00	2,674.00	4,647.00
Cofferdam	530.00	306.98	....	....	....	....	....	....
Soundings	20.00	21.60	10.90	14.50	10.90	12.70	12.70	27.45
Grillage beams	....	....	....	....	....	....	....	....
Contractor's percentage	225.00	125.00	100.00	139.50	262.00	325.50	394.00	541.00
Total	$ 3,698.11	$2,055.58	$1,647.90	$2,142.00	$4,308.90	$5,346.20	$6,459.70	$8,876.45
Pier No.	East abutment	8	9	10	11	12	13	Total
Height from foundation to seat, ft.	35.5	33.0	31.0	32.5	18.7	14.5	9.5	....
Piles	....	....	....	....	$ 485.00	$ 485.00	$606.61	$ 1,576.61
Excavation	$ 420.00	$ 190.00	$ 150.00	$ 600.00	155.00	140.00	150.0	2,875.00
Caisson	6,956.00	3,958.00	3,457.00	2,696.00	801.00	534.40	451.00	31,478.40
Pumping	201.92	150.00	125.00	125.00	90.00	90.00	50.00	1,676.92
Concrete and forms	11,827.45	4,704.00	3,201.00	3,171.00	1,255.00	1,056.00	1,980.00	44,109.56
Cofferdam	....	....	....	....	....	....	520.00	1,356.98
Soundings	81.00	14.50	10.90	14.50	59.60	50.20	....	361.45
Grillage beams	2,460.59	....	....	....	....	....	....	2,460.59
Contractor's percentage	1,255.00	586.00	451.00	430.00	185.00	152.00	244.00	5,415.00
Total	$23,201.96	$9,602.50	$7,394.90	$7,036.50	$3,030.60	$2,507.60	$4,001.61	$91,310.51

Cost of Converting a Pin-Connected Bridge into a Riveted Structure.—The following matter is taken from an article published in Engineering News, Oct. 8, 1914.

The conversion of a pin-connected bridge span into a riveted span is an interesting and very exceptional piece of bridge work recently carried out. The bridge is a single-track swing span on a branch of the Pennsylvania Lines, crossing the Grand Calumet River, at Burnham, Ill., and was built by A. Gottlieb & Co., in 1886. It is 183 ft. long, c. to c., having two 81-ft. arms and a central 21-ft. panel. It was necessary to adapt the bridge to carry heavy loading (Cooper's E-60), and investigation showed that this could be done much more rapidly and at much less cost by strengthening the old structure than by replacing it by a new bridge. The work in general was as follows:

(1) Reinforcing the main trusses; (2) adding an additional row of stringers for each rail; (3) placing new top and bottom cover plates and additional end hanger plates on the floor-beams; (4) strengthening the circular girder of the turntable drum.

Execution of Work.—One arm of the bridge is over shallow water and the other over the navigable channel. The plan of reconstruction adopted was to build falsework under the former arm and make all the alterations to it, such truss pins being removed from it as were necessary to make way for the new parts. The bridge was then revolved, and the other arm treated in the same way. The traffic averaged 20 trains daily.

As the work was done before the navigation season opened, the bridge was not required to be swung for river traffic. When reversed for the reconstruction work, it was swung by means of its hand-operated machinery in the regular manner. A locomotive crane standing on the bridge was used to take out the old members and put the new members in place, while the use of oxyacetylene torches in cutting away old material considerably reduced the time and cost of the work.

In all, about 20 tons of metal were removed and 80 tons of new metal placed, the bridge as now completed having a weight of about 170 tons.

The necessary alterations to the bridge and the methods of carrying them out were planned under the direction of J. C. Bland, Engineer of Bridges of the Pennsylvania Lines. The contract for the execution of the work was awarded Dec. 2, 1913. Work was commenced Jan. 20, 1914, and completed May 13, 1914. The cost was approximately $16,500, while it is estimated that a new bridge to meet the same conditions would have cost about $75,000.

The Cost of a Cable-Lift Drawbridge of the Pennsylvania Lines is given in Engineering News, Nov. 13, 1913. The bridge in question being one of two parallel double-track bridges built in 1913 across the Calumet River at South Chicago. The bridges are on skew, each having an extreme length (including approach spans) of about 340 ft., and a length of 210 ft. c. to c. of end pins of the lift span. The distribution of cost for one span is as follows:

Substructure	$110,000
Towers, including approach spans	88,000
Lift span	70,000
Electrical apparatus	16,500
Operating machinery	45,000
Rail latches	3,000
Cables	13,000
Concrete counterweights	3,400
	$348,900

TABLE XVI.—GENERAL SUMMARY AND CLASSIFICATION OF COSTS

Items	Superintendence and labor	Material	Miscellaneous*	Overhead charges	Total
Overhead charges:					
Construction buildings	$ 1,660.53	$ 1,562.80	650.00	....	....
Timekeeper, tool boys, watchman	2,500.00	....	....	....	....
Shoveling snow	64.00	....	....	....	....
Equipment (handling and repairing)	2,922.00	1,300.00	....	....	....
General expense	....	593.00	....	....	....
Superintendence	2,585.12	....	....	....	....
Caissons	14,800.00	9,770.00	1,524.40	$2,701.00	$ 28.795.40
Crib protection work, etc.:					
Waling	813.72	585.00	94.00	169.00	1,661.72
Booms	1,253.00	780.00	136.00	248.00	2,417.00
Wing protection	3,795.00	4,850.00	660.00	1,000.00	10,305.00
Center protection	7,465.00	12,330.00	1,490.00	2,490.00	23,775.00
Concrete:					
Concrete	11,792.56	17,281.00	6,820.00	4,036.00	39,929.56
Forms	2,941.00	550.00	345.00	344.00	4,180.00
Rubble stone:					
Riprap	960.09	1,127.00	500.00	332.00	2,919.09
Filling cribs	2,543.15	4,713.00	350.00	832.00	8,438.15
Removing old structure:					
Old rest piers	1,010.00				
Old center pier	600.00				
Old wing protection	576.00	1,041.29	....	432.00	4,518.27
Old center protection	614.98				
Old wharf	244.00				
Removing under water by diver	2,148.38	130.00	20.00	258.00	2,556.38
Cutting trestle piles inside caisson	100.00	20.00	2.76	13.75	136.51
Cleaning bottom of piers and cribs by diver	2,400.00	130.00	10.00	286.00	2,826.00
Excavation and cofferdams—E. & W. Abut. and Pier No. 1	1,232.98	235.00	20.00	169.00	1,656.98
Unwatering all piers	797.92	200.00	530.00	149.00	1,676.92
Sounding	256.00	50.00	....	55.45	361.45

TABLE XVI.—(*Continued*)

B. & B. Dept. work:					
By J. S. Metcalfe Co.—					
Resupporting track	1,411.57	200.00	93.44	159.00	1,864.01
Removing old trestle piles	....	....	....	....	....
Cutting foundation piles	100.00	20.00	2.75	13.25	136.00
By G. T. Ry. B. & B. Dept.—					
Resupporting track	415.20	500.00	120.00	71.00	1,106.20
Pile driving	232.00	700.00	80.00	79.00	1,191.00
Motive Power Dept	....	....	$ 329.61	....	329.61
Grillage beams	....	....	2,460.59	....	2,460.59
Dredging:					
Excavation	....	....	600.00	....	600.00
Removing old structures	....	....	245.00	....	245.00
Damage to barge	....	....	75.00	....	75.00
Engineering	....	....	2,705.85	....	2,705.85
Contractor's percentage	....	....	9,188.80	....	9,188.80
Total	$68,234.20	$58,668.09	$29,053.20	....	$155,955.49

* Miscellaneous includes Transportation—$1,573.44, Fuel—$2,159.40, Freight—$9,715.51 and miscellaneous—$15,604.85

The cost of the lift span covers furnishing and erecting the steelwork complete, the machinery and operator's houses, wood walkways and platform sand their railings. The cost for the counterweights includes furnishing and placing the concrete. The cost of dismantling the old span, providing temporary supports for tracks during erection, royalty, extras in erection, and various other items will make the total cost of each double-track bridge about $400,000. To this must be added the proportional share of the cost of the power plant.

Cost of Erecting Structural Steel for Manhattan Elevated Railway Improvements.—Early in 1916 work was completed on the addition of single continuous express track to the Manhattan elevated railway in New York City. The work included the building of 23 miles of single track elevated structure, the erection of 50,000 tons of steel, the building of 638 foundations, and the construction or reconstruction of 29 stations. Most of the work was on city streets often congested with traffic. Traffic on the elevated railway lines was maintained according to the regular schedule throughout the period of reconstruction. In a paper published in the Dec. 1917 Proceedings, Am. Soc. C. E., F. W. Gardiner and S. Johannesson describe the design and construction features of this improvement. The following notes, on the cost of the work, taken from the above-mentioned paper are given in Engineering and Contracting, Jan. 23, 1918.

The work was performed under a contract, dated Feb. 13, 1914, with the Terry & Tench Co., Inc., The Snare & Triest Co., and the T. A. Gillespie Co., which last company acted as executive. The work was distributed as follows;

All foundation work was done by the T. A. Gillespie Co.; the Snare & Triest Co. carried out all work, including steel erection, station finish, and track-laying on Sections Nos. 6-C and 7; the Terry & Tench Co. completed all steel erection and track work on the remaining sections, and the station finish work on these sections was partly carried out by the Terry & Tench Co. and partly by the T. A. Gillespie Co. The contractor's work was in executive charge of a vice-president of the T. A. Gillespie Co.

The sub-contractors for the manufacture and delivery of the steelwork, the tonnage delivered, and the prices per pound of the material delivered, are given in Table XVII.

TABLE XVII.—STEEL WORK FOR "MANHATTAN ELEVATED IMPROVEMENTS"

Section	Sub-contractor	Tons	Price per lb.
1	Milliken Brothers	5,963	$0.0288
2-A	American Bridge Co	4,562	0.0293
2-B	American Bridge Co	3,820	0.0262
3	Phoenix Bridge Co	3,929	0.0239
4-A	McClintic-Marshall Co	5,544	0.0215
5-A	Pennsylvania Steel Co	1,732	0.0290
5-B	Pennsylvania Steel Co	1,440	0.0275
5-C (Structural steel)	Pennsylvania Steel Co	1,100	0.0290
5-C (Machinery)	Pennsylvania Steel Co	163	0.1045
5-D	Pennsylvania Steel Co	1,113	0.0320
6-A	L. F. Shoemaker & Co	2,926	0.0250
6-C	McClintic-Marshall Co	8,075	0.0243
7	L. F. Shoemaker & Co	1,487	0.0254
8-A	American Bridge Co	5,041	0.0245
8-B	Milliken Brothers	1,302	0.0270
8-C	Milliken Brothers	547	0.0254
10-B	Belmont Iron Work	1,200	0.0285

The contracts for the manufacture and delivery of rails were made with the following companies:

Bethlehem Steel Co., Standard rails, 2,961,520 lb., at $0.014 per pound.

Lackawanna Steel Co., standard rails, 2,916,940 lb., at $0.014 per pound.

Illinois Steel Co., manganese rails, 564,060 lb., at $0.0905 per pound.

The track lumber, which was all yellow pine and amounted to about 8,000,000 ft. B. M., was obtained from the D. L. Gillespie Co., of Pittsburgh, Pa., and cost $30.50 per 1,000 ft. B. M.

Other lumber, for shoring, forms, etc., was bought for $23.50 per 1,000 ft. B. M.

The prices paid for materials for concrete delivered were as follows:

Cement, per bbl.	$1.70
Sand, per cu. yd.	1.00
Stone, per cu. yd.	1.70

Cost of Labor.—The wages paid to the men engaged on the work were at the prevailing rates, and were as follows, for an 8-hour day:

Bricklayers	$ 6.00
Iron workers	5.00
Iron workers apprentices	3.00 to $4.00
Carpenters	5.00
Carpenter foreman	7.00 to 8.00
Dock builders	4.00
Water-proofers	4.25
Rock drillers	3.75
Timber men	2.50
Timber men or foreman	3.00 to 3.50
Painters (structural)	2.25 to 2.50
Painters foreman	4.00 to 5.00
Blacksmiths	4.50 to 6.00
Blacksmiths' helpers	3.20
Machinists	3.50
Lead caulkers	4.50
Labor foreman	3.50 to 4.00
Handy man	2.50 to 3.00
Laborers	2.00 to 2.25
Painters for timber work	4.00
General foreman	8.00 to 10.00, straight time
Compressor men	125.00 per month
Hoisting engineers	30.25 to 33.00 per week
Watchmen	12.00 to 14.00 per week

The total cost of the work done by the contractors was $10,273,636. The contractors' expenses for engineering and superintendence amounted to $559,340, or about 5½ per cent of the total cost.

The cost of steel erection varied greatly for the different sections, on account of the varying difficulties connected with the erection. Table XVIII gives for each section the cost of erecting 1 ton of steel and the cost of shoring per ton of steel erected.

As an example of the cost of riveting, etc., it may be stated that, on Section No. 6-C, 365,000 rivets were driven at the cost of 14.2 cts. per rivet, including overhead charges. There were four men in a gang, and each gang averaged 172 good rivets for an 8-hour day. This work was interfered with, on account of the train traffic. About 325,000 holes were drilled from the solid, mostly 15/16 in. in diameter, at a cost of 15.1 cts. per hole; about 40 per cent of these holes were drilled in new steel on the street surface, the remainder in the structure. About 115,000 old rivets and bolts were cut out of the existing structure at a cost of 9.6 cts. each, including replacing the rivets cut out with temporary bolts.

Table XVIII.—Cost of Erection

Section No.	Cost of erection, per ton	Cost of shoring, per ton
1	$ 30.42	$12.57
2-A	21.27	5.41
2-B	13.80	1.50
3	43.71	20.18
4-A	14.22	0.88
5-A	50.85	20.61
5-B	39.62	26.53
5-C	85.76	......
5-D	32.49	6.49
6-A	28.70	17.06
6-C	39.82	10.30
7	93.94	7.34
8-A	33.41	15.33
8-B	.....	.....
8-C	57.80	13.90
10-B	105.24	2.68

The labor charges for the construction of the foundations varied considerably, according to whether the new foundations were at new locations or replaced existing foundations, and also according to the sub-surface structures encountered. On Section No. 2-A, for example, 49 foundations, each containing, as an average, 15.8 cu. yd. of concrete, were placed at new locations at $24.50 per cubic yard, including all excavation, placing of sheathing, forms and concrete, back-filling, and repaving. Seventeen foundations under existing columns were placed at a cost of $37 per cubic yard, and, in addition, the cost of shoring the structure amounted to $210.36 for each foundation.

On Section No. 5-A, 23 foundations, each containing, as an average, 20 cu. yd., under existing columns, were placed at a cost for labor of $18.93 per cubic yard, and the charges for shoring the structure amounted to $255.77 for each foundation.

On Section No. 5-B, 24 foundations, each containing 7.5 cu. yd. of concrete, at new locations, were completed at a cost of $22.47 per cubic yard, or a total of $168.50 per pier, distributed as follows:

Superintendence: Timekeeping, storekeeping, material checking, general foreman		$ 21.02
Carpenter work	Protections	$ 4.00
	Sheathing	20.00
	Making forms	4.00
	Placing forms	7.00
	Stripping forms	3.40
	Repairing forms	6.00
Labor	Excavating	50.80
	Concreting	9.90
	Back-filling	10.16
	Cleaning up	5.00
Watching		12.10
Hauling materials		15.12
		$168.50

Cost of Reinforcing a Steel Bridge with Concrete.—The following is given in Engineering and Contracting, Feb. 22, 1911.

The use of concrete for stiffening the columns of steel trestles and for making old steel trestles permanent, has been successfully accomplished by the Wabash R. R. On one of the bridges, thus reinforced, the St. Charles Bridge over the Missouri River, the saving has been about $140,000 as compared with the cost of a new trestle. The saving per lineal foot is about $32.20 for this trestle which averages about 40 ft. in height.

Before the work was started, estimates were made of the probable cost of a new trestle to replace the present one and also of the probable cost of doing the work as it has now been carried out. Assuming the concrete to cost $6 per cu. yd. and the steel, 4 cts. per lb. in place, it was found that the cheapest new structure that could be built was one consisting of 45-ft. deck girder spans on concrete piers, and the cost of such a structure would be $50 per lin. ft. With the same unit prices, the cost of a new trestle composed entirely of steel with towers 30 ft. in length and intermediate spans of 60 ft., was found to be $53 per lin. ft., and if the intermediate spans were made 30 ft. instead of 60 ft., the cost would be $56 per lin. ft., but if the intermediate spans were made 15 ft. instead of 60 ft., the cost would be $51 per lin. ft.

By way of comparison with the above estimate, the steel columns of the St. Charles bridge approaches have been reinforced with concrete at a cost of $7.30 per lin. ft. of trestle. It is estimated that the cost of steel stringers to replace the old wooden ones will be $10.50 per lin. ft. in place, making the total cost of strengthening the trestle $17.80 per lin. ft. The saving, therefore, over a structure costing $50 per lin. ft. is $32.20 per lin. ft., and as this trestle is 4,342 ft. long, the total saving amounts to about $140,000.

It must be noted that there will be an additional saving, as the amount of salvage that would accrue from the sale of materials in the old trestle would be much less than the cost of removing the trestle. Another fact worth noting is that this kind of work can be done gradually at a cost which would be but little more than the present maintenance expenses. The trestle as now reinforced, as estimated from previous column tests, and inspection of the completed work, will carry any engine that it is possible to build.

Construction Work.—The contractor for the work on both bridges was furnished with materials f.o.b. cars at the site, with "dead-head" freight on all lumber, tools and equipment, and free transportation of laborers, all of which materially reduced the cost of construction to the contractor.

In the two approaches to the St. Charles Bridge there are 300 columns, 40 to 50 ft. high, tied in groups of four, with transverse and longitudinal struts, to form towers. These columns, with the exception of the built-up shapes at the strut crossings, are of the Phoenix section. An 18-in. octagonal section for the Phoenix columns was adopted and a 24-in. square section was used for the sections at the street crossings.

With the exception of the bases, which were poured by hand, each tower was poured monolithically, using a 1:3 mortar reinforced with No. 6 spiral hooping for the Phoenix columns and with 1 in. square bars for those at the street crossings. Despite the excessive length of the columns, the troublesome connecting struts with their knee braces, and the frequent vibrations due to the regular traffic, a remarkably smooth job was obtained, with faces true to line and free from honeycomb or cracks. In placing the reinforcement and the forms, hanging scaffolds were used; the steel gang on one scaffold being closely followed by the carpenter force on another. The scaffolds were used again in the wrecking.

The ⅞-in. forms were cut, in sections of approximately 14 ft. so that they could be used six times, thus reducing the carpenter cost, necessarily high, because of the cutting and framing around the struts and lateral braces. The spiral reinforcement although very effective, was comparatively expensive because of the "cork screw" fashion in which it had to be applied. The experiment of using wire mesh with equivalent cross sectional area of steel, was made and proved less expensive, in labor. This test was made near the close of the job after all the spirals were on hand, and was intended only for the general information of the contractors.

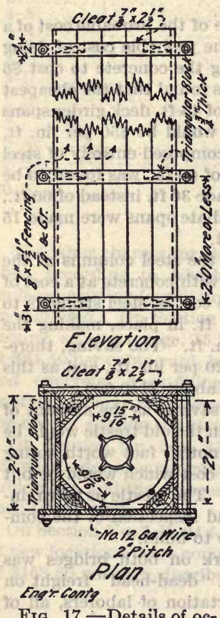


FIG. 17.—Details of octagonal forms for encasing steel columns.

The concrete was made with a mixer mounted on a work train and the materials were carried in bins upon the car with the mixer. The concrete was poured into the forms through spouts leading from the mixer to the column caps. The work train was frequently interrupted and sidetracked for passing traffic, but this lost time was used, as far as possible, in refilling the material bins.

The cost of the work to the contractor, allowing 90 cts. per bbl. of cement and 50 cts. per cu. yd. for sand, was $12.45 per cu. yd. of concrete or an average of $165 per tower. This cost includes the following items: Material for concrete; material for forms; labor building, placing, repairing and removing forms; labor placing reinforcement; labor mixing and placing mortar; labor unloading and rigging; equipment; administration and miscellaneous labor. The contract was let on a percentage basis with a guaranteed maximum which closely approximated the actual cost. The structure was completed in 5 months.

Cost of Constructing Three Single-Track Concrete Arch Bridges, Lake Champlain & Moriah Railroad.—The following costs, given in Engineering and Contracting, June 15, 1910, by Eugene Klapp, are for constructing three reinforced concrete arch railway bridges in the northern part of New York by company forces. The prices of labor and materials were as follows:

Common labor, per day	$1.30
Carpenter foreman, per day	3.00
Boss carpenter, per day	2.25
Common carpenters, per day	1.75
Stationary engineer, per day	2.00
Foreman reinforcement, per day	2.00

A 10-hour day was worked for five days and a nine-hour day on Saturday. Tailings were used for concrete aggregate and cost only the freight and labor for loading, both of which are included in the labor costs given.

Lumber for forms cost $18 per M. ft. B. M. unplaned; the planing was done on the job and is included in the labor costs for forms. Cement cost $1.20 per bbl. after deducting credit for return of bags.

Bridge 1.—This bridge consists of an arch 18-ft. wide, 20 ft. long and 24 ft. high. It was founded on earth and required a spread footing 12 ft. wide.

The bridge contained 560.7 cu. yds. of concrete and was estimated to cost $7,000. The actual itemized cost was as follows:

Item	Total	Per cu. yd. concrete
Temporary constructions—		
Materials	$ 10.51	$ 0.019
Labor	255.42	0.455
Miscellaneous	525.27	0.936
Total	$ 791.20	$ 1.410
Excavation—		
Materials	$ 4.12	$ 0.001
Labor	374.94	0.668
Total	$ 379.06	$ 0.669
Forms—		
Materials	$ 923.95	$ 1.647
Labor	1,228.92	2.191
Total	$2,152.47	$ 3.838
Mixing Concrete—		
Materials	$ 55.19	$ 0.098
Labor	251.73	0.449
Total	$ 306.92	$ 0.547
Placing Concrete—		
Materials	$ 135.20	$ 0.241
Labor	$ 242.51	0.432
Total	$ 377.71	$ 0.673
Reinforcing—		
Materials	$ 397.37	$ 0.708
Labor	198.34	0.354
Total	$ 595.71	$ 1.062
Cement	$ 780.75	$ 1.392
Superintendence	312.50	0.557
A round total	$5,696.72	$10.146

The concrete work proper, therefore, cost as follows per cubic yard:

Forms	$3.838
Mixing	0.547
Placing	0.673
Reinforcement	1.062
Cement	1.392
Total	$7.512
Superintendence prorated say	$0.445
Grand total	$7.957

In comment on these figures it may be noted that the item "materials" for forms includes the lumber used in trestles. Referring to "miscellaneous" charges under "preliminary construction," $262.23 of the total were paid for specifications and plans, or 4.6 per cent of the total cost. Superintendence cost 5½ per cent of the total.

Bridge 2.—This bridge, a much simpler structure than Bridge 1, being founded on rock and having plain abutment and wing walls, is a simple arch 34 ft. wide, with footings 9 ft. wide. A feature of the design is the expansion joint placed across the barrel of the arch about mid length. The bridge contained 1,804 cu. yds. of concrete and its estimated cost was $10,500. The actual itemized cost was as follows:

Item	Total	Per cu. yd. concrete
Temporary construction—		
Materials	$ 60.07	$0.033
Labor	915.73	0.508
Miscellaneous	796.10	0.441
Total	$1,771.90	$0.982
Excavation—		
Materials	$ 27.20	$0.015
Labor	411.84	0.228
Total	$ 439.04	$0.243
Forms—		
Materials	$ 965.91	$0.535
Labor	1,568.76	0.869
Total	$2,534.67	$1.404
Mixing concrete—		
Materials	$ 514.10	$0.285
Labor	572.12	0.316
Total	$1,086.22	$0.601
Placing Concrete—		
Materials	$ 31.25	0.017
Labor	834.09	0.462
Total	$ 865.34	$0.479
Reinforcing—		
Materials	$ 210.12	$0.116
Labor	56.70	0.031
Total	$ 266.82	$0.147
Cement—		
Materials	$1,675.40	$0.928
Labor	19.91	0.011
Total	$1,695.31	$0.939
Superintendence	$ 538.49	$0.299
Grand total	$9,197.79	$4.094

The concrete work proper, therefore, cost as follows per cubic yard:

Forms	$1.404
Mixing	0.601
Placing	0.479
Reinforcing	0.147
Cement	0.939
Total	3.570
Superintendence prorated say	0.225
Grand total	$3.795

In the above items "materials" for forms include trestle lumber and "miscellaneous" charges include $262.23 for plans and specifications. The charge for plans and specifications was 2.85 per cent and the cost of superintendence was 5.85 per cent of the toal cost. The influence of complexity of forms on form costs and cost of placing concrete is indicated by comparing these costs for Bridges 1 and 2.

Bridge 3.—This bridge, founded on rock just below the surface is a simple arch 34 ft. wide and 104 ft. long and has plain abutments and wing walls. A notable feature of the design is the extension upward of the abutment walls to form a cross wall between spandrel walls and the bracing together of the spandrel walls by two intermediate diaphragm walls. There is an expansion joint across the spandrel walls over the center pier. This bridge contained 1320.7 cu. yds. of concrete and was estimated to cost $7,500. The actual itemized cost was as follows:

Item	Total	Per cu. yd. concrete
Temporary construction—		
Materials	$ 34.71	$0.026
Labor	186.38	0.141
Miscellaneous	538.66	0.408
Total	$ 759.75	$0.575
Excavation—		
Materials	$ 3.77	$0.003
Labor	797.57	0.603
Total	$ 800.84	$0.606
Forms—		
Materials	$ 912.51	$0.691
Labor	1,036.49	$0.785
Total	$1,949.00	$1.476
Mixing concrete—		
Materials	$ 487.50	$0.369
Labor	678.04	0.513
Total	$1,165.54	$0.882
Placing concrete—		
Materials	$ 1.05	$0.001
Labor	510.19	0.386
Total	$ 511.24	$0.387
Reinforcing—		
Materials	$ 396.83	$0.300
Labor	45.88	0.035
Total	$ 442.71	$0.335
Cement	$1,221.20	$0.924
Superintendence	$ 176.78	$0.134
Grand total	$7,027.06	$5.319

The concrete work proper, therefore, cost as follows per cubic yard:

Forms	$1.476
Mixing	0.882
Placing	0.387
Reinforcing	0.335
Cement	0.924
Total	$4.004
Superintendence prorated say	0.100
Grand total	$4.104

As with bridges 1 and 2, materials for forms include lumber used for trestles. The cost for plans and specifications was $262.23, and is included under "miscellaneous" preliminary construction charges. Plans and specifications cost 3.7 per cent and superintendence cost 2.5 per cent of the total cost.

Cost of Concreting Bridges of C., M. & St. P. Ry.—The Chicago, Milwaukee & St. Paul Ry., in 1915, completed two single track reinforced concrete viaducts near Rosalia, Wash., thereby replacing a 60-ft. high, 2,100-ft. long frame trestle. The two bridges are separated by 334 ft. of embankment. The easterly structure is composed of a 107½-ft. reinforced concrete trestle abutment, a 100-ft. spandrel arch span and a 79½-ft. reinforced concrete trestle abutment. The westerly structure consists of a 77-ft. reinforced concrete abutment, three 77½-ft. and one 68⅛-ft. spandrel arches, one 58½-ft. encased steel girder and a combination trestle and U-abutment. The following description of the concreting plant used on this work is published in

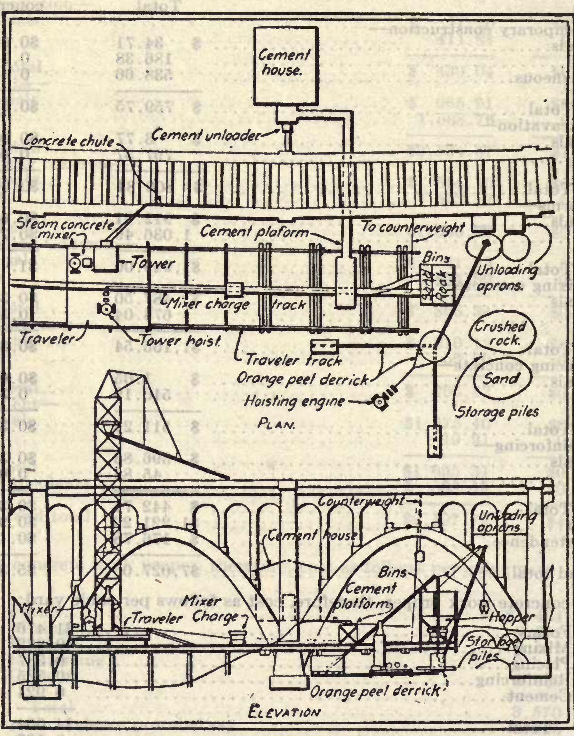


FIG. 18.—Layout of Rosalia, Wash., concreting plant.

Engineering and Contracting, Nov. 22, 1916 and is taken from the report "Efficient Methods of Handling Work and Men," submitted on Oct. 17, 1916, at the annual meeting of the American Railway Bridge and Building Association:

It was impracticable to place the plant on the track grade, and, accordingly, it was located under the westerly bridge, the layout being as shown in Fig. 18. The crushed rock and sand were delivered in hopper bottom cars and unloaded through chutes to the ground below, and then placed in storage piles by a stiff-leg derrick fitted with 60-ft. boom and orange peel bucket. This derrick was so located as to handle the materials to the storage piles and from there to hoppers for loading in small cars for transportation to the mixer. The derrick was operated by a double drum engine fitted with a Dake swinging gear connected to a bullwheel on the base of the mast.

The mixer and tower were placed on a traveling platform that could be moved along the north side of the bridge. Most of the concrete was spouted in this way directly into the forms. The concrete was elevated and the cars containing the dry material were hauled by a hoisting engine on the traveling platform. The empty cars were pulled back to the loading hoppers by a counterweight fastened to the bridge. The cement was unloaded into a storage house immediately underneath the south of the bridge by means of an endless belt with a friction brake which enabled the lowering of the cement at slow speed to prevent damage to sacks by tearing or burning. The cement was then wheeled directly to the cars as they left the loading hoppers.

The same plant was used to mix the concrete for the easterly bridge. In this case, however, the concrete was hoisted into small cars on a narrow-gage track on the north side of the main line and hauled by a gasoline locomotive. Concrete was mixed and placed in the easterly bridge for as low as 34 cts. per cu. yd. in this way, although the average was considerably above this on account of the inability to make continuous runs while concreting.

The steel reinforcement was all cut and bent on the platform at the west end of the westerly bridge and lowered into place from the track level. Portable forms were also built at the same point and handled in the same way. Water was obtained from city mains and in this way the necessity of installing a pump was avoided.

The organization of the forces was as follows:

	Per mo.
One general foreman	$150.00
One timekeeper	75.00
	Per 10 hours
One carpenter foreman	$ 3.50
One blacksmith	3.25
One labor-foreman	3.00
Two sub-foremen	3.25
Twenty-six carpenters	3.00
Two engineers	3.00
One engineer (gasoline)	2.50
One fireman	2.50
Ten carpenter helpers	2.25
Twenty-four laborers	2.00

The size of the crew varied considerably on account of the difficulty in obtaining men and on account of some delay in obtaining material at various times. During the progress of the work the average traffic was eight passenger and about twelve freight trains per 24 hours. There was an average of four passenger and four freight trains on the Northern Pacific track under the easterly bridge; eight passenger and four freight trains on the Spokane & Inland Empire tracks under the westerly bridge and heavy team and automobile travel on the state highway, so that it was necessary to provide special falsework in each case to avoid blocking traffic.

The total amount of concrete placed was 5,924 cu. yd., the average cost per cubic yard for labor and material being $7.56. The total amount of reinforcing placed was 960,000 lb. at $1.80 per 100 lb.

CHAPTER XVIII

STEAM RAILWAYS

This chapter deals mainly with the construction and maintenance costs of steam railways. Costs of bridges and tunnels are given in Chapters XVII and XX respectively.

Further data on steam railway construction, maintenance and operation are given in Gillette's "Handbook of Cost Data."

The "Handbook of Mechanical and Electrical Cost Data" by Gillette and Dana gives costs of electric railway construction and other operating cost data of use to either or both steam and electric railways.

Approximate Costs of Rapid-Transit Lines.—The following relative costs of producing rapid-transit structures, contained in a paper entitled "Provisions for Future Rapid Transit," presented by John Vipond Davies, consulting engineer, of New York City, before the National Conference on City Planning at Toronto, May 25 to 27, are given in Engineering Record, June 6, 1914.

The figures are given as average costs for construction of structures and the installation of structural equipment, but without power or rolling stock. They do not include the value of property for rights of way or easement and are given on the basis of constructing a double track railroad in each case, although reduced to the cost per mile of single track:

Types of Structure
For Double Railway Tracks

	Cost per mile of single track
Trolley railroad in suburban district, either on public roads or private right of way where no paving is required, complete with overhead trolley construction, track bonded; all in operating condition	$ 25,000
Trolley railroad on city streets, including asphalt or granite block pavement for width of tracks and 2 feet outside of tracks; complete with overhead trolley construction, track bonded; all in operating condition	$ 42,000
Underground trolley railroad in congested streets of a city, including necessary pavements, conduits, etc., and with reasonable allowance for changes of subsurface improvements:	
New York	$ 126,000
Washington	49,500
Elevated railroad of a type and for the loading permissible to meet requirements of Public Service Commission of New York; complete with stations, contact rail, ties and track; averages	$ 125,000
Railroad in open cut similar to Sea Beach Railroad of Brooklyn Rapid Transit Company in Brooklyn, where work is executed with steam shovel and with concrete walls; averaging cost of bridges and stations as part of the cost; complete with contact rail, ties and track; averages	$ 225,000
Railroad on masonry viaduct filled in with stone ballast, similar to structure erected on Queens Boulevard from Queensboro Bridge to Greenpoint, on Long Island, New York; complete with stations, contact rail, ties and track; averages	$ 330,000

Subway such as the Fourth Avenue Subway in Brooklyn, where work is unaffected by subsurface improvements, where the digging is easy and can be done with steam shovel and under typical, ideal conditions; complete with structural and track equipment; averages	$ 402,000
Subway such as the Broadway Subway constructed in New York City, where the work is very difficult and involves extreme interference with subsurface improvements of all kinds, the support of street surface, trolley car tracks, underground trolley construction, etc.; complete with structural and track equipment; averages	$1,190,000
Iron lined tube tunnels under waterways or below water level; complete with structural equipment and track; averages	$2,700,000

In connection with these costs, the difference in the first cost of constructing improvements in a city like Washington, where the soil is advantageous to excavate, where the streets are broad and where there is no difficulty in changing subsurface improvements, is in marked contrast to the cost of executing similar work in a city like New York, where the material to be excavated is most difficult, where the streets are congested and where there are numerous and extensive subsurface improvements to be cared for.

Cost of Elevated Railways and Subways.—The following notes are taken from an article by Maurice E. Griest published in Engineering News, May 20, 1915.

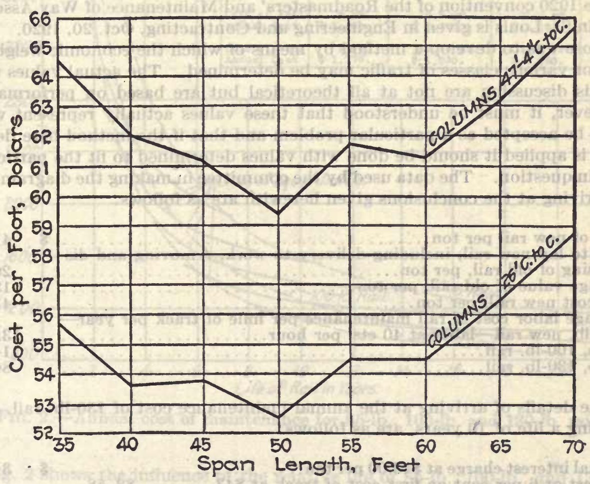


FIG. 1.—Effect of span-length on cost of three-track elevated railway.

Relative Cost of Subway and Elevated Lines with ballasted floor and with open floor are as follows:

COST OF SUBWAY AND ELEVATED STRUCTURE

		Per lin. ft. of structure
Three-track subway		$300 to $500
Three-track elevated	Solid floor	$200
	Open floor	$125

Economic Span Length for Elevated Railway.—Fig. 1 is based on the design of the 3-track elevated structure as used by the N. Y. Rapid Transit System. The costs exclude track, stations and ducts and are based on average prices of recent (1914–15) contracts as follows:

Steel	$54.00 per ton*
Cast iron	48.00 per ton
Concrete	7.00 per cu. yd.
Excavation	2.00 per cu. yd.
Paving	3.00 per sq. yd.

* The cost of steel makes up about 80 per cent of the cost of an elevated structure exclusive of track, signals and station finish.

Plate Girders vs. Latticed Stringers.—Latticed stringers are from 10 to 15% lighter than plate-girder stringers of the same span. The cost of fabrication of the latter, however, particularly without cover-plates, is about 10% less than of a latticed girder without connection plates and 15% less than of a latticed girder with connection plates. The first cost, therefore, is practically the same in either case. Depreciation and maintenance costs of plate-girder construction are less than for latticed girders; details are simpler and the structure is more rigid. Plate-girder stringers were therefore adopted.

Economic Weights of Rail.—The following abstract of a committee report at the 1920 convention of the Roadmasters' and Maintenance of Way Association in St. Louis is given in Engineering and Contracting, Oct. 20, 1920. The purpose was to develop a method by means of which the economic weight of rail for various classes of traffic may be determined. The actual values used in this discussion are not at all theoretical but are based on performance. However, it must be understood that these values actually represent what must be accepted as a particular problem and that if the method here developed is applied it should be done with values determined to fit the particular case in question. The data used by the committee in making the diagram and in arriving at the conclusions given herewith are as follows:

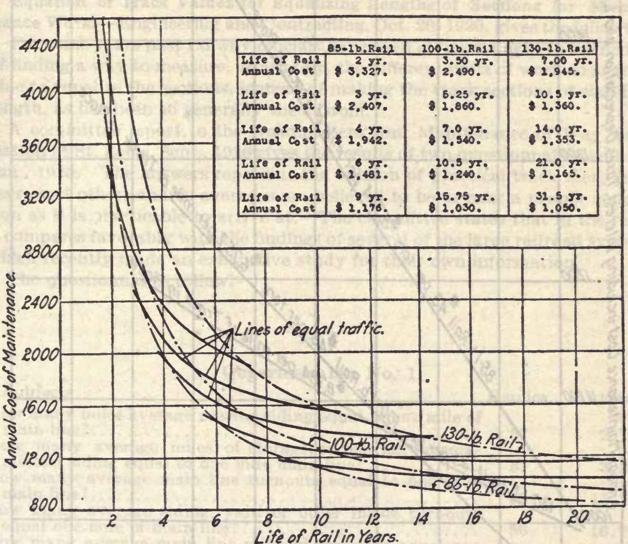
Cost of new rail per ton	$ 41.00
Cost to lay new rail, including delivery to work, removing and disposing of old rail, per ton	20.00
Salvage value of old rail, per ton	18.00
Net cost new rail, per ton	43.00
Average labor cost of rail maintenance per mile of track per year—85-lb. new rail—labor at 40 cts. per hour	135.00
Ditto, 100-lb. rail	114.00
Ditto, 130-lb. rail	86.00

The details of arriving at the annual maintenance cost of 130-lb. rail, considering a life of 10 years, are as follows:

Annual interest charge at $43.00 per ton		$ 3.077
Interest at 6 per cent on first cost of track at $43	$2.58	
Taxes at 1 per cent on first cost of track at $43	0.43	3.010
Interest at 6 per cent and taxes at 1 per cent on $18 salvage per ton when removed		1.260
First cost (10-year life) per ton		$ 7.347
Tons of rail per mile of track (130-lb. rail)		204.29
Annual charge per mile of track based on 10-year life		1,501.00
Annual cost (labor 40 cts. per hour) of maintaining 130-lb. rail in 1 mile of track		86.00
Annual cost of maintenance, including interest, taxes, depreciation and labor		1,587.00

The committee concludes that under similar conditions of traffic, the life of 100-lb. rail is 1¾ times that of 85-lb. rail, and that the life of 130-lb. rail is double that of 100-lb. rail. The relative life of over 100,000 tons of 130-lb. rail compared to the life of 100-lb. rail in the same tracks was actually determined, based on four years' experience with the heavy rail, during which time over 4,300 tons of the heavy rail were actually removed from tracks on account of being worn out.

To allow for the comparatively short period of time for which the data concerning heavy sections were taken, the relationship between the average life of heavy section rail and 100-lb. rail was taken to be 2 to 1. The data concerning the relative life of 100-lb. and 85-lb. rail were of a more extended and broader nature, but had not been kept in as detailed a manner.



	85-lb. Rail	100-lb. Rail	130-lb. Rail
Life of Rail	2 yr.	3.50 yr.	7.00 yr.
Annual Cost	$ 3,327.	$ 2,490.	$ 1,945.
Life of Rail	3 yr.	5.25 yr.	10.5 yr.
Annual Cost	$ 2,407.	$ 1,860.	$ 1,360.
Life of Rail	4 yr.	7.0 yr.	14.0 yr.
Annual Cost	$ 1,942.	$ 1,540.	$ 1,353.
Life of Rail	6 yr.	10.5 yr.	21.0 yr.
Annual Cost	$ 1,481.	$ 1,240.	$ 1,165.
Life of Rail	9 yr.	15.75 yr.	31.5 yr.
Annual Cost	$ 1,176.	$ 1,030.	$ 1,050.

Fig. 2.—Annual cost of maintenance for 85-lb., 100-lb. and 130-lb. rail.

Fig. 2 shows the influence of the relative life of 85-lb., 100-lb , and 130-lb. rail under similar conditions of traffic; that is, lines representing the life of various sections of rails under similar conditions of traffic, from which can be determined the difference in the annual cost of maintenance due to different rail sections. For example, suppose 85-lb. rail gave a life of two years—the average maintenance cost is $3,327—then 100-lb. rail should give a life of 3½ years, with an average maintenance cost of $2,490, while 130-lb. rail should give a life of 7 years with an average maintenance cost of but $1,945—clearly a case where heavy section rail could be used economically from a maintenance point of view.

As a measure for the wear of rail under various conditions of traffic, the committee decided on the number of cars per day passing over a stretch of track as the measure of traffic conditions. Such a unit closely reflects the locomotive tons and gross tons; the average weight of cars, the average cars per train and average locomotive miles per train mile ordinarily varying

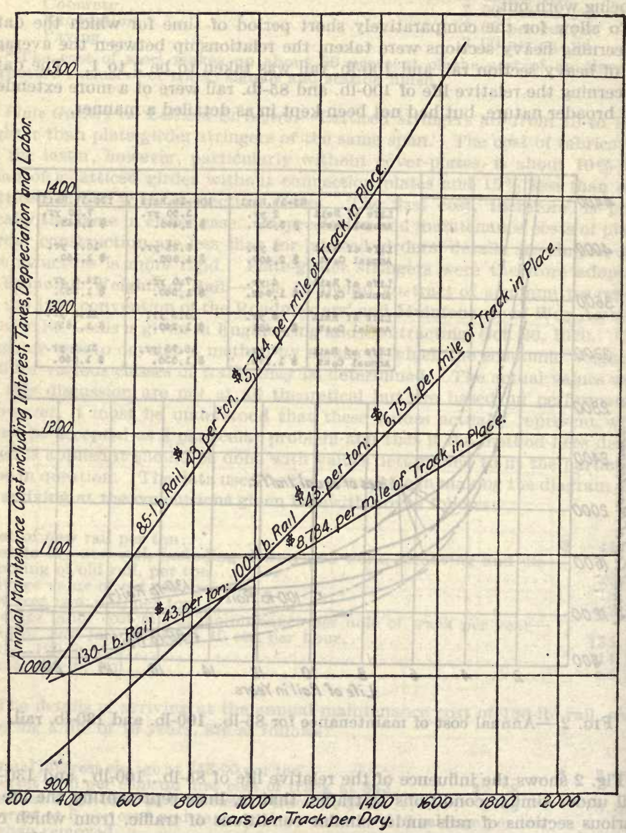


FIG. 3.—Effect of density of traffic on annual maintenance cost.

between narrow limits from month to month. Also the average number of cars passing a particular point over a stretch of track during any period can readily be determined at any time without elaborate machinery or organization.

To determine the proper life to assign to 100-lb. rail under various traffic conditions, 14 stretches of track were selected for which information concerning the car movement and rail renewals was available. From this information was determined the average life of 100-lb. rail in each stretch of track. This data varied from 417 cars per track per day to 1,697 cars per track per day.

The curves in Fig. 3 show that the 100-lb. rail is economical for a traffic of not over 900 cars per track per day and that for a greater car movement the 130-lb. rail is economical. As between the 100-lb. rail and 85-lb. rail, the data would indicate that, on railroads using heavy power and having a wide range of physical characteristics, the 85-lb. rail is no longer economical, but that modern railroading demands a 100-lb. rail. When traffic reaches 1,800 cars per day over a double track railroad, the point is reached to consider increasing the weight of section to about 130 lb.

Equation of Track Values for Equalizing Lengths of Sections for Maintenance Work.—Engineering and Contracting, Oct. 20, 1920, gives the following:

For some years past railway officials have been giving thought to the matter of finding a way to measure, accurately, the different units of work so as to be able to equalize the sections, instead of making the track sections of standard length, as has been so generally the custom.

A committee report to the Roadmasters' and Maintenance of Way Association at St. Louis, Sept., 1920 gives the results of two questionnaires sent out Jan., 1920. The answers represent the opinion of practical track men, engineers and others and as averages are believed to be as near a proper conclusion as it is practicable to arrive at. The committee states that in the main it compares favorably with the findings of several of the large railroad systems which recently made an exhaustive study for their own information.

The questionnaires follow.

Questionnaire No. 1

Subjects	Replies	Average
How many miles average passing siding equal to one mile of main line?	57	2.75
How many average miles of storage, industrial, or commercial siding equal to one mile main line?	57	3.84
How many average main line turnouts equal to one mile main line?	56	15.3
How many average siding, yard or other inside turnouts equal one mile of main line?	56	16.77
How many average main line railroad crossings equal one mile of main line?	56	10.95
How many average siding railroad crossings equal one mile of main line?	55	19.18
How many heavy traffic, important city street crossings equal one mile of main line?	56	9.20
How many (medium) important city street crossings equal one mile of main line?	57	14.00
How many light traffic street crossings or outlying highway crossings equal one mile main line?	57	20.90
How many average farm crossings or other unimportant crossings equal one mile of main line?	57	46.58
How many average stock chutes and pens equal one mile of main line?	45	17.00
How many average re-icing stations equal one mile of main line?	37	4.15
How many average watering stations equal one mile of main line?	46	5.50

How many average interlocking plants equal one mile of main line?	51	3.40
How many average cattle guards equal one mile of main line?	48	48.00
How many average feet of track in tunnels equal one mile of main line outside?	38	2,848
How many average coaling stations equal one mile of main line?	47	3.82
How many average fire or cinder cleaning stations equal one mile of main line,	47	2.47
How many average station grounds equal to one mile of main line?	52	5.68
How many average automatic signals and incidental fixtures equal one mile of main line?	27	20.74
How many miles of average fencing equal one mile of main line?	48	15.07
How many feet of ordinary average ditching will equal one mile of main line?	42	10,160

QUESTIONNAIRE No. 2

Subject	Replies	Average
Assuming a double track railroad having an average normal gross tonnage of 100,000 per day or 40 freight trains, 20 in each direction, with an average normal number of 12 passenger trains, using a maximum speed of 60 miles per hour; grade generally level, 3 per cent maximum; line 3 per cent curvature 6 degree maximum. What length of section should be established at outlying points if no such conditions prevail as are listed in above questions?	54	3.68
What length of section should be established on a single track railroad, having same curvature and gradient, with one-half the gross tonnage and one-half the number of passenger trains listed above?	52	6.0
How much should such sections be lengthened or shortened for each 25,000 gross tons and two passenger trains daily that might be added or taken off on such double track sections?	35	.914
How much for a single track section for each 12,000 gross tons or one passenger train?	30	.867
What difference should be made in the mileage of a double track section having motor cars as compared with hand cars?	28	1.17
What on single track sections?	35	1.20

Cost of Railway Track Reconstruction.—In Engineering and Contracting, Sept. 7, 1910, D. A. Wallace publishes the following records which give the cost per 100 ft. and per mile for reconstructing track on two jobs, one in 1906 and the other in 1908.

1. The work consisted in putting up dirt track on crushed stones, replacing 58-lb. rail with 85-lb. rail and renewing 15 ties per 100 ft. The itemized cost was as follows, using negro labor at $1.25 per day and foreman at $60 per month:

Materials:	Per 100 ft.	Per mile
2,784 cu. yds. stone at 45 cts	$ 23.71	$1,252.80
Ties at 35 cts. f. o. b	5.25	277.20
133,577 tons rails at $30	75.32	3,977.13
Angle bars at 64 cts	3.87	204.80
Bolts at $4.90	1.21	63.70
Spikes at $3.20	2.06	108.80
Total materials	$111.42	$5,884.43

Labor:	Per 100 ft.	Per mile
Unloading stone	$ 3.11	$ 164.25
Raising grade 7 ins	5.53	292.00
Unloading ties at 0.9 cts	0.14	7.13
Applying ties at 10.4 cts	1.56	82.37
Unloading rails	0.18	9.60
Unloading fastenings	0.01	0.53
Laying rails	3.46	184.00
Stone surfacing, 3 ins., 2 ins., raise	7.50	396.00
Unbolting old rails	0.18	9.75
Loading old rails	0.44	23.25
Stripping track	1.25	66.00
Total labor	$ 23.36	$1,234.88
Grand total	$134.78	7,119.31
Credit 9.15 tons old rails at $16	$ 27.33	$1,464.32
Net cost	$107.45	$5,654.99

2. The work comprised 5 miles of track, 21 years old, 50 per cent of which consisted of 6° curves. The track had about 4 ins. napped stone under the ties and spaces between the ties filled in with enough coarse rock to prevent bunching of the ties. The rail was 30-ft., 56-lb. and had been in service 21 years. Approximately 7 ties per rail were broken off or decayed. The rails were replaced with 33-ft., 70-lb. rails, joint ties spaced, and 8 months later the track was raised, 6 ins. in gravel unloaded from hopper bottom coal cars at a cost of 15 cts. per cu. yd. on cars at pit and 15 cts. per cu. yd. for a haul of 80 miles, making a total cost of 30 cts. per cu. yd. on the ground. About 25 ties per 100 ft. were renewed. Negro labor at $1.25 per day and foreman at $75 per month were employed. The cost of the work was as follows:

Materials:	Per 100 ft.	Per mile
110 tons 70-lb. rail	$66.66	$3,520.00
Angle bars at 70 cts. per pair	4.85	256.00
4¼-in. bolts at $5	0.05	30.00
Spikes at $4	1.13	60.00
1,000 cu. yds. ballast at 30 cts	5.68	300.00
1,320 ties at 31 cts	7.75	409.20
Total materials	$86.12	$4,575.20
Labor:	**Per 100 ft.**	**Per mile**
Unloading rail	$ 0.40	$ 26.05
Unloading fastenings	......	0.25
Curving rail	0.55	28.66
Distributing by push car	0.27	14.59
Laying rail	2.83	149.80
Surfacing first raise 4 ins	1.94	102.50
Smoothing second raise	1.37	72.50
Dressing ballast	2.27	119.85
Unloading ties at 1.6 cts	0.40	21.12
Applying ties at 10.7 cts	2.67	141.24
Loading and unloading old rails	0.75	39.77
Total labor	$13.45	$ 716.33
Grand total	$99.57	$5,291.53
Credit 88 tons old rail at $24	$ 4.00	$2,112.00
Net cost	$95.57	$3,179.53

Prices Used in the Valuation of Railways in Nebraska.—E. C. Hurd, Engineer of Valuation, Nebraska State Railway Commission gives the following data in Engineering and Contracting, July 31, 1912.

Table 1 shows the unit prices which were very largely used for reproduction. The unit prices for all material arriving from the east includes commercial freight charges to the Missouri River gateways. The western products, namely that of lumber, were delivered to any point of the state on a flat commercial rate, while rail material from Colorado is estimated delivery at Denver commercial rates.

The Nebraska timber and soil conditions to be met in railroad construction admit of a nearly uniform treatment for the 150 miles in the east part of the state, while some variance is found in the westerly portion. Within the easterly portion certain allowance was made necessary for clearing and grubbing, whereas in the westerly section no allowance was made. The soil conditions are similar throughout, when cost of excavation is considered, and only in the westerly portion is there any rock of consequence.

TABLE I.—ROADWAY ITEMS—UNIT PRICES FOR 1909
Only Including Freight to Gateways

Grading:	
Earthwork, ordinary, per cu. yd	24 and 26 cts.
Overhaul 600 feet, per cu. yd	1½ cts.
Earthwork, terminal, yards, etc., no overhaul	30 to 47½ cts.
Loose rock	65 cts.
Solid rock	$1.00
Rip rap, rough or dumped stone in place	$ 1.80 to $ 2.20
Rip rap, laid up (dry)	4.30
Retaining walls, coursed rubble, per cu. yd	6.00 to 11.00
Retaining walls, concrete, per cu. yd	7.75 to 9.00
Retaining walls, brick, per cu. yd	8.00
Dykes, pile, brush or stone, per lin. ft	10.00 to 13.00
Dykes, earth, per cu. yd	.40
Clearing, per acre	20.00
Grubbing, per acre	50.00
Drain for wet cuts, per lin. ft	.43
Indemnity insurance on rock and extra hazardous	6 % of labor
Tunnels:	
Average basic cost per lin. ft. unlined	$125.00
Rock excavation, per cu. yd	4.50
Earth (Brule clay), per cu. yd	3.50
Shaft excavation, per cu. yd. (additional)	3.00
Timber lining, per M. B. M. in place	45.00
Indemnity insurance	9 % of labor

NOTE.—But one tunnel owned by the Burlington Railroad and located at Belmont lies within the state, excavated almost entirely through Brule clay, length being 694 feet.

Bridging:	
Piling, ordinary foundation and trestle, per lin. ft. in place	$ .45
Piling, 34 feet and longer, per lin. ft. in place	.65 and .70
Piling, sheet, 3-in. plank, per lin. ft	.08
Timber, Douglas fir, per M. B. M. in place	38.50
Timber in Howe truss, per M. B. M. in place	$43.50–48.00
Timber in piers, per M. B. M. in place	41.00
Timber, creosoted, per M. B. M. in place	45.00
Masonry:	
Stone, Ashlar, per cu. yd. in place	$ 12.00
Stone, coursed rubble, per cu. yd. in place	10.00
Stone, broken, per cu. yd. in place	8.00
Stone, dry, per cu. yd. in place	6.00
Stone, Missouri River bridge, per cu. yd. in place	25.00
Stone, arch culverts, per cu. yd. in place	12.00
Concrete, includes forms, foundations and substructures	9.00
Concrete, reinforced, foundation and substructures	11.00
Concrete, Missouri River bridge, foundation and substructures	27.00
Concrete, culvert end walls, per cu. yd	7.50

TABLE 1.—*Continued*

Masonry:	
Concrete, arch culverts, per cu. yd	12.00
Foundation excavation, per cu. yd	1.00
Steel girders, per net ton in place	75.00
I beams, per net ton in place	68.00
Truss towers or bents, per net ton in place	80.00
Railroad viaducts, per net ton in place	90.00
Missouri River bridges, per net ton in place	115.00
Wooden bridge hardware, per lb	.03
Reinforcing bars, per lb	.03
False work, ordinary, per lin. ft	10.00
Vitrified clay pipe, size 6 × 36-in., per lin. ft. in place	37 to 4.00
Wooden Howe truss, excluding foundation, 72-ft. spans in place, per ft.	25.00
Wooden Howe truss, excluding foundation, 116-ft. spans in place, per ft.	36.00
Wooden Howe truss, excluding foundation, 160-ft. spans in place, per ft., covered	52.00
Inside guard rails, two ends, complete	$35.00 to $ 40.00
Cast Iron Pipe Culverts, without end walls, cost per net ton—	
Sizes, in place	$ 36.00
18-in. diameter, per lin. ft. in place	3.00
24-in. diameter, per lin. ft. in place	4.75
36-in. diameter, per lin. ft. in place	8.75
48-in. diameter, per lin. ft. in place	13.50
Cast Iron Pipe Syphons, concrete ends—	
18-in. diam., per lin. ft. in place	$ 5.75 to $ 6.00
24-in. diam., per lin. ft. in place	7.00 to 7.50
36-in. diam., per lin. ft. in place	12.00 to 12.50
Concrete and Stone Arch Culverts (semicircular) complete, including excavation, foundation piling, wings, forms, etc.—	
4 ft. wide at spring line, per lin. ft. of barrel	$ 42.00
6 ft. wide at spring line, per lin. ft. of barrel	50.00
8 ft. wide at spring line, per lin. ft. of barrel	60.00
10 ft. wide at spring line, per lin. ft. of barrel	80.00
16 ft. wide at spring line, per lin. ft. of barrel	140.00
20 ft. wide at spring line, per lin. ft. of barrel	180.00
Timber Box Culverts (12 × 12-in. with 2-in. floor)—	
1 × 2½-ft., per lin. ft	$ 3.75
2 × 2-ft., per lin. ft	4.50
2 × 3-ft., per lin. ft	5.00
3 × 3-ft., per lin. ft	6.00
3 × 4-ft., per lin. ft	6.75
4 × 4-ft., per lin. ft	7.75
4 × 5-ft., per lin. ft	8.50
Ties:	
Missouri white oak, standard, each	.70
Missouri oak, mixed, each	62½ and .65
Northern white oak (6 × 8 × 8), each	.80
Northern white oak (7 × 9 × 8), each	1.00
Northern cedar, each	.74
Southern cedar, each	.70
Southern pine, each	.80
Southern pine, treated, each	90 and .95
Black Hills and Wyoming pine, each	.50
Black Hills and Wyoming pine, treated, each	.65
Douglas fir, sawed, 7 × 9 × 8, each	1.05
Douglas fir, sawed, 7 × 9 × 8, treated, each	1.20
Hemlock, each	.61
Hemlock, treated, each	.76
Switch ties, oak, per M. B. M	31.00
Switch ties, fir or pine, per M. B. M	28.00
Switch ties, fir or pine, treated, per M. B. M	30.00
Bridge ties, fir, per M. B. M	26.00
Bridge ties, oak, per M. B. M	32.00
Labor framing and placing bridge ties, per M. B. M	16.00

TABLE 1.—*Continued*

Rail:

At eastern gateways, per gross ton	30.75
At Denver, gateway, per gross ton	29.00
Relayers, f.o.b. Omaha, per gross ton	25.00
Scrap rail, per gross ton	10.00 to 14.00

Frogs and Switches:

Rigid frogs, material only, per cwt	2.75
Spring frogs, material only, per cwt	2.95
Switch points (15′), material only, per cwt	4.28
Crossing frogs, material only, per cwt	3.75
Derails, each	12.50

Average cost per complete turnout in place:

Weight of rail	60 lbs.	70 lbs.	75 lbs.	85 lbs.
No. 7 frog	$ 94	$103.00	$111.50	$117.00
No. 9 frog	100	107.00	113.00	120.50
No. 10 frog	101	109.00	116.00	122.00
No. 12 frog	....	109.50	117.00	125.00
No. 14 frog	....	114.50	122.00	130.50

Crossings placed at an average of $65.00 each.

Track fastenings and other material:

Angle bars and base plates, per cwt	$ 1.96
Continuous joints ($1.30 to $1.90 per pair), per cwt	2.125
Track bolts, per keg, 200 lbs	5.05
Tie plates, ordinary rigged or corrugated, per cwt	.125
Tie plates, heavy flat, per cwt	....
Average cost, first mention, 7½ cts.; second mention, 12 cts. each.	
Nut locks, ¾-in., per. 1,000	6.00
Nut locks, ⅞-in., per 1,000	6.25
Rail braces, rolled, each	10 to .12
Rail braces, cast, each	12 to .14
Spikes, standard, per keg, 200 lbs	3.75
Screw spikes, per cwt	2.93
Bumping posts, for freight yards, each	55.00
Bumping posts, for passenger yards, each	80.00

Ballast:

Gravel, Sherman Hill, Wyoming, f.o.b. pit, per cu. yd	$ 0.11
Gravel, Atkinson and Eureka, Neb., f.o.b. pit, per cu. yd	.15
Gravel, Chillicothe, Ill., f.o.b. pit, per cu. yd	.12
Gravel, Oral, S. D., f. o. b. pit, per cu. yd	.16
Gravel, Grand Junction, Ia., f. o. b. pit, per cu. yd	.15
Gravel, Cheyenne River and Guernsey, Wyo., f. o. b. pit, per cu. yd	.12
Crushed stone, Louisville and Meadow, Neb., also Blue Springs, Neb., f. o. b. quarry, per cu. yd	.65
Stone quarry screenings, f. o. b. pit, per cu. yd	.20¼
Slag, f. o. b. Omaha, per cu. yd	.20
Cinders, f. o. b. any division point, per cu. yd	.22
Sand, f. o. b. any pit, per cu. yd	.12
Burnt clay, f. o. b. pit, per cu. yd	.48

Average weight of ballast material per cu. yd.:

Gravel, Sherman Hill, lbs. per cu. yd	2,950
Gravel, all others, lbs. per cu. yd	3,200
Crushed stone, lbs. per cu. yd	2,400
Cinders, lbs. per cu. yd	1,680
Burnt clay, lbs. per cu. yd	1,700
Slag, lbs. per cu. yd	3,360
Sand, lbs. per cu. yd	3,300

Track laying and surfacing:

Laying track on main line, 70 to 90-lb. rail, including sidings, per mile	$375.00
Laying track on branch lines, 52 to 70-lb. rail, including sidings, per mile	310.00
Placing additional switches, main line, each	20.00
Placing additional switches, branch line, each	15.00

Above price in track laying contemplates average ½ switch per mile.
Indemnity insurance, 3⅓ per cent of labor.

TABLE 1.—*Continued*

Surfacing	Per track mile Main Line	Based on avg. 6-in. ballast under tie Branch Line
Earth	$335	$300
Cinders & gravel	380	345
Burnt clay	553	516
Crushed stone	620	590
Additional to above allowance on up-keep of track during construction, per mile		$90.00 to 120.00

Roadway tools:	
Average allowance per section gang per set	$120.00
Average allowance per extra gang per set	600.00
Average allowance per bridge gang per set	600.00
Average allowance per roadmaster's inspection car, etc., each	125.00
Average allowance per bridge supervisor car, etc., each	125.00
Average allowance per signal supervisor car, etc., each	125.00
Average allowance per signal maintainer car, etc., each	150.00
Fencing—Right of way:	
4 barbed wires, 32-ft. panels, wood or wire sag lath, per fence mile	128.00
4 barbed wires, 16-ft. panels, wood or wire sag, per fence mile	160.00
For each additional wire to above add	12.50
Cattle guards, single, wood strips, each	15.40
Cattle guards, single, iron strips, each	17.50
Farm gates, wire, each	2.50
Farm gates, wood, each	4.30
Farm gates, iron, each	7.00
Crossings and signs:	
Oak crossing planks in place, per M. B. M.	34.00
Walks, board, per sq. ft	10 to .25
Walks, cinder, per sq. ft	.06¼
Walks, cinder with curb, per sq. ft	.125
Walks, concrete, per sq. ft	12 to .14
Walks, brick, per sq. ft	.125
Wood curbing, per lin. ft	.16⅔
Crossing alarms (electric automatic), per crossing, each	$200.00 to 325.00
Crossing gates, per crossing, each	255.00
Gate towers, per crossing, each	250.00
Highway crossing signs (post and 2 crossboards), each	4.50 to 7.00
Bridge, railroad crossing or station 1 mile signs, each	2.40 to 3.75
Yard Limit, Slow, etc., each	3.50
Post signs, ordinary, each	1.50 to 1.90
Bridge warning, each	19.00
Bridge and culvert numbers, each	.50 to 1.75

Interlocking and other signals:

This item is too varied to undertake to express an average, but some of the costs herewith are typical:

Interlocking plant, single track, wood tower, 16 lever, mechanical	$4,800.00
Crossing gate, with signals and torpedo attachment	650.00
Electrical block signals, single track, per mile	1,150.00
Electrical block signals, double track, per mile	1,500.00
Electric-gas signals, single track, per mile	1,210.00
Interlocking outlying switches with home and distance signals, per switch, each	500.00
Train order signal, high mast, each	120.00
Train order signal, box and board on depot building, each	35.00 to 60.00

Telegraph and telephone lines:

Only a few of the simpler telegraph lines will here be mentioned.

6-in. 30-ft. poles, 30 per mile, with cross arms, 4 No. 10 wires	$194.00
6-in. 30-ft. poles, 30 per mile, with cross arms, 6 No. 10 wires	240.00
6-in. 30-ft. poles, 30 per mile, with cross arms, 8 No. 10 wires	292.00
Station sets, ordinary, each	25.00 to 35.00
Station sets, complete quads, each	135.00

TABLE 1.—*Continued*

Station buildings and fixtures:		
Depots, one story, frame, averages, per sq. ft.		$1.37½ to 1.90
In typical buildings, 16 × 40 ft.		$ 880 to 1,000
In typical buildings, 18 × 56 ft.		1,500 to 1,700
In typical buildings, 20 × 40 ft.		1,100 to 1,350
In typical buildings, 20 × 56 ft.		1,500 to 1,770
In typical buildings, 20 × 80 ft.		2,240 to 2,700
In typical buildings, 24 × 60 ft.		2,100 to 2,500
In typical buildings, 24 × 80 ft.		2,800 to 3,500
In typical buildings, 24 × 100 ft.		3,000 to 3,850
Depots, two story, frame, averages per sq. ft.		$2. 20 to 2. 63
In typical buildings, 20 × 40 ft.		1,600 to 1,900
In typical buildings, 22 × 56 ft.		2,500 to 3,300
In typical buildings, 22 × 80 ft.		3,800 to 4,800
In typical buildings, 24 × 56 ft.		2,800 to 3,200
In typical buildings, 24 × 70 ft.		3,100 to 3,800
In typical buildings, 24 × 90 ft.		4,400 to 5,400
Depot furniture and fixtures—		
Small stations		$100 to 140
Medium stations		250 to 350
Larger stations		400 to 600
Section dwelling houses—		
1 story, frame, per sq. ft.		$1.00 to 1.375
1½ story, frame, per sq. ft.		1.25 to 1.50
2 story, frame, per sq. ft.		1.75 to 2.25
Water closets, coal houses, etc., per sq. ft.		1.25
Section tool houses, per sq. ft.		.52 to .75
Freight houses, frame, averages per sq. ft.		1.25 to 1.50
In typical buildings, 22 × 64 ft.		$1,600
In typical buildings, 24 × 50 ft.		1,800
In typical buildings, 24 × 100 ft.		3,000
In typical buildings (brick), 40 × 80 ft.		$8,000 to 8,800
Shops, engine houses and turntables:		
Shop buildings for ordinary division points containing 3,000 to 8,000 sq. ft.		
Brick and frame, per sq. ft.		$2.10 to 3.50
Brick and steel, per sq. ft.		2.50 to 4.50
Shop buildings for terminals containing 30,000 to 60,000 sq. ft		
Brick and frame, per sq. ft.		$ 2.05
Brick and steel, per sq. ft.		2.50
Engine house, wood, 65 to 70 ft. long, 1 stall		2,200.00
Engine house, wood, 65 to 70 ft. long, 2 stalls		3,100.00
Engine house, wood, 65 to 70 ft. long, 3 stalls		4,250.00
Engine house, wood, 65 to 70 ft. long, 6 stalls		7,800.00
Engine house, wood, brick lined—		
	65 to 70 ft.	80 to 90 ft.
1 stall	$ 2,800.00	....
2 stalls	3,500.00	$ 4,700.00
3 stalls	4,350.00	....
5 stalls	8,600.00	11,700.00
8 stalls	13,200.00	17,000.00
Engine house, brick—		
5 stalls	12,600.00	15,000.00
10 stalls	19,600.00	24,100.00
20 stalls	44,500.00	48,500.00
30 stalls	65,400.00	78,500.00
Turntables, wood, Gallows type, length 50 ft., each		$ 1,250.00
Turntables, steel, permanent center, 60 ft. each		3,950.00
Turntables, steel, permanent center, 70 ft., each		5,760.00
Turntables, steel, permanent center, 80 ft., each		6,950.00
Water stations: Average cost found		
32,000-gal. tank, wooden tub and tower, in place		$ 1,500.00
50,000-gal. tank, wooden tub and tower, in place		1,800.00
65,000-gal. tank, steel tub and tower, in place		3,750.00
Water crane, 10 and 12 in., with piping and pit in place, each		700.00
Pumping plant, machinery and house, in place, each		595.00
Windmills, 20-ft. wheel, 50-ft. tower, in place, each	$400 to	550.00

TABLE 1.—*Continued*

Water stations: Average cost found	
Windmills, 20-ft. wheel, 70-ft. tower, in place, each........650 to	770.00
Typical plant, 50,000-gal. wood tank, 1 track outlet, ordinary steam or gasoline pumping plant, well and piping...........	4,200.00
Typical plant, 65,000-gal. steel tank, 2 standpipes, steam or gasoline pumping plant, well and piping..................	6,900.00
Fuel stations: Average cost found	
Wooden coal shed, hand derrick and buckets, in place, each.......	$ 1,740.00
Coal chute (Williams, White, Clifton, Kerr, etc.).	
5 to 10 pockets, 40 to 50-ton capacity..........................	4,860.00
10 pockets, 80-ton capacity......................................	8,330.00
20 pockets, 100 to 200-ton capacity..........................	12,800.00
Conveyor, bucket type, single, 2 pockets, 100-ton capacity	7,690.00
Conveyor, bucket type, double, 4 pockets, 200-ton capacity.....	11,880.00
Link belt type with scale hopper, single, 2 pockets, 100-ton capacity..	11,880.00
Tipple car type, 35 to 50-ton capacity.........................	9,130.00
Tipple car type, 150-ton capacity..............................	10,580.00
Cable hoist type, 4 pockets, 200-ton capacity.................	12,060.00
Miscellaneous structures:	
Stock yards, average prices found in place—	
Fence, per lin. ft..	$ 0.5
Gates, each..	12.00
Shelter sheds, per sq. ft..	.24
Hog sprinklers, each...	25.00
Feed troughs, each..	5.00
Chutes, single, each..	112.50
Chutes, double, each...	148.00
Scale and rack, 4-ton capacity, each........................	160.00
Scale and rack, 6-ton capacity, each........................	190.00
Scale and rack, 10-ton capacity, each......................	240.00
Windmills, small tank and pipe............................$500 to	750.00
Typical stock yard, 2 pens, 1 chute, each...................	400.00
Additional pens, each...	125.00
Snow fence, portable, 12-ft. panels, each......................	7.50
Snow fence, fixed, 5 ft. high, 10-ft. panels, per lin. ft..............	.245
Snow fence, fixed, 7 ft. high, 10-ft. panels, per lin. ft..............	.315
Snow fence, fixed, 12 ft. high, 10-ft. panels, per lin. ft.............	.375
Mail cranes, Barker and similar types, each, in place..............	22.00
Park fence, 2 and 3 flues, in place, per lin. ft.............. $0.42 to	.45
Adaptation and solidification of roadway:	
Method of determining cost of this item—	
a. Cost of labor spread over a period of three years.	
For main lines—	
First class—single line roadway, including all appertaining tracks, per roadway mile per annum..............................	$312.00
Second class—ditto as above..	240.00
For branch lines—	
First class—ditto as above...	204.00
Second class—ditto as above..	180.00
b. Cost of material account of shrinkage and subsidence.	
For main lines—	
1st class—add to the cost of grading....................................	3 to 8 %
2d class—add to the cost of grading....................................	2½ to 6 %
For branch lines—	
1st class—add to the cost of grading....................................	3 to 6 %
2d class—add to the cost of grading....................................	2 to 4 %
For two or more main line tracks and for each track additional to the first track 75 per cent of the first track.	
Engineering and superintendence:	
Entire as found within the state, per roadway mile...............	$1,034.67
Entire as found within the state, per track mile....................	810.15
Per cent of total value, roadway, equipment, etc....................	2.16 %

Net ton units were adopted for locomotives considering the weight of the engine loaded and the tender light. This plan was adopted primarily for the reason that the information could in that form be most readily obtained from the railroad companies' records. As the appraisal progressed, a further convenience developed in finding that the engine loaded increases in a very direct proportion to its net weight. In assembling the locomotive costs, further development indicated three general classes by weight, the first those exceeding 100 tons, the second those from 60 to 100 tons, and the third all those under 60 tons. Drawing finer lines, further subdivisions have been found in service and utilized in some cases. Tables were prepared showing in detail the methods used in arriving at the cost per ton, and which were adopted in the appraisal. One table shows the average cost per ton for each of the three classes and for each year, in which these classes of locomotives were built. In some cases, however, not sufficient data was obtainable to give a true average. In the year 1909, $2,000,000 actual expenditures for locomotives was deemed sufficient for determining an average, and the result was a cost of $115.81 per ton for engines over 100 tons in weight. For those 60 to 100 tons in weight only about 25 instances were found, the resultant costs represented thereby being $122.70 per ton, but after careful perusal this was not adopted as an accurate average. A seemingly more perfect average was reached by considering a much larger survey for engines in the first and second mentioned classes for five-year periods, ending 1903 and 1909. From this the average cost of the second mentioned class of engines was determined to be $120.26 per ton. The average cost of engines of the third class was determined as $125.93 per ton. The type of locomotive, whether for passenger, freight or switching, seems to evidence little difference in the results of cost per ton. Commercial freight rates were allowed from the eastern manufacturers to the Missouri River, but not within the state, and the freight east of the river was added in addition to the units. The first outfit of tools was a further charge in addition to the units, but extra tools and apparatus not embraced under the classification was excluded.

For passenger cars the units adopted provided for the general items of construction and equipment. Type and size of the car gave no correct results when the finish and equipment for the vehicle influenced the cost to a very large extent. The main items on which unit costs were based are as follows:

1. Car bodies, not including trucks, air brakes and signals; heating and lighting, seats, vestibules, mail racks, dining car equipment, oak finish for passenger cars, painted for baggage and mail or express. These were divided into different types, such as baggage, postal, combination, passenger, dining, etc., and costs were ascertained on the different lengths of each class and type of construction.

2. Trucks, four and six-wheel, with cast and steel-tired wheels, and for each three main sizes of journals.

3. Automatic air signal and brake apparatus per car, with 12-inch, 14-inch and 16-inch cylinders.

4. Vestibules, extra per end for wide or dummy vestibule over open platform.

5. Heating apparatus, cost per car, with various types of equipment.

6. Lighting, cost per car for various types, and cost each for the various kinds of oil, gas and electric light fixtures.

7. Seating, cost with various types used.

8. Mail racks, cost each for various types, in 15, 20, 30 and 60-foot apartments.

9. Smoking apartment, cost where such is installed.

10. Dining car equipment, average cost per car, including stoves, ranges, refrigerators, china, glassware, linen, etc.

11. Finish, including extra for mahogany over oak.

12. Steel under frame, extra over wood under frame, for various lengths of cars.

Additional to the above percentages were obtained, showing the average cost of observation-parlor and parlor cars over coaches of the same description.

Table II gives the cost of the reproduction of passenger cars used for the 1909 appraisal, although circumstances demanded in various instances specific treatment.

TABLE II.—UNIT PRICES ON PASSENGER CARS AND EQUIPMENT

Car bodies exclusive of trucks, air brakes, signals, lights, heating and seats, but having monitor roofs, canvas covered and painted Pullman, wood construction except as specified.

Length of body over end sills	Baggage cars Standard heavy construction; no windows or platforms	Cheaper design	Postal cars Standard heavy construction; no platforms	Cheaper design	Comb. pass., baggage, mail; no vestibules	Pass. cars oak finish, open platform; toilets
75 ft.	......	......	......	......	$5,647	......
70 ft.	......	......	......	......	......	$5,288
66 ft.	$4,117	......	......	......	......	......
65 ft.	......	......	......	......	5,400	......
62 ft.	3,768	......	......	......	......	......
61 ft.	......	......	$4,927	......	......	......
60 ft.	3,656	......	......	......	4,601	4,916
55 ft.	3,543	......	......	......	......	4,590
54 ft.	......	......	......	......	4,185	......
52 ft.	......	......	4,556	......	......	......
50 ft.	3,420	......	......	......	3,858	......
45 ft.	......	......	......	......	3,690	4,173
42 ft.	3,127	$2,115	......	......	......	......
41 ft.	......	......	3,881	$2,430	3,566	......
36 ft.	3,071	2,059	3,769	2,385	......	......
28 ft.	......	.....	3,656	2,295	......	......
For 70-ft. bodies, all steel, mahogany finish, wide vestibules.........						10,372
For 70-ft. bodies, dining cars, oak finish...........................						10,764

LENGTH OF APARTMENTS FOUND IN COMBINATION CARS

Length of car	Baggage	Mail	Passenger
75 ft.	15 ft.	30 ft.	25 ft.
60 ft.	20 ft.	15 ft.	25 ft.
54 ft.	16 ft.	15 ft.	22 ft.

Other sizes relatively in proportion.

Truck per car—composite wood-plated frames

Size of journals	33-in. cast iron wheels: 4-wheel trucks	33-in. cast iron wheels: 6-wheel trucks	37-in. steel tired wheels: 4-wheel trucks	37-in. steel tired wheels: 6-wheel trucks
$4\frac{1}{4} \times 8$	$731	$1,226	$1,103	$1,789
5×9	833	1,373	1,204	1,935
$5\frac{1}{2} \times 10$	928	1,457	1,300	2,020

High speed automatic air brake and signal—complete per car

12-inch cylinder....................................	$ 81.00
14-inch cylinder....................................	90.00
16-inch cylinder....................................	108.00

Vestibules extra, per end	
Wide Pullman	$ 333.00
Dummy	54.00
Heating arrangement	
Direct steam heat equipment only	$ 149.00
Steam heat with Baker heater	360.00
Passenger car wood or coal stove, each	41.00
Passenger car stove, each	18.00
Lighting apparatus	
Oil center lamps, each	$ 32.00
Acetylene gas light equipment, per car	360.00
Acetylene gas center lamp, each	32.00
Acetylene gas bracket lamp, each	2.50
Pintsch gas equipment, 1 tank	167.00
Pintsch gas, each additional tank	81.00
Pintsch coach center lamps, each	36.00
Pintsch baggage car center lamps, each	32.00
Pintsch bracket lamps, each	4.50
Electric wiring only, with axle light system, per baggage car	171.00
Electric wiring only, with axle light system, per coach	230.00
Electric wiring only, with axle light system, per dining car	270.00
Head end dynamo, train line in conduit and train connection—	
Per baggage car	306.00
Per coach	365.00
Per dining car	405.00
Axle light system and batteries	1,325.00
Single pendants, fixtures, each, up	1.10
Combination gas and electric center lamps, over 1 gas lamp, each	16.00
Elaborate designs for parlor and cafe cars	63.00
Seating	
Low back reversible coach seat, rattan	$ 20.00
Low back stationary coach seat, rattan	12.60
Low back reversible coach seat, plush	22.50
Low back stationary coach seat, plush	14.40
High back reversible coach seat, plush	26.10
High back stationary coach seat, plush	16.20
High back reclining chairs, per chair	38.25
Harrison mail racks	
For 15-ft. compartment	$ 68.50
For 20-ft. compartment	100.00
For 30-ft. compartment	135.00
For 60-ft. compartment	293.00
Smoking compartment	
To seat nine, leather upholstered, extra	$ 257.00
Dining car equipment	
Includes refrigerators, ranges, chairs, tables, china, silver, glassware, linen and kitchen utensils, average per car	$3,047.00
Finish, extra for mahogany over oak	
For dining car, add	$ 225.00
For 60-ft. coach, add	144.00
Steel underframe over wood underframe	
60-ft. car, extra per car	$ 787.00
70-ft. car, extra per car	845.00
Observation parlor cars	
Extra above all steel coaches	12%
Parlor cars	
Extra above all steel coaches	10%

Table III gives the reproduction cost of freight equipment for one of the principal properties operating in the state.

TABLE III.—C. & N. W. RY. CO.'S FREIGHT CARS

Class	Size	Date built	Reproduction cost
Box	36′ × 80 Cap.	1907–1903	$ 693
Box	40′ × 80 Cap.	1909–1908	668
Furniture	40′ × 60 Cap.	1905	717
Furniture	50′ × 60 Cap.	1905	747
Flats	40′ × 80 Cap.	1907–1905	520
Flats	40′ × 100 Cap.	1901	700
Flats	40′ × 70 Cap.	1902	427
Gondola	35′ × 80 Cap.	1907–1902	623
Gondola	40′ × 100 Cap.	1909	908
Stock	36′ × 60 Cap.	1907–1905	638
Ore	22′ × 80 Cap.	1907	659
Ore	21′ × 80 Cap.	1902–1903	659
Ore	21′ × 80 Cap.	1909	808
Ballast	36′ × 80 Cap.	1907	927
Ballast	38′ × 80 Cap.	1905	626
Refrigerator	34′ × 60 Cap.	1904	871
Refrigerator	34′ × 60 Cap.	1905	900
Caboose, standard	....	1904–1901	834
Caboose	....	1909–1905	834
Caboose, drovers	....	1909–1901	1,280

Rebuilt work equipment, as an average for all properties, was determined as follows:

Box, bunk and outfit cars, depreciated value per car	$ 106.25
For re-building	160.00
	$ 266.25
Cinder cars, self dumping, converted from old flats or stock, depreciated value per car	$ 89.00
For re-building	280.00
	$ 369.00
Wooden pile drivers, built on old flats, depreciated value per car	$ 287.00
For re-building	3,713.00
	$4,000.00

On one of the principal lines, as a fair example, the statement (Table IV), showing the *value of tools and special equipment*, was determined for the various kinds of rolling stock and allowed in addition to the units heretofore mentioned:

TABLE IV.—VALUE OF TOOLS AND SPECIAL EQUIPMENT

Item	Total
For 573 road locomotives, each	$ 87.27
For 87 switch locomotives, each	53.67
For 268 cabooses, each	268.28
For 10 business cars, first class, each	1,094.29
For 6 business cars, second class, each	656.57
For 9 observation electric lighted cars, each	97.33
For 30 diners, each	1,626.98
For 33 postal, wood, each	207.01
For 14 postal, steel, each	225.32
For 49 chair, each	41.76
For 112 coach, each	41.76
For 66 baggage, each	98.50
For 36 baggage and mail, each	138.55
For 19 baggage and passenger, each	98.98
For 4 baggage, mail and passenger, each	139.03
For 5 mail and passenger, each	114.12
For 7 composite, each	51.78
For 17 motor cars, each	141.69

For the expenditure of inspection and purchase of equipment there was added to each class 1 per cent of the cost in total, not including the freight charges. This amount was fixed after having made considerable investigation as to the proper measure to be allowed, and was based upon a number of instances of actual experience.

Additional to the above averages there was allowed commercial freight to the state.

Prices Used in the Valuation of the New York, New Haven & Hartford R. R.—In the valuation of the physical property of the New York, New Haven & Hartford R. R., under the direction of George F. Swain, the unit prices adopted were based upon the average ruling prices for the various elements during the last few years previous to the appraisal and upon prices actually paid by the railway company. From the report on the valuation, Engineering and Contracting, Feb. 21, 1912, gives the following.

Grading:	
Clearing, per acre	$ 40.00
Grubbing, per acre	160.00
Earth excavation, per cu. yd	0.32
Solid rock excavation, per cu. yd	1.30
Solid rock excavation, per cu. yd	1.15
Loose rock excavation, per cu. yd	0.65
Borrowed excavation	0.32
1st class retaining wall, per cu. yd	15.00
2nd class retaining wall, per cu. yd	8.00
3rd class retaining wall, per cu. yd	6.00
Sodding, per sq. yd	0.30
Riprap, per cu. yd	2.50
Piling, per lin. ft	0.40
Timber, per M. ft. B. M	50.00
Tunnels:	
Excavation, per cu. yd	$ 5.00
2nd class masonry, per cu. yd	8.00
Brick lining, per cu. yd	15.00
Bridges, trestles and culverts:	
1st class deck girders, per ton	$ 70.00
2nd class deck girders, per ton	60.00
1st class through girders, per ton	75.00
2nd class through girders, per ton	65.00
1st class trussed bridges, per ton	80.00
Draw and lift bridges, per ton	120.00
Counterweight bridges, per ton	50.00
Viaducts, per ton	75.00
Howe truss bridges, per lin. ft	90.00
Timber trestles, per lin. ft	10.00
Solid floor, per lin. ft	12.00
Stringers, per M. ft. B. M	50.00
I-beam stringers, per ton	50.00
1st class masonry, per cu. yd	15.00
2nd class masonry, per cu. yd	8.00
3rd class masonry, per cu. yd	6.00
Riprap, per cu. yd	2.50
Paving, per sq. yd	1.75
Wet excavation, per cu. yd	1.00
Dry excavation, per cu. yd	0.50
Timber, per M. ft. B. M	50.00
Piling, per lin. ft	0.40
Bolts, per lb	0.05
Cast iron pipe culvert to 24 ins., per lin. ft	3.65
Cast iron pipe culvert over 24 ins., per lin. ft	11.00
Sewer pipe culvert to 24 ins., per lin. ft	0.85
Sewer pipe culvert over 24 ins., per lin. ft	3.57

Ties:	
Main track, per tie	$ 0.60
Sidings, per tie	0.45
Switches, per M. ft. B. M.	22.00
Bridge floor, per lin. ft.	3.00
Rails:	
Main track, 100-lb. per mile	$4,790.00
Main track, 79-80-lb. per mile	3,830.00
Main track, 74-78-lb. per mile	3,590.00
Main track, 66-72-lb. per mile	3,210.00
Main track, 50-65-lb. per mile	2,880.00
Siding, over 75-lb. per mile	3,590.00
Siding, 65-75-lb. per mile	3,210.00
Siding, 50-65-lb. per mile	2,880.00
Frogs and switches:	
100-lb. rail turnouts	$ 223.00
79–80-lb. rail turnouts	196.00
74–78-lb. rail turnouts	178.00
66-72-lb. rail turnouts	147.00
56-65-lb. rail turnouts	140.00
100-lb. rail derails	18.00
66-80-lb. rail derails	15.00
50-65-lb. rail derails	12.00
100-lb. rail slip	500.00
74-80-lb. rail slip	300.00
50-72-lb. rail slip	300.00
Track fastenings, etc.:	
100-lb. rail per mile (main track)	$ 680.00
74-80-lb. rail per mile (main track)	430.00
66-72-lb. rail per mile (main track)	397.00
50-65-lb. rail per mile (main track)	344.00
75-lb. rail per mile (sidings)	430.00
66-75–lb. rail per mile (sidings)	397.00
50-65-lb. rail per mile (sidings)	344.00
Ballast:	
Stone, per mile	$2,900.00
Gravel, per mile	1,450.00
Other ballast, per mile	1,000.00
Track laying and surveying:	
Main line, per mile	800.00
Sidings, per mile	600.00
Fencing:	
Wire, per mile	300.00
Tight board, per mile	1,800.00
Open, per mile	1,000.00
Stone, per mile	3,000.00
Crossings and signs:	
Cattle guards, per pair	$ 30.00
Timber, piling, excavation, etc., as previously given.	

Cost of Grading, Watauga & Yadkin River R. R.—The following data are taken from an article by H. C. Landon published in Engineering and Contracting, April 1, 1914.

The Watauga & Yadkin River R. R. is a standard-gage line from North Wilkesboro, N. C., where connection is made with the Southern Ry. to Boone, N. C., a distance of 52 miles.

The methods followed in construction were rather unusual, as the company was its own contractor. In other words, the grading was done largely by its own forces under the direction of the Chief Engineer. One small six-mile section was constructed by contract.

The profile of the first 30 miles of projected line, indicated generally light work. There were some heavy cuts and fills, but it was not practicable, on account of poor roads and lack of bridges to entertain any steam shovel proposition, and generally the cuts and fills were too light to make steam shovel operation economical. Labor was scarce, and at a premium everywhere. The plan was to do the work with the aid of teams, machines and powder as far as practicable.

Equipment.—After a careful study of the projected profile, it was decided to purchase the following equipment:

12	1½ cu. yd. Troy wagons at $112.50	$1,350.00
24	drag scrapers at $5.56	133.44
36	No. 2½ wheel scrapers at $36.75	1,323.00
1	elevating grader at $920.00	920.00
4	2,500 lb. wagons at $55.00	220.00
8	16 ft. by 24 ft. tents at $38.63	309.04
2	32½ ft. by 65 ft. mule tents at $149.30	298.60
2	Ingersoll rock drills at $312.50	625.00
1	16 hp. boiler on wheels, 2d hand, at $300	300.00
10	1 yd. dump carts with harness at $46	460.00
4	2 yd. dump carts with harness at $30	120.00
100	steel wheel barrows, 3 and 4 cu. ft. at $3.00	300.00
12	doz. round Pt. D handle shovels at $5.25	63.00
4	blacksmith outfits, including a forge, anvil and other tools, at $40.00	160.00
12	doz. picks with handles at $400	48.00
	Total	$6,630.08

The dump wagons and grader were only used about two months and did fair work in the territory where they were used. They were not used for a longer period on account of inability to get sufficient mules and teams to operate them.

Teams.—Before the company started work, we were advised that all the teams we would require could be secured in the community, but although we paid $3 per day or 50 cts. more than the ruling price, we could only secure 15 to 18 teams and they were not all of the best type. It was then decided to purchase our own mules and 45 teams were purchased in the St. Louis market. These were mules that could pull, the average weight of the animals being over 1,225 lbs. These teams were in almost continuous daily service from Aug. 1, 1912, to June, 1913. Only two mules were lost and it is estimated that there was not over 5 per cent lost time for the mules in service. Our cost of feeding the mules averaged 95 cts. per team per day. For all camps hay averaged $25 per ton and oats 57½ cts. per bushel delivered at the camps.

On June 1, 1913, the work was shut down for short time. At that time had our mules gone on the market they would have brought more than they cost, as their condition was excellent, due to their excellent care. It was the theory of the company that only from well fed and well kept teams could satisfactory efficiency be secured. The teams were taken care of by a competent stable boss. A supply of necessary remedies and an emergency case were kept at each camp. The fact that there was not over 5 per cent lost time for the teams explains the low price and rapid progress.

EARTH EXCAVATION

Organization of Forces.—It was realized that in order to secure efficiency, the organization of the various forces should be fixed. These forces were called "Standard" and only varied when it was shown that the nature of the work demanded it. Thus the Standard wheel scraper force was as follows for hauls not exceeding 300 ft.: 6 wheel scrapers with teams and drivers, 2 teams to plows, 1 snatch team, 1 man dumping, 1 loader, 1 wheeler, 1 waterboy, when required, and 1 foreman.

When the haul increased the number of wheel scrapers was increased, in order to keep the snatch team and other laborers busy. This was very closely watched by the foremen of the various gangs, in order to keep up their records, as every dumper was supplied with a counter and the day's work reported. In this way, a very close estimate could be made of the yardage moved.

The "Standard" drag scraper force consisted of 6 scrapers, with teams and drivers, 2 teams to plow, 1 dumper, 1 loader, who acted as foreman, and 1 waterboy.

The drag scraper work and the wheel scraper work were watched with great care to determine the economical haul. The drag scraper is very efficient and very useful for very short hauls only. Observation of the various hauls up to 200 ft., fully demonstrated the fact that for a distance of over 100 ft. the drag scraper was an expensive implement. Under 100 ft. it will do efficient work. Wheel scrapers ordinarily can be used where the drags can, and had the advantage in making about the same speed with about five times the load. As a general proposition, only a few drags should be used on work of this character. Their advantage is in their cheapness and for a small amount of work with short hauls the drag scraper might be desirable equipment. A gang of wheelbarrow men properly handled will do work about as cheap as a drag and in some instances at less expense.

Cost of Drag Scraper Excavation.—Assuming the haul for a drag scraper to be 100 ft., a lively mule team to a scraper will not make over 1.3 miles per hour on account of the frequent turns and loading, or about 6,900 ft. per hour. This will be at the rate of 3.45 cu. yds. per hour or 34½ cu. yds. per 10-hour day per team. With a "Standard" drag scraper force and teams at $3 per day, 8 drags will handle 27.6 cu. yds. each per 10-hour day, at a total labor cost of $37.50, or nearly 14 cts. per cubic yard. With a haul of from 50 to 75 ft. the cost will not exceed 12 cts. per cubic yard. Seventy-five ft., therefore, should be the maximum haul with drag scrapers. Six drag scrapers with the shorter haul were therefore established as the maximum to use with the minimum haul.

Actual observation on a 110-ft. haul with country teams, indicated that under the best conditions only 25½ trips were made per hour, or a speed of 5,000 ft. per hour. The company teams which were all well fed Missouri mules, made as high as 7,200 ft. per hour with drag scrapers on a haul of 150 ft.

These results were obtained under the best possible conditions where the dumper man counted and reported every load and in addition the teams were under my personal observation.

A few drag scrapers on every job of similar character are a good investment, but their number and use should be limited. An injudicious foreman will often use them at the company's expense.

Our standard forces were modified as the hauls increased, the number of wheelers increased to eight, and, possibly, with very long haul ten or even twelve wheelers could be used to advantage.

Cost of Wheel Scraper Excavation.—In only one instance did the haul with wheelers much exceed 600 ft. and in this instance the haul averaged 1,350 ft.; ten wheelers only were available, but we were able to handle 225 cu. yds. at a cost of 23½ cts. per yard, figuring teams at $3.50 per 10-hour day, although all the teams which we used actually only cost us approximately $3 per day.

With a haul of 415 ft. a careful timing of the teams indicated that they were making four trips in 20 min. The average of twelve trips per hour was made for the entire day. The wheelers were loaded to their capacity, and therefore, an average of nearly 60 cu. yds. per wheeler was secured. The wheeler force using only six wheelers cost $30 per day. The labor cost in this case did not much exceed 10 cts. per yard.

Wheelbarrow Excavation.—The wheelbarrow when properly used is a most useful, necessary, convenient and economical tool. Three types of barrows were purchased: the ordinary railroad wooden barrow, the wooden frame contractors barrow, with steel tray, and the all steel wheelbarrow with one piece tubular bent handles. Barrows of 3 and 4 cu. ft. capacity were bought. The barrow holding 4 cu. ft. in general seemed to suit our work and could be handled about as easy as the barrow holding only 3 cu. ft. The ordinary wooden wheelbarrow gave very poor service. We had a few of the barrows with wooden frames go out of service, but the all steel wheelbarrows are practically as good as new after 8 months fairly good service. The barrows are painted when out of service any length of time.

For side-hill work and to open grade points the barrow is giving very efficient service. Observation on side-hill work with a gang of 25 men handled dirt at the rate of eight wheelbarrows per minute for an hour with a haul of 21 ft. This would mean that they moved over 500 cu. yds. per day in wheelbarrows holding 4 cu. ft. Good runways were always provided, so that the loads could be moved with the least possible waste of energy.

The gangs were placed in the hands of efficient foremen, who taught the men how to handle the most dirt with the least possible loss of time. It was endeavored at all times to have a standard gang of not less than 25 men under each foreman. The work varied as the conditions necessitated. In some cases much drilling was required, in others none at all.

Cost of Dump Car and Cart Excavation.—Four small dump cars with revolving bodies were found to be convenient and useful in short cuts and at the approaches to the one tunnel that has been built. These cars run on a track of 30-in. gage and had a capacity of 2 cu. yds. The cars were particularly useful in small cuts and where the haul was long. The revolving body would permit the car to be dumped in building the fill ahead of it and could be dumped on the side to widen the fill or waste the material. Light rails not being available these cars were run on a track made of 4 × 4 oak timbers. The wooden rails only required a few renewals during their six months of service.

Dump carts can only be used economically upon hauls about 100 ft. long, but two of the cars moved by mules would keep a gang of 10 to 12 shovelers continuously busy—where the haul was from 600 to 700 ft.

In one cut alone, it is estimated two of these cars handled 15,000 cu. yds. of earth and rock, with a maximum haul of 650 ft., at a cost not to exceed 20 cts. per cubic yard. The average gang, including drillers, was about 14 men and a foreman. This number of men loaded about 150 cu. yds. per day at a labor cost of about $25 per day. It took nearly three months to remove the cut.

While dump carts should be used for short hauls of from 100 to 125 ft., yet they have been used to advantage where the maximum haul was 250 ft., provided the roadway was kept in good order and several carts were used to keep a good sized gang moving. In one instance, six carts were used in completing a fill and did the work very rapidly where the haul was approximately 150 ft. Six carts and 30 laborers moved 325 cu. yds. per day, at an expense of approximately $47 or about 15 cts. per cubic yard. As a general proposition our cost of handling earth and rock with dump carts and men is about 26 cts. per cubic yard, exclusive of explosives.

ROCK EXCAVATION

Methods of Using Explosives.—The line as located and the material afforded a splendid opportunity for the use of explosives. Much of the line was located in the side hills in locations where heavy blasts would be made without endangering life or property. The proper using of explosives, however, for moving earth has been given, as a general thing, very little attention. The experienced men that we employed had only used explosives to shatter and break up the rock or hard soil, so that it could be handled by either hand or steam shovels, and the old powder men at first tried to continue the use of that method. Much valuable time and good powder were wasted before we could so improve the use of powder that the blast would move the maximum amount of rock and earth out of or off from the railroad grade.

In all cases where there were over five holes, the battery was tested with a Rheostat and every fuse and finally the line was tested with a galvanometer, so that no misfires occurred. It is not rare that a faulty fuse is found, and when they do occur they can cause annoyance if they are used.

Methods of Spacing, Drilling and Loading Blast Holes.—It was difficult at first to get the desired results as all the old-time powder men rather believed in the single shot or two or three shots plan, the result being that a poor showing was made. I finally made arrangements with the general foreman to lay out or plan the blasts in the other cuts and for some time no heavy blasting was done except under personal direction. The cuts were usually of a length where 30 or less than 30 holes would cover the portion of the cut to be moved, so that a No. 3 blasting machine would explode the blast.

The holes were spaced on lines that have since entered into our general instructions for use of powder and other explosives. In general where the cut at the center line was over 4 ft., and the material earth or soft rock, the first line of holes was placed not more than 2 ft. above the center line. All holes were driven to a point 2 ft. below grade and usually about the same distance apart as the depth of the hole to grade, except when depth was greater than 15 ft. The maximum distance apart was about 15 ft. If the hillside was steep and the lower side of the road bed at grade, one set of holes was sufficient. If the cut under ordinary circumstances was a through cut with the depth of cut 2 ft. or more on the lower side, then a lower set of holes was drilled parallel to the first at the lower ditch line at points midway between the upper holes, so that there would be no question about moving the material out of way. This will not change materially the amount of powder used, as one yard of soft rock should be moved with about 2 lbs. of powder. The soft rock usually was decomposed granite or a Carolina gneiss which was not hard to drill.

The hard rock encountered was usually a mica schist. This was very hard, and in these cases the upper line of holes was placed on the upper ditch line and a distance apart equal to the depth up to 10 ft. No holes were placed farther apart than this. The lower holes were placed on the lower ditch line at the same distance apart but intermediate to the upper line of holes.

The arrangement had to be modified according to the rock, as hard and soft rock would be found in the same cut that was to be demolished by a single blast. The arrangement of the strata changed our plans, although generally the strata we encountered was nearly vertical or leaned slightly to the northwest.

The general tendency was to use too much powder in the soft rock or earth and too little in the hard rock. A careful estimate was made of the quantity in the cut. If soft rock, 2 lbs. or less were used per yard; if hard rock, 3 lbs. per yard or more. The general foreman in charge followed instructions carefully and used good judgment in his large blasts and usually wasted very little or no powder. After he became acquainted with the rock and the mistakes, mistakes were rare.

In all the smaller shots that are being made, the foremen are instructed to use powder judiciously, and they are getting good results with a minimum amount of powder. The holes are made on the center line to a point about 2 ft. below the grade line and are spaced a distance apart equal to the depth of the holes. It is found that the holes drilled on the center line and to this depth below the grade will ordinarily pull down the grade about the amount desired, and will not move the earth too far back of the slope line where soft rock is handled.

Drilling Outfit.—Steam drills are used with hard rock, while a large percentage of the other holes are put down by hand and churn drills. In many places churn drills were successful in soft rock. In all hard rock, steam drills are used when possible. The two drills used were the Ingersoll P-24 type with 3-in. cylinders 6½-in. stroke. One 12 h.p. boiler supplied the two drills.

Cost of Excavating a Rock Sidehill Cut.—Several large blasts have been successfully made along the route in sidehill cuts on different sections of the line, moving almost ½ cu. yd. of material for every pound of powder used. In one cut, estimated at 8,000 cu. yds., 95 per cent of which was solid rock, 33 holes

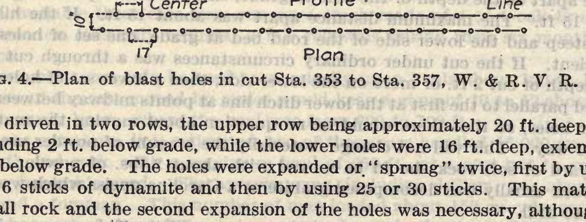


FIG. 4.—Plan of blast holes in cut Sta. 353 to Sta. 357, W. & R. V. R. R.

were driven in two rows, the upper row being approximately 20 ft. deep and extending 2 ft. below grade, while the lower holes were 16 ft. deep, extending 6 in. below grade. The holes were expanded or "sprung" twice, first by using 5 or 6 sticks of dynamite and then by using 25 or 30 sticks. This material was all rock and the second expansion of the holes was necessary, although it is believed that one expansion of the holes, using 10 or 12 sticks of dynamite, would have given better results, as the second expansion tended to fill the holes rather than open them up to sufficient size. An average of 11 kegs of powder was used in the upper holes and 13 in the lower holes. The results of this blast were very satisfactory, 378 kegs of powder being used, moving fully 7,000 cu. yds. of rock. A No. 3 push down battery was used in this explosion, although this was overloading the battery slightly.

Fig. 4 shows the profile of the cut where this blast was made and a plan showing the location, spacing and arrangement of the 33 blast holes.

Fig. 5 shows a typical cross-section of the cut before and after the blast and as completed. A wagon road was shifted farther back from the river after the grading was done.

On a small sidehill rock cut at Sta. 926, holes were drilled by hand for a blast made June 16, 1913. Six lower holes were drilled approximately 4 ft. down hill from the center line having depths of from 7 to 11 ft. Three holes were drilled along the center line, and 17 holes having depths of from 11 to 18 ft. were drilled at an average distance of 7 ft. above the center line. All holes were drilled about 2 ft. below sub-grade. The rock was of hard grey character, and eight cans of powder were placed in most of the deepest holes, although one hole required eleven cans. Three cans were loaded into the shallow holes. The cost of making the blast and cleaning out the cut, which contained a total of 1,300 cu. yds., was as follows, (the item of $126 being for labor in cleaning out the loose material left by the blast and in dressing up the cut):

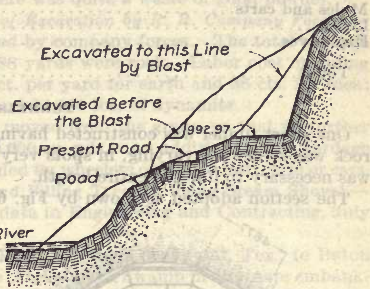


FIG. 5.—Cross section of cut at Sta. 355 + 34, W. & Y. R. R. R.

		Per cu. yd.
121 cans powder at $1.30	$157.30	$0.121
150 lbs. dynamite at $0.15	22.50	0.017
50 20-ft. fuses	3.40	0.003
58 16-ft. fuses	2.78	0.002
Labor drilling and loading holes	135.00	0.104
Labor, 84 men at $1.50	126.00	0.096
Total	$446.98	$0.343

About 320 ft. of holes were drilled at a cost of approximately 40 cts. per lineal foot for drilling labor, which was only 0.24 ft. of hole per cubic yard of rock blasted. Powder was used at the rate of 2.3 lbs. per cubic yard of rock blasted, the springing of the holes requiring 0.12 lbs. of dynamite per cubic yard of rock. It was estimated that 900 cu. yds. of rock were shot out of the cut, so the unit cost for clearing out and dressing the cut was $126 ÷ 400 = $0.31 per cubic yard of rock left in the cut after the blast. The cut was ready for track three days after the blast was fired.

Cost of Excavating a Through Rock Cut.—For the purpose of comparison the cost of excavating a through rock cut between Sta. 1038 + 50 and Sta. 1041 is here given. The material in the cut was medium hard rock, much of it being mica schist, and amounted to 2,200 cu. yds. Thirty-seven holes were drilled and fired in eleven blasts. About 28 pop shots and small shots were required for breaking up rock and removing rock to a point below grade. Some of the material was removed by wheelbarrows to the side of the cut, but the greater portion was moved by carts into a nearby fill, the haul being about 250 ft. The mules were owned by the company but the cost was estimated at $1.50 per 10-hour day. The total cost of excavating the cut was as follows:

Item		
Mules and carts	$ 47.00	$0.021
Labor	1,018.25	0.463
Explosives	174.45	0.079
Totals	$1,239.70	$0.563

TUNNELS

One short tunnel was constructed having a total length of 194 ft. As the rock was somewhat varying, in spots very hard and at other points loose, it was necessary to line the entire length.

The section adopted as shown by Fig. 6 is rather narrow, had it been the intention to maintain a permanent tunnel, but as it is the purpose to make an open cut at this point, the smallest safe section was adopted. The track has a summit about half way through the tunnel which provides for draining track ditches to both ends.

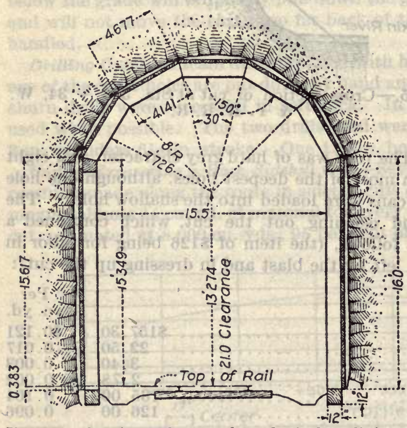


FIG. 6.—Section of tunnel and timber lining, W. & Y. R. R. R.

Cost. — The tunnel was driven by hand, the entire cost being $6,730.74, or $34.69 per foot. This is very reasonable, taking into account the fact that very little experienced labor could be found. No accidents in the tunnel proper occurred. The above cost includes all material, explosives and labor in any way connected with the tunnel. It required 39 days to drive the headings, and about the same time to drive the benches. Labor was scarce and difficult to get.

Method of Using Powder Tunnels for Excavating Rock.—The tunnel approaches contained approximately 40,000 cu. yds. of earth and rock, 75 per cent of which was earth. Nearly 50 per cent of this was moved by two blasts, one on each approach; 30,000 lbs. of powder were used. The powder in these later instances was placed in powder tunnels running about on the ditch line with branch tunnels leading from the main. The powder was emptied into paper flour sacks and then compacted as closely as possible in the extreme end of the main tunnel and branches. After the powder was placed, the balance of the tunnel was filled with earth compacted as well as possible. The fusees and lead lines in these blasts were tested at every step in the wiring of the blasts.

While effective and satisfactory work was done by these two blasts yet it is believed that by the use of more powder somewhat differently placed, had the dirt been better compacted at the tunnel mouth or had there been a solid stone or concrete wall built across the mouth of the tunnel, or in the tunnel next to the powder, better results would have been obtained. The powder tunnels were very dry and it is not believed the powder would have deteriorated very much during 48 hours necessary to give a concrete wall time to set. The fact that there was evidence of considerable force wasted at the mouth of the tunnel was evidence that there was quite a waste of good powder.

Total Amount and Average Cost of Excavation by R. R. Company Forces.— Approximately 24 miles were graded by company forces. The total yardage moved was 475,052, of which 99,688 yards were rock. Labor cost including explosives was approximately .12 ct. per yard for earth and 36 cts. for rock; 213,250 lbs. of powder were used and 24,000 lbs. of dynamite.

It is estimated that the powder moved from the grade, so that no further handling was necessary, at least 80,000 cu. yds. An additional large yardage of material was shaken up to be loaded by wheelers or loaded into carts or cars.

Cost of Raising Embankment and Filling Trestles Using Steam Shovel.— D. A. Wallace gives the following data in Engineering and Contracting, July 20, 1910.

The Frisco line (C. S. N. O. & P. R. R.) from Beaumont, Tex., to Baton Rouge, La., was built through the Atchafalaya Swamp in alternate embankment and temporary trestle. The original plans were made for continuous embankment of station work, but continued high water in the swamp prohibited 50 per cent of the station work and temporary trestling was resorted to for filling in the gaps between the embankment which had been started or completed. The greater portion of the grade was 8 ft. high. The material in the embankment was the black gumbo commonly encountered in Southern Louisiana swamps. The work described consisted of raising the embankment and filling in the temporary trestling. The conditions were difficult.

The track was laid following closely behind the trestle gang, and frequent use of the track by the bridge material train put the track into a very poor condition. A great portion of the embankment built by station work was partially washed out by high water leaving holes 4 ft. deep for 15 or 20 ft. of track. The temporary trestles stood 12 or 18 ins. higher than the approaches. This condition was due to the excessive settlement of the swamp soil when put up by station work and also to heavy rains. The worst holes were cribbed up with ties and tree branches but even then a great amount of delay was caused the unloading trains by derailment and trains breaking in two in attempting to get over the bad places. It was necessary to unload dirt at these places before the track could be surfaced, as the gumbo would not hold a surface under one trainload of dirt. In many instances cars were unloaded standing on track 18 ins. out of level and 3 ft. out of surface in a distance of 10 ft. along the rail.

Hart convertible cars were used and were unloaded by Lidgerwood and plow. Before dirt was unloaded on the fills it was necessary to jack the track up out of the gumbo. It was impossible to move the track with No. 6 Barrett jacks after the dirt was unloaded. In many instances it was found necessary to strip out the track before it could be lifted from the gumbo with 12 No. 6 Barrett jacks, resting on boards, per rail length. The grade on embankment was raised not less than 12 ins. at any point.

The unloading was planned so that when the front gangs were unable to get the track in shape ahead of the unloading or when they were not able to care for the dirt as fast as it came, the unloading was done on the trestles, and as they were being filled a gang was kept busy tamping the dirt in under the caps and stringers. Following a rain, the dirt packed hard and the caps and stringers were removed by the Lidgerwood and cable.

The shovel pits from which the dirt for filling was taken, averaged a 15-ft. face and 1,600 ft. in length. The dirt was a sandy clay compacting very quickly in embankment. The pit was opened up along one side of the main line and track laid behind the shovel in the first cut and used as a loading track for the next cut of the shovel. More difficulty than usual was experienced in keeping the pit properly drained. Good drainage was very necessary to take care of the frequent and heavy rains common to the country. Three trains were used, 1 loading train, which also handled the water cars for the shovel, 1 swing train which made the run of 12 miles to the front in 40 minutes and 1 unloading train. The unloading was started 12 miles from the pit. A siding and water tank were located there affording water to the swing and unloading trains. About 25 minutes were generally consumed there in switching empties and locals.

The work recorded was done from Sept. 12 to Oct. 16, 1907. The daily expenses were as follows:

Loading, transporting and unloading:	
1 Trainmaster at $150 per mo.	$ 5.00
3 Conductors at $100 per mo.	10.00
3 Brakemen at $75 per mo.	7.50
3 Brakemen at $60 per mo.	6.00
3 Engineers at $100 per mo.	10.00
3 Firemen at $75 per mo.	7.50
3 Engine watchmen at $60 per mo.	6.00
1 Hostler at $75 per mo.	2.50
1 Hostler helper at $1.80 per day	1.80
1 Steamshovel engineer at $150 per mo.	5.00
1 Steamshovel craneman at $90 per mo.	3.00
1 Steamshovel fireman at $75 per mo.	2.50
1 Steamshovel watchman at $60 per mo.	2.00
1 Machinist at $0.35 per hour	3.50
1 Machinist helper at $1.80 per day	1.80
1 Blacksmith at $0.35 per hour	3.50
1 Blacksmith helper at $0.20 per hour	2.00
1 Car repairer at $0.25 per hour	2.50
1 Car repairer at $0.225 per hour	2.25
1 Carpenter at $0.275 per hour	2.75
1 Pumper at $60 per mo.	2.00
1 Lidgerwood engineer at $90 per mo.	3.00
6 Pit men at $2 per day	12.00
6 Cablemen at $2 per day	12.00
Total wages	$116.10
20 tons coal at $4	$ 80.00
Supplies	2.56
Ice	1.00
Water at 50 cts. per tank from city	2.00
10 gals. gasoline at 10 cts.	1.00
Total supplies	$ 86.56
1 Steam shovel rent	$ 10.00
3 Engines rent at $5.53 per day	16.59
62 Cars rent at 50 cts. per day	31.00
1 Water car rent at 50 cts. per day	0.50
1 Spreader rent at $2 per day	2.00
1 Lidgerwood rent at $5 per day	5.00
Total plant rental	$ 65.09
Add 10 % super. and 5 % misc.	$ 40.15
Grand total	$307.90

NOTE.—The 5 % misc. includes overtime, etc.

During the total period of 35 days, the total time lost due to Sundays, rain, etc. was as follows:

Sundays	5.0 days
Rain or mud	2.18 days
Moving	1.6 days
Shovel breaking down bank	0.25 days
Failure of transportation	0.22 days
Total	9.25 days

Of this total of 9.25 days, 6 days are accounted for by 5 Sundays and 1 day moving from job.

The total cost of the work, $14,178, was made up as follows:

Pitmen at $75 per mo. and $1.75 per day	$ 727
Labor at the front at same rates as pitmen	3,519
Steam shovel 29 days at $308	8,932
5 days at 200	1,000
	$14,178

Pit cross-section showed a yardage of 35,445 removed thus making the cost 40 cts. per cu. yd.

Dragline Bucket Eliminates Maintenance of Track in Cuts.—The following note is taken from Engineering and Contracting, Jan. 16, 1918.

In planning methods of excavating railway or canal cuts, sight should not be lost of the cost of laying and maintaining tracks over which the spoil is hauled away. This cost mounts rapidly where the bottom of a cut is wet and difficult to drain. In such cases it is frequently economic to use a dragline excavator instead of a steam shovel, for both the track for the excavator and for the muck train can be laid on the surface of the ground instead of in the bottom of a wet cut.

In making a cut for the Nickel Plate Ry. in Cleveland, the contractor, Walsh Construction Co. of Davenport, used a 175-ton Marion dragline with a 100-ft. boom and a 5-yd. Page bucket. Working two 11-hr. shifts daily the dragline averaged 3,600 cu. yd. every 24 hrs. where there were no delays. The earth, a sandy clay, was loaded into 12-yd. Western cars. The bottom width of the cut was 72 ft. and the maximum depth was 24 ft. The dragline dug on both sides of itself as well as behind, and then moved back 30 ft., repeating this operation again and again.

Costs of Railway Ditching by Various Methods.—An interesting comparison of costs at 1918 prices of cleaning railway ditches by different methods was given in a committee report at the 1919 annual meeting of the Roadmasters' and Maintenance of Way Association in Chicago. The following data given in Engineering and Contracting, Dec. 17, 1919, are from this report and are for single track lines with six trains during working hours; roadbed in soft clay; ditches 7 ft. from rails, 3 ft. wide and 2 ft. deep.

Method	Output per day, cu. yd.	Cost per cu. yd.
Ditcher of steam-shovel type, on cars	224	$0.4130
Steam ditcher of drag-scraper type	252	.4034
Push cars and laborers	38½	.5862
Car barrows and laborers	13	.7670
Wheelbarrows and laborers	19	.7142
Casting or shoveling	38½	.3525

The unit costs for the various methods follow:

	Per day
Ditcher of steam shovel type on cars:	
Ditch labor	$ 18.90
Work train labor	23.86
Rental of equipment	31.00
Maintenance of equipment	1.45
Supplies	12.80
Total (224 cu. yd. at 41.3 cts.)	$ 92.51
Steam ditcher of drag scraper type:	
Ditch labor	$ 31.75
Work train labor	28.36
Rental of equipment	30.00
Maintenance of equipment	.93
Supplies	10.62
Total (252 cu. yd. at 40.3 cts.)	$101.66
Two push cars and hand labor:	
1 foreman at $83	$ 2.77
11 laborers at $2.25	19.80
Total (38½ cu. yd. at 58.6 cts.)	$ 22.57
Car barrows and hand labor:	
1 foreman	$ 2.77
4 laborers at $1.80	7.20
Total (13 cu. yd. at 76.7 cts.)	$ 9.97
Wheelbarrows and hand labor:	
1 foreman	$ 2.77
6 laborers at $1.80	10.80
Total (19 cu. yd. at 71.4 cts.)	$ 13.57
Casting or shoveling:	
1 foremen	$ 2.77
6 laborers at $1.80	10.80
Total (38½ cu. yd. at 35.2 cts.)	$ 13.57

Cost of Steam Shovel Work Loading Into Cars for Railway Ballasting and Grading.—D. A. Wallace gives the following data in Engineering and Contracting, July 27, 1910.

Slag for Ballasting.—This slag was loaded by a 45-ton shovel working against a 20-ft. face, into cars placed on a spur track on a 3 per cent grade. The grade permitted the spotting of cars by hand while the engine was unloading the loaded cars. The greatest haul was 4 miles. There was no delay to the slag train due to meeting revenue trains. The slag was in alternate vitrified and spongy layers. The use of the light shovel necessitated some use of powder but not more than the ground gang could drill the necessary holes for and handle. Holes were drilled on an average 9 ft. horizontally into the face 3 ft. from the ground line and about 10 ft. centers. Rodgers ballast cars were used. The size of the slag permitted easy unloading. The train crew with the help of one of the gang did the unloading and sweeping off.

The daily expense was as follows:

Engineer @ $125.00 per month	$ 4.80
Craneman @ $40.00 per month	3.46
Fireman @ $60.00 per month	2.31
Foreman @ $65.00 per month	2.50
6 ground men @ $1.25 per day	7.50
2 tons coal at $2	4.00
Waste and oil	0.50
Dynamite	0.93
Work train	25.00
Total	$51.00

The slag cost $2 per car load of 40 cu. yds. or 5 cts. per cu. yd. Including this the cost of loading, hauling and unloading was as follows per cubic yard:

6 cars, 240 cu. yds	$0.262
7 cars, 280 cu. yds	0.232
8 cars, 320 cu. yds	0.209
9 cars, 360 cu. yds	0.191
12 cars, 480 cu. yds	0.156

Earth for Grade Raising.—Loose earth was loaded into Hart convertible cars spotted on the main line. The shovel was cut in on both sides of the main line and cuts were widened. A 12-ft. face was worked. The dirt was unloaded by the railway company in widening fills or grade raising just as was most convenient, depending on the progress of the gangs and the time of revenue trains. The contractor was paid 7 cts. per cu. yd. pit measure for dirt loaded on cars and the following costs were for loading alone. The shovel used was a 70-ton Giant with a 2-cu. yd. dipper.

About 1½ gals. of cylinder oil at 40 cts. per gallon were used per day and 2 gals. of black oil at 10 cts. per gallon. The daily expenses were as follows:

Engineer @ $150.00 per month	$ 6.00
Craneman @ $90.00 per month	3.60
Fireman	2.00
Watchman	1.85
6-ground hands @ $1.50 per day	9.00
Total labor	$22.45
Cylinder oil	$ 0.60
Black oil	0.20
Waste	0.10
1 ton coal	1.50
Int. at 6 % on $10,000	2.00
Total	$26.85
Grand total	49.30

The shovel loaded 45 cars of 24 cu. yds. per car or 1080 cu. yds. per day, giving a cost of 4½ cts. per cu. yd.

Sand for Ballast.—Two sand pits were opened up, one on each side of the main line, and the lead track to each pit was used as a loading track. A 60-ton Marion shovel was cut into one pit and a 45-ton Vulcan shovel into the other pit. Three work trains were used for spotting cars, hauling and unloading. Each crew handled different parts of the work depending on the arrival of the unloading trains and the speed of loading. One crew usually spotted cars for both shovels. This was done very easily because of the frequent moves of the shovels due to the shallow face of the cut. The sand was a white sand containing about 20 per cent loam. It made a very satisfactory ballast for light traffic. Hart convertible cars were used and were unloaded by Lidgerwood and plow on new track. A large amount of time was lost due to the slow running necessitated by the very rough track.

The following was the total output of the 60-ton Marion for 22 working days in July, 1,075 cars or 29,008 cu. yds.

The number of days worked was 22 or 220 hours, during which time there were 91 hrs. 45 mins. delays distributed as follows:

Cause	Hrs.	Mins.
Moving shovel	23	55
Waiting for cars	53	10
Closing car doors	4	35
Coal and water	5	50
Derailments	3	20
Shovel repairs	0	55
Total	91	45

The following was the output of the 45-ton Vulcan shovel for 7 day's work, 235 cars or 7,570 cu. yds.

The number of days worked was 7 or 70 hours during which time the delays amounted to 49 hrs. 43 mins. distributed as follows:

Cause	Hrs.	Mins.
Moving shovel	7	8
Waiting for cars	28	20
Tank repairs	7	0
Shovel repairs	7	0
Derailments	0	15
Total	49	43

Summarizing the work of the two shovels we have:

Item	60-Ton	45-Ton
No. cars loaded	1,075	235
Cu. yds. loaded	29,008	7,570
Av. no. cars per day	43¾	33½
Av. cu. yds. per day	1,318.5	1,081.4
Av. cu. yds. per car	27.2	32.2

The face worked averaged 10 ft. and the haul was 10 miles.

In August the two shovels worked more nearly the same amount of time. The total working time of the 60-ton shovel was 26 days or 310 hours during which time there were the following delays:

60-ton Marion

Item	Hrs.	Mins.
Moving shovel	43	0
Waiting for cars	82	30
Waiting for laborers	29	0
Waiting on track work	6	25
Miscellaneous	10	0
Total	170	55

45-ton Vulcan

Item	Hrs.	Mins.
Moving shovel	35	0
Waiting for cars	45	30
Waiting for laborers	20	0
Waiting on track work	15	0
Waiting for power	20	0
Repairing shovel	27	0
Miscellaneous	12	0
Total	174	30

Summarizing the work of the two shovels we have:

Item	60-ton	45-ton
No. cars loaded	1,268	1,046
No. cu. yds. loaded	33,486	30,710
Av. cu. yds. per day	1,272	1,121
Av. cars per day	48⅘	40
Av. cu. yds. per car	26½	28⅔

The total yardage for the month for both shovels was 63,196 cu. yds. The cost of loading, transporting and placing this material in the track was as follows:

Item	Total	Per cu. yd.
Loading	$ 1,207.65	$0.019
Transporting	2,973.74	0.0464
Surfacing	9,504.71	0.1504
Fuel and supplies	4,761.56	0.0753
Rental equipment	3,422.07	0.0541
Supervision	1,116.30	0.0183
Total	$23,031.03	$0.3635

The face averaged 8 ft. and the haul was 10 miles.

Cost of Unloading, Spacing and Renewing Ties.—D. A. Wallace gives the following data in Engineering and Contracting, Aug. 10, 1910.

Unloading Ties.—(1) Ties were unloaded from work train while running, with negro labor at $1.10 per day and foreman at $50 per month. Work train cost $25 per day. Six men unloaded 250 ties from a coal car in 30 mins. at the following cost:

Train service, 30 mins	$1.04
Labor, 30 mins	0.45
Total	$1.49

This gives a cost per tie of 0.6 cts.

Thirteen men unloaded 970 ties from 3 box cars in 2 hours. Four men per car were worked with one to follow. The cost was as follows:

Train service, 2 hrs	$ 6.24
Labor, 2 hrs	5.35
Total	$11.59

This gives a cost per tie of 1.2 ct. It will be seen that it cost twice as much to unload from box cars as from coal cars.

2. Work train unloaded 9 cars carrying 2100 ties on a run of 106 miles, picking up section gangs and unloading in spots. Cars were coal cars and train was called at 6:15 a. m. and tied up at 6:15 p. m. Negro labor at $1.10 per day and foreman at $50 per month were employed. The expense per day was as follows:

Work train, including coal, oil, etc	$28.80
Labor	4.40
Foremen	1.00
Total	$34.20

The train was in service 12 hours as follows:

	Hrs.	Mins.	Fraction of day
Delays	3	35	0.300
Unloading time	2	13	0.184
Running time	6	12	0.516
Total	12	00	1.00

The cost of unloading per tie was, therefore, as follows:

Delays	0.48 ct.
Unloading time	0.29 ct.
Running time	0.83 ct.
Total	1.60 cts.

Tie Renewals.—When track is being surfaced out of face in two raises the renewal of ties during the first raise consumes too much time and should be done during the second raise. The following gang organizations were employed in the work for which the records are given.

Good Surface; Foreman and 4 Men; Not more than 2 Ties to Be Removed at a Place.—Foreman will loosen up the spikes on 4 ties on each side of the tie that is to be removed; 2 men can be used in thoroughly cleaning the ballast from around the tie that is to be removed; the other 2 men should each have a jack to raise the rail, so as to let the tie come out easily, without disturbing the general surface. The 4 men should then slip in the new ties, working in pairs. The foreman should drive the spikes home as soon as possible in order to keep the track safe, and should dress up the track.

Foreman and 6 Men; Smoothing Track; 7 or 8 Ties per Rail Length.—Gang as follows: 2 men with jacks, 2 men with claw bars, 2 men pulling ties out of track. Where 3 or 4 ties together come out the foreman should put in the middle tie and spike it to keep the track safe. When about 20 ties are removed the gang should go back and full-tie the track, care being taken not to disturb ties that are not to be taken out of the track, even if it is necessary to loosen up the spikes on 3 or 4 ties on each side of the tie to be removed. Spikes should not be pulled all the way out, and ties left in track should not be raised more than ¼ in. Only 20 ties should be removed at a time before new ties are put in, for the reason that the gang may be picked up by a work train or called away suddenly for some reason and the work be left in bad shape for the regular trains. As the new ties are being put in place the gang can smooth up.

The following are records of tie renewals:

1. An average of 4 ties per rail renewed during a 7-in. raise in rock ballast, with Italian labor at $1.25 per day and foreman at $60 per month. The ties were 7 × 9 ins. × 8½ ft. The average was 11 ties per man day; the best day's work was 20 ties per man day.

The cost of renewing 1 tie was $0.104.

2. Ties put in during a 3-in. raise in rock ballast by section gangs, with negro labor at $1.10 per day and foreman at $50 per month. Ties were 6 × 8 ins. × 8 ft. The best record was 19½ ties per man day; the average was 14 ties per man day.

The cost of renewing 1 tie was $0.08.

3. Ties renewed in rock ballast during a 2-in. raise by section gangs working negroes at $1.10 per day and foreman at $50 per month. The ties were 6 × 8 in. × 8 ft. The best record was 17.5 ties per man day; the average was 13.3 ties per man day.

The cost of renewing 1 tie was $0.082.

4. Ties renewed during a 7-in. raise in rock screenings, working Italians at $1.25 per day and foreman at $60 per month. Ties were 7 × 9 ins. × 8½ ft. The best record was 16 ties per man day, the average was 12.7 ties per man day.

The cost of renewing 1 tie was $0.098.

5. Ties renewed in 2-in. slag by section gangs working white labor at $1.10 per day and foreman at $50 per month. Ties 6 × 8 ins. × 8 ft. The best record was 17.9 ties per man per day, the average was 13.1 ties per man day.

The cost of renewing 1 tie was $0.083.

6. Ties renewed in 2-in. surface gravel working white labor at $1.10 per day and foreman at $50 per month. Ties 6 × 8 ins. × 8 ft.

The best record was 18.2 ties per man day, the average was 13.5 ties per man day.

The cost of renewing 1 tie was $0.08.

7. Ties renewed during rock smoothing working negroes at $1.10 per day and foreman at $50 per month. Ties 6 × 8 ins. × 8 ft. The best record was 17.8 ties per man day, the average was 12.5 ties per man day.

The cost of renewing 1 tie was $0.088.

Spacing Ties.—The spacing of ties in rock ballast in the following record was a good average of the work done on several miles. The ties were special following the first raise and just before the ballast for the second raise was unloaded. The tie spacing in stripped track was done just before the unloading of the ballast for the first raise. Negro labor at $1.10 per day and foreman at $50 per month were worked. The record is as follows:

No. ft. track	No. days worked	Kind of ballast	Feet per man per day
430	15	Rock	28½
495	12	Rock	40
430	9½	Stripped	45
365	6	Stripped	60½
330	5	Stripped	66

One man spaced 6 joints per day in rock ballasted track, no raise, and rail laid broken jointed.

Amounts of Creosote and Zinc Chloride for Cross Ties.—The following table, reprinted in Engineering and Contracting, Dec. 15, 1920, from the Nov. 20, 1920, Cross Tie Bulletin of the National Association of Railroad Tie Producers shows the board feet and cubic feet per tie, number of ties per 1,000 board feet, gallons of creosote and pounds of zinc chloride per 1,000 ties under specified treatments for the more common sized sawed ties. The table was compiled by E. M. Blake:

Dimension	Board ft. per tie	Cu. ft. per tie	No. of ties per 1,000 board ft.	Gals. of creosote per 1,000 ties, sp. grav. 1.0436, or 8.7 lb. per gal. treated under Rueping process 5.5 lb. per cu. ft.	6.0 lb. per cu. ft.	Lbs. of zinc chloride per 1,000 ties at ½ lb. per cu. ft.
LENGTH, 8 FT.						
6″ × 8″	32.00	2.66	31.25	1,686	1,839	1,333
7″ × 8″	37.33	3.11	26.80	1,967	2,146	1,555
7″ × 9″	42.00	3.50	23.80	2,212	2,414	1,750
7″ × 10″	46.66	3.88	21.43	2,459	2,682	1,944
LENGTH 8 FT. 6 IN.						
6″ × 8″	34.00	2.83	29.41	1,791	1,954	1,417
7″ × 8″	39.66	3.31	25.21	2,091	2,281	1,654
7″ × 9″	44.62	3.73	22.41	2,351	2,565	1,860
7″ × 10″	49.58	4.13	20.17	2,612	2,850	2,066

Treated Ties Reduce Maintenance Expense.—C. A. Morse, Chief Engineer of the Chicago, Rock Island & Pacific Ry., speaking on maintenance of way labor before the Roadmasters and Maintenance of Way Association at Chicago, Sept. 17, 1919, made the following statement, which is given in Engineering and Contracting, Oct. 15, 1919.

Today the railroads that began using treated ties 10 years ago are reaping the benefit of the investment in big figures. They are averaging about 200 ties to the mile of all tracks, while the average number of ties used on a road where treatment has not been used is over 300 per mile of all tracks.

This means that a railroad that is using 2,000,000 treated ties per year would have to buy 3,000,000 ties had they not adopted tie treatment ten years before. This means $1,000,000, at the price that ties cost today, for the ties alone, and much more than that—it means saving the cost of transportation, the cost of unloading and the cost of the insertion of a million ties; and the saving on insertion alone, which at this time is from 32 to 40 cts. per tie, is a saving of from $320,000 to $400,000 of expense. There is yet another saving: one has disturbed his track in only two-thirds as many spots, and there is the saving of much retamping required later to get the track as solid as it was before the new tie was inserted.

Treated ties should be adzed and bored by adzing and boring machine before treating. This insures the seat for both rails being in the same plane and gives a full bearing for the tie plates, as tie plates should always be used on both treated and untreated soft wood ties, and on all treated hardwood ties.

The Most Economical Tie for Different Conditions of Track and Traffic.—Much information on the length of life, first cost and annual cost of railroad crossties of various classes under various conditions is contained in a circular and key of instructions on the use of crossties issued by the Baltimore & Ohio Railroad. The following notes published in Engineering Record, May 27, 1916, are taken from the April-June issue of *Wood-Preserving*, which devotes three pages to the circular. The circular is based on an extended investigation, in which the experiences and opinions of both engineers and trackmen were utilized. The instructions were prepared, it is stated, to define the most economical tie for every condition of track and traffic, and to assist in the most economical distribution of ties.

The circular divides ties into five classes according to kind of wood. Class A embraces white, burr and chestnut or rock oak, cherry, mulberry, black walnut and locust (except honey locust). Class B includes chestnut only. Class C includes red, black, scarlet, Spanish, pin and shingle or laurel oak, also honey locust, beech and hard or sugar maple. Silver, soft or white maple, red, soft or swamp maple, red or river birch, sweet or black birch and white, rock and red elm make up class D, while pines—short leaf, loblolly and sap long leaf—form class E. Classes A and B are used without, classes C, D and E with preservative treatment.

As to size, class A has three grades, 7 or 6 × 8 in., 6 × 7 or 6 × 6. The other classes have two grades only, 7 or 6 × 8 and 6 × 7. (Class E ties are respectively 7 × 9 and 7 × 8.) Attention has also been given to length, as this has an important bearing.

Table V gives estimated life lengths for all classes, grades and lengths under various conditions of traffic. It also shows where these classes and grades are and are not used. It will be noted that the use of tieplates adds materially to the life length. The instructions stipulate that all treated ties should be tieplated.

Table VI gives the detailed first cost to the Baltimore & Ohio for the various 8½ ft. classes of ties, and derived therefrom, the annual costs, with interest figured at 6 per cent.

TABLE V.—ESTIMATED LIFE OF TIES IN YEARS UNDER VARYING CONDITIONS OF TRAFFIC

		Untreated																				Treated			
		Class A—8½ ft.						Class A—8 ft.						Class B—8½ ft.				Class B—8 ft.				Class C		Classes D and E	
		*Yes	†No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes
		1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	1	1	2	2	1	2	1	2
Kind of track	Weight of power and traffic	7×8		6×7		6×6		6×8		6×7		6×6		7×8		6×7		6×8		6×7		7×8	6×7	‡7×8	§6×7
Main line	Heavy power, dense traffic	8	5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	11	..	9	..
	Moderate weight, power and traffic	9	6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	14	..	12	..
	Light power and traffic	9	7	..	..	..	..	8	6	..	..	..	..	..	..	..	..	..	..	..	..	15	..	13	..
Branch line	Heavy power and traffic	9	6	8	5	..	..	8	5	7	4	..	..	..	..	..	..	..	..	..	..	14	12	11	10
	Moderate weight, power and traffic	9	7	8	6	..	..	9	6	7	5	..	..	9	5	..	..	7	4	..	..	15	13	12	11
	Light power and traffic	9	8	9	8	8	7	9	8	9	8	8	7	9	7	..	..	8	5	..	..	..	14	..	12
Lead and passing	Heavy power and traffic	9	7	8	6	..	..	8	6	7	5	..	..	8	5	..	..	7	4	..	..	..	14	..	12
	Moderate weight, power and traffic	..	..	9	7	..	..	9	7	8	6	..	..	9	7	..	..	8	5	..	..	..	15	..	13
	Light power and traffic	..	..	9	8	8	7	9	8	9	8	7	6	11	7	..	..	10	6	..	..	..	15	..	14
Yard and industrial	Heavy power and traffic	..	..	9	7	8	6	..	..	8	6	7	5	10	7	9	6	9	6	8	5	..	15	..	13
	Moderate weight, power and traffic	..	..	9	8	8	7	..	..	9	8	8	7	11	8	10	7	10	7	9	6	..	15	..	14
	Light power and traffic	..	..	9	9	9	9	..	..	9	9	8	8	12	10	12	10	12	9	11	8	..	16	..	15
Repair, temporary and storage		..	..	9	9	9	9	..	..	9	9	8	8	..	..	12	10	12	10	12	10	..	16	..	15

* Tieplated. † Not tieplated. ‡7 × 9 for class E. § 7×8 for class E.

Table VI.—Comparative First and Annual Costs of Different Classes and Grades of Ties with Different Lengths of Life

	Class A, 8½ ft., grade						Class B, 8½ ft., grade				Class C— 8½ ft., grade		Classes D and E, 8½ ft., grade	
	1		2		3		1		2		1	2	1	2
	* Yes	† No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes
1. Purchase price......	$ .800	$ .800	$ .680	$.680	$.250	$.250	$.500	$.500	$.350	$.350	$ .610	$ .510	$ .570	$ .470
2. Inspection.........	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010
3. Treatment.........	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.220	.200	.220	.200
4. Freight—														
80 mi. for non treatment.........	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
380 mi. for treated..	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.090	.070	.090	.070
5. Work train service..	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010
(a)............	$ .838	$ .838	$ .718	$.718	$.288	$.288	$.538	$.538	$.388	$.388	$ .940	$ .800	$ .900	$ .760
6. Handling and installing............	.190	.190	.160	.160	.160	.160	.160	.160	.160	.160	.190	.160	.190	.160
7. Two tieplates......	.240	......	.120	.....	.120	.....	.120	.....	.120	.....	.240	.120	.240	.120
8. Interest on (a)—.... 6 months on untreated, 12 months treated..........	$ .025	.025	$ .022	.022	$.009	.009	$.016	.016	$.012	.012	$ .056	$ .048	$ .054	$ .046
9. Supervision.......	.066	.043	.066	.043	.066	.043	.066	.043	.066	.043	.066	.066	.066	.066
(b)............	$1.359	$1.096	$1.086	$.943	$.643	$.500	$.900	$.757	$.746	$.603	$ .492	$1.194	$1.450	$1.152

10. Credit salvage, one-third value tieplate.	.080	.....	.040	.....	.040	.....	.040	.....	.040	.....	.080	.040	.080	.040
Total net cost....	$1.279	$1.096	$1.046	$.943	$.603	$.500	$.860	$.757	$.706	$.603	$1.412	$1.154	$1.370	$1.112
Annual cost per tie with annual life of..														
6 per cent interest added: 4 years...	$ .400	$ .340	$ .320	$.290	$.180	$.150	$.270	$.234	$.220	$.187	$ .440	$ .360	$ .420	$ .350
5 years...	.330	.280	.270	.240	.160	.130	.220	.197	.180	.157	$ .370	$ .300	$ .360	$ .290
6 years...	.290	.250	.240	.210	.140	.110	.190	.171	.160	.137	.320	.260	.310	.250
7 years...	.260	.220	.210	.190	.120	.100	.170	.153	.140	.122	.280	.230	.280	.230
8 years...	.240	.200	.190	.170	.110	.090	.160	.140	.130	.110	.260	.210	.250	.210
9 years...	.220	.190	.180	.170	.100	.090	.140	.129	.120	.103	.240	.200	.230	.190
10 years...	.....	.....	.....	.....	.....	.....	.140	.121	.110	.096	.230	.180	.220	.180
11 years...	.....	.....	.....	.....	.....	.....	.130	.114	.110	.091	.210	.170	.210	.170
12 years...	.....	.....	.....	.....	.....	.....	.120	.108	.100	.086	.200	.160	.200	.160
13 years...	.....	.....	.....	.....	.....	.....	.120	.103	.100	.082	.190	.160	.190	.150
14 years...	.....	.....	.....	.....	.....	.....	.110	.099	.090	.079	.190	.150	.180	.150
15 years...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.180	.150	.170	.140
16 years...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.170	.140	.170	.140

* Tieplated.
† Not tieplated.

Organization for and Progress of Laying Rail with Locomotive Cranes.— The Lehigh Valley R. R. has developed a rail laying method, in which has been incorporated the use of such labor saving equipment as locomotive cranes, air compressors and drills, etc., which has resulted in increased output and reduced costs. With this method daily averages are being made of from 80 to 110 rail length per hour, all completely bolted, spiked, etc., and ready for service, while in special instances as many as 159 rails have been laid in one hour. The following, is from a description of the method given in Railway Age, as abstracted in Engineering and Contracting, Jan. 19, 1921.

In conducting this work the necessary labor has been secured by assembling the section forces employed in the locality where the rail is to be laid. The work in then so planned as to be carried on in a series of progressive stages or steps, such as, pulling spikes, throwing out old rail, etc., each step being assigned to a required number of men. In practically all but a few cases the individual gangs or sub-divisions of the forces are composed of section gangs complete with their foremen or multiples thereof. The foremen work with their men as well as supervise them. This feature in itself has been found to speed up the work materially.

With the forces and equipment assembled and all assignments understood the track upon which rail is to be laid is taken over completely and operations commenced. During the period of laying the remaining track is operated as a single track section. Through the close co-operation of the operating department little delay has been caused by the adoption of this method, even under comparatively heavy traffic. It is a question whether or not the delays caused by laying rail under traffic do not equal or exceed the delays when the track is given over entirely.

As stated before, the method is based on progressive steps with all new materials distributed previously along the section to be laid. The old track is not disturbed under any circumstances until the time when it is taken over. The sequence of the various stages is in general as follows: Joints are broken every 10 rail lengths, spikes pulled, one rail thrown out, old tie plates removed, creosoted wood plugs placed in old spike holes, ties adzed, new tie plates placed, new rail laid with locomotive crane, rail center spiked and gaged, joints placed and bolted, holes drilled and bond wires installed, track gaged and full spiked, signal connected up and work generally finished up.

Where one crane is used a force of about 200 men are required to keep the crane working to its capacity and the work proceeds one rail at a time, the crane being moved back to the point of starting at the completion of laying of the first line of rail and starting on the second rail. With two cranes a duplicate organization follows the first crane preparing the other rail for the second crane, both of which are followed by a finishing gang of about double the size.

Rail bonding is carried on by means of portable units of air compressors and their drills. One compressor generally handles four drills requiring a crew of six men. The saving of labor in this item has been very marked and a much greater output has been obtained in addition to increasing the life of the drills from five to eight times. In connection with this class of equipment several pneumatic wrenches were tried out recently for the purpose of running up the nuts on the track bolts. The average time consumed for running up one 6-bolt splice and moving to the next was about 30 seconds.

Figuring on a one-crane basis, as any multiple up to four can be used efficiently on one set of tracks provided there are sufficient men available, the following is a typical organization in detail: The men comprising this organization are listed in the exact sequence under which they pass over the track.

A TYPICAL ONE-CRANE ORGANIZATION
ADVANCE WORK

3 men removing every tenth joint on the old rail.
24 men pulling spikes. This includes 2 foremen.
14 men swinging out old rail. Two foremen with section gangs.
3 men throwing out old tie plate.
3 men placing creosoted tie plugs in spike holes.
2 men driving creosoted tie plugs in spike holes.
12 men adzing ties. One section foreman included.
2 men sweeping off ties after adzing.
5 men placing new tie plates. One foreman included.

This covers the preparatory work for the crane, which has the following organization:

4 men on rail, two on each end to steady and guide it into place.
1 man on crane hook. The foreman in charge of crane forces.
1 man on expansion template.
2 men driving spikes on inside of new rail.
2 men driving spikes on outside of rail after laid.
1 man with lining bar to bar rail to place as laid.
2 men operating crane. The operator and fireman.

The locomotive crane was followed by the following gang:

1 man adzing joint ties for a 1 to 20 cant.
10 men placing new joints. Two foremen included.
5 men removing rail anchors from old rail.
1 man placing insulated joints.
12 men gaging new rail.
34 men full spiking.
30 men bolting up joints.

This was followed by the bonding layout and the finishing gangs:

4 men operating air drills.
2 men operating motor cars and distributing bond wires.
1 man operating air compressor.
2 men bonding new rail.
5 men clearing out for rail anchors. One foreman included.
5 men placing new rail anchors. One foreman included.
2 men operating motor cars, two trailers with extra tools, etc.
3 men checking up on tie plates, spiking and joints, etc. One foreman included.
3 men carrying drinking water.
1 man charging wire at signal connections.
1 man soldering signal connections.

With the experimental introduction of the pneumatic wrenches the organization was changed slightly from that shown above, the 30 men assigned to bolting being removed and the following substituted for them:

2 men on pneumatic wrenches.
1 man tapping joints into place.
1 man on air hose.
1 man operating motor car.
1 man operating air compressor.

In the particular instance mentioned above a stretch of track between two switches located nearly 2½ miles apart was laid with 136-lb. rail in a total elapsed time of 7 hours 10 minutes, or at the rate of 107 rail lengths per hour for a total of 770 rails. The force shown totals up to 205 men in the first case and 180 men with the introduction of the wrenches.

Cost of Unloading Railway Rails.—D. A. Wallace gives the following data in Engineering and Contracting, Aug. 10, 1910.

For short jobs of rail unloading with men not used to the work and where the ground is smooth, there is no objection to unloading from the sides of the car, provided, of course, that both ends of the rails are released together.

The following are records of unloading rails:

1. The 70-lb., 33-ft. rail was unloaded from the sides of gondola and flat cars by section gangs which had no experience in handling new rail. Two rails were dropped at a place, then the train moved ahead one rail length and the operation repeated.

When unloading gondola cars, one man followed the train to straighten out an occasional rail lying too close to the track; the remainder of the gang unloaded the rails by hand with the assistance of 2 men at each end of the car with lining bars.

Rail unloaded from flat cars was rolled off the sides, using lining bars and shovels. Two men at each end had lining bars and the remainder had shovels. As soon as the bar men had started the rail they were assisted by the shovelers, one bar man at each end always using his bar as a skid, keeping the rail up from the floor, thus giving leverage to the shovel men. One man followed the train to straighten out rails lying in a dangerous position.

Negro labor at $1.10 per day was employed, with foreman at $50 per month. The work train cost $25 per day. The cars unloaded were as follows:

	Rails
Gondola car	84
Gondola car	84
Gondola car	113
Flat car	113
Total	394

The time required for unloading was 3 hrs. 50 mins., and the cost was as follows:

18 men at $1.10 per day	$ 7.59
3 foremen at $50 per month	1.84
Work train	25.00
Total	$34.43

This gives a cost of 8.7 cts. per rail and of $27.84 per mile of track.

2. In the record which follows no charge was made against the Road Department by the Transportation Department for roadway work performed by revenue trains other than overtime made by trains doing the work and in this case the revenue business was light and no overtime was made. The cars unloaded were:

	Rails
One gondola car	84
One gondola car	113
One flat car	113
Total	310

The working time was 1 hr. 30 mins. and the cost was as follows:

13 men	$2.14
4 foremen	0.96
Total	$3.10

This gives a cost of 1 ct. per rail and of $3.20 per mile of track.

3. In the following record a comparison is made between the time of unloading gondola and flat cars. The time of unloading the gondola cars was as follows:

1 car	113 rails	1 hr. 0 mins.
1 car	113 rails	1 hr. 0 mins.
1 car	84 rails	2 hrs. 14 mins.
3 cars	310 rails	4 hrs. 14 mins.

The time for unloading 5 flat cars was:

1 car	141 rails	35 mins.
1 car	114 rails	30 mins.
1 car	78 rails	20 mins.
1 car	73 rails	20 mins.
1 car	76 rails	25 mins.
5 cars	482 rails	2 hrs. 10 mins.
Grand total unloading time		6 hrs. 24 mins.
Delays		1 hr. 42 mins.

In comparison the time per rail and per mile of track was as follows:

1 car 113 rails.. 1 hr. 0 mins.

Item	Gondola	Flat
1 rail, time required	.81 min.	.27 min.
1 mile, time req'd	4 hrs. 20 mins.	1 hr. 25 mins.

Therefore it costs three times as much to unload rails from a gondola car as it does from a flat car.

Where rail was unloaded from flat cars it was customary for half of the gang to unload from one side and half to unload from the other. This was a very good method, as there was always a rivalry between the two gangs, each to unload its half first so that the few bottom rails in the center of the car would be left for the slower gang to unload. The cost of unloading the eight cars, 792 rails, was as follows: The wages for labor were $1.10 per day and for foreman $50 per month, but as the work was done on Sunday time-and-a-half was paid the men. The cost was therefore:

17 men at $1.65 per day	$28.05
4 foremen at $50 per month	6.66
Work train	25.00
Total	$59.71

This gives a cost of 7.5 cts. per rail and of $24 per mile of track.

Summarizing the costs of records 1, 2 and 3 given above, we have:

(1)	394 rails unloaded at	$34.43
(2)	310 rails unloaded at	3.10
(3)	792 rails unloaded at	59.71
	1,496 rails unloaded at	$97.24

This gives a cost of 6.5 cts. per rail and of $20.80 per mile of track.

4. Generally rails are piled on a car in layers. In each layer the rails are placed alternately head up and head down, the head of one rail being always overlapped by the base of the adjacent rail. In this case the rails were loaded loosely on a flat car, with just enough straightening around to put them parallel with the sides of the car. In unloading these rails no difficulty was experienced in loosening up a rail such as is oftentimes the case when rails are piled tightly in layers.

Negro labor at $1.10 per day and foreman at $50 per month were worked. A gang of 10 men unloaded 90 85-lb. rails in 45 mins. The cost of the work was as follows:

Train service	$1.56
Labor	1.05
Total for 90 rails	$2.61

This gives a cost of 2.9 cts. per rail or of $9.30 per mile of track.

Time Tests of Loading 65-lb. Rail on Flat Car by Hand.—A. M. Van Auken gives the following data in Engineering and Contracting, Dec. 17, 1919.

The work was done near Ypsilanti, Mich., on the Michigan Central R. R. on April 12, 1917, the gang consisting of the following:

1 foreman at	$90.00 per month
1 timekeeper at	75.00 per month
1 cook at	2.10 per day
1 water boy at	2.10 per day
15 laborers at	2.10 per day

The equipment consisted of two hand cars.

The gang was surfacing tracks near Milepost 29 until 11:30 a. m. It then knocked off for ½ hour for dinner. The transporting of the men consumed 40 minutes for a distance of 3 miles to a point (Milepost 32) on the main track opposite the pile of rails to be loaded.

The material loaded consisted of 102 odd lengths of used rail including 2,756 ft. of 65-lb. rail and 20 ft. of 80-lb. rail.

The labor time distribution was as follows:

Left mile post 29 at 12:00.
Arrived mile post 32 at 12:40.
Loaded rail and lumber from 12:40 to 3:45; this includes delays.
Left mile post 32 at 3:45.
Arrived mile post 29 at 4:10.

Delays in loading the rails were as follows:

	Mins.
Stopped at Ypsilanti station for foreman to receive reports of trains	8
Removing hand cars from track	2
Walking from hand cars to where rails lay	5
Waiting for rails to be measured before placing on flat car	9½
Moving flat car about 10 ft.	3
Moving flat car about 2,000 ft. (rails were in two piles about 2,000 ft. apart)	22
Loading lumber	35

The latter item involved the loading of 42 pieces of 3 in. × 10 in. × 16 ft. planks in a box car. The lumber lay opposite the pile of rails so no time was lost in moving from rail to lumber. The results of a test made to determine the time required to lift and throw 10 rails on flat car follow:

15 sec.	27 sec.
38 sec.	40 sec.
65 sec.	35 sec.
18 sec.	20 sec.
22 sec.	27 sec.

It will be noted that it took 307 seconds to load the 10 rails (25 to 33 ft. long). This gives an average of ½ minute for loading each rail.

The average time of loading each of the 102 lengths, delays deducted, was 59 seconds. In other words, while under direct time observation, men doubled their output.

Loading Rails with Ditcher at Cost of 2 Cents per Rail.—Engineering and Contracting, Oct. 16, 1918, publishes the following:

By using a railroad ditcher the Crowell Spencer Lumber Co., of Longfileaf, La., was able to load 60-lb. rails from piles onto flat cars at a cost of about 2 cts. per rail. The crew consisted of the ditcher operator, fireman, and a section crew of 3 men and foreman. Its duties were:

One man operating ditcher.

One fireman. As wood was burned, it was his duty to keep a supply of it on the ditcher.

One man to put stakes in pockets, carry water and load spikes and angle bars.

One man on car to keep rails straight and unhook tongs. Frequently entire cars were loaded without it being necessary to unhook the tongs even once. When the operator dropped the rail 1 or 2 feet the tongs usually let go themselves.

One man on the ground to hook the tongs.

One foreman, who kept the rails turned ball up.

This crew with the American ditcher loaded 2,083 rails in 3 days, the actual working time being 4½, 5½ and 6 hours. The ditcher was on its own flat car and loaded onto empties set in front and behind it. The daily cost of the rail loading, according to the American Ditcher Scoopings, was as follows:

Ditcher operator	$ 5.00
Ditcher fireman	2.50
3 laborers at $2.50 each	7.50
Gang foreman	3.25
Fuel (wood)	1.00
Oil, waste, etc	.50
Total	$19.75

Cost of Loading Rail from Roadbed to Cars.—D. A. Wallace gives the following data in Engineering and Contracting. Aug. 3, 1910.

1. The rail was lying on the shoulder of the grade, just as it had been thrown out from the track and disconnected. One pair of angle bars was fastened to each rail by two bolts. Two men with lining bars kept the rails straightened out on the flat car as they were loaded. The train was followed by two men who picked up any loose scrap that might have been left behind. A work train and a gang of 40 men were used; the labor was negro, at $1.25 per day, and foreman at $60 per month. A total of 429 rails was loaded in 3 hrs. 2 mins. at the following cost:

Train service	$25.00
Labor	20.00
Foreman	0.66
Total	$45.66

This gives in round figures a cost of 10 cts. per rail loaded. The work was costly, due to the fact that the banks were very narrow, permitting the rail in many instances to slip down to the bottom of the fill. The work was also hindered by a growth of high weeds.

2. The rail was disconnected with angle bars lying alongside. One man loaded the angle bars and scrap bolts on the rear car; 2 men with lining bars

kept the rail straightened on the flat car as it was being loaded; 11 men loaded the rail on one side of the car until half the load was placed, then the train was backed up while the other side of the car was loaded. The rail was 56-lb. rail left lying along the shoulder; 6 flat cars with a capacity of 100 rails each were loaded. A total of 800 rails was loaded at the following cost:

Train service	$25.00
Labor	20.00
Total	$45.00

This gives a cost of 5.6 cts. per rail or of $19.71 per mile of track. This same crew loaded and unloaded 400 rails with the same shipment. In unloading the rail two greased rails were used as skids. Six men were on the car to start the rails, and 8 men were on the ground to straighten them up in piles. The cost of the work was 11.3 cts. per rail or $39.77 per mile of track.

3. The rails were lying on the shoulder of the grade, disconnected, as taken from the track. A force of 22 men, 18 per rail, and 4 on the car, loaded 160 58-lb. rails in 2 hrs. 45 mins. The rate of wages was negro labor at $1.20 per day and foreman at $60 per month. The cost was as follows

Train service	$ 5.53
Labor	5.12
Total	$10.65

This gives a cost of 6.6 cts. per rail or of $20.25 per mile of track.

4. A gang of 24 men loaded rails into end of gondola car from pile 15 ft. from the track; 16 men to a rail and 8 men on the car. A total of 100 rails were loaded in 1 hour 40 mins. or 1 rail per minute. The labor was negro at $1.25 per day, and foreman at $60 per month. It cost to load the 100 rails $5.30 or 5.3 cts. per rail.

Cost of Tracklaying with Tracklaying Machine.—D. A. Wallace gives the following in Engineering and Contracting, Aug. 3, 1910.

The work was done by contract in June, 1907, on the Frisco line in Louisiana. The record is a poor one, due to faulty working organization. The average day's work was 6,000 ft., full teed, bolted and spiked. Work was greatly delayed on account of the poor handling of material in material yard. A 35-mile run was necessary for the night crew to bring the angle bars and spikes to the front for the next day's work.

The outfit equipped for each half-day's work consisted of a pioneer car, 5 flat cars loaded with 300 ties each and 2 flat cars loaded with 90 rails each.

Two train crews were used. The day crew came on duty at 6 a. m. and was released at 6 p. m. by the night crew, which had had supper when the day crew returned with the gang from the front. The night crew then ran to Eunice, 15 miles, filled up the tank car, left flat cars spotted for loading ties and rails and ran to Opelousas, 20 miles further, for angle bars and spikes, returning to camp with train made up for first half-day's work at 6 a. m. The day crew returned to camp at 12 noon for dinner, getting back to the front at 1 p. m. During the noon hour the night crew switched out the empty tie and rail cars and picked up the loaded tie and rail cars ready for the afternoon's tracklaying. Lining gang handled the back switch work.

The force itemized in the following table was needed to lay 6,000 ft. of track. This force may be reduced to 90 men by half bolting and spiking the track, the track work being done on days when there is delay to the material. The gang required was as follows:

Item	Per day
1 general foreman at $150 per mo.	
1 timekeeper at $75 per mo.	
1 commissary clerk at $90 per mo.	
Total	$ 10.50
Front Gang:	
1 straw boss at $2.25	$ 2.25
1 rope man at $1.75	1.75
1 chain and puddle man at $1.75	1.75
18 men (9 on a side) at $2	36.00
1 spike puller at $2	2.00
1 bolt puller at $2	2.00
23 men. Total	$ 45.75
Machine Gang:	
1 foreman and board at $3	$ 3.00
1 rail feeder at $2	2.00
1 angle bar man at $2	2.00
2 rail pullers at $2	4.00
4 tie buggy men at $2	8.00
6 laborers (3 on side) at $2	12.00
15 men. Total	$ 31.00
Ground Gang:	
1 foreman and board at $3	$ 3.00
1 bolt puller at $1.75	1.75
1 spike puller at $1.75	1.75
2 bridle rod men at $1.75	3.50
2 wrench men at $1.75	3.50
2 jack men at $2	4.00
8 tie spacers at $1.75	14.00
6 gage men at $1.75	10.50
1 maul man at $1.75	1.75
1 bar man at $1.75	1.75
16 spikers at $2	32.00
8 nippers at $1.75	14.00
2 water boys at $1.50	3.00
51 men. Total	$ 94.50
Lining Gang:	
1 foreman and board at $3	$ 3.00
8 liners at $1.75	14.00
1 water boy at $1.50	1.50
10 Men	18.50
Night Loading Gang:	
12 laborers at $1.75	$ 21.00
Camp help:	
1 head cook at $100 per mo	$ 3.30
1 second cook at $35 per mo	1.15
1 flunkey at $30 per mo	1.00
3 flunkeys at $25 per mo	2.50
1 yard man at $40 per mo	1.35
1 camp woman at $40 per mo	1.35
8 Total	$ 10.65
Train Crew:	
2 engineers and board at $100 per mo	$ 6.70
2 firemen and board at $60 per mo	4.00
1 conductor and board at $100 per mo	3.30
2 brakemen at $60	4.00
7 men. Total	$ 18.00
Miscellaneous expenses:	
1 pioneer car, rent $25 per mile	$ 23.40
Rent, equipment, coal, waste	10.00

Summarizing, we have the following:

Item	Per day
Pioneer car	$ 23.40
Gen. foreman, timekeepr and clerk	10.50
Front gang	45.75
Machine gang	31.00
Ground gang	94.50
Lining gang	18.50
Night loading gang	21.00
Camp help	10.65
Train crew	18.00
Equipment, coal, etc	10.00
Total	$283.30

To be deducted from this total are the following amounts:

Item	Per day
Receipts from board	$ 50.00
Commissary profits	12.00
Total	$ 62.00
Net daily expenses (283.30—$62)	$221.30

The contractor received $275 per mile for tracklaying, or for 6,000 ft. of track laid per day, $312.40. His net income per day was $312.40—$221.30 = $81.10. On the basis of a net daily expense of $221.30 the cost per mile of track laid was closely $200.

Cost of Laying Track With Machine.—The following matter is taken from Engineering and Contracting, April 1, 1914.

The conditions affecting track laying are numerous and varying, and it would be practically impossible for anyone except an experienced contractor with well organized forces to attain the results shown by the data below. Forces which have been employed for years in as narrow or specialized a field as track laying, are bound to attain a high degree of efficiency, provided the management is the best, for a body of most able overseers is gradually collected, which assures wide, efficient and progressive supervision. If, in addition to the above, a concern builds up a reputation for paying the best wages and giving absolutely the best treatment possible, consistent with the work required, an asset of no small importance is added.

The track laying described herein was done by a force which showed the results of all the advantages mentioned above.

Make-up of Track Laying Machine Train.—When laying track, the train carrying the machine is made up as follows, beginning with the "pioneer car," which always remains at the "front," and is not changed out as are the other cars in the train. Immediately behind the "pioneer" are four cars of rails, then the locomotive, and behind that eight cars of ties; next comes a car of tie plates, when they are used, the "trailer," which is a car carrying spikes, bolts and base plates, a car of plank for crossings, a car of cattle guards, a tool car and the way car. This makes twenty cars, and all are flat cars except the two last mentioned.

The first car of rail behind the pioneer is "trimmed," that is, on it is loaded angle bars enough to lay the amount of steel carried on the train. The angle bars are carried forward over the pioneer car and delivered as needed to the "strap hangers" in front. The rails underneath the angle bars are the last ones laid from the train, in order that the angle bars may be cleared off by the time rails are needed.

A system of trams is used to carry the ties and rails to the front. The trams are made in sections, each 33 ft. long, the sides consisting of $2\frac{1}{2} \times 10$ in. planks. Tie trams are 14 ins. wide, and rail trams are 12 ins. wide. The trams are held together by bolts on which are pipe separators to hold the sides the proper distance apart. Near the bottom of the trams are live rollers, which complete a trough-shaped way for ties or rails.

On the pioneer car is installed a 20-h. p. upright engine for driving the live rollers in the trams; this is done by means of a tumbling shaft and gear or cog wheels. Steam for the stationary engine is piped from the locomotive. The shaft is fitted with "patent couplings," that is, on one end of each section is a casting containing a square socket into which the end of the next rod fits. Each length of tram has a section of the shaft bolted to it and as the trams are hung the rods are fitted together, thus forming a continuous shaft. The trams are "hung" on iron brackets or trusses which hook into the stake pockets on the cars. The trusses are made with flange rollers on which the trams are placed, thus taking care of the slack of the train in starting and stopping. The trams have a coupling device which holds them together, the ones on the pioneer being permanently fastened to the car.

The tie trams, 660 ft. long, are operated on the right hand side of the train. Those for the rail, 240 ft. long, are on the left. The movement of ties and rail is controlled by the "dinkey skinner," *i. e.*, the stationary engineer, so as to deliver them in front of the train as needed. A tie chute 53 ft. long provided with dead rollers is attached at the front end of the tie tram on the pioneer and through this chute the ties are pushed by the ones coming forward over the live rollers. And as fast as they are delivered at the end of the chute they are taken by the "tie buckers" (laborers) and are placed across the grade ready for the rails.

A similar chute attached to the rail tram provides a way for delivering the rail in front of the pioneer. These chutes are supported at the outer end by cables attached to the rear end of the pioneer car and carried up over a high frame work or "gallows" on the front end. A boom, also attached to the front end of the pioneer car, extends far enough ahead to have the cable attached to it reach the middle of the rail when placing it in position in track. This cable is operated by hand with an ordinary crab. Instead of cranks, a small, light buggy wheel is used by the operator to wind up the cable, which lifts the rail and holds it while the "heeler" and his assistants place it in position on the track. (A newer device handles the cable with compressed air). The rails are placed in the trams by three men, and are handled in front by six more. One man on each car places the ties in the trams. The spikes, bolts and base plates are peddled from the trailer as the train proceeds.

(The rails are held to gage by bridle rods until the train passes over, all spiking being done in the rear. The train moves ahead one rail length at a time when laying square joints, and half a rail length when laying broken joints. The trams are taken down when cars are empty and replaced on the loaded cars when a new train arrives; from 100 to 125 men are required for a full crew.

Material for the track machine is loaded by railway company forces, and great care is taken to have the material loaded, not only in correct proportion but in correct order and position on cars. A train, called the swing train, is then made up of sufficient material for a half day's work, and is transported to the front, or rather to the camp of the contractor, where it is placed in the most convenient place available for the track machine crew to pick up. The swing train crew then takes a train of empties and returns to the material yard. The track machine is served regularly by the same locomotive and train crew. As the track machine does not move ahead by its own power, a locomotive and train crew are required to remain with the machine onstantly.

Briefly, the movement of the machine is as follows in laying square jointed track: ties are trammed and carried ahead constantly and laid on the grade; the machine moves ahead, and a rail is chuted out and heeled in by the rail gang, and the angle bars bolted on loosely with two bolts only; a second rail is placed and held to gage by bridle rods; the machine is then moved ahead a rail length by the locomotive, and the operation repeated. When laying broken jointed track, the machine is moved ahead a half rail length at a time, thus requiring twice as many moves.

Back of the machine the bridle rods are removed, and enough ties are spiked to hold the rails from spreading. Spacing ties, bolt tightening and full bolting are all done behind the machine, and cause it no delay.

Organization of Gang.—A gang of 125 men will easily lay two miles of track per day, provided no unusual difficulties, such as soft grade, etc., are encountered. A gang of this size would be placed about as follows:

1 general foreman at, per day	$ 5.00
1 ass't foreman, with rail gang, at, per day	3.50
1 ass't foreman, watching trams, at, per day	3.50
1 ass't foreman, with spikers, at, per day	3.50
1 ass't foreman, lining track, at, per day	3.50
1 stationary engineer at, per month	75.00
1 pole man at, per month	75.00
1 oiler at, per day	2.50
1 line man at, per day	2.25
16 "tie buckers" at, per day $2.25 and	2.50
2 tie spacers ahead of machine, at, per day	2.25
1 man fiddling ties, at, per day	2.25
6 "rust eaters," handling rail, at, per day	2.50
1 bridle man at, per day	2.25
1 heel nipper at, per day	2.25
2 strap hangers at, per day	2.25
1 man, carrying angle bars from "trimmed" car to pioneer car, at, per day	2.25
3 steel rollers, rolling rails into trams, at, per day	2.50
8 tie trammers rolling ties into trams, at, per day	2.25
2 spike peddlers, distributing spikes, at, per day	2.25
2 bolt and joint plate pedlers at, per day	2.25
2 "bridle men," carrying bridle rods from rear, at, per day	2.25
4 rear bolters at, per day	2.25
2 water boys at, per day	2.25
8 men spacing ties at, per day	2.25
1 gage man at, per day	2.25
32 spikers at, per day	2.50
16 nippers at, per day $2.25 and	2.50
8 liners at, per day	2.25

When the gang is smaller, the force behind the machine is cut down, and 70 men would be organized about as follows:

1 general foreman at, per day	$ 5.00
1 ass't foreman, with rail gang, at, per day	3.50
1 ass't foreman, watching trams, at, per day	3.50
1 ass't foreman, with rail gang, at. per day	3.50
1 ass't foreman on general work, at per day	3.50
1 stationary engineer at, per month	75.00
1 pole man at, per month	75.00
1 oiler at, per day	2.50
1 line man at, pe day	2.25
10 "tie buckets" at, per day	$2.25 and 2.50
2 tie spacers at, per day	2.25
6 rail handlers at, per day	2.50
1 bridle man at, per day	2.25
1 heel nipper at, per day	2.25
2 strap hangers at per day	2.25
1 man carrying angle bars at, per day	2.25
3 steel rollers at, per day	2.50
8 tie trammers at, per day	2.25
2 spike peddlers at per day	2.25
2 bolt and joint plate peddlers at, per day	2.25
1 bridle rod man at, per day	2.25
2 rear bolters at, per day	2.25
1 water boy at, per day	2.25
1 gage man at, per day	2.25
4 men spacing ties at, per day	2.25
12 spikers at, per day	2.50
6 nippers at, per day	2.50

During the work from which the cost data were obtained, the gang varied from about 50 to 100 men. The $2.50 laborers (spikers, nippers, and tie buckers) averaged about 40 per cent of the entire gang. During the 65 days the following expenses were chargeable against track laying:

Overhead charge on machine (interest at 6 per cent, depreciation at 10 per cent)	$ 100.00
Dinkey skinner, 2½ mos., at $100	210.00
Timekeeper, 2½ mos., at $85	177.00
Locomotive and crew, 65 days, at $40	2,600.00
Supervision and labor	8,710.00
	$11,797.00
Force account, or extras allowed	578.00
	$11,219.00
Average cost per mile	$ 280.50

This cost represents the cost to the contractor, plus the cost of the locomotive and crew at $40 per day. The latter charge should be added, however, as it represents a real part of the operation expense of the track machine.

The rail was a 90-lb. section. It was laid on white oak ties, spaced 18 to 21 under a 33 ft. rail on tangent, and 19 to 22 ties per 33 ft. on curves. The joints were made with ordinary angle bars with four bolts, and spring nut locks. The heads of the bolts were staggered, that is, alternate bolt heads were respectively on the inside and outside of rail. The number of ties per rail length were varied to suit their sizes—18 broad faced ties being used, or 21 narrow faced ties, on tangents.

The cost of transporting the machine and the men to the work is not included herein, the data given representing the costs after the machinery and the laborers were on the work.

An inspector was employed by the company, but although his expenses represent a charge against the track by the railway, it is not chargeable against the contractor's expenses.

Grading and Tracklaying with a Ditcher.—By using a railroad ditcher for grubbing, grading and for tracklaying, the Potlatch Lumber Co. materially reduced its construction costs and at the same time dispensed with a considerable force of laborers. The methods employed on this work are described by the Railway Review, from which Engineering and Contracting, July 17, 1918, gives the following abstract.

The main idea in building logging roads is to get the logs to the mill at the lowest possible cost and since the railroad is only temporary in character, considerable latitude is allowed in the construction methods used, the lines being laid out to tap the desired timber land and the ditcher put to work preparing the subgrade.

Where a small amount of filling is necessary the ditcher scoops up the earth alongside the line and dumps it ahead, where it is leveled off by laborers. As the work proceeds the ditcher is moved ahead under its own steam on a portable track built in short sections. Three short sections of track are used, the ditcher standing on two while the third is picked up from behind and swung around to the front with the boom. Ties 10 × 11 in. × 10 ft. long, and closely spaced, are used, and the sections are braced with diagonal pieces of ½ by 1½-in. strap iron held in place by ¾-in. wood screws and extending from corner to corner of the sections. In case a deep fill is required, to prevent too much of a sag in the track where sufficient earth cannot be reached alongside with the regular dipper, logs are pulled in with the boom to form a portion of the fill, and earth is then placed on the logs to build up the desired grade. In localities where the grading required is slight the timber is logged off the right-of-way, the stumps pulled and the necessary clearing done by the ditcher in addition to making the fill.

Side-hill cuts are made with equal facility, the Potlatch Lumber Co. having recently made an 8-ft. cut 300 ft. long on a 6 per cent grade. Fills as deep as 8 to 10 ft. on 4 per cent grades have also been made.

After the grade is completed the machine is run back over the line and mounted on a flat car with steel rails fastened to the deck to permit the necessary amount of shifting of the machine to pick up and handle materials from two cars in rear and place them in the track. In this manner the ditcher is used as a tracklaying machine. The 60-lb. rails, 33 ft. long, are loaded on the car next to the ditcher and the ties piled high on the second car. The dipper boom is removed, so as to allow the use of the machine as a crane, the only extra equipment required being two tie slings made from short lengths of cable with a hook at each end, and a pair of rail tongs.

Two men on the tie car make up bundles of ties which are picked up and swung around onto the grade ahead, where they are distributed, 17 ties to the rail, by a gang of six men. After placing the ties the rails are picked up from the car by center tongs of a special, non-teetering type, a man on the rail car hooking them to the rail. They are then swung around in front and heeled into the angle bars. Two men also put on the bridles to hold the rails in line and to gage until spiked. One man brings the angle bars forward from the front of the rail car and places them on the rails and another man bolts up the joints. One man is employed to carry the bridles ahead, to be used as fast as the rail is laid up to them. These, together with the operator and fireman of the ditcher, make a crew of 16 men required for laying track, the gang being made up as follows:

2 men on tie car.
6 men distributing ties.
1 man attaching rail hooks.
2 men heeling in rails and putting on bridles.
1 man carrying bridles.
1 man placing angle bars on rails.
1 bolter.
2 men to operate the ditcher.

In placing rails the ditcher, after swinging the rail around to the front, is run out to the end of the flat car on which it operates, so as to swing the near end of the rail slightly beyond the joint. The machine then backs up until the line that holds the rail hangs at a considerable angle, in which position the rail is easily heeled into the joint. The rail tongs are so constructed that they release as soon as the rail rests on the ties.

The spiking crew, working behind the machine, consisted of 2 boilers, 15 spikers and 1 spike peddler, a total of 18 men. Thus the total crew required to complete the tracklaying work numbers 34 men. As much as 3,000 ft. of track have been laid in a day by this crew on heavy grades and where trees on the right-of-way must be cleared off. On straight work, without clearing, it is estimated that one mile of track a day can be laid. By the use of the ditcher in this way the company saves the wages of 25 men at $3.50 a day that would otherwise have been required.

Cost of Making 2-In. Lift on Main Line Track.—A. M. Van Auken gives the following data in Engineering and Contracting, Nov. 19, 1919.

This work was done on April 9, 1917, on the Michigan Central R. R. The weather was clear and the temperature was about 50° F. A total length of 1,221 ft. of 3° curved track was lifted. In addition 62 ties were placed in track. The force was as follows:

1 foreman	$90.00 per month
1 assistant foreman	77.50 per month
1 cook	2.10 per day
1 timekeeper	75.00 per month
22 laborers	2.10 per day
1 water boy	2.10 per day
2 flagmen	2.10 per day

Of the above force the timekeeper, cook, water boy and the two flagmen are classed as "dead" labor.

The men left the bunk cars at 6:30 a. m., and began work at 7. They lifted track from 7 to 11:30, took half hour for lunch, and were engaged again from 12 to 4:30 p. m. in lifting track. They left the work at 4:30 and arrived at bunk cars at 5 p. m. It will thus be noted that the working time was 9 hours. However, there was a total delay of 40 minutes due to passing trains, which makes the actual working time 8 hours and 20 minutes.

The equipment used consisted of track tools and three hand cars.

The cost of the work was as follows:

	Per lin. ft. of track
Superintendency	$0.0038
Active labor	.0314
Dead labor	.0074
Delays to entire gang	.0077
Total, cost of 2-in. lift and replacing .05 of a tie	$0.0503

Cost of Renewing Rail.—The following data given by D. A. Wallace in Engineering and Contracting, Aug. 31, 1910, include various items of work besides rail renewal proper but all come within the same general classification.

Job 1.—Relaying 58-lb. with 85-lb. rail, full bolted, full spiked and gaged, with negro labor at $1.25 and foreman at $60 per month, in May, 1906. The work was done by a gang averaging 1 foreman, 31 men and 1 water boy. Delays include delays by trains and time spent in trucking badly distributed rail, etc. The angle bars were 6-hole, 4-in. bars. The work was full bolted, full spiked and completed each day. Connection for trains was made by using a short piece of old rail cut to fit and connected with the new rail by a compromise joint The average number of feet of rail laid per day with the gang of 33, as noted above, was 1305 ft. with an average of 3.5 hrs. delay.

The cost was $3.33 per 100 ft. of track or $176 per mile of track.

Job 2.—Owing to the narrow fills at some places, and to the amount of rock at others, it was occasionally necessary in unloading the rail to skid it off in piles and then redistribute it from the piles with the steel gang thus causing delays. There were also a few delays by trains. The rail was 56-lb. changed to 70-lb. and all rail was curved for curves of 5° and over. About one-fourth of the time was consumed in curving and tracking rail. One-half the entire distance was curves of 5° and over. The average for 24 days showed that a gang of 19.5 men (varying from 2 to 53) laid 945 ft. of rail per day with delays averaging 3.28 hrs.

Negro labor was employed at $1.15 and $1.25 per day and foreman at $75 per month. For the first nine days' work the rate was $1.15 and for the remainder of the time it was $1.25 per day. The cost of the work was as follows:

Item	Per ft.	Per rail	Per mile	Per cent
Unloading	$0.004	$0.13	$ 21.05	9.8
Curving	0.0054	0.179	28.66	13.4
Distributing	0.003	0.097	14.59	6.8
Laying	0.0283	0.936	149.80	70.0
Total	$0.0407	$1.342	$214.10	100.0

Applying Tie Plates.—The tie plates were applied to white oak ties on track in service. These plates were placed under the rail and settled with a sledge. After three or four days they were settled completely with a sledge. During this work, there were an average of 6 braces to a rail to remove. White labor was employed at $1.10 per day and foreman at $50. The best record was 140 plates per man per day, the average was 93 plates per man per day.

The cost of applying each plate was 1.1 ct.

Gaging Track.—(1) This record is of work done by season gangs. The track was in very poor gage due to sharp curvature and rotten white oak ties. In the majority of cases the rail was gaged on each tie. All old spike holes were plugged. Ties were adzed when necessary. The foreman made a hand in every case. There was an average of 6 braces per rail. Negro labor at $1.25 and foreman at $50 per month were employed. The best record was 275 ft. per man per day, the average was 205.4 ft. per man per day.

The total cost of gaging one mile was $28.30.

2. This record was made by a picked gang. Every tie was gaged and holes plugged. No rail braces were used as the track was on tangent. The gang consisted of 1 foreman at $50 per month and 4 laborers at $1.10 per day. On this work 2 men were placed drawing spikes and 2 men spiking, the fore-

man assisting in lining the rail, etc. This gang gaged 1,440 ft. in 10 hours, at a cost of $22 per mile.

Disconnecting Rail.—The work consisted in unbolting 30-ft., 4-bolt rail and in fastening loosely one pair of angle bars to each rail with two bolts. Negro labor at $1.25 and foreman at $75 per month were employed. The average record was 45 rails per man per day, the maximum was 50.

The cost was as follows:

One rail	$0.027
One mile of rail	4.45
One mile of track	8.90

Tightening Spikes.—This work was done by regular gangs on regular maintenance work. Each spike was driven home; each man took one rail length. Negro labor at $1.25 per day and foreman at $60 per month were employed. The average record was 14 rails per man per day, the maximum was 15.

The cost of tightening was 9 cts. per rail length or $14.40 per mile of track.

Applying Rail Braces.—The rail braces were applied by small gangs and track walkers on curves which had been put up to gage. The labor was white at $1.10 per day with foreman at $50 per month. The average record was 183 braces per man per day, the maximum was 200.

The cost to apply one brace was 0.6 ct.

Curving Rail.—Rail 33 ft., 70-lb. was curved to 5°. Rail curved from side and placed in a roller Jim Crow in the center of the track and curved by 8 men. Six men could do the work, but 8 were needed to move the rail.

8 men 10 mins. at $1.15 per day	$ 0.153
1 foreman 5 mins. at $75 per mo	0.020
Total, one rail	$ 0.173

This gives a cost of $55.36 per mile.

Wrenching.—(1) This work was on 4-bolt joints on 56-lb., 30-ft. rail; the bolts had not been tightened in 5 years. At each joint one bolt was broken out and replaced. Negro labor at $1.10 and foreman at $50 per month were employed. The average record was 61 joints per man per day, the maximum was 87.

The cost of tightening was as follows:

1 bolt	$ 0.0045
1 joint	0.018
1 mile of track	6.35

2. On this job the bolts were in good shape in 6-bolt joints on 33-ft. rail. Negro labor at $1.25 per day and foreman at $60 per month were employed. The average record was 80 joints per man per day, the maximum was 85.

The cost was as follows:

One bolt	$0.0025
One joint	0.015
One mile of track	5.00

Time Tests in Relaying 105-lb. Rail.—A. M. Van Auken gives the following data in Engineering and Contracting, Nov. 19, 1919.

In connection with the relaying of 104 pieces of 105-lb., 33-ft. new rail in the yards of the Michigan Central R. R. at Jackson, Mich., on March 2, 1917, several tests were made of different operations to determine the average amount of time used and lost during a day's work on this kind of construction. On the day this work was done the weather was clear and cold with a temperature of + 12° F.

The force engaged was as follows:

	Total daily cost
1 foreman drilling at $87.50	$ 3.40*
1 assistant foreman at $75	2.90*
1 timekeeper at $75	2.90*
2 cooks at $2	4.00
40 laborers at $2	80.00
1 water boy at $2	2.00
2 men drilling at $2.50	5.00
1 man wiring at $2.25	2.25
Total daily cost	$102.45

* On the basis of 26 working days per month. It should be borne in mind, however, that the men on a monthly scale receive pay regardless of whether or not the rest of the gang is working.

The men drilling and wiring were engaged in bonding. With the exception of this bonding crew and the timekeeper, the entire labor force were Turks.

The material used in the work was as follows:

104 pieces of 105-lb., 33-ft. new rail.
103 pieces of 105-lb., 38-in. angle splices.
4 kegs of track spikes.
624 bolts with nuts.
212 pieces of 52-in. copper plated bonding wires.
424 pieces copper plated bonding lugs.
1 pair 105-lb. continuous insulated joint.
2,580 wooden tie plugs.

The labor force left the bunk houses at 6 a. m., on hand cars for Jackson Yards, 3 miles distant. They arrived at the yards at 6:20 a. m. Unloading hand cars and preparing for work took from 6:20 a. m. to 7:00 a. m. From the latter hour to 12:30 they were engaged in laying rail. The dinner hour was from 12:30 to 1:30 and from 1:30 to 5:00 the gang worked relaying rail. They left the yards for the bunk houses at 5 p. m., arriving there at 6 p. m. The above time includes delays from various causes but does not include the time taken for cutting bolts and taking apart old rail.

Waiting for material to be distributed along the track and for a train to pass so track could be broken made 22 laborers idle from 7 a. m. to 7:30 a. m., and 36 laborers from 7:30 a. m. to 7:50 a. m. Breaking and closing track for continuous traffic amounted to 3 hours for the various trains. While this operation does not make the men idle, it delays the progress of the work. The men are kept busy spiking and fastening the rail which had not been completely finished as the work proceeded. An accident to one of the men caused the gang to be idle for 10 minutes.

The time tests of the various operations gave the following results:

Driving Spikes.—It took one man 15 minutes to drive 20 spikes. With a unit of one spike for the same man the following time was used for each spike drive: 1 minute; 45 seconds; 30 seconds; 30 seconds; 25 seconds; 30 seconds; 15 seconds; 30 seconds.

Bonding.—One man drilling four holes in each 105-lb. rail with drilling machine:

Delay in starting	Time from start to finish	Time to move to next joint
	4 min. 15 sec.	35 sec.
15 sec.	5 min. 40 sec.	40 sec.
0 sec.	4 min. 25 sec.	35 sec.
5 sec.	4 min. 20 sec.	40 sec.
25 sec.	3 min. 55 sec.	....

With one man wiring and two men bonding wires to each joint the following records were obtained:

Time from start to finish	Time to move to next joint
1 min., 00 sec.	10 sec.
1 min., 15 sec.	12 sec.
1 min., 18 sec.	15 sec.
1 min., 20 sec.	10 sec.
1 min., 50 sec.	20 sec.
1 min., 20 sec.	10 sec.
1 min., 19 sec.	12 sec.

In addition to this 15 minutes were used to bend 125 bonding wires at one end and distribute them over 2,000 ft. of track.

Pulling Spikes.—One test showed that 18 laborers pulled 700 spikes, in a distance of 1,155 ft., in 30 minutes. At a unit of one 33-ft. rail length, 20 ties to the rail, spikes pulled on both sides of one rail only, it took 7 laborers 12 minutes to pull the 40 spikes. At a unit of one man for 20 spikes (one side of 33-ft. rail) the two records varied greatly as will be seen from the following table:

	Time
1st man	14 min.
2nd man	3 min.,
3rd man	3 min., 30 sec.
4th man	6 min., 25 sec.
5th man	5 min., 20 sec.
6th man	3 min., 50 sec.

Lifting Old Rail and Throwing Off Ties.—Four laborers handled 254 ft. in 14 minutes, and 3 laborers handled 990 ft. in 43 minutes. These entire lengths were in one piece, and on one side of the tracks the rail was lifted over the outside line of spikes, as these were left in to set and line new rail.

Plugging Old Spike Holes and Adzing Ties.—In this work 7 laborers covered 264 ft. in 25 minutes; and 9 laborers covered 990 ft. in 50 minutes. This includes sweeping and removing dirt from the ties.

Placing New Rail.—Ten laborers placed 30 lengths of 105-lb. 33-ft. new rail in 56 minutes, despite the fact they were held up 15 minutes waiting for the adzing gang to clear ties.

Placing Splices.—In this work two bolts were first fastened in the splice after the rail had been placed for passing trains. The remaining bolts were fastened later during spare time of men. The time for placing two bolts and splice was as follows:

Time from start to finish	Time moving to next joint
3 min.	30 sec.
3 min., 30 sec.	30 sec.
3 min.	1 min.
11 min. for insulated joint	1 min.

Small Turntable Cuts Cost of Handling Relay Rails.—John H. Sawkins gives the following helpful suggestion in Engineering News-Record, May 24, 1917.

The turntable shown in the accompanying sketch proved a big labor and time saver in handling rails for the car-repair yard of the Pennsylvania R. R. at Greenville, New Jersey.

The 85-lb. rails used were second-hand, and the ball of each was badly worn on one side. It was therefore necessary to place the unworn side on the inside of the track being laid and it happened that many of the rails had to be turned end for end before placing them. Previous to building the turntable it required considerable maneuvering by a gang of at least six men to turn one rail. With the turntable, however, which is set up about 18 ft. from the track being laid, two men can turn a rail with ease. The device was made complete for $8.

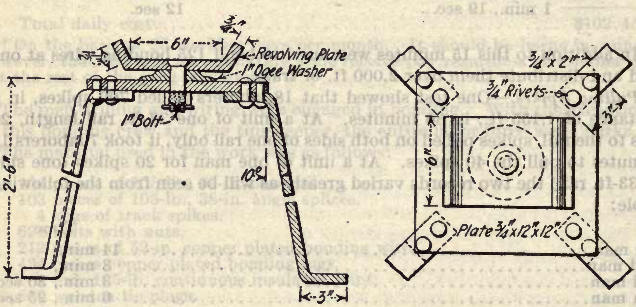


Fig. 7.—Device saves much time in handling old rails.

Unit Costs for Railway Switches.—The following data, relating to switch installations in Detroit, Mich., for the Michigan Central R. R., are given by A. M. Van Auken in Engineering and Contracting, Dec. 17, 1919.

Cost of material in switches from ledger account.

90-lb. rail:	
Number of switches installed	2
Highest cost per switch	$197.28
Lowest cost per switch	195.82
Average cost per switch	196.55
80-lb. rail:	
Number of switches installed	32
Highest cost per switch	$274.90
Lowest cost per switch	142.02
Average cost per switch	178.17
65-lb. rail:	
Number of switches installed	24
Highest cost per switch	$222.19
Lowest cost per switch	131.70
Average cost per switch	163.74
70-lb. rail:	
1 installed, cost	$155.54

Cost of material in industry tracks. Exclusive of switch material.

Number of jobs	35
Total length of track laid, ft.	30.933
Highest cost per foot	$ 1.3094
Lowest cost per foot	.5578
Average cost per foot	.7950

Installing switches, laying switches and setting concrete dumping posts.

Installing switches:	
Number installed	59
Lowest cost of installation	$ 16.06
Highest cost of installation	79.96
Average cost of installation	45.50
Laying track:	
Number of jobs	35
Total length of track, ft.*	30.281
Average length per job, ft	865
Lowest cost per lin. ft	$ 0.0577
Highest cost per lin. ft	.2545
Average cost per lin. ft	.1488
* Exclusive of switches.	
Setting bumping posts:	
Number set	17
Largest number on one job	7
Smallest number on one job	1
Average number on one job	1.7
Highest cost per post	$ 6.40
Lowest cost per post	2.01
Average cost per post	4.21

Cost of Replacing Three Crossing Diamonds.—A. M. Van Auken gives the following data in Engineering and Contracting, Jan. 21, 1920.

This work was done on May 7–9, 1917, by the Michigan Central R. R. It involved the replacing of crossing diamonds at East Main St., Jackson, Mich. One of them was in the westbound main track, another in the eastbound main track, and the third in a sidetrack. The track was crossed by one street railway track of the Michigan Ry. The electric cars averaged 1 per minute during the greater part of the day. Vehicle and pedestrian traffic also was heavy. The weather during the three days was variable, the temperature ranging from 45 to 55°.

The three crossing diamonds were of the Ajax type, 22 ft. 11 in. by 22 ft. 11 in. in size. They consisted of 100-lb. manganese built up. The angle of crossing was 34° 48′. The cost of the three was $2,302.50.

The materials required for the three crossings were as follows:

	Crossing No. 1 West-bound main track	Crossing No. 2 East-bound main track	Crossing No. 3 side track
Ties	19	16	15
Rails, 100-lb., 33 ft	4	4	..
Splices, 100-lb., 23-in. continuous, non-insulated, pairs	8	8	10
Bolts with nut locks	32	32	40
Tie plates, Sellers	14	9	8
Spikes, kegs	2	2	.6

In addition five 12-ft. ties were divided among the three crossings. Crossings Nos. 1 and 3 each had two pairs of special compromise joints furnished by electric railway.

Two roadmasters were on the work part of the day. The laborers included 10 Poles and 3 Americans. Work was started at 7:30 a. m. and continued to 5:30 p. m., with 1 hour off for lunch. Except as noted below the 17 laborers worked full time in removing bricks and planking and excavating at crossings Nos. 2 and 3. Two men worked 2 hours removing bolts from 14 joints—2 bolts to the joint—and 1 foreman and 6 laborers worked 1 hour and 15 minutes in hauling ties. Work was carried on during the night of May 7–8 in changing the sidetrack diamond. Four laborers worked from 6:30 to 9:30 p. m., and 23 laborers, 5 foremen and 1 assistant foreman worked from 9 p.m. to 6:15 a. m. Three oil and two carbide lights furnished illumination. A work train, consisting of engine, crane, 1 flat car and 1 box car, was in service from 10 p. m. to 6 a. m. The charges for this service were:

Train crew and engine crew	$ 4.00 per hour
Engine rental	10.00 per day
Crane rental	20.00 per day
Crane engineer	3.95
Crane machinist	4.44
Box car	.50 per day
Flat car	.50 per day

The day force on May 8 consisted of 5 foremen, 1 assistant foreman and 23 laborers, who worked from 7:30 a. m. to 3 p. m. with pay for 1 day, and 2 foremen, and 12 laborers, working from 2 to 5:30 p. m. In addition there was one team and driver employed from 10 a. m. to 5:30 p. m. with pay for 1 day.

The equipment consisted of track tools and push car.

Work during the night of May 8–9 was carried on at the eastbound main track crossing and westbound main track crossing.

The force consisted of 7 foremen, 1 assistant foreman and 35 laborers, who worked from 10:45 p. m. to 5:45 a. m., and were credited with pay for 1 day.

The force employed on May 9 consisted of three foremen and six laborers, working from 8 a. m. to 11:30 a. m.; two laborers, working from 9 a. m. to 11:30 a. m., and 3 foremen and 12 laborers, working from 12:30 to 5:30 p. m.

In the following summary of the cost of installing the three crossing diamonds, with the exception of foremen, where rate of pay shown is for the month, and train and engine crews where the rate is per hour, the rates shown are the daily wage.

West-bound Main Track Crossing

	Total
Labor:	
Day of May 8—	
1 yard foreman, ¾ day at $90	$ 2.60
1 assistant yard foreman, ¾ day at $75	2.16
4 section foremen, ¾ day at $77.50	8.94
2 section foremen, ⅜ day at $77.50	2.24
20 laborers, ¾ day at $2.25	33.75
12 laborers, ⅜ day at $2.25	10.13
Night of May 8—	
35 laborers, ½ day at $2.25	39.38
Day of May 9—	
1 yard foreman, ⅓ day at $90	1.15
2 section foremen, ⅓ day at $77.50	1.99
9 laborers, ½ day at $2.25	10.13
1 laborer, ⅓ day at $2.25	.75
1 team and driver, ¾ day at $6	4.50
Total labor*	$117.72
Equipment and Service:	
Engine rental, ½ day at $10	$ 5.00
Crane rental, ½ day at $20	10.00
Flat car, ½ day at 50 ct	.25
Box car, ½ day at 50 ct	.25
Train and engine crews, 4 hours at $4	16.00
Crane crew	4.60
Total equipment and service	$ 36.10
Grand total†	153.82

East-bound Main Track Crossing

Labor:	
Day May 7—	
1 yard foreman, ½ day at $90	$ 1.73
2 section foremen, ½ day at $77.50	2.98
1 assistant yard foreman, ½ day at $75	1.44
17 laborers, ½ day at $2.25	19.13
1 team and driver, ½ day at $6	3.00
Day May 8—	
1 yard foreman, ¼ day at $90	.87
1 assistant yard foreman, ¼ day at $75	.72
4 section foremen, ¼ day at $77.50	2.98
2 section foremen, ⅛ day at $77.50	.75
20 laborers, ¼ day at $2.25	11.25
12 laborers, ⅛ day at $2.25	3.38
Night May 8—	
35 laborers, ½ day at $2.25	39.38
Day May 9—	
1 yard foreman, ⅓ day at $90	$ 1.15
2 section foremen, ⅓ day at $77.50	1.99
7 laborers, ½ day at $2.25	7.88
1 laborer, ⅓ day at $2.25	.75
1 team and driver, ¼ day at $6	1.50
Total labor*	$100.88
Equipment and rental same as West-bound Main Track Crossing	36.10
Grand total†	$136.98

Sidetrack Crossing

Labor:	
Day May 7—	
1 yard foreman, ½ day at $90	$ 1.73
2 section foremen, ½ day at $77.50	2.98
1 assistant yard foreman, ½ day at $75	1.44
17 laborers, ½ day at $2.25	19.13
Team and driver, ½ day at $6	3.00
Night May 7—	
23 laborers, 1 day at $2.25	51.75
Day May 8—	
3 laborers, 1 day at $2.25	6.75
1 yard foreman, ⅓ day at $90	1.15
Day May 9—	
2 section foremen, ⅓ day at $77.50	1.99
2 laborers, ½ day at $2.25	2.25
1 laborer, ⅓ day at $2.25	.75
Total labor*	$ 92.92
Equipment and service:	
Engine rental, 1 day at $10	$ 10.00
Crane rental, 1 day at $20	20.00
Flat car rental, 1 day	.50
Box car rental, 1 day	.50
Train and engine crews, 8 hours at $4	32.00
Crane crew	8.39
Total equipment and service	$ 71.39
Grand total†	164.31

* Seven Foremen worked night of May 8 without additional pay.
† This total does not include complete cost of surfacing.

Cost of Maintaining Anchored and Unanchored Track.—The relative cost of maintenance of unanchored track and track anchored to prevent creeping of ties is shown in an article in the Railway Age Gazette, from which Engineering and Contracting, March 27, 1912, gives the following abstract.

The data are taken from records made on the maintenance of 3½ miles of double tangent track of level grade, light gravel ballast, 85 lb. rail and broken joints. The heavy traffic was north bound and consequently all data are based on the north bound track, as the creeping tendency here was decided. This track had been put in service 14 months before, and one mile in the center of the stretch was anchored, leaving 1½ miles on the north and one mile on the south end not anchored. Where the track was anchored, 640 anti-creepers were applied, two per rail length, opposite joints against opposite end of joint ties. The anti-creepers have received no maintenance and have shown no failure, although they had been in service 14 months at the time of inspection.

The character of the work done on the two pieces of track in 14 months is stated in the columns below:

Anchored track—
Track resurfaced once.
Unanchored track—
Track resurfaced twice.
Ties spaced twice.
Rail driven back twice.

The total maintenance cost for the mile where the anti-creepers were applied, including the cost of anti-creepers, is as follows:

Cost of anti-creepers, 640 at 17½ cts. each	$112.00
Applying 640 anti-creepers at ½ ct. each	3.20
Resurfacing, 10 men working 16 days, at $1.55 per day	248.00
Total	$363.20

The total cost of the next mile north of the mile where the anti-creepers were applied, subject to the same conditions of traffic, roadbed, etc., but unanchored, is given below:

Cost of resurfacing twice, each time 10 men, 16 days, at $1.55 per day, $248	$ 496.00
Cost of respacing ties twice, each time 10 men, 17 days, at $1.55 per day, $263.50	527.00
Cost of driving back rail twice, each time 10 men, 2 foremen, 6 days, at $1.55 per day, $111.60	223.20
Total	$1,246.20

This shows a saving in 14 months of $883 in favor of the anchored track.

It will be noted that the original cost of the anti-creepers and of their application have been included in the first 14 months. These costs are properly chargeable over the total number of years anchors are in service, which in all cases is at least as long as the life of the rail on which they are applied. This would make the saving considerably greater than has been estimated. Furthermore, this maintenance cost does not include injury done to ties, spikes and joints, which was considerable where anchors were not applied as the creeping had pulled the ties badly askew, bending or completely destroying the spikes and often causing broken joints. Where the anti-creepers were applied, this wear and tear were hardly worth considering.

The above figures were obtained directly from the railway, and the roadmaster stated that he could have maintained this 3½ miles of track in better shape with three men less per year had he been allowed to anchor the balance.

Railway Maintenance Cost is Increased by Fast Passenger Trains.—The following note is taken from the Engineering News-Record, April 25, 1918.

Speed of trains affects the cost of maintenance of way and structures to the extent that the higher the proportion of passenger traffic, which may be assumed as high-speed traffic, the greater the cost of maintenance. This is the conclusion arrived at in a preliminary report presented by the track committee at the 1918 annual meeting of the American Railway Engineering Association.

In the accompanying diagram, the curved lines represent traffic of which the passenger-car miles constitute 7.5, 12.5 and 20.3% of the total car mileage.

It is recognized by the committee that the assumption of high-speed and low-speed traffic as synonymous with passenger and freight traffic is not entirely correct, but this, the committee says, offers the only opportunity for classifying expenses in accordance with differences of speed. The car-mile was taken as the unit for comparison on the ground that it gives the best measure of the facilities required by each class of traffic.

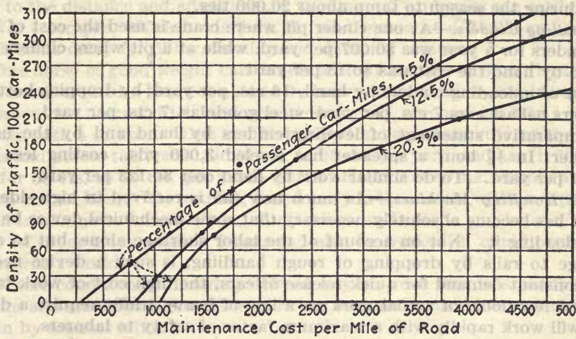


FIG. 8.—Effect of percentage of passenger-car-miles on maintenance cost.

Labor Saving Devices in Maintenance of Way Work.—Much useful information on labor-saving devices for track work was given in a committee report adopted at the 1920 annual meeting of the Roadmasters and Maintenance of Way Association. The following data are taken from an abstract of the report, published in Engineering and Contracting, Feb. 18, 1920.

Mechanical Tie Tampers.—The great majority of those who have used a tamping machine and given it a fair trial will testify to its wonderful value as a labor-saving device. It is the committee's observation that the machine work is more uniform and better than track tamped by hand. It has been proved that a tamping machine is of particular value around frogs and switches, water pans, tunnels, etc., as it is possible to tamp with it in places which cannot be reached by a tamping bar or pick.

Carefully compiled figures for hand and machine tamping from several railways covering a period of three seasons follow:

For a 2-tool machine: 1 foreman, 10 hours at 32 cts., $3.20; 4 men, 10 hours at 22 cts., $8.80; 12 gal. gasoline at 24 cts., $2.88; total, $14.88.

Without machine: 1 foreman, 10 hours at 32 cts., $3.20; 4 men, 10 hours at 22 cts., $8.80; total $12.

Cost per mile of track without machine, 32 days at $12, $384.00; cost per mile of track with machine, 16 days at $14.88, $238.08; balance in favor of machine, $145.92.

For a 4-tool machine the comparison between hand tamping and mechanical tamping was as follows:

Hand gang and foreman, 16 men, 8 hours, tamped 500 ft. of track; machine gang and foreman, 6 men, 8 hours, tamped 528 ft. of track; saving of 10 men and 80 hours for machine.

Expense: Hand gang and foreman, 16 men, $43.50; machine gang and foreman, 6 men, $18.50 (cost to run $6.95); $24.45; saving by machine, $18.05.

Fixed charges are given as follows as near as it is possible to get them: Depreciation at 10 per cent, interest 5 per cent, repairs 5 per cent, total fixed charges 20 per cent.

Experience during the four years this machine has been in use teaches that, under normal conditions in the northern states, each machine will be used during the season to tamp about 20,000 ties.

Handling Cinders.—At one cinder pit where crane is used the cost of loading cinders for a year was $0.007 per yard, while at a pit where cinders were loaded by hand the cost was $0.13 per yard.

Cost of unloading cinders by hand, 16 cts. per yard; by dropping bottoms, Rodgers ballast cars 7 cts. per yard; steel gondolas, 7 cts. per yard.

Comparative statement of leveling cinders by hand and by the use of spreader: In ½ hour a spreader has leveled 3,000 yds., costing less than $0.001 per yard. To do similar work by hand cost $0.123 per yard.

Rail Handling Machines.—As much new rail is received in high-side coal cars it has become absolutely necessary that some mechanical device be used for unloading it. Not on account of the labor shortage alone, but to avoid damage to rails by dropping or rough handling, is such a device needed. The constant demand for quick release of cars, the high cost of work trains, and the few hours of actual work on a line of heavy traffic require a device that will work rapidly with a maximum factor of safety to laborers.

There are rail-handling machines in use which are capable of loading or unloading two cars of rail at the same time. For the operation of these machines nine men are required, one man to operate hoists and four men to each car of rails. The machine is operated by air from the train line. Such machines will unload rails more quickly and without damage to rails or injury to men than could be accomplished by 40 men by hand, thus a saving of 31 men a day is made possible. This machine can also be equipped with tongs to load or unload as many ties with three men as can be loaded or unloaded by 20 men by hand.

Snow Melting Devices.—The committee is not unanimous in its views as to the benefits to be derived from snow melting devices. The following results were submitted by one of the members:

Two laborers at $3.80 per day, $7.60; royalty on cars, $5 per year (used about 5½ months, 2 cars), 6 cts. per day; 6 gal. hydro-carbon fluid at 11 cts. per gallon, 66 cts.; total cost with melting device, $832.

If done by hand: Foreman at $3.35 and 10 laborers at $2.80, total $31.35; 6 rattan brooms at 28 cts., $1.68; total cost by hand, $33.03. Saving by use of device, $24.71.

Another device which can be used successfully for the same purpose is the Hauck snow melting torch.

Motor Cars.—The majority of the committee is in favor of the more general use of motor cars, particularly on lines of light traffic, where the length of sections are such as to warrant their use. Therefore it is the committee's opinion that the economy in the use of motor cars decreases in proportion to the additional number of main tracks, which in turn shortens the length of sections. It has obtained the following figures showing the economy effected by the use of motor cars:

Time spent in carrying 14 men and foreman by motor car 14 miles, 30 minutes; for round trip, 1 hour, or total of 15 hours. Time spent for round trip by hand car, 3 hours, or a total of 45 hours, showing a saving of 30 hours in favor of motor cars. There is still a larger saving in the increased energy of the men when they arrive on the job, in the better class of labor attached, and in the time saved on emergency jobs.

The Horse as a Labor-saver.—On divisions where much ditching must be done by work trains or wheelbarrows, teams with scrapers have been tried, with the following results: One laborer can fill scrapers for 2 to 4 teams, according to the distance and advantage of working. Two horses can easily handle a No. 1 scraper, which holds 7 cu. ft., and moves at a 2-mile-an-hour rate, with some delay for filling, turning and dumping scrapers.

One horse of good weight can handle a No. 2 scraper of 5 cu. ft., and after teams are trained a boy not able to do heavy manual labor can drive a team, or when in a narrow ditch, and one horse is used, one boy can take two single horses with a scraper. Dirt can be handled in very short cuts, at the ends of cuts and across the track, for 20 cts. to 25 cts. per yard, and haul it 500 to 600 ft. for 50 cts. to 60 cts. per yard—this with teams at 80 cts. an hour and labor at 35 cts. an hour. By starting teams early in the season, with an experienced man in charge to handle them, all ditching can be done and balance of gang left on other track work. Teams can also be worked in muddy cuts where men won't work.

Where conditions of mowing right of way are such that it is possible to use teams and mowing machines the work can be done by machinery much cheaper than by manual labor.

Ditching Machines, Dump Cars and Spreaders.—When heavy ditching has to be done the use of steam ditchers is recommended, together with the use of at least two 16 to 20 yd. side-dump cars and a spreader car for short hauls. For a longer haul from 4 to 6 side-dumps should be used. A light locomotive can be assigned to handle this outfit, and with an outfit of this kind, which includes a train crew, ditcher engineer and fireman, dirt can be handled for 10 cts. to 25 cts. per yard, according to the length of haul.

Through long usage the steam ditcher and spreader, especially when the latter is operated by air, has reached such a high state of efficiency that they are practically indispensable, and the fact that they can be used for many different varieties of work places them among the most important labor-saving devices.

A saving of at least 60 per cent over that of manual labor is obtained by using a No. 3 crane for removing ballast from between tracks, in preparing for stone ballast, digging drains under tracks, unloading old ballast on fills, to strengthen shoulder and fill up holes, load and unload rails, and for various other purposes.

The magnet is used very successfully to load and unload scrap of various kinds. This machine is capable of picking up six or eight 33-ft. rails as rapidly as it will one, and eliminates handling the rails by hand, and reduces to a minimum the liability of injuring men.

Labor Saving Equipment Employed in Track Maintenance by B. &. O. R. R.—The following data are taken from an abstract of a paper presented before the New England Railroad Club by E. Stimson and published in Engineering and Contracting, Jan. 15, 1919.

Ditching machines of the "American and Barnhart" types are well adapted to the uses of a steam derrick within the limits of their lifting capacity, and are of great use in unloading and loading rail, ties, timbers, etc. With a clam shell bucket substituted for the dipper arm their uses are still further extended.

Each of these various uses of this machine results in a great saving in man-power, the best example being that of ditching. The loading capacity is about 60 cu. yd. per hour in ordinary material. It would require 100 men to load this amount by hand. As it requires but 5 men to operate the ditcher, the large saving is evident. In handling rail 6 men and the machine will readily do the work of 40 men.

The Use of Horses.—We have found that, including plowing, a 1-horse scoop and driver working in a clay cut averaging 4 ft. in height, and wasting the material on top of the cut, can handle 45 cu. yd. in 9 hours. Another man is required for dressing up the ditch. The two men and one horse, therefore, do the work of at least 10 men. Up to a 300-ft. haul the wheelbarrow is a good proposition as compared with other methods. While these methods may not show great economies over the steam ditcher and work train, and do require much greater time for completion, they are to be recommended where the matter of quick completion is not vital. They require but a small number of men and give steady employment, which promotes efficiency. With the intense traffic conditions prevailing and the great demand for train crews and engines to handle the business it is most desirable to release all the work train service possible. The cost of this service has increased about 40 per cent during the past year and nearly 100 per cent in the past 10 years. These considerations make it desirable, both from necessity and from the standpoint of economy, to adopt methods to reduce work train service.

Rail Handler.—A home-made device which has proven a great labor-saver is an air-operated rail handler. With it a gang of six men and a foreman will load one rail per minute. By hand methods 20 men will load 1 rail every 2 minutes on to flat cars and one rail every 5½ minutes on gondolas. The machine is also used for handling frogs, switches, ties, scrap and other maintenance materials with proportionate labor savings.

Pneumatic Tie Tamping Machines on Track Work.—More labor is used in surfacing and lining of track than on any other item of track work. Normally this will amount to about 35 per cent of the total track payroll. This offers an attractive field for labor saving. About four years ago pneumatic tie tamping machines were introduced for this work. The earlier machines were limited to two tampers, but the later ones have the necessary power to operate four tampers with a consequent reduction in overhead and operating expenses. Our experience indicates that with a 2-tool machine 5 men do the work of 9 men tamping with picks and with a 4-tool machine 7 men will do the work of 17 men without them. There is also an indirect saving made by the more uniform and permanent work done by the tamper, requiring less frequent re-tamping than when the work is done by hand.

Ballast Cleaning Appliances.—Stone ballast, to be fully effective, must be kept clean and the voids unclogged. Where traffic is heavy, particularly on grades, stone ballast will require cleaning at least once in three years and in many places much oftener. To raise the track on dirt ballast and dress off with clean stone is poor practice, and to clean it by forking it over is slow, expensive, and requires a large number of men. A number of methods for cleaning ballast have been considered, even to a gigantic vacuum cleaner which, on account of cost, is out of the reach of most of us. The most practical is the ballast screen. The standard performance with 3 screens and 12 men and a foreman is 200 ft. of double track per 10-hour day. To clean with forks, this length of track would take the same number of men 2.8 days or 36 men with forks to do the work of 13 men with the screens.

Removal of Grass and Weeds.—Much labor is applied each year to the cleaning of grass and weeds from the track and roadbed. Two methods have been more or less effective as "weed killers," burning, and spraying with a solution of arsenite of soda.

About 10 years ago a western railroad designed a weed-burning machine. A strip 7 ft. on each side of center line of track was burned at an average cost of $9.46 per mile. Two burnings were necessary, so that to destroy the weeds the cost would be $18.92. As compared with hand labor it was claimed to save 14 men per day.

The spraying method has been extensively used. In 1916 the cost of spraying 744 miles of single track averaged $18.11 per mile. Including the train crew the work was done by 10 men, averaging 21 miles per day. To do a like day's work by hand where the growth was medium heavy in soft ballast 273 men would be required at an average cost of $23.25 per mile. A large saving in men is thus effected, though not so much in money.

Cost of Cleaning Weeds and Grass From Track.—D. A. Wallace gives the following records in Engineering and Contracting, Sept. 17, 1910.

The cleaning of weeds and grass from track was done by section gangs, the men getting $1.10 per day and foreman $45 per month. In the first two cases the weeds were removed only from end to end of ties. One or two men went ahead with picks and loosened the gravel and 2 men followed pulling weeds and grass by hand, each man working a strip 4 ft. wide. There was considerable crab and Bermuda grass. In the third case the cleaning was done from edge to edge of the ballast, giving an additional width of about 18 ins. While the record is of one man's work only it was selected as an average of several days' work of a gang. The records are as follows:

1. Rock ballast, weeds, medium thick:

Number of feet	Number of days	Feet per man per day
5,280	8	660
5,000	9	555
5,280	9	586
Average		600

The cost per mile was $11.15.

2. Slag ballast, weeds medium thick:

Number of feet	Number of days	Feet per man per day
18,500	12½	1,480
1,400	9½	147
3,200	7	457
390	1	390
3,360	4½	946
8,600	8	1,075
6,100	20½	300
2,640	3½	754
Average		693

The cost per mile was $9.80.

3. This work was in gravel ballast and the weeds were very thick. One man cleaned 210 ft. in one day. The cost per mile was $19.40.

4. Gravel ballast, weeds medium thick:

Number of feet	Number of days	Feet per man per day
1,740	10	174
4,410	14	315
2,760	5	552
7,560	12	630
Average		417

The cost per mile was $15.30.

Records of Work in Surfacing and Smoothing Track.—The following data are given by D. A. Wallace in Engineering and Contracting, July 27, 1910.

1. In this work dirt surface track was stripped and stone ballast unloaded from Rodgers bottom dump ballast cars. The raising was done with a spotboard and four or five days later the second raise of a 3 or 4-in. surface was made with tamping picks. The record for 20 days—first raise 7 ins. in rock from stripped dirt track shovel tamped with Italian labor—was as follows:

	Ft. per man per day
Max	30
Min	18
Average	25

2. This work consisted of surfacing track 4 ins. in rock on top of a 6-in. raise where ties had been renewed at the rate of about 7 per rail length. The work included spacing and gaging. The record for 7 days with negro labor was as follows:

	Ft. per man per day
Max	33
Min	15
Average	22

3. This work consisted of surfacing track 3 ins. in rock on top of a 7-in. raise where ties had been renewed at the rate of about 7 to the rail length. The record for 7 days with negro labor was as follows:

	Ft. per man per day
Max	26
Min	12
Average	20

4. On this work new rail had been laid on track which was in very poor surface. In order to keep the new rail in good condition, a 3-in. stone surface was necessary. Sufficient stone for the raise was taken from the shoulders of the ballast then in place. The surfacing was done immediately after rail renewal. The record for 8 days with negro labor was as follows:

	Ft. per man per day
Max	31.5
Min	21.1
Average	24.8

5. This work was the first raise of 7 ins. in screenings for stripped track, shovel tamped. The record for 4 days with Italian labor was as follows:

	Ft. per man per day
Max.	33
Min.	29
Average	30

6. This work was the second raise of 3 ins. in screenings on a 7-in. raise track lined and dressed, pick tamped. The record for 3 days with Italian labor was as follows:

	Ft. per man per day
Max.	150
Min.	100
Average	116

7. This work was the first raise of 7 ins. on cinders from dirt stripped track, shovel tamped. The record for 2 days with Italian labor was as follows:

	Ft. per man per day
Max.	43
Min.	30
Average	36

8. These records were taken from work of three sections and one extra gang. The track was poorly ballasted with hand napped stone and was raised 4 ins. on gravel consisting of pebbles and non-cementing sand. The rail was laid with broken joints. Gravel was unloaded from bottom dump coal cars at a cost of 30 cts. per cu. yd. on the ground. These records were kept in order to determine the most economical method of making a raise of 4 ins. under these conditions. The track put up by Sec. No. 1 stood 1st. The track put up by Ex gang No. 1 stood 2d. The track put up by Sec. No. 2 stood 3d. The track put up by Sec. No. 3 stood 4th. Negro labor at $1.10 per day and foreman at $50 per month were worked.

Section 1.—Made one raise and pick-tamped the length of the tie except 14 ins. in the middle; raised track one day and dressed up on the following day. The record of 11 days' work at raising track was as follows:

	Ft. per man per day
Max.	40
Min.	31
Average	36

With a gang of 6 men 1 mile is surfaced in 24 days.

The record for 5 days work for dressing was as follows:

	Ft. per man per day
Max.	100
Min.	71
Average	84

With a gang of 6 men 1 mile of track is dressed in 10 days.

Section 2.—Made one raise, pick-tamping heads of ties and shovel-tamping insides except 14 ins. at centers. The track surfaced on one day was dressed the next day. The record of 17 days for surfacing was as follows:

	Ft. per man per day
Max.	54
Min.	37
Average	48

With a gang of 6 men 1 mile is surfaced in 18 days.

The record of 7 days for dressing, working a gang of 7 men, was as follows:

	Ft. per man per day
Max.	100
Min.	77
Average	89

With a gang of 7 men 1 mile was dressed in 8 days.

Section 3.—The track surfaced by this gang was shovel tamped heads and inside. After an interval of 3 days the gang went back over the raised track and caught up low joints with picks and put up the track complete. The record of 10 days for surfacing was as follows:

	Ft. per man per day
Max.	110
Min.	55
Average	74

With a gang averaging 4½ men 1 mile was surfaced in 16 days.

The record of smoothing for 10 days was as follows:

	Ft. per man per day
Max.	83
Min.	45
Average	59.5

With a gang averaging 5½ men 1 mile was smoothed in 16 days.

In dressing the foreman sent 3 men back to work alone; the record for 8 days was as follows:

	Ft. per man per day
Max.	250
Min.	75
Average	133

This gang of 3 men dressed 1 mile in 15 days.

Extra Gang.—This gang made a 5-in. raise shovel tamped ties on first raise and after 3 or 4 days went back over the work picking up low places with the pick. The gang made an average of 70 ft. per man per day on the first raise. With a gang of 25 men 1 mile of track was raised in 3 days.

A gang of 17 men averaged 100 ft. per man per day smoothing up first raise, smoothing up 1 mile in 3 days.

A gang of 10 men dressed an average of 55 ft. per man per day or at a rate of 1 mile in 10 days. The work was slow on account of uneven distribution of ballast unloaded from bottom dump cars.

The surfacing done by these four gangs consumed more time than a 4-in. rise in gravel on account of using a good portion of the stone in the track in tamping with gravel.

9. The following records were secured from the work performed by section gangs. By running surface is meant the work done in bringing track to an easy riding surface, by tamping up the low places, not much attention being given to the general surface as far as appearances go. Surfacing refers to the raising of the track out of face to a uniform grade line. Smoothing up refers to the picking up of low joints and centers to the general level. Negro labor at $1.10 per day and foreman at $50 per month were worked.

Record 1.—Covers 18 days, running surface in slag ballast.

	Ft. per man per day
Max	93
Min	45
Average	66

Record 2.—Covers 31 days running surface in rock ballast.

	Ft. per man per day
Max	86
Min	30
Average	55

Record 3.—Covers 12 days running surface in gravel ballast.

	Ft. per man per day
Max	120
Min	60
Average	87

Record 4.—Covers 20 days smoothing up in slag ballast.

	Ft. per man per day
Max	161
Min	60
Average	116

Record 5.—Covers 75 days smoothing up on rock ballast.

	Ft. per man per day
Max	225
Min	51
Average	120

10. This work was done on the Frisco lines in Louisiana working "Cadian" labor at $1.75 per day and foreman at $75 per month. The dirt was a good solid black loam. The shoulders of the grade were skinned off to a slope of 1 in. to 1 ft. outward from the ends of the ties by a plow constructed on the order of a dirt spreading machine. The dirt was cast up against the ties by the cutting edges of the wings. The amount of dirt, however, was insufficient for the raise, and the remainder was secured by shoveling up from the berm

to the shoulder after having been loosened by plows. The embankment averaged 4 ft. in height.

The average for a 4.1 in. raise was 22.7 ft. per man per day.

Cost of Stopping Trains—When it is Cheaper to Install Interlocking Signals.—(Engineering and Contracting, Nov. 16, 1910.)

Under the laws of Canada, all trains are required to come to a full stop before crossing another railway at grade. C. L. Hackett, in an article on railway signaling in the *Canadian Engineer*, shows that the installation of interlocking signals is an actual saving in operating expenses when trains reach a certain number. The following figures are based on the results secured by Mr. Peabody, signal engineer of C. & N. W. Ry., who having experimented with different trains, concluded that the cost of stopping and again accelerating a train to its original speed average 45 cts. per train. The interlocking plant considered is for a single track crossing, where 16 levers would be required. A day and night towerman would be required, and the following is the estimated annual cost:

Cost of interlocking, complete	$4,800.00
Interest at 4 %	192.00
Depreciation at 7 %	336.00
Maintenance, per year	240.00
Operation, per year	1,200.00
Total cost per year	$1,968.00

The following table shows the saving brought about by such a plant as compared with stopping trains for 14, 20 and 25 trains per day:

Trains Per day	Cost of stopping, per year	Cost of interlocking, per year	Net saving, per year	Years required to pay for installation from savings
14	$1,971	$1,968	$ 3.00	...
20	2,817	1,968	849.00	5½
25	3,521	1,968	1,553.00	5

It is apparent, from this table, that 14 trains a day in this case would justify the installation of the plant, aside from the savings due to increased safety.

Cost of Turntables.—Table VII is complied from data taken from a committee report to the American Railway Bridge and Building Association and published in Engineering and Contracting, Nov. 6, 1912.

The total cost of turntables varies greatly with the type of construction and kind of excavation and to a lesser degree with the weight of engines for which the table is designed.

The cost of excavation and foundations for the through girder type is less than for the deck type. However the steel for the through type is more expensive than the deck type.

A fair average cost of turntable complete with foundations, including pit with concrete wall and paved floor (in 1912) was $100 per lin. ft. of diameter. Thus a 75 ft. turntable cost $7500, an 80 ft. table cost $8,000 and a 100 ft. table cost $10,000.

The cost of the table with center cost about $40 to $50 per lin. ft. of radius.

The cost of mechanical tractor of electric, compressed air or gasoline motor type averaged about $1,150 per installation.

The above costs have about doubled in 1920.

TABLE VII.—COST OF TURNTABLE CONSTRUCTION

Railroad	Type	Loading (wt. of eng. tons)	Power for turning	Length, ft.	Cost: Excav. and foundation	Cost: Table with center	Cost: Tractor	Cost: Misc.	Cost: Total
A., T. & S. F.	Through	243.0	E.M.	85	$5,500	.....	$1,400	.....	$11,000
B. & O.	Through	137.5	E.T.	80	......	.....	......	.....	7,500
B. & L. E.	Deck	Coopers E. 60	E.T.	80	3,000	3,000	1,500	1,000	8,500
B. & A.	Deck	Coopers E. 60	E.T.	85	......	3,500	......	.....	9,000
C. of G.	Deck	Coopers E. 55	Hand	80	2,280	2,100	......	.....	5,100
C. of N. J.	Deck	Coopers E. 55	A.M. E.T.	80	5,000	2,677	......	.....	8,277
C. & O.	Deck	311.5	A.T.	100	....	.....	......	.....	10,000
	Deck	311.5	A.T.	85	......	.....	......	.....	8,500
C. & N.	Deck	.....	A.M. E.M.	80	2,200	2,600	......	.....	.....
C. G. W.	Deck	.....	E.T.	90	4,500	4,960	900	400	10,760
C. M. & P. S.	Through	First class construction concrete center and circle		85	......	.....	......	.....	12,430
	Half through			85	......	.....	......	.....	10,900
	Deck			85	......	.....	......	.....	10,630
C., C., C. & St. L.	Deck	225.0	A.M. E.M.	85	5,000	4,000	......	.....	9,000
C. R. I. & P.	Deck	200.0	A.M.	90	......	.....	......	.....	9,000
	Deck	200.0	A.M.	75	......	.....	......	.....	7,500
C. St. P. M. & O.	Deck	200.0	A.M. E.M.	80	......	4,720	......	.....	....
C. & S.	Deck and through	200.0	A.M. E.M.	80	2,500	3,300	......	.....	5,850
D. & H.	Deck	Coopers E-60	E.M. A.M.	90	5,000	3,500	1,200	150	9,850
E. J. & E.	Deck	200.0	E.M.	80	......	.....	......	.....	6,500
Erie	Deck	.....	E.M.	80	5,000	3,500	......	.....	8,500
G. T. Ry. Stm.	Through	.....	A.M. E.M.	80	2,100	3,900	......	.....	6,000
G. N.	Through	258.0	A.M., E.M., & G M.	90	......	.....	......	.....	9,700
	Through	180.0		80	......	.....	......	.....	7,900
I. C.	Deck	200.0	E.M. & A.M.	85	5,350	3,500	......	.....	8,850
	Deck	200.0		75	3,750	3,000	......	.....	6,950
I. Ry.	Through	200.0	Hand	75	3,200	4,500	......	.....	7,700
I. & G. N.	Half through	200.0	A.T.	75	1,150	3,850	500	.....	5,500

TABLE VII.—*Continued*

Railroad	Type	Loading (wt. of eng. tons)	Power for turning	Length, ft.	Cost: Excav. and foundation	Cost: Table with center	Cost: Tractor	Cost: Misc.	Cost: Total
K. C. S.	Deck	240.0	A.T.	90	......	.....	......	.....	9,500
L. S. & M. S.	Deck	210.0	E.T.	85	......	3,200	......	.....	6,500 to 8,000
L. V.	Deck	Coopers E-60	E.T.	80	4,460	3,880	......	360	8,700
L. I.	Deck	Coopers E-50	G.M. / A.M.	80	......	2,780	......	.....	4,980
M. C.	Deck	Coopers E-50	E.M.	80	......	.....	......	.....	8,300
M. & St. P.	Deck	152.0	Hand	70	......	.....	......	.....	6,570
	Through	152.0	Hand	70	......	.....	......	.....	6,500
M. P.	Deck	200.0	Hand	75	......	.....	......	.....	[1]6,000
		200.0	Hand	75	......	.....	......	.....	[2]4,500
M. & O.	Deck	Coopers E-55	G.M.	75	2,250	2,250	1,250	.....	5,750
N. C. & St. L.	Deck	Special E-60	E.T.	90	3,825	3,500	1,500	.....	8,825
N. Y. C. & H. R.	Deck	246.0	E.T.	85	3,000 to 8,000	2,800	......	.....	6,000 to 11,000
	Through	246.0	E.T.	85		3,600	......	.....	
N. Y., N. H. & H.	Through	190.0	E.T.	75	......	.....	1,000	.....	9,300
	Deck	190.0	E.T.	75	......	.....	1,000	.....	6,800
N. & W.	Through	9,000 lbs. per lin. ft.	E.T.	100	5,000 to 10,000	5,000	......	.....	10,000 15,000
O. S. L.	Deck	192.5	E.T.	66 to 100	......	.....	......	.....	6,000 to 25,000
	Pony Riv. Warren	Mallet	E.T.		......	.....	......	.....	
O.-W. R. & N. Co.	Deck	192.5	E.T. / A.T.	80	......	.....	......	.....	8,000
P. & R.	Deck & through	E-55	E.T. / G.M.	75	......	4,500	......	.....	....
P. & L. E.	Deck	....	E.T.	90	......	4,821	......	.....	....
St. L. & S. F.	Deck	E-55	A.M.	75	3,500	3,000	......	.....	6,500
S. A. L.	Deck	E-50	G.M.	85	5,846	2,000	1,100	.....	8,946

NOTE 1.—Cost with concrete wall and brick paving.
2.—Cost with timber wall and cinder paving.
E.T. = Electric tractor.
A.T. = Air tractor.
G.M. = Gasoline motor.

The Cost of Railroad Signal Protection.—James B. Latimer, Signal Engineer, C. B. & Q. R. R. gives the following data in Engineering and Contracting, June 14, 1911.

Mechanical Interlocking.—The generally accepted unit for rough estimating is the working lever, and very substantial plants can be constructed for, roughly speaking, $400 per lever. This includes the tower and "power" (electric) distant signals, but does not include electric route locking, which adds considerably to the expense.

The accompanying tables (Tables VIII and IX) give the actual cost in detail of 2 interlocking plants installed within the last year, one a plant to protect a grade crossing of 2 single track lines, almost at right angles to each other, with power distant signals on both lines and quite elaborate electric route locking. This machine contained 14 working levers and two spare spaces, and as there was apparently no immediate likelihood of enlargement the tower was made simply large enough for a 16 lever machine. Details of the cost of this plant are given in Table VIII.

The other was a plant to protect a junction of a single and double track line, with a number of switches, one of which was 1,600 ft. from the tower. The machine had 47 working levers and 5 spare spaces—a 52 lever frame. This plant had two power distant signals and two mechanical time locks, but no electric locking. Details of cost are given in Table IX.

In both cases the tower buildings were contracted for and were built by the same contractor. He furnished all material and built the towers complete, including the foundations and service building. The towers are heated by hot water heaters which were installed by the railroad company's forces.

The reader will note that his attention was called to the fact that in the first case the railroad lines were nearly at right angles. This sort of a track layout usually adds to the cost of a plant, and in close estimating should be allowed for. The reason being that pipe lines to the signals and derails each side of the crossing on each line must be run on a separate set of foundations, which require more labor to set; besides which the concrete blocks which carry the pipe carriers cost about 30 cts. each. They are set every 7 ft. and as they will carry 6 lines of pipe as easily as they will 1, there is always a slight economic waste when they are not worked to their limit.

TABLE VIII.—DETAIL COST OF 16-LEVER INTERLOCKING PLANT WITH 14 WORKING LEVERS

1 16-lever frame interlocking tower with concrete foundation and storm sash complete. Cost by contract		$ 925.00
1 hot water heater and necessary piping for same		101.69
Labor section men unloading material—putting in ties and derails		34.20
Labor linemen stringing wires for distant signals		22.80
Labor signalmen installing interlocking and heater		1,608.22
1 interlocking machine with 14 levers and 2 spaces at $22.50 per working lever and $9.00 per space		333.00
10 vertical 90° deflecting bars	$ 6.40	64.00
10 horizontal 90° deflecting bars	4.40	44.00
24 11¾" cranks R. S. A. standard	1.60	38.40
14 compensators R. S. A. standard	4.75	66.50
25 one way pipe carriers	.25	6.25
260 three way pipe carriers	.73	189.80
8 eight way pipe carriers	1.81	12.67
10 one way transverse pipe carriers	.95	9.50
4 two way transverse pipe carriers	1.12	4.48
6 three way transverse pipe carriers	1.35	8.10

TABLE VIII.—*Continued*

104 solid jaws, R. S. A. standard	.61	63.44
10 screw jaws, R. S. A. standard	.81	8.10
1 pipe lug, R. S. A. standard	.86	.86
10 point adjusting screws (turn buckles)	1.22	12.20
2 complete layouts for Wharton derail with facing point lock	41.25	82.50
2 complete layouts for Wharton derail with switch and lock movement	48.25	96.50
2 one blade pipe connected home signals	65.00	130.00
2 two blade pipe connected home signals	86.00	172.00
4 electric distant signals	187.50	750.00
2 electric time locks	30.00	60.00
2 hand releases	25.00	50.00
2 4 ohm indicating relays	11.50	46.00
4 500 ohm relays	19.00	76.00
4 circuit breakers for machine	9.00	36.00
4 floor pushes	1.95	7.80
1 large relay case for tower		14.00
4 commutators for home signal poles with operating rods	10.50	42.00
4 electric locks for machine	22.50	90.00
8 6½″ red roundels	.68	5.44
4 8⅜″ red roundels	1.05	4.20
4 8⅜″ yellow roundels	.70	2.80
4 8⅜″ green roundels	.70	2.80
4 6½″ green roundels	.40	1.60
8 3″ purple roundels	.13	1.04
50 lbs. ¼″ × 1 9/16″ pipe rivets (cwt.)	3.21	1.61
7,000 ft. 1″ signal pipe R. S. A. standard	.055	385.00
10 R. S. A. standard semaphore lamps	3.60	36.00
90 cast piers for cranks, compensators and deflecting bar foundations	.70	63.00
180 bolts for same ¾″ × 2½″	.04	7.20
325 8″ × 12″ × 24″ concrete blocks for pipe line foundations	.30	97.50
650 hook bolts for same	.08	52.00
300 6 way metal bases for pipe carriers	.45	135.00
35 1 way metal bases for pipe carriers	.18	6.30
2,600 ½″ × 1¼″ carriage bolts (C)	.56	14.56
75 bbls. Portland cement	2.15	161.25
87 yards concrete gravel	.30	26.10
32 hook bolts 1″ × 36″ for signal pole foundations	.12	3.84
2 right hand Wharton derails	35.00	70.00
2 left hand Wharton derails	35.00	70.00
8 pcs. oak 10″ × 10″ × 12′ } 2 pcs. oak 10″ × 10″ × 14′ } 1,035′ M	30.00	31.05
20 gals. pipe line paint (mixed) gal	1.15	23.00
¼ gal. red signal paint (mixed)	2.40	.60
¼ gal. green signal paint (mixed)	2.40	.60
⅛ gal. yellow signal paint (mixed)	2.40	.30
2 gals. lard oil	.44	.88
12 gals. black oil	.08	.96
3 lbs. graphite	.10	.30
3 quires fine emery cloth	.20	.60
2 tons blacksmith coal	4.50	9.00
33,000 ft. copper telegraph wire—1,315 lbs	.15	197.25
50 8 ft. 6 wire cross arms	.50	25.00
50 pairs cross arm braces (C)	5.70	2.85
150 cross arm pins (C)	3.50	5.25
150 glass insulators (C)	3.45	5.17
50 through bolts (C)	2.58	1.29
4 small concrete battery wells	12.00	48.00
1,200 ft. trunking 1¾″ groove with capping	.04	48.00
200 creosoted stakes 3″ × 4″ × 3′	.15	30.00
50 creosoted stakes 3″ × 4″ × 4′	.17	8.50
75 creosoted stakes 3″ × 4″ × 8′	.35	26.25
4,500 ft. No. 12 rubber covered wire (M)	21.50	96.75
1,000 ft. No. 8 rubber covered wire (M)	35.50	35.50
50 ft. No. 12 flexible rubber covered wire (M)	22.00	1.10

TABLE VIII.—*Continued*

1 gal. insulating paint	1.55	1.55
24 lightning arrestors	1.25	30.00
12 insulated track joints	5.25	63.00
1 battery cupboard for lower story of tower		7.00
600 bond wires	.015	9.00
1,200 channel pins (M)	6.50	7.80
80 cells caustic soda battery	1.91	152.80
6 cells gravity battery	.85	5.10
2 battery chutes	10.50	21.00
10 lbs. solder	.20	2.00
5 lbs. friction tape	.80	4.00
5 lbs. covering tape	.50	2.50
2 lbs. soldering paste	.50	1.00
100 porcelain cleats for inside wiring (C)	1.44	1.44
1 operator's table		9.00
1 centre lamp for tower		3.50
2 wall lamps for tower (doz.)	9.50	1.59
1 clock for tower		12.50
1 frame for manipulation chart		1.35
1 rubber mat, 3 ft. by 9 ft. 35 cts. per foot		3.15
Total		$7,290.73

TABLE IX.—DETAIL COST OF INTERLOCKING PLANT OF 47 LEVERS AND 5 SPACES WITH NO ELECTRIC ROUTE LOCKING

Tower and service building		$1,828.00
Material for heater		118.97
Labor, sectionmen unloading material and putting in derails and switch timbers		53.60
Labor, linemen stringing wire		37.40
Labor, signalmen putting in heater and installing inter locking		4,002.13
1 interlocking machine with 47 levers and five spaces, at $24.50 per lever and $9.50 per space		1,199.00
42 vertical 90° deflecting bars	$ 6.40	$ 268.00
42 horizontal 90° deflecting bars	4.40	184.00
22 67½° deflecting bars	6.25	137.50
14 22½° deflecting bars	6.25	87.50
90 R. S. A. 11¾″ cranks	1.60	144.00
50 R. S. A. compensators	4.75	237.50
40 1 way pipe carriers	.25	10.00
3,640 pipe carrier sides	.11	400.40
3,200 top rollers	.03	96.00
3,200 bottom rollers	.05	160.00
3,200 straps	.02	64.00
3,700 3⁄16″ × 1⁄12″ spring cotters (C)	.45	16.65
30 1 way transverse pipe carriers	.95	28.50
40 2 way transverse pipe carriers	1.12	44.80
15 3 way transverse pipe carriers	1.35	20.25
15 4 way transverse pipe carriers	1.65	24.75
550 solid jaws	.61	335.50
40 screw jaws	.81	32.40
8 pipe lugs	.86	6.88
42 point adjusting screws	1.22	51.24
20 switch layouts for facing point locks	41.25	825.00
3 1 arm power signals	187.50	562.50
2 2 arm power signals	265.00	530.00
3 1 arm pipe connected home signals	65.00	195.00
2 2 arm pipe connected home signals	86.00	172.00
9 1 arm dwarf signals	11.00	99.00
7 500 ohm relays	19.00	133.00
4 commutators for signal pole, with connection	10.50	42.00
5 small battery wells	12.00	60.00
20 2½″ red roundels	.68	13.60
10 6½″ green roundels	.40	4.00
4 6½″ yellow roundels	.40	1.60
23 R. S. A. semaphore lamps	3.60	76.80
22,000 ft. R. S. A. signal pipe	.055	1,210.00
380 cast piers for cranks and compensators	.70	266.00

TABLE. IX—*Continued*

760 ¾″ × 2½″ bolts for same	.04	30.40
650 8″ × 12″ × 24″ concrete foundations	.30	195.00
1,300 ⅝″ hook bolts for same	.08	104.00
60 one way metal pipe carrier bases	.18	10.80
50 two way metal pipe carrier bases	.24	12.00
20 three way metal pipe carrier bases	.27	5.40
20 four way metal pipe carrier bases	.35	7.00
400 six way metal pipe carrier bases	.45	180.00
110 eight way metal pipe carrier bases	.55	60.50
7,300 ½″ × 1½″ carriage bolts (C)	.56	40.88
500 ft. B. M. 1″ common pine for frames (M)	28.00	14.00
150 bbls. cement	2.15	322.50
180 yards gravel	.30	54.00
160 ¾″ × 5″ lag screws (C)	.85	1.36
36 1″ × 36″ hook bolts	.35	12.60
350 ¾″ × 36″ hook bolts	.23	80.50
20 ¾″ × 6″ machine bolts	.06	1.20
25 ¾′ × 10″ machine bolts	.07	1.75
100 ¾″ × 12″ machine bolts	.09	9.00
3 Wharton derails	35.00	105.00
2 Hayes derails	12.50	25.00
12 pcs. oak 10″ × 10″ × 10′ / 13 pcs. oak 10″ × 10″ × 12′ } 2,300 ft. M.	30.00	69.00
20 steel track ties	2.50	50.00
34 rail braces	.27	9.18
40 lbs. pipe rivets, ¼″ × 9/16″ (cwt.)	3.21	1.28
40 gals. pipe line paint	1.15	46.00
25 lbs. ground white lead	.07	1.75
10 gals. boiled linseed oil	.40	4.00
10 gals. black paint (mixed)	1.50	15.00
¼ gal. red paint (mixed)	2.40	.60
¼ gal. green paint (mixed)	2.40	.60
¼ gal. yellow paint (mixed)	2.40	.60
⅛ gal. blue paint (mixed)		.25
10 gals. black oil	.08	.80
2 gals. lard oil	.44	.88
2 lbs. graphite	.10	.20
2 tons blacksmith coal	4.50	9.00
3 quires emery cloth	.20	.60
48,000 ft. copper telegraph wire, 1,920 lbs	.15	288.00
50 10 ft. 8 wire crossarms	.70	35.00
50 pairs crossarm braces (C)	5.70	2.85
50 through bolts (C)	2.58	1.29
325 glass insulators (C)	3.45	11.21
325 crossarm pins (C)	3.50	11.38
98 cells caustic soda battery	1.91	187.18
1 battery cupboard for tower		7.00
1,000 ft. trunking 1¾″ groove	.04	40.00
100 creosoted stakes 3 ft. long	.15	15.00
3,600 ft. No. 12 rubber covered wire (M)	21.50	77.40
4 lbs. friction tape (C)	.80	.03
5 lbs. covering tape (C)	.50	.03
1 lb. soldering compound	.50	.50
6 lbs. solder	.20	1.20
25 lbs. 8d nails (C)	2.30	.58
30 lbs. 20d nails (C)	2.20	.60
15 lightning arrestors	1.25	18.75
24 porcelain cleats		.45
1 operator's table		9.00
1 rubber mat, 3 ft. by 22 ft		7.70
1 tower lamp		3.50
1 clock		12.50
2 tower indicators	15.00	30.00
4 electric locks for back locks of distant signals	21.00	84.00
2 mechanical time locks with attachments	60.00	120.00
7 circuit breakers for machine	9.00	63.00
Total		$16,290.25

The Railroad Signal Association has adopted a table of so-called "operated units" which is designed to be used as a unit by which to divide the cost of construction and maintenance of joint interlocking plants. These units are shown in Table X.

TABLE X.—"OPERATED UNITS" OF THE RAILWAY SIGNAL ASSOCIATION

Name of operated unit	Value units
Each mechanical signal arm working in two or three positions	1
Each power signal arm working in two or three position on mechanical plants, normal indication locking included	2
Each pair of switch points	1
Each single slip switch (2 pairs of switch points)	2
Each double slip switch (4 pairs of switch points)	4
Each set of movable point frogs (2 pairs of frog points)	2
Each derail	1
Each 55 ft. of detector bar with or without locks	1
Each torpedo placer	1
Each drawbridge coupler	1
Each drawbridge rail surface and alignment lock for one pair of rails	1
Each drawbridge leveling and operating apparatus lock	1
Each track circuit	1

This table works out very evenly as to cost, both of installation and maintenance, and might with advantage be used in place of the levers for estimating. For instance, in the first plant described above there were 24 operated units and in the second 68, which averages $272 per operated unit, which will be found a very fair figure for rough estimates.

The lever basis does well enough where no power signals or electric locking is introduced, but when, as is now pretty generally the case, either or both of these factors come in, the unit basis will be found to give more satisfactory results.

It should be noted also that the labor for both of the interlocking plants described, approximates $65 per unit. These figures are actual and show that the work can be done for that money. Many signal engineers estimate and spend much more than these amounts. All the writer can say is that when the labor exceeds $70 per unit, the person who is to pay the bill had better analyze the figures and discover, if possible, the causes for the excess.

The foregoing are, of course, "Railroad Company's" figures and do not include any charges for transportation of men, tools and materials, or any overhead charges.

Power Interlocking.—The cost of power interlocking (i. e., that in which the signals, switches, etc., are operated by electricity or compressed air), varies much more than does that of mechanical interlocking, and as none of the signal companies publishes a complete price list of the apparatus of this nature manufactured or furnished by it, really reliable estimating figures are hard to obtain. Six hundred dollars a function is a fairly safe figure, including tower and power plant; but as this sort of interlocking is rarely used except in large terminal work, so that the question does not come up often, the signal company whose apparatus is to be used had best be consulted if a very close estimate is desired.

Manual Signals.—The cost of a manual block, train order or station signal is about $100.00 per station. The items are as follows:

One 2-bladed station signal complete with lamp, table levers and connections	$ 74.00
Concrete for foundation	6.00
Labor	20.00
Total	$100.00

If such a signal has to be placed across the track or any distance away from the station, allowance must be made for such fact.

Automatic Block Signals.—The cost of automatic block signals varies with the number of signals used, the type of signal and the number of switches to be insulated.

Straight track circuit (i.e., for unbroken track) may be considered as a constant and costs $256.00 per mile. This cost is shown in detail in Table XI.

TABLE XI.—DETAIL COST OF 1-MILE TRACK CIRCUIT.

700 bond wires	$ .01½	$ 10.50
1,500 channel pins (M)	6.50	9.75
2 battery chutes	10.50	21.00
6 cells gravity battery	.85	5.10
105 ft. trunking	.05	5.25
28 stakes	.16	4.48
150 ft. No. 8 rubber covered wire (M)	30.00	4.50
16 ft. No. 6 bare copper wire		.48
2 relay boxes and posts		28.00
2 relays		37.00
½ yard concrete (for foundations of relay boxes)		3.50
4 insulated joints (each)	5.25	21.00
Paint, tape, solder and nails		2.80
Labor bonding, 350 joints (each)	.06	21.00
Labor putting in insulated joints		4.50
Labor setting batter chutes, trunking and wiring for same		32.50
Labor setting relay boxes and relays and wiring same to track		45.00
Total		$256.36

Each switch in the circuit must be insulated and equipped with a switch indicator. The itemized cost of 1 switch indicator is shown in Table XII and that of 1 signal in Table XIII.

TABLE XII.—DETAIL COST OF 1 SWITCH INDICATOR

4 insulating joints	$ 21.00
2 insulated switch rods	11.00
1 switch box	15.00
1 switch indicator	16.50
155 ft. trunking	7.75
20 stakes	3.20
¼ yard concrete	1.75
Nails, tape, solder and paint	6.00
300 ft. No. 12 rubber covered wire	7.20
100 ft. No. 8 rubber covered wire	3.00
15 ft. No. 6 bare copper wire	.18
4 lightning arrestors	5.00
Channel pins and galvanized bond wires	.80
Total	$ 98.38
Less value of non-insulated switch rods taken off	3.00
Total	$ 95.38
Labor	58.00
Total	$153.38

Table XIII.—Detail Cost of 1 Signal

1 1-blade signal (2 position signal)	$187.50
1 semaphore lamp	3.60
2 red roundels	1.80
1 green roundel	.70
1 relay (500 ohms)	19.00
1 yard concrete for foundation	7.00
4 1″ × 36″ hook bolts	1.40
75 ft. trunking	3.75
15 stakes	2.40
500 ft. No. 12 rubber covered wire	12.00
1 battery well	40.00
5 lightning arrestors	6.25
18 cells caustic soda battery	35.00
Nails, paint, tape, solder	8.00
Total	$328.40
Labor	80.00
Total	$408.40

The usual practice in automatic signal work is to make the sections just about half a mile long. This means in each mile of circuited track there will be 4 insulated joints, 2 sets of track battery and 2 relays. Besides which the rails must be bonded together.

A one-blade, three-position signal costs $245 and requires an additional relay so that in estimating they should be valued at $485 each.

A two-blade signal costs $260 and also requires two relays, and in addition thereto an extra lamp and three extra roundels so that in estimating they should be valued at $505 each.

An average of five line wires all the way is about right, though if a very close estimate is required it would be necessary to have a circuit plan drawn up, as almost every signal engineer or signal company uses a different circuit, and the location of switches has some bearing.

Bare copper wire in place at present prices is worth about $40 per mile per wire, or an average of $200 per mile for line wire.

Insulated copper line wire in place is worth about $70 per mile.

Galvanized iron or copper clad wire, either bare or insulated, is worth less than the above figures.

To summarize, therefore, automatic block signals may be figured as follows:

Track circuit per mile	$256
Each switch in circuit extra	153
Each one-blade two-position signal	408
Each two-blade two-position signal	505
Each three-position signal	485
Line wire, per mile	200

Cost of Changing 17 miles of Railroad Track from Narrow Gage to Standard Gage.—The following data are taken from an article by Henry R. Somes, published in Engineering and Contracting, May 16, 1917.

The railroad on which the work was done was built during the 1880's as a narrow gage road. It runs from Wilmington, Vt., to Hoosac Tunnel Station at the east end of the Hoosac Tunnel on the Fitchburg Division of the Boston & Maine R. R. The length is about 25 miles, and as it runs along a narrow valley bordering the Deerfield River it is a line of sharp curvature and short, steep grades.

The old rails being much worn, enough second-hand rails, 56 lb. to the yard, were purchased of the Ulster & Delaware R. R. to relay the line. About 8½ miles of the line from the Wilmington end were relaid to standard gage outside the narrow gage iron. On the rest of the line the old iron was replaced by these rails, they being laid narrow gage as the ties and roadbed were not in condition to carry standard gage equipment.

In 1913, after some negotiations, a contract was let for changing the 17 miles northerly from Hoosac Tunnel Station. This portion of the line followed the winding of the Deerfield River and lay in a narrow valley with high hills on each side. There were many long, sharp curves, the map of the road showing about 120 curves of 6° or over in the 17 miles. The track was laid with 4-bolt angle bar splices except about 1½ miles where Fisher joints had been used. The first 5 miles had been re-tied where needed.

The work was carried out during July, 1913; the contractor lost money on the job, which loss was due to several factors, some of which were: Labor was scarce and hard to get, and very inefficient. Experienced men could not be obtained and the job was so short that green men could not be properly broken in. The method employed (which was specified by the railroad company) did not allow time to familiarize the men with their work, or allow the work to be started with a small force and gradually increased. There was no labor to be had in the territory tributary to the line and the contractor was obliged to pick up green men in the cities and use them. The weather was excessively hot, and the road lying in a narrow winding valley, the wind could not cool the air; this reduced the output of the men to a marked degree. When men were hired it was with the understanding that experienced spikers were to be paid 25 cts. per hour, and other laborers 20 cts. per hour, but during the first afternoon about two-thirds of the men (inexperienced) struck for 25 cts. per hour. Four passenger trains and two freights per day were being operated over the line at the time the work was done.

The method employed was to divide the men into two gangs and work each gang on a separate line of rails, pull the spikes on one line of rails, throw them out 10¼ in., and respike, while another gang followed at a reasonable working distance, pulling spikes on the opposite line of rails, throw it to standard gage and respike. Of course on the long, sharp curves the outside line of rails would soon stretch so that it would be necessary to break open a joint and start spreading again at the break; the inside of the curve would crowd so that it would have to be broken open and another start made there. As there were many of these breaks, three or four to each long curve, a separate gang was organized to connect up the track at these points.

The short ends of the rails on the inside of the curves were sawed off with the hack saws, and additional holes drilled in the ends of the rails for the angle bars. On the outside of the curves where the rails were too short, a rail was unbolted, cut in two with cold chisels and a longer piece cut from an extra rail and inserted in the line, making a better job than by putting in a short piece. The spiking gangs followed immediately behind the gangs that were spreading rails, leaving gaps where joints were broken open; the gang repairing breaks spiked the track at these points.

	Per mile	Total
Pulling spikes—		
2,001 hours @ $0.25	......	$500.25
Per mile 117.7 hours	$27.42	....
Foremen, 2* (1 @ $10 per day) (1 @ $3 per day)	......	71.50
Foremen, per mile	4.21	....
Average gang, 14.73 men	$33.63	$571.75

* Includes extra payments to 4 men that acted as working foremen. These payments are added to this foreman's pay for simplicity in figuring.

The claw bars had heels and worked satisfactorily. The spikes pulled much easier from the new ties than from the old. In the latter they were rusted in and in many cases where the ties were checked and splintered, the splinters raised up even with or above the spike heads and make it difficult to get the claw bars under the spike heads.

Throwing rails—	Per mile	Total
762 hours @ $0.25	......	$190.50
Per mile, 44.82 hours	$11.20	....
Foremen, 2 (1 @ $10 per day) (1 @ $3 per day)	......	17.00
Foremen, per mile	1.00	....
Average gang, 6 men	$12.20	$207.50

Ordinary lining bars were used for throwing the rails. Owing to the splintered condition of the old ties, causing the rails to catch, it took longer on that part of the track than on the section that had been re-tied. Broken stubs of spikes also caused delay. A special gage bar was made for getting the gage of the first line of rails thrown. This was made of wood shod with iron as shown in the sketch.

Spiking—	Per mile	Total
6,438 hours @ $0.25	......	$1,609.50
Per mile, 378.7 hours	$94.68	....
Foremen, 2 (1 @ $10 per day) (1 @ $3 per day)	......	146.50
Foremen, per mile	8.62	....
Average gang, 48 men	$103.00	$1,756.00

When the old section of the track was reached much trouble was experienced with spiking. The hard shell on the ties made it difficult to enter the spike, and if the tie was at all splintered spikes would rebound so that at times it was necessary to have one man hold a spike while another started it. On this section the spikes were old, and many bent in pulling. These had to be straightened before using, as the railroad was very economical with spikes. Ties averaged 21 per rail.

Adzing ties—	Per mile	Total
249 hours @ $0.25	......	$62.25
Per mile adzed (9 miles)	$6.92	.....
Foremen included in spikers.		
Average gang, 3 men.		

It was necessary to adz only an occasional tie, and this was done by a small gang that worked ahead of the spike pullers.

Cutting Curves, Drilling, Bolting, and Setting Over Frogs and Switches

Cutting curves—	Per mile	Total
978 hours @ $0.25	......	$244.50
Per mile, 57.53 hours @ $0.25	$14.38	......
Foreman @ $4 per day	......	60.00
Foreman, per mile	3.53	....
Average gang, 7 men	$17.91	$304.50

The short ends of the rails were cut with hack saws, the long rails with cold chisels. Gang would cut and connect up from 6 to 13 breaks per single line of rails with the saw, and the same amount with the chisel, each day. The number of breaks taken care of per day depended on the amount of curvature encountered. Days when few cuts were made the gang spent a large part of their time moving from curve to curve or helping the rear spiking gang. This gang had a push car to carry their tools and usually carried one extra rail. This gang made the cuts, drilled one hole on each side of the cut, put on angle bars and spiked the rails at the breaks. The balance of the work was done by another gang that finished drilling the required number of holes, put in the bolts, and completed any other necessary work. Each break on a curve necessitated a cut with the chisel and one with the saw. The hack saws were 14-in. blades in a high frame, and 2 men would make a cut in 20 to 30 minutes.

Each break cost, average of 10 per day—		
Labor, 7 hours @ $0.25		$ 1.75
Foreman, 1 hour @ $0.40		.40
		$ 2.15
Drilling rails at breaks and bolting—		
883 hours @ $0.25		$220.75
Per mile, 52 hours @ $0.25	$13.00	....

Gang—6 men in 2 gangs who worked without foremen. Each gang averaged drilling and bolting 25 holes per day.

Paulus track drills were used. The drills were sharpened in the railroad shop and sent out to the men by the passenger trains.

Frogs and switches were merely set over and spiked. This work was carried out by the gang cutting curves. Balance of switch work and yard work was done by the railroad forces. There were 30 switches on the line and the average cost of setting them over was:

Labor, 4 hours @ $0.25	$1.00
Foreman, ½ hour @ $0.40	.20
	$1.20

The railroad had a small gang following about 2 days behind that put rail braces on some of the curves.

Miscellaneous expenses—	Per mile	Total
Water boy	......	$ 48.85
Labor, 8 hours @ $0.15; 8 hours @ $0.20, per mile	$2.80	....
Superintendence—		
16 days @ $8.00		$128.00
Per mile	$7.53	....

TABLE XIV.—COST OF CHANGING GAGE OF 17 MILES OF TRACK

Development expenses—			
Fees of men, employment bureau			$ 18.00
Fares of men			92.52
Freight on tools and supplies			$ 21.92
Traveling, superintendent			20.00
Rent of camp			25.00
Liability insurance			120.00
Tool charges			50.00
Superintendent's time; looking over job; finding men, making preparatory arrangements, hiring camp site, etc., 8 days @ $8.00			64.00
Per mile		$ 24.21	$ 411.44
Camp outfit for taking care of 65 men—			
Blankets	$ 62.15		
Mattresses	131.50		
Cooking and eating outfit	85.61		
	$279.26		
Less salvage	40.00		239.26
Per mile		14.08	
Development and camp expense		$ 38.28	$ 650.70
Total costs			$3,946.30
Total costs, per mile		$235.58	
Total costs less development expense		$197.29	$3,295.60

The railroad furnished a work train made up of an old passenger coach and two flat cars. This train carried the gangs to and from the camp and carried a few rails, ties, several kegs of spikes, and tool boxes. This train remained at the head of the work all day, just ahead of the spike pullers.

The working time for the 17 miles was 14.3 days, making a speed of 1.19 miles per day, and as the ties averaged 21 to the rail against 17 on some other roads, it would have meant a speed of about 1.5 miles on the latter. There was considerable delay due to transferring passengers, express and mail from the narrow gage to standard gage trains and vice versa. About one-half hour before the train was due at the working point it was necessary to stop pulling spikes and set these men at other work. When the trains arrived nearly all the gangs would help transfer mail, baggage and express. This operation could not be hurried, as neither train could move until the passengers had left the one and boarded the other. Passengers did not take kindly to the operation and showed no desire for speed. Of course after the gang stopped pulling spikes, the other gangs would gain on them and the entire force would be bunched together and working inefficiently until the spike pullers had gained a proper lead again. This delay amounted to about one-half hour for the entire gang for each train, and as there were four of these transfers per day, the delay from this cause amounted to two hours per day, so the gang was only working effectively about 80 per cent of the time.

Life and Cost of Timber Snowsheds of the Southern Pacific R. R.—Engineering News-Record, Jan. 3, 1918, gives the following.

As built on the Southern Pacific, the sheds are constructed of "Shasta pine" cut near the site, which costs the company only about $10 to $15 per 1000 ft. B. M. to cut and deliver on the work. This wood has an average life in these sheds of about 20 or 22 years, which might be divided into three periods, as follows: During the first 10 years virtually no repairs are required. The next 5 or 10 years require increasing repairs, particularly the renewal of footings and sections where dampness has access to the wood. In the third period, from the fifteenth year on, according to conditions, the items requiring replacement include braces, caps, joists and in fact all parts up to the point where it is considered cheaper to renew the shed entirely. In 1918 there was renewed a section of shed which had been in service 27 years—probably the longest life on record for this division.

As renewed under 1918 prices the cost varies, according to the design of the section, from $12 to $14 per lin. ft., this figure being a rough average of single and double-track construction. The average maintenance per foot per annum is figured at about $1.60. This includes renewal made necessary by fire, slides and decay, and also the cost of fire patrols and interest on the first cost.

Tests of snow taken from shed roofs, frequently show a weight of 40 lb. per cu. ft. Based on a safe margin for the 15-ft. snow load likely in this region, all sheds have been designed for a uniformly distributed load of 300 lb. per sq. ft. This loading is approximately the same as would result if the sheds carried a train of consolidation locomotives.

Cost of Locomotive Repairs, Renewals and Depreciation.—Table XV published in Engineering and Contracting, April 17, 1912, is extended from one given in "Railway and Engineering Review" and is of interest as it gives the comparative costs of repairs, renewals and depreciation for locomotives. The figures, except the totals, are calculated by slide rule and are accurate to within a tenth of 1 cent per mile run.

TABLE XV.—SHOWING COST PER MILE RUN OF LOCOMOTIVE REPAIRS, RENEWALS AND DEPRECIATION ON 30 RAILROADS FOR 1911

Name of road	Total miles run	Repairs per mile, cents	Renewals per mile, cents	Depreciation per mile, cents	Total, cents
A., T. & S. F.	47,060,848	13.44	.01	1.50	14.95
Atl. Coast Line	20,980,390	6.44	.01	.60	7.11
Balt. & Ohio	64,708,403	9.03	.07	.96	10.06
B'st'n & Maine	31,870,282	6.78	.07	.99	7.84
Cen. R. R. of N. J.	12,643,323	8.64	.02	1.67	10.33
Chesa. & Ohio	19,223,950	9.39	.04	.70	10.13
Chi. & Alton	9,327,555	11.32	.00	.34	11.66
C. & N. W.	52,418,503	7.08	.02	.57	7.67
C., B. & Q.	48,079,561	7.10	.43	2.68	10.21
C., M. & St. P.	45,961,742	7.14	.00	.43	7.57
C., R. I. & P.	41,972,762	9.47	....	.08	9.55
D., L. & W.	20,019,521	7.66	.01	1.77	9.44
Erie	29,833,271	10.07	.04	.83	10.94
Gt. North	28,098,160	9.40	.00	2.61	12.01
Ill. Central	39,808,246	10.61	.01	.79	11.31
Iowa Central	3,150,061	5.78	.03	.50	9.31
Lehigh Valley	22,249,785	8.78	.02	1.15	9.95
M. & St. L.	3,264,219	8.89	.32	.42	9.63
N. Y. C. & H. R.	70,540,204	7.47	1.13	....	8.60
N. Y., N. H. & H.	30,485,152	7.91	.02	.17	8.10
Norfolk & West	23,323,395	8.26	.01	1.52	7.79
North. Pacific	30,180,346	7.51	.01	2.65	10.17
Pennsylvania	94,207,231	11.09	....	.97	12.06
Phil. & Read	25,462,073	10.48	.75	....	11.23
St. L. & S. F.	26,425,651	9.50	.04	.10	9.64
So. Pacific	40,112,861	11.43	.54	....	11.97
Southern	42,141,667	8.53	.05	.86	9.44
T., St. L. & W.	2,830,808	8.93	....	.32	9.25
Union Pacific	22,564,917	12.17	.01	....	12.18
Wabash	21,770,774	9.52	....	.64	10.16

Life of Railway Rolling Stock.—In the valuation work of the Nebraska State Railway Commission an extensive investigation was made and a large number of data were collected from the records of service of equipment of a number of the large western systems. The following matter is taken from an article by E. C. Hurd published in Engineering and Contracting, Aug. 21, 1912.

The study embraced the following up of each locomotive through its life in type, and also of each car of a kind and series. The final disposition of the article was found. The salvage value was also carefully inquired into at the time of vacation. From this tabulations were made setting out straight lines of depreciation, in combination with the non-depreciating factors of salvage, from which were derived a value per cent of expectancy. These graphic illustrations also developed other interesting features even beyond that of valuation, having reference to the durability of the several classes of equipment and the points at which the life begins to break and vacations from age occur. Further there was demonstrated that liability to accidental destruction in the first few years was practically the same in all classes of cars. In more detail setting out the determination of plans for depreciation for locomotives, passenger cars and freight cars, which plans were made up in an identical manner, that having reference to freight cars will be further mentioned. The average value at the time of vacation expressed in a per cent of reproduction cost was found to be 22.4 per cent and which became the non-depreciating factor for freight cars. From a resume of the study of all classes of freight cars and considering all factors of elimination, 19.92 years, or practically 20 years, was established as the average life. From this information the following formula was obtained as covering all classes of freight cars:

$$\frac{100\% - 22.4\%}{20 \text{ years}} = 3.88 \text{ per cent as the value depreciating per cent per annum.}$$

After having utilized such formula, the result would still be affected in limited measure by recognizing a minimum value if still found in service beyond its expectancy. This minimum value for freight equipment was determined from considerable evidence in hand at 25 per cent of the value new. The present change in material utilized into the construction of cars—namely: that from wood to steel—may show a modification in more or less degree of the results hereabove set out, but the length of life for this class of equipment for study, not over ten years, does not admit of any accurate figures except the factor of

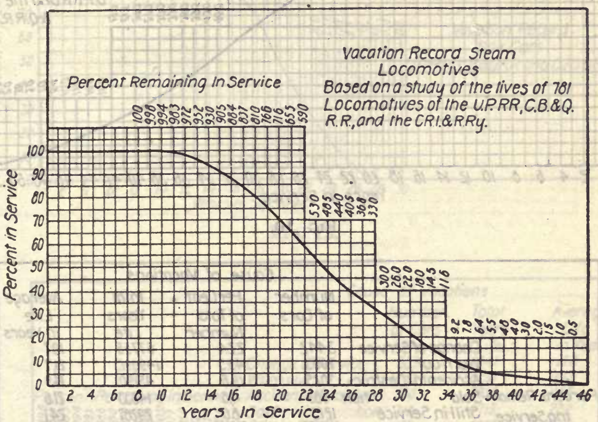


FIG. 9.

accidental destruction seems to remain the same as of the earlier equipment. A very good opinion seems to obtain in that the increase in the strength of design and materials has improved closely in accordance with the demands for increased capacity and service ability, and therefore the history of destruction will be in close accordance to that of the older.

The data described briefly relative to locomotives are shown graphically in Fig. 9, that for passenger cars in Fig. 10, that composite for freight cars. Fig. 11, that for box cars Fig. 12, that for stock cars Fig. 13, that for coal flats Fig. 14, and that for refrigerator cars Fig. 15 herewith. (Vacation record of Ry. rolling stock, Figs. 9 to 15.)

Cost of Locomotives and Freight Cars in 1918.—Engineering and Contracting, June 19, 1918, gives the following note:

The Railroad Administration has ordered 1,025 locomotives to cost \$60,000,000 and 100,000 freight cars of 50 tons each to cost \$300,000,000. This is equivalent to \$60,000 per locomotive and \$3,000 per 50-ton car. Half the cars are gondola coal and half box. The prices of the locomotives range from \$90,000 for the heavy Mallets to \$35,000 for switching engines.

The builders, both of cars and locomotives, will receive a profit of 5 per cent on the estimated minimum cost. The Government guarantees the estimated

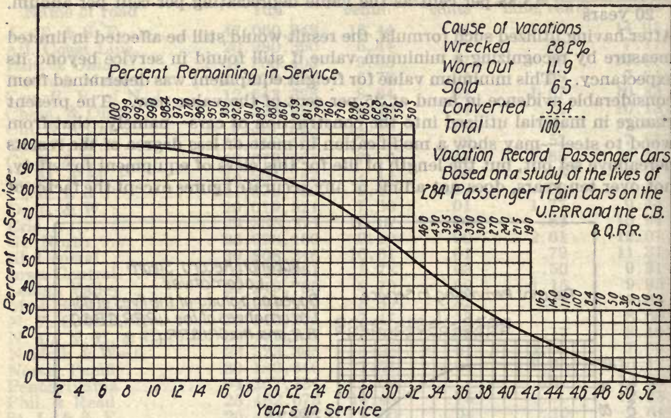


FIG. 10.

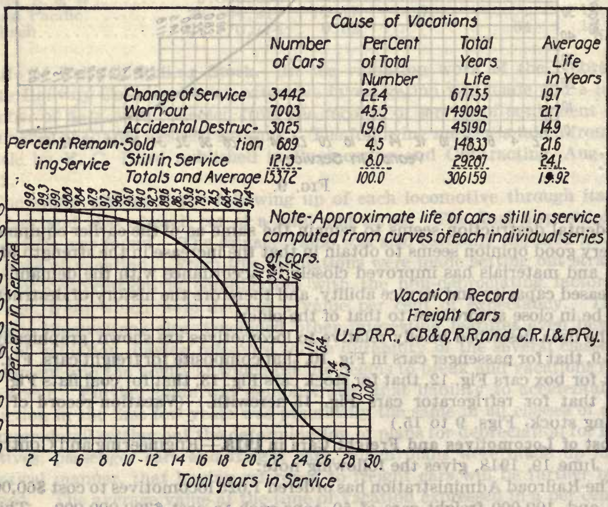


FIG. 11.

cost of the materials, but, if the actual cost is less than the estimate, the Government shares the saving equally with the builders.

The locomotives average 338,000 lb. each; hence the price is almost 18 ct. per pound, or double the price in 1905. The heaviest weighs 540,000 lb.

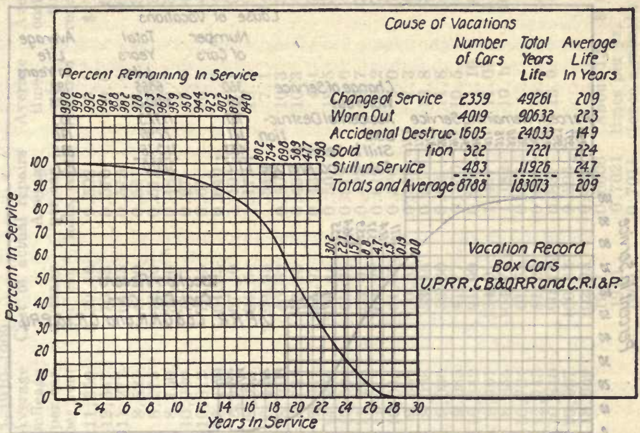


FIG. 12.

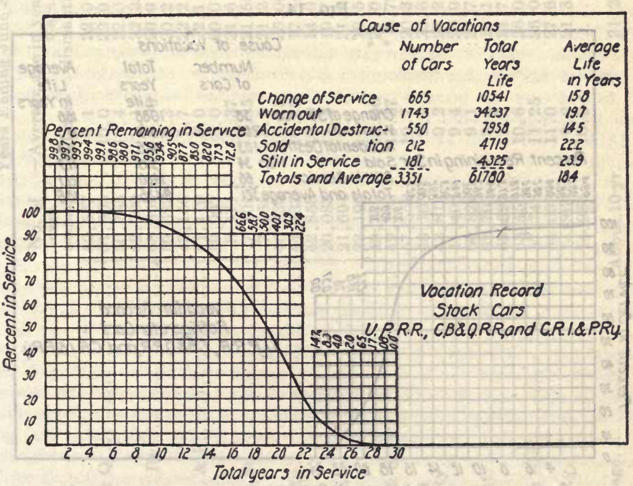


FIG. 13.

Life and Cost of Maintenance of Freight Cars.—Table XVI, reprinted in Engineering News, March 7, 1912, is from the Feb. 10 issue of the *Railway* *and Engineering Review*, which credits it to a Mechanical Engineer of one of the railway companies mentioned.

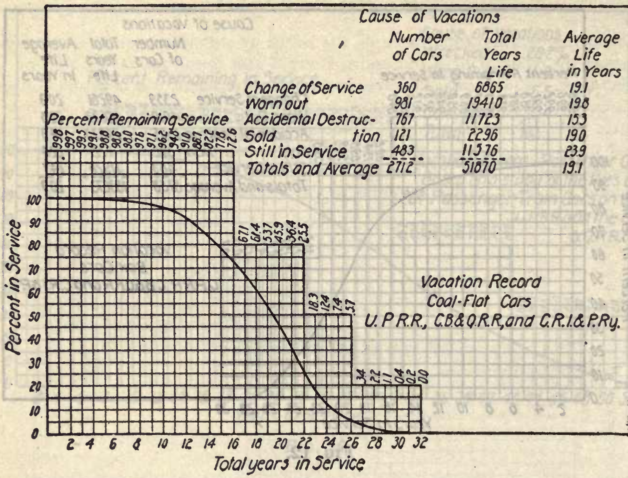


FIG. 14.

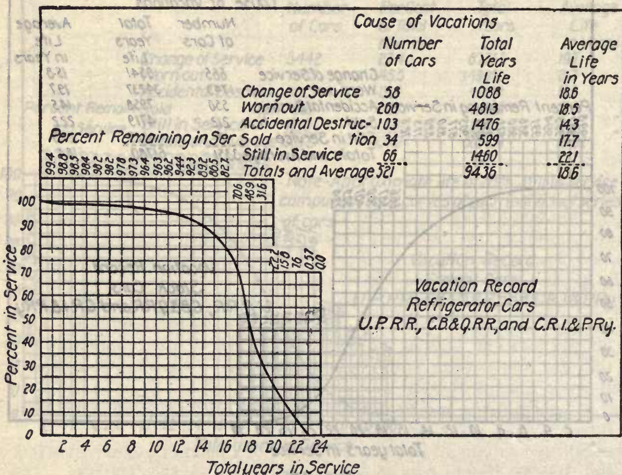


FIG. 15.

The average age of all freight cars in service, according to these figures, is a little less than 10 years; omitting destruction by wrecks the average life is

TABLE XVI.—FREIGHT CARS, AGE, MILEAGE AND REPAIRS

Years Ending June 30, 1911–1910–1909

Road	No. of cars owned	—Average age in years— All cars	Cars dismantled	Average mileage per car per year	Cost of actual repairs Average per car	Average per car mile, cents	Average times car repaired	Average cost per time repaired
C. B. & Q.	52,577	9.1	22.0	11,650	$ 59.16	0.508	10.1	$ 5.86
	51,603	10.0	22.0	12,347	70.33	0.570	10.6	6.64
	50,185	10.4	22.0	11,272	64.85	0.575	10.4	6.21
C. & N. Ry.	62,000	9.11	22.25	8,527	47.90	0.561	13.4	3.62
	68,869	9.00	20.9	8,275	42.30	0.511	12.8	3.29
	59,623	9.3	20.2	8,150	39.56	0.485	10.7	3.72
C. R. I. & P.	43,166	7.7	22.2	10,930	74.77	0.67	17.8	4.20
	41,119	8.0	22.1	10,812	75.65	0.67	16.1	4.53
	39,097	8.0	20.0	10,125	64.85	0.640	14.7	4.41
Colo. & So.	8,471	8.37	21.6	5,982	67.10	1.10	7.1	9.45
	7,101	7.85	21.55	8,019	94.54	1.179	10.2	9.27
	7,155	8.5	21.2	6,455	99.93	1.548	7.1	14.16
G. N. Ry.	46,630	10.75	25.04	8,012	40.62	0.507	10.3	3.96
	44,833	10.13	17.44	8,731	43.16	0.49	10.3	4.21
	42,858	10.0	14.0	7,867	35.97	0.432	4.4	7.65
Wabash	20,083	11.5	19.7	14,266	71.44	0.50	18.5	3.86
	21,694	......	21.7	12,604	65.21	0.517	15.6	4.17
	23,190	......	19.5	11,218	53.01	0.473	13.7	3.88
C. M. & St. P.	48,539	*12.96	*21.0	11,012	68.22	0.619	9.2	7.4
	49,179	*13.57	* 0.79	10,645	61.33	0.576	9.0	7.76
	57,550	10.7	20.3	9,559	50.62	0.529	7.3	6.94
N. P. Ry.	43,100	9.9	23.6	8,028	53.46	0.66	13.8	3.86
	43,813	9.2	23.2	9,036	56.60	0.62	11.8	4.78
	41,498	9.4	20.9	9,083	41.77	0.460	10.5	5.85
Ill. Cent.	60,824	9.1	21.7	10,142	91.99	0.907	11.16	8.07
	62,705	8.4	15.1	9,461	134.01	1.417	11.01	11.65
	63,622	7.6	14.7	8,855	104.71	1.182	10.1	10.46
A. T. & S. F.	63,455	10.6	26.0	10,724	61.53	0.574	....	....
	57,746	11.25	26.0	12,143	81.24	0.669	16.1	5.03
	54,698	11.0	27.6	10,840	90.72	0.837	13.9	6.50
U. P. Ry.	14,863	9.2	21.3	19,987	100.83	0.505	....	......
	14,954	10.0	....	18,659	102.98	0.552	.....	......
Average		About 10 yr.	21.24 yr.		1911,	0.6606	About 12	$ 6.26
					1910,	0.7021	times per yr.	each
					1909,	0.7011	(once a month)	time

* Includes Puget Sound Extension, C. M. & P. S. Ry.

lengthened to 21.24 years. During its life each car is repaired on an average of once a month, at an average cost of $6.26 each time, and therefore, each car requires a total expenditure for repairs of about $1600, or twice the first cost of the car.

The Life of Steel Freight Cars.—Steel freight cars have been long enough in use to make it possible to estimate their average natural life and Engineering and Contracting, April 26, 1916 quotes M. K. Barnum, who states in a recent issue of the Railway Age Gazette, that the oldest steel freight car of which he has knowledge was built in 1896. Two years ago it received a new floor, beside other extensive repairs, and appearances indicate that it may be good for at least 10 years more. However, this car seems to be an exception, and Mr. Barnum puts the average life of steel gondola and hopper cars at about 16 years.

The short life of steel cars is largely due to corrosion of the steel plates. Cars in service near salt water corrode more rapidly than elsewhere. Idle cars corrode much more rapidly than those in use, two months of idleness being equivalent to about two years of use. Frequent painting—every three to five years—prolongs the life 25 to 50 per cent, but relatively few steel cars have been painted.

Natural and Functional Life of Freight Cars.—The following note is given in Engineering and Contracting, May 15, 1918.

Freight cars have heretofore shown an average life of nearly 28 years, about 3.6 per cent of the total number being "vacated" annually (See Gillette's "Handbook of Cost Data"). However, as is well known, though often overlooked in estimates, most of the cars are not retired because they are worn out or too expensive to maintain; but because it is more profitable to substitute cars of greater capacity. The war has brought about conditions that enable us roughly to segregate natural depreciation (wear and tear) from functional depreciation (inadequacy and obsolescence) of cars; for the demand for freight cars has become so great that none are being retired because of functional depreciation.

During 1917 about 119,000 new freight cars were manufactured. The net gain in cars at the end of 1917 was about 72,000 over 1916, indicating a retirement of some 47,000 cars because of wear and tear, or about 2 per cent of the total number in use. This would indicate a natural life of 50 years, as compared with a composite natural and functional life of 28 years. While this estimate is not conclusive, it is very significant, and it has more than academic interest at this time.

Cost of Water Softening for Railroads.—The following data are taken from an abstract, published in Engineering and Contracting, April 8, 1914, of a paper presented before the Illinois Water Supply Association by R. C. Bardwell, chemist of the Missouri Pacific Ry.

On the Missouri Pacific there are at present 45 complete water softening plants in operation, the majority being on the hard waters west of the Missouri River. The average amount of water treated per year, reducing the hardness so that it will form practically no scale, is 1,692,000,000 gals. The total average amount of scale removed from this water is 5,537,000 lbs., which would make over 110 carloads at 50,000 lbs. each; a considerable amount when it is remembered that but for treatment this scale would have to go through the engine boilers and most of it would have to be removed by hand. The total annual cost for the above treatment, interest and depreciation on plants is about $65,000. Conservative figures show, however, that with this expenditure there is a net saving of about $105,000 from cutting down the following losses alone:

1. Frequent renewal of flues and other parts of boiler account of scale accumulation and injury to flue ends from repeated caulking. 2. Labor caulking flues and other engine house boiler repairs. 3. Loss of engine time during boiler and firebox repairs. 4. Loss of fuel due to insulating effect of the scale on the flues and other heating surfaces.

Besides the foregoing there are the indeterminate benefits in the road performance of locomotives by reducing failures and interruptions to traffic with the reduction of the number of locomotives required for a given traffic.

At one terminal approximately 18,000,000 gals. of water are treated monthly, eliminating 5 lbs. of scale per 1,000 gals. or a total of about 80,000 lbs. per month. The cost of chemicals for this is about 4 cts. per 1,000 gals. or a total monthly bill of about $720. The length of life of flues using straight raw water before the installation of the softening plant was from eight to twelve months with serious trouble on account of frequent leaks. The locomotives now using the straight treated water average 18 months between shopping, and the trouble with leaky flues is practically eliminated.

At another terminal shop about 30,000,000 gals. of water are treated monthly, removing 3 lbs. of scale per 1,000 gals. for a total of 90,000 lbs. Prior to the installation of the softener, five boilermaker days and four boilermaker nights were required caulking flues. After the treating plant was put in operation this was reduced to one-man days and one-man nights. The saving in this one item alone is reported to be $5,712 per year on an $8,000 investment. The life of flues was increased from 8 to 15 months.

In most cases where softening plants are installed, the foaming conditions are increased, especially for the first few days after the treatment is started due to the fact that the old scale in boilers is loosened and, falling off, increases the amount of suspended matter making a dirty boiler which seems to be the most important of the contributory causes of foaming.

To soften a water to three grains per gallon, or less, of incrusting salts, which is the object in most cases, demands a purity in this respect of 3 parts in 58,341 or 99.995 per cent. This merely shows the deceptiveness of reporting water softening on the percentage basis, for although sounding complex it is a comparatively simple matter. However, each individual water has its peculiarities such as the temperature at different seasons and the difference in content of magnesium salts which slow up the reaction and without due allowance for same leave a milky water for a final product. Creek waters of course change with the precipitation and I have also found that in some parts of the country well waters become softer in winter while others get harder.

So far the development of water softening on a large scale has centered around lime and soda ash as being the chemicals which produce the results for the least cost. However, barium hydrate is the ideal reagent on account of its leaving no detrimental by-products as in the case of soda ash. So far the expense has retarded its development. Numerous boiler compounds through the high degree of exploitation obtained have been tried by a few railroads but investigation would show that even where the work desired was done the cost greatly exceeds that of the recognized methods. Inert powdered graphite is now being largely exploited as a cure-all for scale troubles, but its economical merits are yet to be proven. The "sunlight on corrugated aluminum" patent, which was supposed to render the scale inert in the water without removing it chemically has been tried at several points in this section

and seems to have proven unworthy. The Permutitt water softener, the artificial zeolite, will never be a universal success in railroad work on account of the replacing of incrusting carbonates with sodium carbonate, that is, waters which are sufficiently hard to warrant the expense of treatment, as a rule contain sufficient incrusting carbonates, which if replaced by sodium carbonate could not be used on account of foaming properties. Therefore it would seem that common lime and soda ash will continue to remain in service.

CHAPTER XIX

SMALL TUNNELS

Notes on management and organization for constructing small tunnels as well as cost and progress data for both earth and rock tunneling are given in this chapter. Further notes of interest and applicable, in a degree, to small tunnels are given in Chapter XX.

Additional data on the methods and costs of driving small tunnels in rock are given in Gillette's Handbook of Rock Excavation.

Costs of 20 Tunnels.—A compilation of tunnel costs, from data personally collected and given in Bureau of Mines Bulletin 57 by D. W. Brunton and J. A. Davis, are published in Engineering and Contracting, June 24, 1914.

There are set forth in the following pages as complete and accurate data as could be obtained, showing the cost of various phases of tunnel work at a number of different tunnels. Although the writers have not had the advantage of auditing the books from which these figures were taken and hence can not vouch personally for the absolute accuracy of the figures, the data were in all cases procured from persons in charge or who were in a position to know what the work actually cost. Accompanying the figures is a brief list of the more important features of the tunnel, without which it is impossible to make even an approximate comparison between any two pieces of tunnel work.

GUNNISON TUNNEL

Important Details.—Location: Montrose, Colo. Purpose: Irrigation and reclamation. Shape of cross section: Horseshoe. Size: 10 ft. wide at the bottom, 10 ft. 6 ins. wide at the spring line, 10 ft. high at the spring line, 12 ft. 4 ins. high at the center of the arch. Length: 30,645 ft. Character of rock penetrated: Chiefly metamorphosed granite with some water-bearing clay and gravel, some hard black shale, and a zone of faulted and broken rock. Type of power: Steam. Ventilator: Pressure blower. Size of ventilating pipe: 17 ins. Drills: At first, pneumatic hammer, 4 drills in the heading; afterwards, pneumatic, piston, 4 drills in the heading. Mounting of drills: Horizontal bar for the hammer drills, vertical columns for the piston drills. Number of holes per round: 20 to 24 in the heading (approximately one-half of the tunnel). Average depth of round: 6 to 7 ft. Number of drillers and helpers per shift: 4 drillers and 2 helpers. Number of drill shifts per day: 3. Explosive: 60 per cent gelatin dynamite, with some 40 per cent. Number of muckers per shift: 5 to 8. Number of mucking shifts per day: 3. Type of haulage: Electric. Wages: Drillers, \$3.50 and \$4; helpers, \$3 and \$3.50; muckers, \$2.50 and \$3; blacksmiths, \$3.50 and \$4; motormen, \$3; brakemen, \$2.50 and \$3; power engineers, \$4. Maximum progress in any calendar month: 449 ft. Average monthly progress: 250 ft., approximately

Cost of Driving

	Cost per foot of tunnel
10,019 feet driven by undercut heading and subsequent enlargement	$87.23
20,626 feet driven by top heading and bench	62.18
Average cost of excavation of entire tunnel	70.66

These costs include all labor, all materials, all repairs, all power, depreciation figured as 100 per cent on all equipment, with a proportionate charge for general (supervisory) and miscellaneous expenses of the entire reclamation project.

Laramie-Poudre Tunnel

Important Details.—Location: Home, Colo. Purpose: Irrigation. Cross section: Rectangular. Size: 9½ ft. wide by 7½ ft. high. Length: 11,306 ft. Character of rock penetrated: Closegrained red and gray granite. Type of power: Hydraulic at the east end, electric at the west. Ventilator: Pressure blower. Size of ventilating pipe: 14 and 15 ins. Drills: 3 pneumatic hammer. Mounting of drills: Horizontal bar. Number of holes per round: 21 to 23. Average depth of round: 10 ft. at first, 7 to 8 ft. later. Number of drillers and helpers per shift: 3 drillers, 2 helpers. Number of drill shifts per day: 3. Explosive: 60 per cent gelatin dynamite, with some 100 per cent in the cut holes. Number of muckers per shift: 6. Number of mucking shifts per day: 3. Type of haulage: Mules. Wages: Drillers, $4.50; helpers, $4; muckers, $3.50; blacksmiths, $5; drivers, $4.50; dumpmen, $3.50. Maximum progress in any calendar month: 653 ft., March, 1911. Average monthly progress: 509 ft. (for the 16 months when complete plant operated). Special feature: Inacces sibility; the tunnel was located about 60 miles from the nearest railroad siding, and the roads were mountainous and very steep in places.

Cost of Driving Tunnel 11,306 Ft

	Cost per foot of tunnel
Superintendents and foremen	$1.50
Drilling	4.47
Mucking and loading	4.92
Tramming and dumping	4.63
Track and pipe	.47
Power house	.35
Blacksmithing	.84
Repairs	.47
Bonus to workmen	1.75
Maintenance of camps, buildings, and fuel	.62
Machinery repairs	.12
Air drills and parts	1.33
Picks, shovels and steel	.84
Explosives	4.50
Lamps and candles	.42
Oil and waste	.38
Blacksmith supplies	.53
Liability insurance	.81
Office supplies, telephone and bookkeeping	.86
	$29.81
Permanent equipment (less approximately 10 per cent salvage)	9.73
	$39.54

The permanent equipment included power plant, camp buildings and furnishings, pipes, rails, etc.

LOS ANGELES AQUEDUCT

Little Lake Division, Tunnels 1 to 10A

Important Details.—Location: Inyo County, Cal. Purpose: Water supply, power, and irrigation. Cross section: See Fig. 1. Size: See Fig. 1. Type of power: Electric power purchased at a nominal cost per kilowatt-hour from a hydraulic plant constructed and owned by the aqueduct. Ventilators: Pressure blowers. Size of ventilating pipe: 12 ins. Drills: Pneumatic hammer, usually 2 in each heading. Mounting of drills: Horizontal bar. Number of holes per round: Usually 14 to 16. Average depth of round: 6 to 10 ft. Number of drillers and helpers per shift: 2 drillers and 2 helpers. Number of drill shifts per day: Usually 1, but sometimes 2. Explosive: 40 per cent gelatin dynamite, with some 20 per cent and some 60 per cent; ammonia dynamite also tried. Number of muckers per shift: Usually 5. Number of mucking shifts per day: Usually 1, but 2 when 2 drill shifts were employed. Type of haulage: Tunnels 1 to 3-N, mules; tunnels 3-S, to 10A-N, electric; tunnel 10A-S, mules. Wages: Drillers and helpers, $3; muckers, $2.50; blacksmiths, $4; helpers, $2.50; motormen, $2.75; dumpmen, $2.50.

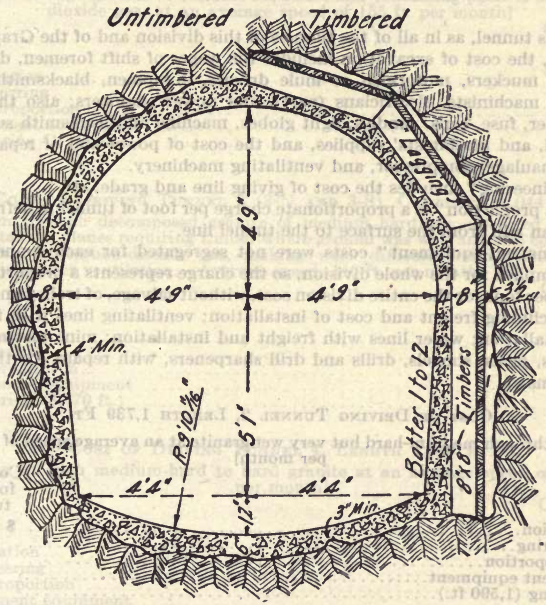


FIG. 1.—Typical cross-section of tunnel, Los Angeles Aqueduct.

Cost of Driving Tunnel 1B-S for 1,341 Ft.

[Driven through medium-hard granite at an average speed of 225 ft. per month*]

	Cost per foot of tunnel
Excavation	$ 9.15
Engineering	.18
Adit proportion	.28
Permanent equipment (estimated)	2.35
Timbering (857 ft.)	1.02
	$12.98

* The average speed given is computed on the basis of one heading per month.

In this tunnel, as in all of the tunnels of this division and of the Grapevine division, the cost of excavation includes the wages of shift foremen, drillers, helpers, muckers, motormen or mule drivers, dumpmen, blacksmiths and helpers, machinists, electricians (part), and power engineers; also the cost of powder, fuse, caps, candles, light globes, machine oil, blacksmith supplies and fuel, and machinists' supplies, and the cost of power and of repairs for power, haulage, compressor, and ventilating machinery.

"Engineering" includes the cost of giving line and grade, etc.

"Adit proportion" is a proportionate charge per foot of tunnel to defray the cost of an adit from the surface to the tunnel line.

"Permanent-equipment" costs were not segregated for each tunnel, but were compiled for the whole division, so the charge represents a proportionate charge per foot for the entire division cost, without salvage, of trolley and light lines, including freight and cost of installation; ventilating lines with freight and installation; water lines with freight and installation; mine locomotives and cars, picks, shovels, drills and drill sharpeners, with repairs for the last four items.

Cost of Driving Tunnel 2, Length 1,739 Ft.

[Driven through medium-hard but very wet granite at an average speed of 170 ft. per month]

	Cost per foot of tunnel
Excavation	$ 8.81
Engineering	.19
Adit proportion	.34
Permanent equipment	2.35
Timbering (1,590 ft.)	3.28
	$14.97

Cost of Driving Tunnel 2A, Length 1,322 Ft.

[Driven through medium-hard granite at an average speed of 150 ft. per month]

	Cost per foot of tunnel
Excavation	$8.05
Engineering	.16
Adit proportion	.34
Permanent equipment	2.35
Timbering (1,322 ft.)	2.51
	$13.41

Cost of Driving Tunnel 3-N for 1,148 Ft.

[Driven through medium-hard granite at an average speed of 150 ft. per month]

	Cost per foot of tunnel
Excavation	$10.10
Engineering	.23
Adit proportion	.51
Permanent equipment	2.35
Timbering (956 ft.)	2.44
	$15.63

Cost of Driving Tunnel 3-S for 1,358 Ft.

[Driven through granite of variable hardness, and containing pockets of carbon-dioxide gas, at an average speed of 155 ft. per month]

	Cost per foot of tunnel
Excavation	$12.38
Engineering	.28
Adit proportion	.16
Permanent equipment	2.35
Timbering (1,244 ft.)	3.28
	$18.45

Cost of Driving Tunnel 3 (3-N and 3-S), Complete, 4,044 Ft.

[Driven through decomposed granite of medium hardness, dissected by slips and talcose planes requiring timber where ground was wet, and also containing pockets of carbon-dioxide gas, making work difficult and requiring extra provisions for ventilation. Average speed, 140 ft. per month]

	Cost per foot of tunnel
Excavation	$12.67
Engineering	.24
Adit proportion	.35
Permanent equipment	2.35
Timbering (3,570 ft.)	2.71
	$18.32

Cost of Driving Tunnel 4, Length 2,033 Ft.

[Driven through medium-hard to hard granite at an average speed of 145 ft. per month]

	Cost per foot of tunnel
Excavation	$12.00
Engineering	.24
Adit proportion	.16
Permanent equipment	2.35
Timbering (1,705 ft.)	2.16
	$17.01

Cost of Driving Tunnel 5, Length 1,178 Ft.

[Driven through medium-hard to very hard granite at an average speed of 120 ft. per month]

	Cost per foot of tunnel
Excavation	$11.10
Engineering	.21
Adit proportion	.08
Permanent equipment	2.35
Timbering (916 ft.)	1.83
	$15.57

Cost of Driving Tunnel 7, Length 3,596 Ft.

[Driven through biotite granite of variable hardness at an average speed of 140 ft. per month]

	Cost per foot of tunnel
Excavation	$13.55
Engineering	.27
Adit proportion	.13
Permanent equipment	2.35
Timbering (2,609 ft.)	3.60
	$19.90

Cost of Driving Tunnel 8-S for 1,334 Ft.

Driven through medium-hard to hard granite at an average speed of 135 ft. per month]

	Cost per foot of tunnel
Excavation	$12.82
Engineering	.19
Adit proportion	.18
Permanent equipment	2.35
Timbering (126 ft.)	.39
	$15.93

Cost of Driving Tunnel 9 for 3,506 Ft.

[Driven through medium-hard to hard granite at an average speed of 195 ft. per month]

	Cost per foot of tunnel
Excavation	$12.19
Engineering	.18
Adit proportion	.07
Permanent equipment	2.35
Timbering (305 ft.)	.29
	$15.08

Cost of Driving Tunnel 10 for 5,657 Ft.

[Driven through medium-hard to hard granite at an average speed of 200 ft. per month]

	Cost per foot of tunnel
Excavation	$13.50
Engineering	.19
Permanent equipment	2.35
Timbering (194 ft.)	.11
	$16.15

Cost of Driving Tunnel 10A–N for 1,496 Ft.

[Driven through medium-hard to hard granite at an average speed of 165 ft. per month]

	Cost per foot of tunnel
Excavation	$13.02
Engineering	.13
Permanent equipment	2.35
Timbering (24 ft.)	.78
	$16.28

COST OF DRIVING TUNNEL 10A-S FOR 2,200 FT.

[Driven through medium-hard to hard granite at average speed of 200 ft. per month]

	Cost per foot of tunnel
Excavation	$12.37
Engineering	.20
Permanent equipment	2.35
Timbering (215 ft.)	1.15
	$16.07

GRAPE VINE DIVISION, TUNNELS 12 TO 17B

Important Details.—Location: Kern County, Cal. Purpose: Water supply, power, and irrigation. Cross section: See Fig. 1. Size: See Fig. 1. Type of power: Electric power purchased from aqueduct plant. Ventilators: Pressure blowers. Size of ventilation pipe: 12 ins. Drills: Pneumatic hammer, usually 2 in. each heading. Mounting of drills: Horizontal bar. Number of holes per round: Usually 18 to 20. Average depth of round: 6 to 8 ft. Number of drillers and helpers per shift: 2 drillers and 2 helpers. Number of drill shifts per day: Usually 2. Explosive: 40 per cent ammonia dynamite, but 60 per cent and 75 per cent gelatin dynamite were employed in hard ground. Number of muckers per shift: 4 or 5. Number of mucking shifts per day: Usually 2. Type of haulage: Electric after the first 400 to 500 ft. Wages: Drillers and helpers, $3; muckers, $2.50; blacksmiths, $4; helpers, $2.50; motormen, $2.75; dumpmen, $2.50.

COST OF DRIVING TUNNEL 12, LENGTH 4,900 FT.

[Driven through hard granite at an average speed of 185 ft. per month]

	Cost per foot of tunnel
Excavation*	$22.10
Engineering*	.32
Permanent equipment*	2.35
Timbering (90 ft.)	.08
	$24.75

* These items include the same costs as for the Little Lake division.

COST OF DRIVING TUNNEL 13 FOR 1,525 FT.

[Driven through hard granite at an average speed of 130 ft. per month]

	Cost per foot of tunnel
Excavation	$20.60
Engineering	.10
Permanent equipment	2.25
Adit proportion	.37
	$23.32

COST OF DRIVING TUNNEL 14, LENGTH 859 FT.

	Cost per foot of tunnel
Excavation	$22.70
Engineering	.13
Permanent equipment	2.25
Adit proportion	.72
Timbering (22 ft.)	.16
	$25.96

Cost of Driving Tunnel 15, Length 895 Ft.

	Cost per foot of tunnel
Excavation	$23.28
Engineering	.11
Permanent equipment	2.25
Adit proportion	2.42
	$28.06

Cost of Driving Tunnel 16, Length 2,723 Ft.

[Driven through hard granite at an average speed of 145 feet per month]

	Cost per foot of tunnel
Excavation	$20.07
Engineering	.17
Permanent equipment	2.25
Adit proportion	.55
Timbering (18 ft.)	.04
	$23.08

Cost of Driving Tunnel 17, Length 3,024 Ft.

	Cost per foot of tunnel
Excavation	$20.47
Engineering	.21
Permanent equipment	2.25
Timbering (142 ft.)	.22
	$23.15

Cost of Driving Tunnel 17½ for 1,345 Ft.

[Driven through medium-hard to hard granite at an average speed of 225 feet per month]

	Cost per foot of tunnel
Excavation	$19.56
Engineering	.31
Permanent equipment	2.25
	$22.12

Cost of Driving Tunnel 17A for 3,275 Ft.

	Cost per foot of tunnel
Excavation	$18.70
Engineering	.17
Permanent equipment	2.25
Timbering (441 ft.)	1.18
	$22.30

Cost of Driving Tunnel 17B for 4,915 Ft.

	Cost per foot of tunnel
Excavation	$2.109
Engineering	.21
Permanent equipment	2.25
Timbering (163 ft.)	1.90
	$25.45

ELIZABETH DIVISION, ELIZABETH LAKE TUNNEL

Important Details.—Location: Los Angeles County, Cal. Purpose: Water supply, power and irrigation. Cross section: Rectangular, with arched roof. Size: 12 by 12 ft. Length: 26,870 ft. Type of power: Electric power purchased from aqueduct plant. Ventilator: Pressure blower. Size of ventilating pipe: 18 ins. Drills: Pneumatic hammer, 3 in the south heading and 2 in the north. Mounting of drills: Horizontal bar. Number of holes per round: 25 in the south heading, 16 in the north heading. Average depth of round: 8 to 10 ft. Number of drillers and helpers per shift: 2 drillers and 2 helpers at the north end, 3 drillers and 3 helpers at the south end. Number of drill shifts per day: 3. Explosive: 40 per cent and 60 per cent gelatin dynamite. Number of muckers per shift: 6. Number of mucking shifts per day: 3. Type of haulage: Electric. Wages: Drillers and helpers, $3; muckers, $2.50; blacksmiths, $4; helpers, $2.50; motormen, $2.75; dumpmen, $2.50. Maximum progress in any calendar month: 604 ft., April, 1910. Average monthly progress per heading: 350 ft. per month.

COST OF DRIVING THE NORTH HEADING, ELIZABETH LAKE TUNNEL

[Driven through altered granite, requiring much timbering, 13,370 ft.]

	Cost per foot of tunnel
Drilling and blasting	$11.25
Mucking and tramming	11.70
Engineering and superintendence	1.27
Drainage	.45
Ventilation	.22
Light and power	5.55
Timbering (13,031 ft.)	8.48
Cost of auxiliary shaft	.93
Permanent equipment (full charge, no salvage; estimated)	3.70
	$43.55

COST OF DRIVING THE SOUTH HEADING, ELIZABETH LAKE TUNNEL

[Driven through medium-hard to hard granite, requiring but little timbering, 13,500 ft.]

	Cost per foot of tunnel
Drilling and blasting	$14.65
Mucking and tramming	11.10
Engineering and superintendence	.86
Drainage	.17
Ventilation	.41
Light and power	4.93
Permanent equipment (without salvage; estimated)	3.70
Timbering (3,424 ft.)	2.19
	$38.01

LUCANIA TUNNEL

Important Details.—Location: Idaho Springs, Colo. Purpose: Mine development and transportation. Cross section: Square. Size: 8 by 8 ft. Length: 12,000 ft. projected; 6,385 ft. driven December 1, 1911. Character of rock penetrated: Hard granite. Type of power: Purchased electric

Current. Ventilator: Pressure blower. Size of ventilating pipe: 18 and 19 ins. Drills: Pneumatic hammer, 3 in the heading. Mounting of drills: Vertical columns. Number of holes per round: 25. Average depth of round: 8 to 9 ft. Number of drillers and helpers per shift: 3 drillers and 2 helpers. Number of drilling shifts per day: 1. Explosive: 50 per cent gelatin dynamite. Number of muckers per shift: 3. Number of mucking shifts per day: 1. Type of haulage: Horses. Wages: Head driller, $5; drillers, $4; nipper, $3.50; boss mucker, $5; muckers, $4; drivers, $4; power engineers, $4; blacksmith, $5. Maximum progress in any calendar month: 263 ft., September, 1911. Average monthly progress: 125 ft. per month for the first 4,800 ft., 240 ft. per month for the last 1,575 ft.

AVERAGE COST OF DRIVING FIRST 4,800 FT.

	Cost per foot of tunnel
Labor	$ 8.86
Powder	7.86
Fuse and caps	.17
Candles and oil	.21
Horse feed and shoeing	.18
Power	1.64
Repairs	.14
Tunnel equipment	2.75
Surface plant	1.25
	$23.06

"Tunnel equipment" includes the cost of materials and installation of the pressure air line, the ventilating line, rails, ties and fittings, and the drainage ditch. "Surface plant" includes buildings, compressor blower, transformers, motors and drill sharpener.

Cost of driving next 1,575 ft.: The contractor received $21.50 per foot to cover the cost of labor, powder, fuse, caps, candles, oil, horse feed and shoeing, power and repairs, and the installation of the tunnel equipment.

MARSHALL-RUSSELL TUNNEL

Important Details.—Location: Empire, Colo. Purpose: Mine drainage, development and transportation. Cross section: Rectangular. Size: 8 ft. wide by 9 ft. high. Length: 11,000 ft. projected; 6,700 ft. driven January 1, 1913. Character of rock penetrated: Granite and gneiss. Type of power: Purchased electric current; also a small auxiliary hydraulic plant. Ventilator: Fan. Size of ventilating pipe: 12 and 13 ins. Drills: 2, pneumatic hammer. Mounting of drills: Vertical columns. Number of holes per round: 18 to 20. Average depth of round: 9 to 10 ft. Number of drillers and helpers per shift: 2 drillers and 2 helpers. Number of drill shifts per day: 1. Explosive: 40 per cent gelatin dynamite; with some, 80 per cent. Number of muckers per shift: 4. Number of mucking shifts per day: 1. Type of haulage: Horses. Wages: Drillers, $4; helpers, $3; blacksmith, $4; helpers, $3; muckers, $3.25; trammers, $3.75; dumpmen, $3.25; power engineer, $3.50; shooters, $3.25. Maximum progress for any calendar month: 187 ft., June, 1909. Average monthly progress: 125 ft.

Cost of Driving Tunnel 6,700 Ft.

	Cost per foot of tunnel
Labor	$ 9.37
Powder, fuse, caps and blacksmith coal	3.35
Drills, steel and repairs (less 30 per cent salvage)	1.34
Power	1.41
Permanent equipment and general expense (less 30 per cent salvage on permanent equipment)	3.41
	$18.88

MISSION TUNNEL

Important Details.—Location: Santa Barbara, Cal. Purpose: Water supply. Cross section: Trapezoid. Size: 6 ft. wide at the base, 4½ ft. wide at the top, 7 ft. high. Length: 19,560 ft. Character of rock penetrated: Shale, slate, and hard sandstone. Ventilator: Pressure blower. Size of ventilating pipe: 10 ins. Drills: 1 pneumatic hammer. Mounting of drills: Horizontal bar. Number of holes per round: 12 to 14. Average depth of round: 7 to 8 ft. Number of drillers and helpers per shift: 1. Number of drilling shifts per day: 3. Explosive: 40 per cent and 60 per cent gelatin dynamite. Number of muckers per shift: 4. Number of mucking shifts per day: 3. Type of haulage: Electric. Wages: Drillers, $3.50; helpers, $3; muckers, $2.75; blacksmiths, $4; helpers, $3; motormen, $2.75; dumpmen, $2.50; power engineers, $2.75. Maximum progress in any calendar month: 414 ft., February, 1911. Average monthly progress: 210 ft.

Cost of Driving the South Portal, Mission Tunnel, May, 1909, to September, 1911, 5,515 Ft.

	Cost per foot of tunnel
Administration	$ 1.14
Labor	9.20
Power	2.12
Explosives	1.97
Timbering (563 ft.)	.30
Track and pipe	1.22
Miscellaneous supplies	2.46
Drill parts (including steel)	1.02
Bonus	.48
	$19.91

"Administration" includes superintendence, office supplies, and general charges. "Miscellaneous supplies" includes candles, light globes, shovels, picks, blacksmiths' supplies and fuel, and machinists' supplies.

NEWHOUSE TUNNEL

Important Details.—Location: Idaho Springs, Colo. Purpose: Drainage and transportation. Cross section: Square. Size: 8 by 8 ft. Length: 22,000 ft. Character of rock penetrated: Idaho Spring gneiss. Type of power: Purchased electric current. Ventilator Pressure blower. Size of ventilating pipe: 18 ins. Drills: Pneumatic hammer. Mounting of drills: Vertical column. Number of holes per round: 14 to 22. Number of drill shifts per day: 1 and 2. Explosive: 40 per cent gelatin dynamite, with some 100 per cent in the cut holes. Number of muckers per shift: 3. Number of mucking shifts per day: 1 and 2. Type of haulage: Electric. Wages:

Drillers, $4 to $4.50; helpers, $3.25 to $4; muckers, $3.50; motormen, $3.50; dumpmen, $3; blacksmiths, $3.50 to $4.50; helpers, $3.

COST OF DRIVING THE NEWHOUSE TUNNEL

	Jan. to Aug. 1909, 2,233 ft.	Sept. to Dec. 1909, 1,098 ft.	Apr. to Aug. 1910, 693 ft.
Labor	$ 6.72	$ 6.98	$11.73
Explosives	4.15	3.52	4.57
Fuse and caps	.39	.36	.44
Transportation of materials broken	1.49	1.47	2.22
Power	1.99	2.16	2.82
Blacksmithing	1.57	2.61	2.00
Use of drills, repairs and steel	1.50	2.74	2.86
Equipment, ties, rails, pipe, etc.	1.74	1.78	2.19
Sundries	.79	.80	1.85
	$20.34	$22.42	$30.68

RAWLEY TUNNEL

Important Details.—Location: Bonanza, Colo. Purpose: Mine drainage and development. Cross section: Trapezoidal. Size: 8 ft. wide at the base, 7 ft. wide at the top, 7 ft. high. Length: 6,235 ft. Character of rock penetrated: Tough, hard andesite. Type of power: Steam with wood for fuel. Ventilator: Pressure blower. Size of ventilating pipe: 12 and 13 ins. Drills: 2, pneumatic hammer. Mounting of drills: Horizontal bar. Number of holes per round: 23 to 25. Average depth of round: 8 to 9 ft. at first, 5 to 6 ft. later. Number of drillers and helpers per shift: 2 drillers and 2 helpers. Number of drill shifts per day: 2 at first, 3 later. Explosive: 40 per cent and 60 per cent gelatin dyanmite (in the proportion of about 2 to 1). Number of muckers per shift: 4. Number of mucking shifts per day: 2 and 3. Type of haulage: Horses and mules. Wages: Drillers, $4.50; helpers, $3.75; muckers, $3.50; blacksmiths, $4.50; drivers $3.50; power engineers, $4. Maximum progress in any calendar month: 585 ft., July, 1912. Average monthly progress: Approximately 350 ft.

COST OF DRIVING THE TUNNEL, 6,235 FT.*

	Cost per foot of tunnel
Drilling and firing	$ 5.25
Mucking	2.16
Tramming	1.13
Track and pipe	.44
Miscellaneous underground expenses	1.44
Power plant	2.50
Blacksmithing	.73
Miscellaneous surface work	.83
General expenses	1.98
Permanent plant	3.24
Timbering (1,618 ft.)	1.18
Boarding house, debit balance	.04
	$20.98
Credit by salvage on permanent plant	1.11
	$19.87

* A more detailed statement of the cost of this tunnel may be found in an article entitled "A Problem in Mining, Together with Some Data on Tunnel Driving," by F. M. Simmons and E. Z. Burns, Bull. Am. Inst. Min. Eng., March, 1913, p. 369.

"Drilling and firing" includes labor, powder, fuse, caps, supplies, and repairs. "Mucking," "Tramming," and "Track and pipe" include labor and supplies. "Miscellaneous underground expenses" include wages of foremen, underground telephone, etc. "Power plant" includes labor, supplies, and fuel. "Blacksmithing" and "Miscellaneous surface work" include labor and supplies. "General Expenses" include salaries, office supplies, telephone, etc. "Permanent plant" includes machinery and buildings, with labor of installation, steel rails, permanent supplies, and repairs. "Timbering" includes labor and supplies. The salvage of the permanent plant is approximately 50 per cent on salable articles, such as machinery, rails, cars, etc.

ROOSEVELT TUNNEL

Important Details.—Location: Cripple Creek, Colo. Purpose: Mine drainage. Cross section: Rectangular, with large ditch at the side. Size: 10 ft. wide by 6 ft. high. Length: 15,700 ft. Character of rock penetrated: Pikes Peak granite, chiefly. Type of power: Purchased electric current. Ventilator: Purchased electric current. Ventilator: Pressure blower. Size of ventilating pipe: 16 and 17 ins. Drills: 3, pneumatic hammer. Mounting of drills: Horizontal bar. Number of holes per round: 24, usually. Average depth of round: 6 to 7 ft. Number of drillers and helpers per shift: 3 drillers, 2 helpers. Number of drill shifts per day: 3. Explosive: 40 per cent, 60 per cent, and some 100 per cent gelatin dynamite. Number of muckers per shift: 4, usually. Number of mucking shifts per day: 3. Type of haulage: Horses and mules. Wages: Drillers, $5; helpers, $4; muckers, $3.50; power engineer, $4; blacksmith, $5; helper, $3.50; dumpman, $3.50; drivers, inside, $5; outside, $4. Maximum progress in any calendar month: 435 ft., portal heading, January, 1909. Average monthly progress: Portal heading, 300 ft.; shaft headings, 270 ft.; all headings, 285 ft.

Cost of Driving Tunnel

Total cost of portal work	$111,980.06
Contractor's percentage	11,404.88
Cost of shaft heading	262,126.55
Total cost of tunnel	$386,421.49
Number of feet driven	14,167
Average cost per foot	$ 27.27

Cost of Driving the Portal Heading

	Feet	Cost per foot
1908—		
February and March	514	$22.690
April	262	30.970
May	268	26.760
June	187	35.010
July	203	29.600
August	300	21.760
September	351	19.600
October	287	23.000
November	360	21.120
December	334	18.350
1909—		
January	435	16.410
February	290	22.206
March	340	21.745
April	316	21.266
May	402	18,762
June (8 days)	62	40.600

Cost of Driving Shaft Headings

	Feet	Cost per foot
1908—		
October (2 headings)	49	$105.52
November (2 headings)	141	44.38
December (2 headings)	177	40.11
1909—		
January (2 headings)	261	24.06
February (2 headings)	601	23.70
March (2 headings)	639	26.256
April (2 headings)	670	25.02
May (2 headings)	552	28.34
June (2 headings)	498	27.375
July (1 heading)	319	32.871
August (1 heading)	410	27.747
September (1 heading)	355	32.40
October (1 heading)	380	28.178
November (1 heading)	298	34.20
December (1 heading)	251	35.153
1910—		
January (1 heading)	282	28.82
February (1 heading)	259	30.636
March (1 heading)	344	27.62
April (1 heading)	376	25.313
May (1 heading)	393	24.856
June (1 heading)	373	26.616
July (1 heading)	350	25.247
August (1 heading)	372	25.029
September (1 heading)	342	28.45
October (1 heading)	372	27.361
November (1 heading)	192	27.786

Typical Distribution of Expenses, Portal Heading, July, 1908, 203 Ft

	Cost per foot of tunnel
Machinery and repairs	$ 0.61
Air drills and parts	.99
Picks, shovels and steel	1.90
Ditch men	1.09
Explosives	6.90
Candles	.36
Oil and waste	.09
Electric power	2.06
Blacksmith supplies	.09
General expense	.16
Liability insurance	.17
Lumber, ties and wedges	.01
Horses and feed	.01
Compressor men	1.79
Drillers and helpers	4.21
Blacksmiths and helpers	3.43
Muckers and drivers	4.11
Foremen	1.50
Bookkeeper	.12
	$29.60

TYPICAL DISTRIBUTION OF EXPENSES, SHAFT HEADING, FEBRUARY, 1910, 259 FT.

	Cost per foot of tunnel
Maintenance of buildings, tents, etc	$0.096
Machinery and repairs	1.158
Air drills and parts	1.930
Shovels, picks and steel	1.930
Pipe and fittings	.193
Ditch men	1.480
Explosives	5.032
Lamps and candles	.217
Oil and waste	.252
Electric power	2.440
Blacksmith supplies	.150
Liability insurance	.213
General expense	.342
Lumber, ties and wedges	.119
Horses and feed	.324
Machine men and helpers	4.050
Muckers	3.065
Blacksmiths and helpers	1.362
Engineers	1.300
Pipe and track men	.675
Drivers and dump men	2.355
Foremen	1.752
Mine telephone	.008
Bookkeeper	.193
	$30.636

STILWELL TUNNEL

Important Details.—Location: Telluride, Colo. Purpose: Mine drainage and development. Cross section: Square, with ditch at side. Size: 7 by 7 ft. Length: 2,950 ft. Character of rock penetrated: Conglomerate and andesite. Type of power: Purchased electric current. Ventilator: Fan. Size of ventilating pipe: 10 ins. Drills: Started with electric drills, finished with pneumatic piston drills, using 2 in the heading. Mounting of drills: Vertical columns. Number of holes per round: 16. Average depth of round: 6 to 6½ ft. Number of drillers and helpers per shift: 2 drillers and 2 helpers. Number of drill shifts per day: 1. Explosive: 40 per cent gelatin dynamite. Number of muckers per shift: 3. Number of mucking shifts per day: 1. Type of haulage: Horses. Wages: Drillers, $4.50; helpers, $4; muckers and trammers, $3.50; blacksmith, $4.50. Maximum progress in any calendar month: 170 ft., August, 1904. Average monthly progress: 150 ft. (last 10 months.)

COST OF DRIVING THE TUNNEL

	Feet	Cost per foot of tunnel
1901	12	$23.88
1901–2	490	22.98
1902–3	377	27.94
1903–4	702	21.69
1904–5	1,077	21.19
1905	292	30.37
Average for	2,950	$23.38

These costs include all labor, supplies, repairs, powder, fuse, caps, candles, tools, lubricants, and general expenses, and the total value on the electric-drill plant with which the tunnel was started, and the total value of the air-drill plant which succeeded it, together with tunnel buildings, pipe, rails, and the ventilator, with no credit for salvage on any of this permanent equipment. The fiscal year dated from Sept. 30. The tunnel was driven in 1901–3 with electric drills, and the high cost for 1905: 292 ft., $30.37.

STRAWBERRY TUNNEL

Important Details.—Location: Utah and Wasatch Counties, Utah. Purpose: Irrigation and reclamation. Cross section: Straight bottom and walls, with arched roof. Size: 8 ft. wide by 9½ ft. high. Length: 19,100 ft. Character of rock penetrated: Limestone with interbedded sandstone, and sandstone with interbedded shale. Type of power: Electric power generated in a hydraulic plant operated in connection with the tunnel. Distance of transmission from west portal to power house approximately 23 miles. Ventilator: Pressure blower. Size of ventilating pipe: 14 ins. Drills: Piston pneumatic, usually 2 in the heading. Mounting of drills: Vertical columns. Number of holes per round: 16 to 18. Number of drillers and helpers per shift: 2 drillers and 2 helpers. Number of drill shifts per day: 3. Explosive: 40 per cent gelatin dynamite. Number of muckers per shift: 6. Number of mucking shifts per day: 3. Type of haulage: Electric after first 2,000 ft. Wages: Drillers, $3.50; helpers, $3.25; muckers, $2.75; motormen, $3.25; brakemen, $2.75; blacksmiths, $4; helpers, $2.75. Maximum progress in any calendar month: 500 ft., November, 1910. Average monthly progress: 320 ft. per heading.

COST OF DRIVING THE TUNNEL

	Feet	Cost per foot of tunnel
West heading—		
Previous to 1909	1,613	$60.05
During 1909	3,892	33.58
During 1910	5,021	30.56
During 1911	3,491	41.52
January to July, 1912	2,382	36.79
East heading, October, 1911, to July, 1912	2,682	33.04
Average for	19,081	$36.78

DETAILED COST OF DRIVING THE WEST HEADING FOR THE YEAR 1909, 3,892 FT.

	Cost per foot of tunnel
Labor—	
Engineering	$ 0.49
Superintendence	.73
Shift bosses	1.22
Timekeepers	.36
Drillmen and helpers	3.15
Miners (for handwork, trimming, etc.)	.23
Muckers	2.96
Track and dump men	.74
Mule drivers	.39
Motormen and brakemen	.44
Electricians and blower men	.07
Disabled employes	.19
Timbermen	.22
Miscellaneous	.40
	$11.59

	Cost per foot of tunnel
Materials—	
Powder, fuse, caps, etc	3.08
Lumber	.29
Oils, candles, etc	.22
Ventilating pipe	.64
Track, including ties	.68
Pressure air pipe	.40
Drill repair parts (including hose)	.18
Miscellaneous	.19
	$ 5.68
Repairs—	
Machine shop expense (including labor and supplies)	.93
Blacksmith shop expense (including labor and supplies)	1.22
	$ 2.15
Power (all purposes)	7.65
Depreciation—	
Haulage equipment	.09
General equipment	1.00
	$ 1.09
General expense	3.96
Camp expense	1.21
Corral expense	.25
	$ 5.42
Total	$33.58

"General expense" includes a proportionate charge for the expenses of the Provo office, such as salaries, stationery, telephone, and supplies; also a proportionate charge for the expenses of the Washington, the Chicago, and the supervising engineer's offices. The Provo office covers approximately 68 per cent of this charge, the Washington office 23 per cent, the Chicago office 2 per cent, and the supervising engineer's office 7 per cent.

DETAILED COST OF DRIVING THE WEST HEADING FOR THE YEAR 1910, 5,021 FT.

	Cost per foot of tunnel
Labor—	
Engineering	0.61
Superintendence	.60
Shift bosses	1.25
Timekeepers	.22
Drillmen and helpers	2.85
Miners	.28
Muckers	2.93
Track and dump men	.71
Motormen and brakemen	1.49
Electricians and blower men	.13
Disabled employes	.16
Timbermen	.28
Miscellaneous	.07
	$11.58

	Cost per foot of tunnel
Materials—	
Powder, fuse, caps, etc	3.52
Lumber	.22
Oils, candles, etc	.20
Ventilating pipe	.65
Track, including ties	.74
Pressure air pipe	.28
Drill repair parts (including hose)	.24
Miscellaneous	.07
	$ 5.92
Repairs—	
Machine shop expense (including labor and supplies)	.90
Blacksmith shop expense (including labor and supplies)	1.23
	$ 2.13
Power (all purposes)	5.70
Depreciation—	
Haulage equipment	.20
General equipment	1.00
	$ 1.20
General expense	3.32
Camp expense	.63
Corral expense	.08
	$ 4.03
Total	$30.56

DETAILED COST OF DRIVING THE WEST HEADING, FOR THE YEAR 1911, 3,419 FT.

	Cost per foot of tunnel
Labor—	
Engineering	$ 0.45
Superintendence	.82
Shift bosses	1.65
Timekeepers	.38
Drillmen and helpers	4.07
Miners	.37
Muckers	5.13
Track and dump men	2.00
Motormen and brakemen	1.87
Electricians and blowermen	.08
Disabled employes	.48
Timbermen	1.72
Miscellaneous	.05
	$19.07
Materials—	
Powder, fuse, caps, etc	2.61
Lumber	.80
Oils, candles, etc	.43
Ventilating pipe	.77
Track, including ties	1.52
Pressure air pipe	.36
Drill repair parts (including hose)	.34
Miscellaneous	.25
	$ 7.08
Repairs—	
Machine shop expense (including labor and supplies)	2.16
Blacksmith shop expense (including labor and supplies)	1.54
	$ 3.70
Power (all purposes)	5.20

	Cost per foot of tunnel
Depreciation—	
Haulage equipment	1.85
General equipment	.50
	$ 2.35
General expense	3.00
Camp expense	1.10
Corral expense	.02
	$ 4.12
Total	$41.52

DETAILED COST OF DRIVING THE WEST HEADING, JANUARY TO JULY, 1912, 2,382 FT.

	Cost per foot of tunnel
Labor—	
Engineering	$ 0.36
Superintendence	.56
Shift bosses	1.08
Timekeepers	.26
Drillmen and helpers	3.08
Miners	.43
Muckers	4.95
Track and dump men	1.55
Motormen and brakemen	1.33
Electricians and blowermen	.18
Disabled employes	.48
Timbermen	2.59
	$16.85
Materials—	
Powder, fuse, cap, etc	2.72
Lumber	2.13
Oils, candles, etc	.32
Ventilating pipe	.70
Track, including ties	1.51
Pressure air pipe	.30
Drill repair parts (including hose)	.32
Miscellaneous	.39
	$ 8.39
Repairs—	
Machine shop (including labor and supplies)	1.39
Blacksmith shop (including labor and supplies)	1.02
	$ 2.41
Power (all purposes)	3.75
Depreciation—	
Haulage equipment	2.20
General equipment	.50
	$ 2.70
General expense	1.90
Camp expense	.79
	$ 2.69
Total	$36.79

DETAILED COST OF DRIVING THE EAST HEADING, OCTOBER, 1911, TO JULY, 1912, 2,682 FT.

	Cost per foot of tunnel
Labor—	
Engineering	$ 0.49
Superintendence	.77
Shift bosses	1.36
Timekeepers	.31
Drillmen and helpers	3.62
Muckers	4.03
Track and dump men	2.00
Mule drivers	.89
Timbermen	1.80
Electricians and blowermen	.30
Disabled employes	.09
Miscellaneous	.21
	$15.87
Materials—	
Powder, fuse, caps, etc	$ 2.67
Lumber	.93
Oils, candles, etc	.36
Ventilating pipe	.45
Track, including ties	.56
Pressure air pipe	.12
Drill repair parts (including hose)	.38
Miscellaneous	.21
	$ 5.68
Repairs—	
Machine shop expenses (labor and supplies)	.62
Blacksmith shop expenses (labor and supplies)	.65
	$ 1.27
Power (all purposes)	$ 3.21
Depreciation—	
Haulage equipment	.47
General equipment	1.02
	1.49
General expenses	1.86
Camp expenses	1.35
Corral expenses	.95
	$ 4.16
Pumping (labor and material)	1.36
Total	$33.04

Labor Costs of Constructing Six Small Tunnels and Shafts in Earth and Rock, Chicago.—The following data are abstracted and greatly condensed from the original given by Myron B. Reynolds in Engineering and Contracting, July 3, 1912.

There were constructed during the year 1906–7 six water pipe tunnels for the city of Chicago, three in clay and three in limestone. During construction inspectors were kept on the work for the full 24 hours. From the inspectors' reports which classified the different labor the costs given further on have been compiled. These costs are believed to be fairly accurate for the actual labor on the work. No costs are given for materials, office expenses, interest or depreciation, or for capital put into plant or into financing the work. No costs of teams or scows or other charges for the disposal of spoil are included other than the actual labor required to remove it out of the way of the work or say within a radius of 200 ft. from the shafts. In the rock tunnels the stone excavated was crushed and removed for use in the concrete and no cost of this is given. It is doubtful whether any money can be saved by so using the excavated stone unless the work is so large that a plant for screening can be installed.

The data common to all tunnels were as follows:

Inside diameter all shafts	10	ft.
Outside diameter of shafts in earth	12	ft.
Outside diameter of Ashland Ave. shaft in rock	10	ft. 8 ins.
Outside diameter of other shafts in rock	12	ft.
Inside dimensions of egg-shaped tunnels . . 7 ft. ×	8	ft. 2 ins.
Concrete lining Ashland Ave. tunnel	4	ins.
Concrete lining all other tunnels	12	ins.
Excavation per foot depth shafts in earth	4.2	cu. yds.
Excavation per foot depth shafts in rock	4.2	cu. yds.
Excavation per foot Ashland Ave. shaft in rock	3.33	cu. yds.
Excavation per foot Ashland Ave. Tunnel	2	cu. yds.
Excavation per foot all other tunnels	2.8	cu. yds.
Lining per foot Ashland Ave., shaft in rock	0.42	cu. yd.
Lining per foot all other shafts	1.3	cu. yds.
Lining per foot Ashland Ave. tunnel	0.31	cu. yd.
Lining per foot all other tunnels	1.1	cu. yds.

ASHLAND AVE. WATER PIPE TUNNEL

The shafts of this tunnel were through clay and solid rock, and the tunnel was entirely in rock requiring no timbering. The shafts in earth were excavated and lined with concrete and the shafts in rock and tunnel were excavated complete before concreting was begun.

The work was started under one foreman but he was soon discharged and the work placed in charge of a first-class man, who, as is shown by the table of excavation cost, reduced the cost per foot.

An average of eighteen holes were drilled, six cut, four helpers and eight rim holes. The cut holes were finished with a 6-ft. steel and the other holes with a 5½-ft. steel. A round comprised generally three shots, the cut first. The guns left from the cut were reloaded and again fired together with the helpers and side rim holes. The top and bottom holes were fired last. About 5 ft. were broken down per round.

For the purpose of ballast for track from 2 to 3 ft. of muck was left in the bottom, and upon removing was found to be very expensive, being very compact on account of trampling, water and blasting. Men would not work very hard at it with a pick because occasionally they would find a quarter of a stick of dynamite or live cap.

The cost of the different classes of work in the construction of the Ashland Ave. tunnel are based upon the following rates of wages.

	Per shift
Foreman	$8.00
Assistant foreman	$5.00–$6.00
Miners	$3.75
Miner's helpers	3.00
Laborers, top	2.75
Laborers, bottom	2.75
Engineers	4.80
Firemen	2.40
Carpenters	4.20
Blacksmiths	4.80
Blacksmith's helper	3.00
Teams and drivers	5.50
Timekeeper	2.50
Watchman	2.50

The above rates of wage are also applicable to the other tunnels described in this article.

Preliminary and General Work.—The cost of unloading coal, sand, cement, etc., from cars; clearing shaft and tunnel; sharpening and maintaining tools, placing ladders and general work; was $5,479.35 divided as follows.

Cost per ft. charged to shaft	$ 5.20
Cost per ft. charge to tunnel	2.60

Installing Plant.—The cost of installing plant was: South Shaft—$724.50; North Shaft—$290.90, divided as follows:

Cost per ft. charged to shaft	$ 1.00
Cost per ft. charged to tunnel	.50

Shaft Sinking in Earth.—The character of ground encountered in the South Shaft was: 1.5 ft. macadam; 14.9 ft. fill; 12.1 ft. blue clay; 7.5 ft. hard clay; 16.7 ft. hardpan and boulders: Total 52.7 ft. Powder was used for lower half. On the North Shaft (60.6 ft. deep) powder was used for the bottom 40 ft. The following costs include lagging up the sides and placing iron rings.

	South shaft	North shaft
Total	$550.95	$496.00
Per lin. ft	10.45	8.20
Per cu. yd	2.45	1.95

Shaft Sinking in Rock.—The time distribution was: Setting up, 5%; drilling, 44%; shooting, 24%; mucking 27%. The costs follow.

Total—South shaft	$ 809.75
North shaft	1422.50
Per lin. ft	44.50
Per cu. yd	13.30

Excavation of Tunnel.—As noted before the change in foreman had a marked effect on the cost. This is shown clearly in the following unit costs

	South end		North end	
	Foreman No. 1	Foreman No. 2	Foreman No. 1	Foreman No. 2
Per lin. ft	$ 17.20	$ 12.40	$ 27.00	$ 10.80
Per cu. yd	8.10	6.20	13.50	4.40
Length excavated, ft	340.5	596.5	61.5	669.

The average unit costs for the total length were $13.30 per lin. ft. or $6.65 per cu. yd.

Trimming and Mucking Bottom.—The mucking consisted of 400 cu. yds. of rock which had been left for ballast. The unit cost of trimming and mucking bottom was $5.00 per lin. ft.

Lining Shafts and Tunnel.—The following are the unit labor costs for lining shafts and tunnel. The costs for concreting the shafts in rock are high due to the fact that the shafts were excavated larger than called for in the specifications, thus necessitating about 3 times as much concrete as should have been used.

Unit Labor Costs of Lining Shafts and Tunnel.—

LINING SHAFTS

	South shaft	North shaft
In earth—		
Depth, ft	50	58
Cost per lin. ft	$5.30	$5.40
Cost per cu. yd	4.10	4.13
Bailing and removing forms—		
Cost per lin. ft	1.65	2.35
Cost per cu. ft	1.27	1.81
Total cost per cu. yd	5.37	5.94
In rock—		
Cost per lin. ft	7.50	7.00
Cost per cu. yd	5.90	6.85

CONCRETING AND PLASTERING TUNNEL

Concreting—per lin. ft	$2.85
per cu. yd	5.70
Plastering—per lin. ft	0.18

DRAINAGE CANAL TUNNEL AT WESTERN AVE.

This tunnel was similar in section to the Ashland Ave. Tunnel except that the lining of the tunnel was 12 ins. instead of 4 ins. of concrete. A great amount of water was encountered in driving the shafts and tunnel. The specifications required the lining to be water-tight. To accomplish this end a large number of 1-in. pipe weepers were inserted as the lining progressed, to which afterward was to be attached a hose to permit grout to be pumped in behind the lining. The grout passed out into crevices in the rock and the scheme was abandoned. Plastering was of no avail. An average of 10 ft. per 24 hours was maintained in the driving of this tunnel, and 3 to 4 ft. in the shafts in rock.

This work was prosecuted under the direction of a competent foreman. An average of 18 holes were drilled and shot in the same manner as in the Ashland Ave. Tunnel.

The cost of the different classes of work in the construction of the Drainage Canal Tunnel follow.

Cost of Preliminary and General Work.—This included: erecting headframe; setting engine and compressor; fitting up pump; building engine house; overhauling plant; installing cage and track; placing ladders in shafts; grouting tunnel; etc. The total cost was $2,524.10 which is charged to shafts and tunnel in the following proportions: cost per ft. shaft $6.60; cost per ft. tunnel $3.30.

Shaft Excavation in Earth.—South Shaft 12 ft. clay, dry; 10 ft. stiff blue clay, wet; 22 ft. hardpan; 19.5 ft. hardpan and boulders, wet. North Shaft 17 ft. clay fill; 23 ft. medium blue clay; 10 ft. hardpan and boulders.

	South shaft	North shaft
Total cost	$837.30	$943.90
Depth, ft	63.5	60.4
Cost per lin. ft	13.20	15.65
Cost per cu. yd	3.15	3.70

Shaft Excavation in Rock

	South shaft	North shaft
Total cost	$744.30	$1,367.95
Progress, ft	26	37.6
Cost per lin ft	28.80	36.50
Cost per cu. yd	6.80	6.70

Tunnel Excavation, Drainage Canal Tunnel

	Three 8-hr. shifts per day	Two 10-hr. shifts per day
Total cost	$1,495.45	$2,980.40
Cost per ft	14.50	10.20
Cost per cu. yd	5.20	3.65
Total per cu. yd	5.75	4.20
Lin. ft	103.2	292

Trimming and Mucking, Drainage Canal Tunnel

	Working two 10-hr. shifts per day
Total cost	$597.20
Cost per ft	1.50
Cost per cu. yd	0.55
Lin. ft	395

Concreting Shafts in Earth, Drainage Canal Tunnel

	South shaft	North shaft
Total cost	$296.50	$232.40
Progress, ft	60	57
Cost per ft	4.95	4.10
Cost per cu. yd	3.80	3.15

Removing Shaft-Forms in Earth, Drainage Canal Tunnel

	South shaft	North shaft
Total cost	$81.80	$157.40
Cost per ft	1.35	*2.80
Cost per cu. yd	1.05	2.10
Cost of concreting and removing forms per cu. yd	4.85	5.25

* Forms under water 60 days.

Concreting Shafts in Rock, Drainage Canal Tunnel

	South shaft	North shaft
Total cost	$296.40	$276.95
Cost per ft	7.90	7.10
Cost per cu. yd	5.30	5.20
Depth, ft	37.6	26 shaft 13 tunnel

Removing Forms, Shafts in Rock, Drainage Canal Tunnel

Total cost	$40.85
Progress, ft	63.6 shaft 13 tunnel
Cost per lin. ft	$ 0.65
Cost per cu. yd	0.15

Total cost of concreting and removing forms per cu. yd.; North Shaft, $5.45; South Shaft, $5.35

Concreting Tunnel, Drainage Canal Tunnel

Total cost	$1,536.95
Cost per ft	4.00
Cost per cu. yd	3.65
Length ft	382

WESTERN AVE. TUNNEL UNDER THE WEST FORK OF THE SOUTH BRANCH OF THE CHICAGO RIVER

This tunnel was similar in all respects to the tunnel under the Drainage Canal. The first 10 or 15 ft. of the north shaft in rock had to be timbered, the rock being of such loose character.

On account of a change in alignment 150 ft. of the bottom varying in depth from 0 to 3 ft. had to be removed in order to obtain the proper grade. The charge of this should not be made directly to the tunnel excavation. The method of blasting was the same as in the Ashland Ave. Tunnel, the work being done under the supervision of the same foreman.

The costs of the different classes of work in the construction of the West Fork Tunnel follow.

Cost of Preliminary and General Work, West Fork Tunnel

This includes erecting head frame, setting machinery, building engine house, installing cage and track, etc.

Total cost	$3,145.35
Cost per ft. charged to shaft	11.00
Cost per ft. charged to tunnel	5.50

Excavation, Shafts in Earth, West Fork Tunnel

	South shaft	North shaft
Total cost	$358.00	$186.20
Depth, ft	37	21
Cost per ft	9.70	8.90
Cost per cu. yd	2.30	2.10

Ground—South Shaft; 5 ft. fill; 11 ft. blue clay; 16 ft. hard dry clay; 5 ft. hardpan and boulders. North Shaft; 6 ft. fill; 10 ft. medium clay; 5 ft. hardpan and boulders.

Shaft Excavation in Rock, West Fork Tunnel

	South shaft	North shaft
Total cost	$439.05	$1,444.65
Depth, ft	19	46
Cost per ft	23.00	31.50
Cost per cu. yd	5.50	7.50

Tunnel Excavation, West Fork Tunnel

Total cost	$5,495.95
Length, ft	350.00
Cost per ft	15.65
Cost per cu. yd	5.60

Excavating Bottom, 150 ft. × 2 ft. Deep

Total cost	$ 841.65
Cost per ft	5.60
Cost per cu. yd	2.50

Trimming Tunnel

Total cost	$ 103.00
Cost per lin. ft	0.30

Concreting Shafts in Earth, West Fork Tunnel

	South shaft	North shaft
Total cost	$244.40	$117.80
Depth, ft	35	19
Cost per ft	7.00	6.15
Cost per cu. yd	5.40	4.70

Concreting Shafts in Rock, West Fork Tunnel

	South shaft	North shaft
Total cost	$237.60	$393.05
Depth, ft	19	46
Cost per ft	12.50	8.55
Cost per cu. yd	9.60	6.00

Concreting Tunnel, West Fork Tunnel

Total cost	$1,670.20
Length, ft	325
Cost per ft	5.15
Cost per cu. yd	4.70

INDIANA ST. WATER PIPE TUNNEL

This tunnel was constructed under favorable circumstances to its completion. But little water (bailing only was necessary at times) was encountered, and in only two places was it necessary to hold up the roof by timbering.

When the full shift was at work 16 ft. were mined and concreted during the three 8-hour shifts. Mining was carried on from 12 o'clock midnight until 3 o'clock P. M., and on the 3-11 shift the concrete linning was placed.

It was first attempted to use 40 per cent dynamite to loosen up the clay, but following the first shot a lump of clay fell on the leg of one man and broke it, after which the ground was grubbed out. The bottom half was hard clay and hardpan and the top half was medium clay.

In the shafts with four miners per shift working 10 ft. were excavated per 24 hours. About 4⅛ cu. yds were averaged per 8 hours for each man digging in both the shafts.

In concreting the shafts the steel rings holding the lagging were removed from the shaft and the lagging taken away from the excavation and placed against centers for forms. A platform was made to fit over the forms and upon it the concrete was dumped and then shoveled into place and tamped.

In concreting the tunnel the bottom was first placed and graded to templet. A board floor was then laid over this concrete, the centers placed and the lagging set in as the concrete came up.

The concrete was hand mixed on a platform at the top of the shaft, loaded into cars and let down on a cage into the tunnel.

The costs in the different classes of the work in the construction of the Indiana Street Tunnel follow.

Preliminary and General Work, Indiana Street Tunnel

Total cost	$1,185.35
Cost to be charged to shaft per ft	3.60
Cost to be charged to tunnel per ft	1.80

Shaft Excavation, Indiana Street Tunnel

	East shaft	West shaft
Total cost	$1,004.30	$775.00
Depth, ft	92	73
Cost per ft	10.90	10.60
Cost per cu. yd	2.60	2.50

Tunnel Excavation, Indiana Street Tunnel

Total cost	$2,080.85
Progress, ft	335
Cost per ft	6.25
Cost per cu. yd	2.25

Excavation was half medium and half hard clay.

Concreting Shafts, Indiana Street Tunnel

	East shaft	West shaft
Total cost	$444.60	$365.90
Lin. ft	90	71
Cost per ft	4.95	5.15
Cost per cu. yd	3.80	3.95

Concreting Tunnel, Indiana Street Tunnel

Total cost	$1,156.40
Lin. ft	335
Cost per ft	$ 3.55
Cost per cu. yd	2.25

ILLINOIS AND MICHIGAN CANAL TUNNEL AT WESTERN AVE.

This tunnel was constructed by the same firm and under the supervision of the same foreman as was the Indiana tunnel. Powder was used in excavating this tunnel, but the clay was too springy for good results.

Some bad cement was delivered and used before testing which did not set up. As a consequence, 60 ft. of the tunnel lining had to be removed and replaced.

The north shaft of this tunnel was excavated and lined by using a windlass for raising and lowering. It appeared as cheap as though a hoisting engine had been used, but the time was much longer.

The costs of the different classes of work in the construction of the Illinois and Michigan canal tunnel follow.

Cost of Tunnel Work, Illinois and Michigan Canal Tunnel

Total cost	$1,138.40
Cost per ft. to be charged to shaft	4.80
Cost per ft. to be charged to tunnel	2.40

Cost of Excavating Shafts, Illinois and Michigan Canal

	North shaft	South shaft
Total cost	$672.60	$830.10
Progress, ft	58	58
Cost per ft	11.60	14.30
Cost per cu. yd	2.75	3.25

Cost of Excavating Tunnel, Illinois and Michigan Tunnel

Total cost	$1,571.30
Progress, ft	225
Cost per ft	7.00
Cost per cu. yd	2.50

Excavation was hard clay. Powder was used.

Cost of Concreting Shafts, Illinois and Michigan Tunne

	North shaft	South shaft
Total cost	$332.30	$365.90
Progress, ft	55	58
Cost per ft	6.05	6.30
Cost per cu. yd	4.65	4.85

Cost of Concreting Tunnel, Illinois and Michigan Tunnel

	Concreting	Replacing condemned lining
Total cost	$793.00	$263.40
Progress, ft	225	60
Cost per ft	3.50	4.40
Cost per cu. yd	3.20	4.00

DIVERSEY BOULEVARD TUNNEL

This tunnel and shafts were shown on the plans to have the same cross section as the other water pipe tunnels in clay. The borings indicated, however, that quicksand would be encountered in the sinking of both shafts and that the tunnel would be in solid rock. Acting on this the contractor elected to use 8 × 8 ft. octagonal bracing instead of the usual circular iron rings. This necessitated placing a much larger amount of concrete in the shaft lining than was actually called for in the specification.

Upon excavating the shafts to about half their depth the method of holding up the excavation was changed from timbering to the use of a steel shield, which was let down in sections and jacked into place as the excavating progressed. Water in large amounts was encountered, a large Nye pump being used in both shafts all the time.

When the elevation was reached for the tunnel grade no rock other than large boulders was found, and a boring 10 ft. deeper did not discover rock. It was presumed that in the original borings large boulders had been struck and mistaken for solid rock. The tunnel was driven through water bearing sand and gravel on top and hard clay on the bottom from the east shaft and through hard clay from the west shaft.

When the eye in the west shaft was cut for the tunnel the ground fell into the shaft and the surface of the ground at the top of the shaft sunk 10 ft., tipping over the hoisting engine and compressor.

No timbering was necessary to hold the ground in the tunnel from the west shaft, but the tunnel sides, roof and face from the east shaft had to be sheeted tight.

In the tunnel from the east shaft one miner worked with two muckers each shift. The miner on one shift was an Assyrian with experience in this class of work. The tunnel was excavated and lined in 4 ft. sections. The excavation was started at the crown, and by removing the upper half the center vertical plank, which had been previously placed to hold up the face, the wet sand and gravel could be removed by hand until there was room to place the crown plank and place a post under it. This method was continued down each side in turn until the springing lines were reached, at which point ground was reached which would stand up. The timbering, except the posts, was left in and the concrete lining placed. The posts were removed as reached by the concrete.

The costs of the different classes of work in the construction of the Diversey Blvd. tunnel follow.

Cost of General Work, Diversey Blvd. Tunnel

Total cost	$2,820.50
Cost per ft. to be charged to shaft	7.80
Cost per ft. to be charged to tunnel	3.90

Cost of Shaft Excavation Diversey Blvd. Tunnel, East Shaft

	—Excavating—	—Timbering—	Placing shield
Total cost	$1,074.50	$405.50	$174.50
Progress, ft	65.8	....	....
Depth of timbering, ft	....	50	....
Depth of shield, ft	....	....	16
Cost per ft	16.30	8.10	10.90
Cost per cu. yd	3.05	....	....

Cost of Shaft Excavation, Diversey Blvd. Tunnel, West Shaft

	—Excavating—	—Timbering—	Placing shield
Total cost	$1,122.50	$482.75	$211.00
Progress, ft	71	....	....
Depth of timbering, ft	....	35	....
Depth of shield, ft	....	....	36
Cost per ft	15.80	13.75	5.85
Cost per cu. yd	2.80	....	....

Cost of Excavating Tunnel, Diversey Blvd. Tunnel

	From East shaft	From West shaft
Total cost	$2,747.00	$1,190.00
Progress, ft	328	122
Cost per ft	8.40	9.75
Cost per cu. yd	3.00	3.50

Cost of Concreting Shafts, Diversey Blvd. Tunnel

	From East shaft	From West shaft
Total cost	$718.00	$485.50
Progress, ft	62	69
Cost per ft	11.60	7.05
Cost per cu. yd	4.00	4.70

Cost of Concreting Tunnel

	From East shaft	From West shaft
Total cost	$695.00	$309.50
Cost per ft	2.10	2.50
Cost per cu. yd	3.10	3.30
Progress, ft	328	122

Tables I to III give a summary of the foregoing costs.

TABLE I.—SUMMARY OF UNIT COSTS OF SHAFTS AND TUNNEL EXCAVATION

	Sinking and driving only		Preliminary and overhead charges added	
	Cost per cu. yd.	Cost per lin. ft.	Total cost per cu. yd.	Total cost per lin. ft.
Ashland Avenue tunnel—				
Shaft in clay	$ 2.20	$ 9.35	$ 3.10	$12.85
Shaft in rock	10.70	35.75	12.30	40.85
Tunnel in rock	6.65	13.30	7.75	15.50
Drainage Canal tunnel—				
Shaft in clay	3.40	14.40	4.50	18.80
Shaft in rock	7.75	32.65	9.05	37.90
Tunnel in rock	5.00	13.85	5.85	16.40
West Fork tunnel—				
Shaft in clay	2.20	9.30	4.05	17.00
Shaft in rock	6.50	27.25	8.35	34.95
Tunnel in rock	5.60	16.00	7.20	20.10
Indiana Street tunnel—				
Shaft in clay	2.55	10.75	3.15	13.15
Tunnel in clay	2.25	6.25	2.65	7.45
Illinois & Michigan Canal tunnel—				
Shaft in clay	3.00	12.45	3.80	15.80
Tunnel in clay	2.50	7.00	3.10	8.80
Diversey Boulevard tunnel—				
Shaft in clay	4.85	25.25	6.35	31.45
Tunnel in clay	3.15	9.10	4.20	11.70

TABLE II.—SUMMARY OF UNIT COSTS OF SHAFTS AND TUNNELS—CONCRETE LININGS

	Cost of placing lining only		Miscellaneous work added	
	Cost per cu. yd.	Cost per ft.	Cost per cu. yd.	Cost per ft.
Ashland Avenue tunnel—				
Shaft in clay	$ 5.65	$ 7.35	$ 7.75	$10.05
Shaft in rock	6.40	7.00	6.60	8.10
Tunnel in rock	5.70	3.05	5.50	3.95
Drainage Canal tunnel—				
Shaft in clay	5.05	6.60	6.75	8.80
Shaft in rock	5.40	8.15	7.30	9.50
Tunnel in rock	3.65	4.00	4.30	4.75
West Fork tunnel—				
Shaft in clay	5.05	6.55	7.60	9.85
Shaft in rock	7.80	10.50	6.70	14.35
Tunnel in rock	4.70	5.15	6.00	6.55
Indiana Street tunnel—				
Shaft in clay	3.90	5.05	4.80	6.25
Tunnel in clay	3.25	3.55	3.80	4.15
Illinois & Michigan Canal tunnel—				
Shaft in clay	4.75	6.20	6.00	7.80
Tunnel in clay	3.20	3.50	3.70	4.10
Diversey Boulevard tunnel—				
Shaft in clay	4.50	9.20	6.00	10.80
Tunnel in clay	3.20	2.30	3.70	3.60

TABLE III.—SUMMARY OF UNIT COSTS, GIVING COST PER LIN. FT. FOR GENERAL AND PLANT, AND GRAND TOTALS PER LIN. FT. FOR SHAFTS AND TUNNELS

	Shafts in clay	Shafts in rock	Tunnels in clay	Tunnels in rock
Ashland Avenue tunnel—				
Plant and general per lin. ft....	$ 6.20	$ 6.20	......	$ 3.10
Grand total per lin. ft......	22.90	48.95	......	19.45
Drainage Canal tunnel—				
Plant and general............	6.60	6.60	......	3.30
Grand total................	27.60	47.40	......	21.15
West Fork tunnel—				
Plant and general............	11.00	11.00	......	5.50
Grand total................	26.85	49.30	......	26.65
Indiana Street tunnel—				
Plant and general............	3.60	......	$ 1.80	......
Grand total................	19.40	......	11.60	......
Ill. & Mich. Canal tunnel—				
Plant and general............	4.80	......	2.40	......
Grand total................	23.60	......	12.90	......
Diversey Blvd. tunnel—				
Plant and general............	7.80	......	3.90	......
Grand total................	32.25	......	15.30	......

Cost of Tunnel for the Tallulah Falls Hydro-Electric Development in Georgia.—Charles G. Adsit and Eugene Lauchli give the following data in Engineering and Contracting, May 6, 1914.

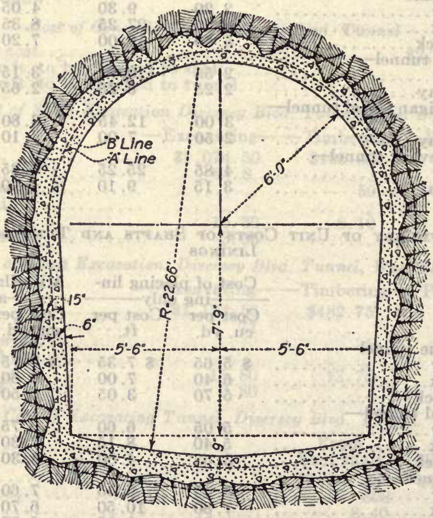


FIG. 2.—Section of tunnel, Tallulah Falls development.

The tunnel 6,665 ft. long and of dimensions indicated in Fig. 2 was driven to convey water from the diverting dam to a forebay or surge reservoir.

The tunnel was driven on a 2 in 1,000 grade, sloping from the intake down to the forebay, through a grey blueish granite, dipping downstream at an angle of 22°, wich occasional mud seams. The ground stood well generally, and only 6 per cent of the tunnel length required timbering during construction.

For the purpose of expediting the work, it was found desirable to drive the tunnel from the intake and forebay ends, as well as from two adits 7 ft. high, 13 ft. wide, 105 and 217 ft. long, respectively, (adits No. 1 and 2) driven on a 1 per cent grade. Before starting work at the intake end, 4,000 cu. yds. of material, mostly rock, had to be excavated. At the forebay, consisting of a shaft 35 ft. wide, 75 ft. long and 70 ft. deep, some 10,800 cu. yds. of rock had to be excavated. Later on, adit No. 3, 150 ft. long, was provided and an 8 × 10-ft. shaft, 112 ft. deep, was sunk between the intake portal and adit No. 1.

The work under consideration involved the following quantities:

	Cu. yds.
Adit excavation	1,250
Main tunnel:	
Heading	23,330
Bench	29,650
Concrete lining within specified lines	15,430
Concrete lining beyond specified lines	3,540

Seventy-five per cent of the tunnel length was driven with a top heading and bench, and the balance with a bottom heading, the overlying material being stoped down on the heading floor. Attention is called here to the fact that, owing to the relatively small section of the tunnel, heading excavation represented about 49 per cent of the total excavation.

Power Plant and Equipment.—The contractor, the Northern Contracting Co., built a temporary power plant housing two 500-HP. S. Morgan Smith hydraulic Francis turbines, operating under an average head of 48 ft. and driving two Laidlaw Dunn Gordon air compressors, each having a capacity of 2,500 cu. ft. of free air per minute, 110 lbs. pressure. A wooden dam, 10 ft. high and 60 ft. long, was thrown across the Tallulah River, at Lador Falls, and a 7.5-ft. steel penstock 80 ft. long served to convey water from a masonry intake located at one end of the dam to the turbines. A 3-ft. diameter steel penstock also diverted water from the intake to 125-HP. Francis turbine driving a 50-KW. generator used for lighting purposes.

The tunnel sub-contractor, Condon, Graham & Millner of Knoxville, Tenn., was furnished, free of charge, with 4,000 cu. ft. of air per minute and also with electric current. Owing to low water conditions, in 1912, it was found necessary to increase the capacity of the air plant, and a steam-driven Sullivan straight line air compressor, with a capacity of 1,875 cu. ft. of free air per minute, and two 200-HP. Scotch Marine type boilers were installed near to the forebay and connected with the main air line, consisting of 10, 8 and 6-in. wrought iron pipe, partly laid along the T. F. Ry. track.

Piston drills were used first, but owing to the hardness of the rock and its abrasive properties, necessitating much sharpening, thus being a serious hindrance to progress, Leyner water core air drills No. 7. were adopted, and their use immediately caused a general improvement in progress. With piston drills, starting holes was found a chief difficulty to overcome, and drilling of dry holes gave little satisfaction.

No. 2 Leyner bit sharpeners were installed at each adit and points of attack. At the shaft the following plant was installed:

1 set 10 × 15-in. Jaw crushers.
1 set sand rolls.
1 60 H.P. steam engine.
1 two-drum 18 H.P. hoist engine operating the shaft cage.
1 set of sand screens.
1 cement house.

Owing to the steepness of the gorge, at the mouth of the adits and intake portal, much of the tunnel muck, necessary for the concrete aggregate was lost, and it was found necessary to open a quarry at adit No. 3.

As a whole, the labor available was extremely poor and unreliable for this class of work. Negro labor was used chiefly. Some Hungarians and Cherokee Indians gave somewhat better results. Rainy weather (annual rainfall varying from 70 to 80 ins.) was a serious hindrance to progress. During holidays a large number of men would leave, thus resulting in onerous transportation charges, and it was no small task to organize and break in two shifts of men for 10 working points. Thus labor conditions account chiefly for the somewhat slow progress in driving the tunnel.

Two shift were worked per day at each heading, a shift consisting of 4 drillers, 4 helpers, 6 muckers, 2 trammers, 1 foreman. Mules were used for haulage. At the adits, forebay and intake, one blacksmith and one helper did the drill sharpening.

The following wages prevailed: Drillers, $2.50; drill helpers, $1.75; muckers, $1.65; foremen, $4.50; blacksmiths, $3.50; helpers, $2.00; carpenters, $3.00; concrete men, $1.75.

Work at the intake heading and driving of adit No. 1 was started during July, 1911, and work at adit No. 2 on the following month. The intake top heading was first excavated for a length of 800 ft.; at this point ground pressure necessitated heavy timbering and in some instances the roof caved in for a height of 10 ft. Progress was very slow and costly; some water was encountered, and as the tunnel was being driven down grade, pumping had to be resorted to in order to keep the heading dry. It was then deemed advisable to carry the bench excavation close to the heading, and work was suspended pending the completion of the bench excavation.

The headings at adit No. 1 and 2 were carried at the top of the tunnel. A top heading was also started in September, 1911, from the bottom of the forebay, the material excavated being handled with a derrick located at the mouth of same. After the heading had been driven some 500 ft., a soft seam was struck, necessitating timbering.

In June, 1912, after the shaft between the intake and adit No. 1 had been sunk to grade, and adit No. 3 had been driven to the main tunnel, headings 8 ft. high were driven at the bottom of the tunnel section, and the overlying material was stoped down on the tunnel floor.

The average progress for heading and bench excavation during the year 1912 was 30 and 38 ft., respectively, per week (6 days). Twice the progress was made in stoping work as in bench excavation, at a less cost of about 50 cts. per cubic yard. During April, 1912, about 1,784 cu. yds. of bench material were excavated at a cost of $4.315 per cubic yard, and during May of the same year 3,807 cu. yds. of rock were stoped down at a cost of $3.789 per cubic yard, or at a lesser cost of $0.526 per cubic yard. The cost of bench and stoping work was as per Table IV.

TABLE IV

	Per cu. yd. stoping work	Per cu. yd. bench work
Labor	$2.415	$2.965
Supt. and walking bosses	.141	.067
General expenses	.036	.101
Office force	.103	.085
Storeroom force	.027	.028
Repairmen	.115	.102
Carpenters	.053	.050
Dynamite	.339	.416
Exploders	.029	.038
Connecting wire	.015	.014
Kerosene	.002	.002
Lubricating oil	.013	.012
Tamping bags	.002	.002
Lamps	.011	.010
Piping and fittings	.015	.029
Drill repairs	.204	.095
Miscellaneous supplies	.041	.063
Drill steel	.107	.080
Blacksmith coal	.027	.027
Freight	.063	.079
Feed	.031	.050
Total	$3.789	$4.315

The cost of driving 830 lineal feet of heading (2,856 cu. yds.) was as given in Table V.

TABLE V

Items—	Cost per cu. yd.
Labor	$4.18
Overhead charges	0.295
Blacksmiths' repairs	0.107
Machinists' repairs	0.135
Supply house labor	0.043
Office force	0.082
Outside force	0.12
Drill steel	0.06
Blacksmith's coal	0.035
Mules' feed	0.051
Freight	0.144
Drill repairs	0.324
Piping and fittings	0.09
Miscellaneous supplies	0.076
Dynamite	0.035
Exploders	0.051
Connecting wires	0.033
Gasoline	0.013
Lubricating oil	0.033
Tamping bags	0.006
Total	$6.913

The cost of excavating 39,831 cu. yds. of tunnel, from February, 1912, to April, 1913, was as given in Table VI.

TABLE VI.—TOTAL COST OF TUNNEL EXCAVATION, 39,831 CU. YDS. February 1, 1912 to April 31, 1913

Items—	Cost per cu. yd.
Labor	$3.833
Explosives	.604
Lubricants	.019
Piping	.026
Drill repairs	.172
Miscellaneous supplies	.237
Freight	.087
Transportation	.247
Liability insurance	.181
Miscellaneous charges	.066
Depreciation on equipment	.150
Power*	.306
Total	$5.928

* This item represents that part of the original cost and cost of operation of compressor plant No 1 chargeable to tunnel excavation.

Concrete Lining.—Work on the lining was not started until September, 1912, i.e., at a time when the tunnel had been practically completely excavated. About 120 ft. of tunnel invert was concreted first at adit No. 3, and Blaw collapsible steel forms were then erected and concreted. It was soon found out that it would be preferable to concrete the side walls and arch first, and later on the invert, and this procedure was then followed throughout.

A total length of 240 lin. ft. of Blaw forms were used, the lining being carried on simultaneously at three points. Three concreting machines furnished by the Concrete Mixing & Conveying Co. of Chicago were installed and operated by air at 100 lbs. pressure. The best results were obtained when conveying concrete to the steel forms, erected in 20 ft. lengths only, through 6-in. diameter spiral pipes. The concrete was a 1:3:5 mixture, the aggregate being not over 2 ins. in size. In using these concrete conveying machines, great care had to be exercised in order to prevent the formation of voids within the lining, as its thickness was relatively small. In general, it was found that a somewhat better finish would have been obtained had the lining been given a greater thickness, as it was somewhat difficult to clean thoroughly the forms after these had been used. However, the results obtained were satisfactory for the purpose intended; in wet places the concrete was somewhat honeycombed, but this defect was corrected during the grouting process.

In places where the tunnel roof was high, it was found cheaper to use concrete rather than spalls for back filling, inasmuch as all voids were to be grouted.

The average progress of concreting varied from 30 to 60 ft. per week (6 days), the average for the whole tunnel being about 60 ft. The invert was laid without air concreting machines, as it was found that, in order to obtain satisfactory results, the concrete had to be delivered in a confined space. The invert was laid at a rate of about 745 ft. per week.

The cost of the concrete lining is given in Table VII. Cement was sold by the Northern Contracting Co. to the sub-contractor for the sum of $1.80 per barrel.

TABLE VII

Items—	Cost per cu. yd.
Labor	$5.12
Cement	2.995
Miscellaneous materials	0.411
Lumber	0.138
Freight	0.066
Transportation	0.157
Insurance	0.168
Royalty on concreting machine	0.420
Miscellaneous expenses	0.106
Crushing rock	2.02
Quarrying rock	0.87
Plastering concrete	0.206
Cleaning up tunnel	0.382
Total*	$12.041

* Blaw concreting forms and depreciation on equipment not included.

Grouting.—The specifications called for a mixture to be used for this purpose, consisting in 1 to 1½ part sand to 1 part cement. Grout and vent pipes 1½ ins. in diameter were provided in the tunnel arch, or in other places where necessary, 15 ft. apart, more or less. Four grouting machines were used for this purpose, under 40 lbs. pressure. Little trouble was encountered, although in a few places local flaking of the lining occurred where voids had been left. In wet places the grout oozed through the honeycombed concrete, thus making a somewhat rough surface, which was smoothed up later up. The cost of grouting was about $1.10 per cubic yard of concrete placed.

Cost of Driving 8,700 Ft. of Tunnel by Station Men.—In connection with the reconstruction of its canal system the Naches-Selah Irrigation District, comprising some 10,500 acres of orchard lands in the Yakima Valley, Washington, will construct 16 tunnels of an aggregate length of 21,000 ft. Eight of these tunnels, totaling 8,718 ft., were constructed in 1918. The following data are given in Engineering and Contracting, Dec. 17, 1919 by E. M. Chauder who prepared the designs for the work.

The tunnels are 7 ft. wide in the clear, with flat bottoms, side walls from 4 to 5½ ft. high to the spring line of a segmental arch with a 2 ft. rise. The reinforced concrete lining, except in the timbered sections is 6 in. thick, with the exception that in rock the floor thickness is 4 in. The tunnels were driven through soft and dry sand rock and shale, and in all cases but one the drilling was done with coal augers.

The tunnels were driven by station men, who in some instances were paid at the rate of $6 per lineal foot. Three men constituted a shift. The tunnel driving was doubled ended and double shifted. The station men netted from $10 to $15 per day, and at the same time set the pace for speedy, economical tunnel driving.

The holes were bored about 8 ft. deep, usually 9 ft. on a face. No springing was required. The coal auger was held in place by being jacked against the floor and roof. Varying lengths of auger were used as the hole progressed. About an hour usually was required to drill and load the holes. The three men did the mucking, using large scoop shovels for this purpose. One of the three drove the loaded car hauled by a mule to the dump. The haul was short and took only a few minutes. An average of 20 lin. ft. per day was made on some of the tunnels driven in soft shale.

In the tunnels where sandrock was encountered, a little more time for drilling and more powder were required; but there was very little difference in the progress made.

In lining the tunnels, the floor was run in first, contrary to the usual practice, then the sides and then the roof. The mix for the latter was 1:3:5; for the floor and sides it was 1:2:4. The mixing was done outside by machines and carried in by cars on track. Four men in the tunnel, two taking turns shoveling overhead, and two, one on each side, tamping back into place, would ordinarily put in 60 ft. of roof in 8 hours. The maximum run was 70 ft. in 8 hours.

During most of the work labor was paid $4.50 per 8-hour day, and part of the time $5.50.

The following tabulation summarizes the cost of driving and lining the eight tunnels:

Tunnel No.	Length, ft.	Total cost per lin. ft.	Excavation cost per cu. yd.	Lining cost per cu. yd.
1	1,920.0	$21.20	$4.10	$22.20
2	782.5	24.20	5.20	22.80
9	1,363.0	20.00	3.33	23.40
10	1,080.5	19.70	3.39	22.30
11	883.0	18.20	3.89	21.00
12	893.0	18.00	3.51	22.00
13	651.0	18.70	3.32	22.40
14	1,145.0	19.60	3.13	27.20
Total.......	8,718.0	$20.10	$3.73	$23.00

Tunnel No. 1—Sandstone of varying hardness and irregular fracture.
Tunnel No. 2—Cemented gravel and large boulders. Could not use augers or machine drills. Much overbreak.
Tunnel No. 3—Soft sandstone. Concrete run in from one end only.
Tunnel No. 4—Soft sandstone.
Tunnel No. 5—Soft shale with considerable gravel intermixed.
Tunnel No. 6—Soft shale. Lined in winter. Water hauled several miles under bad conditions.
Tunnel No. 7—Soft shale. Concrete material hauled 5.7 miles.
Tunnel No. 8—Soft shale with considerable overbreak. Concrete material hauled 6 miles and water 3 miles in winter over almost impassable roads.

Cost of Cross Cutting, Amador County, California.—Important factors in cross cutting based on actual mining operations are outlined by Edwin Higgins in a bulletin issued on July 1 by the California Metal Producers' Association. The data are the result of an investigation conducted at the mines in Amador County, California. The matter following is taken from an abstract of the bulletin published in Engineering and Contracting, Sept. 19, 1917.

A summary of the data relating to the driving of 10 cross cuts in various California mines is given in Table VIII. In this table costs are figured only on labor and explosives, the following charges being made for labor: Drill men, $3; chuck tenders and muckers, $2.50.

All the cross cuts are in the hard greenstone of Amador County except operation No. 8 (hanging wall slate), operation No. 9 (andesite and schist) and operation No. 10 (slate). Five degrees of hardness were selected, No. 5 being the hardest. Most of the rock encountered was uniformly hard. The strength of the caps used was 6X.

TABLE VIII.—DATA RELATIVE TO THE DRIVING OF TEN CROSS CUTS IN VARIOUS CALIFORNIA MINES

No.	Hardness of rock, 1–5	Distance driven, ft.	Size of cross cut, ft.	Average length of tram, ft.	Type of drill used	Kind of bit	Air pressure at drill, lbs. per sq. in.	Depth of holes, ft.
1	5	94	6 × 8– 7 × 9	Various	Piston	Cross	85–90	5½–6
2	5	346	7 × 9	Various	Water Hammer	Carr	85–90	5½–6
3	4	100	5 × 6½	1000	Water Hammer	Carr	90	5
4	4	500	6 × 9½	275	Stoper Water Hammer	Carr	90–95	5
5	4	427	5½ × 7	1318	Water Hammer	Cross	70–90	5 –6
6	5	172	7 × 9	140	Piston	Cross	75	5 –6
7	4	357	7 × 9	180	Piston	Cross	80	5½–7
8	3–4	450	5 × 6	2190	Piston	Cross	80	6
9	4–5	150	6 × 7½	85	Water Hammer	Cross	90	5 –6
10	3	432	5 × 7	210	Piston	Cross	85	5

No.	No. of holes per round.	Shifts to drill round.	Advance per drill shift, ft.	Shafts worked per 24 hrs.	Days pay, contract	Kind of fuse used.	Kind of powder used	Lbs. powder per round	Cost per ft. labor & explos.
1	15–16	3	1.5–2	2	DP	Comet	30 % Ammo-Gel.	62	$6.12
2	15–16	1–1½	4.0	2	DP	Comet	30 % Ammo-Gel.	62	3.82
3	16	1	4.25	1	DP	Delay Expl.	35 % Gel. Dyn.	50	3.62
4	16	1	4.5	2	DP	Delay Expl.	35 % Gel. Dyn.	50	3.42
5	11–13	1¾	2.60	1	DP	Eclipse Special	40 % Gel. Dyn.	30	4.38
6	15	2	2.0	3	DP	Pacific	40 % Ammo-Gel.	50	5.87
7	12	1	5.0	2	C	Pacific	40 % Ammo-Gel.	62	3.94
8	11	1¼	3.66	3	DP*	Anerold	40 % Nit. Gly.	30	4.07
9	12	⅝ ⅝	5.0	3	DP	Pacific	35 % Ammo-Gel.	38	3.07
10	8–10	⅝	4.5	1	C	Pacific	40 % Ammo-Gel.	30	3.36

* Bonus paid: Machinemen received $3 per day; chuck tenders and muckers $2.50 per day. For every 5 ft. over 50 ft. per week, all men received 25 cts. per day additional.

For fear of creating an erroneous impression regarding the use of some particular drill, it was decided not to mention the make, but simply to divide the drills into two classes, piston drills using solid steel, and hammer drills using water through hollow steel. In practically all of the operations 1-ton, steel, end-dump cars were used, and shoveling was done either from a steel sheet or from planks. Hand-tramming was used in all of the operations except No. 3, in which mules were used. The track gage in all cases was 18 in., and 16-lb. rails were used except in operations Nos. 6 and 10, where 12-lb. rails were used. No. timber was used, except in operations Nos. 5, 6 and 7, which required a few sets each.

Operation No. 1: This work was done in 1915, the cost of the 94 ft. being as follows:

	Cost	Percentage of total cost
Drilling (labor)	$295.25	41.2
Mucking and tramming	192.50	26.8
Supplies	48.50	6.8
Powder (at 11 cts. per lb.)	181.45	25.2
Total	$717.70	
	or $7.63 per ft.	

Operation No. 2: Of the 346 ft., 239 were driven in 1916 and 107 ft. in 1917. The 1916 costs were as follows:

	Cost	Percentage of total cost
Drilling (labor)	$ 785.25	31.4
Mucking and tramming	583.25	23.3
Powder	946.45	37.9
Track, ties and incidentals	186.43	7.4
Total	$2,501.38	
	or $10.46 per ft.	

The costs during 1917 (107 ft.) were as follows:

	Cost	Percentage of total cost
Drilling (labor)	$ 292.00	27.6
Mucking and tramming	327.00	30.9
Supplies	84.20	8.0
Powder (at 17 cts. per lb.)	354.20	33.5
Total	$1,057.40	
	or $9.88 per ft.	

Operation No. 3: Firing was done electrically from a 110-volt line with switch, using delay exploders.

Cycle of Operations: Machineman goes to work at 7:00 a. m., finding clean set-up. He drills and shoots at about 3:00 o'clock. Two muckers go on at 7:30 p. m., muck out, clean up and put in platform for next shift. All drill parts are kept available in duplicate.

Operation No. 4: Practically same cycle of operations as No. 3, except that two shifts are worked. Machineman comes on to a clean set-up, drilling and shooting about 3:30 p. m. Two muckers come on at 4:00 p. m. and muck back for a clean set-up. They muck out their round, machineman coming on at 7:00 p. m. He drills and shoots at about 3:30 a. m. Two muckers come on at 4:00 a. m. and muck back so that a machineman coming on at 7:00 a. m. will have a clean set-up.

Since this work was done a change has been made which has resulted in greater efficiency. The 1¼-in. round, hollow steel, with cross bit, one set of which sufficed to drill only one hole, has been discarded in favor of 1-in. hexagon, hollow steel, with Carr bit. Drilling speed has increased 25 per cent or more and new steel drills from five to eight holes without resharpening. The drill has been equipped with a striking block, or anvil block.

Operation No. 5: Most of this work was done with one drillman on the first shift and one mucker on the second shift. The 426.5 ft. were driven in the period from July, 1916, to February, 1917, at the following cost:

	Cost	Percentage of total cost	Cost per foot
Timbering	$ 51.88	1.8	$0.12*
Drilling	1,084.16	36.9	2.54
Mucking and tramming	521.73	17.8	1.22
Explosives	670.48	22.8	1.59
Candles	18.60	0.6	0.04
Hoisting	591.10	20.1	1.38
Total	$3,937.95	100.0	$6.89

* Not timbered throughout.

163.5 drill-shifts were worked, which gives an average advance of 2.6 ft. per drill shift.

Operation No. 6: The cost for the 172 ft. was $1,255 ($7.30 per ft.), which does not include air, hoisting, drill sharpening or superintendence. The work was done in July, 1916.

Operation No 7: Drillers and muckers made from $4 to $4.50 per foot on contract. Ventilation was by compressed air, with water spray used after shooting.

Cycle of operations: Driller, chuck tender and two muckers came on at 7:00 a. m. Machine was set up for back and breast holes and muckers started mucking. By noon the round was half drilled and the muck was all out. After dinner the round was finished, muckers putting in track and platform. Shot at 3:20, blowing out with compressed air. Next shift comes on at 6:00 p. m. and has the same cycle of operations.

Following is detailed cost per foot:

Drillers (2)	$2.78
Trammers and shovelers	2.22
Timbermen	.30
Powder	2.42
Fuse	.19
Caps	.06
Candles	.10
Timber	.36
Powder	.58
	$9.01

Cost per foot for 1,015 ft. of drifting under all conditions: all timbered and from soft to very heavy ground:

Drillers	$ 3.90
Engineers	.12
Trammers and shovelers	3.81
Timbermen	1.20
Powder	1.19
Fuse	.13
Caps	.05
Candles	.20
Timber	1.90
Power	.60
	$13.10

Operation No. 9: Detailed cost for 150 ft. of cross cut:

Explosives	$ 142.00
Steel	20.00
Timber	37.30
Pipe	22.50
Air	20.00
Labor	993.60
Total	$1,235.40
	or $8.24 per ft.

Track, superintendence, surveying and power bring the total cost up to $10.34 per foot.

Cycle of Operations: Start setting up horizontal bar and machine at 7:00 a. m. Top holes drilled by noon and by the time muckers had the previous round mucked out; would then tear down and set up for the lifters. Round would be ready to shoot by 2:00 p. m. This operation continued for three shifts.

Operation No. 10: The best progress was 53 ft. over a 10 day period, or at the rate of 160 ft. per 30 days. The average rate was about 120 ft. per month. Actual drilling time for a round was 5 hr., setting up and tearing down taking up 2 hr.

Expenses over a distance of 100 ft.:

700 lb. power, at 17 cts	$119.00
220 caps, at $1.30 per 100	2.86
1320 ft. fuse, at $5.20 per 100 ft	6.86
160 lb. steel, at $0.093 cts. per lb	14.90
100 ft. 2-in. pipe, at 16 cts. per ft	16.00
Contract 100 ft., at $4.50 per ft	450.00
Air	20.00
Total	$629.62
	or $6.30 per ft.

Track, superintendence, surveying, assaying, apportionment of power, hoisting, etc., bring the cost up about $3.60 per ft., making the total cost $9.90 per ft.

All drilling and shooting was done on day shift. Mucking and laying planks and track was done on night shift.

378.5 man-shifts were worked, or 153 shifts day and night.

Comments on the Various Operations.—Nos. 1 and 2: These two operations afford a fair comparison of the solid-steel, piston drill, as compared with that of the water hammer drill. The 94 ft. of operation No. 1 were driven with a piston drill, 5 shifts being required to put in a round of holes. At this point (see operation No. 2) a change was made to the water-hammer drill, after which a round of holes was drilled in from 1 to 1½ shifts.

Attention is directed to the greater percentage of total cost chargeable to drilling in operation No. 1, as compared with No. 2. The increased cost of explosives and supplies in operation No. 2 is due largely to the increase in the cost of these materials in 1916 and 1917.

No. 3: This is one of two operations out of the ten in which delay exploders were used. A minimum of misfires occurred and results were reported better than blasting with cap and fuse. This cross cut was run with a hammer stoper and good progress was made. The section of the drift was small compared with the other operations. It was reported that the fact that drilling was done on one shift and mucking on the next made for economy, but not speed. Keeping of drill parts in duplicate was an important factor in lessening delays.

No. 4: This was an efficient operation. Note that the muckers came on three hours ahead of the drillers. A very important bit of information was brought out at this mine, namely: the change from 1¼ in. hollow, round steel, with cross bit, to 1-in. hollow, hexagonal steel, with Carr bit, which greatly increased the drilling speed and the number of holes that could be drilled with one set of steel.

No. 6: The striking feature here is the slow progress made with the solid-steel, piston drill.

No. 7: This is a case in which good progress was made with the piston drill. However, the ground was not of the hardest at all times and the fact that the work was done on contract had some effect on the speed. The detailed costs are interesting.

No. 8: This operation is a striking illustration of what can be done in cross cutting by day's pay plus a bonus. An average of 77 ft. was made every week. A little figuring will show plainly that the company was the gainer by paying the bonus.

No. 9: This operation showed the lowest cost in labor and explosives.

No. 10: The total cost shown for this operation was abnormally high, for the reason that there was no other work being done in the mine and all charges were directed towards this one cross cut. The progress was excellent, but on account of the fact that the ground was not as hard as any of the other operations it is hardly fair to use this operation in comparison with the others.

As indicated previously, it is believed that Operations 1 and 2 afford the best comparison between the solid-steel, piston and the water-hammer drills. However, one such operation cannot be taken as conclusive. While comparisons from the table are by no means accurate, on account of varying conditions, it is of interest to note the following: Omitting operation No. 10, the average number of shifts required to drill one round of holes was 1.81 for solid-steel, piston drills, and 1.14 for the water-hammer drills. The average advance per drill-shift was 3.10 ft. for the piston drills, and 4.07 ft. for the water-hammer drills. The average cost per foot in labor an explosives was $5 for the piston drills, and $3.66 for the water-hammer drills.

Making a further distinction, the average cost per foot in labor and explosives shows $3.62 for the water-hammer drills using the Carr bit; $3.72 for the water-hammer drills using the cross bit, and $5 for solid-steel piston drills, with cross bit.

Important Considerations.—Based on the information secured during this investigation, the following conclusions and suggestions are offered:

In the hard greenstone and slate found in the Amador County mines, the water-hammer type of drill is superior to the solid-steel piston drill.

Apparently the Carr bit does faster work in this rock.

Working by day's pay with a bonus makes for speed and economy.

The use of 1-in. hollow, hexagonal steel, with Carr bit, as against 1¼-in. hollow, round steel, with cross bit, makes for speed and economy.

It was brought out that in an operation the same progress was made by working two shifts as had previously been made working three shifts. This was due chiefly to the fact that the ventilation was very poor. The further fact was brought out that in poorly ventilated headings the efficiency of the men is often impaired, and sometimes they are entirely overcome, by powder gas. It appears that this trouble is more acute where the rock is hard. Best results seem to have been attained by blowing out the heading with a combined air and water spray after blasting. Where water is available the muck pile should be sprayed from time to time, as an aid in keeping down powder gas.

Inasmuch as the prime factor in drilling efficiency is the force and frequency of the blow struck by the drill, it is of importance to keep compressors working up to efficiency and to watch carefully for leaks in the air line so that the proper pressure may be maintained at the drill.

Drilling economy may be secured by conducting experiments on the proper strength and amount of powder to be used, the kind of bit to be used and the proper number, angle and size of drill holes.

Electrical blasting is recommended where current is available.

The keeping of detailed costs on each operation enables the operator to estimate closely the cost of proposed work. It also affords a check on work in progress, the operator at any time being able to locate any item that might be causing an unnecessary increase in cost.

Costly delays may be eliminated by keeping duplicate drill parts close at hand.

Misfires are a most important factor in causing delays. It is recommended that records be kept of misfires so that remedial measures may be taken should they exceed 2 per cent.

A good drill-steel blacksmith is an absolute necessity for efficient work.

Cost of 10 × 12 Ft. Tunnel at Copper Mountain, B. C.—Very rapid progress was made in the driving of the main haulage level at the Copper Mountain Mines of the Canadian Copper Corp., Ltd., near Princeton, B. C. The methods employed in this work were described by Oscar Lachmund, in a paper presented in the fall of 1918 at the Chicago meeting of the A. I. M. E. from which the matter in this article was abstracted in Engineering and Contracting, March 19, 1919.

Conditions were unfavorable for economical operations. The cost of power was high, for the fuel was of poor grade; besides, during the time the work was in progress, very little other power was needed so that most of the power cost was charged against the footage. The transmission line consisted of No. 4 galvanized iron wire with the result that the line loss was considerable. The voltage transmitted was about 30,000. The plant was operated under a lease, which was due to expire about the same time this work was supposed to be completed; an extension was refused; therefore speed was most important.

The plans called for a straight adit 2,900 ft. in length. At a point 2,800 ft. from the portal, two raises were to be put up to the next nearest workings, a difference in elevation of about 800 ft. One of these was to be a 2-compartment hoistway and the other a zigzag ore pass, or muck run. A location for these raises had been determined by a number of diamond-drill holes, but the material to be penetrated by the adit was not known. It seemed imperative to get the tunnel work completed as rapidly as possible, in order to allow for delays in the raising program, which were certain to occur.

The plans called for a tunnel 9 ft. high by 11 ft. wide; but owing to the "blocky" nature of some of the rock a considerable "over break" occurred. This enlarged the tunnel cross-section to 10.4 ft. by 12 ft. indicated by measurements taken at 200-ft. intervals after the work was finished and slowed up the work on account of the extra waste handled, besides increasing the cost per foot of driving. Several regions of geological disturbance were crossed and the heavy ground encountered called for timber supports. More than 350 ft. of heavy timbering was necessary at various points along the course of the tunnel; this also retarded the work to the extent of about 6 ft. per day for each set of timber placed. Once the working force was organized and the work well under way, three shifts were put on, working 8 hours each.

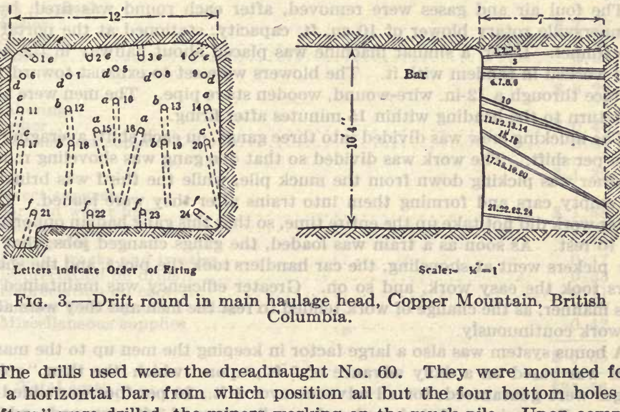


FIG. 3.—Drift round in main haulage head, Copper Mountain, British Columbia.

The drills used were the dreadnaught No. 60. They were mounted four on a horizontal bar, from which position all but the four bottom holes or "lifters" were drilled, the miners working on the muck pile. Upon completion of the upper part of the round, most of the muck had been removed; that which was left was rapidly thrown back from the face, all hands helping on this work. The horizontal bar was then torn down and dropped to the lower position, from which the lifters were drilled. The change of the bar from the upper to the lower position, together with drilling the lifters, loading, and firing the entire round, was frequently made in 50 minutes. The holes were pointed to pull a 7-ft. round and average about 9 ft. in depth. The center, or "cut holes" were fired first, after which followed the side holes, then the back holes, and finally the lifters. The drift round commonly used in this work is illustrated in Fig. 3, which also indicates the firing of the holes in groups. The blasting was done by hand, the fuses being "spit." The timing of the shots was regulated by cutting the fuse in different lengths; the shortest for the center holes, the next longest for the side holes, and so on. The lifters were loaded with extra heavy charges of powder, so as to throw the muck back from the face as much as possible. This was sometimes helped by placing charges of explosive outside and beneath the lifters; these were called muckers, and were set to go off after the rest of the round had been fired.

The powder used was a non-freezing kind, varying in strength from 40 to 60 per cent nitroglycerin, depending on the hardness of the rock at the face.

The rock was handled in small, V-shaped, hand-dump cars of about 1,000-lb. capacity. Tramming was done by hand until the distance from heading to dump became too great, when horse haulage was substituted; later this was replaced by an electric installation. Steel plates were laid on the bottom for a distance of 30 to 40 ft. from the face, to facilitate shoveling, also to permit shunting empty cars past the loaded trains and thereby eliminating the need for double track.

The cars, being light, were easily pulled from the track and, with bodies tilted, were passed on the steel plates, alongside of the loaded cars and then pushed back on to the track at the muck pile and loaded. Temporary track was laid close up to the face before firing a round. The T-rails were laid on their side, allowing the flanges of the car wheels to run on the grooves thus formed.

The foul air and gases were removed, after each round was fired, by a Connersville rotary blower of 10 cu. ft. capacity, stationed at the portal of the tunnel. Later, a similar machine was placed about halfway in the adit and worked in tandem with it. The blowers were set to exhaust toward the surface through a 12-in. wire-wound, wooden stave pipe. The men were able to return to the heading within 15 minutes after firing.

The mucking crew was divided into three gangs, on each shift, averaging 11 men per shift. The work was divided so that one gang was shoveling muck, another was picking down from the muck pile, while the third was bringing up empty cars and forming them into trains after they were loaded. This latter work did not take up the entire time, so that this gang had an opportunity to rest. As soon as a train was loaded, the gangs changed jobs; that is, the pickers went at shoveling, the car handlers took the picks, and the shovelers took the easy work, and so on. Greater efficiency was maintained in this manner, as the change of work tended to rest the men and they were able to work continuously.

A bonus system was also a large factor in keeping the men up to the mark. This was based on a daily advance of 9 ft., upon which the then "going wages were guaranteed; for all advance over 9 ft., $6 per foot was added as bonus. For each set of timber placed, an allowance of 3 ft. was made, which applied on the bonus. Current wages at the time were $4.50 for miners, $4 for helpers, and $3.50 for common labor. The bonus distribution brought these amounts up to $5.91 for miners, $5.25 for helpers, and $4.59 for muckers. The foreman and the shift bosses also shared in the bonus, the distribution being made by pro-rating the bonus in the same ratio as the amount of regular wage received by each man. Everybody seemed satisfied and no difficulties were experienced as far as the labor situation was concerned.

The work was begun on Oct. 9, 1917, and the tunnel was finished March 11, 1918, a total of 154 days. The actual working time was 150 days, four days being lost on account of a break in the power line.

The length of the adit is 2,903 ft. and the daily average progress was 19.3 ft. for each working day. The greatest advance in any one month was in December, 1917, when a total of 645 ft. was driven. The amount of rock handled is estimated at 185 tons per day. The material penetrated was granodiorite, for the greater part of the distance. The total cost of driving the tunnel was $103,242, which brings the cost per foot of tunnel to $35.56. Certain equipment and supplies were charged against the work that should have been carried in a suspense account, as most of these had a certain salvage value because it was intended to use them in the future operation of the mines. For reasons already mentioned, such as expensive power, the cost given does not really represent the actual expense of driving. Had speed not been so important no doubt the work could have been done more cheaply.

The cost items are as follows:

	Per ft
Total driving cost:	
Labor	$ 8.80
Explosives	5.72
Drills, parts and repairs	0.95
Steel, sharpening and replacement	1.37
Miscellaneous supplies	0.66
Power	2.90
	$20.40
Rock disposal:	
Labor	$ 7.52
Supplies	0.57
Power	0.20
	$ 8.29
Timbering:	
Labor	$ 0.46
Timber and supplies	0.86
	$ 1.32
Indirect expense:	
Air and water lines	$ 1.88
Electric lighting	0.35
Ventilation	1.10
Dump, tracks and trestles	0.17
Depreciation on drills	0.33
Depreciation on cars	0.11
Surface hoisting and hauling	1.19
Miscellaneous supplies	0.42
	$ 5.55
Total cost	$35.56
Timbering details:	
53 sets timber installed, cost per set	$72.62
354 ft. of tunnel timbered, cost per foot	10.83
Drilling details:	
Actual drilling hours	8.022
Actual working days	149 11/12
Average drilling hours per day	53.50
Cost of upkeep per drilling hour, in cts	22.53

Organization and Progress in Driving 7 × 12 Ft. Drift, in Hard Gneiss.— Engineering and Contracting, June 16, 1920, abstracts the following data from the Engineering and Mining Journal.

A 7-ft. × 12-ft. drift at the Harmony Mines at Mineville, N. Y., was driven a distance of 213 ft. in 36 8-hour shifts. The gang per shift consisted of two machine men and three men mucking and tramming. No. 248 Ingersoll-

Leyner drills with 1¼-in. round hollow drill steel with crossbits and ¼-in. change were used. The gage of the starter bit is 2¼ in., four changes were made, and the holes drilled according to the V-type cut system. Time fuses, No. 8 caps, and Du Pont gelatin were utilized in blasting. The two machine men drilled, loaded, and fired 26 9-ft. holes per shift, which is 234 ft. of drilling per round. The muckers loaded the dirt in 1½-ton cars and pushed them to the main slope.

Size of drift	7 ft. × 12 ft.
Holes drilled per round	26
Number of feet drilled per round	234
Number of men per shift	5
Advance of heading per shift	5.92 ft.
Advance of heading per man per month	31.93 ft.
Cu. ft. rock removed per man per shift	99.46

Cost of Small Tunnel for Sewer in Very Hard Rock.—In Engineering News Record, May 3, 1917, Charles C. Hopkins gives the cost of a tunnel 410 ft. long driven under his supervision in 1904–5 at Saugerties, N. Y. in very hard rock—Cauda galli formation.

The tunnel was 4 × 6 ft., with no water to contend with, and was to contain a sewer. The mucking was distributed and at a short distance from the tunnel entrance. The contract price for the tunnel was $7 per lin. ft. and the contractor sublet the labor at $6, furnishing the mucking equipment, explosives and hand drills. The equipment consisted of a second-hand car and track. The actual cost of 183 ft. of this tunnel was as follows:

1,500 lb. dynamite @ 10½cts	$ 157.50
2,000 ft. fuse @ ½ct	10.00
1,100 exploders @ 3cts	33.00
800 fuse caps @ 1ct	8.00
Labor @ $6.00 per ft	1,098.00
Total	$1,306.50
Cost per lineal foot	7.14

The use of the plant would be covered by not to exceed 10cts. per ft. No appreciable difference in cost was noticeable in the driving of the remainder of the tunnel. The contractor made no money on this work, but the subcontractor, after paying his helpers, earned $454.55 for the 1110 hours of his time on the 183 ft., or 40cts. per hour. The subcontractor paid his men 20 and 15cts. per hour and made about 2½ ft. per day.

Cost of One-Man-Per-Heading Tunnel Driven Through Shale.—Engineering News-Record, April 12, 1917, gives the following:

A sewer tunnel 3147 ft. long, lined with vitrified-clay segmental blocks to an interior diameter of 36 in., is a feature of the Close's Creek sewer system at Des Moines, Iowa. The tunnel is in hard shale rock that disintegrates on exposure. It is 50 to 60 ft. below the surface. Shafts for manholes were sunk at intervals of 300 ft. and headings driven in both directions from each shaft.

The excavation was sublet to miners, who used coal miners' hand drills as a rule. There was one man to each heading, and he loaded his own car and ran it to and from the shaft. The cars were of wood, with a capacity of 8 cu. ft. and ran on a track of 24-in. gage. The price for excavation was $1.75 per ft., the contractor supplying the dynamite and installing the shaft hoists. No cages were used, the cars being hitched to chain slings. The muck was dumped into wagons for removal. Some gas was encountered, and men were overcome at times, owing to lack of ventilation. No explosions occurred. There was very little water. The progress averaged 2 ft. per heading per 9-hr. day, with six to eight headings under way most of the time.

Cost of Constructing Brick Sewer in Tunnel Under Compressed Air.— Ivan A. Greenwood, gives the following in Engineering and Contracting, Jan. 10, 1912.

The Main Intercepting Sewer of Cleveland extends 13 miles along the lake shore with an outlet about 9 miles east of the center of the city.

The size varies from 5 ft. up to 13 ft. 6 ins. The grade is 2 ft. to the mile, giving a velocity of about 4.3 ft. per second and about 405,000,000 gals. capacity for 24 hours at the outlet.

The contracts for the sections completed between East 61st St. and East 79th St. were let to John Wagner, Bratenahl, Ohio. This section, 12 ft. 3 ins. in diameter, 6,850 ft. long, built by tunneling about 40 ft. under ground, was constructed with three rings of No. 1 shale brick laid with Portland cement mortar mixed in the proportions of 1 to 2. A 6-in. ring of wooden cants extended around the outside of the brickwork. The cants served the double purpose of providing a temporary roof during the mining and also saved the brickwork from damage when the shield was shoved forward by the hydraulic jacks, which braced directly against the cants.

The material encountered for the most part consisted of hard blue clay which was readily knifed. Two pockets of quicksand were encountered one of which necessitated open cutting.

But two shafts were used, one situated at the west end of the work, at East 61st St., operated with one heading; the other, situated at about two-thirds of the way between beginning and end of the work at East 70th St., had two headings. The working plant at the East 70th St. shaft contained a hoisting engine which operated the cage used for conveying material; two hydraulic pumps with a capacity for a pressure of 6,000 lbs. per sq. in., one being used on each heading; two compressors, one for each heading; two 60 h. p. boilers; one dynamo capable of lighting 200 electric lights at 110 volts, and a 30 h. p. engine for operating the dynamo. The cants were made at this plant in a separate shed by sawing sticks of 6 × 8-in. timbers, 3 ft. long, so as to conform to the circumference of the tunnel. The East 61st St. shaft had practically the same machinery, with the exception that only one boiler, one compressor and one hydraulic pump were required. The Lake Shore & Michigan Southern Ry. furnished convenient facilities for receiving material.

The work was carried on day and night. The mining was done during the day and the bricklaying at night. The work was started Oct. 1, 1909, and finished April 1, 1911. Considerable difficulty was encountered due to water and poor roof at each of the shafts when the headings were first started, and before compressed air was used. As soon as about 50 ft. of sewer had been built, brick masonry locks were constructed and the compressors started. About 14 lbs. pressure was all that could be obtained, as beyond that, the air could not be held because of the comparatively shallow depth. The average pressure used was scarcely 6 lbs. and served to keep the face and roof dry. The 3-in. pipe conveying the air was not stopped at the face end of the locks, but was carried along with the construction. Another similar pipe extended from the shaft side of the lock up to the face. This was provided with a valve and was used to take out any water accumulating at the face. It also served as a means of rapidly changing the air at the face.

The shields were of the ordinary variety, consisting of a circular steel shell with a 4-ft. follower for the roof. Two different sizes were used, one only slightly in excess of the required diameter of the tunnel and the other about 4 ins. larger. The larger proved to be much more satisfactory, for the reason that if the shield were tipped slightly in order to go up for grade, the rear end of the follower of course would come down, the result being that the cants were forced downward. This often made it difficult to get in the three full rings of brickwork in the arch. Since the removal and replacement of the cants in the arch was an arduous and sometimes dangerous piece of work, it was found much more satisfactory to have a larger shield and to carry this a little high as the time saved much more than compensated for any slight excess of brickwork required. Each shield was provided with eight hydraulic jacks 4 ins. in diameter. While it was possible to obtain a pressure of 6,000 lbs. to the square inch, as a matter of fact a pressure much over 2,000 lbs. per square inch was seldom used, because the lesser pressure proved sufficient to move the shield. The jacks were the ordinary single action jacks, long enough to shove the shield 2 ft. The jacks were pushed back into their cylinders after a shove by releasing the water and prying them with crowbars. The double acting jacks would have been much more satisfactory for this purpose. The water from the hydraulic pump was carried in a high pressure ¾-in. pipe, especial care being used to secure perfect joints at the coupling. An extension arrangement at the shield fitted with movable joints allowed the shield to progress without uncoupling during a shift.

Progress.—The actual process of mining was carried on by a force of six miners, two muckers, one timber man for the cants, and a boss miner. These men by means of knife and mattocks would dig out the clay about 2 ft. ahead of the shield. The shield would then be forced ahead, and cants set and the process repeated. Each shove would take about five or ten minutes, but the mining for each shove generally took about two hours. As a rule about five shoves a day were made. The greatest distance made for one heading in one day was a little over 17 ft., but the average per heading was about 9 ft. As fast as the material was cut out, it was placed on cars, each holding ½ cu. yd., and hauled by mules to the shaft. The cars ran directly from the tunnel onto the hoist and were raised to a platform, above the street, run out on the platform and dumped into wagons, which carried the clay to the lake shore where it was dumped into the lake. At the East 70th St. shaft the clay was dumped into cars which were hauled on a narrow gage track to the lake about a quarter of a mile away. The brick shift came on at about 7 o'clock in the evening, and stayed until the brickwork was brought up to the face. Two bricklayers with seven helpers could take care of the day's work in eight hours. Steel ribs with wooden lagging 2 ins. square and 12 ft. long were used for the arch, with 2-ft. strips of block lagging for the key.

The contractor employed one superintendent for each shaft. Each superintendent was assisted by a boss miner and mason foreman.

The sawing of the cants was sublet by the contractor. One sawing equipment did the work for both shafts.

The following tables show the make-up of each shift together with the average wage paid for each class of labor:

Mining Shift at East 61st St. Shaft (One Heading)

6	Miners at $4.50 per day	$27.00
1	Timberman at $4.50 per day	4.50
2	Muckers at $2.50 per day	5.00
1	Boss miner at $5.00 per day	5.00
2	Mule drivers at $2.50 per day	5.00
1	Lock tender at $2.50 per day	2.50
1	Cage man at $2.00 per day	2.00
1	Tipple man at $2.00 per day	2.00
2	Yard laborers at $2.00 per day	4.00
2	Dump laborers at $2.00 per day	4.00
2	Teams at $5.00 per day	10.00
1	Engineer at $4.00 per day	4.00
1	Repair man at $4.00 per day	4.00
1	Fireman at $2.00 per day	2.00
1	Superintendent at $6.00 per day	6.00
25	Total	$87.00

Bricklaying Shift at East 61st Street Shaft

2	Bricklayers at $8.00 per day	$16.00
7	Helpers at $2.00 per day	14.00
1	Lock tender at $2.50 per day	2.50
2	Mule drivers at $2.00 per day	4.00
3	Laborers at $2.00 per day	6.00
1	Engineer at $4.00 per day	4.00
1	Foreman at $3.50 per day	3.50
17	Total	$50.00

Mining Shift at East 70th Street Shaft (2 Headings)

12	Miners at $4.50 per day	$ 54.00
4	Muckers at $2.50 per day	10.00
2	Timbermen at $4.50 per day	9.00
2	Boss miners at $5.00 per day	10.00
4	Mule drivers at $2.00 per day	8.00
2	Lock tenders at $2.50 per day	5.00
2	Cage men at $2.00 per day	4.00
1	Tipple man at $2.00 per day	2.00
2	Dump men at $2.00 per day	4.00
4	Yard laborers at $2.00 per day	8.00
1	Engineer at $4.00 per day	4.00
1	Repairman at $4.00 per day	4.00
1	Fireman at $2.00 per day	2.00
1	Superintendent at $6.00 per day	6.00
39	Total	$130.00

Bricklaying Shift at East 70th Street Shaft

4	Bricklayers at $8.00 per day	$32.00
12	Helpers at $2.00 per day	24.00
2	Lock tenders at $2.50 per day	5.00
2	Mule drivers at $2.00 per day	4.00
1	Foreman at $3.50 per day	3.50
1	Cageman at $2.00 per day	2.00
3	Yard laborers at $2.00 per day	6.00
1	Fireman at $2.00 per day	2.00
1	Repairman at $3.00 per day	3.00
1	Engineer at $4.00 per day	4.00
28	Total	$85.50

The tables show clearly the advantage in economy of operating two headings from one shaft. As a matter of fact this did not work out all the time, due to a bad quicksand pocket struck in the heading going east from East 70th St., which delayed that heading until the other two headings came together.

About 750 bricks per running foot were used in construction laid with ½-in. joints. The cement used was Lehigh Portland; between 7 and 8 bags being used with about 0.6 cu. yds. sand per running foot. The cants required about 282 ft. B. M. per running foot. The contract price for the section running between E. 61st St. and E. 67th St. was $35.97 per lin. ft. and for the section running for E. 67th St. to E. 79th St. it was $32.73 per lin. ft.

Cost of Water Works Tunnels Through Waban Hill, Newton, Mass.—William E. Foss* gives the following data in Engineering and Contracting, July 22, 1914.

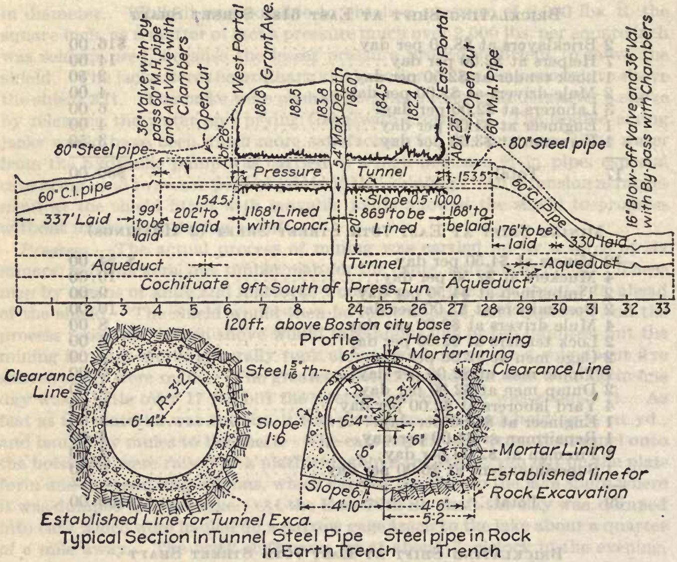


FIG. 4.—Profile and sections of pipe lines and pressure tunnel of Sect. 7 of the Weston Aqueduct supply mains.

The pressure tunnel in rock through Waban Hill in Newton, Mass., profile of which is shown in Fig. 4 was carried on under contract in 1910 and 1911, and included the construction of 2,042 ft. of 76-in. concrete lined pressure tunnel in rock, the laying of 363 ft. of 80-in. steel pipes in deep cut and lining them

*Asst. to the Chief Eng., Metropolitan Water & Sewerage Board, Boston, Mass.

with cement mortar, and the laying of 935 ft. of 60-in. cast-iron water pipe. In this article the item numbers used in the specifications are retained.

The work was begun May 24, 1910, and was suspended for the winter on December 31 of that year. It was resumed on April 1 of the following year and completed on Nov. 25, 1911.

Prior to July 1, 1911, the working day included 9 hours, from 7:30 a. m. to 5 p. m. with ½ hour for lunch, with the exception that during the driving of the tunnel the night shift worked from 7:00 p. m. to such time as the drilling was completed, with one hour for lunch. As blasting was not allowed between 6:30 p. m. and 6:30 a. m., the night shift remained on the work until the blasting was completed after 6:30 a. m. The steam plant was operated continuously through the 24 hours, the engineers working 8-hour shifts.

After July 1, 1911, all work was conducted on an 8-hour per day basis. The work of lining the tunnel with concrete was carried on continuously for six days per week. All wages were substantially the same for the 8-hour day as for the 9-hour day.

Steam plants for driving air compressors, for operating the drills, dynamos, for lighting the tunnel, and the engines for operating the stone crushers were installed at both ends of the tunnel, and the work was carried on from both portals.

Construction Plant.—An approximate estimate of the value of the plant when new is as follows:

Plant at East End of tunnel:	
2 Erie City Iron Works 75 hp. horizontal locomotive type boilers, 54 ins. diameter, 18 ft. long	$1,800.00
1 Buffalo Forge Co. dynamo engine	500.00
1 30 kw. Eddy 120-volt D.C. dynamo, with appurtenances	500.00
1 Rand Drill Co. 110 hp. air compressor	1,650.00
1 Air receiver	45.00
1 No. 3 Austin gyratory stone crusher, conveyor and screens, complete	1,975.00
1 Nagle 55 hp. crusher engine	535.00
1 Blacksmith's outfit, complete	65.00
2 2-in. Canton duplex pumps	120.00
1,200 ft. 2-in. iron pipe	120.00
1,200 ft. ¾-in. iron pipe	40.00
1 wooden water tank, 4 ft. by 5 ft.	25.00
Total cost of plant at East End	$7,375.00
Plant at West End of Tunnel:	
2 Erie City Iron Works 75 hp. horizontal locomotive type boilers, 54 ins. diameter, 18 ft. long	$1,800.00
1 Nagle 32 hp. dynamo engine	500.00
1 110-volt D.C. dynamo, with appurtenances	550.00
1 1890 Model Rand Drill Co. 110-hp. air compressor	1,650.00
1 Air receiver	45.00
1 No. 4 Austin gyratory stone crusher, conveyor and screens, complete	2,365.00
1 Buckeye Engine Co. 50 hp. crusher engine	500.00
1 Friction hoist	400.00
250 ft. ¾-in. cable	45.00
1 Blacksmith's oufit, complete	65.00
1 2-in. Canton duplex pump	60.00
2,800 ft. 2-in., 1-in. and ¾-in. iron pipe	270.00
Total cost of plant at West End	$8,250.00

General plant:

15 tons steel rails	$ 600.00
1 Smith concrete mixer, ½ cu. yd. capacity	700.00
13 3¼-in. Rand rock drills	2,795.00
6 ¾-in. Chicago Tool Co. jap drills	300.00
9 columns, arms, etc., for rock drills	450.00
3 tripods for rock drills	135.00
1 Tidewater Iron Works Cunniff type grout machine	200.00
42 steel dump cars, ⅔ cu. yd. capacity	2,100.00
10 slip scrapers	70.00
2 single dump carts	150.00
1 2-horse wagon	150.00
1 4-ton differential hoist	76.00
1 large vise	5.10
1 pipe vise	4.00
2 2-in. pipe stocks and dies	7.20
1 lead heating outfit	36.50
1 breaking up plough	24.50
6 wheelbarrows	22.50
1 stiff leg pipe derrick	56.00
Total cost of General Plant	$ 7,881.80
Total estimated value of entire plant when new	$23,506.80

Total Cost.—Including an allowance at the rate of 25 per cent per year on this valuation, for interest and depreciation on the plant during the time that it was in use, the total cost of the work exclusive of the expense of the contractor's Chicago office, his personal traveling and other expenses, and his expenses in connection with the litigation and settlement of the claims made by several property owners in the vicinity of the work for alleged damages from the blasting, is as follows:

Interest and depreciation on plant	$ 7,386.81
Labor and teaming, on payrolls	47,821.56
Materials and expenses, on bills	43,744.74
Expenditures for extra work not included above	504.88
Total expenditures	$ 99,457.99
Amount of final estimate	114,472.13
Profit	$ 15,014.14
Profit per cent of expenditures	15.1

Wages.—The prices paid for labor were as follows:

Superintendent, per month		$200.00
Clerk, per month		100.00
Brick mason, per day	$4.00 and	5.60
Blacksmith, per day	$3.50 and	4.00
Calker, per day	$3.00 and	3.60
Carpenter, per day		4.50
Drill runner, per day		3.50
Drill runner's helper, per day		2.50
Engineer, per day	$3.00 to	5.00
Foreman, per day	$4.00 and	5.00
Sub-foreman, per day	$2.50 and	3.00
Laborers (per day);		
Crusher man, lead man, powder man, stableman and teamster		2.50
Tunnel man		2.25
Ordinary		2.00
Teams (per day):		
4-horse hitch, with driver and helper		12.00
2-horse cart and driver		6.00
1-horse cart with one driver for two carts		3.00
Mules, cost of maintenance at contractor's stable, per day		1.03

Materials and Miscellaneous Expenses.—The prices paid for materials and miscellaneous expenses on bills were as follows:

Accidents, damages, etc.		$ 48.64
Blacksmith and jobbing		579.99
Bond premium ($5 per annum per $1,000 on amount of contract, as shown by canvass of bids)		818.14
Bricks, at $9.50 per M		171.50
Brick mason		49.70
Cement, delivered on work $1.72 per bbl., including cost of bags—actual net cost on work, including teaming, storage, loss of bags and cement damaged, 7,308 bbls. at $1.386		10,129.21
Coal—		
1,226 tons bituminous at $3.83 f. o. b. cars per gross ton	$4,694.02	
152 tons at $4.60 delivered on work per gross ton	698.63	
Blacksmith, 8.69 tons at $4.85	42.12	
		5,434.77
Drills and incidentals		2,394.73
Dynamite—		
40 %, 951 lbs. at $0.1225	$ 116.50	
60 %, 25,294 lbs. at $0.1625	4,110.29	
Exploders, 2,000 at $3.43 per 100	68.60	
		4,295.39
Express		294.95
Forms for concrete and mortar lining, rental		1,617.00
Grouting machine, rental		18.00
Hay and grain		1,379.33
Insurance		1,486.03
Jute, 400 lbs. at $0.06		24.00
Lead, 1,050 tons at $95.00, 4.772 tons at $97.50		565.10
Livery		65.93
Lumber—Georgia pine at $35.00; hemlock boards at $25.00; spruce, 8-in, and under, at $28.00; spruce, over 8-in., at $30.00		2,516.95
Oil—Castor at $0.35 per gal. f. o. b. Boston; compressor at $0.20 per gal., f. o. b. Boston; cylinder at $0.215 per gal., gasoline at $0.15 per gal.; kerosene at $0.13 per gal., machine at $0.185 per gal.		502.94
Repairs to plant		1,079.25
Sand—		
Coarse, 1,830.4 cu. yds. at $0.90 delivered on work	$1,647.36	
Fine, 238.3 cu. yds. at $1.25 delivered on work	298.20	
		1,945.56
Sand blasting steel pipe		701.80
Teaming		1,292.32
Telephone		231.19
Tools, hardware and miscellaneous		4,490.28
Transporting plant		1,183.97
Water		428.07
Total for materials and miscellaneous		$43,744.74

Itemized and Unit Construction Costs.—The cost of the various items of work under this contract, in detail, was as follows:

Item 1.—Top Soil Excavation (1412 *cu. yds.*)—Under this item the top soil was excavated from an area of about 0.95 of an acre for an average depth of 11 ins., where other excavations were to be made or embankments were to be built. The material was loosened with plows and transported about 180 ft. to spoil banks and slip scrapers. The cost of the work was as follows:

	Cost per cu. yd.
Superintendence and general labor	$0.04
Labor	0.21
Teaming	0.11
Small tools, etc	0.02
Incidental expenses and insurance	0.014
Plant, interest and depreciation	0.01
Total cost	$0.404
Value of work	0.60
Profit	$0.196

Item 2.—Top Soil Surfacing (1390 *cu. yds.*)—Under this item an area of about 1 acre was covered with loam from spoil banks to an average depth of 6 ins. at the west end of the tunnel, and at the east end an area of about 0.27 acre was covered to an average depth of 1 ft., and another area of about 0.27 acre was covered to an average depth of 3 ins. The entire work was done with teams. The haul averaged about 210 ft. The cost of the work was as follows:

	Cost per cu. yd.
Superintendence and general labor	$0.05
Labor	0.25
Teaming	0.19
Small tools, etc	0.03
Incidental expenses and insurance	0.015
Plant, interest and depreciation	0.001
Total cost	$0.536
Value of work	0.546
Profit	$0.01

Item 3.—Earth Excavation in Open Trench (4184 *cu. yds.*)—Under this item about 480 lin. ft. of trench for the 60-in. pipe line and 350 lin. ft. of trench for 80-in. pipe line was excavated at both ends of the tunnel. The trench for the 60-in. line averaged about 8 ft. in depth, and that for the 80-in. line was made in open cut and varied from 10 to 25 ft. in total depth in earth and rock, the depth of the earth ranging from 5 to 14 feet. The width of the trench was from 20 to 35 ft. at the top and 10 ft. at the bottom, and no attempt was made to brace the sides, which were allowed to take a natural slope. The earth was loosened with picks and shoveled into cars, which were hauled by mules to the spoil banks. The haul averaged about 350 ft. The earth excavated in the 80-in. pipe trench at the east end of the tunnel was a compact binding gravel; so hard that dynamite was used in loosening it. The large percentage of loss on this item was due to the extremely hard material in the 80-in. pipe trench at the east end of the tunnel, and to the nature of the material in the 60-in. pipe trench at this end which was largely a mixture of stone

chips and clay and was hard to excavate and brace. The cost of the work was as follows:

Item	Cost per cu. yd.
Superintendence and general labor	$0.11
Labor	0.64
Teaming	0.05
Lumber for bracing	0.01
Small tools, etc	0.07
Incidental expenses and insurance	0.04
Plant, interest and depreciation	0.02
Total cost	$0.94
Value of work	0.52
Loss	$0.42

Item 4.—Rock Excavation in Open Trench (788 *cu. yds.*)—About two-thirds of the rock excavation under this item was in the deep open cut at the east end of the tunnel, where the rock was extremely hard. On account of the liberal dimensions of the trench and the isolated location, conditions were favorable for excavating the rock cheaply. The rock was loaded on cars and transported by mules to the crusher. The haul averaged about 380 ft. The cost of the work was as follows:

Item	Cost per cu. yd.
Superintendence and general labor	$0.20
Labor	1.11
Teaming	0.10
Explosives	0.19
Drill incidentals	0.25
Small tools, etc	0.16
Incidental expenses and insurance	0.10
Plant—	
Transportation erection, repairs, operation and dismantling	0.94
Interest and depreciation	0.27
Total cost	$3.32
Value of work	3.26
Loss	$0.06

Item 5.—Refilling Open Trenches and Building Embankments (8,569 *cu. yds.)* In refilling the pipe trenches and building embankments selected fine material thoroughly consolidated with rammers and tamping irons was used for bedding the pipe. The remainder of the material was delivered from the spoil bank in cars and was spread in 6-in. layers. About one-fourth of the material paid for under this item was a sharp sandy gravel from the spoil bank of the surplus material from the 60-in. pipe trench on the adjoining section to the west. The remainder of the material was a clayey gravel

excavated from the trenches. The average haul for this work was about 300 ft. The cost of the work was as follows:

Item	Cost per cu. yd.
Superintendence and general labor	\$0.05
Labor	0.33
Teaming	0.03
Small tools, etc	0.03
Incidental expenses and insurance	0.025
Plant, interest and depreciation	0.009
Total cost	\$0.474
Value of work	0.554
Profit	\$0.08

Item 6.—*Tunnel Excavation* (2,042.5 *lin. ft.;* 6,125 *cu. yds.*)—The tunnel was excavated in rock for the entire length of 2042.5 lin. ft. The volume of material excavated was 6,125 cu. yds. which is equivalent to an average excavation of 3 cu. yds. per lineal foot. The average cross-sectional area of 81 sq. ft. is equivalent to the area of a circle 10.15 ft. in diameter, and as the established line for tunnel excavation provided for an excavation 9 ft. in diameter, with a cross-sectional area of 63.62 sq. ft. the actual cross-section exceeded the established section by 17.38 sq. ft., or about 27 per cent. It was provided that the excavation should be trimmed so that the minimum distance from the axis of the tunnel to the rock should be 3 ft. 11 ins., which would leave 9 ins. as a minimum thickness for the concrete lining. Very little trimming was necessary.

For a distance of 600 ft. from the easterly portal the tunnel was excavated in hard trap rock. For the remainder of the distance the excavation was in conglomerate with quartzite pebbles varying from 3 or 4 ins. to ¼ in. in diameter. The felsite cement was very hard in some places and extremely soft at other points, where it had changed to kaolin. About 75 ft. from the west portal a seam of clayey gravel was encountered in the roof of the tunnel, and it was necessary to support the roof on timbers for a distance of about 26 ft. Timbering was also necesssary at five other points to support the side of the tunnel where the excavation broke through into the loosely backfilled shafts of the old Cochituate Aqueduct tunnel, which is located about 9 ft. south of and 20 ft. below the new tunnel. This old tunnel was constructed by the city of Boston in 1848. At one of the old shafts the entire filling caved into the tunnel and had to be removed. Less drilling and explosives were required for the excavation of the trap rock than for the conglomerate, but it frequently broke wide of the desired line and formed an unnecessarily large section, which delayed the progress of the work because of the increased quantity of material to be moved and the caution required to prevent accidents from falling rocks. The work was carried on at both headings with day and night shifts. From 15 to 21 holes from 5 to 6 ft. in depth were drilled and blasted per shift at each heading. The force usually employed included about 12 men and 1 mule. The progress averaged about 5 ft. per shift at each heading. The drilling was done with Ingersoll-Rand drills mounted on vertical columns and operated by compressed air under a pressure of about 100 lbs. per square inch. The following cost of the tunnel excavation includes the cost of loading the excavated material on cars and transporting it to the crusher or dumps by mules. The haul averaged about 750 ft.

Item	Cost per lin. ft.	Cost per cu. yd.
Superintendence and general labor	$1.13	$0.38
Labor	6.40	2.13
Teaming	0.62	0.21
Explosives	2.03	0.68
Lumber	0.05	0.02
Drill repairs	1.08	0.36
Small tools, etc	0.96	0.32
Incidental expenses and insurance	0.78	0.26
Plant—		
Transportation, erection, repairs, operation and dismantling	5.43	1.80
Interest and depreciation	1.85	0.62
Total cost	$20.33	$6.78
Value of work	25.01	8.33
Profit	$4.68	$1.55

Item 7.—Crushing Stone (9,779 *cu. yds.*)—About 80 per cent of all the rock excavated was crushed. At the east portal the rock was delivered directly on the crusher platform and at the west portal the rock was hauled from the tunnel in cars which were left in the open cut at the foot of an incline, up which they were hauled to the crusher platform by a friction hoist operated by the crushing machinery. At both crushers the product was screened and separated into three sizes, one including stones 2 ins. to ¾ in. in diameter, another stones ¾ to ¼ in. in diameter, and the remaining portion included all materials less than ¼ in. in diameter. At the east portal it was necessary to haul about 70 per cent of the product about 100 ft. to storage piles, and at the west portal the entire product was hauled about 125 ft. to storage piles. Most of the rock was delivered to the crusher in convenient size for crushing and very little hand breaking of material was necessary. The large crusher at the west portal was operated during the day only and crushed the 24-hour output from the tunnel easily, as there were ample storage facilities for the muck at this place. At the east portal, on account of the limited storage facilities and smaller size of the crusher, it was necessary to operate the crusher during both shifts. The cost of the work was as follows:

Item	Cost per cu. yd.
Superintendence and general labor	$0.03
Labor	0.17
Teaming	0.02
Small tools, etc	0.03
Incidental expenses and insurance	0.013
Plant—	
Transportation, erection, repairs, operation and dismantling	0.15
Interest and depreciation	0.19
Total cost	$0.603
Value of work	0.75
Profit	$0.147

Item 8.—Portand Cement Concrete Masonry in Tunnel. (2,330 cu. yds. were placed within the line of the established excavation; 144 cu. yds. were placed in old shafts; 1,268 cu. yds. were placed beyond line of established excavation

but only 50 per cent of this last amount was estimated for payment, according to terms of the contract; total, 3,742 cu. yds.)

The 3,742 cu. yds. of concrete placed in lining the tunnel is equivalent to an average of 1.83 cu. yds. per linear foot. The concrete was mixed in the proportion of 380 lbs. of Portland cement, 8 cu. ft. of loosely compacted sand, and 15 cu. ft. of loosely compacted mixture of 2-in. and ¾-in. size crushed stone, giving a 1:2.22:4.17 mixture. The concrete was mixed in a steam-driven Smith mixer of ½-cu. yd. capacity, set on the platform at the tunnel so that the concrete was discharged directly into cars which were run through to the point where the lining was being placed. The concrete was dumped upon a temporary floor of steel plates inside of the circular forms which consisted of channel iron ribs spaced 5 ft. on centers, to which the curved side plates were bolted. The concrete was shoveled from the floor into the space between the forms and the rock walls and was thoroughly spaded and churned. Successive side plates were bolted to the ribs as the work progressed, and this portion of the work was completed by filling the key space at the top, the keying plates being 2.5 ft. in length, so that the concrete could be firmly packed. One hundred and fifty linear feet of forms were used, and as no inside braces were required cars could be run through them. The forms made the mould for the entire cross-section of the tunnel, except the invert strip which was 2.5 ft. wide. In placing the concrete the bottom layer was put in to within 1 ft. of the invert. The side walls and key were then filled and the 2.5 ft. wide invert was placed later.

In the westerly portion of the tunnel the bottom layer was placed on both sides of the track, which was left supported on a central strip of muck which was later removed, just before placing the invert.

In the easterly portion of the tunnel the track was thrown to one side while the bottom layer of concrete was placed on the opposite side. The track was then shifted on to the concrete already placed and concrete was then placed on the other side. The work was carried on in three 8-hour shifts. Forms were removed and set up in one shift and concrete was placed during the remaining 16 hours. The average progress per 24 hours was about 35 lin. ft. of completed section, except for the 2.5 ft. invert strip which was placed and finished to line with a screed after the track and forms were removed.

The concrete was transported an average distance of 620 ft. and the crushed stone an average distance of 240 ft. from the storage pile to the mixer. The sand and cement were usually delivered to within a short distance of the mixing platform.

The cost of this work has been sub-divided to show the cost of forms separate from the cost of mixing and placing the concrete, as follows:

Item	Cost per cu. yd.
Forms:	
Superintendence and general labor	$0.08
Labor	0.45
Teaming	0.06
Lumber	0.03
Small tools, etc	0.07
Incidental expenses and insurance	0.06
Rental and transportation of forms	0.40
Plant—	
Transportation, erection, repairs, operation and dismantling	0.38
Interest and depreciation	0.06
Total cost	$1.59

Item	Cost per cu. yd.
Mixing and placing concrete:	
Superintendence and general labor	$0.20
Labor	1.13
Teaming	0.11
Sand	0.38
Cement	2.11
Small tools, etc	0.17
Incidental expenses and insurance	0.13
Plant—	
Transportation, erection, repairs, operation and dismantling	0.96
Interest and depreciation	0.27
Total cost	$5.46
Total.	
Superintendence and general labor	$0.28
Labor	1.58
Teaming	0.17
Lumber	0.03
Sand	0.38
Cement	2.10
Small tools, etc	0.24
Incidental expenses and insurance	0.19
Rental and transportation of forms	0.40
Plant—	
Transportation, erection, repairs, operation and dismantling	1.35
Interest and depreciation	0.33
Total cost	$7.05
Value of work	8.44
Profit	$1.39

Item 9.—Portland Cement Concrete Masonry in Open Trench (451 *cu. yds.)*—With the exception of a little concrete used for anchorages and backing on the 60-in. cast-iron pipe line, the concrete masonry placed in open trenches was used for covering the 80-in. steel pipe line. The quantity used for this purpose averaged about 0.84 cu. yd. per linear foot of pipe line. This concrete was mixed in the proportion of 380 lbs. of Portland cement to 10 cu. ft. of loosely compacted sand and 18 cu. ft. of a loosely compacted mixture of 2-in. and ¾-in. size crushed stone, making a 1:2.78:5 mixture.

At the west portal the concrete was hand mixed and as the trench was almost entirely in earth, wooden forms were used for the entire section. At the east portal, where the trench was almost entirely in rock, the concrete was placed up to the springing line of the arch, without forms, wooden forms being used for the remainder of the section. At this place the concrete was mixed in a steam-driven Smith mixer and hauled about 100 ft. Before constructing the forms and placing concrete around the steel pipe, it was braced inside to true circular form, and the outside was cleaned to bright iron with a sand blast and then painted with a thick coat of cement paint made by mixing 10 lbs. of cement with 5 lbs. of water. Holes were left in the concrete at the top of the pipe, through which the cement mortar lining was placed later.

The cost of the work has been sub-divided to show the cost of forms separate from the cost of mixing and placing the concrete, as follows:

Item	Cost per cu. yd.
Forms:	
Superintendence and general labor	$0.12
Labor	0.65
Teaming	0.05
Lumber	0.20
Small tools, etc	0.07
Incidental expenses and insurance	0.04
Plant, interest and depreciation	0.001
Total cost	$1.131
Mixing and placing concrete:	
Superintendence and general labor	$0.27
Labor	1.50
Teaming	0.13
Sand	0.53
Cement	1.63
Sand blasting	0.78*
Small tools, etc	0.20
Incidental expenses and insurance	0.12
Plant—	
Transportation, erection, repairs, operation and dismantling	0.60
Interest and depreciation	0.07
Total cost	$5.83
Total:	
Superintendence and general labor	$0.39
Labor	2.15
Teaming	0.18
Lumber	0.20
Sand	0.53
Cement	1.63
Sand blasting outside of 80-in. pipe	0.78
Small tools, etc	0.27
Incidental expenses and insurance	0.16
Plant—	
Transportation, erection, repairs, operation and dismantling	0.60
Interest and depreciation	0.07
Total cost	$6.96
Value of work	6.43
Loss	$0.53

* Cost per sq. ft. of surface cleaned = 4.6 cts.

Item 10.—*Brick Masonry* (*36 cu. yds.*)—This item included brick masonry used in constructing valve chambers and raising manholes on the Cochituate Aqueduct. The cost of the work was as follows:

Item	Cost per cu. yd.
Superintendence and general labor	$ 0.84
Labor	6.12
Sand, obtained on work	0.14
Cement	2.19
Bricks	4.62
Small tools, etc	0.53
Incidental expenses and insurance	0.34
Plant, interest and depreciation	0.01
Total cost	$14.79
Value of work	15.59
Profit	$ 0.80

Item 11.—*Cement Grout in Tunnel* (292 *cu. yds.*)—When the concrete tunnel lining was placed, 1½-in. steel pipes with couplings on the outer ends, which were temporarily plugged with wood, were run into all seams and cavities which could not be properly filled with concrete. The spacing of the grout pipes was governed to a large extent by the character of the walls of the tunnel at various points. Extra pipes were placed at each of the old shafts on the Cochituate Aqueduct, and in the section where the roof was supported by timbers in the gravel about 75 ft. from the west portal. Under ordinary conditions the average distance between grout pipes was about 20 ft. The pipes and couplings were furnished by the Commonwealth. The specifications provided that grout pipes should be placed so that all voids could be filled without forcing the grout more than 10 ft. in any direction, but it was found that the grout actually traveled much greater distances.

The grouting was not begun until after the lining was entirely completed and the concrete had attained considerable strength and most of the shrinkage cracks had developed. It was required that the sand used for grouting should all pass through a sieve having 64 meshes per square inch, and that at least 40 per cent should pass through a sieve having 1 600 meshes per square inch. In making the grout 4 cu. ft. of sand was mixed dry with 380 lbs. of Portland cement. The mixed material was then divided into nine equal parts and put up in bags in which it was transported to the point where grouting was in progress. Three bags of this material and 1.2 cu. ft. of water were used in charging the grout machine. The machine was a tight steel cylinder about 4 ft. high and 18 ins. in diameter, with a 1-in. connection for admitting the compressed air, and a 2½-in. outlet. It was charged through an opening at the top provided with a heavy cover fitted with a rubber gasket. The compressed air for operating the machine was obtained from the plant at the east portal, which at this time it was necessary to keep in operation solely for this purpose. The pressure averaged about 80 lbs. per square inch. The grout was mixed by turning in compressed air at the bottom, which kept the mixture "boiling" and prevented the sand and cement from settling and choking the outlet pipe. About 0.14 cu. yd. of grout was used per linear foot of tunnel. Three hundred and eighty pounds of cement made about 0.9 cu. yd. of grout. The amount of grout required was probably increased about 25 per cent on account of the amount required at the old Cochituate Aqueduct shafts and at the point where timbering was required near the west portal of the tunnel. The cost of the work was as follows:

Item	Cost per cu. yd.	Cost per lin. ft.
Superintendence and general labor	$ 0.60	$0.09
Labor	3.34	0.48
Teaming	0.01	0.002
Sand	0.76	0.11
Cement	4.58	0.65
Small tools, etc	0.50	0.07
Incidental expenses and insurance	0.30	0.04
Rental, transportation and repairs of grout machine	0.09	0.013
Plant—		
Transportation, erection, repairs, operation and dismantling	2.83	0.40
Interest and depreciation	0.22	0.03
Total cost	$13.23	$1.884
Value of work	12.66	1.810
Loss	$ 0.57	$0.074

Item 12.—*Cement Mortar Lining of* 80-*In. Steel Pipe* (363 *lin. ft.*)—The mortar lining for the 80-in. steel pipe was made 2 ins. thick and was cast in place by pouring a thin mortar into the space between the steel pipe and a central collapsible steel form of the Blaw type, which was held in correct position by means of adjustable bolts, located around the circumference of the form and which were brought to a bearing upon the steel pipe so as to provide the desired 2-in. space for the mortar. The forms were made in sections 7 ft. long, each section consisting of five circular segments bolted together with an adjustable wooden key piece at the top. The mortar was poured through 2-in. holes in the top of the pipe, the lining being cast in sections 14 ft. long, without interruption in the flow of mortar after the pouring of a section was once started.

The end of the section was closed by means of a hose extending around the circumference and expanded by means of water pressure, forming a bulkhead at the end of the annular space between the steel pipe and the form.

Before setting up the forms, the interior of the pipe was cleaned to bright iron with a sand blast and it was then painted with a cement wash in the same manner as the outside of the pipe, described under Item 9. The mortar was mixed in the proportion of 1 part of Portland cement, two parts of sand and water amounting to about 25 per cent of the volume of these materials.

On account of the short length of pipe to be lined, the mortar was mixed by hand in barrels supported on a wooden platform above the top of the pipe. One cubic yard of mortar required four barrels of cement, and was sufficient for lining 7.9 ft. of the pipe.

The cost of the work has been sub-divided to show the cost of forms separate from the cost of mixing and pouring the lining, as shown in Table IX.

TABLE IX.—COST OF PLACING 2-IN. MORTAR LINING OF 80-IN. STEEL PIPE

Item	Cost per lin. ft. of pipe	Cost per sq. ft. surface covered
Forms:		
Superintendence and general labor	$0.13	
Labor	0.74	
Teaming	0.04	
Small tools, etc	0.08	
Incidental expenses and insurance	0.05	
Rental, transportation and repairs of forms	0.77	
Plant, interest and depreciation	0.002	
Total cost	$1.812	$0.086
Mixing and pouring lining:		
Superintendence and general labor	$0.12	
Labor	0.67	
Sand blasting	0.97	
Sand	0.21	
Cement	0.74	
Small tools, etc	0.07	
Incidental expenses and insurance	0.05	
Plant, interest and depreciation	0.002	
Total cost	$2.832	$0.135

TABLE IX.—*Continued*

	Cost per cu. yd.	Cost per lin. ft.	Cost per sq. ft. of surface covered
Total:			
Superintendence and general labor	$ 1.97	$0.25	
Labor	11.10	1.41	
Teaming	0.29	0.04	
Sand blasting	7.62	0.97	
Sand	1.66	0.21	
Cement	5.80	0.74	
Small tools, etc	1.24	0.15	
Incidental expenses and insurance	0.79	0.10	
Rental, transportation and repair of forms	6.03	0.77	
Plant, interest and depreciation	0.03	0.004	
Total cost	$36.53	$4.644	$0.222
Value of work	45.50	5.78	0.276
Profit	$ 8.97	$1.136	$0.054

Items 13 *and* 15.—*Laying* 60-*In. Cast Iron Pipe* (935 *lin. ft.*)—The work of laying the 60-in. cast iron pipes included the teaming of the pipes about two miles, unloading them from the wagons and laying them in trenches, including the furnishing of all materials required. The excavation and refilling of the trenches was paid for under Items 3, 4 and 5. The cost of the portion of the work included under these items was as follows:

Item	Cost per lin. ft.
Superintendence and general labor	$0.23
Labor	1.30
Teaming	0.38
Jute	0.03
Lead	0.60
Blocking and wedges	0.14
Small tools, etc	0.02
Incidental expenses and insurance	0.05
Plant, interest and depreciation	0.003
Total cost	$2.753
Value of work	2.113
Loss	$0.64

The cost of teaming the pipe was $0.38 per ton mile.

Item 14.—*Laying* 80-*In. Steel Pipe* (363 *lin. ft.*)—The 80-in. steel pipe was delivered to the contractor in sections 20 ft. in length and was hauled by him to the work, a distance of about two miles. It was necessary to roll the pipes on skids for an average distance of 100 ft. from the point of delivery to place them in position. The steel pipes were furnished by the Hodge Boiler Works of East Boston, and were placed, riveted together, lined and covered by the contractor for building the tunnel. Each 20-ft. section of the pipe was made of three alternately large and small courses, each course being formed of a single sheet of flange steel 6 ft. 11 ins. wide and 5/16 in. thick. The longitudinal joints were lapped 4⅜ ins. and double-riveted with ¾-in. rivets spaced 2⅞ ins. from center to center. The circular joints were lapped 2½ ins. and single-riveted with ¾-in. rivets spaced about 2⅛ ins. on centers. At intervals of about 40 ins., pads 6 ins. in diameter and ½ in. in thickness were riveted on top of the pipe, through each of which was drilled and tapped a hole for a 2-in.

diameter steel plug. As previously stated these 2-in. holes were used for introducing the Portland cement mortar for lining the steel pipe. At the junction between the 76-in. mortar-lined steel pipes and the 60-in. cast iron pipes, 76 × 60-in. cast iron branches were set and the 60-in. outlet capped for future use when an additional main shall be required. The cost of the work under Item 14 was as follows:

Item	Cost per lin. ft.
Superintendence and general labor	$0.374
Labor, laying pipes	1.08
Labor, riveting	1.03
Teaming	0.20
Small tools, etc	0.234
Incidental expenses and insurance	0.15
Plant, interest and depreciation	0.004
Total cost	$3.072
Value of work	3.376
Profit	$0.304

The cost of teaming the pipe was $0.62 per ton mile.

Item 16.—Extra Work.—The extra work required under the contract included the excavation and timbering of six old shafts on the Cochituate Aqueduct tunnel, where the excavation for the new tunnel broke through into these old shafts, and also some miscellaneous work. For this work the contractor received the actual cost of the work plus 15 per cent, and the total amount paid under this item was $925.89.

Organization and Progress of St. Louis Water Works Tunnel.—C. H. Hollingsworth, superintendent for the contractors, gives some interesting data in regard to the St. Louis Waterworks Tunnel in Engineering and Contracting, May 6, 1914, and Engineering Record, May 9, 1914, from which articles the following data are taken.

The tunnel was driven in both directions from a drainage shaft at the river bank, the shore tunnel being 537 ft. long and the river tunnel 2252 ft.

When the work became well organized it was found that with only one shot in eight hours there was considerable spare time. About 1¾ hours were required to muck out the heading, ½ hour to set up, 3 hours to drill the round of holes, from ½ to ¾ hour to blow out and load and from 50 minutes to 1 hour to shoot. This left from 1 to 1½ hours idle time per shift, part of which was taken up in clearing out the smoke. The smoke was taken care of by a No. 2 Roots reversible blower with 10-in. opening.

Arrangement of Holes.—If it had been possible a longer round would have been drilled to take up the spare time. As it was, however, an 8-ft. round was drilled and would not break the ground to advantage. The trouble was that the tunnel was so narrow that it was impossible to give the cut holes much of an angle with each other. A center cut of six holes, three on each side, was adopted after several other methods had been tried. The arrangement of the holes used through the greater part of the work called for sixteen holes, but occasionally seventeen were drilled. By drilling a 6 or 7-ft. cut and a 4 or 5-ft. side round the ground could be broken with less powder.

Late in December a schedule of four shots in twenty-four hours was started. Working this way the day shift came on at 8 a. m. when the preceding shift had finished shooting. They mucked out the heading, set up, drilled and finished shooting at 2 p. m. Then they mucked out and set up the machines ready for the next shift. The 4-to-12 shift drilled a round and finished shooting it about 8 p. m., and then mucked out, set up and drilled ten or twelve holes on the second round before midnight. The 12-to-8 shift then came on and finished the drilling of the round and shot it about 2 a. m., after which they mucked out, set up, drilled and shot another round before 8 o'clock.

While it was found that after getting this system working the gangs had plenty of time for the various operations, the scheme never worked satisfactorily, for the reason that it is never advisable for one shift to leave work for the next shift to complete. For instance, the way in which the columns were set up by the day shift never suited the 4-to-12 shift and they often tore them down and reset them, while the 12-to-8 shift was always displeased about the way the 4-to-12 shift started the round of holes and claimed that they often had to drill some of them over again.

The time taken for the different operations with four shots per day was about as follows: Mucking out, 1 hour; setting up, 30 minutes; drilling, 3 hours; blowing out and loading, 30 minutes; shooting, 45 minutes; blowing out smoke, 15 minutes.

In order to arrange so that the shifts would each finish their own work I decided to try two shots every shift, and if necessary drill shorter rounds. At first a 6-ft. cut with a 4-ft. side round was drilled, but after the gangs had shaken down to the proper swing 7 and 8-ft. cuts and 5 or 6-ft. side rounds were drilled. The only extra men put on to carry out this schedule were an extra helper in the heading and a foreman and from four to six men on the day shift to fix track and attend to the ditching.

With four shots per day all three shifts used the columns and when the six shots per day started one of the gangs preferred the columns as the heading foreman on that shift was not familiar with the use of the bar. The bar, however, was finally used on all three shifts. A 4½-in. bar 10 ft. long with a single screw was used with four arms on it. The machines were mounted on clamps on these arms, two above and two below the bar. It was necessary even with the bar to muck out the heading to a great extent before setting up the drills, as there was positively no room for even one mucker in the heading after the machines were up and the heading gang working. To help clear the muck away from the face after the four-shot schedule was started two muck shots were placed in the heading and fired with the last holes of the round. These muck shots consisted of from 7 to 10 lb. of powder each, and one was placed on each side of the tunnel close to the face.

When the two-shots-per-shift program was in progress the time was divided about as follows: Mucking out heading, 45 minutes; setting up, 15 minutes; drilling, 2 hours; blowing out and loading holes, 20 minutes; shooting, 30 minutes; clearing out smoke, 10 minutes.

Plant.—The plant used on the tunnel work included three 75-h.p. locomotive-type boilers supplying steam for the compressors for the pumps at the bottom of the shaft and for the hoisting engine for the cages. While sinking the shaft a stiffleg derrick was used and this was later used on the excavation for the screen chamber. The pumps used to take care of the water from the tunnel included a Knowles piston pump and two duplex Worthington plunger pumps. A Norwalk two-stage compressor was used, assisted later on by a single-stage Ingersoll compressor. Current was obtained from the city at 2300 volts, alternating current, and transformed to 220 volts.

Mucking.—A 3-ton General Electric storage-battery locomotive was used to handle the muck cars to and from the shaft after the headings had progressed a few hundred feet from the shaft. The muck cars were specially designed for the work and were wooden box cars, with a door in one side for dumping, and an incline in the bottom of 1 ft. toward the door. The bottom of the car was covered with steel plate and the box itself was built of 2-in. oak well bolted together and fastened at the corners with angle irons. At the ends were eye-bolts running through the frame so that the cars could be coupled in a train. Usually three cars were handled by the locomotive.

In the heading slick sheets of ⅜-in. boiler plate were used to cover the end of the track and to facilitate the shoveling. In working into the muck pile only four men, or occasionally five, could work abreast, and even then it was necessary to select carefully the right and left hand shovelers and keep them on their respective sides. The usual method was to use four men abreast with two more on the muck pile throwing over their heads and loosening up the muck. Two more men worked behind the car picking up bottom, fixing track and helping dump the cars off the track and back on again. On the locomotive there was a motorman and also a switchman, both of whom helped dump off cars.

At the bottom of the shaft were two men who pushed the cars on and off the cages and on top were a top man and three men for pushing cars. One man took care of the pumps which were at the bottom of the shaft and did the pipe fitting. An extra gang consisting of a foreman and from four to six men was employed on the day shift cleaning out the ditch along the tunnel and laying new track. All permanent track was laid on the day shift. The other two shifts put down short sections of rail temporarily. From forty to sixty-five cars of muck were taken out of the one heading on each eight-hour shift, the cars holding about 1 cu. yd. of muck.

Organization and Wages.—In the regular gangs on each shift there were the following men at the rates given:

Force on top: Number and grade	Rate per day
1 compressor engineer at	$7.00
1 hoisting engineer at	7.00
1 fireman at	3.20
1 signal man at	2.80
3 top men or car pushers at	2.40
Force in the tunnel:	
1 pump man and pipe fitter at	4.00
2 cage men at	2.80
1 motor man at	4.00
1 switchman at	2.80
1 muck foreman at	4.80
6 to 8 muckers at	2.80
1 heading foreman at	5.00
4 drill runners at	3.60
4 or 5 helpers at	3.00
1 nipper at	3.00
1 electrician at	4.00
Force of extra men on Day Shift (on top):	
1 blacksmith at	5.00
1 helper at	4.00
1 machinist at	4.00
1 machinist helper at	2.40
In the tunnel:	
1 extra muck foreman at	4.80
4 to 6 extra muckers at	2.80

Rate of Progress.—Taking all things into consideration, the progress was very satisfactory, especially while making the six shots per day.

During the month from 8 a. m. Jan. 21 to 8 a. m. Feb. 21 the progress was 744.7 ft., and for the best week, which was the week ending at 8 a. m. Feb. 20, the progress was 184 ft. This latter was for the full week of seven days or 21 shifts. The month's progress, however, was for 29 days and two shifts, as during the 31 days of the month there were four shifts lost time. The best progress made in one day was 29.1 ft.

The east heading was finished March 4, and a gang on each shift was started immediately cleaning up the bottom and trimming. The gang on each shift consisted of a foreman and ten men mucking, besides one drill runner and three helpers, with the usual cage men, top men, etc. On March 19 a second gang was started on each shift, there being a foreman and ten men in this second gang also. One of these gangs worked from the heading toward the shaft and the other worked from the shaft toward the heading, and on April 1 the trimming was completed and practically all of the bottom had been taken up. In places there were from 50 to 75 ft. that required no trimming at all and less than 200 ft. of the roof required trimming. On the other hand there was less than 100 ft. of the roof that was outside of the 11 ft. circle.

Bonus System.—A bonus system was put in force in the early stages of the work and helped materially in the progress. A minimum of 72 ft. of tunnel per week was set and for all over that the following bonus rates were paid:

	Cts. per ft.
Heading foreman	50
Muck foreman	30
Drill runners	30
Drill helpers	20
Nipper	20
Muckers and cage men	10

From the total weekly progress ending every Friday morning at 8 o'clock 72 ft. was subtracted and each shift received bonus on one-third of the remainder, each shift being credited with one-third of the extra progress.

Cost of Tunnel No. 7 of the Los Angeles Aqueduct.—The following study by C. H. Richards, Division Engineer Little Lake Division, Los Angeles Aqueduct (Engineering News, Nov. 18, 1909) covers the unit costs of driving a timbered tunnel during the 15 day period from Aug. 15 to Aug. 29, 1909. The figures refer to the north heading only.

During this period 90 ft. were driven in 15 8-hour shifts. The tunnel is approximately 10 × 10 ft. in section and contains 3½ cu. yds. in place per lineal foot to pay line. The over-breakage was about 17 per cent, making a total of 6½ cu. yds. of broken material per foot of tunnel.

The heading is 800 ft. in from the portal. It is lighted by electricity in 110 volts, and ventilated by a No. 3 Champion blower through 12-in. pipe, the heading being cleared in fifteen minutes after shooting.

Drilling is done by one No. 7 Leyner drill, water being forced through the hollow steel. This drill used approximately 66 cu. ft. air per minute at 83 lbs. pressure, drilling holes to 10 ft. in depth.

Mucking is facilitated by steel sheets laid down before shooting. The muckers use No. 3 D-handle square-point shovels. Dirt is hauled away in 32 cu. ft. rocker dump cars pulled by a 3½-ton locomotive running on a single 24-in. gage track laid with 25-lb. steel.

The rock is a close-grained hard gray granite, with numerous seams, causing the drill to run from alignment, but it breaks well. The seams and water combined make it necessary to timber all this ground. The ground carries enough water to make disagreeable mucking, and to require pumping.

The timbering comprises sets of 6 × 8-in. Oregon pine, spaced 5 to 8 ft. apart, as ground permits, and 2 × 6 lagging. Each set consists of two vertical posts and a four-segment arch.

The crew consisted of one shift boss at $3.50 per day; four miners at $3 five muckers at $2.50, and one trammer at $2.50. The blacksmith doing the repair work was paid $4 per day.

The four miners worked on day shift, drilling the ground, timbering and shooting. The muckers followed on night shift. This arrangement resulted in a clean heading for the drill crews, and nothing interfered with the mucking crew.

The cost of work during the 15-day period is tabulated below in detail (Table X).

TABLE X.—SHOWING UNIT COSTS OF TUNNELING AND TIMBERING, NORTH HEADING OF TUNNEL NO. 7, LITTLE LAKE DIVISION OF LOS ANGELES AQUEDUCT
For 15-day period, Aug. 15–Aug. 29, 1909; advance 90 ft.

Class of work	Totals for 90 ft. length Labor Hours	Totals for 90 ft. length Labor Cost	Cost lin. ft. tunnel
Labor:			
Inside labor:			
Squaring heading	23.5	$ 9.03	$ 0.10
Setting up and tearing down machine (1)	36.0	16.59	.184
Drilling, incl. time of shift boss (3.6 cts. per ft. of hole)	55.33	43.21	.48
Blowing out holes	5.75	4.15	.046
Loading and shooting	56.25	22.31	.248
Mucking (412 cars)	835.0	268.44	2.98
Trimming, stulling, caves, etc	102.0	39.24	.436
Timbering ($11.32 per M)	107.25	40.82	.453
Lost time	40.75	15.66	.174
Bonus (30 cts. per man per ft. over 2.3 ft. per shift)		112.08	1.24
Repairs to trolley, pump, etc	3.25	1.20	.013
Totals, inside labor	1,265.08	$ 572.73	$ 6.354
Outside labor:			
Sharpening steel (with Leyner No. 2 machine)	44.0	$ 17.83	$ 0.198
Repairing drill	7.5	2.88	.032
Framing timbers at shop ($2.42 per M)		8.75	.097
Light and power	90.0	33.75	.375
Totals outside labor	141.5	$ 63.21	$ 0.702
Auxiliary labor:			
Laying track, 90 ft	31.5	$ 12.75	$ 0.141
Drainage line, 90 ft	43.5	14.33	.16
Ventilation line, 72 ft	11.0	3.44	.048
Trolley line, 95 ft	18.0	6.35	.067
Air line, 80 ft	2.5	.80	.01
Water line, 80 ft	2.5	.79	.01
Lights line, 90 ft	8.0	2.86	.032
Totals auxiliary labor	117.0	$ 41.32	$ 0.468
Local administration and engineering:			
Proportion of division engineer and assistant's time		$50.40	$ 0.56
Total labor cost		$ 727.66	$ 8.084

TABLE X.—*Continued*

Material:		
Construction Material and Supplies:		
Drill repairs	$ 22.47	$ 0.25
($0.018 per ft. hole)		
Drill supplies, oil steel, coal	9.41	.104
($0.008 per ft. hole)		
Mucking supplies, oil, etc	.73	.008
Power and lighting current	71.52	.795
(4,207 kw. hrs., at 1.7 cts.)		
Explosives, powder, fuse, caps, etc	157.69	1.752
(11.66 lbs. powder per ft. tunnel)		
Timbers, wedges, dowels, nails, etc	122.16	1.36
(3,579 ft. B. M. = 40 ft. B. M. per ft. tunnel)		
Lighting (candles $8.59, el. lt. globes $3.09)	11.67	.13
Totals, constr. material	$ 395.65	$ 4.399
Auxiliary material:		
Trackage, 25-lb. rail, ties, etc	$ 21.11	$ 0.235
Drainage, 2-in. pipe and el. wire	7.87	.087
Ventilation, 12-in. pipe (for 72 ft.)	29.21	.405
Trolley, wire, etc. (for 95 ft.)	9.73	.102
Air line, pipe, etc. (for 80 ft.)	7.25	.09
Water line, pipe, etc. (for 80 ft.)	7.25	.09
Lights line, wire, etc	2.22	.025
Totals, auxiliary material	$ 84.64	$ 1.034
Total material	$ 480.29	$ 5.433
Live stock:		
Mule, 15 days at 90 cts	$ 13.50	$ 0.15
Total direct and auxiliary field charges	$1,221.45	$13.667

To explain the table further the following particulars are noted as to drilling and powder:

Drilling.—During the 15-day period 150 holes were drilled, aggregating 1,202.3 ft. in length. The average depth of hole therefore was 8 ft. The average speed of drilling was 21.74 ft. hole per hour of actual drilling time, or 15.84 ft. per hr. if lost time is included. This means that the average hole (8 ft.) was drilled in 22 mins. The fastest hole, however, was 9 ft. 6 ins., drilled in 10 mins., while the slowest was 8 ft. 6 ins., drilled in 78 mins. The average cost of drilling per foot of hole was 3.6 cts., as given in the table.

Explosives.—There were used 650 lbs. of 1⅛-in. 40 per cent gelatine; 250 lbs. 1-in. 40 per cent gelatine, and 150 lbs. 1-in. 60 per cent gelatine, a total of 1,050 lbs. This is 11.66 lbs. per lin. ft. of tunnel, or 3.3 lbs. per cu. yd. place measurement. The cost (delivered) was $140.87. Adding the cost of fuse (2,700 ft. $13.85), caps (306 = $2.49), and tamping stick ($0.48), makes the total cost $157.69, which is about $0.50 per cu. yd. place measurement and $0.27 per cu. yd. loose.

The following summarized the above cost, together with the field and office charges assessable to the work. Attention may be called to the fact that the figure $12.165 given as direct charge differs from the previous total of $13.667 by the amount ($1.502) charged for tracks, the latter being included in the previous detail tabulation. In the recapitulation the auxiliary charge is reduced by the estimated amount of salvage on the track material.

RECAPITULATION OF UNIT COSTS

Class of charge		Cost per foot of tunnel
Direct charges:		
Labor	$7.056	
Material and supplies	4.399	
Local administration and engrg	0.56	
Live stock service	0.15	
		$12.165
Auxiliary charges:		
Labor on tracks, etc	$0.468	
Material for tracks, etc	1.034	
	$1.502	
Salvage on material about 66 %	.69	
		0.812
Roads and trails*		1.50
Buildings*		0.20
Water supply*		0.22
Machinery and tools		1.06
Total fixed charges		$15.957
Add 3 % for executive office administration		0.475
Total cost of tunnel, timbered and ready for lining, per lin. ft.		$16.432

* The total cost of these works on the entire division, apportioned to the severa parts of the permanent construction, gives as estimated charges per foot of this tunnel the figures noted.

Deducting from the total of $13.667 of Table X the charges that obviously belong to timbering we get a cost of $11.75 per lin. ft. for excavation, which is equivalent to $3.36 per cu. yd.

Bonus System for Tunnel Work of the Los Angeles Aqueduct.—The following notes are abstracted from the Report on the Los Angeles Aqueduct.

To complete the Los Angeles Aqueduct within a reasonable time limit so as to avoid undue interest charges on the bond issue the controlling factor was recognized by all to be the great length of tunnels, 164 in number, and especially the Elizabeth Tunnel, which is more than 5 miles long. This tunnel, passing through the crest of the Coast Range, more than 20 miles from a railroad base of supplies, had to be driven from two headings only and lined throughout with concrete. A fair rate of progress for tunnels of this size, and in a similar geological formation, has been a mile a year from the two headings, or five years in all.

It was therefore important to devise some method of work which would develop speed and the bonus scheme was adopted. This was modified from time to time, as experience was gained in its application, and the following schedule is the final outcome.

Theory of the Bonus System.—The tunnels were driven for a few months, and the number of men who could work efficiently in the headings, together with their progress, was noted under different conditions. A standard size crew was then authorized, which could not be exceeded. In the Elizabeth tunnel, the number was 16 men for untimbered tunnel and 23 for timbered tunnel. Only those engaged inside on the driving of the heading, trimming, timbering, etc., were included in the bonus crew. The required progress was fixed. At the Elizabeth tunnel it was 8 feet per day, or 2⅔ feet per shift for untimbered tunnel, requiring the excavation of 4.18 cubic yards per lineal foot, and 6 feet per day, or 2 feet per shift for timbered section of the tunnel, requiring the excavation of 5.02 cubic yards per lineal foot, and the placing of 115 feet board measure of lumber. A base wage was paid of $3.00 per day for miners and timbermen, and $2.50 per day for muckers (shovelers). In wet tunnels, 50 cents a day additional was paid. Eight-hour shifts were worked.

For all excess footage over the base rate made by a shift each man on the shift was paid 40 cents a foot in the Elizabeth tunnel. In other tunnels the bonus paid varied from 20 cents to 40 cents per foot, depending on the character of the rock. Each tunnel was inspected by the Chief Engineer or his assistant, and a reasonable rate of progress and bonus pay determined, which when approved by the Board of Public Works, was effective for that tunnel. The superintendent and foremen did not share in the bonus pay, as it was their duty to see that the quality and quantity of the work was up to par. Measurements were made on the 10th, 20th and last day of each month to determine the progress. Any man receiving bonus was required to work continuously through the ten-day bonus period.

The theory of the schedule is to pay the men a fair wage for the day's work, and in addition to give them a share approximating 50 per cent of the estimated saving, in case the base rate of progress is exceeded. It must be kept in mind that the labor charge per day for the driving of a tunnel is a fixed amount, including not only those engaged in the tunnel, but also the outside organization of mechanics, superintendent and clerks. The cost of explosives and power varies with the footage made. Therefore, the greater the rate of progress, the lower the final unit cost of the work will be.

Effect of the Bonus.—The sharing of the benefits with the men by means of the bonus system resulted in an improved relation with them. They became interested in the success of the work. The men in a bonus crew themselves eliminated the drones and did not tolerate loafing. The duties of the foremen and superintendent were almost entirely confined to getting the necessary supplies and equipment. As the bonus profits materialized, the miners not only remained longer on the work, but sent for other workmen whom they knew and who would do their share in increasing the speed.

In fixing the bonus and the base rate, it is important to reach a reasonable balance, which will allow the men a fair share in the saving, giving them a chance to earn from $10.00 to $30.00 a month as a reward for unusual effort. In some places where the bonus has been tried by other organizations, the base rate was placed so high that there was little opportunity for the men to profit by it, resulting in discouragement to them and no benefit to the organization.

In November, 1909, the tunnel work on the Los Angeles Aqueduct was in full swing. This particular month is selected for consideration only because the bonus pay rolls were so large that the City Auditor asked for an investigation of the bonus system to justify its use. A detailed study was made of it, which satisfied the Board of Public Works that it was decidedly beneficial. During this month, 9,131 feet of tunnels were excavated, of which 4,033 feet was excess footage over the base rate as fixed, which is an increase in speed of 72 per cent. Ninety per cent of the crews earned bonus ranging from 12 cents to $1.95 per day for each man. In the 39 tunnel headings, the total wages for that month were $76,837.38, of which $13,133.94 was bonus, or 17 per cent. The average cost per foot of tunnel for labor and bonus was $9.87. If only the base progress, which was the estimated ordinary progress, had been made, the cost per foot for labor would have been $13.80. The footage gained over the estimated base rate cost in bonus pay an average of $3.25 per foot for all tunnels.

In the Elizabeth tunnel, the base progress of 420 feet for the two headings for the month was exceeded 429 feet. In this tunnel, where speed was particularly desired, the muckers, who had the hardest work to do and who largely controlled the rate of advance, worked in relays. A car holding 33 cubic feet would be pushed up to the pile of debris thrown down by the explosion and four of these shovelers would fill it. They would then push it back to the switch, and four fresh men shoved up an empty car and filled it—the first crew meantime doing light work or resting. This process was kept up, so that a fresh crew would come up with each empty car. The result was that the American records for rapid hard rock tunnel work were repeatedly broken, and the world's record for soft rock tunnel driving, (so far as known) was beaten at Tunnel 17 M, in the Jawbone Division, where 1,061 feet were driven at one heading by hand work in August, 1909. The material in Tunnel 17M was a soft sandstone which could be bored with augers.

The entire 26,870 feet of the Elizabeth tunnel was completed on February 28, 1911. The four years and seven months time set for the driving of this tunnel was beaten by 450 days, or 32 per cent. The average progress was 10.8 feet per day for each heading. This includes the time during which the tunnel was driven by hand, while the equipment was being purchased and installed. The rock is granite, favorable for rapid work at the south end, but uneven, full of water, difficult and dangerous at the north end.

The average cost per foot of the Elizabeth tunnel was:

Excavation, including timbering	$41.35
Lining	9.65
Local administration and superintendence	2.10
Equipment	7.92
Buildings, water supply, etc	5.83
Engineering and surveys	1.00
Total	$67.85

This does not include general administration costs, which amounted to 3.55 per cent or $2.35 per foot, making a total cost of $70.20 per foot. The estimate of the Board of Consultng Engineers was $75.33 per foot plus 16.5 per cent for contingencies and water supply, making a total of $87.93 per foot. The saving therefore amounted to approximately $18.00 per foot or about $500,000 for the entire tunnel.

On the Jawbone division, bids were asked for all the construction of this part of the work, excluding siphons, but including 65,000 feet of tunnel. They ranged from $2,294,000 to $4,258,000. After a consideration of the bids received, it was decided that the work would probably cost the City less if it were done by day labor under the Engineering Department. This was done—the bonus system was used in all of the tunnels and the actual field cost of all the work was $700,000.00 less than the lowest price bid.

Rules Governing Payment for Bonus Footage.—1. Ten days shall constitute a period. The first period to be from the 1st to the 10th of the month, inclusive; the second from the 11th to the 20th inclusive; the third from the 21st to the end of the month. Bonus payments shall be allowed upon the basis of measurements made at the close of each ten-day period.

2. The following named classes of employes shall be allowed to participate in bonus payments:

Tunnel Foremen,
Shift Bosses,
Miners,
Muckers

3. The tunnel foreman shall not be considered as one of the crew except when in charge of a single shift, when he shall share in the bonus on the same basis as the men of the crew under his direction. If he is in charge of more than one shift, he shall be allowed bonus based upon the average bonus progress of all headings under his supervision.

4. The shift boss shall be considered as one of the shift crew. He will participate in the bonus on the same basis as the men of the crew under his direction. An exception to this rule is made when a shift boss is placed in charge of two or more shifts in different headings. In this case, he would be placed on the same basis as a foreman—to wit: not to be considered as one of the crew, and would be allowed bonus upon the mean bonus progress.

5. The number of shifts worked in a heading during a day of 24 hours shall be determined by the engineer or superintendent in charge of the work after consultation with the Chief Engineer.

6. All back trimming must be done by the crew sharing the bonus. If the timbers are placed by the miners from the standard crew in a given ten-day period, then the portion of the tunnel shall be considered as a timbered section; otherwise it shall not be so considered.

7. Only men who work continuously through the ten-day period, with the following exceptions, shall be entitled to bonus:

(a) Any employe, entitled to bonus earnings, who is injured or becomes ill during a period from conditions arising directly from tunnel construction, shall participate in bonus in proportion to the number of shifts worked by him during said period.

(b) If an employe, entitled to bonus earnings, is transferred during a period from a heading to another part of the work for reasons other than his own request, he shall participate in bonus in proportion to the number of shifts worked by him on such heading.

8. If the work is interrupted by the failure of power, shortage of material or supplies, floods, cave-ins, or other causes beyond the control of the men, the men shall be entitled to bonus pay in proportion to the number of shifts worked by them during period in which such interruptions occurred.

9. To establish a uniform system of computing bonus earnings in above case, the following formula will be used:

$$\frac{x + y}{\dfrac{x}{a} + \dfrac{y}{b}} = \text{Average base rate per shift.}$$

Let x = Timbered progress = 25 ft.
y = Untimbered progress = 30 ft.
a = Required timbered per shift = 2 ft.
b = Required untimbered per shift = 2.5 ft.
s = Number of shifts during period = 20

Then

$$\frac{x}{a} = \text{shifts required at base rate.}$$

$$\frac{y}{b} = \text{shifts required at base rate.}$$

Or substituting values,

$$\frac{25}{2} = 12.5 \text{ shifts required at base rate.}$$

$$\frac{30}{2.5} = 12.0 \text{ shifts required at base rate.}$$

Total 24.5 shifts required at base rate.

$$\frac{25 + 30}{24.5} = 2.245 \text{ average base rate.}$$

$$20 \times 2.245 = 44.9 = \text{progress required.}$$

$$55 - 44.9 = 10.1 \text{ ft.} = \text{bonus footage.}$$

10. The computation of bonus footage shall be made by dividing the total number of feet run during the period by the total number of shifts worked during the period. From this average footage per shift there shall be deducted the base rate of progress required, and the remainder, if any, will be the bonus footage per shift. The bonus earned per man during the period will be the number of shifts in which he worked, times the average bonus footage, times the bonus price per foot. (Provided all conditions as outlined in these rules are complied with.)

Example 1.—3 shifts working 10 days

Total progress for period — 150 feet.
3 shifts × 10 days = 30 shifts worked.
150 ft. ÷ 30 shifts = 5 ft. per shift.
Base rate of progress 3.5 ft. per shift.
Bonus footage 1.5 ft. per shift.
Bonus earned for per man = 1.5 ft. × 10 shifts × 25 cts. per ft. = $3.75.

Example 2.—1 shift working 10 days

Total progress for period — 50 feet.
1 shift × 10 days = 10 shifts worked.
50 ft. ÷ 10 shifts = 5 ft. per shift.
Base rate of progress 3.5 ft. per shift.
Bonus footage 1.5 per shift.
Bonus earned for period per man = 1.5 ft. × 10 shifts × 25 cts. per ft. = $3.75.

Bonus Schedule for Tunnel Work in the Little Lake Division

Capacity of tunnel	Class of rock	Timbered or untimbered	Class of work	Base rate per shift	No. of men per shift	Rate per man per bonus foot
430 sec. ft.	Soft	Untimbered	Hand	4.5 ft.	9	20 cts.
430 sec. ft.	Soft	Timbered	Hand	4.5 ft.	9	20 cts.
430 sec. ft.	Hard	Untimbered	Hand	2.5 ft.	10	25 cts.
430 sec. ft.	Hard	Timbered	Hand	2.0 ft.	10	25 cts.
430 sec. ft.	Hard	Untimbered	Machine	3.0 ft.	11	30 cts.
430 sec. ft.	Hard	Timbered	Machine	2.3 ft.	11	30 cts.
430 sec. ft.	Hard	Untimbered	Machine	3.0 ft.	11	40 cts
430 sec. ft.	Hard	Timbered	Machine	2.3 ft.	11	40 cts.
430 sec. ft.	Hard	Untimbered	Machine	5.0 ft.	14	30 cts.
430 sec. ft.	Hard	Timbered	Machine	4.3 ft.	14	30 cts.

Bonus Schedule for Tunnel Work in the Elizabeth Tunnel, North and South Portals

Class of rock	Timbered or untimbered	Class of work	Base rate per shift	No. of men per shift	Rate per man per bonus foot
Hard	Untimbered	Machine	2⅔ ft.	16	40 cts.
Soft	Timbered	Machine	2 ft.	23	40 cts.

Noteworthy achievements in tunnel driving by the Aqueduct organization were at Tunnel 17-M, which is in a soft sandstone at the head of the Red Rock Canyon, where a tunnel 10,596 feet in length was excavated in seven months from two headings. As far as known the driving of 1,061.6 feet in the month of August, 1909, is the world's record for fast tunnel driving for one month's run. This tunnel was completely lined in eight months. In other words, this two-mile tunnel was driven and lined in a year and a quarter.

One hundred and sixty-four tunnels were excavated, and practically all of them were driven from two or more headings. There was not an error in instrumental work, either in line or grade, in any of the tunnels, or elsewhere on the work.

Cost of Tunnel in Clay for the Alton, Ill. Sewer Outlet.—Engineering and Contracting, Feb. 10, 1915, publishes the following data given by J. E. Schwaab in a paper before the Thirtieth Annual Meeting of Illinois Society of Engineers and Surveyors.

The outlet necessitated the construction of 1,000 ft. of tunnel through a ridge. The grade of the tunnel varied from 20 ft. to 39 ft. below the natural surface of the ground. Shafts were sunk every 200 ft. These shafts were made 4 ft. by 8 ft. in dimension and were properly braced with oak timbers. Clay was removed from the tunnel by the use of 5 cu. ft. wooden buckets which were raised and lowered into the shafts by the means of an ordinary hoisting engine and swinging boom. This equipment was also used for lowering the 12-in. cast-iron pipe into the shaft and for dragging it along the tunnel. At the bottom of the shaft the heading was driven in both directions for a distance of 100 ft. at the same time. The sides and top were sheeted with 3-in. oak planking as the tunnel was being driven. To operate one shaft there were five men in the tunnel—one man to hook the cable onto the buckets, two men at the headings, and two men wheeling muck to the shaft. On the top there were three men, one man unhooking the bucket and emptying it, and one man with team and scraper to remove the earth from the shaft, and one man to cut timber.

One difficulty experienced was the lack of ventilation. It was impossible to keep a light burning in the tunnel so that the men could see. The air became foul, thus preventing the men from remaining in the tunnel. This obstacle was overcome by the use of an ordinary blower fan operated by a 1½-HP. gasoline engine. To the discharge end of the blower fan 3-in. spouting was connected and run down into the shaft and each way into the headings. This fan furnished sufficient air to enable the men to work in the tunnel without experiencing any discomfort as regards ventilation.

The time required to complete this tunnel was 60 days, average progress being 17½ ft. per day. The maximum progress was 34 ft. per day. The total cost, including labor, material and lumber, was $10,000.

Following are the wages paid for the labor for constructing the tunnel. Each shift consisted of:

One foreman, per month	$75.00
One engineer, per hour	0.25
Two diggers, per hour	0.30
Five laborers, per hour	0.25
One team, per hour	0.50
One water boy, per day	1.00

Eight hours constituted a day's work for each shift; at times there were three shifts working in the 24 hours.

The material through which the tunnel was driven was wet, sandy clay excepting 50 ft. of small gravel and quicksand. The elevation of ground water was 13 ft. below the natural ground surface. The men at the headings used ordinary round pointed spades; picks were used when gravel was encountered.

Cost of a Circular Brick-Lined Water Works Tunnel 8-Ft. in Diameter.—The following data are taken from Engineering and Contracting, April 2, 1913.

The Chicago Avenue Tunnel connection, completed in March, 1913, for the Chicago Water Works, is 8 ft. in diameter; is lined with three rings of brick, and is 1,216 ft. long. It cost $34.82 per lineal foot. This is a moderate figure, considering the quality of the work done; the length of the tunnel; the curves and grades upon which it is built; that air pressure was used, and that engineering and inspection costs are all included. The new tunnel joins the lake section of the 7-ft. Cross Town Tunnel with the 8-ft. Blue Island Avenue Tunnel, which was completed in 1909. The tunnel parallels the curb 10 ft. away on LaFayette Court for a distance of 721 ft. It has a compound curve at the south end consisting of one arc 308.5 ft. long on a radius of 175 ft. and one arc of 55 ft. radius and 141.2 ft. long, which connects with the lake end of the old Cross Town Tunnel. At the north end the main tangent is deflected 30° on a curve of 12 ft. radius, to avoid making a right angle connection with the Blue Island Ave. Tunnel. From this curve the tangent continues about 30 ft. to the juncture with the Blue Island Tunnel with which it makes an angle of 60°.

The grade on which the tunnel is built is level between the construction shaft and the Blue Island Avenue Tunnel, then rises at a rate of 1.3 per cent from the shaft south to the point of curvature whence it dips at a rate of 6 per cent on a curve to the junction with the lake end of the old Cross Town Tunnel. The rising grade is introduced to provide a safe clearance between the new tunnel and three other tunnels which pass under the new bore.

Shaft Construction.—Construction was commenced on May 20, 1912, with the erection of the office building and tool house. The following month was occupied in building a cement shed and men's dressing house; the head house framing; the frames and sheeting for starting the excavation for the shaft; in assembling the 1-cu. yd. tunnel cars, which were built at the city water works shops, and in setting the 100-hp. fire-box boiler, and building under it a foundation and ash pit. The preparations for active work excavating the shaft were continued during the early part of July and the actual excavation was started July 15, 1912, when a hole 15 ft. square was started. This had been carried about 10 ft. below the surface using 2 × 10-in. sheeting held in place by three sets of timber frames spaced 3 ft. apart vertically, when water was encountered. The excavation was then interrupted until the first sections of the steel shell could be placed.

The shell was built by John Mohr & Sons, Chicago, and delivered in place for $930. It consisted of five sections each 11 ft. 5 ins. in diameter and 6 ft. high, made of ⅜-in. boiler plate. The two bottom sections were riveted together in the shop and provided with a beveled cutting edge stiffened around the inside with an additional plate and a 6 × 8 × ½-in. angle 1 ft. above the cutting edge. The total weight of the shell was 21,385 lbs. with the rivets. Its cost delivered was, therefore, 4.35 cts. per pound. Each section was thoroughly calked and all the rivets were countersunk on the outside of the shell. By July 26 the two bottom sections had been placed and another 6-ft. section had been riveted and calked. The shell had also been lined up by vertical guide timbers placed on four sides. The brick lining was then started, the 6 × 8-in. angle serving as a footing; and on July 30 had been carried to a height of 14 ft. With this additional weight the shell was forced down to elevation −4 or 16.6 ft. below the street grade. Preparations were then made to sink the 18 ft. of erected shell deep enough to permit the erection and riveting of the remaining two sections.

All the material removed from the shaft was taken on cars running on a narrow-gage track to a dump on the east side of the street where, by previous arrangement, the city had obtained permission to fill in vacant property to the level of the street. A No. 4 Nye pump was suspended in the bottom of the shaft at this time as the material encountered was a water-bearing stratum of lake sand. This sand was 13 ft. deep, overlying the soft blue clay through which the balance of the shaft was sunk.

By Aug. 8, 1912, the last two sections of the steel shell were erected and the brick lining was then completed to within 6 ins. of the top of the shell. The excavation was next resumed and the shell gradually sank, with the weight of the brick lining, until it reached an elevation of −13 or 25.6 ft. below the street, when it became necessary to add weight to sink it further. About 20 tons of pig iron were loaded on 10 × 10-in. timbers placed across the top of the shell. With this additional weight the cutting edge was sunk 4 ft. or to elevation −17. More weight was added and the shell was finally sunk to elevation −24.20. The total weight used to sink the shell was 163,646 lbs. With the weight of the timbers the entire load amounted to 82 tons.

To estimate the friction between the soil and the shell we have:

	Pounds
Load	184,000
Shell	21,385
Brick lining	126,904
Total weight	312,289

The total area of the shell in contact with the soil when it reached its final position was 970 sq. ft. Dividing the total weight by 970 gives approximately 322 lbs. friction per square foot of contact area. Comparing this figure with the friction indicated when the shell was sunk to elevation −4, we find that at that time the weight of the shell and its brick lining was about 116,000 lbs. and that the area of contact between the shell and the soil was approximately 240 sq. ft. This indicates that a friction of 480 lbs. per square foot existed when the shell ceased to sink at −4. In this case the shell was forcing its way through sand, the area of contact with sand being 145 sq. ft. and with earth fill about 94 sq. ft. In its final position the shell was forcing its way through clay and was in contact with 405 sq. ft. of clay, 471 sq. ft. of sand, and 94 sq. ft. of earth fill. This indicates that the coefficient of friction was reduced as the percentage of area of the shell in contact with clay increased.

The excavation of the shaft was carried 20 ft. below the cutting edge to the top of the tunnel bore and the brick lining from 13 to 18 ins. thick was placed after each day's excavation. The brick lining was suspended by eight 1 in. hanging rods having plate washers. Each rod had an eye at its lower end, which supported the plate and provided for hooking on the next rod below. In the 6 × 8-in. angle which supported the brick work for the steel shell, small eye bolts were placed before any brick work was started, and to these were attached the first set of rods. The shaft was carried down to tunnel grade, and the two tunnel "eyes" excavated 10 ft. each way from the shaft and lined during the last four days of August. A sump also was built, as shown by Fig. 5 with ledge projecting 4 ins. inside the 10 ft. diameter of the shaft to support the cage landing and the floor built over the sump.

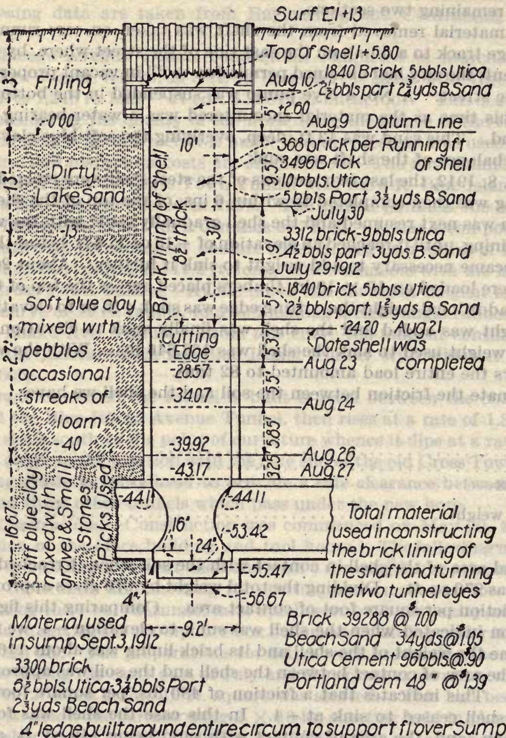


Fig. 5.—Completed shaft.

The total cost of the material and labor for the construction of the shaft including the two tunnel eyes and the brick lining was $4,675, or $66.79 per lin. ft., as follows:

39,288 brick at $7	$ 275.00
34 cu. yds. beach sand at $1.05	35.70
96 bbls. Utica cement at $0.90	86.40
48 bbls. Portland cement at $1.39	66.72
3,000 ft. lumber at $25	75.00
Steel sheet	930.00
Hanging rods	50.00
Labor	2,981.18
Teaming, for pig iron	175.00
Total, 70 lin. ft	$4,675.00
Cost per lin. ft	66.79

The cage, used for the balance of the work, consisted of a light platform suspended in a frame, and was operated by a cable from the hoisting engine in the power house.

Tunnel Construction.—Mining was begun in the south heading on Sept. 5, 1912. The bore of the tunnel was made 10 ft. 2 ins. to accommodate the 13 in. brick lining laid in cement mortar. Labor troubles at this time caused a suspension of mining for four days, during which time a new gang was organized, and an air compressor installed. Air pressure on the tunnel was provided as a precautionary measure to prevent leaks from the four water tunnels over which the new tunnel passed and to prevent damage to the apartment buildings near which the tunnel passed. A Laidlaw-Dunn-Gordon compressor, 12 × 18 × 18 ins. of 626 cu. ft. capacity at 50 lbs. pressure was installed in the power house. It was at first rented for $100 per month, and later was purchased for $800.

The air locks were not installed until Sept. 25, when the mining and lining had proceeded to a point 107 ft. from the shaft. The driving tunnel was then stopped for five days during the installation of the airlock diaphragms. These were placed 21 ft. 7 ins. apart, the nearest one being 63.2 ft. from the shaft. The lock was not quite long enough for the cars on account of the space needed to swing the outer door. The assembling and bricking in of the diaphragms required five days' time.

To insure tightness of the lock, a slot was cut through the tunnel lining about 2 ft. south of the south diaphragm and the soil around the south end of the lock was grouted. The lock walls and the walls of the tunnel for 35 ft. south from the diaphragms were washed with Portalnd cement grout. Tests were made to determine air leakage and the Portland cement grout was put on during a pressure of about 18 lbs. No trouble was had because of leakage throughout the work and the compressor was able to maintain 10 to 15 lbs. pressure running at its lowest speed.

About 135 ft. from the shaft the character of the ground changed from a hard blue clay, that required picking, to a soft clay with a tendency to swell. After this point was reached clay knives were used. This work proceeded without change from this time until the end of the tunnel was reached on February 8, 1913.

The average progress made during October was 7.98 ft. per day, during November 8.25 per day, during December 11.8 per day and during January 13.58 ft. per day. After Dec. 12, to the end of the work, two shifts per day were worked. The progress per shift during this time was 7.8 ft. for December and 6.79 ft. for January. The work slowed up, it will be noted, on the long curve on a −6 per cent grade.

The south end of the tunnel joins the lake end of the old crosstown tunnel at a point midway between two 10 ft. shafts which are about 200 ft. apart. This short section of tunnel was cut out by closing a gate at each shaft. To overcome any leaks around the gate in Shaft *F*, this shaft was filled with soft blue clay to elevation −22.

When the drift was excavated to within a few feet of this tunnel, a hole was drilled through to the old tunnel and a suction pipe connected. The pump was then started and the air pressure run up to from 42 to 48 lbs. to aid the pumping. After the water was pumped out about 10 lbs. air pressure was maintained while the remainder of the excavation was made and the connection bricked up. The material excavated in making the tunnel connections was thrown back into the abandoned tunnel towards Shaft *F*.

The work in the north drift had been extended 12.6 ft. or to 23.6 ft. from the shaft by two days' work during the month of September. It was resumed on Feb. 11, and completed to a point 55.4 ft. from the shaft and 13.8 ft. from the connection with the Blue Island tunnel. A gate shaft about 350 ft. west of the connection permitted the closing of this section of the Blue Island tunnel as the end of this tunnel is about 100 ft. east of the connection. The tunnel was pumped out and the connection made. As the Blue Island tunnel is lined with concrete, this material was used to make the connection and was carried back in the connecting tunnel for a distance of 14.55 ft.

The compressor was shut down on Feb. 9 and the pressure allowed to give out by the working of the air lock during the work of tearing up track. The lock shields were removed and the slots, left in the lining by their removal, were concreted. By Feb. 28 both drifts were entirely cleaned out and a cover of steel beams and concrete was placed on the shaft. The equipment and construction buildings were then removed, leaving the site clear by March 15.

The total itemized labor time in days, and of labor costs are shown in Table XII. This includes the time of all men and teams for the work from the commencement of operations until March 17 when all plant and buildings, with the exception of the office building, had been removed. The total cost as given is $50,556.29.

TABLE XI.—TOTAL AND UNIT COSTS

	Shaft		Tunnel		Grand
	Per lin. ft.	Total	Per lin. ft.	Total	total
Engineering and inspection	$10.12	$ 708.04	$ 2.05	$ 2,434.47	$ 3,142.51
Labor	34.97	2,447.96	24.90	29,529.06	31,977.02
Materials	21.70	1,519.00	7.02	8,320.27	9,839.27
Plant	8.32	582.05	4.23	5,015.44	5,597.49
Total	$75.11	$5,257.05	$38.20	$45,299.24	$50,556.29

Table XI gives the total and unit costs for the work as distributed for the various classes of work on the shaft and on the tunnel. The unit cost for the shaft is given in this table as $75.11 as compared with $66.79 given previously. The difference is due to the addition of a proportionate charge to the shaft work of the total cost of the plant. The plant included in this charge is as follows:

Machinery, cars, etc	$3,757.51
Rails and switches	464.59
Lumber	773.52
Pipe fittings	138.98
Miscellaneous	462.89
Total	$5,597.49

The plant has been charged entirely into the work according to the figures in Table XI and distributed between the shaft and tunnel proportionately to the total costs of those items. This charge is an arbitrary charge and should be reduced by charging only the depreciation of the plant against the work. To do this 2 per cent of its value should be charged against the work each month, or 20 per cent for the ten months. This would reduce the plant charge on the shaft by $6.64 making the total cost of the shaft $68.47 per lin. ft., and would reduce the cost of the tunnel $3.38 per lineal foot making this item $34.82 per lineal foot instead of $38.20. In calculating the unit cost of the tunnel 1,186 lin. ft. was used as the total length, as 30 ft. of the length of the tunnel is included in the construction of the shaft and in the turning of the eyes, and this length was charged to the shaft construction.

The materials used per lineal foot of tunnel are indicated by the following table which is prepared from a record of materials used from Oct. 4 to Jan. 16, during which time 840 lin. ft. of tunnel were built:

Number brick per lin. ft. of tunnel	522.5
Barrels Utica cement per lin. ft.	.92
Barrels Universal cement per lin. ft.	.50
Cu. ft. sand per lin. ft.	1.14

The tunnel was constructed by the City by day labor under the supervision of the construction division of the Bureau of Engineering.

TABLE XII.—TOTAL ITEMIZED LABOR COST OF CHICAGO AVENUE TUNNEL CONNECTION

	Rate per day	Total Time	Total Amt.
Asst. engineer	$ 5.61	227	$ 1,380.69
Rodman	2.96	240	836.82
Mining inspector	5.00	185	925.00
Supt. and foreman	8.06	....	....
Supt. and foreman	*250.00	147	1,387.02
Bricklayer foreman	11.00	....	....
Bricklayer foreman	*250.00	186½	1,968.50
Tunnel miners	4.00	1,233½	4,934.00
Muckers	3.50	740½	2,591.75
Laborers	3.00	1,423⅝	4,270.88
Hoist engineers	5.80	416⅛	2,413.89
Firemen	*90.00	....	....
Firemen	2.90	475	1,587.94
Carpenters	5.20	336	1,747.20
Blacksmith	5.00	216	1,080.00
Watchmen	2.50	443	1,163.50
Heading boss	4.50	225½	981.75
Lock tender	4.00	236½	1,024.00
Bricklayers	10.00	222⅓	2,223.00
Laborers	2.75	72	198.00
Bricklayer tenders	4.00	581½	2,330.88
Mule and driver	5.50	69.2	380.46
Electrician	6.00	8⅞	53.25
Double teams	5.50	228	1,254.00
Asst. foreman	6.00	64½	387.00
Totals	....	7,977.65	$35,119.53

* Month.

Cost of a Brick Lined Tunnel for 36-In. Water Main Under Chelsea Creek, Boston, Mass.—William E. Foss gives the following data in Engineering and Contracting, Aug. 5, 1914. The work was done by day labor.

For the purpose of guarding against the interruption of the supply of the East Boston low-service district by the breaking of the existing mains, a new 36-in. main was laid in a different location. This new main connects with existing 20-in. and 24-in. mains in Chelsea and extends along the northerly shore of the creek to a point near the Chelsea Street bridge leading to East Boston, where it turns easterly and crosses under the channel through a tunnel 504 ft. long to the East Boston shore. Construction of this brick-lined tunnel, for carrying the 36-in. cast-iron water main under the creek, was carried out by day labor from July, 1910, to January, 1911.

The tunnel is located about 25 ft. down stream from the westerly side line of the Chelsea Street bridge, and includes a vertical shaft at each side of the creek, 9 ft. 4 ins. outside diameter, with top at elevation 14 on the Chelsea shore and at elevation 10 on the East Boston shore. The horizontal section of the tunnel, joining the shafts, is 400 ft. in length, 8 ft. 2 ins. outside diameter with the top 36 ft. below mean low water at the Chelsea end. The shafts were constructed with 12-in. and the horizontal portion of the tunnel with 8-in. brick walls.

The Chelsea shaft rises about 12 ft. above the bed of the creek and is protected by a steel casing which extends about 13 ft. into the silt bottom. The East Boston shaft was sunk through the earth filling, back of the masonry sea wall, and is protected by a steel casing for a distance of 8 ft. below the top.

The axis of the horizontal section of the 36-in. pipe, which was laid in the tunnel, is at elevation − 40. The pipes were laid with ½-in. opening between the end of the spigot and the bottom of the socket, and the joints were run solid with lead and were calked both inside and outside after the pipe was laid. The space between the pipe and the brick wall was filled with Portland cement concrete.

Special 36-in. branches were used at the junction of the horizontal and vertical portions of the pipe line. Thirty-six-inch ¼ curves with manholes were set at the top of the shafts. The pipes used were 1.61 ins. thick.

The steam plant for operating the air compressors, hoists and electric lighting plant was set up on the Chelsea shore of the creek during the latter part of July, and the work of sinking the shaft was begun during the week ending August 13. After August 21, when the air lock was in place, the work was carried on continuously during 24 hours per day, with three shifts. While excavating the mud and silt just below the bed of the creek some inconvenience was experienced on account of gas, which entered the shaft and affected the eyes of the workmen.

The work of excavating and lining the shaft was completed about September 1. An air lock was then built at the entrance to the horizontal portion of the tunnel, and the small lock which had been used for sinking the shaft was removed. The excavation and lining of the horizontal portion of the tunnel progressed at the rate of about 5 ft. per day. The air pressure maintained varied from 14 to 23 lbs. per square inch, according to the stage of the tide in the creek above.

On October 13 a blow-out occurred about 150 ft. from the Chelsea shaft at a point where a pile had been removed. As a result, the tunnel was flooded with water to a depth of about 4 ft. After the hole was stopped the water was pumped out, and the work proceeded without further mishap.

On the East Boston side of the creek the material excavated was hardpan containing boulders, which required some blasting, so that the rate of progress was less than it had been in the sand and clay on the Chelsea side of the creek. A 2½-in. steel pipe was driven, during the week ending November 12, on the center line of the tunnel near the East Boston end, from the surface of the ground to the center of the tunnel, for use in supplying compressed air for sinking the East Boston shaft.

Work in the tunnel was discontinued on November 17, when steel sections of the East Boston shaft and the hoisting engine were set up on the East Boston side of the creek. On November 18 the work of excavating the East Boston shaft was begun, and on November 24 air pressure was applied.

An opening was made from the bottom of the shaft into the tunnel on December 3. All excavation and the brick lining for the tunnel were completed on December 6, and the air pressure was removed on the morning of

December 9. A total of 104 lin. ft. of shaft and 400 ft. of tunnel were built. The tunnel was cleaned out and plastered and, after calking a few small leaks, was substantially watertight.

The force employed on this work while working continuously under air pressure averaged about 15 men for each of the three shifts. After the air pressure was removed the work was carried on with three shifts working six days per week, the force employed averaging about 16 men per shift. The wages paid, price of materials and general expenses were as follows:

PRICES PAID FOR LABOR

	For 8-hour day
Engineer in charge of plant	$5.00
Engineer	4.00
Fireman	2.40
Head miner and foreman	4.00
Miner	2.80
Tunnel laborer	2.40
Laborer	2.00
Calker	3.50
Head mason	7.20
Mason	6.40
Boy	1.60
Double team with driver	5.00

PRICES PAID FOR MATERIALS

Brick, delivered on work, per M	$9.70
Portland cement, delivered on work in bags (credit for empty bags returned, 6½ cts. each), per bbl	1.68
Coal, delivered on work (for 14,700 B.t.u. per pound of dry coal), per gross ton	4.10
Ipswich sand, delivered on wharf, for brickwork, per ton	0.75
Plum Island sand, delivered on wharf, for concrete, per ton	0.75
Bank sand, delivered on cars at bank, per cu. yd	0.35
Freight, additional, per cu. yd	0.35
Teaming, additional, per cu. yd	0.40
Screened gravel for concrete, delivered on cars at bank, per cu. yd	0.75
Freight, additional, per cu. yd	0.35
Teaming, additional, per cu. yd	0.43
Broken stone for concrete, delivered on work, per ton	1.50
Lead, per 100 lbs	4.675

GENERAL EXPENSES

Superintendence and rental of plant		$ 7,700.00
Installing plant:		
Labor	$ 412.90	
Teaming	130.00	
Supplies	121.19	
		664.09
Housing plant:		
Labor	525.85	
Lumber, $743.77; $205.36 received for old lumber	538.41	
Miscellaneous supplies	39.78	
		1,104.04
Operating plant:		
Labor	4,234.40	
Coal	1,947.65	
Water for boilers and compressors	225.35	
Miscellaneous supplies	538.49	
		6,945.89
Removing plant:		
Labor	230.80	
Teaming	106.00	
		336.80
Rental of land		195.00
Miscellaneous expenses		88.35
Total general expenses		$17,034.17

The plant was operated from 7 a. m. Aug. 11, 1910, to 4 p. m. Jan. 11, 1911, a total of 4,017 hours. The cost of general expenses per hour was therefore $4.24.

Earth Excavation.—About 1,040 cu. yds. of earth were excavated under air pressure of 14 to 23 lbs. per square inch. Work was continuous for three shifts per 24 hours. The mud and silt was excavated just below the bed of the creek at the shaft on Chelsea shore. Fine sand and gravel were excavated for 10 ft. below the silt, and the bottom 5 ft. of excavation was in clay.

The shaft on the East Boston shore was excavated through filling of clay and ashes for a depth of 25 ft., coarse gravel for a depth of 15 ft., and below this line the excavation was in hard pan. The horizontal portion of the tunnel was excavated through stratified sand, clay and gravel, the strata dipping about 6° towards the Chelsea shore, so that for the first portion of the work the floor was in clay and the arch in sand. As the work progressed the floor was in gravel and the arch in clay, and at the East Boston end the entire excavation was in hard pan, with some boulders which required blasting. The cost of earth excavation was as follows:

	Cost	Per cent of total
General expenses	$10,190.40	40.0
Steel casings for shaft	833.00	4.1
Roof plates for tunnel	1,387.31	6.8
Lumber	98.96	0.5
Tools	112.36	0.5
Labor	7,778.70	38.1
Total	$20,400.73	
Cost per lin. ft. of tunnel	40.68	
Cost per cu. yd	19.62	

Brick Lining.—Approximately 320 cu. yds. of brick masonry were built under air pressure of 14 to 23 lbs. per square inch. Work was continuous for three shifts per 24 hours.

	Cost	Per cent of total
General expenses	$ 3,078.64	29.2
Brick	1,971.52	18.7
Cement	1,129.00	10.7
Sand	331.39	3.1
Mason	1,210.80	11.5
Labor	2,786.25	26.5
Miscellaneous supplies	36.76	0.3
Total	$10,544.36	
Cost per lin. ft. of tunnel	21.03	
Cost per cu. yd. of tunnel	32.95	

Laying 36-In. Pipe.—Five hundred and three feet of 36-in. pipe were laid. Work was continuous for six days per week with three shifts per 24 hours.

	Cost	Per cent of total
General expenses	$1,708.96	42.2
Lead	382.41	9.4
Calking	252.00	6.2
Labor	1,661.10	41.0
Tools and miscellaneous	50.25	1.2
Total	$4,054.72	
Cost per lin. ft. of tunnel	8.08	

Portland Cement Concrete Protection for Pipe.—Four hundred and seventy-eight yards of concrete were placed. Frost was removed from the sand and gravel for concreting, by steam. The materials were mixed in the following proportions: 380 lbs. of cement, 10 cu. ft. of sand, 18 cu. ft. of gravel. Work was continuous for six days per week with three shifts per 24 hours.

	Cost	Per cent of total
General expenses	$2,056.17	35.8
Cement	917.11	16.0
Sand and gravel	744.15	13.0
Labor	1,994.70	34.8
Miscellaneous expenses	25.00	0.4
Total	$5,737.13	
Cost per lin. ft. of tunnel	11.44	
Cost per cu. yd. of tunnel	12.00	

COST OF CAST IRON PIPE AND SPECIALS

The cost of the cast iron pipe and special castings was as follows:

36-in. cast iron pipe, class H:	
157.348 tons straight pipe, delivered on wharf, at $24.40 per ton	$3,839.29
Cost per lin. ft. of tunnel	7.65
36-in. cast iron specials:	
11,1605 tons, delivered on wharf, at $49	546.86
Cost per lin. ft. of tunnel	1.09

SUMMARY OF COSTS

	Total cost	Cost per lin. ft. of tunnel
Earth excavation	$20,400.73	$40.68
Brick lining	10,544.36	21.03
Laying 36-in. pipe	4,054.72	8.08
Portland cement concrete protection for pipe	5,737.13	11.44
	$40,736.94	$81.23
6-in. cast iron pipe	$3,839.29	$7.65
36-in. special castings	546.86	1.09
Total*	$45,123.09	$89.97

* Exclusive of land damages and engineering and testing and miscellaneous. These items amounted to a sum of $5,687.53 additional, making the total cost $50,810.62.

Construction Plant.—Following is a list of the construction plant units employed and their estimated value when new:

	Est. value when new
1 air compressor, Ingersoll No. 119, 24 × 24¼ × 30 ins	$ 2,700
1 air compressor, Ingersoll No. 82, 18 × 18½ × 24 ins	2,200
2 75 hp. vertical Manning boilers, 60 × 13 ins	2,400
1 60 hp. horizontal Economical boiler, 50 ins. × 10 ft	700
2 air receivers, 4 × 12 ft	200
1 shaft lock, 6 × 6 ft	700
1 tunnel lock, 6 × 12 ft	225
1 4 × 3-in. Worthington duplex pump	200
1 4 × 3-in. Knowles duplex pump	200
1 head house and conveyor	200
1 12 hp. Paine dynamo engine	500
1 Crocker-Wheeler generator, 50 amperes, 110 volts, 12,000 r.p.m.	130
1 two-drum, 20 hp. double cylinder, Floyd Mfg. Co. hoisting engine and boiler	1,200
1 20 hp. double cylinder Kendal & Roberts hoisting engine, without boiler	600
5 tons steel rails	200
3 car trucks, with wheels, axles and boxes	105
Centers, ribs and lagging	100
Pipe and fittings	500
Total	$13,240
6 skips, 5 × 2½ × 2½ ft	180

Cost of Water Pipe Tunnel Under Mystic River, Chelsea, Mass.—The work of widening and deepening the draw at the Mystic River bridge between Charlestown and Chelsea necessitated an extension, in 1912, of the existing tunnel a distance of 273 ft. from the old shaft on the Charlestown side of the former channel. William E. Foss describes this work in Engineering and Contracting, Oct. 14, 1914, from which article the following data are taken.

The work was begun March 8 and was completed Sept. 11, 1912. It was done by the pneumatic process, the pressure varying from 19 to 27.5 lbs. per square inch. The work was carried on continuously with a day labor force working in three 8-hour shifts per 24 hours.

The work of setting up the boilers, air compressors, electric light plant, hoisting engines, pumps, etc., was begun on March 8, and during the week ending March 23 the water was pumped out of the old tunnel, the old pipes removed from the shaft and a brick bulkhead 24 ins. thick built into the tunnel about 12 ft. from the shaft. An air lock was then bolted to the top of the shaft and on April 1 the air pressure was applied. The brick lining was then removed at the bottom of the shaft and the work of driving the tunnel extension began on April 8. While a circular steel shield, and wooden lagging were used in 1900, steel roof plates have been used and the wooden lagging has been omitted in all subaqueous tunnel work since that date.

Rock was encountered in the lower part of the heading and rose as the heading advanced until at a distance of 24 ft. from the center of the old shaft the tunnel was entirely in rock and so continued for a distance of 200 ft. The work of lining the tunnel with brick was commenced on April 13 and both excavation and lining were carried forward at the rate of about 2 ft. in 24 hours until July 17, when the brick lining had been advanced 206.5 ft. beyond the old shaft. A brick bulkhead was then built near the end of the finished brickwork and the lined portion of the tunnel cleaned, plastered with cement mortar and washed with cement grout. A concrete bulkhead reinforced with steel rails was then built into the old shaft, above the tunnel, and on July 25 the removal of the brickwork of the old shaft was commenced.

The tunnel is 6 ft. in interior diameter with a 12-in. wall of brick masonry, except at places in solid rock where the wall is 8 ins. thick. The center line of the tunnel is about 43.5 ft. below mean low water.

The following prices were paid for labor:

Engineer, per week averaging 5¼ days	$25.00
Fireman, per week averaging 5¼ days	17.00
Head miner, per week averaging 7 days	33.60
Miner, per 8-hour day	3.20
Miner, per 8-hour day	2.80
Locktender, per 8-hour day	2.80
Topman, per 8-hour day	2.80
Laborer, per 8-hour day	2.40
Laborer, per 8-hour day	2.25
Blacksmith, per 8-hour day	3.00
Mason (day work), per 8-hour day	6.40
Mason (piece work, tunnel), per linear foot of tunnel	2.00
Mason (piece work, shaft), per linear foot of shaft	3.00

The following prices were paid for materials:

Brick, delivered on work, per M	$ 9.20
Portland cement, delivered on work in bags, per bbl	1.46
Coal, per ton	5.25
Coal, per ton	4.20
Coal, per ton	3.95
Lumber, spruce, per M. ft. B. M	$24 to 29.00
Lumber, hard pine, per M. ft. B. M	35.00
Sand, delivered on work, per cu. yd	1.30
Stone, broken, delivered on work, per ton	1.40
Clay, delivered on work, per cu. yd	2.50
Dynamite, not delivered, per 100 lbs	18.40
Large tunnel plates, each	1.00
Small tunnel plates, each	0.65
Lighter, per day (and lump sum prices for special work)	25.00
Rental of plant and services of assistant per day	30.00

Construction Plant.—The construction plant employed was as follows:

		Estimated value when new
1	Air compressor, Ingersoll-Rand, 18 × 14 × 24-in.	
1	Air compressor, Knowles, 12 × 18 × 18-in.	
2	75-hp. vertical Manning boilers, 60 ins. × 13 ft	$2,400.00
1	Air receiver, 3 ft. × 7 ft.	
1	Shaft lock, 6 ft. × 6 ft	700.00
1	Knowles 4 × 3-in. duplex pump	200.00
1	Worthington 2 × 1-in. duplex pump	200.00
1	Edson pump, 1½-in. discharge.	
1	Head house wheel, 2.75-ft. diameter.	
1	12-hp. Paine dynamo engine	500.00
1	Generator, 50 amperes, 110 volts	130.00
1	Two-drum, 20-hp., double cylinder hoisting engine and boiler	1,200.00
1	Ton steel rails	40.00
3	Car trucks with wheels, axles and boxes	105.00
3	Skips, 5 × 2.4 × 2.1	90.00
6	Cylindrical buckets	180.00
5	3-ft. radius ribs for lagging.	
	Pipe and fittings.	
36	12-in. bracing jacks.	
1	Portable forge	30.00
2	Wheelbarrows	6.00
1	150-lb. medium anvil.	

General Expenses.—The following general expenses were incurred:

Superintendence		$ 2,400.00
Rental of plant and services of assistant		5,520.00
Installing Plant:		
Labor	$ 690.03	
Teams and lighter	135.00	
Supplies	562.76	
		1,387.79
Hoisting plant:		
Labor	$ 797.00	
Lumber	532.92	
Supplies	54.20	
		1,384.12
Operating plant:		
Labor	$7,860.22	
Coal	2,889.60	
Miscellaneous supplies	208.52	
Miscellaneous teaming	48.00	
		11,006.34
Removing plant:		
Labor	$ 421.25	
Teams and lighter	190.00	
		611.25
Preliminary and incidental expenses:		
Pumping water from old tunnel	$ 388.32	
Building and removing bulkheads	382.58	
Cutting brickwork in old tunnel	491.08	
Cleaning out finished tunnel, etc	276.38	
		1,538.36
Total general expenses		$23,847.86

The plant was operated 4,248 hours, from 7:30 a. m., March 13, to 7:30 a. m., Sept. 6, 1912. Cost of general expenses per hour, $5.61.

Earth Excavation.—About 301 cu. yds. of earth was excavated under air pressure of 19 to 27½ lbs. per square inch. Work was continuous for three shifts per 24 hours. Material encountered in the shaft varied from fine silty sand at the bed of the river to sand and coarse gravel, with some boulders, at the elevation of the tunnel. In the horizontal portion of the tunnel the material was largely blue gravel.

		Per cent of total
General expenses	$5,277.34	56.8
Steel casing for shaft	760.00	8.2
Roof plates for tunnel	510.85	5.5
Clay	96.99	1.1
Tools	21.58	0.2
Miscellaneous supplies	23.86	0.3
Labor	2,506.10	26.9
Use of lighter setting steel Casing	93.33	1.0
Total	$9,290.05	
Cost per linear foot		$61.18
Cost per cu. yd. of excavation		30.90

Rock Excavation.—Approximately 302 cu. yds. of rock was excavated in the horizontal portion of the tunnel. The rock was of a hard, though seamy, texture and required blasting. The air pressure used was the same as when the heading was in earth. When the heading was in solid rock, about 2.6 lbs. of dynamite was used per linear foot.

		Per cent of total
General expenses	$12,025.43	59.1
Roof plates for tunnel	493.53	2.4
Blasting supplies	91.38	0.5
Clay	60.45	0.3
Tools	21.56	0.1
Miscellaneous supplies and expenses	47.22	0.2
Labor	7,594.73	37.4
Total	$20,334.30	
Cost per linear foot		$130.85
Cost per cu. yd. of excavation		67.29

Brick Lining.—About 310 cu. yds. of brick masonry (including concrete base at foot of new shaft and concrete plug in old shaft) was built, with an air pressure of 19 to 27½ lbs. per square inch. Brick masons were paid largely by piece work.

		Per cent of total
General expenses	$ 4,368.84	39.7
Brick	1,304.96	11.8
Cement	727.22	6.6
Sand	186.37	1.7
Lumber	53.48	0.5
Miscellaneous supplies	88.52	0.8
Use of lighter placing shaft	121.67	1.1
Brick mason	793.40	7.2
Labor	3,369.08	30.6
Total	$11,013.54	
Cost per linear foot		$33.18
Cost per cubic yard		35.55

Removing Old Shaft.—About 29 cu. yds of brickwork were removed from the old shaft with the use of dynamite and bull pointing. The upper 18 ft. of brickwork were left in the steel casing, which was withdrawn by lighters and transported to the Naval Hospital pier.

General expenses	$2,176.25	
Blasting supplies	19.91	
Clay	30.05	
Miscellaneous	32.37	
Labor	1,155.36	
Use of lighter handling shaft	440.00	
		$ 3,853.94
Credit for steelwork sold as junk		72.00
Total for removing old shaft		$ 3,781.94
Cost per linear foot		$ 74.16

SUMMARY OF COSTS

Earth excavation	$ 9,290.05
Rock excavation	20,334.30
Brick lining	11,013.54
Removing old shaft	3,781.94
	$44,419.83
Engineering	2,200.63
Total cost	$46,620.46
Cost per linear foot of complete tunnel	140.85
The total cost per foot of the original tunnel built in 1900–1901 was	$ 156.00

Cost of Two Tunnels in Rock Under the Erie Canal for the Buffalo, N. Y., Water Works.—In order to run four 60-in. mains from the new pumping station to the main part of the city of Buffalo all four are obliged to cross the Erie Canal a short distance from the pumping station. Two of these mains run up Jersey St. and two up Porter Ave. and it was decided to tunnel under the canal at these two points.

The following data relative to this work are taken from a series of articles by C. H. Hollingsworth, Supt. for the contractors, appearing in Engineering and Contracting, April 17, May 1 and May 8, 1912.

The sections of the Jersey Street and Porter Ave. tunnels were the same in size and length, i.e.—18 ft. wide by 10 ft. high (finished) and 220 ft. c. to c. of shafts. The main difficulties arose in excavating the shafts where large volumes of water had to be pumped. The finished dimensions of the shafts were 10 by 21 ft. in plan and 56 and 65 ft. deep respectively.

Since the work had to be carried on in winter (in order not to block the towpath during the summer months while the canal is in use) the difficulties were greatly intensified. Mr. Hollingsworth gives no data relative to the cost of excavating the shafts but says:

The shaft sinking was one of the hardest propositions in that line that the writer has ever seen. At the dryest shaft (No. 4) the pumpage averaged 300 gals. per minute when the shaft was sunk to grade. At Shaft 3 the leakage was 350 gals. per minute after it had been sunk the full depth, but at times during the sinking the leakage amounted to 1,050 gals. per minute. At shaft 2 the leakage at times during the sinking ran as high as 1,650 gals. per minute and when the shaft was down to grade it was 400 gals. per minute. In Shaft 1 the leakage at times ran as high as 1,300 gals. per minute, and when sunk to grade the leakage ran about 500 gals. per minute. From these figures it can be seen that the pumping was a very considerable item and after drilling a round it was a serious problem to remove the pumps before shooting and replace them after the shot. Oftentimes there was 6 ft. of water in the shaft before the shot could be fired. Added to this was the fact that the severe weather caused everything in the shafts to be coated with ice and it was remarkable that the men stuck so well to the work. Only one shaft pump was used and all the other pumps—of which there were 12 in all, used at different times—were horizontal, duplex plunger pumps of various sizes. These pumps were hung in the shaft, being suspended from the timbering.

Jersey St. Tunnel.—The Jersey St. tunnel was driven from Shaft 4 and was started Feb. 6, but as the first two rounds had to be drilled from tripods, allowing the use of only two machines, the progress was retarded for the first two days. The rock in this tunnel was partly black flint and partly a very hard limestone. The rock being hard, the blasting made considerable concussion, and as the district nearby was thickly populated, a steady stream of complaints began to come in. To make matters worse, the weather, which at the start of the blasting was mild and wet, suddenly turned very cold, freezing the ground so that the slightest shock was transmitted a long way. Windows were broken and crockery was shattered. In order to shut off some of the complaints, the following system was tried: First a round of 8-ft. holes was drilled and fired every eight hours in the heading, the holes being spaced as shown by Fig. 6, and two rounds were drilled on the bench. In shooting, in order to make as little disturbance as possible, the four bottom cut holes were fired first, next the two top cut holes, next the six holes in the side round and lastly the five dry holes. This did not seem to please the public any better than when the entire six holes in the cut were fired in the first shot, so shorter holes were tried. The scheme was to drill a 6-ft. round in the heading and shoot four times in 24 hours, instead of three times. The result showed that about the only way to please the residents in the neighborhood was to stop blasting entirely, and as this could not be done, the writer concluded to try a method of his own, which was to hurry up and get the agony over, so the three

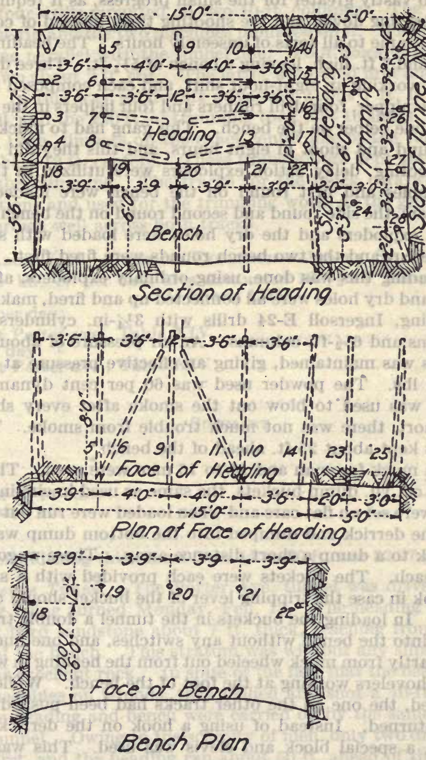


FIG. 6.—Spacing of holes for blasting in tunnels.

Holes 6, 7, 8, 11, 12 and 13 = cut holes, 1st shot in heading—ordinary exploders.
Holes 2, 3, 4, 15, 16 and 17 = side round, 2d shot in heading—1st delay exploders
Holes 1, 5, 9, 10 and 14 = dry holes, 2d shot in heading—2d delay exploders.
Holes 18, 19, 20, 21 and 22 = trench holes, 1st shot in heading—ordinary exploders.
Holes 23 and 24 = 1st shot in trimming—ordinary exploders.
Holes 25, 26, 27 and 28 = 1st shot in trimming—1st delay exploders.

shot schedule was resumed, and 8 ft. rounds were drilled, the entire cut being fired in the first round. As an interesting side light on the question of short holes versus long holes in drilling a heading, it was found that, while the three shots could easily be made in 24 hours, with an average advance of about 5.5 ft. the four 6-ft. rounds could not be drilled and shot in 24 hours. The best that could be done was at the rate of seven shots in two days, averaging 4.1 ft. per shot; so that with the long holes the daily advance was 15.6, while with the short holes the daily progress was 14.3, showing a percentage in favor of the former method. The amount of work required by the short hole method was also vastly greater for the small progress, as it required an extra setting up and tearing down, and the shooting time, instead of coming at the end of the shift, came to all sorts of unseemly hours. The heading was taken out 15 ft. wide and 7 ft. high, leaving a bench of 5½ ft. Three drilling gangs were used, each working an eight-hour shift, and each composed of one heading foreman, one nipper, four drill runners and four helpers in the heading and one runner and one helper on the bench. This gang had to muck out, set up, drill an 8-ft. round and shoot in eight hours, and this they did without any trouble. In shooting, delay action exploders were utilized in the following way: The cut holes and first round on the bench were loaded, using the ordinary exploders, the side round and second round on the bench were loaded with first delay exploders and the dry holes were loaded with second delay exploders. The cut and the two bench rounds were fired first. Then if the cut needed reloading this was done, using ordinary exploders, after which it and side round and dry holes were all connected up and fired, making only two shots. In drilling, Ingersoll E-24 drills with 3¼-in. cylinders were used, mounted on arms and 6½-ft. columns. An air pressure of about 105 lbs. at the compressors was maintained, giving an effective pressure at the drills of about 90 or 95 lbs. The powder used was 60 per cent dynamite and the compressed air was used to blow out the smoke after every shot. As the tunnels were short, there was not much trouble from smoke. The heading was at all times kept about 25 ft. ahead of the bench.

In mucking a muck foreman and 14 to 16 men were used. The muck was loaded into 1½ cu. yd. dump buckets, the same as used in sinking the shafts. These buckets were set on flat cars and when loaded were run out to the shaft, picked up by the derrick and dumped into the bottom dump wagons, which hauled the muck to a dump a short distance away. These wagons took just one bucketful each. The buckets were each provided with a safety chain, with a snap hook in case the tripping lever of the bucket should catch on any of the timbers. In loading the buckets in the tunnel a double track was laid from the shift into the bench without any switches, and one bucket was run in and loaded partly from muck wheeled out from the heading in wheelbarrows and partly by shovelers working at the foot of the bench. While this bucket was being loaded, the one on the other tracks had been pushed out, set up, dumped and returned. Instead of using a hook on the derrick to hook on to the buckets, a special block and clevis was used. This was to prevent accidents from the bucket striking a timber when being lowered and becoming unhooked. The clevis was about as quick to attach and take off as a hook, and was much safer. Owing to the hard and blocky nature of the rock in this tunnel, no extra fast progress was made, although a fair rate was maintained. During the first week a progress of 77.5 ft. was made, but for the first two days of the week only two drills on tripods could be used in starting the heading from the shaft and a shot was lost later on, as the gang had to be taken back to the shaft to drill a sump and some trimming holes. For the second week, ending Monday forenoon, Feb. 20, the progress was 108.2 ft. of both heading and bench. The third week the heading was completed on Wednesday forenoon, Feb. 22, and up to then 35.3 ft. were driven, making the total distance from the south side of shaft 4 to the south side of shaft 3 of 222 ft. in 15 working days (including time of turning the heading), or about 15 ft. per day.

In trimming off the additional 5 ft. to widen the tunnel to 20 ft., it was first trimmed out to full width for a distance of about 20 ft. at a point midway between the two shafts. From this point the trimming was worked both ways, using four drills mounted on two 10-ft. columns. The column was set up close to the rib and the two machines mounted on it. Then 8-ft. holes were drilled running parallel with the tunnel line. Four holes were drilled close to the rib and two about 2 ft. out. The latter were fired first and the other four holes later. In this way each shift advanced about 7 ft. in each direction, or 14 ft. in all, and the 220 ft. of trimming took just 16 shifts, or 5⅓ days. A line of 12 × 12-in. timbers on the exact center line of the tunnel was placed with the timbers 12 ft. centers. These timbers were kept about 12 ft. behind the face of the trimming. The tracks for the muck cars were left in their original locations and used for the trimming work, as the greater part of this muck was thrown well across both tracks.

Table XIII.—Cost of Excavating Jersey St. Tunnel

(Progress 18 lin. ft. per day; area excavated 187½ sq. yds.; cubic yards per 24 hours, 121)

	Cost
Excavation per day:	
Same as at Porter ave., Table XIV	$199.50
Disposal per day:	
Same as at Porter ave., Table XIV	99.00
Total	$298.50

Summary

Item	Per cu yd.
Excavation	$1.65
Disposal	.82
3 lbs. powder at 14 cts	.42
Exploders, wire, etc	.04
Total	$2.93

The cost of widening this tunnel from 15 to 20 ft. was $2.97 per cubic yard.

Porter Avenue Tunnel.—The Porter Ave. tunnel was driven from Shaft 1, the heading being turned Monday, Feb. 13. The heading was in a belt of fine grained hard sandstone about 7 ft. thick, reaching from the roof grade to the top of the bench. This stratum was without any slips or seams whatever and was excellent rock. In spite of the fact that the heading was turned with two machines on tripods, they drilled and shot a 10-ft. round in eight hours. The heading and bench were carried on by the same methods as the Jersey St. tunnel. Owing to the scarcity of men, only two drilling shifts were put on at first, and the heading ran about 50 ft. ahead of the bench the first week, but this was reduced to 25 ft. during the second week. As the rock drilled and broke well, a 10-ft. round could have been drilled and fired every eight hours, but for the fact that the city authorities about this time limited the depth of holes to 8 ft. on account of complaints regarding the jar of the blasting. The progress was much better in this tunnel than at Jersey St. As stated before, only two drilling shifts were worked during the first week, and the progress for that week ending Feb. 20 was 96 ft., including in this, however, two shots made on Sunday, the 19th, or 15 shots in all, averaging 6.4 ft. per shot. On Monday, the 20th, three drilling gangs and three full mucking gangs of 14 to 16 men each were started and the progress for the week ending Monday forenoon, Feb. 27, was 126 ft. of heading and bench. In fact a gain of 25 ft. was made on the bench. This progress was made in the six days and one extra 6-ft. round fired on Sunday to finish up the tunnel to the further side of Shaft 2. The advance made on the 6-ft. round was 5 ft., and deducting this the average advance of the other 18 shots was 6.7 ft. per shot. The only difference between here and the Jersey St. work in the men employed was that at Porter Ave. during this last week an extra muck foreman was used in the heading and this resulted in a much faster handling of the muck with the same number of muckers. The entire distance of 222 ft. was taken out in 34 shots or 11⅓ working days, averaging about 6.5 ft. per shot.

TABLE XIV.—COST OF EXCAVATING PORTER AVE. TUNNEL, ORIGINAL SECTION

(Progress 21 lin. ft. per 24 hours; and of section excavated 187½ sq. ft.; cubic yards per 24 hours 146)

Excavation per shift:	Cost
1 heading foreman	$ 5.00
5 drill runners at $3	15.00
5 helpers at $2.25	11.25
1 nipper	2.25
1 muck foreman	3.00
14 muckers at $2.00	28.00
1 bottom signal man	2.00
Total per shift	$ 66.50
Total per 24 hours (three shifts)	$199.50
Disposal per shift:	
1 top signal man	$ 2.00
2 dumpers at $1.75	3.50
2 men at dump at $1.75	3.50
4 teams at $6	24.00
Total per shift	$ 33.00
Total per 24 hours (three shifts)	$ 99.00
Grand total	$298.50

SUMMARY

Item	Per cu. yd.
Excavation	$1.36
Disposal	.68
Powder 2¾ lbs. per cu. yd. at 14 cts	.39
Exploders and wire	.04
Total	$2.47

TABLE XV.—COST OF WIDENING PORTER AVE. TUNNEL FROM 15 FT. TO 20 FT.

(Progress 42 lin. ft. per day; and excavated 62½ sq. ft.; cubic yards per 24 hours 97)

Excavation per shift:	Cost
1 heading foreman	$ 5.00
4 drill runners at $3	12.00
4 helpers at $2.25	9.00
1 nipper	2.25
1 muck foreman	3.00
10 muckers at $2	20.00
1 bottom signal man	2.00
Total per shift	$ 53.25
Total per 24 hours (three shifts)	$ 159.75
Disposal per shift:	
(Same as in Table XIV.)	
Total per 24 hours (three shifts)	$ 99.00
Grand total	$258.75

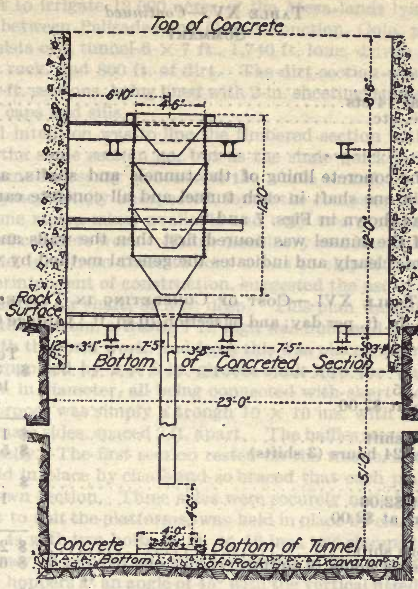


Fig. 7.—Installation of Haines mixer in shaft.

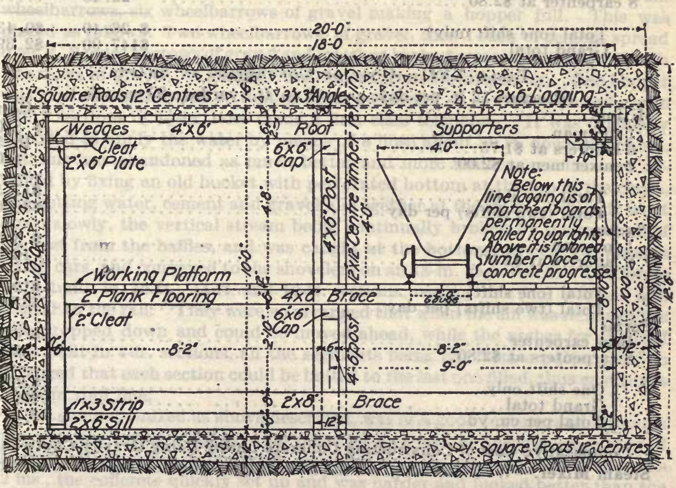


Fig. 8.—Cross section of tunnel showing details of concrete forms.

TABLE XV.—*Continued*

SUMMARY

Item	Per cu. yd.
Excavation	$1.64
Disposal	1.02
Powder 2 lbs. at 14 cts	.28
Exploders, wire, etc	.03
Total	$2.97

In placing the concrete lining of the tunnels and shafts, a Haines mixer was installed in one shaft in each tunnel and all concrete carried from that point in cars as shown in Figs. 7 and 8.

The floor of the tunnel was poured first then the walls and roof. Fig. 8 shows the forms clearly and indicates the general method by which the work was done.

TABLE XVI.—COST OF CONCRETING IN TUNNELS

(Progress 24 lin. ft. per day; and of section 70 sq. ft.; yardage 62 cu. yds.)

	Total	Per cu. yd.
Mixing:		
1 foreman	$ 3.00	......
6 men at $1.75	10.50	......
2 mixer men at $2.00	4.00	......
Total per shift	$ 17.50	......
Total per 24 hours (3 shifts)	$ 52.50	$0.847
Placing:		
1 foreman	$ 3.00	......
8 laborers at $2.00	16.00	......
2 car pushers at $2.00	4.00	......
Total (one shift)	$ 23.00	......
Total per 24 hours (3 shifts)	$ 69.00	$1.113
Forms:		
Boss carpenter	$ 4.00	......
8 carpenter at $2.80	22.40	......
Total (one shift only)	$ 26.40	$0.430
Grand total	$147.90	$2.39

TABLE XVII.—COST OF CONCRETING IN SHAFTS

(Progress 12 ft. per day; area 66 sq. ft.; yardage 29 cu. yds.)

	Cost
Mixing:	
1 foreman	$ 3.00
6 laborers at $1.75	10.50
2 mixer men at $2.00	4.00
Total one shift	$17.50
Total (two shifts) per day	$35.00
Placing:	
1 foreman	$ 3.00
8 laborers at $2.00	16.00
Total (one shift)	$19.00
Total (two shifts) per day	$38.00
Forms:	
Boss carpenter	$ 4.00
8 carpenters at $2.80	22.40
One shift only	$26.40
Grand total	$99.40
Total per cu. yd	$ 3.43

Comparative Cost of Constructing Concrete Lining Using Gravity Chute and Steam Mixer.—W. D'Rohan gives the following in Engineering and Contracting, July 6, 1910.

In a project to irrigate 12,000 acres of the Mesa lands lying south of the Grand River between Palisades and Grand Junction, Colo, part of the construction consists of a tunnel 6 × 7 ft., 1,740 ft. long, driven through 940 ft. of black shale rock, and 800 ft. of dirt. The dirt section was timbered, roof and sides, in 4-ft. sections, being lined with 2-in. sheeting, supported by 6 × 6-in. posts with caps and sills.

The original intention was to line the timbered section with 9 ins. of concrete and let the shale section go, but as the shale quickly disintegrated in the air, it became necessary to concrete the whole tunnel.

This contingency totally unexpected, found the company in a remote locality with but one steam mixer available and only two months to complete a large amount of concrete work. Extra machinery was immediately wired for, and as it would take from three to four weeks to ship it from Chicago, the writer, as superintendent of construction, suggested the use of a gravity chute through the central air shaft, 82.5 ft. deep. This plan was adopted.

Starting at the bottom, a trestle 7 ft. high was built and arranged so as not to interfere with the form work, and from this was placed a series of platfroms 8 ft. apart, supported by 2 × 8-in. girders sunk into the walls of the shaft which was 4 ft. in diameter, all being connected with short ladders.

The chute proper was simply a trough 10 × 10 ins. with a series of baffles nailed on alternate sides, spaced 2 ft. apart. The baffles were made by cutting 4 × 4s diagonally. The first section rested on the trestle, and the remaining parts were held in place by cleats and so braced that each platform bore the weight of its own section. Three sides were securely nailed, and the fourth, which was cut to suit the platforms, was held in place by clamps made of two pieces of 2 × 4s with two bolts ⅜ in. × 16 ins., two clamps to each section. This made it easy to remove one side for repairs. The top of the chute had two V-shaped hoppers at an angle of 45° with the vertical fitted with a wooden slide door. Into these hoppers the gravel and cement were dumped from wheelbarrows, six wheelbarrows of gravel making a hopper full. This was placed as follows: Two wheelbarrows of gravel, then 1 sack of cement spread over it, 2 more barrows of gravel and another sack of cement, finishing off with 2 barrows of gravel. This kept the cement from blowing away. One hopper was kept continually full so that no delay resulted. A cowbell with some wire and 3 sections of ½-in. hose made a first-class telephone. It was originally intended to apply the water by means of a hose about 30 ft. down the chute, but this was abandoned as much better and more uniform results were obtained by fixing an old bucket with perforated bottom at the top of the chute, and getting water, cement and gravel all together at the start. The mix went down slowly, the vertical stream being continually broken by the rebound of the rest from the baffles, and was caught at the bottom in ½ cu. yd. wooden scoop cars, and conveyed to the shovelers on an 18-in. gage track. The forms were built in 12-ft., 14-ft. and 16-ft. sections, resting on a 2 × 6-in. sill and braced to the rail. They were so arranged that when the sill was removed the side dropped down and could be moved ahead, while the arches for the roof were built in 4-ft. sections, all the segments being cut from a pattern and so arranged that each section could be bolted to the last one filled, thus ensuring a uniform roof line.

The concrete mixed as above described, was of a good texture, and although the weather varied from freezing point to zero and no mechanical means of heating either water or materials was used and the ice formed on the tanks 2 ins., the concrete quickly set up and was harder and looked better than the machine mixed concrete, where water heated by the exhaust steam was used. In handling the steam mixer, 6 men and an engineer were required, while with the chute, 3 men got out twice as much concrete, and so satisfactory to the engineers, promoters and contractors that the new machinery was never used.

A total of 1,500 cu. yds. of concrete were mixed in this manner, and required but one renewal of the baffles, the second set being placed opposite the worn ones to keep the sides from wearing into holes where the concrete hit on the rebound off the baffles. The total cost of chute, renewal of baffles and labor of building in place was $75 or 5 cts. per cu. yd.

Gravel, cement, lumber and water for this work had to be hauled 5 miles over a rough mountain road and were delivered by contract at $1.25 per yard for gravel, cement 75 cts. per ton, and water 10 cts. per barrel. Lumber cost $30 per M. ft. B. M. Ideal Portland cement, a Colorado product, cost $3.25 on the job; labor cost $2.50 for carmen and outside men, $2.75 for overhead shovelers; carpenters 40 cts. per hour, and foremen $4 per day. Two 10-hour shifts were worked and the whole tunnel lining of 2,400 cu. yds. of concrete was completed in 40 working days.

The comparative itemized cost of lining by steam mixing and by the chute were as follows:

STEAM MIXER

1 engineer	$ 4.20
4 men feeding	10.00
1 roustabout	2.50
2 men loading into cars	5.00
4 men placing in forms	11.00
3 carpenters	12.00
3 carpenters' helpers	7.50
2 carmen	5.00
1 trackman	2.50
1 general foreman	6.50
Total labor for 15 yds	$66.20
Labor, per yard	$ 4.41
Gravel, per yard	1.50
Cement, per yard	2.50
Water	0.20
Lumber	0.08
Light	0.10
Coal and oil for mixer	0.25
Wear and tear of mixer	0.25
Total cost per yard	$ 9.29

GRAVITY CHUTE

3 men mixing	$ 7.50
4 carmen	10.00
6 men placing in forms	16.50
4 carpenters	16.00
4 carpenters' helpers	10.00
2 trackmen	5.00
1 general foreman	6.50
Total labor for 35 yds	$71.50
Labor, per yard	2.04
Gravel, per yard	1.50
Cement, per yard	2.50
Water	0.20
Lumber	0.08
Light	0.10
Mixer	0.05
Total cost per yard	$ 6.47

The biggest run with steam mixer was 26 cu. yds. and the smallest 8 cu. yds., due to breakdowns, while the chute made 54 cu. yds. maximum and 21 minimum, due to water giving out.

Cost of Lining Wilson Ave. Water Supply Tunnel Chicago with Pneumatic Mixer.—The following extract, Engineering and Contracting, May 15, 1918, is from a paper by H. B. Kirkland presented before the Western Society of Engineers.

This tunnel is 8 miles long and 12 ft. in finished diameter for 1 mile of its length at the lake end. It is located in solid limestone rock about 150 ft. below datum and has a monolithic concrete lining 1 ft. thick. In lining this tunnel the concreting was carried on simultaneously with the mining, the mine run rock excavated from the heading being used for concrete work.

A pneumatic mixer was mounted on wheels, together with air supply tanks and a measuring hopper above it. In addition a belt conveyor outfit, also mounted on wheels, was used to convey the rock from under the screen to the measuring hopper over the mixer. Upon the framework which held this belt conveyor an electric winch was mounted for hauling 1 cu. yd. cars of mine run up the incline, to be dumped over a flat screen with 4½-in. holes. The rock which passed through the holes fell onto the belt conveyor and was carried up to the measuring hopper. The rejections passed over the screen and fell into an iron plate laid on the floor, from whence they were shoveled into the car to be hauled from the tunnel.

Two Blaw traveling steel forms were used. One of these forms was about 500 ft. away. The 8-in. pipe for conveying the concrete from the mixer to the forms was laid alongside of the tunnel through the first form to the second one, and there it was directed up a 45° angle and into the top of the form. When this form was filled with concrete the pipe was disconnected and arranged for filling the other form and as the concrete set the forms were moved alternately toward the mixer, until about 1,000 ft. of tunnel was completed. The mixer was then moved 1,000 ft. farther and the same cycle of operation was repeated.

One of the new features of placing the concrete at the Lawndale shaft was the use of the pneumatic mixer for placing the concrete in the footing wall. This footing wall is usually built by hand in advance of the regular concrete work and is a wall about 1 ft. high, used as a guide for the forms to follow. In placing this at the Lawndale shaft the concrete was first delivered to the Blaw forms by the pneumatic mixers in the regular manner. But a keyplate was left out of the steel forms and a chute was placed in it, operating so that the concrete being placed by the pneumatic method would overflow through the chute into the car placed beneath the forms under the chute. The car then carried the concrete ahead and dumped it into the forms for the footing wall. In this way the footing wall was placed about three times as fast as it could have been placed by hand.

The number of men required for the operation of the concrete work was as follows:

Screening rock from heading—

3 men pushing up cars to incline, hooking on cable, dumping same on screen and pushing back empty cars to make train bound for heading.
1 man operating motor hoist for pulling cars up incline and operating belt conveyor for carrying screened rock to hopper over mixer.
2 men shoveling rejections from screen into cars to be hauled out of tunnel.

Cement Delivery—
- 2 men unloading cars of cement and storing same on platform above air tanks adjacent to mixer hopper.

Mixing and placing concrete—
- 3 men operating hopper over mixer, feeding cement, water and screen run rock.
- 1 man operating mixer, air valves.
- 1 man at end of pipe in concrete form.

When there was sufficient rock on hand for continuous concreting the forms were filled very rapidly, one form having been filled in 1 hour and 40 minutes. The forms contained from 50 to 70 yd., of concrete, depending upon the excavating section. During January, 1917, one machine at Lincoln Ave. placed 2,707 lin. ft. of tunnel lining.

Working between 16 and 24 hours a day, one machine at the Lincoln shaft put in 2,900 lin. ft. of tunnel in a month, and the yardage of the lining runs 2 cu. yd. per lineal foot. The ultimate capacity of the mixer is 60 cu. yd. per hour.

Quantity of Grout Required for Typical Aqueduct Tunnel.—The following data are taken from an article by James F. Sanborn, published in Engineering Record, April 15, 1916.

The Canniff tank is well adapted for handling grout rapidly. As high as 1,500 batches or 115 cu. yd. of grout have been placed in one day of three shifts by a pair of tanks. A small force operates the tanks and no high-priced men are required for repairs or operation. Either rich or weak grout can be used, and the tank is adapted for low as well as for very high pressure.

A disadvantage of the Canniff tank is shown when used for high pressure work, when the grout is discharged very slowly into fine seams, taking a long time. In such cases the cement has time to settle out of the mixture and clog the openings. However, as very thin grout should be used in such cases, the difficulty is not very serious practically.

The quantity of grout placed in a typical stretch of 12-ft. tunnel of the Catskill Aqueduct was as follows:

	Length of tunnels grouted	No. of connections made	Shifts worked	Cu. yd. liquid grout
Low pressure grouting*	10,113 ft.	170	69	1,744
High pressure grouting†	10,113 ft.	1,670	113	150

* Most of the grout placed in the low pressure operation filled the space above the concrete in the tunnel roof.

† Most of the high pressure grouting was to cut off leaks from seams in the rock, and to fill pans.

The Overbreakage in the Catskill Aqueduct Tunnels.—In building the Catskill aqueduct to New York City careful records were kept of the amount of overbreakage in the different sections of the 49 miles of tunnel. The specifications were so drawn as to encourage the contractors to reduce the overbreakage to a minimum. Engineering and Contracting, Aug. 15, 1917, gives the following brief outline of the specified method of determining the pay yardage both of excavation and of concrete lining and a summary of the data as to overbreakage.

Where the tunnel dipped below the hydraulic grade line and there would consequently be an internal pressure of water on its walls, it was 41 ft. in diameter inside the concrete lining. Let us call this inside concrete line (a circle 14 ft. diam.) "the inside line." Parallel to this line and 10 ins. outside of it is another line within which no rock must project, and this may be called "the clearance line." Parallel thereto and 23 ins. outside of "the inside line" is the "payment line," beyond which neither excavation nor concrete is paid for at the regular contract price. Excavation beyond this "payment line" may be called "overbreakage."

In the Catskill aqueduct specifications it was provided that the contractor should be paid 2.50 or $3 per cu. yd. of overbreakage as compensation for both this extra excavation and the extra concrete lining necessitated by the overbreakage. Since the contractor did not furnish the cement, it was believed by the engineers that this payment for overbreakage would be a fair compensation for any unavoidable overbreakage, but not so large a compensation as to make it profitable to the contractor. Between "the payment line" and "the clearance line" there was another line that may be called "the average line," which was 15 in. outside "the inside line;" and it was specified that the concrete in any cross-section must average 15 in. thick.

The above dimensions relate to the "pressure tunnel" sections, aggregating 35 miles in length. There were 14 miles of "grade tunnels" of horseshoe section that did not dip below the hydraulic grade line, and the inside maximum dimensions of a "grade tunnel" were 13 ft. 4 in. across by 17 ft. high. The "clearance line" of a "grade tunnel" was 5 to 7 in. outside "the inside line;" and the "payment line" was 13 in. outside the "clearance line." These lines relate only to the side walls and roof.

There was considerable variation as to overbreakage, not only because of difference in the kind of rock (which ranged from soft shale to tough granite), but because of the position of the tunnel with respect to the dip of the rock strata, also because of the variation in the managerial skill of the different contractors. In nearly 12 miles of tunnels through shale and slate, there was no overbreakage at all, as the average of 8 contracts; but in fact the average excavation fell half an inch inside of "the payment line." One contractor managed to average a full inch inside "the payment line," but another contractor averaged an overbreakage 2¼ in. outside "the payment line."

In four tunnels through limestone, totaling about 1¼ miles, the overbreakage averaged 1¾ in. outside the payment line.

In 19 tunnels through granite and gneiss, totaling about 8 miles, the overbreakage averaged 3¾ in. outside the "payment line;" but in one 900 ft. tunnel there was an average underbreakage of ¾ in., while in another tunnel (7,330 ft.) the overbreakage averaged 5¾ in. In this last named tunnel the contractor purposely excavated well beyond "the payment line" in order to avoid the expense of trimming projecting rock. Moreover this gneiss was blocky and joints were numerous.

In 10 tunnels through Manhattan schist, totaling about 8½ miles, the average overbreakage was 2½ in., but in one tunnel the overbreakage averaged only ¾ in., whereas in another it averaged 8 in. because the schist was much disintegrated.

Those experienced in tunnel work will see that the overbreakage would have been somewhat less had it not been for the specifying of an average thickness of concrete (see "the average line" above defined). Ordinarily only a "clearance line" (or neat line) and a "payment line" are specified.

In the softer rocks, like shales and limestones, where air-hammer drills can be effectively used in trimming the sides, the overbreakage averages considerably less than in the tough rocks, like granite, gneiss and schist. In tough rocks the contractor drills his blast holes deep enough to insure breakage beyond the "payment line," so as to reduce the trimming. One of the contractors used a large number of horizontal rim holes in excavating the lower half a pressure tunnel through gneiss, and thus secured an underbreakage of ½ in. inside the "payment line."

Cost of Excess Yardage in Tunneling.—The following data are given in the Report on the Los Angeles aqueduct.

Too much care cannot be exercised to avoid overshooting in tunnels, because of the excess yardage that is involved when it comes to lining them with concrete. Some tunnels were driven and trimmed so closely that this excess yardage of concrete did not exceed 15 or 20 per cent of the theoretical yardage of concrete, but the cost of this trimming amounted to as much as $2.00 per lineal foot of tunnel, and probably too much time and care were put upon it. As a rule the excess yardage of concrete was from 40 to 50 per cent of the theoretical, and in some tunnels as much as 100 per cent. Experience indicates that rock tunnels should be driven so that the excess yardage of concrete lining may not be over 30 or 40 per cent. In driving tunnels, frequent measurements should be made of their cross-section to determine what this excess is. Where a yard of concrete to the lineal foot of tunnel is being placed, 100 per cent excess could readily amount to $6.00 or $7.00 per foot, and a 30 per cent excess would represent $1.80 per foot. Tunnels in ordinary rock should be driven with a small amount of trimming; as close as this percentage. It has been found to be the best practice to so excavate the sub-grade at the start that the top of the ties is on the bottom of the theoretical sub-grade, so as to avoid expensive trimming and delays when it comes to concrete lining.

Depth and Number of Drill Holes in Tunnels.—The following tables are taken from Bulletin 57 of the Bureau of Mines prepared by D. W. Brunton and J. A. Davis, as abstracted in Engineering and Contracting, July 8, 1914. The authors in summarizing the discussion of the advantages of shallow and deep holes state that it is, of course, impossible to set any definite standard or guide for the proper depth of hole that will be applicable to all cases. There are too many variables influencing the result. The proper depth must be determined by experiment in each individual case. However, from an extended examination of the results obtained from the methods employed in American practice, from a careful analysis of European practice as outlined in available published accounts, and from a study of all other procurable modern authority, the authors are of the opinion that for the majority of cases the proper depth of drill hole, the one that most equitably balances the advantages and disadvantages inseparable from the problem, is 60 to 80 per cent of the width of the tunnel heading. Table XVIII gives an analysis of American practice in this respect.

TABLE XVIII.—DEPTH OF DRILL HOLES USED IN AMERICAN TUNNELS

Name of tunnel	Type of cut, (wedge, bottom or pyramid)	Height of heading, ft.	Width of heading, ft.	Av. depth of cut holes, ft.	Av. depth of other holes, ft.	Av. depth of round drilled, ft.	Percentage of width of heading of average round	Character of rock penetrated
Buffalo (water)	W	8	15	8	7	7	46.5	L.
Carter	B	7½	5½	9	8	8	*106	Gn., gr. and po.
Catskill aqueduct:								
Rondout (siphon)	W	8	14	10	8	8	57	L., sn. and sh.
Wallkill (siphon)	W	8	14	12	10	10	71.5	Sh.
Moodna (siphon)	W	8	14	10	8	8	57	Sn. and sh.
Yonkers (siphon)	W	8	14	8	6	6	48	Gn.
Central	W	7	5	8	7	7	140	Gn.
Ft. William (water)	B	6½	5	6	5	5	*77	Ba.
Gold Links	B	8	6	6	5	5	*62.5	Gr. and gn.
Gunnison	W	6	10	7	6	6	60	Gr.
Joker (drainage)	W	11	12	10½	9	9	75	
Laramie-Poudre	W	6½	9½	8	7	7	74	Gr.
Lausanne	W	8	12	8	7	7	58	Cong. sh. and coal
Lucania	W	8	8	9	8	8	100	Gr.
Marshall-Russell	P	9	8	10	9	9	112	Gr. and gn.
Mission	B	7	5	8	7	7	*100	Sh. and sl.
Mission†	P	7	5	8	7	7	140	Sn.
Newhouse	P	8	8	6½	5½	5½	69	Gn.
Nisqually	B	11	9½	8	6½	6½	*59	Rhy.
Northwest (water)	W	10	13	10	9	9	69	Sed.
Ophelia	W	9	9	7	6	6	67	Gr.
Rawley	W	7	7½	9	8	8	106	And.
Raymond	W	9	9	12	10	10	111	Gn. and gr.
Roosevelt	W	6	10	7	6	6	60	Gr.
Siwatch	B	7½	6	5	5	5	*67	Gr.
Snake Creek	W	6½	9½	6½	5½	6	63	Dia.
Spiral	W	10	16	12	10	10	63	L.
Stilwell	W	7	7	6½	6	6	86	Cong and and.
Strawberry	W	6	8	7	6	6	75	L., sn. and sh.
Utah Metals	B	8	10	6½	6	6	*75	Qu.
Yak	P	7	7	5	4	4	57	L., sn., sh. and gr.

* The height of the heading, instead of its width, is considered in this ratio when the bottom cut is employed. † Hard ground.

L., Limestone; gn., gneiss; gr., granite; po., porphyry; sn., sandstone; sh., shale; sl., slate; ba., basalt; cong., conglomerate; rhy. rhyolite; sed., sedimentary; and., andesite; dia., diabase; qu., quartzite.

Determination of the number of holes which secures the best results in driving tunnel headings is affected by too many conditions to permit in any work of precisely following previous experience. Such experience, however, furnishes hints which are of use and for this reason Table XIX is given.

TABLE XIX.—NUMBER OF HOLES USED IN DRIVING TUNNEL HEADINGS IN VARIOUS AMERICAN TUNNELS

Name of tunnel	Number of holes	Character of rock penetrated	Approx. area of heading, sq. ft.	Sq. ft. of heading per hole — Sedimentary rocks	Sq. ft. of heading per hole — Igneous rocks
Burleigh	16	Gr. and gn.	42	....	2.6
Buffalo (water)	22	L.	120	5.5	....
Carter	10–11	Gn., gr. and po.	41	....	3.7–4.1
Catskill aqueduct:					
Rondout siphon	22	L., sn., and sh.	120	5.5	....
Wallkill siphon	24	Sh.	120	5.0	....
Moodna siphon	24	Sn. and sh.	120	5.0	....
Yonkers siphon	21	Gn.	120	....	5.7
Central	18–24	Gn.	35	....	1.5–1.9
Chipeta	15–19	....	57	....	3.0–3.8
Fort William (water)	14–20	Ba.	35	....	1.7–2.5
Gold Links	12	Gn. and gr.	48	....	4.0
Grand Central sewer	18	Gn.	40	....	2.2
Gunnison	24	Gr.	60	....	2.5
Joker	19–21	....	130	6.2–6.9	....
Laramie-Poudre	21–26	Gr.	70	....	2.7–3.3
Lausanne	15–21	Sh., cong. and coal	85	4.0–5.6	....
Los Angeles Aqueduct:					
Elizabeth Lake	25	Gr.	145	....	5.8
Little Lake division	14–16	Gr.	90	....	5.6–6.4
Grape Vine division	20–21	Gr.	90	....	4.3–4.5
Lucania	25	Gr.	65	....	2.6
Marshall-Russell	18–20	Gr. and gn.	72	....	3.6–1.0
Mission	12–14	Sh. and sl.	37	2.6–3.1	....
Newhouse	19	Gn.	65	....	3.4
Nisqually	18	Rhy.	95	....	5.2
Northwest (water)	22	Sed.	110	5.0	....
Ophelia	20–24	Gr.	80	....	3.6–4.0
Rawley	25–27	And.	55	....	2.0–2.2
Raymond	14	Gn. and gr.	80	....	5.7
Roosevelt	24–26	Gr.	60	....	2.3–2.5
Siwatch	12	Gr.	45	....	3.7
Snake Creek	16	Dia.	65	....	4.0
Spiral	21	L.	175	8.4	....
Stilwell	16	Cong. and and.	50	3.1	....
Strawberry	16–18	L., sn. and sh.	50	2.8–3.1	....
Utah Metals	12–16	Qu.	80	5.0–6.6	....
Yak	18	L., sn., sh. and gr.	50	2.8	....

Comparative Drilling Speeds As Reported at Twenty-Four Tunnels.—The rate of drilling as reported at 24 tunnels is recorded in Table XX, abstracted in Engineering and Contracting, Aug. 5, 1914, from Bureau of Mines, Bulletin 57, by D. W. Brunton and J. A. Davis.

TABLE XX

Name of tunnel	Type of drill, (hammer or piston)	Character of rock penetrated	Drilling speeds per machine per hour, feet	Remarks
Carter	H	Granite	10	Approx.
Catskill aqueduct:				
Rondout	P	Shale	8	Fair average.
Wallkill	P	Shale	10.5	Normal conditions
Central	P	Gneiss	8–16	
Fort William (water)	P	Trap	2	Phenomenally hard rock
Gold Links	H	Gneiss	8–10	Approx.
Joker	H	Breccia	12–15	
Laramie-Poudre	H	Granite	15	Ordinary conditions
Los Angeles aqueduct:				
Little Lake	H	Hard granite	15.84	Av. of 15 accurately timed shifts
Grape Vine	H	Granite	10	Estimated average
Lucania	H	Granite	13	Average of 3 drills
Marshall-Russell	H	Granite	10–20	
Mission	H	†	30	Medium ground
Newhouse	H	Gneiss	10	
Nisqually:				
Headworks end	P	Rhyolite	8–10	
Discharge end	H	Rhyolite	10	Rock is much harder than at other end
Ophelia	P	Granite	8–10	
Rawley	H	Andesite	15–20	Av'ge of 4 accurately timed drill shifts, 19.7 feet
Raymond	H	Granite	8–12	
Siwatch	H	Granite	10–15	
Snake Creek	P	Diabase	*8–12	
Stilwell	P	Andesite	.5–10	
Strawberry	P	Shale	13	Test run
Utah Metals	P	Quartzite	6–8	

Includes time used in setting up and tearing down column or bar, in shifting machine to new holes, and in changing steel, but does not include time used in mucking for set-up or in loading, blasting and clearing smoke.

* During a competition test in which both drills were mounted on the same bar in order to obtain identical conditions of rock, etc, the piston machine drilled 21 feet per hour, whereas a hammer drill made only 20 ft. The conditions were unusual, however, because water under pressure was encountered in practically every hole drilled, and doubtless influenced the results greatly.

† Shale and sandstone.

Air Pressures Used in Tunneling.—Engineering and Contracting, July 1, 1914, gives the pressures of air employed at different tunnels as compiled in Bureau of Mines Bulletin 57 by D. W. Brunton and J. A. Davis as follows:

Tunnel—	Lbs.	Tunnel—	Lbs.
Carter	112	Nisqually	90–95
Central	120	Rawley	100
Gold Links	100	Raymond	90
Gunnison	90	Rondout	100
Laramie-Poudre	120	Roosevelt	110
Mauch Chunk	100	Siwatch	80
Los Angeles Aqueduct	100	Snake Creek	110
Lucania	115	Stilwell	100
Marshall Russell	110	Strawberry	85
Mission	100	Utah Metals	110
Modern	95–100	Wallkill	110
Newhouse	110	Yak	90
Average			102

Cost of Repairs of Drills Employed in Tunneling.—From data collected by personal visits to and special reports from a large number of tunnels, D. W. Brunton and J. A. Davis, in Bulletin 57, Bureau of Mines (reprinted in Engineering and Contracting, July 22, 1914) present the following statement:

From September, 1905, to March, 1906, hammer drills were employed at the Gunnison tunnel with a drill-repair cost per machine of 13 cts. per foot of hole drilled; but when piston drills were substituted the repairs were reduced to 3 cts. per foot. In addition to the cost of materials these figures include also a charge for the labor of the machinist making the repairs, which is not em-

TABLE XXI.—COST OF REPAIRS FOR HAMMER AIR DRILLS, LITTLE LAKE DIVISION, LOS ANGELES AQUEDUCT, JULY, 1909, TO MAY, 1911

Name of tunnel	Distance, excavated, lin. ft.	Cost of drill repairs per foot of tunnel
1B, south	1,030	$0.156
2, north	926	.195
2, south	419	.154
2A, north	460	.100
2A, south	375	.148
3, north	864	.131
3, south	2,149	.235
4, north	448	.149
4, south	725	.297
7, north	1,911	.209
7, south	1,024	.482
8, north	225	.651
8, south	1,334	.398
9, north	777	.297
9, south	2,479	.163
10, north	2,626	.223
10, south	1,776	.325
10A, north	1,373	.221
10A, south	1,756	.204
Average		$0.24

braced in any of the values which follow. This fact must be considered in making comparisons. Two years later (September, 1907, to August, 1908), in driving the last 3,000 ft. of the Yak Tunnel, the cost of materials only for repairs to the hammer drills employed was only 1¾ cts., approximately, per foot of hole. At the Marshall-Russell tunnel, where hammer drills were employed, the average cost of drill repairs from June, 1908, to June, 1911, was 1½ cts. per foot drilled. Piston machines were used at the Strawberry tunnel from January, 1909, to September, 1911, the cost for repairs being nearly 2½ cts. per foot drilled. On the Little Lake division of the Los Angeles aqueduct, where hammer drills were employed, the average cost of drill-repair materials from July, 1909, to May, 1911, as shown by Table XXI, was only 24 cts. per foot of tunnel excavated. As each of the two machines in the heading drills approximately 8 ft. of hole for every foot of tunnel excavated, the cost per machine per foot of hole is 1½ cts.

For 1910 and the first half of 1911 the repair cost of hammer drills at the Carter tunnel was 2 cts. per foot drilled. At the Lucania tunnel the repairs cost ½ ct. per foot drilled, but the hammer drills had been in use only one month at the time the tunnel was visited. The hammer drills at the Rawley tunnel were new also, the repairs for June and July, 1911, averaging 1 ct. per foot of hole.

Adequate Ventilation Greatly Increases Tunnel and Shaft Progress.—The following note is given in Engineering and Contracting, Oct. 17, 1917.

An interesting example of the effect of poor ventilation on the efficiency of men engaged in underground work was cited by Dr. A. J. Lanza of the Bureau of Mines in a paper presented at the recent meeting of the National Safety Council. A mine, driving a long drift about 3,000 ft. below the surface, was paying $15 per foot, day's pay. The place was hot and moist. A small blower fan was installed at the entrance to the drift, with a canvas pipe leading nearly to the working face, and without any other change the cost was reduced to $8 per foot, day's pay. In shaft sinking this mine had made 50 ft. in one month and 60 ft. in another. A small blower with canvas pipe was installed and the next month 120 ft. was the progress made.

CHAPTER XX

LARGE TUNNELS

References.—In Section XI of the "Handbook of Cost Data" by Gillette, the first 60 pages contain many valuable data on the cost of railway tunnels. Further information on this subject will also be found in Gillette's "Handbook of Rock Excavation."

Cost of Beckwith Pass Tunnel of Western Pacific Ry.—The Beckwith Pass Tunnel of the Western Pacific Ry. at the summit of the Sierra Nevada mountains was constructed between 1906 and 1909. It is a single track bore 6,006 ft. in length. The roof of the tunnel is 24.08 ft. above the top of the foot block; the top of the wall plate is 16.54 ft. above grade, and the width between plumb posts is 17 ft. Cost data on the construction of this tunnel are given by H. Devereux, consulting engineer, San Francisco, Cal., in the Feb., 1917, Western Engineering, from which the matter in this article is abstracted in Engineering and Contracting, Feb. 21, 1917.

The quantities per linear foot of tunnel were as follows:

Excavation, Cu. Yd.

	Heading	Bench
Neat section	3.25	10.39
Enlarged section, side-lagged	4.905	12.351
Enlarged section, lagged	.....	12.04
Enlarged section, increase lagged	.....	1.961
Packing between lagging and 3-in. line	0.267	0.306

Timber, Ft. B. M.

	Heading	Bench
Solid sets	327.4	408.0
2-ft. centers	285.0	210.4
3-ft. centers	234.6	141.6
4-ft. centers	209.4	107.2

For full lagging, add 124 ft. B. M. per linear foot of bench.

Iron, Lb.

	1-bolt	2-bolt	Large washers
Solid sets	10.786	11.571	12.000
2-ft. centers	5.687	6.374	6.750
3-ft. centers	3.944	4.355	4.881
4-ft. centers	3.056	3.607	3.906

Large washers were used after Nov. 1, 1907.

The following scale of wages was in force. As a result of the business depression, the force and in many cases, the wage-rates were reduced on Nov. 25, 1907. Wages are per day unless otherwise noted. Men paid by the month received their board also.

	Before Nov. 25, 1907	After Nov. 25, 1907
Foreman	$ 4.50	$ 4.50
Machine-men	4.00	3.50
Machine-helpers	3.50	3.00
Shovelers	3.00	2.50
Teamsters	3.00	2.50
Cornermen	3.50	2.75
Nippers	3.00	2.50
Carpenters	4.00	3.50
Carpenters' helpers	3.00	2.50
Pump-men	3.00	3.00
Steam-shovel engineer	150.00*	150.00*
Steam-shovel cranesmen	100.00*	100.00*
Dinkey skinners	75.00*	75.00*
Brakemen	50.00*	2.50
Pitmen	3.50	2.75
Dumpmen	2.50	2.25
Timbermen	3.00	2.50
Outside laborers	2.50	2.00
Two-horse teamsters	2.75	2.50
Blacksmiths	100.00*	3.50
Blacksmiths' helpers	2.75	2.50
Electrician	75.00*	75.00*
Compressor engineer (day)	90.00*	90.00*
Compressor engineer (night)	75.00*	75.00*
Master mechanic	125.00*	110.00*
General foreman	150.00*	150.00*
Car repairer	75.00*	75.00*

* Per month.

The following force was employed during December, 1907, when both headings were closed:

OUTSIDE OF TUNNEL

	East end Day	East end Night	West end Day	West end Night
Compressor engineer	1	1	1	1
Compressor fireman	1	1	1	1
Dinkey skinner	1	1	1	1
Brakeman	1	1	1	1
Dumpmen	2	2	3	..
Blacksmiths	2	..	1	..
Blacksmiths' helpers	2	..	1	..
Carpenters	1	..	1	..
Electrician	1	..	..	1
Car repairer	..	..	2	..
General foreman	1	..	1	..
Total	13	6	13	5

IN THE TUNNEL

	East end Day	East end Night	West end Day	West end Night
Foreman	1	1	1	1
Drillers	4	3	3	3
Chuckmen	4	3	3	3
Nipper	1	1	1	1
Shovelers	8	8	16	16
Cornermen	..	..	4	4
Pitmen	4	4	..	..
Teamsters	2	2	1	1
Timbermen	6	..	6	..
"Jumbo" engineer	..	..	1	1
Shovel crew	2	2	..	..
Total	32	24	36	30

When the headings were being driven an additional force of 21 men per shift was required inside the tunnel or 84 men in all. On the outside, seven additional men were required on each shift on the west end, and three additional men on each shift on the east end, or forty in all. On the west end, a traveling platform called a "jumbo" was used to load the material, and on the east end, a model No. 20 Marion shovel operated by air.

The rock at the west end was a decomposed granite. At the east end the granite was hard, "blocky" and "seamy." The cost per cubic yard to the contractor was as follows:

	—Heading—		—Bench—	
	East	West	East	West
Drilling and blasting	$3.65	$2.93	$2.10	$1.20
Shoveling and loading	1.95	2.14	1.15	1.50
Powder	0.80	0.35	0.20	0.12
Outside men	0.63	0.55	0.35	0.30
Plant	0.49	0.33	0.32	0.19
Fuel oil	0.69	0.59	0.43	0.29
Superintendence	0.20	0.17	0.11	0.10
Total	$8.41	$7.06	$4.66	$3.70
Labor timbering	0.58	0.73	0.25	0.45

Average, $5.40 per cubic yard.
Powder cost, $0.15 per lb. and fuel oil, $1 per barrel.

Mount Royal Tunnel—Methods and Progress.—The following data are given in a series of articles published in Engineering Record, Jan. 8, 15, and 22, 1916, by S. P. Brown, Chief Eng'r., Mount Royal Tunnel and Terminal Co., Ltd.

Features of Mount Royal Tunnel.—The Mount Royal tunnel forms the entry into Montreal for the Canadian Northern Railway, the new transcontinental line. The tunnel under Mount Royal, 3.1 miles long between station sites, is double-track, roughly 22 × 30 ft. in excavation, sufficient space being allowed for a central wall and bench between the tracks. In general it will be lined throughout with concrete.

The character of the ground encountered was very diverse and in places extremely complex. The headings were in soft ground in both station sites, and at the city end the tunnel roof was in soft ground for about ¼ mile. Here a roof shield was used with O'Rourke interlocking blocks. The rock at the two ends of the tunnel was Trenton limestone, massive at the west end and somewhat stratified at the city end for the first 1800 ft. Toward the mountain proper the limestone became more crystalline, especially on the west side, where it was unusually hard and dense. The main body of the mountain is an igneous intrusion of Essexite, very hard and tough with a specific gravity of about 3.4. The number of steels dulled per foot of hole in this rock often ran from five to seven, although as a usual thing it required only about 1000 steels sharpened per day in one heading averaging 20 ft. of progress. All the main bodies of rock in the mountain were cut by numerous dikes and sheets of other very hard igneous rock, such as Bostonite, Camptonite, Tinguite, Nepheline Syenite, etc., running up to several feet in thickness. These dikes intersected the tunnel and each other in every direction, sometimes averaging several score in 100 ft. This necessitated drawing the temper of every steel to color suitable for the particular rock encountered. The ordinary method of plunging the steel proved an absolute failure. Of many steels tried, the best was F.J.A.B. (Swedish).

The method of excavation adopted in the Mount Royal tunnel was briefly as follows: First, a bottom heading, 7½ to 10 ft. high by 12 to 14 ft. wide was driven on subgrade along the center line. The points of attack were in the two portal station sites, 3.5 miles apart, and at an intermediate shaft, 234 ft. deep, 1 mile from the west portal. As the headings progressed break-ups were started, at 500 to 800-ft. intervals, along the heading, where the full-sized tunnel was excavated above the grade of the heading roof. At these break-ups, the heading was timbered, so as to give a substantial roof over the tracks, upon which the upper portion of the tunnel excavation could be blasted down safely and through which the muck, thus dislodged, could slide into cars in the gangway below, with a minimum of labor. After the break-up excavation was completed the timbering was removed and the benches, remaining on either side of the heading gangway, were drilled and blasted for air-operated steam shovel excavation. This completed the entire excavation of the tunnel cross-section. Drill carriages were used, first, in the headings, second, on the bench ahead of the steam shovel, and finally for trimming the finished section. In common with all modern drill carriages, these carried the full drilling equipment assembled complete and permanently connected with the manifolds and main hose lines.

The ordinary method of heading excavation was by means of a horizontal bar mounting four drills. The drills were supported on arms similar to those used on the columns common to American tunneling operations, or on special saddle arms particularly designed for this job. Sullivan reciprocating, or percussive, drills were used, so constructed that where the ground made it economically desirable a jet of water and air could be injected through the pistons and steel into the bottom of the holes being drilled. For this reason hollow steel was generally used.

Heading Without Drill Carriage.—Before the rock in the heading became so hard as to require very heavy drills, no drill carriage was used, the drilling equipment being carried and erected by hand. By this method in Trenton Limestone, before the rock had become too crystalline, the maximum progress of 810 ft. was made in an 8 × 12-ft. heading in 31 working days, a record-breaking performance. Six rounds were drilled and fired each day, two each shift. The maximum day's progress was something over 30 ft., while on days when igneous dikes of importance were encountered the progress would sometimes drop below 20 ft., and occasionally a shot would be lost.

Seven muckers were used to handle this excavation, three casting back from the face and four shoveling into the cars. All mucking was done off slick sheets and the cars were designed especially low. Thus the four muckers shoveling into the car handled all the muck made on their shift, which amounted to from 12 to 15 cu. yd. per man per shift. This record is particularly interesting when it is remembered that nearly 2 hours out of each 8-hour shift were lost in blasting.

To break this rock required from 18 to 22 holes and about 500 steels per day for an advance of 26 ft. Four 2⅝-in. Sullivan water drills were used, with the water emulsion through the steel. Each driller averaged about 12.5 ft. per hour, deducting only the time lost in blasting. About 6.8 ft. of hole were drilled per cubic yard of place measurement and about 5.5 lb. of 60 per cent Forcite powder were used per cubic yard with 30-grain detonators.

Headings With Drill Carriages.—As the rock became harder and more complex, requiring more powerful drills, it became imperative to devise some mechanical means of handling the equipment, which had attained a weight of several tons. The common type of European drill carriage, was not suitable in the present case. This was principally because the Mount Royal headings, averaging from 50 to 100 per cent larger than the Alpine tunnel headings, broke so much ground that time could not be spared to muck out the heading before setting up the drills. It was, therefore, necessary to devise a drill carriage with a long cantilever arm by which the drilling equipment could be extended ahead over the muck pile in the heading, without any material delay after the blasting was completed.

In order to bring the carriage near enough the face for an arm of reasonable dimensions to reach the point where the drills were to be set up the track on which the carriage ran was riveted to steel plates, which could act as slick sheets and could be mucked off rapidly. Thus, after the blasting, the muckers cleared this track to within about 25 ft. of the face by throwing the muck that had fallen on it to the sides. As soon as this was done the drill carriage was

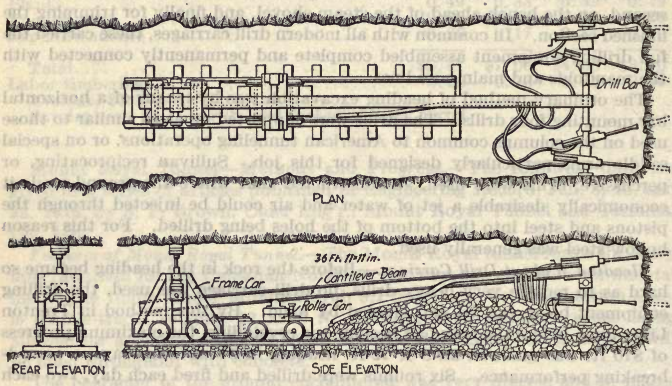


Fig. 1.—Simplest type of carriage, a long adjustable cantilever arm extends drills on horizontal bar over muck pile.

run in, hard up against the muck pile, the cantilever arm carrying the drill bar was extended and the drill bar jacked into place. The drills were thus always in the heading by the time drillers had the roof and sides barred down and sufficient muck thrown back from the face to permit the drill bar to be set. While the drillers were jacking up the bar the pipe-fitter was connecting the two large drill carriage hoses to the ends of the water and air pipes entering the heading. None of the drills was ever dismounted from the bar or disconnected from its manifold. The drillers started work as soon as the bar was tight.

Two types of carriages were designed and built. One (Fig. 1) was very simple, for use in the small 8 × 12-ft. heading; it was merely a carriage proper somewhat similar to the Carter carriage except that the cantilever beam moved with the drill bar instead of having the bar slide on the beam. The other (Fig. 2) had the moving beam, and as it was for use in the large heading, 10 × 13 to 14 ft., it also had a muck-handling attachment for transporting the excavated material from the face to cars in the rear.

Although the muckers lost a few minutes while placing the machine, and only one central track was used at the face, no more muckers were required to clear out the heading with the drill carriage than were used before the drill carriage was installed. This was probably due to having the track cleared down the center of the heading, which permitted all the muckers to work to better advantage while the mucking was actually going on.

Drill Carriage Increases Progress.—The effect of drill carriage work is shown by the results obtained, for instance, in heading 3 E where the muck-handling drill carriage operated for over six months. For the six months prior to the installation of the drill carriage in this heading the average progress was 350 ft. per month in crystalline limestone cut by numerous dikes and in places highly impregnated with various contact minerals. For the six months after the installation of the drill carriage the average progress was 485 ft. per month, almost entirely in Essexite. The hardness of the rock may be realized from the fact that 20 to 24 holes were required to break the ground and about 1,000 steels were used a day for an advance of 19 ft.

Saving Effected.—Four 3⅝-in. Sullivan drills were used. The water attachment was not used, as the length of time required to put down a hole caused the water to freeze and gave trouble in operation. Each driller averaged about 8 ft. per hour, deducting only the time lost in blasting. About 7 ft. of hole were drilled per cubic yard of place measurement, figuring the heading 9½ ft. high by 13 ft. wide. About 7 lb. of 60 per cent powder were used per cubic yard with 30-grain detonators. As the force employed with the drill carriage was practically the same as that employed without it the increase of 38 per cent was made at considerable saving.

It is interesting to note that the progress made with the simple drill carriage was almost identical with that made with the muck-handling drill carriage, the former requiring slightly more muckers per cubic yard.

Muck-Handling Carriage.—The muck-handling drill carriage, which was the first one to be actually built (Fig. 2), was a very heavy machine, having all of its parts operated mechanically, and was designed to remain in the heading while the drilling and mucking were going on. The conveying belt, 16 in. wide by 75 ft. between head and tail pulleys, was driven by a Dake air engine. All other power was electrical. The carriage consisted actually of two separate machines or carriages: First, the drill carriage proper, which supported and operated the cantilever arm carrying the drill bar; and, second, the muck conveyor, which slipped through the lower part of the drill carriage and was supported a few inches above the track on cross shafts. The belt was elevated in order to cantilever out over three muck cars in the rear.

When the tracks were cleared and the drill carriage run in, one man at the electric switches was able to extend the beam over the muck pile, raise or lower it, or swing it to right or left, as the case might be, to fit the heading as it happened to break. Although this machine appears at first glance to be cumbersome and complicated it is an interesting fact that breakdowns of any sort were very rare. In fact, during the six months of its operation the total delays in any way connected with the drill carriage did not aggregate one shift in lost time.

The principal advantages of the muck-handling drill carriage are these: As the carriage remains in the heading after the drills are set up the mass behind the drills is so great as to practically eliminate all vibration during the drilling. Its movements are mechanical, so that the setting up and taking down are more rapid. Since the muck is thrown off the track to the side, the carriage

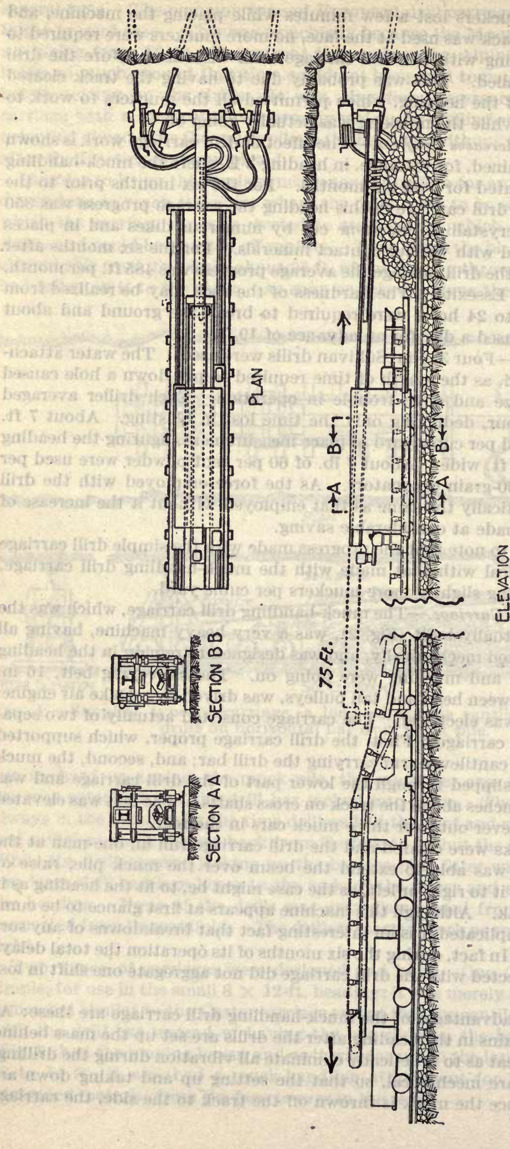


FIG. 2.—More complicated carriage provides for mechanical operation in extending and adjusting bar and equipped with mechanical mucking device.

track being laid at one side of the gangway, the muckers can work with equal efficiency anywhere along the line. As the conveyor is very low, less exertion is required by the men than in shoveling into the higher cars. Three cars are run in at a time by the locomotive so that the muckers lose less time through the shifting of cars.

Heading Carriage Conclusions.—In a heading where the section is large, or the rock reasonably soft, so that the yardage to be handled each day is very considerable, the muck-handling drill carriage is far preferable to the simple carriage. This is especially so where the drilling is rapid, so that a good number of shots per day are obtained, since the time saved in setting up and taking down, as well as the rapidity of mucking, is an important factor. If, however, the rock is hard and the heading small the simple drill carriage will give just as good progress and for a reasonable amount of muck the cost per yard is just as low.

It is the writer's opinion, after having operated both machines under very similar conditions, that the simple carriage is superior to the heavier machine except where a large volume of muck has to be handled or inefficient muckers must be employed. This is principally on account of first cost, since that of the simple carriage is insignificant.

Bench Excavation.—After the heading and break-up work in the tunnel had been completed, two benches remained to be excavated, one on either side of the original heading gangway. These benches aggregated from 8 to 10 cu. yds. of solid excavation per foot of tunnel. The problem of drilling on the benches was a particularly difficult one due to their tendency to slope toward the gangway and the extreme irregularity of their tops. Another complication was the continuous traffic in the gangway since the drilling had to be started long before the completion of the break-up excavation in the central part of the mountain. It was decided therefore to use a drill carriage for this work also and the bench drill carriage as finally designed is quite original both in type and detail. Mr. Brown found this carriage was the greatest money saver in the excavation equipment at Mount Royal.

Bench Drill Carriage.—The carriage proper consisted of a heavy traveler, 30 ft. long, which was moved along the heading gangway as the drilling progressed. The wheels were double-flanged and had very heavy axles, sufficiently long to give lateral play that would enable the wheels to follow the local irregularities of the track horizontally. The vertical play required was given by the spring of the traveler frame itself. The gage of the carriage track was of such a width that the side trusses comfortably cleared the gangway sides in all places and at the same time permitted a single muck track to operate between them. The traveler was fitted at each side with an adjustable outrigger supporting a horizontal quarry bar, which in turn carried from four to six drills mounted on column arms or special saddle arms and connected to the air line through a single manifold thus giving great flexibility in setting up and operating.

The extra width in the tunnel allowed at the haunch for the arch support very much facilitated the drilling. Two parallel lines of bench holes were usually drilled. The outside line next the rib acted as channel or line holes, varying in spacing from about 4 ft. to 8 in., depending on the character of the rock and the accuracy of the line required in the tunnel wall. The second line of breaker holes was spaced farther apart. The line holes were only loaded when the rock was such that it would not break to line from the breaking holes. Thus the sides of the tunnel were not shattered by heavy blasting, and the overbreak was unusually small. This was also true of the break-up excavation, since all the blasting there, being to two faces, required only the lightest kind of shooting. While the headings used 5 to 7 lb. of 60 per cent powder per cubic yard, the break-up and bench excavation averaged less than 1 lb. to the yard.

As the drill carriages kept well ahead of the blasting, and as all the bench muck was handled by steam shovel, only two muckers were required in each drill-carriage crew. These two men cleaned off the top of the bench and extended the drill carriage track, with the aid of the helpers, as the carriage moved ahead. One electrician attended to all the trolley and lighting work connected with both drill carriages, and one mechanic did all the pipe-fitting and drill repairs necessary for both drill carriage outfits. The platform on each carriage above the muck track was mainly used for repairing drills and the storage of extra drills, spare parts, steel and supplies for daily use.

Progress.—The progress obtained with this drill carriage amounted to from 30 to 90 ft. of tunnel per day, depending principally upon the character of the rock and the configuration and condition of the bench. When the ground was particularly irregular and was cut by dikes or when the bench was found to be somewhat shattered from previous blasts the drilling would be slow and uncertain, often several holes being necessary to secure one of the proper depth and direction. Again, when the top of the bench was very irregular or sloped at a steep angle, it was often tedious work to start the holes. Compared with the time required for drilling with columns or tripods, however, the progress was more than merely satisfactory.

It has been found that even under favorable conditions on outside rock the lost time in tripod drilling often amounts to 50 per cent of the time actually spent with the machines. This is due not only to the delay in setting up, but to the time lost in shifting the tripod to "follow the hole." Practically all of this lost time is eliminated in the case of the drill carriage, where the drills supports are rigid and the drills may be shifted accurately and expeditiously with a minimum of labor.

After the drill carriage had got a good start a powder crew was sent in from the west portal and the benches blasted well ahead of the steam shovel. By this method the shovel, a model 41 Marion, never had to back up for shooting, full time being spent in excavation. Five to six hundred cars of muck were usually handled per day of two 10-hr. shifts. This aggregated 1,200 to 1,500 cu. yd. of loose material, or about 700 to 1,000 cu. yd. solid. The linear progress of the shovel sometimes exceeded 600 ft. per week where there was nothing but bench excavation removed.

The Trimming Carriage.—The final trimming of the tunnel section, preparatory to lining, is too often a very measurable percentage of the total cost of any tunnel excavation. There are many cases where the cost of trimming, added to the cost of extra concrete and packing required to fill in cavities left by falls and careless or inaccurate excavation, has exceeded the actual first cost of excavation. For some reason this is an item very often overlooked by a contractor, especially if he is not thoroughly experienced in making up his bids for tunnel work. In the case of the Mount Royal Tunnel however, the actual overbreakage averaged less than 5 per cent and the cost of trimming including squaring up the hitch for the concrete arch and removing the debris ready for the concrete form carriages, added less than 5 cents to the yardage cost of tunnel excavation.

The trimming drill carriage is very similar in construction to the bench carriage except that it is only 20 ft. long instead of 30 ft. In fact, much of the material used in its construction came from one of the bench drill carriages. It consists of two side trusses, 20 ft. long, traveling on six double-flanged wheels. As in the former carriages these trusses are so spaced as to permit the passage of a train of tunnel cars, both for muck and concreting materials. Immediately above the track is a platform for storage and repairs. In this carriage, however, the outriggers with their quarry bars and heavy drilling equipment are at the bottom, where the only heavy drilling occurs. These outriggers mount heavy piston drills and were used in excavating the toe lift in places because the bench was so high that the line holes could not be drilled to sub-grade.

Self-rotating hand hammer drills, operated from extension platforms were used for drilling for the hitches and were also used from the top platform for trimming.

The advantages of this carriage are its lightness and ease of movement. It also eliminated the laborious scaffolds usually required for trimming and also the danger to the workmen from these scaffolds which are hurriedly and too often carelessly erected. Moreover, it is a noteworthy fact that a man works faster and more effectively where he has a sense of security and is entirely familiar with his immediate surroundings.

Cost of Tunnel of the Canadian Pacific Ry.—The Rogers Pass tunnel of the Canadian Pacific Ry. was completed Dec., 1916, 11 months ahead of the contract time. It is a double track tunnel, slightly more than 5 miles in length. One of the most interesting features of the construction was the employment of a pioneer or auxiliary heading. The methods employed in the driving of the tunnel are described by A. C. Dennis, superintendent in charge of the work for the contractors, in a paper presented before the A. S. C. E. and printed in the Jan. Proceedings of the Society, from which the following is abstracted in Engineering and Contracting, March 21, 1917.

The tunnel, except for 1,200 ft. of the east end and 400 ft. of the west end, is all in solid rock, classified as quartzite in the geological reports, but consisting largely of schists.

East Pioneer Heading.—The east pioneer heading was started in September, 1913, about 50 ft. north of the main tunnel, 700 ft. west of the east portal, and about 60 ft. above the main tunnel level. This location was adopted in order to save 700 ft. of pioneer tunneling, to reduce the quantity of soft ground heading, to enable work on the heading to start sooner than that on the approach cut, and to get rid of the muck readily. The power was furnished by the temporary erection of an old compressor along the Canadian Pacific Ry. track above and a pipe line down the hill to the work. This heading was run as nearly level as drainage would permit. The grade of the main heading reached the grade of the pioneer at the third cross-cut, the two former cross-cuts being driven to the dip, and material from the main heading being hoisted up the incline. The heading reached solid rock about 600 ft. in, at which point the first inclined cross-cut was started, at about the beginning of 1914. The pioneer tunnel, in rock, was driven about 2 miles in 1½ years. The maximum progress was 776 ft. The daily average was 20 ft. for the entire drift in rock.

West Pioneer Tunnel.—The west pioneer heading was started by an incline, 300 ft. long, from the rock outcrop, 700 ft. east of the west portal, about 150 ft. above the main heading level, and 50 ft. south of the main tunnel line. This location was selected in order to provide dumping ground, shorten the length of heading to be driven, avoid soft ground tunneling, and permit an earlier beginning than by waiting for the approach cut excavation. This incline was very wet and took 2 months to drive, being finished in the latter part of July, 1914. This pioneer tunnel was driven for a length of more than 1½ miles in less than a year, the maximum monthly progress being 932 ft. The daily average of 24 ft. for nearly a year, largely through very hard quartzite is also unusual.

Pioneer Headings in General.—The pioneer tunnel, in rock, was 7 ft. high and 8 ft. wide. It was driven with light hammer drills, using hollow steel, with water attachments. Three drills, in general, but four in the hardest rock, were used in a heading. Spare drill machines, for the replacement of drills out of order, were kept conveniently at hand in the heading. No repairs were made under ground. The hammer drills are convenient and rapid, the delay and expense of their constant breakage perhaps balancing the advantage of speed under ordinary conditions. The drills are mounted on a light horizontal bar, about 18 in. below the roof line. Air and water are taken over the muck pile, or on hooks in the side, by a single hose line for each, to a manifold from which short individual hose lines supply the drills.

Light cars (½ cu. yd.) were used for muck, and the latter was taken off the track, instead of building sidings for this purpose. Shoveling plates were used at the face and on the side away from the track for some distance back of the face, in order to facilitate the handling of empty muck cars. The ventilating pipe was a 12-in. wooden water pipe connected to the Connersville blowers used for the exhaust. This pipe was hung on the side away from the track, close up to the roof, and was carried to within 20 ft. of the face. Little damage was done to this pipe by blasting. The blowers were started exhausting when the first shot was fired, or a little before, and were run for 20 minutes. The men got back to work in from 5 to 10 minutes. No compressed air was allowed to be blown out for ventilating purposes. After a round was shot, the drillers followed the smoke back, barring down the roof, bringing explosives to reshoot, and wetting down the muck piles, sides, roof and face with water hose. The muckers cleared the track and began loading the muck which was scattered back.

When no further blasting was required, the lights were hung, the foreman sighted the line and grade point in the face, and the drilling gang set up the horizontal bar, placed their drills and proceeded. There was rarely any muck to be handled before the drilling could be started, as it was thrown back from the face by the heavy loading in the bottom holes and the fact that they were shot last, for this purpose. There were two helpers to three drills, who brought up and changed the steel and adjusted the drill machines. When the drilling from the upper set-up was completed, the drillers took down the machines and carried them back, with the hose connections still attached, and oiled them up. After the mucking was done, the bar was dropped to the lower set-up, near the floor, and the drills were set to drill the bottom holes or lifters. The drills were carried forward, put on the bar, and were drilling sometimes in less than 2 minutes after the bar was dropped. While the bottom holes were being drilled, the muckers laid the track, adjusted and covered the mucking sheets with muck, and brought up the explosives. The holes were loaded by the machine men, helpers and foremen.

For the small part of the tunnel where re-shooting was not necessary, an 8-hour shift could do two rounds per shift, or a little better. Two men pick down the muck, and three men load the car and push it out, while three others

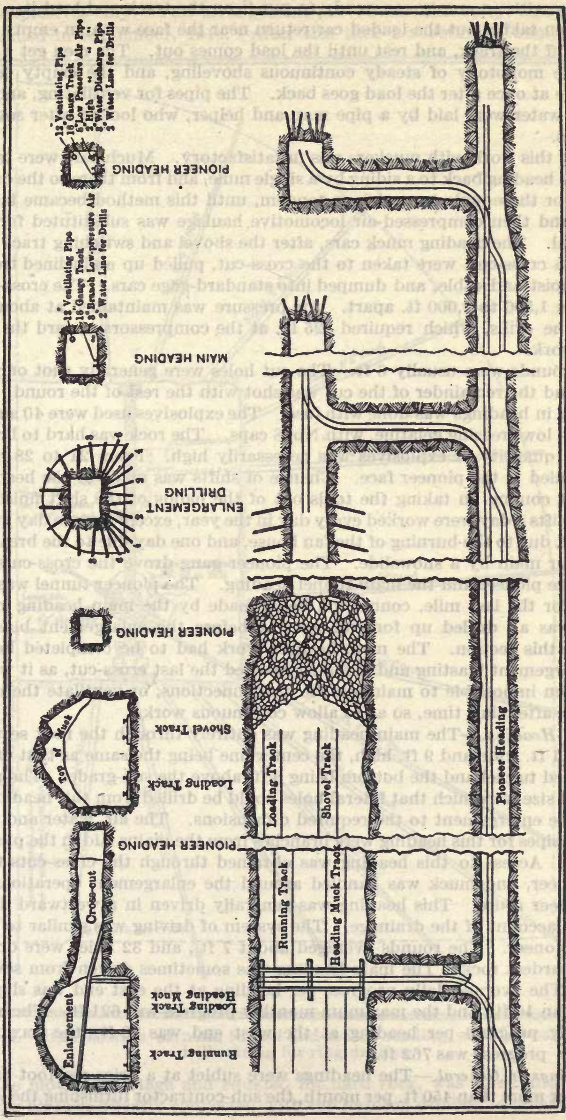


FIG. 3—Details of pioneer heading and its relation to main tunnel.

stand by with an empty car, ready to put it on the track and load it. The three men taking out the loaded car return near the face with an empty car, take it off the track, and rest until the load comes out. The men get a rest from the monotony of steady continuous shoveling, and the empty car is available at once after the load goes back. The pipes for ventilating, and for air and water were laid by a pipe man and helper, who looked after several headings.

Doing this work with muckers was unsatisfactory. Much cars were taken from the heading back to a siding by a single mule, and from there to the dump by two or three-mule team driven tandem, until this method became inadequate, and then compressed-air locomotive haulage was substituted for the long haul. The heading muck cars, after the shovel and switching track had cleared a cross-cut, were taken to the cross-cut, pulled up an inclined trestle by air hoist and cable, and dumped into standard-gage cars. The cross-cuts are from 1,500 to 2,000 ft. apart. Air pressure was maintained at about 90 lb. at the drills, which required 125 lb. at the compressors toward the end of the work.

The rounds were usually 6 ft. The cut holes were generally shot once or twice, and the remainder of the cut was shot with the rest of the round. All shooting in headings was done with fuse. The explosives used were 40 and 60 per cent, low-freezing gelatine, with No. 8 caps. The rock was hard to break, and the quantity of explosives was necessarily high. From 21 to 28 holes were drilled in the pioneer face. Change of shifts was made at the heading, the shift coming on taking the tools out of the hands of the shift finishing. Three shifts a day were worked every day in the year, except for one day at the east end, due to the burning of the fan house, and one day due to the breaking of the air main by a snowslide. The pioneer gang drove the cross-cuts between the pioneer and the main tunnel heading. The pioneer tunnel was not driven for the last mile, connection being made by the main heading only, which was all drilled up for enlargement before the enlargement blasting reached this section. The main heading work had to be completed before the enlargement blasting and mucking reached the last cross-cut, as it would have been impossible to maintain the air connections, or ventilate the main heading, after that time, so as to allow continuous work.

Main Heading.—The main heading was entirely through the rock section. It was 11 ft. wide and 9 ft. high, the center line being the same as that of the completed tunnel and the bottom being 6 ft. above the sub-grade. The position and size were such that lateral holes could be drilled from this heading to break the enlargement to the required dimensions. The air, water and ventilating pipes for this heading were branches from the mains laid in the pioneer heading. Access to this heading was obtained through the cross-cuts from the pioneer, and muck was handled around the enlargement operations by the pioneer route. This heading was generally driven in a westward direction, on account of the drainage. The system of driving was similar to that in the pioneer. The rounds averaged about 7 ft., and 32 holes were drilled in the hardest rock. The main heading was sometimes driven from several faces. The average daily progress per heading at the east end was slightly more than 16 ft., and the maximum monthly progress was 621 ft. The average daily progress per heading at the west end was 20 ft.; the maximum monthly progress was 762 ft.

Headings in General.—The headings were sublet at a price per foot and a bonus for more than 450 ft. per month, the sub-contractor furnishing the labor and explosives only. This arrangement proved unsatisfactory, and was discontinued in September, 1914. After this time a substantial bonus, based

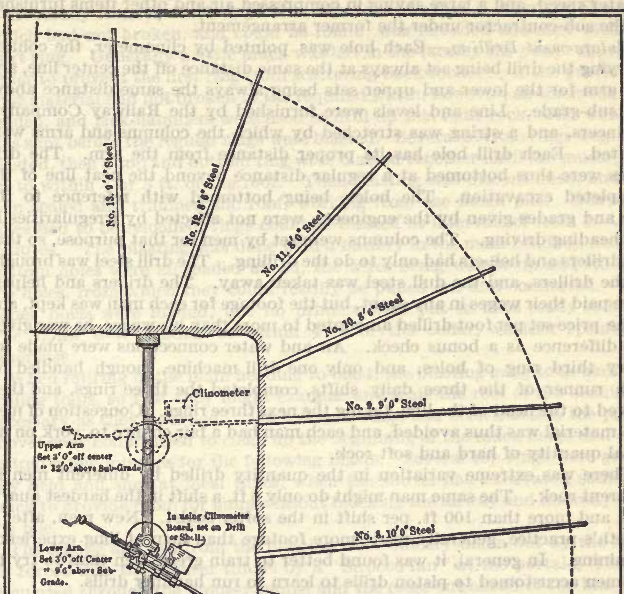


FIG. 4.—Half section of main tunnel and center heading, showing column and drill setting for ring drilling.

on the monthly footage and equated for hard rock, was given and divided among all men directly connected with the heading driving, in proportion to their regular wages earned for the month. It was agreed that the rate of bonus would not be reduced. The latter arrangement resulted in 23 per cent greater speed, and a large saving in compressed air and other items furnished to the sub-contractor under the former arrangement.

Enlargement Drilling.—Each hole was pointed by clinometer, the column carrying the drill being set always at the same distance off the center line, and the arm for the lower and upper sets being always the same distance above the sub-grade. Line and levels were furnished by the Railway Company's engineers, and a string was stretched by which the columns and arms were located. Each drill hole has its proper distance from the arm. The drill holes were thus bottomed at a regular distance beyond the neat line of the completed excavation. The holes, being bottomed with reference to the line and grades given by the engineers, were not affected by irregularities in the heading driving. The columns were set by men for that purpose, so that the drillers and helpers had only to do the drilling. The drill steel was brought to the drillers, and the dull steel was taken away. The drillers and helpers were paid their wages in any event, but the footage for each man was kept, and if the price set per foot drilled amounted to more than his wages, he was given the difference as a bonus check. Air and water connections were made for every third ring of holes, and only one drill machine, though handled by each runner of the three daily shifts, completed the three rings, and then moved to the head of the line, taking the next three rings. Congestion of men and material was thus avoided, and each man had a fair chance to work on an equal quantity of hard and soft rock.

There was extreme variation in the quantity drilled by different men in different rock. The same man might do only 6 ft. a shift in the hardest quartzite, and more than 100 ft. per shift in the softer schist. New men, after a month's practice, generally made more footage than men of long experience in mining. In general, it was found better to train green men than to try to get men accustomed to piston drills to learn to run hammer drills.

Most of the rings were 6 to 6½ ft. apart. When explosives rose in price it was found economical to space the rings 5 ft. apart, as the extra drilling cost was balanced by the saving in explosives, with the added advantage that the muck was broken into smaller pieces and scattered farther back. Where the roof was soft and full of slips, so that trouble was anticipated, the upper set of arms on the column was lowered 1 ft., in order to leave some trimming of the roof to be done by jack-hammer, flat holes and light blasting. The air and water for the enlargement drilling, as well as the supplies, came by the pioneer tunnel and the cross-cuts, so that this drilling was not disturbed by the enlargement blasting. The drilling for the last mile, where no pioneer tunnel was driven, was started at the middle and progressed toward the portal, the track, pipe, etc., being removed as the drilling was finished.

The stopping of the pioneer tunnel was well-timed, as the main heading was driven and the enlargement drilling completed just in time to avoid delaying the enlargement blasting and mucking at the east end.

Enlargement Blasting.—There was considerable difficulty in breaking the bottom to sub-grade when the rock excavation was first started. This was overcome by dropping the floor of the main heading 1 ft. and drilling the holes in the bottom 1 ft. deeper. Difficulty was found also in getting the sides below the springing line to break for the full width. This was overcome by drilling one or two relief holes at this locality in tough breaking rock. In tough rock, two, four, six and sometimes eight holes were sprung. If over-sprung, the ring being shot was likely to break into the next ring and explode it, or shake it up so as to spoil the effect of the blast.

Generally from 10 to 15 rings were kept loaded ahead. Any part of a hole which had not broken, and could be found, was reloaded and shot with the next ring. Generally a little muck was left in the face by the power shovel in order to prevent the first ring from scattering back too far. If the previously shot material had not broken to the required width, however, all the muck was loaded, and jack-hammers were used to drill up this tight rock, after which it was shot before the regular rings were blasted. Several bottom rings were first blasted, then a top and bottom ring were blasted together until the muck piled up to within 4 or 5 ft. of the roof. Then blasting was discontinued, and the men scaled and trimmed the roof, working from the muck pile. Where no holes had to be reloaded, rings could be blasted at intervals of from 15 to 20 minutes. The blasting was done with a battery in the main heading, and the bottom holes were all loaded ahead, the wires being wound up and stuck in the holes, from which they could readily be pulled out and connected. The upper holes were loaded, but no primers were put in until ready to blast. The holes were loaded to within 4 ft. of the collar, whether sprung or otherwise.

When retiring in the main heading to blast, the blasting gang took back the scaling tools, so that they might examine and scale the roof of the heading if necessary as they returned. After several rings had been blasted, the power shovel crew commenced to clean up the beginning of the muck heap, and only retired a few minutes for the following blasts. Several top rings were generally held and shot at meal times, when the shovel had excavated sufficient muck to provide room for more without blocking the airway and manway over the pile.

The smoke and gas from the blasting were quickly taken out by the fresh air forced into the pioneer tunnel by a "Sirocco fan" at the portal. The air circulated through the pioneer tunnel and the cross-cut ahead of the blasting, and then back through the main heading, over the muck pile, and out at the portal of the main tunnel. This circulation was prevented from short circuiting by stopings and doors in the cross-cuts passed by the shovel. The quantity possible to shoot depended on the distance the muck was thrown back, or the quantity of muck for which there was room without interfering with the scaling and trimming of the roof; it varied from 24 to 110 ft. Much time was lost in taking up the track before blasting, in cleaning up the thinly scattered muck directly after a blast, and by other delays incidental to each clean up, which made it desirable to shoot as many rings as possible.

Enlargement of Mucking.—Mucking was done with small steam shovels, with cylinders enlarged so as to be efficient at 100 lb. air pressure, and with the boom sheaves set back so as to shorten the booms and protect the sheaves. The shovels loaded the muck into 12-yd., standard-gage, air-dump cars. The cars were shifted to the shovel by two small compressed-air locomotives, and were taken from a spur near the shovel to the portal by a larger compressed-air locomotive; they were taken by a steam locomotive from the portal to the dump. During the past year the shovels mucked 18,550 ft. throughout 3½ miles of tunnel, or more than 2 ft. per hour. Blasting and trimming took about one-quarter of the time. The best monthly run for one shovel was 946 ft. at the east end, and 1,030 ft. at the west end. The ground between the third and fourth cross-cuts at the west end became so dangerous, owing to the material in the roof and sides falling, that one shift out of three had to be devoted to scaling this section until it was concreted. About 2,500 cu. yd. fell or was scaled in this section, on account of the disintegration of the material on exposure to the air. The scaling car throughout the work was handled by the air locomotive, and the scaling was done by the shovel crew or others during the time the shovel was stopped for enlargement blasting. Any rock not broken to the required dimensions was drilled off the muck pile, or from the floor, as the shovel cleaned up as far as possible, or from a car left at the shovel crew's meal time, and shot before the next rings were blasted. The enlargement drill holes were the general guide as to the trimming required, such points as were missed being marked by the Railway Company's engineer. There was very little over-breakage.

Concreting.—About 1½ miles of the tunnel, including the soft ground at each end, required concreting. This work was sublet. The sub-contractors used wooden forms, and deposited the concrete from a platform near the roof reached by an inclined trestle. The concrete mixer was on the car, and the materials were on other cars back of it. The concrete from the mixer flowed into a small car which was hauled by cable up the trestle incline to the high platform, from which it was shoveled into the forms. Much of the lining required back as well as front forms, and the space behind the back forms was filled with rock or wood. This back form and back-filling work was slow and expensive, especially where there were only a few inches between the back forms and the rock.

Mr. Dennis in Engineering and Contracting, April 18, 1917, states that the cost of the total improvements which includes considerable line outside of the tunnel was approximately $6,500,000.

The tunnel proper for excavation, concreting and so forth, including contractor's profit, was below $150 per foot, which, being a double-track tunnel, compares very favorably with $180 per foot for the Great Northern single-track tunnel.

The general wages paid were 40 cts. per hour to drill runners and 35 ct. per hour to others. The bonus probably averaged 25 per cent in addition to these rates.

Summing up the reasons for the rapid progress and low cost of the Rogers Pass tunnel, they seem to be:

First, the method of tunneling, involving the driving of a pioneer tunnel off the line of the main tunnel.

Second, the excellent administration of the work.

Third, the payment of liberal bonuses to the workmen, which bonuses were adhered to.

Fourth, the use of hammer drills.

In the Aug. (1917) Proceedings of the A. S. C. E., as showing the probable economics of using the pioneer tunnel method, J. G. Sullivan, chief Engineer of the railway, quotes the following from his report of March 13, 1913, to officials of the Canadian Pacific Ry.:

This method, of course, is only applicable where the rock will stand without artificial support, at least during the time of construction. Where the material must be artificially supported, then the top heading is the surest, and I think, the best way. The progress of the work by this method, as I said before, depends only on the speed that the pioneer tunnel can be driven. If rock is self-supporting, I see no reason why from 20 to 25 ft. per day could not be made. Placing the cost of driving the small tunnel at $30 per foot; that is the only part of the work that would be rushed under high pressure, and the heading proper can be taken out at least $5 per foot cheaper than if the work must be done under pressure, then the bench containing 18 cu. yd. per foot (neat section) can, on account of there being no interruptions to wait for drilling or cleaning up to put in breast holes or knocking down material in order to get pipes into the heading, at a low estimate, be taken out 75 cts. per cubic yard cheaper, or $13.50 per foot, which would make a saving in excavation of tunnel proper of $18.50 per foot, leaving $11.50 to be taken care of in interest saved account making greater speed. In my report to you of Oct. 22, 1912, I estimated an annual saving of about $226,000, but all my figures were very conservative, and I took into account only one or two of the larger factors of the extra expense. Mr. Bogue's more accurate figures show a saving of over $370,000. However, his estimate for fuel per hp. hour was 40 per cent higher than the figure I used, and the price of coal was 17 per cent higher than the price I assumed. His price is more accurate than the one I used, but assuming for the sake of being conservative, that the average between the two estimates would be approximately correct, that would mean, say $300,000 per year saving, to say nothing of the interest on the $3,000,000 or $4,000,000 that will be invested in construction, from which we will not be receiving any benefit until the work is completed. Therefore, if this tunnel can be completed one year sooner by using this method, the saving thus made will a great deal more than save the $11.50 additional cost of the pioneer tunnel.

The results, states Mr. Sullivan, proved that these estimates were conservative. The pioneer tunnel, from the most careful studies of the information at hand, cost about $28 per foot instead of $30, as estimated. There was a great deal larger difference than 75 cts. per cubic yard between the actual cost of enlarging the tunnel by this method and the estimated cost of enlarging without the use of the pioneer tunnel; and another item, not taken into account in this estimate, was the fact that the pioneer tunnel only had to be driven less than four-fifths of the total distance.

It has been stated by some that this method is not applicable where there are soft spots in the rock. If the soft rock encountered does not exceed 50 per cent of the total, Mr. Sullivan is confident that this method would still prove more economical than any other which has yet been tried, for the reason that when the soft places are encountered, there is plenty of time to stope out the upper part of the arch and timber it, so that when the steam shovel arrives at those places, there will be no delay whatever, and, instead of having to stope out the entire section by hand, as is necessary in the under-heading method, only about half, or less, of the material in the section requires to be removed in this manner.

Regarding the actual costs Mr. Sullivan quotes further from the report of March 13, 1913:

I figure that by this method the pioneer tunnel can be driven for about $30, the main heading for about $40, and that the bench can be taken out for about $54, making a total of $124. There will be incidentals; contractors' profit should not amount to over $20 per foot. Of course, this method of driving the tunnel, working so many drills at one time, will require a larger plant than if only one heading was driven, and that at a lower speed than we contemplate.

The expectations of the railway company, stated Mr. Sullivan, have been more than realized, as is proved by the speed and the cost of the work. The cost of driving this tunnel through rock, including in this price the cost of driving 19,610 lin. ft. of pioneer tunnel, 12 cross-cuts, each about 40 ft. long, erecting the plant (including freight), the proportionate cost of building about 5 miles of temporary railway tracks, and other overhead charges, plus 10 per cent on all expenditures, will amount to a little less than $5 per cu. yd. for excavation in the tunnel proper.

In his discussion, Mr. Dennis, who was in charge of the work for the contractor, stated that the idea of the pioneer heading originated in the desire to get away from the congestion, smoke, general confusion, and interference of one operation with another, observed in tunnel driving, and to provide muck in large quantities for handling by shovel. His work in coal mines, with air course run with the main entry, suggested the pioneer as a means to the desired end.

Cost of the St. Paul Pass Tunnel.—The following data are taken from an article by K. C. Weedin, in Engineering and Contracting, April 5, 1911.

The St. Paul Pass tunnel is on the line of the Chicago, Milwaukee & Puget Sound Ry. where the latter crosses the Bitter Root range of mountains on the Montana-Idaho state line. It is 8,750 ft. long; 3,412 ft. being in Montana and 5,338 ft. in Idaho. The summit grade in tunnel is elevation 4,169 ft. at a distance of 3,520 ft. west of the east portal and this point is 1,020.7 ft. below the surface. The gradient is 0.2 per cent in both directions from the summit. The location lies in a zone of extremely great snow fall, possibly the greatest in the United States; the actual fall during the winter of 1907–08 being 33 ft. 4 ins. Fortunately there is little wind.

Construction was begun Jan. 18, 1907, and was completed March 4, 1909. The writer assumed charge for the company on Dec. 6, 1907, or about one year after the work was started.

The C., M. & P. S. Ry. practically parallels and lies near the Northern Pacific from Missoula to Taft, Mont.; there they diverge.

Taft being the nearest point to the tunnel on an operated railroad, 2.5 miles distant, it was decided to locate the power house there, generate the electricity and transmit it to substations, one at each end of the tunnel.

A wagon road was constructed from Taft across the range at great expense, over which all supplies, machinery, timber, etc., were transported both for the west end of the tunnel and for the grading and bridge work on the west slope.

This road required a great deal of attention. The average traffic over it was about 100 four-horse teams per day and the maximum about 160 four-horse teams. About 60 men were required in summer to keep the road open, and about twice that number were required in winter and spring. These men were stationed in three camps along the road, one at each portal and one at the summit. The road was about 4½ miles long and the summit was about 1,000 ft. above the portals. Fresh snow was attacked with a steel logging plow pulled by 24 horses, then a 30-horse wooden wedge plow was used and the work was finally finished with shovels. In spite of this work the road bed was steadily elevated during the winter until it was well up to the roofs of the camp houses.

During the winter of 1907–08 a cableway one mile long was built from the east portal to the summit. This cableway was driven by a 30-hp. motor. Supplies, fuel, timber, etc., were teamed from Taft to the lower terminal near east portal, carried on the cableway to the summit, there transferred to wagons and hauled down the west slope. This method obviated the long, heavy team haul up the mountain and greatly lessened the time.

The main power station equipment consisted of the following items:

6 150-hp. Atlas high pressure tubular boilers, set up in batteries of two.
2 Blake 8 × 5 × 10-in. boiler feed pumps.
2 Fairbanks-Morse 5½ × 3½ × 5-in. boiler feed pump.
1 Blake 14 × 7½ × 12-in. underwriters fire pump, normal capacity 500 gals. per minute.
1 Blake 14 × 22 × 24-in. air pump and jet condenser.
2 20 × 48-in. Corliss engines.
1 14 × 28 × 20-in. tandem compound McEwen engine direct connected to a 200-kw. 3-phase, 60-cycle, 2,200-volt generator.
1 17 × 22-in. Atlas engine.
1 10 × 16-in. Atlas engine, driving exciters.
2 200-kw. 3-phase, 2,200-volt, 60-cycle, G. E. generators belted to the Corliss engines.
1 200-kw. 3-phase, 2,200-volt, 60-cycle, engine type, Westinghouse generator, direct connected to McEwen engine. A 17½-kw. 125-volt Westinghouse exciter was belted to this generator.
1 35-kw. 125-volt G. E. direct connected generator, used for exciter.
3 250-kw. 2,200 to 6,600-volt, 60-cycle transformers—oil cooled.
3 Sets of 6,600-volt multigap lightning arresters with choke coils and all necessary switch board panels, connections, volt meters, circuit breakers, etc.

The machine shop equipment was as follows:

1 24-in. × 14-ft. New Haven heavy duty engine lathe.
1 Four-jaw chuck, 16-in. diameter.
1 20-in. Hoefer back geared drill press fitted for No. 3 drill socket.
1 30-in. Wallcott & Wood geared shaper, extended base and counter shaft.
1 No. 96 Forbes belt and hand driven pipe machine with dies from 1 in. to 6 ins. with cutting off attachment.
1 Blacksmith outfit complete.

The power station was protected by a good gravity water system in addition to that afforded by fire pump. The capacity of plant was 750 kw. and the alternating current was carried to the sub-station at each end of the tunnel—2½ miles to the east end and 4½ to the west end.

At each sub-station the current is stepped down from 6,600 volts to 440 volts through three 100 kw., oil cooled transformers.

The east end sub-station equipment comprised the following items:

2 220-hp. 60-cycle, 3-phase, 440-volt, G. E. induction motors, driving compressors.
1 100-hp., 60-cycle, 3-phase, 440-volt, G. E. induction motor.
1 100-kw. 575-volt, G. E., D. C. generator.
1 50 hp. 2-pole Thompson-Houston 500-volt D. C. generator.
1 50-hp. 500-volt Westinghouse D. C. motor.
1 30-hp. 4-pole, 500-volt Westinghouse motor.
2 Westinghouse-Baldwin electric locomotives fitted with 2 No. 64, 500-volt, D. C. motors, 24-in. gage.
2 7½-kw. 500 volt motors.
3 100-kw. 6,600 to 440-volt, 60-cycle, G. E., oil cooled transformers.
3 7½-kw. 440 to $^{110}\!/\!_{220}$-volt Westinghouse oil cooled transformers.
2 1,205 cu. ft. of free air per minute each, running at 135 r.p.m. Ingersoll-Sergeant, belt driven, air compressors, type J-2.
1 Size K Exeter fan with 2,000 ft. 16-in. galvanized iron air pipe.
1 No. 2 Root blower with 5,000 ft. 8-in. galvanized iron air pipe.
1 16-in. swing saw.
1 Numa drill sharpener.
1 No. 1, 20-in. self feed drill press.
1 Walcott engine lathe, 18-in. swing, 12-ft. bed.
1 Model 20 Marion shovel.
25 Ingersoll-Rand 3½-in. air drills.

The equipment at the west end was practically a duplicate of that at the east end except that the air drills used were Wood drills made by the Wood Drill Works, Paterson, N. J.

The compressors at each end furnished power to 13 drills (8 in heading and 5 on bench), the Marion model 20 shovel, the drill sharpening machine, a welding hammer and two forges. The Marion shovels were constructed especially for this character of work, the booms being short to permit swinging between the lining timbers and were equipped with 1¼ cu. yd. dippers. Drill bits were upset, reshaped and sharpened on a Numa, air driven, drill sharpening machine that proved to be a great factor in making rapid progress.

The ventilation of the tunnel was accomplished by the use of an Exeter fan operated as an exhauster, exhausting through a 24-in. galvanized iron pipe made up in 30-ft. lengths with flanged joints and paper gaskets. The end of this pipe was maintained at a distance behind the bench sufficient to prevent the pipe from being dented and perforated by shooting. A No. 2 Root blower was also operated to pump fresh air into the tunnel through an 8-in. galvanized iron pipe. The latter pipe was carried close to the heading face.

The tunnel was driven by the top heading method. The material in general was a laminated quartzite with talc between the strata, but the character changed often, which necessitated changes in the method of conducting the work.

The heading was, when the material permitted, driven with a full face following it as closely as practicable, usually from 50 ft. to 60 ft. with the timber lining, but often it became necessary to drive small side drifts for the wall plates and carry the arch timbers within 2 ft. of the face. Usually 6 drills were operated abreast, driving the full heading face, two on one column about 3 ft. each side of the center line and one on a column in each corner. These were followed by a "trimmer" taking off all points to obtain the correct section. This work was followed by a special timber crew erecting the timber lining.

The packing back of lagging on side walls from the sills to the height a man could shovel is the natural material excavated from the bench; from this elevation to the wall plates and over the arch the packing is cord wood driven tight and wedged. Wood packing was not particularly objectionable here as the tunnel was very wet. The heading material was shoveled into 1 cu. yd. end dump cars, pushed by hand to a chute back of the bench and dumped into a car on a side track on the bench level. The heading track was supported over the bench by timbers spanning the tunnel and resting on the wall plates.

The bench was driven by 4, and at times, 5 drills working on the floor level; occasionally it was necessary to drill "down" holes and also at some places where the material was particularly hard it was necessary to take out a sub bench. In fact, many different tunneling methods were resorted to, as circumstances dictated. The timber lining on the bench was done by the regular bench crew.

The air shovels loaded all bench material into 1½ cu. yd. Peteler cars which were spotted by horses, but hauled out of and into the tunnel by two 15-hp. electric locomotives at each end—from 8 to 11 cars to the train.

The heading muck cars were run out on a platform over the bench workings a distance of 150 ft. to a muck chute leading to the tunnel trains on a track below. This platform was built ahead as the bench progressed and new chutes were added as required. In front of the bench were two narrow gage tracks on the sides of the tunnel with a crossover beyond the chute for the heading muck.

The electric locomotive hauled the cars to the crossover and the cars were hauled by a horse from here to be loaded and returned to the outgoing track. At the east portal the dump began just outside the approach. Here a 60-ft. fill had to be made for the main line. At the west portal there was a haul of about 2,500 ft. to a 70-ft. fill about 600 ft. long. Snow gave trouble on the dumps and 10 or 12 men were required in winter to keep the track open on the west side and on the east side a temporary snow shed was erected over the dinky track.

The overbreak was carefully measured every 8 ft.—oftener when necessary —and averaged 2.94 cu. yds. per lin. ft. of tunnel. The total quantity removed was 21.5 cu. yds. per lin. ft.

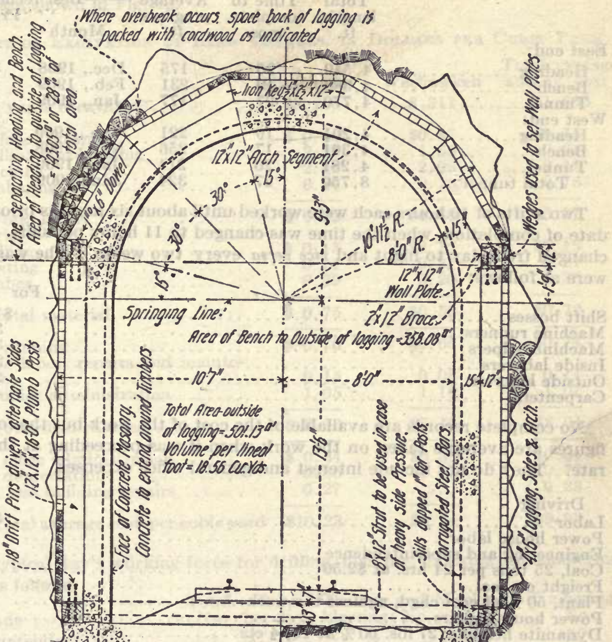


FIG. 5.—Cross section of St. Paul Pass Tunnel, showing type of timbering.

A track incline connecting the heading and bench tracks was utilized for transporting timber and tools to the heading. This incline was so arranged that, as the bench advanced, it could easily be moved forward, and the timbers supporting the heading track could be taken down and used ahead. The incline kept all heading operations away from the bench, and as the work was conducted on the bonus system the bench operations were not interfered with by the carrying of tools, machines and timber into the heading, and consequently the bench operatives could not complain of being discriminated against.

The bonus system consisted in giving $2 to the foreman and $12.50 for distribution among the men for both heading and bench above 3½ ft. per shift based on the monthly average.

The progress record is shown in Table I. The monthly average for the twelve-month 1908, was 544.6 ft.; for 1907, 80.3 ft. The highest records of daily progress were Nov. 17, 18 and 19, 1908, and were, respectively, 23.5 ft., 32.5 ft., and 28.5 ft.

TABLE I.—PROGRESS REPORT OF ST. PAUL PASS TUNNEL

	Total length, ft.	Time to complete, mos.	Average progress, ft.	Best record— Month	Best record— Progress, ft.
East end:					
Heading	4,549	26	175	Dec., 1908	357
Bench	4,389	19	231	Feb., 1909	350
Tunnel	4,770	27	177	Jan., 1909	337
West end:					
Heading	4,201	19	221	Jan., 1909	385
Bench	4,361	17	256	Nov., 1908	527
Tunnel	4,281	20	214	Jan., 1909	416.5
Total tunnel	8,750	27	324	Jan., 1909	753.5

Two shifts of 10 hours each were worked until about six months prior to the date of completion, when the time was changed to 11 hours per shift. Shifts changed from day to night and *vice versa* every two weeks. The wage rates were as follows:

	For 10 hrs.
Shift bosses	$4.75
Machine runners	3.75
Machine helpers	3.25
Inside laborers	2.75
Outside laborers	2.25
Carpenters	4.00

No complete records are available of the cost of the work but the following figures are averages taken on the work when it was proceeding at the usual rate. They do not include interest and general office expenses.

Driving	Per lin. ft.
Labor	$ 84.50
Power house labor	7.00
Engineering and superintendence	3.00
Coal, 25 tons per 24 hrs. at $2.50	4.16
Freight on coal	3.20
Plant, 50% of cost chgd, against the work	15.00
Power house repairs	8.75
Dynamite heading, 27 lbs. 60% at 16½ cts	4.45
Dynamite bench, 23 lbs., 40% at 12 cts	2.76
Caps and fuse	2.10
Rubber clothes	4.62
Drill repairs, small tools, etc	13.65
Water system	.35
Camps	1.10
Total	$154.64

Timbering	Per M. ft. B. M.	Per lin. ft.
Timber delivered at Taft	$18.50	$ 9.25
Timber teaming from Taft, 2½ miles	4.00	2.00
Timber framing	4.50	2.25
Cord wood: cutting $2, teaming $2	4.00	.40
Iron		.40
Erecting on bench		2.00
Erecting in heading		2.35
Total		$ 18.65
Grand total cost of timber lined tunnel		$173.29

Cost of Land Sections of Pennsylvania R. R. North River Tunnels at New York.—The following data are given in an abstract in Engineering and Contracting, May 11, 1910, of a paper by B. H. M. Hewett and W. L. Brown, Proc. A. S. C. E., Vol. XXXVI.

The following summary of the cost of excavating the land tunnels is based on actual records carefully kept throughout the work. Types of tunnel sections are shown in Fig. 12.

COST OF EXCAVATION OF LAND TUNNELS, IN DOLLARS PER CUBIC YARD

	Manhattan	Weehawken	Total yardage and av. cost
Cubic yards excavated	43,289	8,311	51,600
Labor:			
Surface transport	$ 0.49	$0.87	$0.55
Drilling and blasting	2.37	1.55	2.24
Mucking	2.49	2.08	2.42
Timbering	0.87	0.18	0.76
Total labor	$ 6.22	$4.68	$5.97
Material:			
Drilling	$ 0.15	$0.15	$0.15
Blasting	0.21	0.21	0.21
Timber	0.39	0.20	0.36
Total material	$ 0.75	$0.56	$0.72
Plant running	$ 0.76	$0.65	$0.74
Surface labor, repairs and maintenance	0.15	0.08	0.14
Field office administration	1.05	1.18	1.07
Total field charges	$ 8.96	$7.15	$8.64
Chief office administration	$ 0.34	$0.38	$0.34
Plant depreciation	0.66	1.01	0.72
Street and building repairs	0.27	.....	0.23
Total average cost per cubic yard	$10.23	$8.54	$9.93

A typical day's working force for drilling, blasting, mucking and timbering was as follows.

Grade	Total No.	Rate per day	Drilling and blasting: No.	Mucking: No.	Timbering: No.
Superintendent	1	$7.70	½	⅛	⅜
Assistant engineer	1	5.80	½	⅛	⅜
Electrician	1	3.50	½	⅛	⅜
Engineer	1	3.50	....	1	...
Signalman	1	2.00	....	1	...
Foreman	3	4.00	1	1	1
Driller	5	3.00	5	....	...
Driller's helper	5	2.00	5	....	...
Laborers	14	2.00	....	14	...
Timbermen	3	3.00	....	....	3
Timbermen helpers	4	2.00	....	....	4
Machinist	1	4.00	1	....	...
Blacksmith	2	3.50	2	....	...
Blacksmith helper	2	2.00	2	....	...
Nipper	2	2.00	2	....	...
Waterboy	1	2.00	1	....	...
Total	47	.....	20½	17⅜	9⅛

Where there was any large amount of soft ground in the roof, the timber gang was much larger than shown above and was helped by the mucking gang. The drillers did most of the mucking out of their heading before setting up the drills.

The following is an analysis of the cost of drilling.

ANALYZED COST OF DRILLING

Item of cost	Cost per ft. of hole drilled 15 ft. 4 in.	19 ft. 6 in.	24 ft. 6 in.	Average
Drilling labor	$0.25	$0.28	$0.31	$0.28
Sharpening	0.02	0.02	0.01	0.016
Drill steel (5 in. per drill shift)	0.007	0.007	0.006	0.007
Drill repairs	0.02	0.02	0.02	0.02
High pressure air	*0.05	0.04	0.07	0.07
Totals	$0.35	$0.38	$0.41	$0.385

* This is an estimated figure, ascertained by taking a proportion of the whole charge for plant running.

Based on the records of 5 months, in which 12,900 cu. yds. were excavated, the following data were derived.

Portion of excavation	Feet of hole drilled per cubic yard of excavation 15′ 4″ span—twin tunnel	19′ 6″ span—twin tunnel	24′ 6″ span—twin tunnel	Lbs. of powder used per cubic yard of excavation 15 ft. 4 in.	19 ft. 6 in.	24 ft. 6 in.
Wall-plate heading*	13.0	10.97	10.97	3.77	2.85	2.85
Total heading*	7.87	8.17	7.81	2.31	2.02	1.78
Bench and raker bench*	5.97	6.15	7.56	0.94	0.93	1.13
Trench*	9.82	15.96	18.10	1.84	2.48	2.73
Average for section*	6.69	7.43	8.95	1.28	1.30	1.45
Actual amount†	6.82	7.27	8.95	1.22	1.24	1.27

* Figures taken from typical cross-sections.

† This gives the actual amount of drilling done and powder used per cubic yard for the whole period of 5 months of observation, but as this length included 280 ft. of heading and only 220 ft. of bench, the average figures (for powder especially) are too low.

Comparative Cost of Tunnelling in Soft Earth Using Poling Board Method and Hydraulic Roof Shields.—The following data are given in Engineering Record, Feb. 27, 1915.

A pair of hydraulic roof shields, designed and built for the job, was used to complete the Point Defiance tunnel of the Northern Pacific Railway, near Tacoma, Wash. When this work was commenced, a high rate of progress was expected with ordinary timbering methods, owing to the apparently firm and well drained condition of the earth to be encountered, and to the known absence of rock. However, when the bore had been driven through the outer crust, which was comparatively dry, a wet, sandy formation was encountered, which called for heavy timbering and made progress by the poling-board method very difficult. The west heading was advanced at an average of only 126 ft. per month for four months, and at the end of this time the contractors faced the necessity of finding some new method of handling the work, or losing heavily on the contract.

A New Shield Developed.—The material encountered was very heavy and had a tendency to "flow" around the breast boards into the heading. It was decided that some means must be provided for carrying the weight of this material and protecting the workmen while handling muck and placing timber. Accordingly a steel shield of semi-cylindrical shape was built, designed to be thrust forward by hydraulic jacks, and just large enough to clear timbers and lagging placed beneath it. The weight of this shield and its load was carried on the wall plates at the forward end, and upon the timber segments at the rear.

A segmental I-beam rib, projecting on the inner side of the shield and forming part of it, 4½ ft. behind the cutting edge, served as a shoulder against which the jacks could thrust. Twelve 120-ton hydraulic jacks were used, these being set between this I-beam shoulder and the last segment placed. The width of the shield between wall plates was 31 ft., the rise of arch 14 ft. 10 in., and the overall length 14 ft. In addition to the rib for taking the thrust, the frame had a 4 × 6-in. channel-iron brace in four segments, and a 2½-in. steel tie-rod with turnbuckle. The shell was built of two thicknesses of steel plates ¾ in. thick for the inside and ⅝ in. for the outside. All bolt and rivet heads on the outside of the shield were countersunk. The cutting edge consisted of 1-in. plates, bolted to the shield to facilitate easy renewal. Their forward edges were bent upward slightly to prevent wedging. The shoes on which the weight of the shield was carried at the forward end were steel castings arranged to slide on angles laid on the wall plates.

Equipment.—A bench, 24 to 28 ft. long, and of convenient height, was left in the middle of the heading, on which to handle muck and timbers, and as a safeguard against overbreak. The jacks were fed from a hydraulic pump, and driven by an electric motor, set on this bench. This motor also operated a conveyor belt which delivered muck from the heading across the bench to a Marion 40-ton steam shovel running on the tunnel floor. The shovel, which ran with compressed air, loaded this material into 4-cu. yd. cars and also excavated the bench. These cars, of 3-ft. gage, were handled, in trains of two to six at a time, by a 6½-ton electric locomotive. Motor-driven belt conveyors were also used to remove muck from the two wall-plate drifts. These conveyors were arranged so that they could be reversed and used to carry timber into the drifts.

The timber was sawed into standard lengths outside the tunnel and sent in as needed. In order to maintain easy access and thus facilitate the handling of timber, a "high-car" was constructed, whose platform cleared the top of the shovel. A bridge was used to connect this platform with the bench, and the car was thus kept back of the sweep of the shovel boom. The car ran on rails placed on either side of the track provided for the shovel.

Operation.—The normal working pressure on the hydraulic jacks was about 10 to 13 tons, although the initial pressure at starting sometimes rose to 30 tons. The maximum pressure was 50 tons, or a total of 600 tons on the entire shield. After each advance of 4 ft., timbers for a new segment were set. The rate of advance through sandy formation was usually 1 in. per minute, which was found to be about as fast as miners and muckers could handle the material. In order to measure and control the movement of the shield, three measuring rods graduated in inches were attached to it, parallel to the tunnel, one at the top and one at each of the wall-plate shoes. The man who controlled the operation of the jacks stood where he could watch the advance of the top rod, and assistants at each of the other rods called to him the advance of the shield on each side. By closing or opening one or more jacks on either side, the direction of the shield was easily controlled. Curves were successfully driven

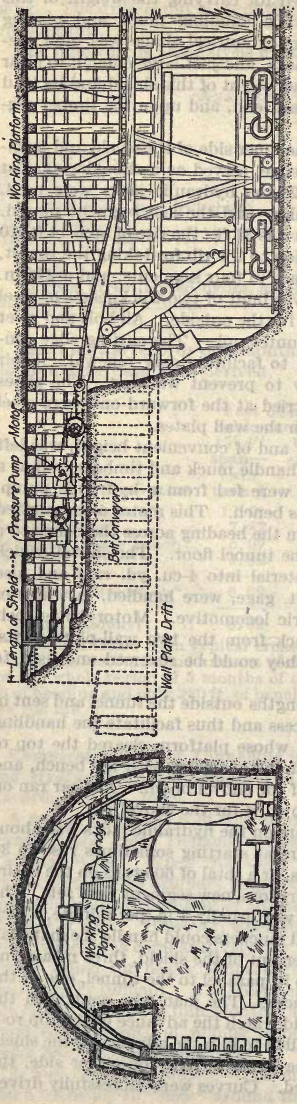


FIG. 6.—Top heading of tunnel worked under roof shield—spoil handled with belt conveyors and steam shovel.

by maintaining different rates of progress on the two sides.

In soft ground the workmen excavating at the cutting edge stood on the turnbuckle thrust-rod which afforded a good footing while they leaned against the face of the heading. Four shovel men cut away the material a few inches ahead of the cutting edge, or took it out through holes in the I-beam ring when it packed up ahead of this projection. About eight muckers were usually required to shovel into the conveyor and keep the bench clear.

The wall-plate drifts were so worked that their headings were always 18 or 20 ft. in advance of the cutting edge. As the shield advanced the earth at the sides of the bench was cut away below the wall plates to the tunnel floor, and plumb posts put in place in the usual way. The wall-plates were placed by the engineer in charge of the work and securely blocked.

Cost and Progress.—With the poling board method the progress with a shift of thirty men had been only 4 to 6 ft. a day, but with the shield in full operation the same number of men advanced the heading 12 to 16 ft. a day, and eliminated all the false timber work required by the former method. The first shield built was tried out near the west portal. Progress with it was very satisfactory, and it was decided to build a second shield. The shields were fabricated by the Seattle Drydock & Construction Company at a cost of about $3500 each. They were made in five sections, and after being assembled in the shop were taken apart for shipment and re-erected in the tunnel. The shield was designed and patented by W. M. McDowell, of Tacoma, and the work done with it in the Point Defiance tunnel was carried out under his personal supervision.

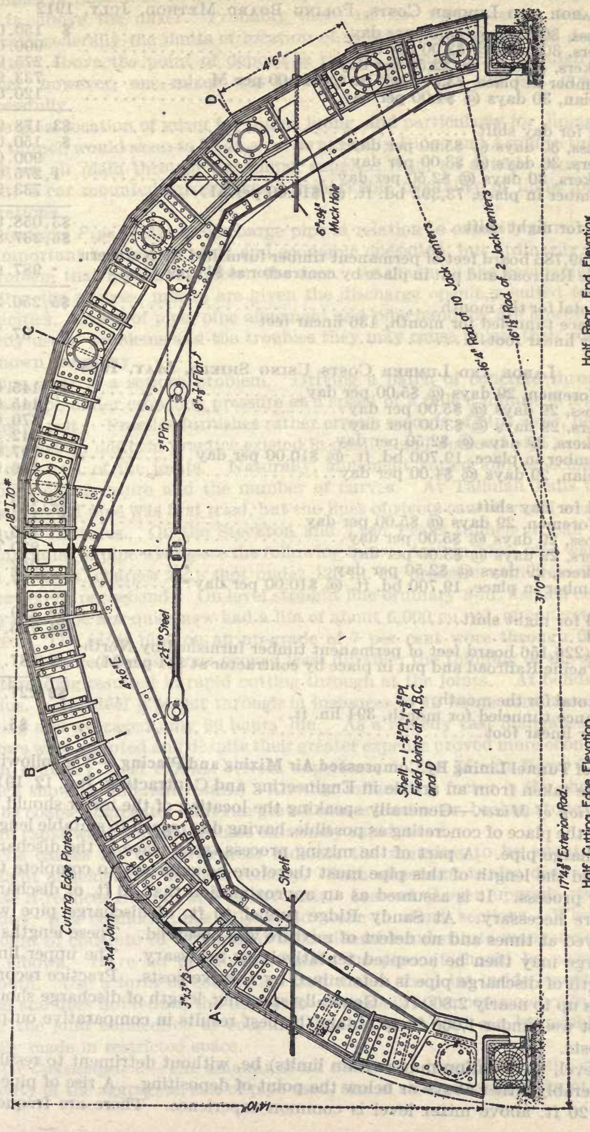


Fig. 7.—Specially designed roof shield for driving Point Defiance Ry. tunnel in soft soil.

LABOR AND LUMBER COSTS, POLING BOARD METHOD, JULY, 1912

Shift boss, 30 days @ $5.00 per day	$ 150.00
10 miners, 30 days @ $3.00 per day	900.00
17 muckers, 30 days @ $2.50 per day	1,275.00
False timber in place, 73,392 bd. ft. @ $10.00 per M	733.92
Electrician, 30 days @ $4.00 per day	120.00
Total for day shift	$3,178.92
Shift boss, 30 days @ $5.00 per day	$ 150.00
10 miners, 30 days @ $3.00 per day	900.00
17 muckers, 30 days @ $2.50 per day	1,275.00
False timber in place, 73,392 bd. ft. @ $10.00 per M	733.92
Total for night shift	$3,058.92
Total	$6,237.84
Credit (89,786 board feet of permanent timber furnished by Northern Pacific Railroad and put in place by contractor at $11 per M)	987.64
Net total for the month	$5,250.20
Distance tunneled for month, 136 linear feet	
Cost per linear foot	$ 37.77

LABOR AND LUMBER COSTS USING SHIELD, MAY, 1913

Shield foremen, 29 days @ $5.00 per day	$ 145.00
Shift boss, 29 days @ $5.00 per day	145.00
10 miners, 29 days @ $3.00 per day	870.00
13 muckers, 29 days @ $2.50 per day	942.50
False timber in place, 19,700 bd. ft. @ $10.00 per day	197.00
Electrician, 29 days @ $4.00 per day	116.00
Total for day shift	$2,415.50
Shield foremen, 29 days @ $5.00 per day	$ 145.00
Shift boss, 29 days @ $5.00 per day	145.00
10 miners, 29 days @ $3.00 per day	870.00
13 muckers, 29 days @ $2.50 per day	942.50
False timber in place, 19,700 bd. ft. @ $10.00 per day	197.00
Total for night shift	$2,299.50
Total	$4,715.00
Credit (226,156 board feet of permanent timber furnished by Northern Pacific Railroad and put in place by contractor at $11 per M)	2,487.71
Net total for the month	$2,227.29
Distance tunneled for month, 394 lin. ft.	
Cost per linear foot	$5.65

Cost of Tunnel Lining By Compressed Air Mixing and Placing.—The following data are taken from an article in Engineering and Contracting, Jan. 12, 1916.

Location of Mixer.—Generally speaking the location of the mixer should be as near the place of concreting as possible, having due regard to suitable length of discharge pipe. A part of the mixing process takes place in the discharge pipe and the length of this pipe must therefore be sufficient to complete the mixing process. It is assumed as an approximation that 50 ft. of discharge pipe are necessary. At Sandy Ridge tunnel 40 ft. of discharge pipe was employed at times and no defect of mixture was observed. These lengths of discharge may then be accepted tentatively as necessary. The upper limit of length of discharge pipe is determined by relative costs. Practice records lengths up to nearly 2,800 ft. Generally speaking, length of discharge should be kept well under 1,000 ft. to obtain the best results in comparative output and costs.

In level, the location may (within limits) be, without detriment to results, considerably either above or below the point of depositing. A rise of pipe of 15 to 20 ft. above mixer level is common experience. There are frequent examples of rises of 20 to 30 ft. In experiments concrete has been deposited 100 ft. above the mixer. Probably these are not the extremes, but they indicate generally the limits of location of mixer below the point of deposit. Location above the point of deposit is rare in practice. At Tallulah Falls tunnel, however, one mixer was located at the shaft top and operated successfully.

The ideal location of mixer for tunnel lining, and particularly for lining railway tunnel, would seem to be on a car as at Sandy Ridge and Arminto tunnels. With an air main through the tunnel supplied from an outside compressor plant, a car mounted mixer gives a remarkable flexibility of lining placing operations.

Discharge Pipe.—Size of discharge pipe in relation to capacity of mixer has an important bearing on rapid and economic operation, but ordinarily this is a problem that need not concern the user. As made by the companies controlling the process, mixers are given the discharge openings suited to their capacities. Wear of pipe, pipe alinement and pipe handling are however distinctly users' problems and the troubles they may cause unless their solution is known are many.

Pipe wear is a serious problem. Driving a batch of concrete through a closed pipe under crowding pressure at a speed of a mile a minute is a severe abrasive test. Practice furnishes rather erratic records of pipe wear, because in the past no uniform practice existed in quality and make of pipe used or in the character of the joints. Naturally, alinement varied and especially the amount of curvature and the number of curves. At Tallulah Falls tunnel spiral riveted pipe was first tried, but the lines of rivets caused rapid wear and frequent ruptures. On the Stockton and Twin Peaks tunnels in San Francisco studies of pipe wear gave the following facts: An 8-in. steel pipe was used and 16 cu. ft. charges were shot under 120 lb. air pressure with velocities of 75 to 100 ft. per second. On level straight line ordinary 8-in. flanged connection steel pipe not quite new had a life of about 6,000 cu. yd. of concrete conveyed. The same pipe on an up-grade of 7 per cent wore through first on top. Threaded connections proved least durable; the thinning of the section by threading resulted in rapid cutting through at the joints. At bends, 4 ft. radius, ½-in. steel pipe cut through in instances in 12 hours continuous conveying and averaged only 60 hours' life. As a remedy cast manganese steel elbows were adopted and despite their greater expense proved more economical than ordinary steel elbows. (Note experience in the Mount Royal Tunnel which shows a different result.) Another influencing factor is the character of the coarse aggregate. Pit run gravel causes least wear, broken stone causes more rapid wear and slag causes extremely rapid wear.

The causes for excessive wear indicate the remedies to be adopted. A straight alinement is the first remedy. Such alinement is also desirable because it reduces friction and so saves air. Instead of even upgrade rises use elbows; this confines unusually rapid wear in short sections. When the amount of concrete to be handled is considerable substitute manganese steel for elbows. Have no projections inside the pipe; it should be absolutely smooth. Use a form of connection that makes the joint inside smooth and even and does not reduce the thickness of the shell. For convenience in handling the joint connection or coupling should be one that can be quickly and easily made in restricted space.

Air Consumption.—The amount of air consumed depends upon the specific gravity of the aggregate, size of pipe used, size of storage tank, horizontal and vertical distances of discharge, kind of pipe, number of bends in the discharge pipe and principally upon the operator. Table II gives the theoretical capacities for continuous operation at various horizontal distances.

The figures in Table II are based on observation for the shorter distances of discharge and are computed for the longer distances. At the St. Louis

TABLE II

Distance, ft.	100	200	500	800	1,000	1,200	1,500	2,000	2,500
Time of shooting	10	15	25	40	50	60	75	100	125
Time of loading, secs.	20	20	20	20	20	20	20	20	20
Time per batch, secs.	30	35	45	60	70	80	100	130	145
Batches per min.	2.0	1.8	1.3	1.0	.85	.75	.6	.46	.41
Batches per hour	120	108	78	60	51	45	36	27	24
Yards per hour	40	36	26	20	17	15	12	9	8
Actual free air required, cu. ft. per min.	400	720	1,300	1,600	1,700	1,800	1,840	1,840	2,000
Size of air reservoir, cu. ft.	50	100	150	240	300	360	450	500	750

waterworks tunnel the air consumption was from 1.2 to 1.7 cu. ft. per lineal foot of discharge pipe. At Richmond Tunnel, San Francisco, the consumption was 1.3 cu. ft. per lineal foot of pipe. Another tabulation given by H. A. Leeuw and stated to be based on three years' study and experience, is Table III.

TABLE III.—CUBIC YARDS OF CONCRETE PER HOUR, MIXER CAPACITY ½ CU. YD.

Actual amount of compressed air required	Length of horizontal discharge					
Cu. ft. of free air per minute	100 Lin. ft.	300 Lin. ft.	400 Lin. ft.	600 Lin. ft.	800 Lin. ft.	1,000 Lin. ft.
600	20	15	10	..	..	..
800	30	20	18	12	6	..
1,200	40	30	25	20	12	8

Time Studies.—Tables IV and V give two time studies which were made during the course of a regular day's run on one job. The air supply was about 600 cu. ft. per minute and the mixer was a ½-cu. yd. size. It was charged from overhead bins by hand, operated by sliding gates immediately over the

TABLE IV.—TIME-STUDY NO. 1

Consec. No. of shot	Charging mixer, sec.	Closing door, sec.	Discharging mixer, sec.	Wait for rise in air pressure, sec.
1	10.0	4.0	13.0	23.0
2	10.0	2.0	13.0	11.0
3	9.0	3.0	17.0	15.0
4	8.0	5.0	14.0	16.0
5	10.0	5.0	17.0	20.0
6	11.0	2.0	20.0	14.0
7	11.0	6.0	19.0	20.0
8	9.0	6.0	15.0	29.0
9	10.0	5.0	18.0	....
Average	9.8	4.2	16.2	17.2

Average time per shot, 47.4 seconds. Length of conveyor pipe line, 315 feet. Vertical rise of pipe, 15 feet. Bends in pipe, 270 degrees.

TABLE V.—TIME-STUDY NO. 2

Consec. No. of shot	Charging mixer, sec.	Closing door, sec.	Discharging mixer, sec.
1	8.0	3.0	7.0
2	5.0	3.0	11.0
3	9.0	1.0	9.0
4	7.0	4.0	8.0
5	6.0	4.0	9.0
6	7.0	5.0	9.0
7	5.0	5.0	12.0
8	7.0	9.0	11.0
9	6.0	3.0	10.0
10	5.0	5.0	11.0
11	7.0	5.0	10.0
12	5.0	4.0	13.0
Average.........	8.7	4.4	10.0

Average time per shot, 23.1 seconds. Length of conveyor pipe, 102 feet. Vertical rise of pipe, 37 feet. Bends in pipe line, 205 degrees.

measuring hopper; two laborers controlled the sand and stone gates and one laborer operated the gate to the measuring hopper and also the air valves, and another laborer operated the water valve and assisted the mixer operator, making five men at the mixer.

Note that a 600-ft. compressor was used and that the average time of waiting for the air pressure to come up was 17.2 seconds in time study No. 1, where the distance was 350 ft. In study No. 2 where the distance was only 102 ft. there was no wait for air pressure.

Lining Mount Royal Tunnel by Pneumatic Mixer.—The following data are taken from an article, by F. C. K. Stuart, published in Engineering News-Record, Jan. 24, 1918.

In placing the lining of the Mount Royal tunnel several experimental pneumatic mixing plants were tried out before determining the best arrangement for carrying on the work.

TABLE VI.—OPERATING STATISTICS OF THIRD AND FOURTH PNEUMATIC MIXING PLANTS

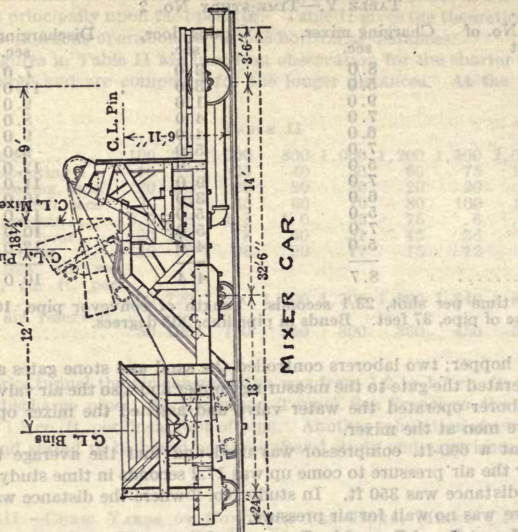
	Third plant	Fourth plant
Mixer capacity.................	½-yd. or 2-bag-batch	½-yd. or 2-bag-batch
Minimum air pressure, lbs.[a]......	70	70
Total cu. yds. placed..........	18,100	37,265
Total time, mos..............	6.7	8
Best monthly output............	4,170[b]	5,811[c]
Force employed:		
Mixer plant..................	7 }	16[d]
Forms.........................	3–5 }	
Max. distance between mixer and forms, ft....................	1,200	......
Average distance, ft............	600	......
Speed of discharge.............	1,200 ft. per min.	......
Time required to move and set up, hrs.........................	......	2.5

[a] When air pressure got below 70 lb. plugs in line were frequent.

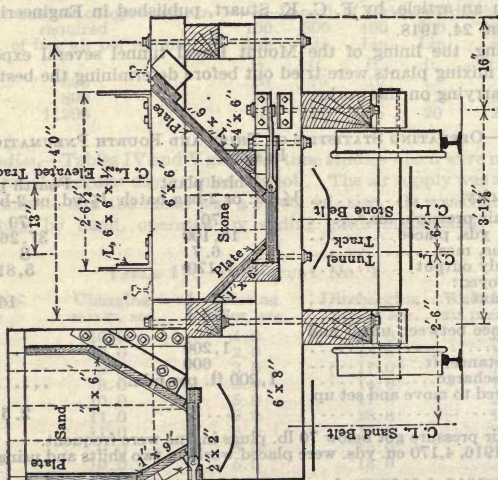
[b] March 1916, 4,170 cu. yds. were placed working two shifts and using five sets of forms.

[c] October, 1916, 5,811 cu. yds. were placed working two shifts and using seven sets of forms.

[d] The average force for one shift in the tunnel on concrete work was a foreman, a mixer operator, a hoist runner, thirteen laborers, three dinky runners, three brakemen, a pipe fitter and a handy man. The carpenters worked one shift.



MIXER CAR



SECTION A-B

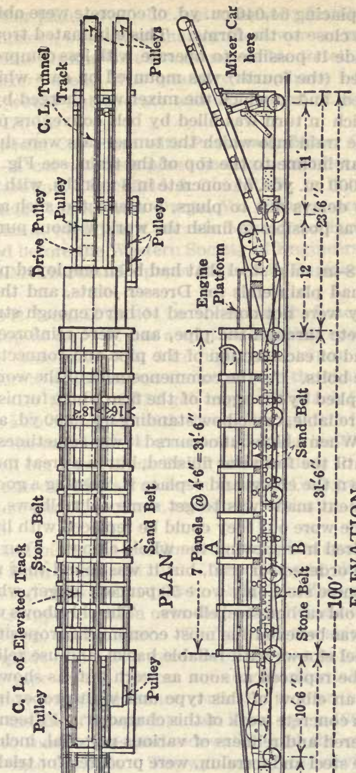


FIG. 8.—Cars ran up on elevated track, side dump discharging sand and bottom dump stone into bins from which two conveyors took material to hopper of mixer car which loaded charging skip.

The best results in placing 64,040 cu. yd. of concrete were obtained by keeping the mixing plant close to the forms. This eliminated trouble with plugging the line and made it possible to operate with less compressed air. The plant finally developed (the fourth) was mounted on cars which could move as the work progressed, and in which the mixer was charged by a skip loaded from a small bin, which in turn was filled by belt conveyors passing beneath bins, mounted on the train into which the tunnel cars were dumped. These cars were hauled up an incline to the top of the train, see Fig. 8. This plant placed more than 37,000 cu. yds. of concrete in 8 months. with 7 sets of forms, not only reduced the delays due to plugs, but effected such a saving in wear on the pipe that it was possible to finish the work without purchasing a large extra quantity.

The pipe used was 8-in. mild steel that had been employed previously as an air line. This pipe had plain ends for Dresser joints, and these joints were used. However, they were not considered to have enough strength to resist the pull of the concrete through the pipe, and were reinforced by fastening two angles to each end of each section of the pipe and connecting angles by a pair of ¾-in. machine bolts. At the commencement of the work ordinary cast steel elbows were supplied by the agent of the firm which furnished the mixers. They proved very unreliable, one elbow standing up 1,000 yd. and another one for less than 100 yd. When a blowout occurred it was sometimes possible to put on a patch to last until the form was finished, but in a great many cases it was necessary to take down the elbow and replace it, wasting a good deal of time.

The first improvement made was to get some split elbows, the idea being that as the backs alone wore out they could be replaced with little more than half the trouble required in removing the whole elbow. Four split elbows of manganese steel were ordered for trial, but it was found that under the same conditions the manganese steel only wore 50 per cent longer, while the cost was four times that of the old carbon steel elbows. The old elbows wore out only in one place, so that it was believed the most economical proposition would be to split a few carbon steel elbows with reliable backs, and use reliners consisting of blocks that could be replaced as soon as worn out, as shown in one of the photographs. With an elbow of this type and with proper inspection there should be no delays in concrete work of this character. Fifteen 45-deg. elbows of this type were ordered and reliners of various material, including cast iron, icast steel, manganese steel and ferralun, were procured for trial. Pure rubber in the shape of old sections of motor truck tires was tried, but could not be held in place in the elbow. The most economical lining was found to be cast iron, though ferralun outlasted all the other materials.

This elbow was a great improvement and was used for the rest of the job. It gave very satisfactory service, though after being relined several times the block reliners had a tendency to blow out owing to wear of the elbow itself alongside the liners. When the elbow reached this stage a forged reliner in one piece was put in to fill up all the worn spots. This type of elbow has since been patented and considerably improved.

The pipe wear was considerable, but no figures are available as to the amount actually destroyed. Most of the wear occurred at the ends, and when a length was worn through the ends were cut off and the pipe used again until entirely worn out. The reinforced Dresser joints gave satisfactory service, but there were occasional blowouts due to bad plugs. Where the end of the horizontal pipe connected to the mixer elbow and to the elbow at the bottom of the vertical pipe, a flange was screwed on the pipe.

The compressor plants available had a capacity far above the rated requirements for the mixers, but unfortunately there were so many drills and pumps run from the same air line that it was impossible to tell exactly the amount of air that the mixers used. The quantity was above 1,100-cu. ft. per minute, and the mixer would not operate without danger of plugging if the pressure dropped below 70 lb.

Output of Special Car Plant with Pneumatic Mixer Outfit for Lining Railroad Tunnel.—A car concrete plant having a number of novel features was used by the Carolina, Clinchfield & Ohio R. R. in lining the 7,804-ft. single track Sandy Ridge tunnel near Dante, Va. The arrangement was described by H. B. Kirkland, president Concrete Mixing & Placing Co., Chicago, in a paper presented before the Western Society of Engineers. The matter following taken from Mr. Kirkland's paper is given in Engineering and Contracting, May 5, 1918.

The car is 40 ft. long, 10 ft. 4½ in. wide near the braces and 17 ft. 9 in. from top of rail to top of car. It has a central chamber open on the sides, 8½ ft. long, 9 ft. 8 in. wide and 10 ft. 3 in. high, in which on one side is located the pneumatic concrete mixer and on the other side the charging skip. Over this chamber is a water tank of 1,850 gal. capacity, which furnishes water for the concrete and is also connected with the cooling system for the gasoline engine. On one end of the car, facing the central chamber, is a stone bin of 30 cu. yd. capacity. Each bin has a chute 20 in. wide leading to the charging skip and each chute is controlled by an under-cut gate. Under the stone bin is a space occupied by a 96-cu. ft. receiver, standing vertically, and the storage of the cement in bags.

Under the sand bin is the gasoline engine and its auxiliary equipment, completely housed from water and dust. The charging skip in its lower position stands with its top rim about 1 ft. 3 in. above the floor and travels on inclined guide rails to its upper position over the mixer, being hoisted by a compressed air cylinder 9¼ in. in diameter. The gate of the skip works automatically by means of a guide rail. The mixer is for a 2-bag batch (0.4 cu. yd.) and has an 8-in. outlet pipe at the bottom running horizontally and curving to the outside of the rear truck and thence vertically to near the top of the car, where it branches by means of a wye into two lines, one a 180° bend to the rear for "shooting" into foundations and sidewalks, and the other going to the roof for "shooting" into the arch. The wye is a special device with a sliding plate controlling the movement of material into either arm. The arrangement of the pipe, traveling with the car and being in position at all times for "shooting" concrete, results in a material saving of time and expense.

Along one side of the car, level with the main floors, is a folding platform 2 ft. wide used by the men carrying cement and to gain access to the engine room. During the ordinary work of the car this platform remains down. The arrangement is compact and arranged with a view to save manual labor. One man controls the hoisting of the skip, the injection of water and the mixing and discharge of the batch. One man is placed at each chute and two men carry, open and empty the cement bags.

The gasoline engine is of the 6-cylinder, 4-cycle tee-head type and is rated 200 hp. at 350 r.p.m. It can be throttled to 125 r.p.m. The motor and its frame constitute one of the trucks of the car. The cylinders stand in a row at right angles to the track and the whole construction is compact but accessible. The engine is started by admitting compressed air into three cylinders, then the explosion of the gasoline takes place in the other cylinders and continues the motion. The transmission is by means of a Morse chain on the driven axle (one only being used) and the control is through a friction clutch of special design.

The loading and storage trestle is so arranged that the concrete car goes under it and receives crusher-run stone, sand, bag cement and water by gravity. The sand and stone are drawn from overhead bins by means of under-cut gates. Cement is conveyed into the car by a chute. The trestle has a track over its deck upon which stone and sand in hopper cars are stored or unloaded into the bins below. There is a continuous row of 27 bins with an aggregate capacity of 324 cu. yd. and a total length of 162 ft., and 5 loaded cars can be stored over these bins to give an additional storage capacity of 200 cu. yd.

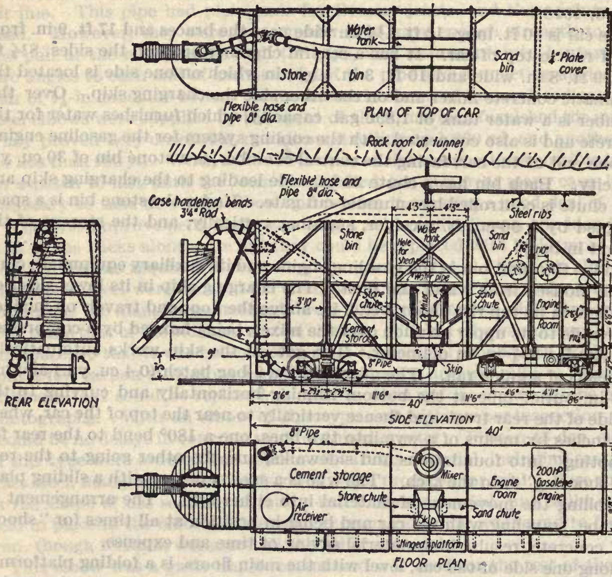


FIG. 9.—Plan and elevation of mixer car.

The compressor plant was exceptional for a temporary outfit. To save money on foundations and at the same time to increase the space, the floor level of the boilers and compressors was fixed 4½ ft. above sub-grade, the concrete foundations and walls were built up to this height and the cellular space underneath was utilized for water tanks and ash pit. The building was built of 1-in. boards covered with tar paper. The arrangement chosen permitted coal to be dumped from cars on the trestle to a pile in front of the boilers. There were two boilers, both locomotive type, one new one of 150 hp., and one old one of 70 hp. The piping connections were such that either one could be cut in or out of service for cleaning or repairs. Two compressors are installed, but an extra foundation for another unit was provided, for reasons which appear elsewhere. The compressors were alike and of the Ingersoll-Rand F. R. I. Rogler valve class, a high speed, single stage type with a steam cylinder 12 in. by 12 in., an air cylinder 12 in. by 14 in., a piston displacement at 250 r.p.m. equal to 528 cu. ft., an actual output of about 375 cu. ft. of free air per minute each. This worked under 125 lb. steam pressure and compressed air to 115 lb. They were cooled by water brought by gravity from the mouth of an old coal mine. From the compressors a 6-in. pipe leads

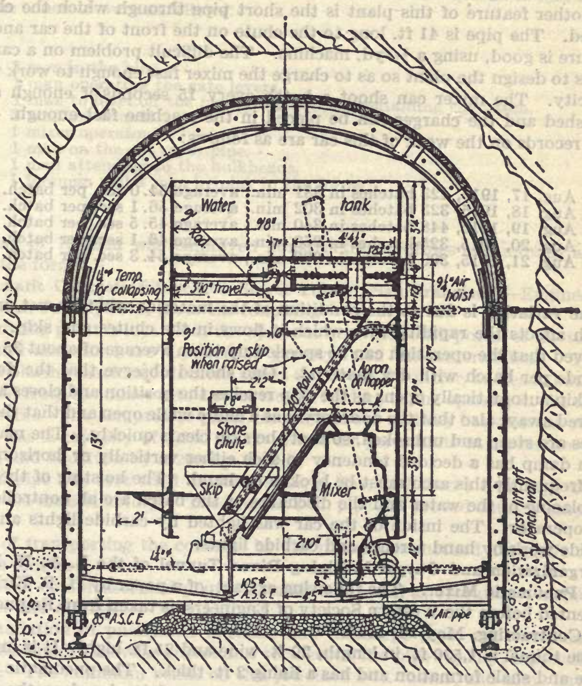


FIG. 10.—Cross-section through tunnel and car.

to a 150-cu. ft. air receiver, from which a 4-in. pipe line led on a steady 0.5 per cent down grade entirely through the tunnel. At the lower end was a pet cock to draw off any water. In order to provide for expansion and contraction, the pipe line was laid alternately on the east and west sides of the track in lengths of about 1,000 ft., connected by curves of 2 ft. radius. The bottom of the pipe was at the level of the bottom of the ties and 1 ft. out from their end. About every 100 ft. a long radius tee was placed and about 20 mine cocks of 4-in. size were provided; these could be shifted to the various tees as the progress of the work demanded. From the mine cock a 3-in. hose 60-ft. long connects with the 96 cu. ft. air receiver on the car which can thus be connected to the 4-in. pipe line from any position in the tunnel.

Several runs of 180 cu. yd. per day and one run of 201 cu. yd. were made. The work consisted of putting in the foundation and the initial lift of bench wall 4 ft. 4 in. high, which involved moving the car more than was necessary when "shooting" into the arch form.

Another feature of this plant is the short pipe through which the charge moved. The pipe is 41 ft. long to the chute on the front of the car and the mixture is good, using a ½-yd. machine. The difficult problem on a car like this is to design the plant so as to charge the mixer fast enough to work to its capacity. The mixer can shoot a batch every 15 seconds if enough air is furnished and the charges can be placed in the machine fast enough. The time records on the work of this car are as follows:

Aug. 17, 1915, 423 batches in 381 min., average 54.0 sec. per batch.
Aug. 18, 1915, 323 batches in 302 min., average 56.1 sec. per batch.
Aug. 19, 1915, 448 batches in 340 min., average 45.5 sec. per batch.
Aug. 20, 1915, 325 batches in 250 min., average 46.1 sec. per batch.
Aug. 21, 1915, 309 batches in 309 min., average 54.3 sec. per batch.

The variation is due to the condition of the material, whether wet or dry, which affects the rapidity with which it flows in the chutes and skip. It is believed that the operation can be speeded up to an average of about 35 to 40 seconds per batch with dry material. One should observe that the door of the skip automatically opens as the skip reaches the position and closes as it is lowered away; also that the door serves as a chute while open and that the side slopes are steep and unbroken, so that the skip clears quickly. The material when damp has a decided tendency to arch either vertically or horizontally, and frequently this arch must be broken by hand. The hoisting of the skip, the placing of the water and the discharge of the batch are all controlled by one operator. The inside of the car was lighted by carbide lights and the outside work by hand torches and carbide lights.

Organization and Output in Lining Diana Tunnel of the L. & N. R. R. with Pneumatic Mixer.—The following extract, of a paper by H. B. Kirkland presented before the Western Society of Engineers, is taken from Engineering and Contracting, May 15, 1918.

The tunnel is 1,520 ft. in length, 29 ft. wide and 25 ft. high. It is in limestone and shale formation and has a lining 2 ft. thick. The pneumatic mixer with storage bins and measuring hopper, etc., was first placed on the south end of the tunnel. One set of Blaw traveling forms was started at the south portal and the second set was started 400 ft. in the tunnel. These forms progressed away from the mixer until the first form had reached the work started by the second form and the second form had reached approximately the center of the tunnel. Then the mixer was moved from the south end of the tunnel to the north end and the forms moved up so that the first form would start at the center of the tunnel and the second form half way between that point and the end of the tunnel. The forms then progressed toward the mixer until the tunnel was completed.

The compressor plant consisted of two Ingersoll-Rand steam-driven compressors, which delivered about 960 ft. of free air per minute at the mixing plant.

At the beginning of the work the engineers permitted the moving of the forms after 6 days, but after a time this period was reduced to 4 days. In all there were 41 form sections, each of approximately 35 ft. and containing about 250 cu. yd. in each section. The longest distance which concrete was transported was 925 ft. and the average distance was about 400 ft. The average time required to concrete one 35-ft. section was approximately 24 hours, although some forms were filled in 15 hours. The men required to mix and place the concrete were as follows:

3 men in the bins.
1 man operating the gate levers.
1 man to level off the measuring hopper containing the batch.
1 man on cement.
1 mixer operator.
1 man on the conveyor pipe.
1 man attending to the bulkheads.
1 foreman and 4 men helping in the forms.

A gang of 10 men was employed constructing footings and moving and setting the forms.

Pneumatic Concreting Stockton Street Tunnel, San Francisco.—Engineering Record, July 4, 1914, gives the following:

The mixing plant is located in the open cut near the south portal of the tunnel. Sand and stone are supplied by gravity from the material bins. The concrete placing machine is located about 8 ft. from the mixer, and each batch is dumped from the mixer into a steel trough leading to the opening in the top of the drum. The compressor plant, situated about midway between the two portals, has a capacity of 1,250 cu. ft. of free air per minute at a pressure of 115 lbs., and is driven by a 200-hp. motor.

A 4-in. pipe was first tried on the discharge line, and then a 6-in. pipe but both proved unsatisfactory. The present 8-in. pipe has proved entirely ample in size.

Costs of transporting the concrete by the pneumatic method are made up chiefly as follows:

1. Cost of compressor and plant (installation as well as operation), including power and air lines.

2. Installation of pneumatic machine and discharge pipe, and wear and tear. The rapidly moving gravel and rock scour the pipe rapidly, especially at bends. The minimum bends on this job have 3-ft. radius, and some have been worn out in two days. A more durable metal, as manganese steel, is considered best for these sharper bends.

3. Royalty on use of system.

The material travels through the discharge pipe at an estimated velocity varying from 3 to 8 ft. per second. The impact of the discharging concrete mass against fresh concrete or against the steel reinforcement was found to erode the concrete rapidly and to displace the reinforcing steel. To remedy this trouble the pipe was raised so that the discharge end is about 1 ft. above the tunnel arch. The concrete then drops without damage into the forms at the crown and then runs downward on either side to fill up the arch ring.

OPERATING FORCE REQUIRED

1 Man operating gate on chute from rock bin.
1 Man operating gate on chute from sand bin.
2 Cement men.
1 Mixer operator.
1 Man at pneumatic machine.
2 Concrete tampers inside tunnel.
1 Concrete foreman, who also watches the pipe line to guard against clogging.
1 Man operating the air compressor.
2 Laborers in the dumping platform above the material bins.

The total concrete crew required is as shown above. Under the most favorable conditions, a batch of 16 cu. ft. can be mixed and placed in a minute. A rate of forty batches per hour or about 190 cu. yd. per 8-hr. day is a fair average when running steadily.

Relining Brick Lined Tunnel with Steam Jetted Concrete.—The brick lining of the Chicago Great Western single track R. R. tunnel 2,600 ft. long at Winston, Ill. was badly disintegrated by the action of water, coal gases and by freezing caused by the cold air forced into the tunnel by a Diesel engine driven ventilating fan. Harold P. Brown describes the situation, his recommendations and the work done in a paper, read at the Feb., 1916 meeting of the American Concrete Institute, and published in Engineering and Contracting, Feb. 23, 1916, from which the following is taken.

About a year ago the writer was called upon to examine the tunnel and suggest a method of relining which would meet the very difficult and unusual conditions. It was evident that the foundation was in satisfactory shape and that the side walls were but little injured. The roof, however, was in dangerous condition and required a lining which would take its proper share of the load.

My report advised a slight lowering of the track level; the drilling of a large number of weep holes 3 in. in diameter; the washing out of the clay between the upper brick and the old timber lining and filling the space with grout under pressure, and the removal of the cracked bricks. These should at once be replaced by an adhering layer of steam-jetted concrete, sufficiently reinforced, if necessary, to take its share of the load and continued 2 in. below the old surface.

In August, 1915, a work train was equipped for the job. The engine was provided with an extra air compressor, a steam pump and a dynamo for electric lighting. A pressure reducing valve set at 90 lb. was connected from an extry heavy nipple on the dome and a 2-in. steam connection carried with Franklin ball and socket joints and suitable couplings to a flat car on which was placed the concrete atomizer. The same car carried the cement, sand and gravel. As it would be difficult to control by hand a nozzle for jetting the concrete on to the roof, I designed for this purpose a nozzle car and trowelling machine which would place the concrete, would indicate the depth applied and would trowel or finish the final layer. The second flat car in the train carried this machine which was mounted on a platform capable of vertical or lateral adjustment, so that it could be made to swing from center line of arch. The nozzle was secured to a shaft mounted on suitable journals and was moved from side to side by a reversible two-cylinder steam engine. The same shaft carried the distance indicator and the trowelling devices. The nozzle car was mounted on wheels running on channel irons and could be moved back and forth 10 ft. by means of a stationary windlass. Steam connections to the engine and to the nozzle were made by means of suspended lengths of wire protected rubber hose. Beyond the second flat car was a box car provided with a railed platform on the roof. Here three men operated a water jet to clean the soot and dirt from the walls, and light pneumatic hammers for removing the defective brick. A signal whistle mounted on the engine which could be sounded from any part of the train was used to control the flow of air, water, steam and concrete. Two acetylene headlights as well as a number of incandescent lamps were used for general illumination.

When the work was started on Sept. 4, I found that the pneumatic drills provided were not heavy enough to penetrate the brickwork for the necessary 3-in. weep holes. Rather than delay until the proper drills could be obtained, I started operations at the eastern portal where water was pouring in streams through the roof. A mixture of 1 part cement, 3 parts of sand and 2 parts of pebbles were used with 10 per cent of water. These were mixed in the concrete atomizer at 90 lb. pressure, with the superheat obtained by dropping from engine working pressure through reducing valve. The concrete was carried through 2-in. hose and shot on to the brick by a steam jet. Although the pebbles at first dropped away, they nevertheless forced the mortar into all the interstices of the brickwork and checked the flow of water. But very little material bounded off and this was collected and used.

Before shooting a load, steam was jetted through the nozzle to complete the cleaning of the brickwork and heat it to the temperature of the concrete. In some places a layer of concrete 7 in. thick was jetted on to the roof and it set up so quickly that the work train could be immediately followed by an east bound freight without trouble from the engine exhaust.

In the final layer lime hydrate was added and the pebbles were omitted. The proportions were 1 part of hydrate to 10 parts of cement and 30 parts of sand. This gave a smooth flowing mixture and delayed the setting so that when the steam jet from the nozzle car was passed over the surface a second time without concrete, a smooth finish was obtained and trowelling was unnecessary.

The work was in charge of my superintendent while the men composing the crew were employes of the railway. Three men cleaned the roof, one man operated the nozzle car, one worked the windlass, one ran the atomizer and two men measured and loaded the materials. The improved machine is arranged so that but one man is needed to work the nozzle car and the windlass. It required about 5 minutes for the gang to clean 10 ft. of roof, load the atomizer, steam the roof and treat and apply the load. As it was important not to interfere with train service upon a double track road through a single track tunnel, only about 6 working hours per day were available in the tunnel. An average of 262 ft. of lining 12 ft. wide and 3 to 4 in. thick was applied in 6 hours, using 35 bags of cement. The concrete was found to be so strong that no reinforcement was needed, nor was it necessary to fill with grout the space above the arch. The work was finished in 41 days, and C. G. Delo, Chief Engineer, pronounced it entirely satisfactory.

Cost Data on Lining Two Tunnels, One with Brick and One with Concrete and Brick.—In Engineering and Contracting, Jan. 14, 1914, George Harper publishes the accompanying data which give the cost of lining two tunnels, exclusive of the portals. The figures for the West Virginia tunnel are for brick arching and packing alone. On the Pennsylvania tunnel the entire lining from footings up is concrete exclusive of one course of fire brick lining in arch area affected by gas and smoke. This single course lining was tied into the concrete with headers every fourth course.

The West Virginia work was put up by thoroughly experienced tunnel contractors, whose system, organization and general methods were of the best and had been evolved from the result of years of experience. The work on the tunnel in Pennsylvania was done by another firm with not so much experience in this line of work, and whose methods were somewhat more expensive, cumbersome and inexperienced. The costs are from private notes and from close contact with both of these undertakings. The brick lining cost in the tunnel in West Virginia is $26.15 per lin. ft., for the arching and packing, and with the concrete walls and footings added it will approximate in all about $40.15 per lin. ft.

West Virginia Tunnel.—The length of this tunnel is 4,211 ft. The tunnel width is 31 ft. The radius of the arch is 15 ft. 6 ins. The arch consists of five rings of brick laid up in five courses with 1 to 3 mortar. An individual brick measured 3 × 4 × 9 ins. The bricklayers worked 167 shifts. Only one shift was worked by others than bricklayers. The time lost due to moving, delays, etc., amounted to 28 shifts. The number of shifts as calendar days amounted to 196. The average length of tunnel lined per shift for the 168 shifts of actual working time was 25 ft. The tunnel lining was carried on simultaneously at different points along the length of the tunnel and for this reason four closures were made. For each lin. ft. of arch 1,227 bricks were required, making in all 5,166,897 bricks in the arch. In each spandrel wall, spacing 5 ft. 4 ins., there were 1,564 bricks; 156,400 bricks in all were used for the spandrel walls. For extra work including portals, bad ground, etc., 31,825 bricks were used. The number of culls, bats, etc., amounting to ¾ of 1 per cent, were 40,878, making the total number of bricks used for the lining 5,396,000. The packing averaged 2 cu. yds. and 4 cu. ft. to each lineal foot of tunnel. The cost data on the West Virginia work are given in Tables VII to X, inclusive. The cost data on the Pennsylvania tunnel are given in Tables XI to XIV, inclusive. The former work was done in 1911 and 1912, while the latter was done in 1912, from July to December.

TABLE VII.—COST OF BRICK ARCH TUNNEL LINING (4,211 LIN. FT.) IN WEST VIRGINIA TUNNEL

	Total shifts	Total cost	Cost per lin. ft.
Bricklaying	7,392	$ 20,580	$ 4.84
Moving centers	672	1,806	0.43
Lagging	504	1,176	0.26
Packing	2,520	4,410	1.05
Key	840	1,075	0.26
Material; delivery from west portal	1,176	3,570	0.85
Air service and pipe line	168	6,093	1.45
Center erection and dismantling	168	3,000	0.71
Mixer, erection, etc	168	600	0.14
Tracks and switches	168	590	0.12
Lighting, oil, etc	168	1,600	0.38
Timekeeper, office and plant	168	2,430	0.55
Brick (5,396,000)	168	44,517	10.57
Cement (6,600 bbls.)	168	9,240	2.20
Sand (3,500 cu. yds.)	168	2,800	0.66
Packing stone (9,050 cu. yds.)	168	6,787	1.61
Extra brick (portal and bad ground)	....	292	0.07
Total cost		$110,476	$26.21

TABLE VIII.—COST FOR 4,211 FT. OF BRICK ARCHING IN WEST VIRGINIA TUNNEL
(168 shifts were worked advancing 25 ft. per shift)

	Rate	Labor cost per lin. ft.
1 General foreman	$6.00	$0.25
1 Foreman bricklayer	9.00	0.36
4 Bricklayers	8.00	1.29
1 Labor foreman	4.00	0.16
5 Mortar tenders	2.25	0.45
1 Mortar mixer	2.25	0.09
3 Mortar laborers	2.00	0.24
1 Mortar box	2.00	0.08
3 Mortar laborers	2.00	0.27
1 Mortar mule and driver	3.50	0.14
1 Mortar hoister and runner	2.00	0.08
20 Brick laborers	1.75	1.37
1 Water boy	1.75	0.07
1 Light and lamp tenders	1.75	0.07
44 men		$4.84
Total		
Moving centers:		
1 Foreman carpenter	$4.00	$0.16
3 Laborers	2.25	0.27
Total	.....	$0.43
Lagging:		
1 Carpenter	$3.00	$0.11
2 Laborers	2.00	0.15
Total	.....	$0.26
Packing:		
15 Laborers	$1.75	$1.05
Key:		
1 Bricklayer	$4.00	$0.16
4 Laborers	.60	0.10
Total	.....	$0.26

TABLE IX.—MISCELLANEOUS COST DATA ON WEST VIRGINIA TUNNEL

Material, delivery from W. portal to work	Rate	Cost per lin. ft.
2 Dinkeys	$ 5.00	$0.40
2 Dinkey engineers	2.75	0.22
2 Dinkey brakemen	2.00	0.16
1 Dinkey watchmen	1.75	0.7
		$0.85
Air service:		
Hoisting, mixing, etc	36.32	$1.45
Center erection and dismantling	1,000.00	0.71
Mixer erection and moving	200.00	0.14
Tracks and switches:		
Propn. charges	500.00	0.12
Lighting and oils:		
9,000 gals. gasoline at 17 cts	.17	0.36
200 gals. kerosene	.15	0.01
400 gals. blackoil (centers)	.10	0.01
Interest on plant, etc.:		
Arbitrary	750.00	0.18
Propn. timekeeper and office	10.00	0.38

TABLE X.—COST OF MATERIAL FOR ARCH AND PACKING OF WEST VIRGINIA TUNNEL, F. O. B. PORTAL

	Rate	Cost per lin. ft.
Brick (5,396,000 M.)	$8.25	$10.57
Cement (6,600 bbls.)	1.40	2.20
Sand (3,500 cu. yds.)	.80	0.66
Packing stone (9,050 cu. yds.)	.75	1.61
		$26.14

TABLE XI.—COST DATA ON LINING AND ARCHING ON 4,000 LIN. FT., AND WITHOUT PORTALS, PENNSYLVANIA TUNNEL

Cost, walls, footings and arches	Cost per cu. yd.	Cost per lin. ft.	Basis of figures
Arches, walls with footings and brick	$7.74	$54.20	154.02 cu. yds. concrete in walls.
Arches, walls with brick and without footings	7.43	51.98	
Arches, walls with footings and without brick	7.00	49.01	120.24 cu. yds. concrete in arch.
Arches, walls without brick and footings	6.68	46.79	
Footings:			
Material and labor, 8,000 ft.—1,777 cu. yds.—at $5	.....	2.22	11.08 cu. yds. concrete in footings.
Bricklaying and labor:			
On 4,000 ft. arch only		5.19	286.07 cu. yds. concrete in sec. of 40 ft.
			28,000 cu. yds. concrete, cement and brick used as concrete unit, and without footings.

ESTIMATED QUANTITIES OF MATERIAL

Cement, bbls., 34,500 "Alphia,"	@ $ 1.10 per bbl.	Does not include footings
Sand, cu. yds., 12,160	@ 1.40 per c. y.	
Gravel, cu. yds., 14,560	@ 1.20 per c. y.	
Stone, cu. yds., 7,280	@ 1.30 per c. y.	
Fire brick, M.'s, 900	@ 11.60 per M.	

Work consumed 163 days, an average of 24.50 ft. per day, inclusive of all delays.
Proportion used mortar, 1 and 3.
Proportion used concrete, 1-3 and 5.

TABLE XII.—COST OF PENNSYLVANIA TUNNEL LINING, CONCRETE WALLS AND ARCHING, FOR ENGINES, CARS AND LABOR ONLY

(4,000 lin. ft.)

Walls, bricklaying and arching	Av. No. of men, basis of 13-hour shift	Unit of time for each 40′ sect. 39 hours	Rate per hour	Cost per lin. ft.
Arching—bricklayers	1	39	$1.00	$0.98
Foremen	1	39	.40	0.39
Labor	10	390	.20	1.95
Carpenters	1	39	.35	0.34
Walls—foreman, ppn	½	39	.40	0.20
Labor	6	234	.20	1.17
Bulkhead carpenter	1	39	.35	0.34
Forms—foreman, ppn	½	39	.40	0.20
Labor, ppn	2	78	.25	0.49
Walls and arching:				
Hoister runner	1	39	.25	0.24
Dinkey engines	3	117	.50	1.46
Dinkey engineers	3	117	.27½	0.80
Dinkey brakemen		117	.20	0.58
Cement and brick cars		351	.04	0.35
				$9.49

TABLE XIII.—COST OF PENNSYLVANIA TUNNEL LINING FOR MATERIAL, PLANT, LIGHTING AND OVERHEAD CHARGES

(4,000 lin. ft.)

Estimated costs	Cost per cu. yd.	Cost per lin. ft.
Cement, sand, gravel and stone	$2.9258	$20.48
Brick, 900 M	0.3750	2.63
Blaw forms	0.3214	2.25
Blaw forms, erection and dismantling (4)	0.2760	1.93
Plant E. portal, boilers, machy., storage bins W. H., etc., erection and dismantling	0.5357	3.75
Electric and gasoline lighting	0.1690	1.18
Superintendence, 5½ months	0.0535	0.38
Office, etc., 5½ months	0.1236	0.87
Air and pipe lines, $50 per day for 173 days	0.3089	2.16
Tracks, switches, etc	0.0535	0.37
Interest and incidentals (estimated)	0.0893	0.62
Stock, cement, etc., mixer and labor	0.8384	5.87
Walls and arching, labor and machinery	1.3551	9.49
8,000 lin. ft. footings	0.3173	2.22
Total cost	$7.7420	$54.20

TABLE XIV.—COST OF PENNSYLVANIA TUNNEL LINING, STOCK PIPE LINES, CEMENT, WAREHOUSE AND MIXER, LABOR ONLY

(4,000 lin. ft.)

Warehouse, material and mixing stock, pipe line, etc.	Av. No. of men on basis of 13-hour shift	Unit of time for each 40' sect. 39 hours	Rate per hour	Cost per lin. ft.
Industrial crane engr., ppn	1	13	$0.35	$0.11
Industrial crane fireman, ppn	1	13	0.25	0.08
Industrial crane watchman, ppn	1	13	0.25	0.08
General foreman	1	26	0.50	0.32
Foreman	1	39	0.40	0.39
Laborers	12	468	0.20	2.34
Incline runner	1	39	0.25	0.24
Mixer bin laborers	3	117	0.20	0.58
Cement W. St. laborers	2	78	0.20	0.39
Mixer laborers	3	117	0.20	0.59
Mixer engineer	1	39	0.25	0.24
Mixer fireman	1	39	0.25	0.24
Pump fireman	1	39	0.25	0.24
				$5.84

Comparative Cost of Excavating and Lining Tunnel With and Without Compressed Air.—The Detroit River Tunnel built for the Michigan Central

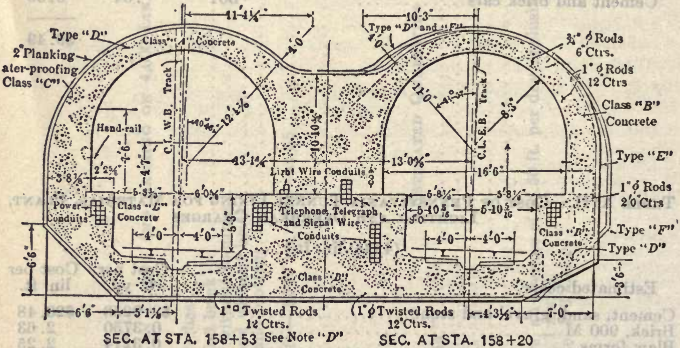


FIG. 11.—Typical section of westerly approach tunnel, Detroit River.

R. R. is a twin tube structure comprising a subaqueous section 2,668 ft. long, a westerly approach tunnel 3,669 ft. long, including 1,510.5 ft. of open cut approach, and an easterly approach tunnel 6,449.2 ft. long, including 2,900 ft. of open cut.

Fig. 11 gives, at a glance, the general type of construction.

According to W. S. Kinnear, (Proc. Am. Soc. C. E., Vol., XXXVII) Engineering and Contracting, Sept. 27, 1911, the rate of progress of excavation at Windsor, with the shields and in the drifts, under favorable conditions, was about the same as at Detroit, being approximately 10 ft. per day of 24 hours with the shields and 12 ft. per day in the drifts. The maximum distance covered by one of the shields in a single day was 19 ft. 10 ins.

The cost of excavating in drifts without compressed air averaged about $2.40 per cu. yd. under favorable conditions; with compressed air, the cost was about $3.50 per cu. yd., except for the work near old Shaft No. 1, where the cost ran as high as $16 per cu. yd. With the shields the fair average cost was $4.90 per cu. yd. These costs include timbering, compressed air, and incidentals. The cost of the compressor plant for supplying air to two side-shield headings and two center-wall headings was a trifle more than $80 per day.

Concrete.—In the easterly approach tunnel the concrete was placed in the same manner as for the westerly approach, except that all concrete was delivered in dump-cars in the tunnel. Arches were filled by shoveling the concrete into the form from the end, as the form for a 12-ft. section was set up complete before concreting was started. Concrete for the center wall, back of the center shield, was delivered in cars up to a level just below the water-proofing course, and above that through chute holes put down from the surface at intervals of about 30 ft. All concrete for the portion of the center wall built under compressed air was delivered in the drifts in cars, as previously stated. The average cost of the 1:2:4 concrete was about $8.25 per cu. yd. in the side-shield headings, and a little more than $6 per cu. yd. in the center wall, where it was deposited through chutes; in the drifts, under fompressed air, the cost was about $10.70 per cu. yd.

Cost of Concrete and Brick Linings of the Land Sections of the Hudson River Tunnels of the Pennsylvania Railroad.—The following matter, published in Engineering and Contracting. May 4. 1910, is extracted from a paper by B. H. M. Hewett and W. L. Brown, Proceedings A. S. C. E., Vol. XXXVI.

The land tunnels of the North River Tunnels of the Pennsylvania R. R. at New York city consist of 1,207 lin. ft. of double tunnel, 977 ft. on the New York side and 230 ft. on the New Jersey side.

The general design of the cross-section consists of a semi-circular arch, vertical side-walls and a flat invert, as shown in diagram by Fig. 1. The tunnel is adapted for two lines of track, each being contained in its compartment or tunnel. The span of the arch is wider than is absolutely necessary to take the rolling stock, and the extra space is utilized by the provision of a sidewalk or "bench" forming by its upper surface a gangway, out of the way of traffic, for persons walking in the tunnels, while embedded in its masss are a number of vitrified earthenware ducts, for high and low-tension electric cables. The provision of this bench enables its vertical wall to be brought much nearer to the side of the rolling stock than is usually possible, thus minimizing the effects of a derailment or other accident. Refuge niches for trackmen, and ladders to the top of the bench, are provided at frequent intervals. In cases where a narrow street limits the width of the structure, as on the New York side, the two tunnels are separated by a medial wall of masonry, thus involving excavation over the entire width of both tunnels, and in such case the tunnels are spoken of as "Twin Tunnels;" where the exigencies of width are not so severe, the two tunnels are entirely distinct, and are separated by a wall of rock. This type is found on the Weehawken side. The arches are of brick, the remainder of the tunnel lining being of concrete.

The general sequence of building the masonry lining is shown in Fig. 12. The operations were as follows:

1. Laying concrete for the whole height of the sand-walls, and for the floor and foundations for walls and benches up to the level of the base of the conduits.

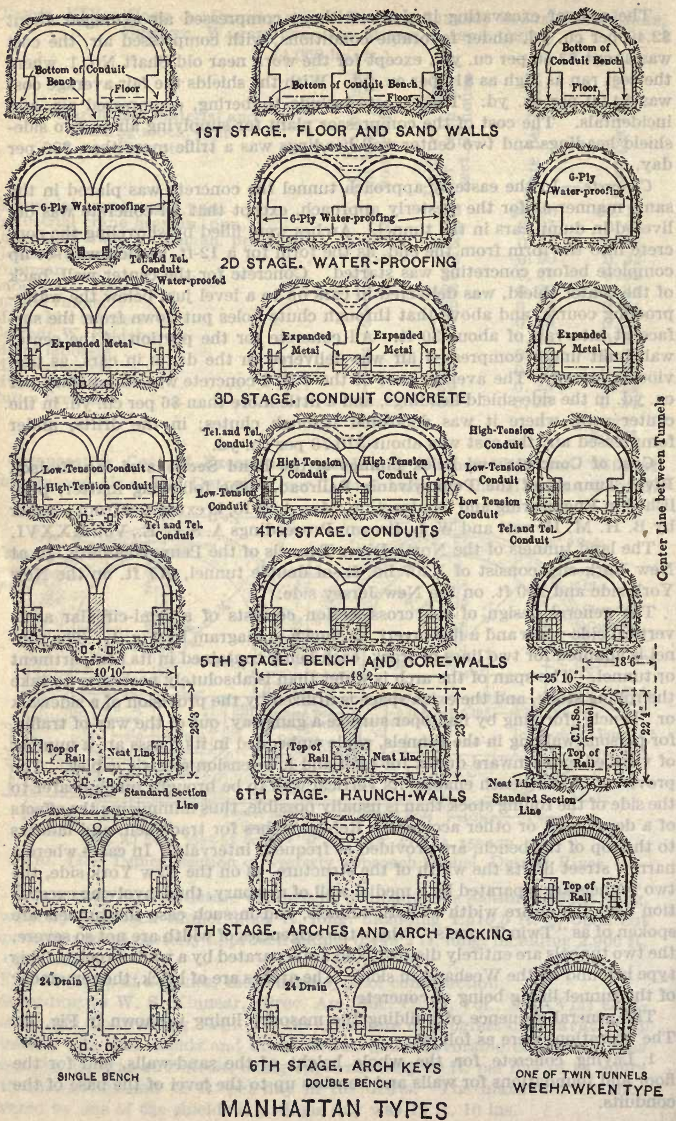


FIG. 12.—Sections showing sequence of operations in placing concrete tunnel lining.

2. Water-proofing the side-walls, and, where there was a middle trench containing subgrade conduits, laying and water-proofing these conduits.

3. Building concrete wall for conduits to be laid against, and where there was a middle trench, filling up with concrete between the conduits.

4 Laying conduits.

5. Laying concrete for benches and middle-wall.

6. Building haunches from top of bench to springing of brick arch.

7. Building brick arch and part of concrete back-filling.

8. Finishing back-filling.

The whole work will be generally described under the headings of Concrete, Brickwork, Water-proofing and Electric Conduits.

Concrete.—The number of types and the obstructions caused by the heavy posting of the timbering made it inadvisable to use built-up traveling forms at the Manhattan side, though they were used in the Weehawken Rock Tunnels.

The specifications required a facing mixture of mortar to be deposited against the forms simultaneously with the placing of the concrete. This facing mixture was dry, about 2 ins. thick, and was kept separate from the concrete during the placing by a steel diaphragm. The diaphragm was removed when the concrete reached the top of each successive layer, and the facing mixture and concrete were then tamped down together. This method was at first followed and gave good results, which was indeed a foregone conclusion, as the Weehawken shaft had been built in this way. However, it was found that as good results, in the way of smooth finish, were to be obtained without the facing mixture by spading the concrete back from the forms, so that the stone was forced back and the finer portion of the mixture came against the forms; this method was followed for the rest of the work. All corners were rounded off on a 1-in. radius by moldings tacked to the forms. The forms were used about four times, and were carefully scraped, planed, filled at open joints and oiled with soap grease each time they were set up. When too rough for face work they were used for sand-wall and other rough work.

The mixing was done by a No. 4 Ransome mixer, driven by 30-hp. electric motors. The mixer at Manhattan was set on an elevated platform at the north end of the intercepting arch; that at Weehawken was placed at the entrance to the tunnels. The sand and stone were stored in bins above the mixers, and were led to the hoppers of the mixers through chutes. The hoppers were divided into two sections, which gave the correct quantities of sand and stone, respectively, for one batch. The water was measured in a small tank alongside. A "four-bag" batch was the amount mixed at one time, that is, it consisted of 4 bags of cement, 8¾ cu. ft. of sand, and 17½ cu. ft. of broken stone, and was called a 1:2½:5 mixture. It measured when mixed about ¾ cu. yd.

The cement was furnished to the contractor by the railroad company, which undertook all the purchasing from the manufacturer, as well as the sampling, testing and storing until the contractor needed it. The railroad company charged the contractor $2 a barrel for this material.

The sand was required by the specifications to be coarse, sharp, and silicious, and to contain not more than 0.5 per cent of mica, loam, dirt or clay. All sand was carefully tested before being used. The stone was to be a sound trap or limestone, passing a 1½-in. mesh and being retained on 2⅜-in. mesh. The contractor was allowed to use a coarser stone than this, namely, one that had passed a 2-in. and was retained on a 1½-in. mesh.

The concrete was to be machine-mixed, except in cases of local necessity. The quantity of water used in the mixture was to be such that the concrete would quake on being deposited, but the engineer was to use his discretion on this point. Concrete was to be deposited in such a manner that the aggregates would not separate. It was to be laid in layers, not exceeding 9 ins. in thickness and thoroughly rammed. When placing was suspended a joint was to be formed in a manner satisfactory to the engineer. Before depositing fresh concrete, the entire surface on which it was to be laid was to be cleaned, washed and brushed, and slushed over with neat cement grout. Concrete which had begun to set was not to be used, and retempering was not to be allowed The forms were to be substantial and hold their shape until the concrete had set. The face forms were to be of matched and dressed planking, finished to true line and surfaces; adequate measures were to be taken to prevent concrete from adhering to the forms. Warped or distorted forms were to be replaced. Plastering the face was not allowed. Rock surfaces were to be thoroughly washed and cleaned before the concrete was deposited. These specifications were followed quite closely.

A typical working gang, as divided among the various operations, is shown below:

	Per month
Superintendence:	
½ superintendent at	$250
½ assistant engineer at	150
1 assistant superintendent at	150
Surface transport:	Per day
1 foreman at	$2.50
1 engineer at	3.00
1 signalman at	2.00
16 laborers at	1.75
3 teams at	7.50
Laying:	
1 foreman at	$4.00
8 laborers at	2.00
Forms:	
1 foreman at	$4.50
4 carpenters at	3.25
5 helpers at	2.25
Tunnel transport:	
¼ foreman at	$3.25
¼ engineer at	3.00
¼ signalman at	2.00
4 laborers at	1.75
Mixers:	
¼ foreman at	$3.25
2 laborers at	1.75

The superintendent and assistant engineer looked after the brickwork and other work as well as the concrete. The surface transport gang handled all the materials on the surface, including the fetching of the cement from the cement warehouses.

The tunnel transport gang handled all materials in the tunnel, but, when the haul became too long, the gang was reinforced with laborers from the laying gang. Of the laying gang, two generally did the spading, two the spreading and tamping, and the remaining force dumped the concrete. The general cost of this part of the work is shown in Table XV.

The figures in Table XV include the various items built into the concrete and some that are certificate extras in connection with the concrete, such as drains, ironwork and iron materials, rods and bars, expanded metal, doors, frames and fittings, etc.

Water-Proofing.—According to the specifications, the water-proofing was to consist of seven layers of pitch and six layers of felt on the side-walls and a ½-in. layer of mastic, composed of coal-tar and Portland cement, to be plastered over the outside of the arches.

By the time the work was in hand, some distrust had arisen as to the efficiency of this mastic coating, and a great deal of study was devoted to the problem of how to apply a felt and pitch water-proofing to the arches. The difficulty was that there was no room between the rock and the arch or between the timber and the arch (as the case might be) in which to work. Several ingenious schemes of putting the felt on in layers, or in small pieces like shingles, were proposed and discussed, and a full-sized model of the tunnel arch was even built on which to try experiments, but it was finally decided to overcome the difficulty by leaving out the arch water-proofing altogether and simply building in pipes for grouting through under pressure, in case it was found that the arch was wet.

As to the arch built through the length excavated by cut-and-cover on the New York side, it was resolved to water-proof that with felt and pitch exactly as the side-walls were done, the spandrel filling between the arches being raised in a slight ridge along the concrete line between tunnels in order to throw the water over to the sides. The portions of arch not water-proofed were rather wet, and grouting with a 1:1 mixture was done, but only with the effect of stopping large local leaks and distributing a general dampness over the whole surface of the arch.

TABLE XV.—COST OF CONCRETE IN LAND TUNNELS, IN DOLLARS PER CUBIC YARD

	Manhattan	Weehawken	Total yardage
Cubic yards placed	14,706½	3,723	18,429½
Labor:			
Surface transport	$ 0.31	$ 1.43	$ 0.54
Superintendence and general labor at point of work	0.31	1.31	0.51
Mixing	0.52	0.56	0.53
Laying	1.38	1.45	1.39
Tunnel transport	1.30	1.47	1.34
Cleaning	0.21	....	0.17
Forms, erecting and removal	1.58	1.51	1.56
Total labor	$ 5.61	$ 7.73	$ 6.04
Material:			
Cement	$ 2.30	$ 2.22	$ 2.28
Sand	0.34	0.40	0.36
Stone	0.91	0.61	0.85
Lumber for forms	0.47	0.45	0.47
Sundry tunnel supplies	0.16	0.17	0.16
Total materials	$ 4.18	$ 3.85	$ 4.12
Plant running	$ 0.44	$ 0.44	$ 0.44
Surface labor, repairs and maintenance	0.25	1.24	0.44
Field office administration	0.50	1.72	0.75
Total field charges	$ 10.98	$ 14.98	$ 11.79
Plant depreciation	$ 0.62	$ 1.57	$ 0.81
Chief office administration	0.24	0.31	0.25
Total average cost per cubic yard	$ 11.84	$ 16.86	$ 12.85
Cost of miscellaneous items in concrete:			
Amount, in dollars	$6,184.83	$1,756.79	$7,941.62
Unit cost	0.42	0.47	0.43

The 24-ft. 6-in. tunnel adjoining the Terminal Station-West was water-proofed by a surface-rendering method which, up to the present time, has been satisfactory. Generally speaking, the arches of the land tunnels, though not dripping with water, are the dampest parts of the whole structure from Tenth Ave. to Weehawken, and it would seem as if some form of water-proofing over these arches would have been a distinct advantage.

There was no difficulty in applying the water-proofing on the side-walls, after a little experience had been gained as to the best methods. The specifications required the sand-wall to be covered with alternate layers of coal-tar pitch and felt, seven layers of the former and six layers of the latter, the felt to be of Hydrex brand or other equally satisfactory to the engineer. The pitch was to be straight-run, coal-tar pitch which would soften at 60°F., and melt at 100°F., being a grade in which distillate oils, distilled from it, should have a specified gravity of 1.105. The pitch was to be mopped on the surface to a uniform thickness of 1–16 in., and a covering of felt, previously mopped with pitch, was to be applied immediately. The sheets were to lap not less than 4 ins. on cross-joints and 12 ins. on longitudinal joints, and had to adhere firmly to the pitch-covered surface. This layer was then to be mopped, and another layer placed, and so on until all the layers were in place. This water-proofing was to extend from the bottom of the cable conduits to the springing of the brick arch. Where sub-track conduits were used, these were to be surrounded with their own water-proofing. The work was carried out as specified; the sand-walls were not rendered, but were built smooth enough to apply the water-proofing directly to them. They were dried with gasoline torches before the application of the pitch, and in very wet sections grooves were cut to lead the water away.

The first attempts were with the felt laid in horizontal strips. This ended very disastrously, as the pitch could not sustain the weight of the felt, and the whole arrangement slipped down the wall. The felt was then laid vertically, being tacked to a piece of horizontal scantling at the top of the sand-wall and also held by a row of planks braced against it at about half its height. A layer of porous brick was laid as a drain along the base of the water-proofing, covered by a single layer of felt to prevent it from becoming choked with concrete.

The water-proofing of the sub-track conduits was troublesome, as the numerous layers and the necessity for preserving the proper laps in both directions between adjacent layers made the whole thing a kind of Chinese puzzle. Various modifications to suit local conditions, were made from time to time. Conduits outside the general outline of the tunnel are difficult to excavate, to lay, and to water-proof, and should be avoided wherever possible.

TABLE XVI.—COST OF WATER-PROOFING, IN DOLLARS PER SQUARE FOOT

	Manhattan	Weehawken	Total
Square feet covered	47,042	13,964	60,736
Labor	$0.07	$0.07	$0.07
Material	0.12	0.09	0.11
Total field charges	$0.19	$0.16	$0.18
Chief office and plant depreciation	0.01	0.03	0.02
Total average cost	$0.20	$0.19	$0.20

The usual force in water-proofing consisted of a foreman, at $3.50 per day, and nine laborers at $1.75 per day. These men not only laid the water-proofing, but transported the materials, heated the pitch, and cut up the rolls of felt. In general, two men transported material, one tended the heater, and the other six worked in pairs, two preparing the surface of the concrete sand-wall, two laying pitch, and two laying felt.

The cost of the water-proofing operation was about as shown in Table XVI.

Brickwork in Arches.—Owing to the heavy timbering, the brickwork at Manhattan was interfered with to a considerable extent, and the gang was always kept at work at two or more places. The work was carried up to a point where it was necessary to back-fill, or prop or cut away encroaching timbers, and then the men were moved to another place while this was being done.

The centers were set up in sets of seven, spaced 4 ft. apart. Two 14-ft. lengths of 3 by 4-in. yellow pine lagging were used with each set of ribs, with 24 × 8-in. block lagging in the crown.

All centers were set ¼ in. high, to allow for settlement, except in the 24-ft. 6-in. span, in which they were set ½ in. high. This proved ample, the average settlement of the ribs being 0.01 ft. and of the masonry 0.003 ft. In the 24-ft. 6-in. span the ribs were strengthened with 6 × 6-in. blocking and 12 × 12-in. posts to subgrade. Great trouble was here encountered with encroaching timbering, due to the settlement of the wide flat span. Grout pipes were built in, as previously mentioned.

Each mason laid an average of 0.535 cu. yd. of brickwork per hour, or 4.28 cu. yds. per day. The number of bricks laid per mason per hour was 218, or 1,744 per day.

The bricks were of the best quality of vitrified paving brick, and were obtained from the Jamestown Brick Co., of Jamestown, N. Y. The average size was 8¾ × 3 15–16 × 2 7–16 ins.; the average number per cubic yard of masonry was 408, the arches being from 19 ft. to 24 ft. 6 ins. in span and from 22 to 27 ins. thick. The joints were 3–16 in. at the face and averaged 9–16 in. through the arch.

The proportions for mortar were 1 of cement and 2½ of sand. One cubic yard of masonry was composed of 73.5 per cent brick and 26.5 per cent mortar. The volume of the ingredients in a four-bag batch was 12.12 cu. ft. and the resulting mixture was 9.54 cu. ft. The number of barrels of cement was 0.915 per cu. yd. of masonry, and about 17.7 per cent of the mortar made was wasted. The average force employed was:

	Per day
Laying:	
1 foreman at	$8.00
4 layers at	6.00
8 tenders at	2.00
2 mixers at	2.00
Forms:	
1 foreman at	$4.50
4 carpenters at	3.50
5 helpers at	2.25
Transport:	
¼ hoist engineer at	$3.00
¼ signalman at	2.00
4 laborers at	2.00

For materials, the following prices prevailed: Cement, $2.00 per bbl.; Sand, $0.90 to $1.00 per cu. yd.; Brick $16 per thousand, delivered at yard; Centers, $26 each; Lagging, $45 per 1,000 ft. B. M. The cost of the brickwork is given in Table III.

TABLE XVII.—COST OF BRICKWORK

	Manhattan	Weehawken	Total
Cubic yards placed	4,137	790	4,927
Labor:			
Surface transport	$ 0.35	$ 1.19	$ 0.48
Superintendent and general labor at point of work	0.17	0.04	0.16
Laying and mixing	2.58	3.20	2.60
Forms: erection and removal	2.62	0.32	2.25
Tunnel transport	1.19	1.12	1.18
Total labor	$ 6.91	$ 5.87	$ 6.75
Material:			
Brick	$ 6.56	$ 6.56	$ 6.56
Cement	1.76	1.75	1.76
Sand	0.20	0.28	0.22
Forms	0.92	0.98	0.93
Overhead conductor pockets	0.15	0.09	0.11
Total material	$ 9.59	$ 9.66	$ 9.60
Plant running	$ 0.55	$ 0.30	$ 0.51
Surface labor, repairs and maintenance	0.36	1.30	0.51
Field office administration	0.55	0.88	0.60
Total field charges	$17.96	$18.01	$17.97
Chief office administration	$ 0.60	$ 0.66	$ 0.61
Plant depreciation	0.35	0.64	0.39
Total average cost per cubic yard	$18.91	$19.31	$18.97

In Table XVIII the cost of grout is expressed in terms of barrels of cement used, because that was in the schedule of prices attached to the contract as the unit of payment for grout.

TABLE XVIII.—COST OF GROUT OVER ARCHES IN LAND TUNNELS, IN DOLLARS PER BARREL OF CEMENT USED

	Manhattan (Gy- East only)	Weehawken	Total
Barrels used	3,000½	261½	3,262
Labor	$0.55	$0.46	$0.53
Material	2.30	2.25	2.28
Field office administration	0.08	0.06	0.08
Plant and supplies	0.10	0.07	0.09
Total field charges	$3.03	$2.84	$2.98
Chief office and plant depreciation	0.21	0.22	0.22
Total average cost	$3.24	$3.06	$3.20

Vitrified Earthenware Conduits for Electric Cables.—The general drawings will show how the ducts were arranged, and that manholes were provided at intervals. They were water-proofed, in the case of those embedded in the bench, by the general water-proofing of the tunnels, which was carried down to the level of the bottom of the banks of ducts; and in the case of those below subgrade, by a special water-proofing of felt and pitch wrapped around the ducts themselves.

The portion of wall in front of the ducts was bonded to that behind by bonds, mostly of expanded metal, passing between the ducts. Examples of the bonding will be seen in the drawings.

The joints between successive lengths of 4-way and 2-way ducts were wrapped with two thicknesses of cotton duck, 6 in. wide, those of single-way ducts were not wrapped, but plastered with cement mortar. The ducts were laid on bed of mortar, and were made to break joints at top and bottom, and side to side with the adjacent ducts. They were laid with a wooden mandrel; a square leather washer at the near end acted as a cleanser when the mandrel was pulled through.

The specifications required the ducts to be laid at the same time as the concrete and be carried up with it, but this was found to be a very awkward operation, as the tamping of the concrete and the walking of men disturbed the ducts, especially as the bonds lay across them. It was resolved, therefore, to build the portion of the wall behind the ducts first, with the bonds embedded in it at the proper heights and projecting from it, then to lay up the banks of ducts against this wall, bending the bonds down as they were reached, and finally, after all the ducts were in, to lay the concrete in front of and over the top of the ducts. Several detailed modifications of this general scheme were followed at one time or another when necessary or advisable.

The laying of ducts below subgrade was not complicated by the presence of bonds; the water-proofing caused the trouble here, as before described.

The specifications called for a final rodding after completion. Ordinary ¾-in. gas pipe was used for the rod, and a cutter with rectangular cross-section and rounded corners was run through ahead of the mandrel; following the cutter came a scraper consisting of several square leather was ers, of the size of the ducts, spaced at intervals on a short rod. The mandrel itself was next put through, three or four men being used on the rods. All the ducts in a bank were thus rodded from manhole to manhole. When a duct was rodded it was plugged at each end with a wooden plug. A solid wooden paraffined plug was used at first, but afterward an expansion plug was used.

Very little trouble was met in rodding the power conduits, except for a few misplaced ducts, or a small mound of mortar or a laying mandrel left in. At such points a cut was made in the concrete and the duct replaced.

In the subgrade telephone and telegraph ducts east of the Manhattan Shaft, much trouble was caused by grout in the ducts. The mandrel and cutters were deflected and broke through the web of the ducts rather than remove this hard grout. Trenches had to be cut from the floor to the top of the water-proofing, the latter was then cut and folded back, and the ducts replaced. To do this, a number of ducts had to be taken out to replace the broken ones and get the proper laps. The water-proofing was then patched and the concrete replaced. This grout had not penetrated the water-proofing, but had got in through the ends of the ducts where they had not been properly plugged and protected. The duct gang, both for laying and rodding, generally consisted of 1 foreman, at $3.50 per day, and 9 laborers, at $1.75 per day. When laying: 4 men were laying, 2 men mixing and carrying mortar, and 3 were transporting material. When rodding: 4 men were rodding, 2 men at adjacent manholes were connecting and disconnecting cutters and mandrels, 1 was joining up rods, and 2 men assisting generally.

The cost of this work is shown in Table V.

TABLE XIX.—COST OF CONDUIT WORK

	Manhattan	Weehawken	Total
Duct feet	115,962	35,155	151,117
Labor	$0.035	$0.032	$0.034
Material	0.043	0.052	0.045
Total field charges	$0.078	$0.084	$0.079
Chief office and plant depreciation	0.005	0.008	0.006
Total average cost	$0.083	$0.092	$0.085

Economy Effected by the Rogers Pass Tunnel.—The following article, reprinted in Engineering and Contracting, Nov. 17, 1915, from the Cornell Civil Engineer for December, 1914 was written by J. G. Sullivan, Chief Engineer of the Western Lines of the Canadian Pacific Ry.

The calculations showing the economy to be attained over the present alignment by constructing the Rogers Pass Tunnel of the Canadian Pacific Railway are here given.

The data to be taken into account are as follows: Present location, total distance 23.1 miles, revised location 18.68 miles. Grades consist on the present location, of 16.65 miles up hill for westbound traffic on maximum grade of 2.2 per cent, 6.45 miles down grade same maximum with a total rise of 1,726 ft. and a drop of 692.1 ft. with 1,860° of curvature on the up-hill and 1,288° on the downhill portion of the line. The revised location consists of 16.77 miles up hill with about 5 miles of 2.2 per cent pusher grade, the balance 1 per cent and a down-hill run of 1.91 miles with a maximum of 2.2 per cent grade; a total rise of 1,178.2 ft. and a drop of 144.3 ft., with 635° of curvature on the up-hill grade and 66° on the down-hill. The average traffic for the years 1912 and 1913, which is made the basis of calculation, was 1,342½ passenger trains in each direction; the average weight of the passenger trains, exclusive of locomotives, was 443 tons; 980 of the passenger trains required pusher engines; the weight of the passenger and pusher engines for passenger trains was 175 tons each; there were 1,738½ freight trains in each direction per year; the average weight of the freight trains eastbound, exclusive of locomotives, was 950 tons; the average weight of freight trains westbound was 898 tons; all freight trains had to be pushed in both directions; weight of freight locomotives and pushers, 181 tons each. The tonnage eastbound and westbound was as follows:

Eastbound

	Tons
1,342½ trains @ 443 tons each	594,727.5
2,322 locomotives @ 175 tons each	406,350.0
1,738½ freight trains @ 950 tons each	1,651.575.0
3,477 locomotives @ 181 tons each	629,237.0
Total	3,281,889.5

Westbound

	Tons
1,342½ trains @ 443 tons each	594,727.5
2,322 locomotives @ 175 tons each	406,350.0
1,738½ freight trains @ 898 tons each	1,561,173.0
3,477 locomotives @ 181 tons each	629,237.0
Total	3,191,487.5

Comparison of Comparable Factors Affecting the Cost of Operating Over Rogers Pass, Via Present Line and Via Tunnel Line, Now Under Construction, Average Traffic for the Years 1912 and 1913

E. B. tonnage per year, including weight of engines, 3,281,890 tons
Resistance to Overcome, on Present Line

	Ft.	Ft.
Actual rise, 692.1 ft	692.1	
Curve resistance, 1,288° × .04 ft	51.5	
Friction resistance, 6.45 mls. × 15 ft	96.7	
Total		840.3

Resistance to Overcome, Tunnel Line

	Ft.	Ft.
Actual rise, 144.3 ft.	144.3	
Curve resistance, 66° × .04 ft.	2.6	
Friction resistance, 1.91 mls. × 15 ft.	28.6	
Total		175.5
Difference		664.8

3,281,890 tons × 664.8 ft. equals 2,181,800,472 foot-tons.

W. B. Tonnage Per Year, Including Weight of Engines, 3,191,488 Tons

Resistance to Overcome, Present Line

	Ft.	Ft.
Actual rise, 1,726 ft.	1,726.0	
Curve resistance, 1,860° × .04 ft.	74.4	
Friction resistance, 16.65 mls. × 15 ft.	249.7	
Total		2,050.1

Resistance to Overcome, Tunnel Line

	Ft.	Ft.
Actual rise, 1,178.2 ft.	1,178.2	
Curve resistance, 635° × .04 ft.	25.4	
Friction resistance, 16.77 mls. × 15 ft.	251.5	
Total		1,455.1
Difference		595.0

3,191,488 tons × 595 ft. equals 1,898,935,360 foot-tons.

	Foot-tons
Total work done (extra)	2,181,800,472
	1,898,935,360
Total	4,080,735.832

One thousand foot-tons equals approximately 1 horsepower hour. Assuming that 5 lbs. of coal is consumed in doing 1 horsepower hour's work and that coal on locomotive costs $4.60 per ton, the saving in fuel will amount to

$$\frac{4{,}080{,}736 \times 5 \text{ lbs.} \times \$4.60}{2{,}000 \text{ lbs. (one ton)}} = \$\,46{,}928.46$$

Extra Wages Train and Engine Crews

Present Line

6,162 trains for 23.1 miles	142,342.2 train miles
5,437 push. engs. for 23.1 miles	125,594.7 push. eng. miles

Tunnel Line

6,162 trains for 18.68 miles	115,106.2 train miles
5,437 push. engs. for 13 miles	70,681.0 push. eng. miles
Amount saved	27,236.0 train miles
	54,913.7 push. eng. miles

27,236 train miles at 22 cts.	$ 5,991.92
54,913.7 pusher miles at 25 cts.	13,728.40

Note.—25 cts. to cover engine crew wages, cost of repairs to pusher locomotives and extra cost of maintenance account of running pushers.

Extra cost maintenance of way, 4.42 miles at $200 plus 27,236 train miles at 20 cts.	$ 6,331.20
Extra cost, maintenance of way, account of extra number of degrees of curvature, assuming that 400° of curvature per mile would increase rate at 20 cts. per train mile for maintenance by 30 per cent—	
6,162 trains × 2,447° × $\frac{1}{40}$ ct.	3,769.60
Special maintenance, account 4½ miles snow sheds	85,000.00
Extra cost, maintenance of equipment, 27,236 train miles at 21 cts.	5,719.56
Extra cost, maintenance of equipment, account of extra number of degrees of curvature, assuming that 400° of curvature per mile would increase rate of 21 cts. per train mile by 40 per cent—	
6,162 trains × 2,447° × $\frac{21}{1,000}$ ct.	3,166.47
Total annual saving in cost of operation	$170,635.61

The rate at which traffic has been increasing would indicate that shortly after the work of constructing the tunnel was completed the traffic would have doubled. In this case, if no further economies were made in methods of operating this section of track, the annual saving on account of operating over tunnel line would be—

$$\$85,635.61 \times 2 + \$85,000.00 = \$256,271.22$$

In arriving at the above figure no account is taken of whether line was single or double track and for comparative figures it was assumed that methods of operation would be the same. Now, as a matter of fact, the present single track line with double the present traffic would make the business too congested for economical single-track operation. Therefore, it was apparent that it was time to study the question of double tracking the present line or seeking a new line for double track. It was decided to double track on the 5-mile tunnel location. Now to operate successfully a 5-mile tunnel we will require the installation of an electric plant and the purchase of electric locomotives. All the details of the proposed electrification have not as yet been worked out, but even if they were, the reader is not interested in the details of cost. He can see at once that the problem was to find out if the cost of operating and maintaining the tunnel line, taking into account the extra costs of operating on account of having a short section of electric operation and extra cost of maintaining tracks in the tunnel, plus the interest on the cost of building the new double track line, including the cost of electrifying the tunnel, would be less than the cost of operating and maintaining a double track line on the present location plus the interest on the cost of building the second track. The figures would not have been very decisive one way or the other if not for the fact that there is now 4½ miles of wooden snow sheds on the present location which will be all done away with on the new location. The maintenance and cost of renewals of these sheds cost between $85,000 and $100,000 per year. To maintain and renew a double-track wooden shed would probably cost at least 50 per cent more than the above, so that with a saving of about $125,000 per year in maintenance and renewals of snow sheds and a calculated saving in operation and maintenance of $171,271.22 on a traffic that surely will be reached in the near future, there was no doubt as to the proper course to pursue.

As to the details of figuring economics of railway location, the writer is well aware that it is impossible to devise any method that will show absolutely the saving in cost of operating one line over another, but he believes that the method herein followed, namely, that of comparing cost of fuel on the basis of work done rather than on a train-mile or any other unit, is much more logical and will give more reliable results than other methods that have been followed. The train mile is possibly the best unit for comparison in cost of wages and for cost of maintenance of equipment. In figuring maintenance of way a fixed sum should be taken plus a rate per daily train rather than a fixed rate alone per train mile, for the reason that a certain amount of expense must be incurred regardless of whether trains are run or not. The fixed sum of $200 per mile taken in this problem is probably about one-half the actual sum that would be assumed if the entire cost of maintenance was to be included in this fixed sum per mile plus the rate per train mile for the reason that cost of maintenance of terminals and other items are not affected by the details of location between fixed terminals.

Frictional resistance, normal conditions, warm weather, modern freight equipment, speed between 7 and 35 miles an hour,

$$R = 2.2T + 121.6\ C.$$

R = total resistance on level tangent.
T = total weight cars and contents in tons.
C = total number of cars in train.

This amounts to 4 lbs. per ton to 8 lbs. per ton, depending on whether cars are fully loaded or empty. This is equivalent to a rise of from 10 ft. to 20 ft. per mile. For mixed traffic a conservative estimate is train resistance equals rise of 15 ft. per mile.

It may appear that the rate of 25 cts. per actual pusher mile covering the cost of repairs and engine crew wages and extra cost of maintenance is too high, but as a matter of fact it is very conservative for the repairs, maintenance and renewals of the locomotives alone will run somewhere between 7 cts. and 10 cts. per mile and we have had cases where the engine crew wages alone averaged 25 cts. per mile for the actual mileage run, on account of delays to the pusher.

Reference to Subaqueous Shield Driven Tunnel Costs.—Many valuable data are given in the paper of B. H. M. Hewett and W. L. Brown on the Pennsylvania R. R. Tunnels under the North River, New York. Proceedings of the A. S. C. E., Vol. XXXVI. Certain parts of this paper may be found in abstract form in Engineering and Contracting as follows.

Methods and Cost of Placing Concrete Lining—issue of May 11, 1910.

Labor Required and Average Progress in Constructing Shield Driven Tunnels—issue of May 18, 1910.

First Cost and Cost of Operating Power Plants—issue of May 25, 1910.

Methods and Cost of Calking and Grummeting Joints in Cast Iron Lining—issue of June 15, 1910.

CHAPTER XXI

BANK AND SHORE PROTECTION

In this chapter are given the methods and costs of constructing certain structures for preventing erosion to river banks and also similar data in regard to the construction of breakwaters of various types. Further references, giving costs of bank and shore protection may be found in Gillette's Handbook of Cost Data.

Costs of Brush Mattresses.—The following statements of methods and costs are compiled from various portions of the Report of the Chief of Engineers, U. S. A. for 1910–11 and are printed in Engineering and Contracting, Nov. 13, 1912.

Hopefield Bend, Ark.—The work done during the year comprised 3,505 squares of mattress and 11,332 sq. yds. of paving. The cost of the mattress work was as follows:

Strand ½ in., 1,654 lbs	$ 46.80
Strand 5/16 in., 6,311 lbs	160.30
Strand ¼ in., 19,027 lbs	523.24
Wire No. 12, 8,896 lbs	195.71
Staples, 950 lbs	19.95
Clips ½ in., 156	3.92
Clips 5/16 in., 1,894	136.37
Brush, 5,632 cords	9,287.82
Stone, 4,009 cu. yds	5,482.82
Steamboat expense	1,836.00
Labor, subsistence and supervision	11,824.66
	$29,517.59
No. of squares	3,505.0
Cost per square	$ 8.42
Cords of brush and poles per square	1.60
Cu. yds. of stone per square	1.14
Cu. yds. of stone per cord of brush and poles	0.712

The cost of grading 2,265 lin. ft. of bank involving 33,200 cu. yds. was as follows:

Coal, etc	$ 281.00
Labor, subsistence and supervision	1,736.00
Total	$2,017.00
Cost per lin. ft	$ 0.89
Cost per cu. yd	0.061

The cost of paving 2,265 lin. ft. of bank or 11,332 sq. yds. of paving was as follows:

Stone, 3,342 cu. yds	$4,162.99
Labor, subsistence and supervision	3,170.00
	$7,332.99
Cost per lin. ft	$ 3.83
Cost per sq. yd	0.647
Cu. yd. stone per sq. yd. paving	0.29

A summary of the total cost of the work is as follows:

Total field cost	$38,867.42
Office expense	1,419.53
Surveys	1,392.07
Care of plant	475.18
Repairs to plant	2,267.93
Depreciation to plant	2,135.33
Total cost	$46,557.46

Walnut Bend, Ark.—During the first part of the season no unusual difficulties were encountered. During the latter part of the season, however, rapid rises in the river gave considerable trouble on account of the flooding of the dead-men holes. The paving consists of the usual form of rip-rap except 500 lin. ft. which is concrete 4 in. thick.

The cost of the mattress work follows:

CHANNEL MATTRESS NO. 8
(1,480 ft. long by 254 ft. wide, 3,759 squares)

Strand ½ in., 17,192 lbs	$ 453.08
Strand 5/16 in., 6,386 lbs	162.20
Strand ¼ in., 22,797 lbs	624.64
Wire No. 12, 7,520 lbs	165.44
Wire, silicon bronze, 1,431 lbs	214.51
Staples, 700 lbs	14.70
Clips ½ in., 1,712	44.51
Clips 5/16 in., 2,064	148.61
Miscellaneous material	1,803.01
Brush and poles, 5,077 cords	8,377.05
Stone 2,999 cu. yds	3,548.42
Steam boat expense	3,129.82
Labor, subsistence and supervision	12,170.74
Total	$30,856.73
Cost per lin. ft	$ 20.85
Cost per square	8.20
Cords of brush and poles per lin. ft	3.43
Cords of brush and poles per square	1.35
Cu. yds. of stone per lin. ft	2.02
Cu. yds. of stone per square	0.71
Cu. yds. of stone per cord of brush and poles	0.59

CHANNEL MATTRESSES, NOS. 9 AND 10
(596 ft. long by 250 ft. wide, 1,514 squares)

Strand, ½ in., 6,843 lbs	$ 172.72
Strand, 1/16 in., 3,184 lbs	78.64
Strand, ¼ in., 9,057 lbs	248.16
Wire, No. 12, 4,573 lbs	100.61
Wire, silicon bronze, 650 lbs	97.43
Staples, 400 lbs	8.40
Clips, ½ in., 559	14.53
Clips, 5/16 in., 988	12.45
Brush and poles, 1,881 cords	3,103.65
Stone, 860 cu. yds	1,017.55
Steamboat expense	1,271.70
Labor, subsistence and supervision	8,827.92
Total	$14,953.76
Cost per lin. ft	$ 25.09
Cost per square	9.21
Cords of brush and poles per lin. ft	3.16
Cords of brush and poles per square	1.24
Cu. yds. of stone per lin. ft	1.44
Cu. yds. of stone per square	0.57
Cu. yds. of stone per cord of brush and poles	0.46

CONNECTING MATTRESSES, NOS. 17 TO 26, INCLUSIVE, 2,542 SQUARES

Strand, ½ in., 1,817 lbs	$ 47.24
Strand, 5/16 in., 7,287 lbs	179.99
Strand, ¼ in., 14,560 lbs	398.94
Wire, No. 12, 7,862 lbs	172.96
Staples, 725 lbs	15.23
Clips, ½ in., 223	5.80
Clips, 5/16 in., 2,126	101.39
Brush and poles, 3,790 cords	6,253.50
Stone, 3,241.45 cu. yds	3,835.28
Steamboat expenses	2,135.28
Labor, subsistence and supervision	9,666.06
Total	$22,811.67
New work	2,291 squares
Repair work	251 squares
Cost per square	$8.96
Cords of brush and poles per square	1.49
Cu. yds. of stone per square	1.28
Cu. yds. of stone per cord of brush and poles	0.81

The bank grading amounted to 51,617 cu. yd. for new work and 6,268 cu. yds. for repair work, or a total of 57,885 cu. yds., and its cost was as follows:

6,492 bus. coal	$ 714.00
Labor, subsistence, and supervision	3,318.00
Total	$ 4,032.00
Cost per lin. ft. (new work)	$ 1.50
Cost per cu. yd	0.0696

The bank paving with stone amounted to 25,225 sq. yds., of which 3,772 sq. yds. were repair work. The cost of this paving was as follows:

Stone, 6,352 cu. yds	$11,546.00
Steamboat expense	1,500.00
Labor, subsistence, supervision, etc	7,517.00
Total	$20,563.00
Cost per sq. yd	$ 0.815
Cost per lin. ft. (new work)	9.22
Cu. yds. of stone per sq. yd	0.25

The amount of concrete paving was 5,196 sq. yds., or a stretch of bank 500 ft. long and 93½ ft. wide; its cost was as follows:

Gravel, 631 cu. yds	$ 441.70
Cement, 1,702 sacks	765.90
Coal, 438 bushels	48.18
Wire, Pittsburgh fence, 49,500 sq. ft	245.03
Lumber	25.00
Labor, subsistence and supervision	926.75
Total	$ 2,452.56
Cost per sq. yd	$ 0.472
Cost per lin. ft	4.905
Cu. yds. of gravel per sq. yd	0.12
Sacks of cement per sq. yd	0.33

A summary of the total cost follows:

Total field cost	$115,374.68
Office expense	2,200.36
Surveys	478.60
Care of plant	3,088.73
Repairs to plant	14,741.57
Depreciation of plant	13,879.66
Total cost	$149,763.60

The unit costs for the whole work summarize as follows:

Channel mattress, per lin. ft	$28.45
Connecting mattress, per lin. ft	8.93
Grading, per lin. ft	1.95
Paving per lin. ft	10.82
Total cost per lin. ft. of bank protected	$50.15
Field cost per lin. ft. of bank protected	$38.58

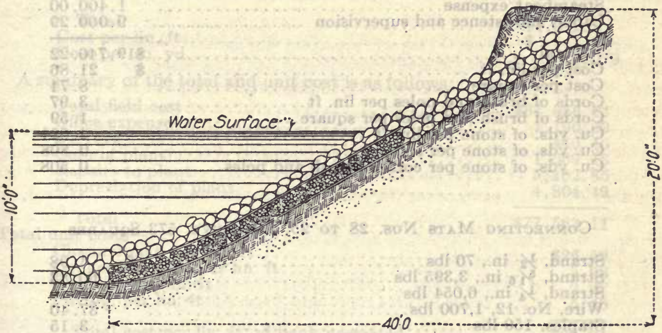


FIG. 1.—Cross section of mattress construction for shore and levee protection

Old Town, Ark.—The work comprised an extension of 1,700 ft. to the previous season's work. The following is the cost of the mattress work:

CHANNEL MATTRESS NO. 9

(798 ft. long by 250 ft. wide, 1,995 squares)

Strand, ½ in., 13,432 lbs	$ 380.13
Strand, 5/16 in., 4,072 lbs	103.43
Strand, ¼ in., 11,243 lbs	309.18
Wire, No. 12, 4,770 lbs	104.94
Wire, silicon bronze, 860 pounds	128.91
Staples, 400 lbs	8.40
Clips, ½ in., 976	24.50
Clips, 5/16 in., 1,406	101.25
Brush and poles, 3,019.7 cords	4,227.58
Stone, 1,682 cu. yds	2,312.30
Steamboat expense	1,236.73
Labor, subsistence and supervision	9,023.53
Total	$17,960.88
Cost per lin. ft	$ 22.50
Cost per square	9.00
Cords of brush and poles per lin. ft	3.78
Cords of brush and poles per square	1.51
Cu. yds. of stone per lin. ft	2.11
Cu. yds. of stone per square	0.84
Cu. yds. of stone per cord of brush and poles	0.55

Channel Mat No. 10

(903 ft. long by 250 ft. wide, 2,257.5 squares)

Strand, ½ in., 12,931 lbs	$ 365.95
Strand, 5/16 in., 5,556 lbs	141.12
Strand, ¼ in., 14,616 lbs	401.94
Wire, No. 12, 6,350 lbs	139.70
Wire, silicon bronze, 704 lbs	142.91
Staples, 450 lbs	9.45
Clips, ½ in., 449	11.27
Clips, 5/16 in., 544	18.73
Brush and poles, 3,589 cords	5,184.14
Stone, 1,825 cu. yds	2,924.72
Steamboat expense	1,400.00
Labor, subsistence and supervision	9,000.29
Total	$19,740.22
Cost per lin. ft	$ 21.86
Cost per square	8.74
Cords of brush and poles per lin. ft	3.97
Cords of brush and poles per square	1.59
Cu. yds. of stone per lin. ft	2.021
Cu. yds. of stone per square	0.808
Cu. yds. of stone per cord of brush and poles	0.508

Connecting Mats Nos. 28 to 25, Inclusive, 573 Squares

Strand, ½ in., 70 lbs	$ 1.98
Strand, 5/16 in., 3,395 lbs	60.83
Strand, ¼ in., 6,054 lbs	160.49
Wire, No. 12, 1,700 lbs	37.40
Staples, 150 lbs	3.15
Clips, ½ in., 36	1.40
Clips, 5/16 in., 650	8.19
Brush and poles, 8,677 cords	1,214.78
Stone, 520 cu. yds	977.08
Steamboat expense	380.00
Labor, subsistence and supervision	2,801.34
Total	$5,646.64
Cost per square	$ 9.85
Cords of brush and poles per square	1.51
Cu. yds. of stone per square	0.91
Cu. yds. of stone per cord of brush and poles	0.60

Connecting Mat No. 27, 191 Squares

(Repairs to old work)

Strand, ½ in., 420 lbs	$ 11.88
Strand, 5/16 in., 600 lbs	15.24
Strand, ¼ in., 1,680 lbs	46.20
Wire, No. 12, 524 lbs	11.53
Staples, 50 lbs	1.05
Clips, ½ in., 10	.25
Clips, 5/16 in., 132	1.66
Brush and poles, 280 cords	396.00
Stone, 180 cu. yds	338.22
Steamboat expense	100.00
Labor, subsistence and supervision	1,082.00
Total	$2,004.03
Cost per square	$ 11.07
Cords of brush and poles per square	1.54
Cu. yds. of stone per square	1.00
Cu. yds. of stone per cord of brush and poles	0.65

The cost of 2,149 lin. ft. or 11,975 sq. yds. of paving was as follows:

Stone 3,711 cu. yds	$6,054.51
Labor, subsistence and supervision	3,632.95
Total	$9,687.46
Cost per sq. yd	$ 0.808
Cost per lin. ft	4.50
Cu. yds. stone per sq. yd. of paving	0.31

The cost of 51,758 cu. yds of grading was as follows:

Coal	$ 570.0
Labor, subsistence and supervision	3,502.0
Total	$4,072.0
Cost per lin. ft	$ 1.89
Cost per cu. yd	0.079

A summary of the total and unit cost is as follows:

Total field cost	$64,956.14
Office expense	1,190.29
Surveys	440.16
Care of plant	1,069.18
Repairs to plant	5,102.85
Depreciation of plant	4,804.49
Total	$77,563.11
Total unit costs—	
Channel mat, per lin. ft	$26.59
Connecting mat, per lin. ft	3.98
Grading, per lin. ft	2.27
Paving, per lin. ft	5.40
Total cost per lin. ft. of bank protected	$38.24
Field cost per lin. ft. of bank protected	$31.87

Panther Forest, Ark.—The work consisted in constructing 2,037 ft. of standard revetment down stream from the lower end of previous work. Two mats were constructed, 1,131 × 253 and 946 × 253 ft., and four shore mats containing 264 squares, to connect the main mattress with the upper bank paving. The bank was cleared of heavy timber for a distance of 2,300 ft., the clearing extending about 1,000 ft. below the end of the revetment. Work was begun Aug. 23 and completed Nov. 12, 1910. The cost was as follows:

	Cost
5,254 squares channel mat, at $6.477	$34,032.86
1,960 squares paving bank, at $7.307	14,322.85
Property	4,892.59
90 days' towing, at $48.338	4,350.39
264 squares pocket mattress, at $8.103	2,139.34
Sundries	2,056.87
1,900 lin. ft. hydraulic grading, at $1.002	1,904.86
1,900 lin. ft. grade dressed, at $0.461	876.51
Supervision	860.82
Outfitting	735.84
2,300 lin. ft. bank cleared, at $0.31	711.77
Transportation of labor	424.25
250 lin. ft. hand grading, at $1.299	324.89
475 lin. ft. ditching, at $0.271	128.94
Repairs to old paving	75.70
10 squares revetment, at $5.464	54.64
Total	$67,893.12

Leland Neck, Ark.—The work comprised the extension of existing revetment 1,057 ft. down stream by a channel mat 250 ft. wide, and two shore or connecting mats containing 652 squares. Its cost was as follows:

	Cost
2,642 squares channel mat, at $8.4257	$22,260.63
652 squares pocket mat, at $6.9897	4,557.26
1,173 squares bank paved, at $6.8063	7,983.77
309 squares revetment, at $6.4986	2,008.06
63 days' towing, at $58.31	3,673.77
1,287 lin. ft. hydraulic grad'g, at $1.9254	2,478.10
1,287 lin. ft. hand grading, at $0.477	614.05
Supervision	393.75
Transportation of labor	706.80
Engineer office charges	727.74
Hire of barges, etc	5,332.86
Loading stone	944.10
Total	$51,680.89

Albemarle Bend, Miss.—The work carried out here is designed to prevent further caving in this bend, where this action has progressed for a great many years, destroying many levees and involving large expenditures for new ones. During the past four years the bank has been eroded at the rate of about 500 ft. per year. The approved project contemplated the construction of about 10,000 ft. of revetment, and work was begun in August, 1910, and during the period Aug. 17, 1910, to Mar. 3, 1911, 11,650 ft. of revetment were constructed, located so as to cover the zone where the caving had been most active for several years past. Since the completion of the work the main force of the current has been changed, so that it now strikes the bank along the lower third of the completed revetment.

The work was done by forces from three engineer districts, but the report gives details for one district force only, and these follow.

The grading was unusually heavy, due to the old levee near the edge of the bank, which had to be cut in several places for the mat cables to pass through. It was necessary to wash a large portion of this levee into the river and then regrade the bank, fully one-half of the bank having to be graded a second time for this reason. Brush and poles for the revetment work were obtained under contract. Stone was procured from the reserve at Greenville; from contract delivery on the bank at Greenville, loaded on barges at Vicksburg, and delivered at the different revetments on contractors' barges.

On account of lack of familiarity with this portion of the river and difficulty in obtaining a suitable willow bar, mattress construction was somewhat slow. A sudden rise of the river and the caving in of one set of ways tended to delay the work and to increase the cost, as did also the necessity of bringing some of the brush by barges from a considerable distance. The field cost was as follows:

90,230 ft. B. M. 3 × 6 in. lumber	$ 1,398.56
140,000 ft. B. M. 2 × 4 in. lumber	2,170.00
2,000 ft. B. M. miscellaneous lumber	31.00
6,000 lbs. 9-in. steel wire nails	138.00
16,600 lbs. 6-in. steel wire nails	348.60
5,000 lbs. 4-in. steel wire nails	105.00
3,500 lbs. No. 12 galvanized wire	82.25
4,100 cords brush	5,398.62
10,000 9-in. treenails	28.80
40,000 6-in. treenails	107.20
Steamers and tugs	1,825.00
Miscellaneous	40.60
Provisions	1,318.58
Pay rolls, services	5,371.96
Total	$18,364.17
Sq. ft. of mattress built	394,620
Cost per sq. ft. for construction	$ 0.04653

The item of 4,100 cords of brush given in the foregoing table is analyzed as follows:

Cutting and piling, building roads, etc.	$4,047.29
Transportation to ways	1,184.37
Privilege of cutting brush	166.96
Total	$5,398.62
Estimated cords of brush used	4,100
Cost per cord delivered at ways	$ 1.316

Of the 4,100 cords of brush used, 750 cords had to be transported from outlying bars on barges.

Three sets of ways had to be built, one on the mainland at Salem, one on the towhead, and one on Arcadia bar. Their cost is included in mattress construction, but is separated and analyzed as follows:

Lumber and nails	$161.60
Labor and superintendence	425.07
Total	$586.67
Average cost of each set	$195.56

The expense of towing lumber and other materials, except rock, has been added to and is included in the cost of such materials delivered at the site of the work. As Salem bar is located only a short distance above Albemarle Bend, the cost of towing the mattresses from the place where built to the locality where sunk is too small to be given as a separate item, and is included in the cost of construction and sinking.

The cost of sinking 394,620 sq. ft., or 3,946.2 squares of mattresses, was as follows:

487 tons of rock, at $2.40	$ 1,168.80
2,473.61 tons of rock, at $2.25	5,565.62
Steamers and tugs	2,105.00
Lumber, wire nails, wire, etc	432.56
Miscellaneous	64.74
Provisions	990.34
Pay rolls, services	3,110.69
Total	$13,437.75
Cost per sq. ft. to sink	$ 0.03405

Summarizing the field cost of construction and sinking we have:

Construction of mattress per sq. ft	$0.04653
Sinking of mattress per sq. ft	0.03405
Total field cost per sq. ft	$0.08058

All grading was done with a hydraulic grader. Operations were commenced Nov. 3 and completed Nov. 13, during which time 1,586 lin. ft. of bank was graded. The grader was operated with a single crew. The total cost of grading 1,586 lin. ft. of bank was $2,045.55 being $1.29 per lin. ft.

A total of 129,121 sq. ft., covering 1,635 lin. ft. of bank, was paved. The cost was as follows:

Steamers and tugs	$ 877.00
1,271.19 tons of rock, at $2.40	3,050.86
1,271.71 tons of rock, at $2.32	2,950.37
437.04 tons of rock, at $2.25	983.34
896 tons of rock, at $1.93	1,729.28
Miscellaneous	35.00
Provisions	441.62
Pay rolls, services	1,606.95
Total	$11,970.42
Cost per sq. ft. for paving	$ 0.0919

Clearing the bank of logs, etc., preparatory to grading cost $375.30.

Rock for this work was obtained from various sources and at various prices. A total of 6,837 tons was used, of which 3,807 tons was obtained under contract delivered on barges at Vicksburg, Miss., 1,758 tons delivered on barges in Albemarle Bend, and 1,272 tons purchased in open market, delivered on railroad cars at Vicksburg, Miss. The lack of rock at times delayed the work and increased its cost.

The same plant was used in Albemarle Bend as was operated at Reid-Bedford, and the actual expense of moving it upstream about 40 miles was not very great, but has been prorated with the Reid-Bedford work and assumed to be $1,500.

The cost of such survey work as was necessary to the location and placing of the revetment was $129.

The total length of completed revetment placed by the district force mentioned above was 1,615 ft., and the summarized cost was as follows:

Const. of mattress, incl. 3 sets ways	$18,364.17
Sinking of mattress	13,437.75
Grading bank	2,045.55
Paving bank	11,970.42
Clearing	375.30
Installation, estimated	1,500.00
Surveys	129.00
Miscellaneous	62.00
New plant, manila rope, etc., estimated	2,000.00
Total field cost	$49,884.19
Total field cost per lin. ft. completed revetment	$ 30.89

A summary of the unit and total costs of work done by the two other district forces which were engaged at Albemarle Bend is as follows:

27,172 squares channel mat, at $7.851	$213,296.35
4,960 squares connecting mat, at $9.089	45,079.50
5,468 squares bank paved, at $9.897	54,120.09
32 squares revetment, at $7.207	230.64
8,550 lin. ft. slope dressed, at $0.497	4,254.88
12 acres bank cleared, at $135.47	1,625.68
3,000 lin. ft. ditching, at $0.068	202.47
11,000 lin. ft. hydr'lic grad'g, at $1.190	12,310.97
200 days' towing, at $173.914	34,782.71
Outfitting	671.42
Inspection	3,181.70
Supervision	4,737.62
Property	10,426.01
Transportation of labor	3,090.81
Rent of barges	7,134.23
Engineer office charges	1,500.00
Sundries	17,703.74
Total	$414,348.82

Reid Bedford Bend, La.—The conditions at this bend of the river were very unfavorable for either revetment or levee work. It has a sloughing bank, where large sections settle slowly and slide out. The adjacent land is low and swampy, and the current attains a high velocity in the deep water close to the bank. Each of the numerous sections of abandoned levees has its borrow pit, from which the impounded water seeps through the bank, assisting in its destruction.

Work was begun in 1906, when about 2,000 ft. of revetment was placed, but on account of high stages of the river no upper-bank paving was possible. The work described consisted in adding 1,880 ft. of revetment and some repairs to old work.

Mattress construction was commenced when the river was at about a half stage, and as the employes were unfamiliar with the low-water conditions in this part of the river, some errors were made in the location of the ways, with the result that the cost of mattress construction was more than it would have been under favorable conditions. The detailed field cost is as follows:

103,986 ft. B. M. 3 × 6-in. lumber	$ 1,611.78
205,398 ft. B. M. 2 × 4-in. lumber	3,183.67
2,000 ft. B. M. miscellaneous lumber	31.00
8,000 lbs. 9-in. steel wire nails	184.00
19,600 lbs. 6-in. steel wire nails	411.60
4,100 lbs. 4-in. steel wire nails	86.10
2,400 lbs. No. 12 galvanized wire	56.40
6,000 cords brush	6,912.65
10,000 9-in. treenails	28.80
40,000 6-in. treenails	107.20
Steamers and tugs	2,389.50
Miscellaneous	218.10
Provisions	2,387.32
Pay rolls, services	7,174.63
Total	$24,782.75
Total sq. ft. mattress built	573,100
Cost per sq. ft. for construction	$ 0.04324

The item of 6,000 cords of brush given in the foregoing table is analyzed as follows:

Cutting and piling, building roads, etc	$4,472.00
Transportation of ways	2,146.27
Privilege of cutting brush	294.38
Total	$6,912.65
Estimated cords brush used	6,000
Cost per cord delivered at ways	$ 1,152

Two sets of ways were built. Their cost is included in mattress construction but is separated and analyzed as follows:

Lumber and nails	$182.00
Labor and superintendence	268.60
Total	$450.60
Average cost of each set	$225.30

The expense of towing lumber and other materials, except rock, has been added to and is included in the cost of such materials delivered at the site of the work. As Browns Point and Halpino bars, where the mattresses were built, are less than 30 miles above Reid-Bedford Bend, the cost of towing the mattresses from the place where built to the locality where sunk is too small to be given as a separate item, and is therefore included in the cost of construction and sinking.

The work of sinking was somewhat difficult. On account of the swift current three tow boats were required to handle the plant and mattresses. At times the current attained a velocity of 8 ft. per second. No disasters occurred, but the cause stated made the work of placing mattresses slow and expensive. The total field cost was:

4,289.93 tons rock	$ 9,661.09
Lumber, wire, nails, etc	588.66
Steamers and tugs	4,877.00
Miscellaneous	194.47
Provisions	2,022.21
Pay rolls, services	7,238.81
Total	$24,582.24
Total sq. ft. mattress sunk	573.000
Cost per sq. ft. to sink	$ 0.04289

Summarizing the field cost of construction and sinking of mattresses in place we have:

Construction of mattress per sq. ft	$0.04324
Sinking of mattress per sq. ft	0.04289
Total field cost per sq. ft	$0.08613

The grading consisted of 2,082 lin. ft. of new work and of 1,017 lin. ft. of regrading; it cost as follows:

Grading	$4,950.14
Re-grading	1,814.07
Total	$6,764.21
Cost per lin. ft. to grade	$ 2.33
Cost per lin. ft. to re-grade	1.78

A total of 119,066 sq. ft. covering 1,750 lin. ft. of bank was paved on the extension of revetment and 31,169 sq. ft., covering 565 lin. ft. on the repairs to work placed in previous years. The cost was as follows:

Steamers and tugs	$ 703.16
2,106.36 tons of rock, at $2.25	4,739.31
1,193.68 tons of rock, at $2.32	2,769.34
Miscellaneous	51.00
Provisions	887.58
Pay rolls, services	2,388.49
Total	$11,538.87
Cost per sq. ft. to pave	$ 0.077

Kempe Bend, La.—During the year the upper revetment was extended upstream 900 lin. ft. and the lower revetment downstream 2,373 lin. ft. The upper bank along the lower extension was graded and 1,439 lin. ft. was paved. The timber along the bank between the upper and lower revetments was cut to prevent its caving in and obstructing future work. Mat construction cost $28,919 for 882,300 sq. ft. or about 3.27 cts. per square foot. The mats had to be towed 50 miles and the cost was as follows:

Tug "Tuniaca," 6 days, at $29	$ 174.00
Tug "Marengo," 30 days, at $26	780.00
Steamer "Tensas," 15 days, at $24	360.00
Total	$1,314.00
Total sq. ft. towed	882,300
Cost per sq. ft	$0.001489

It required 180,000 sq. ft. to extend the upper revetment upstream 900 lin. ft. and 702,300 sq. ft. to mattress the 2,373 ft. of bank at the lower end of the bend. The following is the detailed cost of this part of the work:

Steamers and tugs	$ 1,510.57
Lumber, wire, nails, etc	287.45
5,198 tons of rock, at $1.93	10,032.14
761 tons of rock, at $2.377	$ 1,808.39
Miscellaneous	66.96
Provisions	1,755.57
Pay rolls	6,408.41
Total	$21,870.00
Total sq. ft. sunk	882,330
Cost per sq. ft. to sink	$ 0.02479
Total cost per sq. ft. in place	$ 0.05905

The grading was done by a hydraulic grader, the bank being dressed also by hand where necessary. The material was mostly stiff clay on top, with layer of sand at bottom. At the lower end of the bend two thousand five hundred lin. ft. of bank were graded. The following is the detailed cost:

Hydraulic grader No. 1:	
Steamers and tugs	$ 450.00
Coal	821.10
Miscellaneous	80.65
Provisions	772.75
Pay rolls	2,495.98
Hand grading (labor and provisions)	627.53
Total	$5,248.01
Lin. ft. of bank graded	2,500
Cost per lin. ft. to grade	$ 2.099

A total of 92,606 sq. ft. or 1,416 lin. ft. was paved with rock as an extension to the lower upper bank revetment; the following is the detailed cost of the work:

Steamers and tugs	$ 687.00
2,454 tons of rock, at $1.93	4,736.22
405 tons of rock, at $2.377	962.69
Miscellaneous	40.00
Provisions	420.00
Pay rolls	1,871.60
Total	$8,717.51
Cost per sq. ft	$ 0.094

New Orleans, La.—A total of 1,960,000 sq. ft. of mattress was built at the following cost:

265,204 ft. B.M. 3 × 6-in. lumber	$ 3,702.40
670,349 ft. B.M. 2 × 4-in. lumber	9,048.09
16,000 ft. B.M. miscellaneous lumber	382.00
22,100 lbs. 9-in. steel wire nails	472.42
61,700 lbs. 6-in. steel wire nails	1,240.36
7,600 lbs. 4-in. steel wire nails	224.16
8,700 lbs. No. 10 galvanized wire	220.95
30,500 9-in. treenails	72.89
145,000 6-in. treenails	295.80
20,000 cords brush	20,676.07
Steamers and tugs	4,259.50
Miscellaneous	176.83
Provisions	5,443.09
Pay rolls, services	21,759.25
Total	$67,973.81
Cost per sq. ft. for construction of mattress	$ 0.0347

The item of 20,000 cords of brush given in the foregoing table is analyzed as follows:

Cutting and piling, building roads, etc.	$11,273.69
Transportation to ways	8,467.68
Privilege of cutting brush	934.70
Total	$20,676.07
Cost per cord delivered at ways	$ 1.0338

Six sets of ways were built and their cost is included in mattress construction. Of the six sets the cost of only four was kept in detail, as follows:

Lumber and nails	$610.00
Labor and superintendence	380.75
Total	$990.75
Average cost of four sets, each	$247.69

The expense of towing lumber and other materials for mattress construction has been added and is included in the cost of such materials delivered at the site of the work. The cost of towing mattresses from the places where they were built to New Orleans is given below. A total of 1,960,000 sq. ft. of mattress was towed, of which 505,500 was from Halpino bar, 390 miles; 315,000 from Warrenton bar, 360 miles; 300,000 from Kempe Island, 315 miles, and 839,500 from Palmetto bar, 237 miles. The cost was as follows:

Steamer "Ramos," single crew, 11 days, at $35.50	$ 379.50
Steamer "Ramos," double crew, 43 days, at $58	2,494.00
Steamer "Plaquemine," double crew, 68 days, at $65	4,420.00
Tug "Morganza," single crew, 15 days, at $30.50	457.50
Total	$7,751.00
Average cost per sq. ft. for towing	$ 0.00395

With the exception of some slight difficulties caused by the high stage of the river at which some of the mattresses were sunk, work proceeded in a routine manner. The detailed cost was as follows:

13,644.02 tons rock	$27,393.67
Lumber, wire, wire nails, etc	917.66
Steamers and tugs	3,473.50
Miscellaneous	153.45
Provisions	3,500.43
Pay rolls, services	9,153.67
Total	$44,792.28
Cost per sq. ft. to sink	$ 0.02285

Summarizing the field cost of construction, towing, and sinking of mattresses, we have:

Construction of mattress, per sq. ft	$0.03470
Towing of mattress, per sq. ft	.00395
Sinking of mattress, per sq. ft	.02285
Total field cost per sq. ft. in place	$0.06150

Proposals for furnishing 13,000 tons of rock were opened Nov. 5, 1910, and contract awarded for delivery on railroad cars in New Orleans at $1.90 per ton. The cost of transferring from cars to barges was 25 cts. per ton.

A summary of the New Orleans work is as follows: A total of 7,850 lin. ft. of revetment was constructed, of which 2,765 lin. ft. on the Gretna Front was 300 ft. wide; 3,975 ft. in the Carrollton Bend was 200 ft. wide; and 675 and 435 ft. in the third district reach, respectively, 300 and 200 ft. wide. This work involved the placing of 1,960,000 sq. ft. of mattress, and the detailed cost of it is as follows:

Construction of mattress, including cost of ways	$ 67,973.81
Towing of mattresses	7,751.00
Sinking of mattresses	44,792.28
Installation	2,141.00
Surveys	275.00
Rock, lumber, etc., on hand for future construction	20,419.89
Repairs to plant	288.17
Care of plant	680.78
New plant	2,649.38
Office and administrative expenses	5,680.17
Total	$152,651.48
Deduct value of material on hand for future work	20,419.89
Gross cost of season's work	$132,231.59
Deduct repairs and care of plant, new plant and office and administrative expenses	9,298.50
Net field cost of season's work	$122,933.09
Gross cost per sq. ft. for mattress in revetment	$ 0.0675
Gross cost per lin. ft. for revetment 200 ft. wide	13.55
Gross cost per lin. ft. for revetment 300 ft. wide	21.09
Net field cost per sq. ft. for mattress in place in revetment	0.0627
Net field cost per lin. ft. for revetment 200 ft. wide	12.58
Net field cost per. lin. ft. for revetment 300 ft. wide	19.74

Cost of Plank Mattresses.—These are used whenever cull lumber can be procured cheaper than brush. They are woven of 1 in. boards, 4, 6 and 8 in. wide and 10 to 20 ft. long. A cheaper construction consists in merely joining the boards by nailing. Plank mats have been built and successfully sunk in sections 150 ft. wide and 10,000 ft. long. Charles W. Durham furnishes the following cost data in Engineering and Contracting, Aug. 13, 1913.

For a 30-ft. wide mat, built in 1911, in which 62,590 ft. B. M. of lumber were used, the cost of 1,969 lin. ft. was as follows:

62,590 ft. lumber at $10 per M	$625.90
438 hrs. labor at 1.75 per day of 8 hrs	95.81
280 lbs. wire at 3 cts	8.40
800 lbs. 10-penny nails at $2.05 per 100 lbs	16.40
	$746.51

or $0.379 per lin. ft. Had the mat been built of brush, the cost per lin. ft. would have been as follows:

1.7 cu. yds. brush at 16¾cts	$0.2847
Labor $^{16}/_{300}$ day, at $1.75	.0933
Wire	.0070
	$0.3850

This shows very little saving, but the plank mat has the advantage in the less number of material barges needed. One barge will carry from 100 to 120 M. ft. B. M. of lumber, an equivalent to which in brush would require 10 barges. This indicates a considerable saving when we figure the value of the barges at $3.50 per day.

In 1912, a better showing was made in work done in the vicinity of Hannibal, Mo. It was found that in a mat 20 ft. in width, 1 cu. yd. of brush is equivalent to 15.9 ft. B. M. of lumber, or in other words, 63 cu. yds. brush equal 1,000 ft. lumber. As, however, some extra pieces are used in the 30 and 40-ft. lumber mats, 60 cu. yds. brush are used as the average equivalent of 1,000 ft. of lumber. The width of boards should be 4, 6 and 8 ins. Boards of less width than 4 ins. are deficient in strength and those of greater width than 8 ins. leave too large spaces and a consequent waste of small rock, if the standard plan of making the space equal to the width of board is adhered to. The length of boards is an important factor in the cost, for, the longer the boards, the less cross pieces, less nailing, less handling and moving of ways, but this

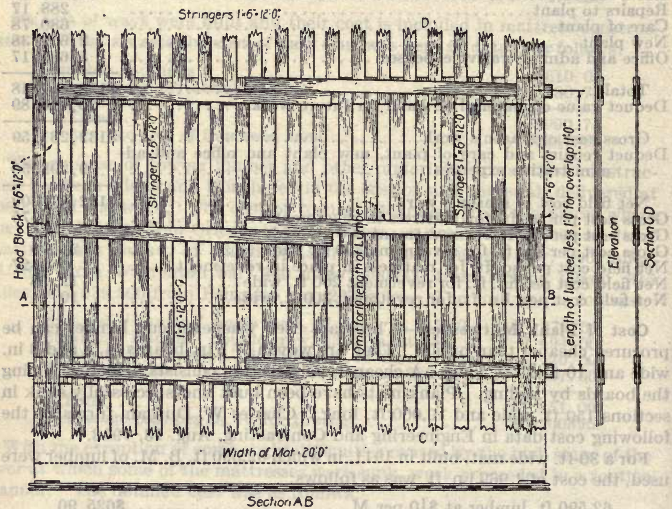


FIG. 2.—Standard lumber mat for shore protection, Upper Mississippi River improvement.

advantage may be wholly or in part offset by the increased cost of the longer lumber. With brush at 21 cts. per yd., we can afford to pay $14.44 per M. ft. for lumber, for

Cost per lin. ft. nails in 20 ft. lumber mat	$0.0034
Labor cost per lin. ft. building 20-ft. lumber mat	0.0412
Labor cost per lin. ft., sinking 20-ft. lumber mat	0.0352
	$0.0798
Cost per lin. ft. of 20-ft. brush mat in place	0.0352
Cost per lin. ft. of 20-ft. brush mat in place	$0.2820
Available for lumber	$0.2022

At 14 ft. per lin. ft. this is equivalent to $14.44 per M.

In a 20 ft. mat there are 14.0 ft. B. M. of lumber or 0.88 cu. yd. brush per lin. ft. It was also found that within practical limits an increase of 2 ft. in length warrants paying $1.25 more per M. for the lumber. The actual saving in 1912 of 4.3 cts. per lin. ft. of mat amounted to $551.26 for the 12,820 ft. of lumber mat built in the vicinity of Hannibal, Mo. There was also a saving on the barges as only two were required for the lumber service, while to have handled an equal amount of brush would have required at least five barges and the consequent extra towing.

Comparative Cost of Board Mat and Brush Mattress for River Bank Protection.—In 1915 records were kept by the U. S. Engineer Office at Rock Island, Ill., of board mat and brush mattress construction which are quoted by Engineering and Contracting, June 14, 1916, as follows:

The average quantities required per square (100 sq. ft.) of apron mat were: 66 ft. B. M. lumber, or 4.8 cu. yd. of brush. In other words, 13.75 ft. B. M. lumber was equivalent to 1 cu. yd. of brush. The cost of material (on barges) was: Lumber, $11.95 per M ft. B. M. and brush, $0.24 per cu. yd., making the initial cost per square, $0.789 for lumber and $1.152 for brush. During the same season, it was found that eight laborers could construct an average of 120 squares (12,000 sq. ft.) of lumber apron mat per day, while with brush the average was 75 squares (7,500 sq. ft.) per day. The best day's work with twelve laborers was 180 squares of lumber mat. There was used in bank revetment work in this division during 1915, 136,206 ft. B. M. of green cull lumber, made up of elm, willow, cottonwood, etc. This amount was carried on two standard barges (100 × 20 × 5 ft.), whereas the average barge load of brush is about 400 cu. yd. Using 13.75 ft. B. M. lumber to 1 cu. yd. of brush, the above 136,206 ft. B. M. of lumber would be equivalent to 9,905 cu. yd. of brush, which would make approximately 25 barge loads. The cost of towing the above amount of lumber was $40, or about 30 ct. per thousand. The cost of towing the equivalent in brush fascines at 4.2 ct. per cubic yard was $416, which shows a large percentage in favor of lumber. Owing to the greater buoyancy of a brush mat, it requires more than twice as much rock to anchor it safely on the bottom. The average amount of rock used to sink a square (100 sq. ft.) of apron mat was: For lumber, 0.77 cu. yd.; for brush fascines, 1.70 cu. yd. The following tables give the comparative costs of lumber and brush fascine apron mats for season 1915:

Cost of Brush Fascine Mat, 1,000 Ft. Long, 30 Ft. Wide (300 Squares)

Brush, 1,440 cu. yd. at 24 cts.	$ 345.60
Rock, 510 cu. yd. at 85 cts.	433.58
Towing brush, 1,440 cu. yd. at 4.2 cts.	60.40
Towing rock, 510 cu. yd. at 21 cts.	107.10
Labor constructing mats, 8 laborers 4 days at $1.75 per day	56.00
Labor sinking mat, 510 cu. yd. rock at 4 cts.	20.40
Wire, 80 lb. at 3 cts.	2.40
Total	$1,025.48

Cost of Lumber Mat, 1,000 Ft. Long, 30 Ft. Wide (300 Squares)

Lumber, 19,800 ft. B. M. at $11.95 per M	$ 236.61
Rock, 231 cu. yd. at 85 cts.	196.35
Towing lumber, 19,800 ft. B. M. at 30 cts. per M	5.94
Towing rock, 231 cu. yd. at 21 cts.	48.51
Labor constructing mat, 8 laborers 2½ days at $1.75 per day	35.00
Labor sinking mat, 231 cu. yd. of rock at 4 cts.	9.24
Nails, 4 kegs at $2.05 and 25 lb. wire at 3 cts.	8.95
Total	$ 540.60

The above shows a balance of $484.88 in favor of lumber mat (300 squares) of $1.62 per square.

Cost of Concrete Paved Bank Revetment.—This is described in Engineering and Contracting, March 20, 1918, being an abstract of a paper by G. C. Haydon in Professional Memoirs. In this case a departure from the standard form of brush mattress construction was made which consisted in paving the upper bank with a 4-in. layer of reinforced concrete slabs instead of broken stone, and the protection of subaqueous willow mattress for about 10 ft. width from the shore edge with reinforced concrete blocks connected to the solid upper pavement.

The plant used on the work consisted of the following: One double-decked quarterboat with a capacity of housing from 60 to 70 laborers and necessary foremen, 1 hydraulic grader, 1 mattress barge, 1 barge for concrete mixer plant, 6 material barges, and 1 tow boat. The working plant was supplemented by an 8-in. suction pump, installed on a material barge, for procuring gravel. The value of this plant is estimated at $60,000.

The principal material used, which was procured locally and delivered by barge, consisted of willow brush at $1.60 per cord; stone at $0.68 per cubic yard, and sand and gravel at $0.08 per cubic yard; manufactured material

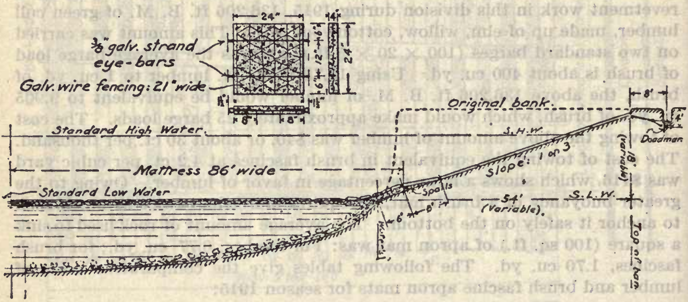


FIG. 3.—Cross section of combination concrete and willow mattress.

delivered by freight consisted of ⅜-in. galvanized strand at $0.71 per linear foot; 50-in. galvanized woven fence wire, for the paving, at $0.06 per linear foot; 22-in. fence wire, for blocks, at $0.03 per linear foot; lumber, for forms, at $22 per M. B. M., and Portland cement at $0.75 per barrel (f. o. b. factory).

The bank is graded by the hydraulic method to 1 on 3, which gives a length of slope from 42 to 54 ft. according to height above standard low water, which also determines the length of a slab.

After the bank is graded the continuous mattress, 86 ft. wide, is woven of bar-growth willows, from ½ to 2 in. in diameter at the butt end and 10 to 25 ft. long. The header, about 12 in. in diameter, is formed by lapped bundles of willows bound together to the desired width of mattress, by ⅜-in. strand. The stitch is then started by inserting single willows into the bundle at an angle of about 45°, from one end of the header to the other; then the willows are inserted at the same angle to the reverse direction, the last willow inserted being on top. This makes the weaving of a continuous over process, the stitch having an over and under appearance. The willows are placed in such numbers and closeness of weave as to make a mattress 12 in. thick. As the weaving progresses a selvage is made along each side of the mattress by turning in the tops of the outer willows, or an equally good selvage (known as the "sidewalk") is made by platting willows, longitudinally along the edges.

The mattress is strengthened by a longitudinal and cross system of ⅜-in. in diameter galvanized strand. The longitudinal system for an 86-ft. mattress consists of 6 pairs of strands, spaced as required, each pair consisting of 1 strand underneath and 1 strand on top of the mattress. The cross systems are in pairs, one underneath and 1 on top, spaced 16⅔ ft. apart. At each intersection of the 2 strands underneath and the 2 strands on top, all 4 are drawn together tightly with a 7/16-in. U-shaped clip, after all the slack has been taken out of the strands by block and tackle. The head of the continuous mattress, or any section of mattress, is anchored by 3 pairs of strands fastened to the respective longitudinal strands, 1 pair 4 ft., 1 pair 16 ft., and the remaining pair of 46 ft. back from the outer corner and run ashore at 45° angle with the upper edge of the mattress and fastened to deadmen 50 ft. back from the edge of the bank. The continuous mattress is anchored to the bank by each pair of cross strands carried up the slope and fastened to a deadman placed 8 ft. back, and 4 ft. below the top of slope.

The mattress was weighted down with one-man stone sufficiently to make it sink into close contact with the river bed, after which, the concrete paving was placed.

The statement given below contains only field expenditures with the cost divided as follows:

	Per lin. ft.
Grading bank	$0.55
Weaving mattress	1.98
Concrete blocks in place	1.16
Ballasting mattress	1.13
Concrete paving	2.76
Total, per linear foot	$7.58

As two other pieces of this type of revetment have since been completed under similar conditions, their costs are given here for general comparison, and, to a certain extent, permit the establishment of a proper basis for estimates.

Marthasville Bend: 11,960 ft. at $8.05 per linear foot, completed Nov. 25, 1914. The cost was as follows:

	Per lin. ft.
Grading bank	$0.84
Weaving mattress	1.85
Concrete blocks in place	1.56
Ballasting mattress	.83
Concrete paving	2.97
Total, per linear foot	$8.05

Dewey Bend: 7,215 ft. at $8.13 per linear foot, completed Dec. 17, 1915. The cost of this was as follows:

	Per lin. ft.
Grading bank	$0.67
Weaving mattress	2.31
Concrete blocks in place	1.45
Ballasting mattress	1.22
Concrete paving	2.48
Total, per linear foot	$8.13

Additional data on the cost of this work are given by Lt. Col. J. F. McIndoe, Corps of Engineers, as an addendum to Mr. Haydon's article. These figures follow:

Bates Island Bend: The cost, per square (100 sq. ft.) of the completed concrete paving of upper bank, was $6.59; and of subaqueous work, was $4.65, of which $2.31 was cost of mattress, $1.34 the cost of concrete blocks, and $1 the cost of ballast. The quantities and unit costs of materials for each square were approximately as follows:

Upper bank work—
- Grading, 33 cu. yd. at $0.025 per cubic yard.
- Concrete for paving, 1.24 cu. yd. at $4.52 per cubic yard.

Subaqueous work—
- Brush for mattress, .6 cord, at $1.59 per cord on barge.
- Stone for ballast, .8 cu. yd., at $0.67 per cubic yard on barge.
- Concrete blocks, 24, at $0.28 each.
- Strand for mattress, 9.2 lb., at $0.085 per pound.
- Clips for mattress, 3 lb., at $0.06 per pound.

Marthasville Bend: The cost, per square (100 sq. ft.) of the completed upper bank paving, was $7.17; and of subaqueous work, was $4.86, of which $2.12 was cost of mattress, $1.70 the cost of concrete blocks, and $0.95 the cost of ballast.

The quantities and unit costs of materials for each square were approximately as follows:

Upper bank work—
- Grading, 33 cu. yd., at $0.046 per cubic yard.
- Concrete for paving, 1.24 cu. yd., at $4.57 per cubic yard.

Subaqueous work—
- Brush for mattress, .7 cord, at $1.58 per cord on barge.
- Stone for ballast, .7 cu. yd., at $0.693 per cubic yard on barge.
- Concrete blocks, 25, at $0.313 each.
- Strand for mattress, 9.2 lb., at $0.085 per pound.
- Clips, .3 lb., at $0.06 per pound.

Dewey Bend: The cost, per square (100 sq. ft.) of completed upper bank paving, was $6.55; and of subaqueous work, was $5.80, of which $2.69 was cost of mattress, $1.69 the cost of concrete blocks, and $1.42 the cost of ballast.

The quantities and unit costs of materials for each square were approximately as follows:

Upper bank work—
- Grading, 29 cu. yd., at $0.048 per cubic yard.
- Concrete for paving, 1.24 cu. yds. at $4.08 per cubic yard.

Subaqueous work—
- Brush for mattress, .56 cord, at $1.96 per cord on barge.
- Stone for ballast, .86 cu. yd., at $0.86 per cubic yard on barge.
- Concrete blocks, 25, at $0.21 each.
- Strand for mattress, 9.2 lbs., at $0.085 per pound.
- Clips for mattress, .3 lb., at $0.06 per pound.

Concrete Slab for Bank Protection.—Where the bottom consists of material not washable by the force of the current, concrete has been successfully used on the Southern Pacific Ry. for protection of their fills.

Engineering and Contracting, Feb. 14, 1912, gives the following data on such a protection (Fig. 4). The slab is 6 ins. thick and is reinforced at the center with wire netting. In one case where it was put on a new fill which settled badly, the concrete did not pull apart and did not allow the water to wash the fill.

A slab containing 376 square yards was constructed as follows: The bank was sloped 1½ to 1, and 12 × 18 in. trench was dug along the foot of the slope. This trench was filled with concrete embedding the ends of the strips of mesh reinforcement. A strip of reinforcement was then stretched up-bank and its edges were clamped by forms as shown by Fig. 4. Braces driven between the edge forms made the mesh taut, and the forms held it 3 ins. clear of the slope surface. The space between forms was next concreted, the forms serving as templets for thickness of slab. When the concrete had hardened the forms were removed leaving a 4-in. selvage of mesh projecting beyond the slab edges. The next strip of mesh but one was then stretched and concreted and so on completing alternate sections of the slab. The intermediate sections were constructed by stretching the strip of mesh up-bank and wiring its edges

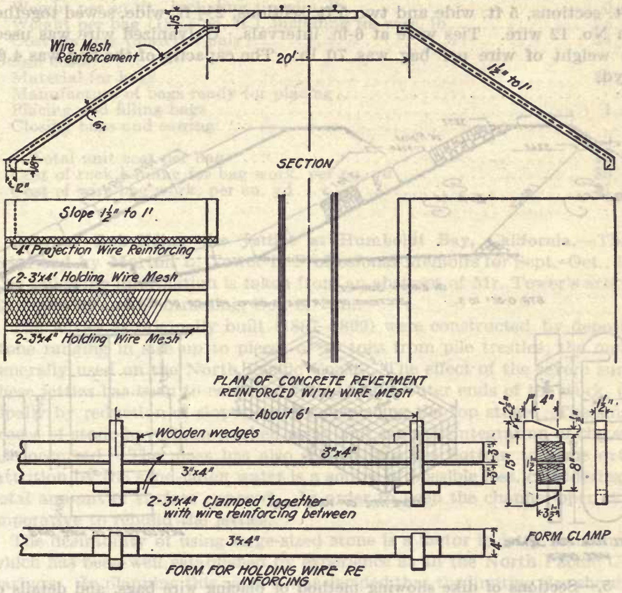


FIG. 4.—Reinforced concrete slab for bank protection, Southern Pacific Ry. Co.

to the selvage edges projecting from the completed slabs, and by concreting the open spaces. The cost of the 376 square yards of slab was as follows:

Materials:		Revetment, per sq. yd.
2 rolls fence wire, 50 rods, at 45 cts. per rod	$ 22.50	$0.0598
82 cu. yds. gravel and sand at 30 cts	24.60	0.0654
82½ bbls. cement at $1.70	140.25	0.3731
Total material	$187.35	$0.4983
Labor:		
Building mixing platform	$ 11.50	$0.0305
Unloading gravel	25.00	0.0665
Unloading cement	10.50	0.0279
Putting up forms and wire	116.50	0.3099
Placing concrete	119.00	0.3165
Total labor	$282.50	$0.7513
Total materials and labor	$469.85	$1.2496

The work was done by a gang of eleven men working 10 hours per day at the following daily wages: One foreman, $4.50; one concrete mason, $3.25; six laborers, each, $2.25, and three laborers at $2.50.

Cost of Riprapping Embankment with Wire Bags.—The following is abstracted by Engineering and Contracting, Feb. 12, 1919, from an account by L. E. Foster in the Reclamation Record.

On certain work the toe of an embankment had to be protected against water velocities of from 5 to 16 sec. ft. Wire bags were used, composed of two 15 ft. sections, 5 ft. wide and two 5 ft. sections, 2½ ft. wide, sewed together with No. 12 wire. Ties were at 6-in. intervals. Galvanized wire was used. The weight of wire per bag was 70 lb. The capacity of the bag was 4.63 cu. yd.

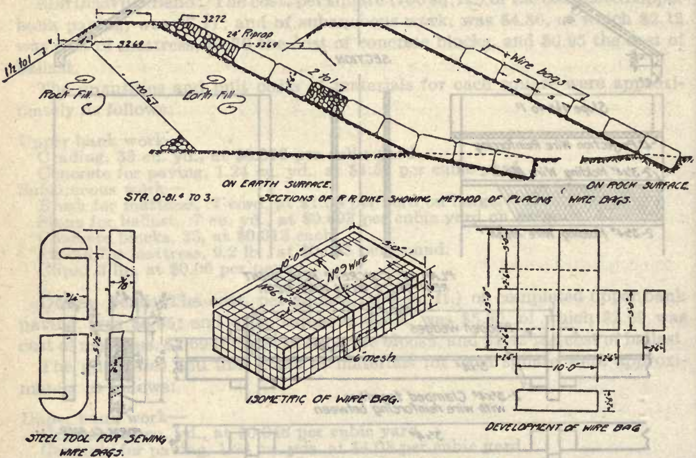


Fig. 5.—Sections of dike showing method of placing wire bags, and details of wire bag and tool for its manufacture.

The bag material was cut and sewed in the shop into the developed form shown in the right-hand corner of the drawing, then folded together flat, and hauled to the work. The bags were then sewed into rectangular form with the lid loose. The bags were set in a horizontal row in place and filled directly from the rock wagons. The labor of filling the bags proved to be less than to lay riprap of the same thickness.

Care was taken to have all rock next to the wire mesh of greater dimensions then 6 by 6 in. Since this is a relatively small sized rock, much rock is available for bag work and would be too small for riprap.

After the bags were level full the top was closed down and sewed securely on the front and two sides. The bags were also tied to each other along these edges, thus forming a continuous mat. Quarrying and loading on this job was charged to another feature as excavation.

Besides the 181 bags placed on spillway No. 1, 78 bags were placed as protection at the toe of spillway No. 2. The costs given below are based on a total of 259 bags.

Material required per bag.	
31 lin. ft. of 60-in. wire mesh.	
11 lin. ft. of 30-in. wire mesh.	
5 pounds No. 12 tie wire.	
Cost:	
Cost per sq. ft., including tie wire	$0.0229
Weight per sq. ft., including tie wire, lb	0.38
Weight per bag (182.5 sq. ft.), including tie wire, lb	75.4
Cost per bag (material only)	$4.20
Detail costs:	
Material for bags	$4.20
Manufacture of bags ready for placing	.905
Placing and filling bags	1.125
Closing bags and sewing	.446
Total unit cost per bag	$6.676
Cost of rock hauling for bag work, per cu. yd	$0.17
Cost of wire bag work, per cu. yd	$1.681

Cost of Rebuilding the Jetties at Humboldt Bay, California.—This is described by Morton L. Tower in Professional Memoirs for Sept.–Oct., 1913. The following information is taken from an abstract of Mr. Tower's article in Engineering and Contracting, Oct. 8, 1913.

The jetties as originally built (1887–1899) were constructed by depositing stone ranging in size up to pieces of 10 tons from pile trestles; the method generally used on the North Pacific Coast. The effect of the severe surf on these jetties has been to cause subsiding of the outer ends of the work, principally by reduction of slopes and by displacing the top stone. The smaller pieces of stone have been washed away and some disintegration of the stone has occurred. The mass has also settled into the bottom to some extent. Attrition by the sand-laden water is a source of possible loss, considering the total amount of surface exposed. In order to keep the channel open it was imperative to rebuild the jetties.

The desirability of using large-sized stone is a factor in jetty maintenance which has been well established by experience at all the North Pacific Coast harbors. In planning this work it was decided that the limiting size should be 20 tons. It was also considered desirable that these stones be lowered to place to avoid breaking them or the stone they fell on, which often occurs when stone is deposited by dumping from cars on an elevated track. The use of an unloading crane also permits the placing of stone in a selected position in the jetty, which cannot be done when it is dumped from a tramway.

All the quarries adjacent to Humboldt Bay are at a considerable distance from the navigable channels, thus rendering rail transportation essential from the quarry to tide water. The quarry used is seven miles from the nearest landing.

The largest single item of plant involved in the construction is the cars. It was deemed that it would be cheaper in the end if these were of standard design and hence salable when the work was completed.

A tramway of sufficient strength to carry a 20-ton crane and standard 40-ton railroad equipment is necessarily much heavier and more expensive than the jetty tramways used along the Oregon and Washington coasts, where narrow gage, special dump cars are used.

The storms of many years had beaten the old enrockment into a compact mass, such that it would have been impossible to drive piles into it, and for a tramway it would have been necessary to place a portion of the piles of each bent in the sand to give it any lateral stability.

The estimated cost of a suitable trestle is as follows:

Six-pile bents 14 feet apart with two lines of 10 by 18-in. stringers under each rail and 6 by 8-in. ties. Rails to be 28 ft. above mean low water.

MATERIAL

6 piles, each 50 ft. long, 300 lin. ft at 15 cts	$ 45.00	
3,500 ft. B. M. lumber, at $20 per M. ft	70.00	
170 lbs. bolts, nuts and washers, at 3 cts. per lb	5.10	
2 rail joints, at $3 each	6.00	
1,120 lbs. rails, at 2½ cts. per lb	28.00	
107 lbs. nails and spikes, at 5 cts. per lb	5.35	
Material for 14 ft	$159.45	
Material for 1 ft		$11.39
Labor, fuel and supplies, per day, $59.		
Rate of progress (estimated 2 bents, 28 ft.), cost per ft.		2.11

PLANT REQUIRED

1 revolving driver, complete	$20,000	
1 supply and material car	5,000	
3 flat cars, at $600	1,800	
Material yard platforms	5,000	
For 9,000 lin. ft. tramway	$31,800	
Plant charge per foot		$ 3.53
Cost per foot		$17.03

In addition to the cost of the tramway over the actual length of the jetty to be rebuilt, about 9,000 ft., it would have been necessary to raise the short tracks across the sand on a short trestle, amounting in all to about 7,000 lin. ft. at an estimated cost of $10 per foot. While the cost of the shore track at elevation 12 has been:

For labor	$1.13
For rails, spikes and ties	2.50
Cost per foot	$3.63

The low elevation for the shore tracks possible with the system used has therefore effected a total saving of $44,590 over the cost of the shore trestle necessary to reach a tramway 24 to 28 ft. above low water at the ocean beach line.

The desirability of making full use of the existing enrockment with its established slopes and compact mass, as well as the advantage of having a thoroughly stable foundation for the stone unloading crane, and the high cost of the tramway of sufficient strength to permit the use of the large stone proposed, were the conditions which led to the adoption of the concrete cap.

The main idea of the concrete is to hold the track when the jetty is swept by waves. The only portions of the structure that will float are the ties, and these are firmly imbedded in concrete and held in place. A further advantage of the concrete cap method is that the ties are the only portion of the structure which is not of a permanent nature and an addition to the value of the structure as a jetty. The concrete top on the crest of the structure will greatly retard the unraveling action of the waves, and when finally broken up by the settlement and washing away of the rock slopes it will still be of value as jetty material.

The cost of the concrete cap and tracks has been:

For labor		$ 2.86	
4½ tons class 3 stone in voids of jetty enrockment	$6.75		
2 tons of class 4 stone	3.00		
.95 bbls. cement	2.00		
Total concrete material		$11.75	
50 ft. B. M. lumber, at $14 per M	$0.70		
Fuel, oil, repairs, etc	.66		
		1.36	
			$15.97
Rails and joints (recoverable)			2.13
Total cost per linear foot			$18.10

Some loss of freshly laid concrete has occurred when it has been exposed to severe wave action within four or five hours after placing. This loss has not been sufficiently great to add materially to the cost. One severe storm carried away 25 ft. of the outer end of the track, but to all appearance the damage was caused by unraveling the enrockment which allowed the concrete to break down.

The above costs include the cost of portions of track lost by wave wash before the concrete had time to set, amounting to 1 per cent.

The plant cost for the concrete method had been:

One concrete mixer, complete, with boiler and engine	$1,500
One flat car	600
Tanks and small tools	250
Labor assembling plant	200
Total	$2,550
Cost per ft., for one jetty, 53 cts.	

Construction Methods.—The method of construction is as follows: The enrockment is first brought to an elevation averaging 2 ft. below the finished grade with Class 2 stone; pieces weighing from 1,000 lbs. to 10 tons. None of the pieces of Class 2 stone are allowed to project above 6 ins. below grade—the bottom of the ties. Voids in the mass are then filled with Class 3 stone, pieces weighing from 3 lbs. to 500 lbs., and the top is leveled off at from 18 to 10 ins. below grade. Holes are chocked by hand-placed stone. A rough form is made by tying wale pieces, 6 × 8 in. × 20 ft. ties, together with wires 5 ft. apart, and nailing to them short vertical boards with bottoms in contact with the rock. A rock dam is built at the front end of the form. Concrete is mixed rather dry, deposited with a 1 cu. yd. self-dumping and self-righting bucket, handled by the stone-unloading crane. The concrete is brought to within an inch or so of the bottom of the ties. The end tie is brought to grade, the crane rails laid, and the ties placed and spiked. Concrete is then continued to the top of the ties.

The concrete mixer is mounted on the end of a standard flat car, the discharge shoot delivering over the end. Mixing water is supplied by gravity from a tank on the opposite end of the car. Oil fuel is supplied by gravity from a tank near the water tank. The oil and water tank also supply the stone unloading crane. Oil is pumped and water flows by gravity to the crane supply tanks. Cement for a day's operation is carried on the concrete mixer car. The concrete is machine mixed in a Foote Batch Mixer of 21 cu. ft. capacity, end-discharge type, steam driven.

At the outer end of the jetty there are two working tracks. All material and equipment are regulation master-car builders' pattern and dimensions. The tracks are 14 ft. 7¾ ins. center to center. When in operation the concrete mixer car occupies the left-hand track, and the car containing the aggregate the right-hand track. A working movable platform fills the space between the cars, leaving about 1 in. clearance over the stake pockets. The elevation of the platform is the same as that of the car decks. The aggregate is shoveled directly from the cars into the charging skip and a large barrow. The charging skip is marked by a row of rivets at the height containing the charge required. In order to work a sufficient number of shovelers to keep the depositing bucket in motion it was found necessary to provide a greater length than was possible by shoveling into the skip alone. A two-wheel barrow, running on rails and holding about 15 cu. ft., was mounted on the mixer car. This allows the charging shovelers to be distributed over the whole length of a standard flat car.

The most economical crew for depositing concrete is eight laborers charging aggregate, one laborer charging cement and one engineman operating mixer. The concrete is placed, spread, and tamped by the regular stone unloading crew, consisting of engineman, four laborers and the foreman. This crew will generally build a section of track 18 to 20 ft. in length in 2 hours and 15 minutes, including the construction of forms and placing ties and rails.

Under the specifications for the material the contractors are allowed to supply either broken stone, crusher run, or unscreened river gravel for aggregate. The material supplied is tested for proportioning in the following manner: The aggregate as delivered is screened and the portion passing a plate containing ¼-in. diameter holes is considered sand, and the balance stone. If necessary, sand is added to form a mixture corresponding to a 1:2½:5½. The gravel supplied contains rather larger proportion of sand than is required. When broken stone is delivered it is necessary to add about 16 lbs. of sand per 100 lbs. of aggregate as received.

Stone for the work is supplied under contract by the Hammon Construction Company at the following prices:

	Per ton
Class 1	$1.74
Class 2	1.56
Class 3	1.50
Class 4	1.50

The following is taken from the specifications under which the stone is being supplied:

Descriptions of Material.—Class 1 Stone. To be of large pieces only, weighing from 10 tons to 20 tons each piece. These stones will be used for slopes on the outer end of the work, and none will be received until the jetty repairs have been extended 2,300 ft. from the high water shore lines. Delivery of this stone will be required up to 500 tons per day when work is in progress on the outer ends of both jetties. Stone of Class 1 will be loaded directly on the flat car without the use of skips.

Class 2 Stone. To be in pieces of 1,000 lbs. each to pieces of 10 tons each, in the following proportions:

One-fourth of each day's supply may be in pieces of 1,000 lbs. to pieces of 3 tons; one-half of each day's supply must be in pieces of from 3 tons to 6 tons each; and one-fourth of each day's supply must be in pieces from 6 to 10 tons each.

This class of stone will form the major portions of the repairs to the jetties. It is expected that the delivery required will not be less than 1,000 tons per day after the work has been well commenced on both jetties, and about 500 tons per day for the first season's work.

Stones of Class 2, when in pieces under 6 tons each, must be loaded on suitable skips holding up to 10 tons of stone each. Skips will be strong and designed for lifting at the four corners. Four corner hooks will be provided on each skip for the convenient attachment of the unloading crane spider chain. Skips will be kept in good working order by the contractor.

Class 3 Stone. Will be used only for bringing the top of the rough mound to a nearly smooth, tight surface and for concrete displacers. It will be in pieces not less than 3 lbs. nor more than 500 lbs. each, delivered on skips similar to those above described. Stone of Class 1 or Class 2 must not be loaded on cars carrying stone of Class 3. Stone of Class 3 will be used in decreasing amount as the jetties are extended. From 120 tons per day at the commencement of the work to about 10 tons per day when the outer end of the work is reached.

Class 4 Stone. Will be used for making concrete. It may be clean crusher run of the same rock as used for the other classes, or a good selected or washed river gravel may be used. It must vary in size from pieces with greatest dimension not more than 3 ins. to the finest product of the crushers. If river gravel be used, it must be thoroughly washed, all organic matter of any nature removed, and screened, if necessary, to exclude pieces greater than 3 ins. largest dimension. Either gravel or stone must be of hard, durable rock which will not disintegrate in the finished work.

Broken stone or gravel will be loaded on flat cars, provided with suitable sides. The amount required will vary from about 70 tons per day during the first part of the work to 8 tons per day for the outer ends of the jetties.

The larger portion of the stone supplied is a close-grained igneous rock, weighing about 198 lbs. per cu. ft. It is very difficult to quarry, breaking into very uneven fragments. However, by proper manipulation, a minimum of waste is secured and, as there is no covering soil to be contended with, the quarry is very satisfactory.

A second stone supply from the same vicinity is a close-grained metamorphic sedimentary rock with irregular planes of division of argillaceous material. This stone weighs 167 lbs. per cu. ft. and is easily worked. On account of the seams and a considerable covering of soil, which cause a large amount of waste, it has not been found advantageous to furnish any considerable quantity of this stone so far.

The stone is loaded by the contractors on standard flat cars and hauled 7 miles to a loading point on a navigable channel, where it is placed on barges carrying eight cars each. When delivered at the jetty receiving plant, it is unloaded and the empty cars are returned to the barges. From the loading point to the jetty landing is 9 miles.

The above arrangement permitted the contract to be made for the material only and the contractors have nothing to do with the actual jetty construction. The United States is not required to pass on the rock until it is offered for use at the jetty wharf.

The contractor's crew has numbered generally about 100 men, employed for 7 10-hour days per week. The following plant has been installed by the contractors:

Four 20-ton stiff-leg derricks, 100-ft. booms, with steam-driven hoisting and swinging engines; one steam crane, with shovel attachment, used for grading pits and tracks and for loading cars; one two-stage, 16 × 10 × 14-in. Ingersoll-Rand cross compound air compressor, electrically driven; one small jaw rock-crushing plant, electrically driven. In addition, there is the usual equipment of air drills, small tools, shop and mess equipment and appliances.

Hollow drill bits are used, and since the installment of an air-driven Leyner sharpener no difficulty has been experienced in successfully quarrying the stone. The contractor's transportation plant consists of fifty flat cars, 60,000 lbs. capacity, 36 ft. long, two car ferry barges and two tow boats. From the quarry to the landing the cars are handled over a logging railroad by the logging companies' motive power. The contractors are now providing 15 additional cars and a third barge.

The receiving and depositing plant at the jetty, belonging to the United States, consists of a 100-ft. span, three track apron for transfer from barge to shore tracks, adjusted to tidal elevation at barge end by counterweights, and fixed at 10-ft. elevation at shore end; two locomotives; three flat cars for miscellaneous materials; a 20 cu. ft. concrete mixer mounted on a flat car; a 10-ton revolving and traveling unloading crane, gage of gantry 14 ft.; water supply and distributing system; fuel oil storage and distributing system; a repair plant with power-driven tools for ordinary blacksmith, carpenter, and light machine work; an electric light plant; store house, mess house; crew quarters and necessary minor equipment for the work in progress. A new stone unloading crane of 20 tons capacity is now in course of construction. The jetty crew varies from 40 to 50 men working 6 8-hour shifts per week.

Cost of Repointing Sea-Wall with Cement Gun.—A cement gun was used for repointing about 22,000 lin. ft. of joints in the west side of the Government sea wall at Governors Island, N. Y. The work is described by Henry W. Babcock, in the July–Aug., 1917, Professional Memoirs. The following notes have been taken from an abstract of Mr. Babcock's article published in Engineering and Contracting, Aug. 15, 1917.

The sea-wall is built of heavy stones laid in courses; none of the courses were required to be of uniform height throughout except the coping, which was 1 ft. high and 3 ft. wide. The joints were ordinarily 1 to 1½ in. thick, sometimes reaching 2 in. On the northwest, or Hudson River, side of the wall the mortar had come out of the joints, almost generally, indicating that the joints had not been made full, but voids had been left in which ice formed. Frequently the joints were found open to a depth of 2 ft. or more.

The Cement Gun Co. furnished the cement gun at $250 a month; the air compressor at $5 a day; an operator for the gun at $6 a day, and an engineman to run the compressor at $4 a day. The United States furnished 5 to 7 laborers, a horse and cart and an overseer. The lease with the Cement Gun Co. also provided for payment to them of transportation charges on the plant and for 4 days' time allowed for transportation. The transportation charges were $216, being about trebled for the requirement of delivery on the island.

Work was begun at the north end of the extension sea-wall near Castle William on June 1, 1916, and was stopped June 29, 1916, at a point of 4,170 ft. from the beginning. The linear feet of joints pointed was about 22,320, averaging 900 ft. to the working day. At the beginning, although the location was near the sand pile and the cement storage, the rate was much slower on account of inexperience and bad weather. The rate also varied on account of tides, more work being accomplished when low tides occurred near the middle of the day.

In filling the joint, the operator turned on water only until the joint was washed clean, then the mixture of cement and sand with the water, sweeping over any convenient length of 4 to 8 ft. at a time. The mortar filled the joint gradually in from 2 to 5 minutes, depending largely on the voids as well as on the length covered. When the joint was nearly full, the visible completion appeared sudden.

The operator stood on the riprap foundation of the wall during work until the tide rose too high for rubber boots, when a plank swing was hung over the wall for a platform; this was for about 33 per cent of the time.

Some difficulty was met with in the lower joints, which are under water at high tide. They could be filled only at low tide, and the swash of waves or swells from passing steamers would often wash out the mortar for a depth of 3 to 6 in., a result which would happen from any pointing. Covering these joints with a weighted canvas screen was tried, but it was not effectual. Towards the close of the work, a few linear feet of joint were covered with plaster of Paris, which set at once and stayed on for a day, when the cement had hardened. It was rather slow and expensive for general use.

This kind of work unavoidably makes a joint without finish and spatters mortar on the face of the wall. One of the laborers was assigned to smoothing off the joint and cleaning away the surplus mortar before it had set.

It was at first intended to mix the cement and sand at 1 to 2. The Cement Gun men said that their experience led them to believe that the force with which the mortar was driven caused some of the sand to rebound, and that 1 to 3 was a better proportion. This was adopted. In these closed joints, however, the loss of sand from this cause was small. It is estimated that between 10 and 15 per cent of the mortar was wasted from spattering and overfilling the joints, and that this contained practically the same proportion of sand as the original mixture.

To drive the cement and sand through the hose with compressed air, it is essential that the mixture be quite dry. In the early part of June there was much damp, foggy weather and the sand got damp and, although the cement was kept quite dry, the mixture clogged in the hose. It is very probable that the compressed air was also fully saturated. The trouble was overcome by heating the sand on an iron plate over a fire of drift wood.

The cost of the work follows:

Expenditures:		
Rental of cement gun	$250.00	
Rental of compressor	125.00	
Services of operator	150.00	
Services of compressor engineman	100.00	
Transportation, including 4 days' rental time	216.00	
		$ 841.00
Rental, 3 tarpaulins to cover cement		41.85
Services:		
Manisees and Ingalls and crew, freighting supplies and general assistance	$171.58	
U. S. inspector and overseer, with 5 to 7 men	641.09	
2 horses, carts, and drivers, 34 days	136.00	
1 double team and driver, 1 day	8.00	
		956.67
Materials:		
800 bags cement	$324.00	
$125\frac{28}{100}$ cu. yd. sand	91.71	
635 gallons gasoline	152.40	
Force pump, fittings, and hose for water	81.66	
Lumber, runways and mortar beds	59.76	
Tools: Wheelbarrows, shovels, sand screen, etc	34.60	
Rope, for moving machines	24.09	
Miscellaneous: Canvas, rubber boots, etc	39.48	
		807.70
Office expenses and travel	$258.93	
Photographs	7.45	
		266.38
Total		$2,913.60

This cost will be reduced by a rebate of about $60.00 on cement bags returned in good condition.

The value of materials and tools not used up on the work is estimated at $262.70. This will not far exceed the cost of removing them and storing them until needed, and must be regarded as part of the cost of work in a locality such as Governors Island.

The length of joints repointed, 22,320 ft., was measured, and is essentially correct. The open widths varied from 2½ in. to nothing, and the depths repointed from 36 in. to 3 in. These cannot be averaged with any accuracy, being almost wholly out of sight. It is roughly estimated that the average thickness of joint is slightly less than 1 in., and the average depth perhaps 12 to 15 in.

The cost of this work with the cement gun was not far from the cost for the same lengths of joint repointed by hand. Hand work would give a better finish, but would hardly extend more than 4 in. into the wall.

The cost at Governors Island is 10 to 15 per cent more than it would be at an accessible point in the city.

In operating the cement gun, a large supply of compressed air is needed. It is used to turn the cement and sand free as well as to carry the dry mixture. This mixture will choke in the hose unless diluted with a large amount of air. From such observations as could be made, it appeared that the volume of sand and cement carried was from 1 to 2 per cent the volume of the air used as a vehicle.

The amount of water required was given by the Cement Gun Co. as 5 gal. per minute, at a pressure of about 45 lb. This quantity was seldom used, and the stated pressure is not needed. The suction from the air blast would draw in the water if delivered at the nozzle under a much lower head.

At Governors Island, fresh water could not be had along the line of the sea-wall; and salt water from the bay was used, pumped up through a fine brass mesh.

An examination was made Oct. 9, 1916, and another May 17, 1917. In neither case was there found any deterioration since the repointing was done. For about half the length of wall repointed, the lower joints, at and below half tide, are from 2 to 3 in. slack; and for a length of 125 ft., near the lighthouse, the lower joint is from 10 to 15 in. slack. This 125 ft. was repointed June 22, 1916, when the sea from a strong northwest wind washed the mortar out while it was fresh.

On May 17, test drills were driven 6 in. into the joints at these places; the mortar was everywhere firm and very hard. With hand pointing, the joints would not be filled to a depth of 6 in.

Percentage of Voids and of Settlement in Rubble Mount Breakwater.—In Jan.-Feb., 1918, Professional Memoirs, abstracted in Engineering and Contracting, Feb. 20, 1918, Clarence Coleman describes the methods of constructing the breakwater extension at Marquette, Mich. In this paper Mr. Coleman shows that the percentage of voids in the rubble foundation (deposited by being dropped or dumped into the water) was 37.43 per cent, and the voids in the remainder of the breakwater including the covering stone (10–15 ton size) were 40.57 per cent. In estimating for the work an allowance of 8 per cent additional tonnage was made to cover loss from settlement. The final results checked this figure very closely.

Cost of Unloading Stone for Rubble Mound Breakwater.—Table I, from the records of H. F. Alexander, gives the cost of unloading small or hand stone from deck scows, and is taken from Engineering and Contracting, Jan. 24, 1912.

TABLE I.—COST OF UNLOADING STONE FROM SCOWS BY HAND

Scow	Tons	Total number of hours required	Av. No. of tons per man per hour	Cost	Cost per ton
1st	828	326	2.54	$ 84.17	$.1015+
2nd	849	334	2.542	86.17	.1014
3rd	702	344	2.04	88.67	.1263
4th	485	160	3.03	41.67	.0859+
5th	914	274	3.335	72.00	.0787+
6th	444	174	2.55	45.17	.1017
7th	840	327	2.57	84.08	.1000
8th	641	250	2.564	64.83	.1011+
9th	592	243	2.436+	63.08	.1065
Totals	6,295	2,432	average 2.623	629.84	average $.1000

The high cost per ton on the third scow was due to unfavorable weather conditions. Owing to a severe storm the work of discharging this load had to be done on two different days, and considerable time was lost during a heavy rain. It will be seen that the average tons per man per hour on both the fourth and fifth scows, was much higher than on any of the other scows. When the fourth scow was unloaded, a number of ore shovelers and experienced men were employed; on the fifth scow, nearly all the men were of this class.

Although these men were paid more per hour than the men employed on the other scows, the results show them to have been the cheaper in the end. The men who unloaded the other scows were unskilled, being simply picked up on the streets, and while paid less per hour, they finally cost the contractor considerably more than the experienced and higher-priced men.

Method of Making Rapid Cost Estimates for Crib Pier and Breakwater Construction.—G. A. M. Liljencrantz has developed a method, which he describes in "Professional Memoirs," for making rapid cost estimates of pier and breakwater construction. Engineering and Contracting, June 5, 1912 publishes the following abstract of Mr. Liljencrantz's article.

Types of Structures.—There are six different types of structures considered. These are illustrated by Figs. 1 to 6. Each consists of a crib construction 100 ft. long. The first four types are 16, 20, 24, and 30 ft. wide and rest on piles. The last two are 30 ft. wide each and rest on stone foundations, 4 ft. and 6 ft. deep, respectively.

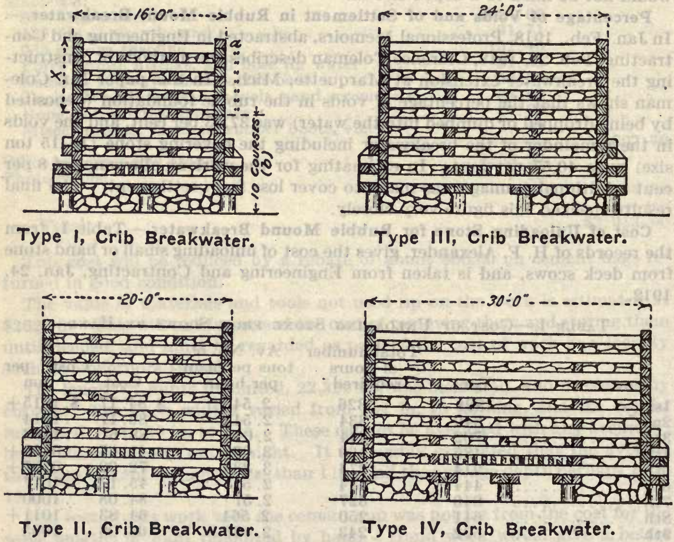


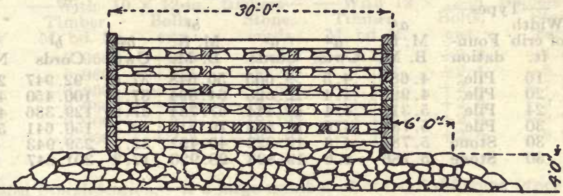
FIG. 6.—Types I–IV, crib breakwaters.

An examination of the various plans will show that in each of the above types the amount of materials contained in the ten lower courses (counting from the lake bottom) is a constant quantity for that type; and that in every two successive courses above the tenth course the quantities are the same for each type, respectively.

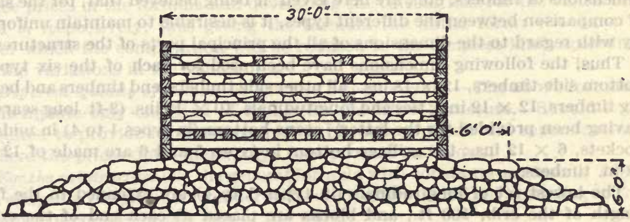
This fact suggested the practicability of using the formula for a straight line for the computation of the total cost of a crib of any desired height, after the materials of the ten lower courses, and in the two upper courses, respectively, have been ascertained. Thus we have the formula $Y = aX + b$, in which Y represents the cost of a crib structure 100 ft. long, according to either of the types; a represents the cost of all materials in one of the upper courses (the constant given in the table below being the average of the two upper courses), X equals number of courses desired above the tenth course; and b equals the cost of all materials used in the lower ten courses. The height of the timberwork above the lake bottom (2 ft. in types 1 to 4, inclusive) is counted as two courses. The stone foundations in the other types shown are counted as four and six courses, respectively. The bottom course of the crib work is 1.5 ft. high, all other courses being 1 ft. each.

There is one discrepancy in the formula which would affect the accuracy of the results if not remedied. This is accounted for later on.

Use of Formula.—As stated, the constants a and b represent the cost of *all* materials in the different parts of the crib as noted. These materials consist



Type V, Crib Breakwater.



Type VI, Crib Breakwater.

FIG. 7.—Types V and VI, crib breakwaters.

of lumber, drift bolts and stone and (in types 1 to 4), of piles and screw bolts. The unit prices of each of these materials will also be factors. The formula containing all these items will be as follows:

$$Y = (a^tT + a^dD + a^sS)\,X + b^tT + b^dD + b^sS + pP + cC$$

In this a^t and b^t, a^d and b^d, a^s and b^s, p and c represent, respectively, the quantities of timber drift bolts, stone piles and screw bolts (as shown in Table II), for each type, and T, D, S, P and C the unit prices of materials, viz., per thousand board feet of timber, per hundred weight for bolts per cord of 128 ft. for stone, and for each pile. All prices are for materials "secured in the work." It must be particularly remembered that X represents the number of courses above the tenth course.

As has already been stated, the constant a^t represents the amount of timber required in *one* of the courses above the tenth course, and the constant b^t

the total amount in the ten lower courses. From this it follows clearly that the total amount of timber required in 100 lin. ft. of a crib of any of the types, respectively, will be found by means of the simple formula:

$$Y^t = a^t X + b^t,$$

using the respective values for the constants in Table II. In the same manner the amount of drift bolts, stone, etc., may be obtained.

The discrepancies referred to above have been remedied and the constants have been corrected accordingly and are to be used *as given* in the table.

TABLE II.—CONSTANTS FOR TYPES WITH TIES AND LONGITUDINALS OF 10 × 12-INCH TIMBERS

——Types——										
No.	Width of crib ft.	Foundation	a^t M. ft. B. M.	a^d Cwts.	a^s Cords	b^t M. ft. B. M.	b^d Cwts.	b^s Cords	p No.	c Cwt.
1	16	Pile	4.680	4.3	9.605	56,648	37.0	92.947	27	5.1
2	20	Pile	4.996	4.4	12.525	64.894	37.5	100.450	40	6.7
3	24	Pile	5.312	4.4	15.444	67.734	37.8	129.336	40	6.7
4	30	Pile	5.786	4.6	19.823	79.518	38.3	150.641	53	8.4
5	30	Stone	5.786	4.6	19.823	40.492	25.9	259.943	0	0
6	30	Stone	5.786	4.6	19.823	28.920	17.3	301.547	0	0

Chief Elements in the Structures.—It may be found desirable to verify the various amounts entering into the calculation, and for that purpose the general dimensions of timbers, etc., are here given; it being believed that, for the sake of comparison between the different types, it is desirable to maintain uniformity with regard to the dimensions of all the principal parts of the structures.

Thus, the following dimensions have been used for each of the six types: bottom side timbers, 12 × 18 ins.; all other side timbers, end timbers and bearing timbers, 12 × 12 ins.; ties and longitudinals, 10 × 12 ins. (2-ft. long searves having been provided for the latter); stone bottom (in types 1 to 4) in middle pockets, 6 × 12 ins.; the grillage bottom in types 5 and 6 are made of 12 × 12-in. timbers.

The lowest set of longitudinals (in types 1 to 4) are extended to the full length of the crib, 100 ft., and blocks are placed at each end of the crib, between these longitudinals and the bearing timbers, which are also 100 ft. in length. An extra bearing timber, 12 × 12 ins., is provided—in type 4, above the stone bottom. All cross ties are dove-tailed into the side timbers and the longitudinals into the end walls. Stone has been provided for in the walls between the cribs, the calculation thus covering the filling of the crib for its entire length.

In estimating the amount of stone required, calculation has been made on the assumption that the whole volume of the crib, less the space occupied by timber, is filled with stone. While this is not strictly correct, it has been done to compensate for such stone that will usually settle down into the sand bottom and work out on the sides; also, to some extent, for irregularity in the lake bottom.

Drift bolts, 32 × 20 ins. in length, are provided for in regular columns in the side and end walls; also through bearing timbers and protruding ties, and in the crossings of ties and longitudinals, alternately in each crossing.

Discrepancy in the Formula and Its Remedy.—It was stated above that the quantities in each set of two courses above the tenth course are constant amounts for each type. There is an exception to this rule. The top course of every structure has less timber and stone than each of the other courses, because there are no longitudinals in this course and no stone in the upper half of it. There are, however, more bolts in the top course, as a 20-in. bolt is placed in each of the top, side and end walls, in each column of 32-in. bolts, where these reach only to the upper face of the third course from the top.

To remedy this, the respective amounts are deducted—for timber and stone —and added for drift bolts, to the corresponding materials in the constants *b*. for each respective type. These amounts are given in Table III. The figures given in Table II are the corrected amounts, as already mentioned.

TABLE III.—CONTENTS USED TO COMPENSATE FOR DISCREPANCY IN THE TOP COURSES

	With 10 × 12-in. timbers			With 12 × 12-in. timbers		
Types	Timber, M. bd. ft.	Bolts, cwt.	Stone, cords	Timber, M. bd. ft.	Bolts, cwt.	Stone, cords
1	−0.960	+2.3	−4.747	−1.152	+2.3	−4.625
2	−0.960	+2.4	−6.279	−1.152	+2.4	−6.157
3	−0.960	+2.4	−8.591	−1.152	+2.4	−7.687
4	−0.960	+2.5	−10.107	−1.152	+2.5	−9.984
5	−0.960	+2.5	−10.107	−1.152	+2.5	−9.984
6	−0.960	+2.5	−10.107	−1.152	+2.5	−9.984

Suggested Simplification.—If a large number of cribs of different types and heights are to be estimated for, and prices suitable to the locality and period have been determined, the formula may be materially simplified by inserting these prices in the formula and developing the calculations for the values of *a* and *b*, respectively, thus giving the formula the initial form: $Y = aX + b$, after which the computation will be reduced to the simplest kind, according to the variations in the values of X.

Different Quality of Timber in Sub and Superstructure.—The above formulas contemplate only one kind of timber for the whole structure. Should it be required to provide for different quality of timber for sub and superstructure (where the prices differ materially) then proceed as follows:

For the substructure use the general formula with constants as given in Table II; adapting the prices for timber to be used, and with X fixed according to the number of courses in *this part* of the work.

For the superstructure use the same formula with the constant *a* as above; but for the constant *b* substitute the values for this constant (with + or − signs as indicated) as given in Table IV and make X = the number of courses desired in the superstructure, and use the price for the proposed kind of timber accordingly.

Rebuilding Superstructure.—Should it be required to prepare an estimate for the cost of rebuilding the superstructure over old crib work the same method should be followed, adding, however, only the cost of removing the old work.

Modification in Types.—If it is preferred to use 12 × 12 in. timbers for ties and longitudinals, this would increase the constants for timber and decrease the constants for stone. The constants for bolts would not be affected. Table V gives the constants calculated to fit such cases, all other elements remaining unaltered.

Decking.—The crib work is generally covered by some kind of decking to protect the stone filling, especially if the work is exposed to severe storms. The form of decking generally used in this district consists of 6 × 10 in.

planking laid flat, 2 ins. apart, and spiked to the cross ties with $\frac{1}{2} \times 14$ in. spikes, washers being used under the heads of the spikes, which has proved very advantageous in giving much better hold. One hundred linear feet of a deck plank contains 500 ft., B. M., and the spikes required for that length of deck plank, including washers, will weigh approximately 50 lbs.

The total cost of the decking, of the kind described, for any of the types of cribs may be obtained by the simple formula: $Z = \frac{(E + K)X}{2}$ in which Z represents the cost of the decking over 100 lin. ft. of the crib; E = the cost per M. ft. B. M. of the deck timbers; K = the cost per cwt. of the spikes and washers, and X = the width (*inside* of the side timbers) of the crib to be covered.

Intermediate Decking Supports.—When a pier or breakwater is greatly exposed to severe gales, it is very desirable to place intermediate supports under the decking, half-way between the cross ties. These supports may be made of 3×12 in. planks placed on edge and resting on the two top longitudinals and, at each end, on a 3×12 in. $\times$ 2-ft. piece of plank spiked to the side walls, with their tops level with the tops of the longitudinals. The length of each plank will be equal to the inside width of the crib. If, however, they are estimated equal to the *outer* width of the crib + 2 ft., in length, the two pieces to be spiked to the side walls will be provided for. The decking should, as a matter of course, be spiked to this planking. As there are twelve spaces between the ties in each crib, the cost of the decking supports will be obtained by the formula: $Y = 0.036\ F.\ (W + 2) + 0.3\ K\ (W - 2)$ in which Y represents the total cost of the decking supports for a crib 100 ft. long; F equals the cost per M. ft. B. M. of the planks; K equals the cost per cwt. of spikes and washers and W equals the outside width of the crib.

TABLE IV.—CONSTANTS FOR TYPES WITH TIES AND LONGITUDINALS OF 12 × 12-IN. TIMBERS

Types	a^t M. ft. B. M.	a^d Cwt.	a^s Cords	b^t M. ft. B. M.	b^d Cwt.	b^s Cords	p Piles	c Screw bolts
1A	5.064	4.3	9.383	59.622	37.0	91.374	27	5.1
2A	5.424	4.4	12.273	68.220	37.5	98.648	40	6.7
3A	5.784	4.4	15.164	71.052	37.8	128.068	40	6.7
4A	6.316	4.6	19,500	83.706	38.3	148.267	53	8.4
5A	6.316	4.6	19.500	43.320	25.9	258.238	0	0
6A	6.316	4.6	19.500	30.672	17.3	300.493	0	0

Types of Breakwater Construction and Their Costs.—This is given in the report of J. F. Hasskarl before the 12th International Congress of Navigation. The following notes are taken from an abstract of Mr. Hasskarl's paper in Engineering and Contracting, June 26, 1912.

Delaware Breakwater.—The Delaware Breakwater was commenced in 1828 and completed in 1869. Its principal dimensions and cost are: Length 2,558 ft.; length of Gap and Ice Breaker, which are connected with the same, 2,709 ft.—making the total length of this structure 5,267 ft. Area of average cross section above sea bottom, 4,067 sq. ft. Area of average cross section above mean low water, 547 sq. ft. Area of average cross section below mean low water, 3,520 sq. ft. Tons per average lin. ft., 277.69. Cost per average lin. ft., $608.95. *Note:* The great excess of material placed in the structure over the enrockment at present remaining above the bottom is explained as follows: The bottom is very soft, there are no mattresses, and much of the material has sunk into the soft mud. The weight of a cubic yard of solid stone is approximately 2.24 tons, and a cubic yard of enrockment weighs about 1.68 tons.

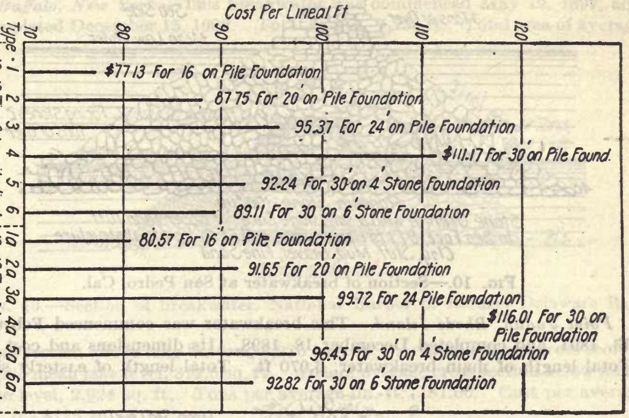


FIG. 8.—Relative costs of crib breakwaters of different types.

San Pedro, California.—This breakwater was commenced November 12, 1898, and is still (1912) under construction. Its dimensions and cost are: Total length when completed, about 11,100 ft. Total area of average cross section above sea bottom, 6,466 sq. ft. Area of average cross section above mean low water, 412 sq. ft. Area of average cross section below mean low

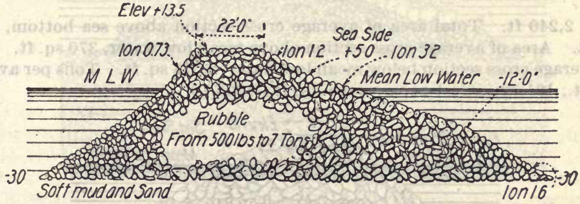


FIG. 9.—Section of Delaware breakwater.

water, 6,054 sq. ft. Tons per average lin. ft., 344.31. Cost per average lin. ft., $285.

Colon, Panama, West Breakwater.—This breakwater was commenced in 1910 and is still under construction. Its dimensions and cost are: Total length when completed, 11,322.5 ft. Total area of average cross section above sea bottom, approximately 6,777 sq. ft. Area of average cross section above mean sea level, approximately 335 sq. ft. Area of average cross section below mean sea level, approximately 6,442 sq. ft. Tons per average lin. ft., 340. Estimated cost per average lin. ft., $481.

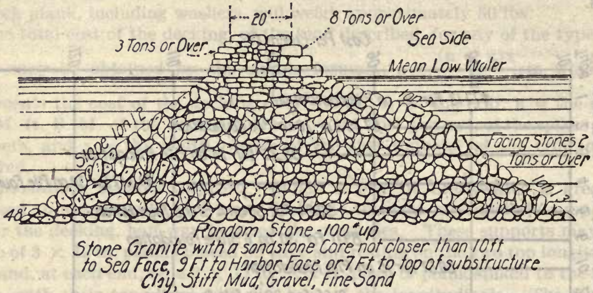


FIG. 10.—Section of breakwater at San Pedro, Cal.

Point Judith, Rhode Island.—This breakwater was commenced February 13, 1891, and completed December 18, 1898. Its dimensions and cost are: Total length of main breakwater, 6,970 ft. Total length of easterly shore

FIG. 11.—Section of Colon breakwater, Panama.

arm, 2,240 ft. Total area of average cross section above sea bottom, 2,948 sq. ft. Area of average cross section above mean low water, 370 sq. ft. Area of average cross section below mean low water, 2,578 sq. ft. Tons per average lin. ft., 161.72. Cost per average lin. ft., $206.70.

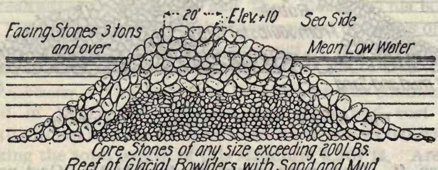


FIG. 12.—Section of Point Judith breakwater, Rhode Island.

National Harbor of Refuge, Delaware Bay.—This breakwater was commenced in 1897 and completed in 1901. Total length, 8,040 ft. Total area of average cross section above sea bottom, 3,474 sq. ft. Area of average cross section above mean low water, 550 sq. ft. Area of average cross section below mean low water, 2,924 sq. ft. Tons per average lin. ft., 183.82. Cost per lin. ft., $217.60.

GREAT LAKE BREAKWATERS

Buffalo, New York.—This breakwater was commenced May 19, 1897, and completed December 15, 1902. Total length, 7,250 ft. Total area of average

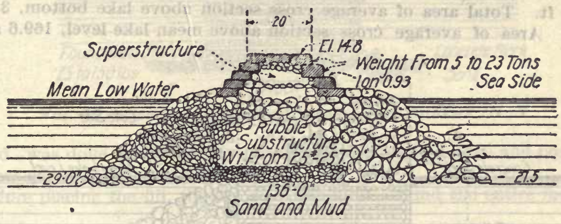


FIG. 13.—Section of breakwater, National Harbor of Refuge, Delaware Bay.

cross section above lake bottom, 3,236.5 sq. ft. Area of average cross section above mean lake level, 312.5 sq. ft Area of average cross section below mean lake level, 2,924 sq. ft. Tons per average lin. ft., 181.60. Cost per average lin. ft., $125.26.

Buffalo, New York.—Original breakwater built October 7, 1898—October 27, 1900. New superstructure work commenced June 18, 1901, completed May 18, 1902. Total length, 1,800 ft. Total area of average cross section

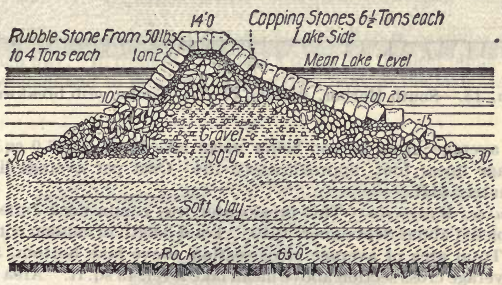


FIG. 14.—Sorted rubble mound breakwater at Buffalo, N. Y.

above lake bottom, 2,417.68 sq. ft. Area of average cross section above mean lake level, 302.68 sq. ft. Area of average cross section below mean lake level, 2,115 sq. ft. Tons per average linear foot above lake bottom, 105.34. Cost per average linear foot above lake bottom, $242.53. Total tons per average linear foot, including gravel fill in trench, 268.84. Cost per average linear foot including trench and gravel fill, $278.89.

Dunkirk, New York.—This breakwater was commenced August, 1897, and completed August, 1898. Total length, 310 ft. Total area of average cross section above lake bottom, 535.2 sq. ft. Area of average cross section above mean lake level, 175.2 sq. ft. Area of average cross section below mean lake level, 360 sq. ft. Tons per average lin. ft., 28.557. Cost per average lin. ft., $65.12.

Cleveland, Ohio (Eastern Extension).—This breakwater was commenced May 4, 1903, and is still under construction. Total length when completed, 15,600 ft. Total area of average cross section above lake bottom, 3,246.5 sq. ft. Area of average cross section above mean lake level, 169.6 sq. ft.

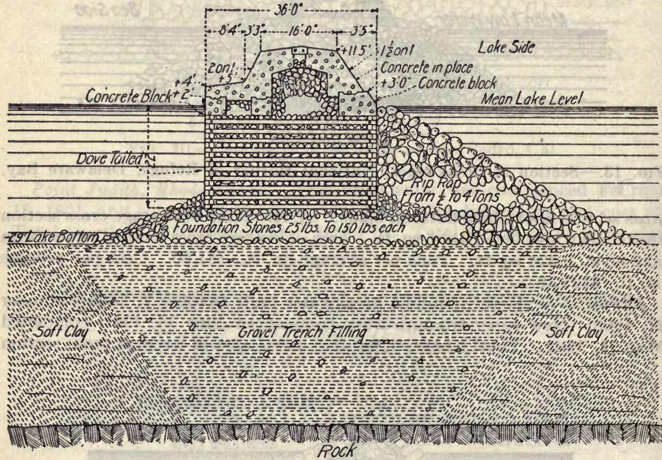


FIG. 15.—South Harbor, Buffalo, N. Y. Timber crib breakwater.

Area of average cross section below mean lake level, 3,076.9 sq. ft. Tons per average linear foot, approximately 164. Cost per average linear foot, approximately $175.

Milwaukee, Wisconsin.—This breakwater was commenced June 14, 1909, and completed about September, 1910. Total length of caisson construction, 577 ft. Total area of average cross section above lake bottom, 531 sq. ft. Area of average cross section above mean lake level, 43 sq. ft. Area of average cross section below mean lake level, 488 sq. ft. No data for weight per linear foot obtainable. Cost per average linear foot, $117.94. *Note:* Stone for riprapping caissons, except about 800 tons of large stone placed on lake side, was obtained from the razing of an old pier and is not included in above estimate of cost.

Cost of Sea Wall for Land Reclamation at New Orleans.—Engineering News, June 25, 1914, gives the following data from the report of a commission of the Sanitary District of Chicago.

The city of New Orleans in making about 27 acres of new land at the "West

End" for municipal purposes, constructed a pile and concrete sea wall on Lake Pontchartrain, about 2,650 ft. long, and dredged and deposited a fill averaging 8 to 12 ft. deep behind this wall. This dredging, amounting to about 400,000

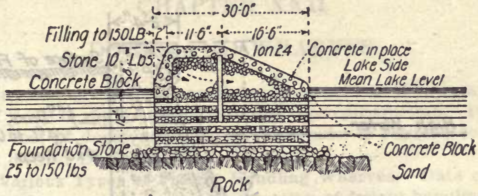


FIG. 16.—Section of detached breakwater, Dunkirk, N. Y.

cu. yd., was done in the lake by means of a hydraulic dredge and cost 11.37 cts. per cu. yd., placed in fill.

Before placing the fill, the sea wall was built around the entire inclosure.

FIG. 17.—Extension of East breakwater, Cleveland, Ohio.

The wall is of concrete, placed on a double row of 50-ft. oak piles spaced 5 ft. c. to c. each way. In front of this piling a triple row of sheet piling was driven as a coffer-dam and to prevent the fill sliding back in the lake. About 3 ft.

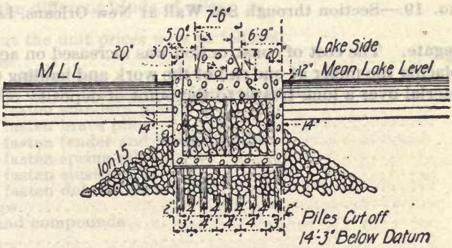


FIG. 18.—Reinforced concrete caisson, South Pier, Milwaukee, Wis.

of material was excavated for the base of the concrete cap, so that the piles are entirely protected from the action of the teredo. The wall is provided with two rows of weep holes, and has expansion joints 50 ft. apart.

Including the piles, excavation and concrete, the wall has cost about $26 per lin. ft., or $13 per cu. yd. of concrete. The labor costs were $1.75 to $2 for common labor and $3 per day for skilled labor. Gravel was used for the

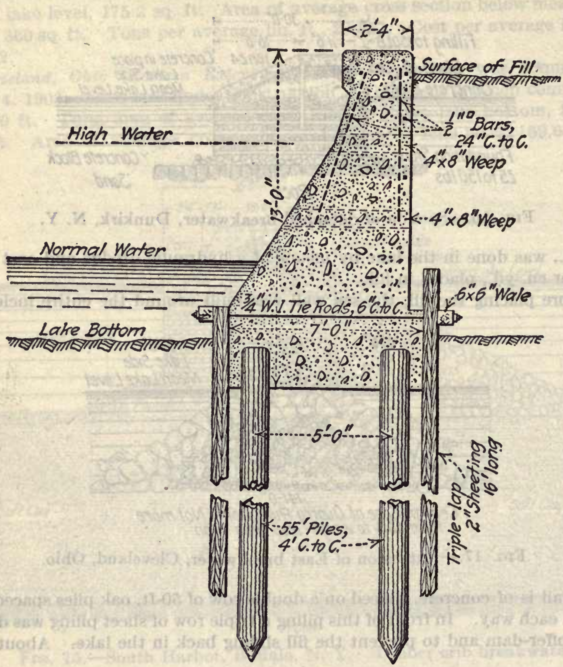


FIG. 19.—Section through Sea Wall at New Orleans, La.

concrete aggregate. The cost of construction was increased on account of the necessity of placing the mixer at one end of the work and hauling the concrete and other material over a long trestle to the point of deposit.

CHAPTER XXII

DOCKS AND WHARVES

This chapter contains costs of complete pier structures of various types and also costs of items of work entering into this type construction. For further data on the cost of docks and wharves the reader is referred to Gillette's "Handbook of Cost Data."

Costs of Various Types of Freight Handling Wharves.—Data concerning the latest and best practice in the construction of freight-handling wharves has been collected by a committee of the American Railway Engineering Association. The information was obtained from members of the association and is summarized in the July (1917) Bulletin of the association by W. H. Hoyt as a portion of an article on the design of docks and wharves. The following abstract of Mr. Hoyt's article is given in Engineering and Contracting, Sept. 26, 1917.

Docks at San Francisco, Ferry Point and Oakland, Santa Fe System.—The Atchison, Topeka & Santa Fe Ry. Coast Lines has about 4,000 ft. of frontage of wharf at San Francisco, practically all of which is over a rock seawall and is supported on creosoted piles, spaced 10 ft. each way. The intermediates are 4 in. by 12 and tracks are carried with two pieces of 12-in. by 12-in. under each rail over the 10-ft. spans. At Ferry Point the railway has a wharf 70 ft. wide by 700 ft. long. In 1913 this wharf was extended and a new freight apron built on the end. The extension was designed primarily for the accommodation of barges handling cars. The wharf on either side of this dock was constructed as a support for the spring line of the slip. This also is true of a new slip at Oakland. The latter wharf was driven with a 10-ft. spacing of piles. In all of the wharf work piles treated with 16 lb. of creosote are used for salt water driving. All the above mentioned jobs were constructed by contract covering the labor only, the railway company furnishing all the material. Each contract was made up on the basis of unit prices covering each kind of lumber and the different kinds of piles.

At Ferry Point the unit prices were as follows:

Pulling piles	$15.00 each
Taking out old lumber	6.00 per M
Cutting piles off on present wharf to new grade	1.25 each
Drive and fasten standard piles	9.35 each
Drive and fasten brace piles	15.50 each
Drive and fasten fender and mooring piles	7.15 each
Drive and fasten spring piles	11.00 each
Drive and fasten cluster piles	16.00 each
Drive and fasten dolphin piles	18.50 each
Placing caps	21.00 per M
Stringers and compounds	16.00 per M
Planking	11.35 per M
Guard rail	9.60 per M
Chocks	32.00 per M
Ribbing	31.70 per M
Spring line chocks	45.00 per M
Sheathing	18.50 per M
Intermediate stringers	12.75 per M
Total labor (approximately)	$15,000

At Oakland the unit prices were as follows:

Drive and fasten standard piles	$ 9.00 each
Drive and fasten brace piles	15.00 each
Drive and fasten dolphin piles	18.00 each
Drive and fasten cluster piles	12.00 each
Drive and fasten spring piles	12.00 each
Placing caps and sub-caps	21.00 per M
Placing stringers and compounds	16.00 per M
Placing intermediate stringers	12.75 per M
Placing planking	11,00 per M
Placing guard rail	9.00 per M
Placing ribbing	34.00 per M
Placing chocks	40.00 per M
Placing sheathing	18.00 per M
Taking up old timber	6.00 per M
Total labor (approximately)	$19,000

At San Francisco the unit prices were as follows:

Drive and fasten fender piles	$ 8.00 each
Drive and fasten standard piles	8.00 each
Drive and fasten mooring piles	8.00 each
Placing caps	20.00 per M
Compound stringers	16.00 per M
Track stringers	16.00 per M
Intermediate stringers	15.00 per M
Fillers	10.00 per M
Guard rail	10.00 per M
Planking	10.00 per M
Removing old lumber	6.00 per M
Placing chocks	32.00 per M
Breaking off old piles	3.00 each
Pulling piles	12.00 each
Placing sub-caps	25.00 per M
Total labor (approximately)	$17,500

Pier No. 5, Weehawken, N. J., New York Central & Hudson River R. R.—Designed for handling outward business (boats to cars) only. Built on pile foundations. Has adequate floor space and numerous gangways to make short trucking possible. It is securely sway braced with 4-in. × 8-in. plank bolted to each pile, also girt timbers running across piling underneath wharf. Has double layer deck, consisting of a lower 4-in. plank deck covered with 2-in. × 4-in. beech flooring. The total contract cost of the substructure and superstructure, including heating, dry fire protection line, electric wiring and fire alarm system, was about $3 per square foot.

Pier and Bulkhead Platforms, James Slip and Olive St., New York City.—Has a 9-in. reinforced concrete deck on timber stringers and pile foundation. On top of the 9-in. concrete is a 2½-in. asphalt wearing surface. The front of the wharf is fendered with oak piling and timber securely bolted to the main frame work. The unit costs are stated to be as follows: Timber decks, including rangers, about 52 cts. per square foot; reinforced concrete deck, 46 cts. per square foot, and with 2½ asphalt wearing surface 55 cts. per square foot. The figures for concrete do not include the cost of timber construction at deck level on the sides of the dock.

Dock at Sandusky, O., for Pennsylvania R. R.—This is a new dock for coal machine. It is a good example of filled timber crib on rock foundation with monolithic concrete superstructure. The average height of crib is 18 ft. The unit cost per lineal foot of dock was as follows:

	Per lin. ft. of dock
Hemlock lumber	$ 35.00
Framing, placing and sinking	25.00
Iron (tie bolts, drift bolts, etc.)	14.00
Stone (for sinking cribs)	12.00
Leveling foundations	2.00
Concrete top	19.50
Cast iron mooring posts	1.50
Total	$109.00

Dock at Port Bolivar, Tex., Gulf, Colorado & Santa Fe Ry.—This dock is a timber platform supported on pile foundations. Back of the dock proper sheet piling has been driven and tied back by ½-in. iron rods to anchor piles, and the dock filled. The geological formation at the site consists of alternate layers of water, sand and sea inlet to an indefinite depth. It is estimated that the cost of a pile foundation for concrete walls with the cost of the necessary caisson work would more than equal the entire cost of the present bulkheads and aprons. The unit costs were as follows:

Total cost of bulkhead per lin. ft	$33.27
Total cost of apron 30 ft. wide per sq. ft	0.7343
Cost per linear foot marine treated piles	0.385
Cost per linear foot untreated piles	0.085
Cost per M. feet B. M. marine treated timbers	47.80
Cost per M. feet B. M. full-cell treated timbers	31.00
Cost per M. feet B. M. untreated timbers	21.80
Cost per linear foot driving marine treated piles	0.17
Cost per linear foot driving untreated piles	0.15
Cost per M. feet B. M. placing marine treated timbers	16.00
Cost per M. feet B. M. placing other timbers	15.00

Average cost of freight on piles about $0.05 per lin. ft., and on timbers about $5 per M. B. M.

Pier No. 9, Hoboken Terminal, Delaware, Lackawanna & Western R. R.—This pier has been in use for about 8 years. It is a 2-story steel and reinforced concrete structure supported on pile foundations stiffened with riprap and rubble filling. The cost was $4.25 per square foot.

Lumber-Handling Dock, Lake Superior, Duluth, Winnipeg & Pacific Ry.—This dock was designed exclusively for handling lumber from railroad cars to boats.

Its cost was as follows:

Engineering charges	$ 1,409
Freight charges on piling, ties and planking	5,089
Piling, 103,185 lin. ft	17,539
Timber, 818,230 ft. B. M	22,702
Machine bolts, drift bolts, etc	1,480
Iron cleats, 25, at $8.75	219
Contract price driving piles, 92,791 lin. ft. left in work at 5¾ cts	5,335
Contract price framing deck and bracing, 781,699 ft. B. M. left in work, at $6.90 per M	53,94
Excavation for mud sills on bank	119
Crib at end of dock:	
Iron rods for tieing crib	19
Labor applying rods	44
Stone for filling crib, 64 cords at $7	448
Dredging, 177,427 cu. yd. at 11 cts	19,517
Track, 60-lb. rail, and fastenings, second-hand	1,689
Track, labor	320
Saunders car stoppers, 2 at $45	90
Freight on car stoppers	7
Total	$81,422

Dock, Toledo, O., Hocking Valley Ry.—This structure is typical of the ore and coal-handling docks on the Great Lakes. It is an excellent sample of crib-filled structures and of concrete pier supported directly on piling. On account of the heavy distributed loads to be carried and the heavy machinery foundations it requires a very solid substructure. It is also thoroughly tied back with anchor rods. The unit costs were:

12-in. × 12-in. timber grillage placed	$43.00	per M. B. M.
2-in. plank, hardwood	38.00	per M. B. M.
2-in. plank, hemlock	35.00	per M. B. M.
Timber piling driven	.28	per lin. ft.
Steel piling driven	.02	per lb.
Concrete placed	6.80	per cu. yd.
Steel "I" beams placed	.02	per lb.
Steel reinforced rods placed	.02½	per lb.
Wrought iron rods placed	.05	per lb.
Dredging and waste	.23	per cu. yd.
Dredging and backfill	.27	per cu. yd.

The above do not include company freight or supervision.

Dock on Chicago River, Chicago, Milwaukee & St. Paul Ry.—This is a very simple structure composed of a front row of piling with sheet piling anchored back to anchor timbers and piles with 1¼-in. rods. The dock is then filled. These docks in Chicago and Milwaukee cost from $18 to $25 per lineal foot, depending upon local conditions.

Costs of the Terminal Piers of the Norfolk & Western Ry. at Norfolk, Va.—In Engineering News-Record, May 16, 1918, F. P. Turner gives the following matter.

The general layout and dimensions of the piers are shown in Figs. 1 and 2.

The outbound or northbound freight is cared for on the southerly of the two piers, which is 800 ft. long and 222 ft. wide and carries a warehouse 208 × 750 ft. Incoming freight is handled by the northerly pier, which is 222 × 1,200 ft. in plan with a 208 × 1,150 ft. warehouse. A water depth of 28 to 30 ft. is provided in the slips around the piers.

The type of construction, determined after a thorough investigation of the first cost, annual repairs and life of various kinds of floors and roofs, was such that the average life of the component parts would be the same.

The pier-shed, being of steel, will under normal conditions have double the life of substructure supporting the floor. The pedestals around the edge of the pier are creosoted piles protected by a steel cylinder, extending two to three feet below maximum depth of water and filled with earth. Experience on similar structures has led to the belief that steel cylinders will last 20 to 25 years and that creosoted piles, after exposure, will last equally as much longer.

The roof, floor and pile substructure may be renewed in sections after 20 to 25 years' service without taking down the steel trusses or interfering with the remainder of the pier. Since the renewal of the substructure would require the destruction of the floor and roof it was not considered advisable to select the more expensive concrete fireproof construction for these two elements, but to use materials having a normal service the same as the substructure.

Creosoted pile substructure was adopted for the entire pier area outside of the bulkhead line established by the War Department. Inside the bulkhead line it proved more economical to drive an uncreosoted bulkhead at the location shown upon the plan and fill it with dredged material for supporting the pier-shed floor and tracks. Creosoted posts, caps, bracing and floor stringers were used above the low-water line. A 3-in. white-oak floor, dressed on one side and two edges, was adopted for wearing surface, this type of floor having

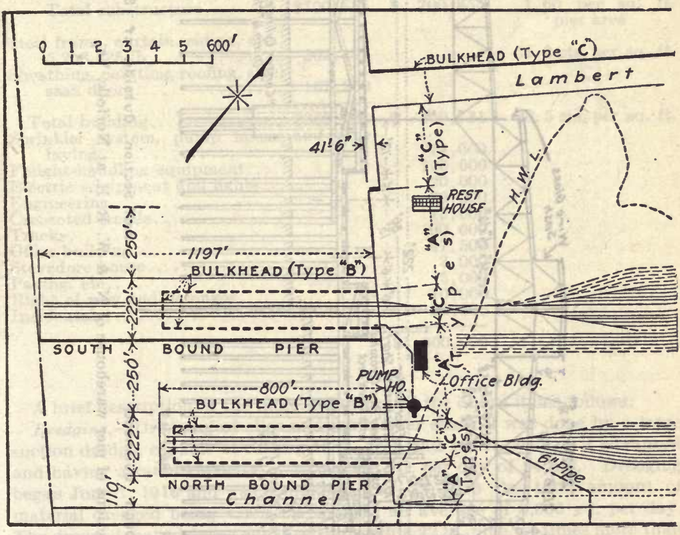


FIG. 1.—General plan of piers of the N. & W. R. R. at Norfolk, Va.

a record of long service in similar warehouses of this company. The roof selected was a 5-ply felt, pitch and gravel, laid on 1¾ in. tongue-and-groove yellow pine sheathing resting on steel purlins.

Dimensions and spacing of timbers and steelwork entering into the construction of these piers are indicated on the accompanying drawings. The loads assumed in the design are as follows:

Floor—500 lb. per sq. ft.
Roof—Purlins, 40 lb. per sq. ft.
Trusses, 50 lb. per sq. ft.
Piles—17 tons each.

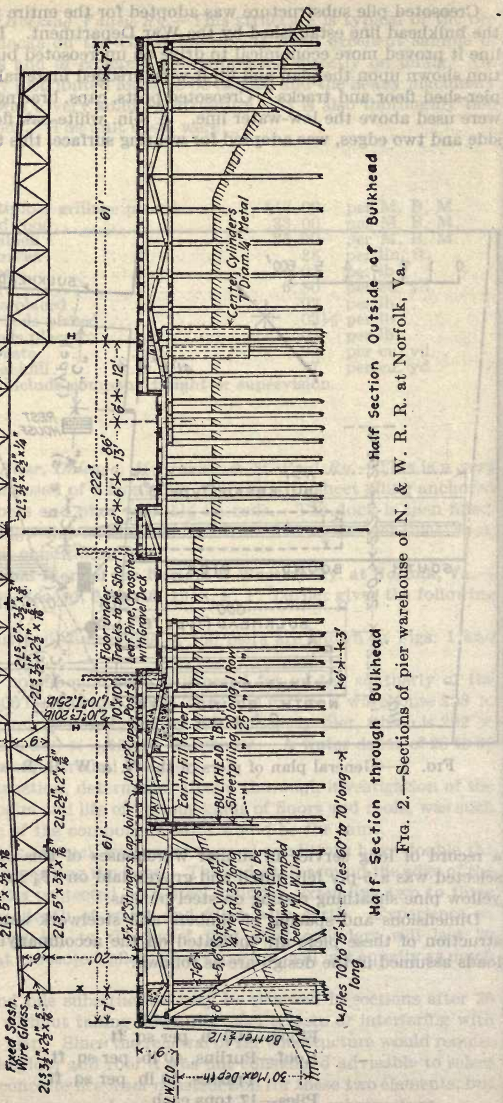


FIG. 2.—Sections of pier warehouse of N. & W. R. R. at Norfolk, Va.

The quantities and cost of the development, which was built during 1916 and 1917, follow:

Dredging—1,373,226 yd.		$ 108,922	$0.0794 per cu. yd.
Bulkhead A—775 ft. long		37,565	$48.50 per ft.
Bulkhead C—8,300 ft. long		138,291	16.70 per ft.
Main pier substructure:			
Bulkhead B, 3,320 ft. long	$ 65,355		19.70 per ft.
Pile and timber work	577,675		
Steel cylinders, 700,800 lb.	23,000		
Floor	34,825		
Total substructure	$700,855	$ 700,855	1.60 per sq. ft. pier area
Steel frame, curtain, siding, etc., 5,258,425 lb.	202,481		51.2 cts. per sq. ft.
Sheathing, painting, roofing, steel sash doors	167,250		
Total building	$369,731	$ 369,731	93.5 cts. per sq. ft.
Sprinkler system, pump house and pipe laying		74,000	
Freight-handling equipment		126,600	
Electric equipment and lights		20,000	
Engineering		30,000	
Creosoted trestle		12,000	
Tracks		90,000	
Office building		47,500	
Stevedore house		3,000	
Paving, etc.		5,000	
Right of way and damages		10,000	
Incidentals		26,536	
		$1,800,000	

A brief description of the more important of the above items follows:

Dredging.—Dredging of slips and main river channel was done by a large suction dredge, capable of cutting 16 ft. deep and 150 ft. wide as it advanced and having a rated capacity of 10,000 cu. yd. per day of 24 hrs. Dredging began June 1, 1916 and was completed Nov. 23, 1916 the total amount of material dredged being 1,373,226 cu. yd., an average of 8,000 yd. per day. The dredged material was conveyed through a 22 in. pipe, at times more than 4,000 ft. long, and was discharged along the line of the bulkhead. Thus, the heavy material was deposited immediately adjacent thereto and the light silty material was forced to the interior. Most of the material dredged was white sand and clay and it immediately gave good resistance after depositing.

The results of this method reduced the pressure against the bulkhead and no failures resulted. Spillways were provided in the bulkhead, at the extreme end of the area to be reclaimed, for water to return to the channel.

Bulkheads.—Figs. 2 and 3 show the type of construction of Bulkheads A, B and C.

Pile and Timberwork.—Creosoted piles were generally 14-in. diam. 2 ft. below butt with 7-in. points, in lengths varying from 50 to 80 ft.; untreated piles driven inside the bulkhead B were 12-in. diam. 2 ft. below butts and 6-in. points. All bulkhead piles were creosoted and of the larger size.

Sound square edge short-leaf pine lumber, creosoted with 12-lbs. of dead oil of coaltar per cu. ft. was used for all exposed bracing and floor supports.

Steel Cylinders.—The pedestals supporting the center columns, outside bulkhead B, were constructed in cylinders 7-ft. diam. Six creosoted bearing piles were driven in each cylinder.

Floor.—Interior floors consisted of 3-in. white oak dressed one side and two edges, outside the building long leaf yellow pine similarly dressed being used.

At about 300-ft. intervals the two buildings have concrete floor slabs 9-ft. wide resting on pile bents and extending from side to side. Precast reinforced concrete fire walls 4-in. thick, 10 to 13 ft. long are hung from this concrete panel and extend 1.5 ft. below low water.

Steel Frame.—The steelwork of the two buildings, 5,167,000 lbs. was erected in 62 working days. A locomotive crane was used in setting the columns and

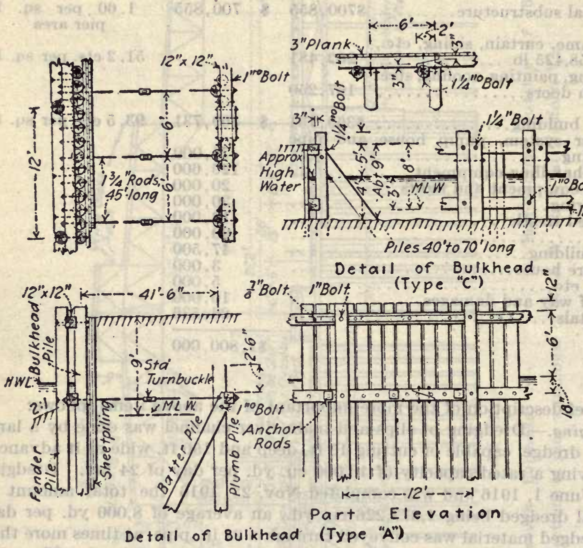


FIG. 3.—Details of bulkhead types A and C.

trusses which were shop riveted complete with the exception of the center longitudinal and transverse trusses; the latter were shipped in two pieces and riveted at the splice before erecting.

Sides.—The sides of the piers were practically solid vertical rolling lift doors, the width and spacing being such that the doors of practically all vessels using the piers would be accommodated. Three lines of windows fitted with steel sash, wireglass, ventilators and operating device are provided on either side for admitting light and ventilation. No. 22 ga. galvanized corrugated steel siding covers the ends and sides, with the exception of window and door space.

Sprinkler System.—The warehouses are equipped with an automatic dry-pipe sprinkler system to meet the underwriters' requirements. In each of the 14 fire areas two dry valves are located, one on either side of the building. From these dry valves the sprinkler pipes radiate, the total number of sprinkler heads being 5,158. Hose valves are provided on each dry valve, and each one is equipped with 75 ft. of 1½ in. linen hose, nozzle and rack. Alarm gongs are also placed outside the buildings, one to each dry valve.

Water-supply is furnished from a 100,000-gal. steel tank, the bottom of which is 90 ft. above the ground. Emergency water-supply will be furnished from an intake in the edge of the river and will be forced into the mains by two 750-gal. per min. underwriters' centrifugal pumps, each driven by a 100-hp. motor. The piping system is so arranged that the water may be pumped into the tank or direct to the mains.

The unit cost of the sprinkler system complete was $14.33 per sprinkler head. Each sprinkler head covers an average area of 77 sq. ft., the unit cost per sq. ft. being 18.7 cents.

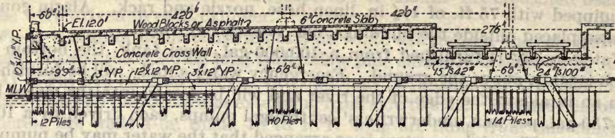
Freight-handling Equipment.—To reach the decks of vessels at various stages of the water and loading, hinged ramp bridges, constructed of steel with wood floors, are provided. These bridges are 27 ft. long and 13 ft. wide, set on a hinge 20 ft. inside the building and having a movement up or down of 20° (9 ft.) from the level position. The bridges are supported by heavy chains, being hung from an overhead gallows frame set 18 ft. from the hinge end. Counterweights are used to assist in lifting the bridges and the movement is controlled by chain and worm gearing. The bridge has a capacity of 10,000 lb. either concentrated on a small 4-wheel truck or distributed.

An endless sprocket chain sliding on the surface of the bridge in a steel trough, with teeth 6-in. above the floor level, is electrically driven through transmission shaft and sprocket wheel set at the hinge end, and pulls trucks from a low level into the warehouse, from warehouse up into a boat, or holds back a load going in the opposite direction. This chain is driven by a 20-hp. reversible motor operating at 220 volts d.c. and has a variable speed to accommodate any class of material being loaded or unloaded. The teeth on the chain engage the axle of a truck, and a load of 4,000 lb. may be handled at a speed of 125 ft. per min. At 250 ft. per min. four individual loads of 1,000 lb., and at 400 ft. per min. eight individual loads of 500 lb. may be handled, the total load at all speeds amounting to 4,000 lb. The chain is located 4½ ft. from the edge of the ramp bridge, and will permit an empty truck to pass in one direction while the load is moving in the opposite direction.

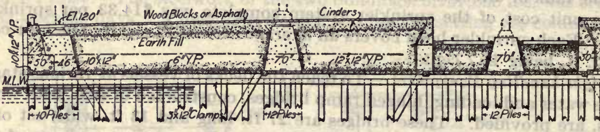
Forty-six bridges are provided on the two warehouses, 34 being equipped with elevators, and the spacing has been made to fit the doors in any vessels operated by the different steamship companies discharging at the space assigned.

Costs of Steamship Piers, Philadelphia, Penn.—In 1913 and 1914, the department of Docks, Wharves & Ferries of the city of Philadelphia, received bids for two steamship piers to be located in the Delaware River, in the new Southwark improvement. On account of radical local differences of opinion as to the relative economy of various types of design, the department made five different designs, three for one pier and two for the other, all of the designs being for the same dimensions and loadings. Bids were received on all five designs and in addition one bidder submitted a sixth design. The following details of the designs, the bid figures, the department's comments upon the designs and bids are given in Engineering News, May 28, 1914.

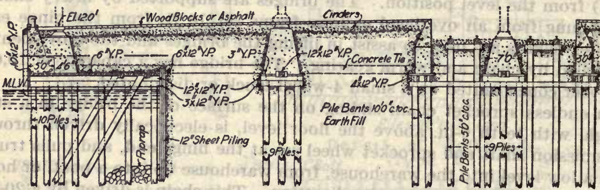
Comments by Department of Wharves, Docks and Ferries.—The accompanying prices are for the construction of the substructures only, and do not include any portion of the sheds. All of the pier types mentioned are similar in general dimensions, in height of deck (12 ft. above mean low water), and in the superposed loads for which they are designed. The main deck slab is designed for



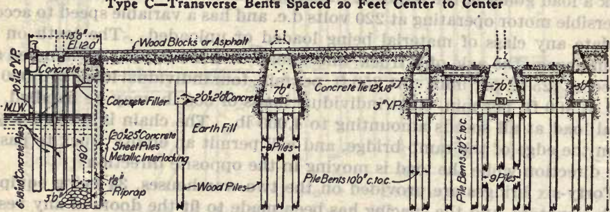
Type A—Double Rows of Piles—Bents 20 Feet on Centers



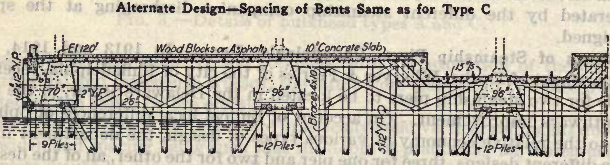
Type B—Pile Bents 5 Feet, Column Bents 20 Feet on Centers



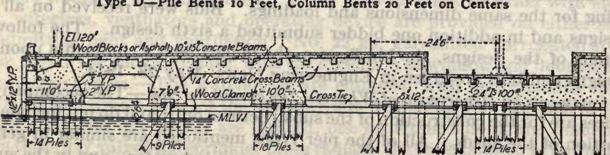
Type C—Transverse Bents Spaced 20 Feet Center to Center



Alternate Design—Spacing of Bents Same as for Type C



Type D—Pile Bents 10 Feet, Column Bents 20 Feet on Centers



Type E—Transverse Bents Spaced 20 Feet Center to Center

Fig. 4.—Transverse half sections, with superstructure omitted. General dimensions on Type A apply to all; depth of dock, 35 ft.

a superposed load of 600 lb. per sq. ft., and the column bases for a second floor superposed load of 300 lb. per sq. ft. and a roof total load of 70 lb. per sq. ft.

In comparing the prices obtained under schedules "A," "B" and "C," in November, 1913, with those under schedules "D" and "E," in March, 1914, the following differences in conditions should be taken into consideration: In the "A," "B" and "C" bids the deck paving was included. The price on this in the low bid was about $18,000, or $0.18 per sq. ft. of gross area of the pier. This should be added to the square-foot price of bids "D" and "E" to make a proper comparison. Also, owing to a change in the specification requirements for piles between the first and second biddings, changing from 15 in. diameter 4 ft. from the butt in the first, to 14 in. diameter 2 ft. from the butt in the latter, an estimated allowance of $10,000, or $0.10 per sq. ft. of pier area, should be added to the square-foot prices of bids "D" and "E" to make a proper comparison.

The quotation for the "C" type includes $25,000 for riprap. This was to be deposited at the toe of the sheet piling and was included because it is an essential portion of the design. The prices for the other different types do not include cobble or gravel fill. It is estimated that there will probably be $10,000 expended for this material to give lateral support to the piles. This costs per square foot of pier area for all types but "C," approximately $0.10.

The prices under Alternate Bids are the quotations of the Raymond Concrete Pile Co. and were used in determining the minimum and maximum costs.

Following is a brief description of each type:

Type "A" consists of: A double row of piles in transverse bays, on 20-ft. centers longitudinally, cut off in a plane approximately 1.5 ft. above low water. The piles are clamped and capped, and this framing covered with a light timber deck, upon which are set concrete walls approximately 11 ft. high. These support a system of reinforced-concrete floor-beams and slabs. On the slabs the deck paving is laid.

Type "B" consists of: Timber piling driven on 5-ft. centers longitudinally and transversely, cut off approximately 1.5 ft. above mean low water, then clamped and capped, and upon the caps a heavy decking placed, which forms a timber platform covering the whole pier area at an elevation of approximately 3 ft. above mean low water. On the outer edges of this decking, along the sides and ends of the pier, concrete walls are constructed approximately 11 ft. in height. A dry fill is deposited on the platform, retained by these concrete walls, and brought to the subgrade of the paving. Upon this fill, a 6-in. concrete base is placed, on which the paving is laid.

Type "C" consists of: A solid earth fill retained by bulkhead walls on the sides and outshore end of the pier. For these bulkheads, piles are driven approximately 5 ft. on centers in both directions, clamped and capped, upon which a heavy timber platform, approximately 25 ft. wide, is laid. Its surface is 3 ft. above mean low water. Timber sheet-piling is driven along the inner edge of this platform and a concrete wall approximately 11 ft. high constructed on the outer end of it. This construction is essentially a bulkhead type and practically consists merely of the standard bulkhead section as used at the ends of the docks, extended around the three sides of the pier. Transverse reinforced-concrete ties connect the longitudinal bulkhead wall together. A wet or dry fill is deposited behind the sheet-piling and on the platform and brought to the underside of the 6-in. concrete slab which supports the paving.

Alternate Bid (Raymond Concrete Pile Co.) consists of: A solid earth fill retained by reinforced-concrete sheet-piling 20 in. thick. This sheet-piling

TABLE I.—COST DATA FOR PIERS NOS. 38 AND 40, SOUTH DELAWARE WHARVES, PHILADELPHIA (SOUTHWARK IMPROVEMENT)
From bids received in November, 1913, and March, 1914

Types of construction (For description see text)	"A" Pier 40	"B" Pier 40	"C" Pier 40	Alternate Pier 40	"D" Pier 38 551 × 180 ft. bulkhead sheds	"E" Pier 38 551 × 180 ft. bulkhead sheds
Dimensions	551 × 180 ft. 99,200 sq. ft.	551 × 180 ft. 99,200 sq. ft.	551 × 180 ft 99,200 sq. ft.	551 × 180 ft. 99,200 sq. ft.	306 × 34 ft 109,700 sq. ft.	306 × 34 ft. 109,700 sq. ft.
Low bids	$276,000	$296,000	$300,000	$319,960	$235,730	$245,200
High bids	359,000	340,500	355,000	....	279,000	290,000
Cost per sq. ft. under low bid	2.77	2.97	3.02	3.225	2.15	2.23
Cost per sq. ft. under high bid	3.63	3.43	3.58	....	2.54	2.63

UNIT PRICES BID ON PRINCIPAL ITEMS OF WORK
(All prices are for materials in place at the work)

Types	"A," "B" and "C"	Alter.	"D" and "E"
Gravel or cobble filling, per ton	$ 0.65 to $ 0.80	......	$ 0.50 to $ 0.75
Riprap, per ton	1.50 to 2.25	$ 1.25	....
Piles	16.00 to 20.00	21.00	14.00 to 20.00
Spur piles	18.00 to 33.55	23.80	15.00 to 25.00
12-in. sheet piling, per ver. lin. ft	0.70 to 1.25	0.80	....
Timber—clamps, caps, wales, decking	47.00 to 70.20	65.00	52.00 to 70.00
White oak fenders, per 1,000 ft. B. M	70.00 to 98.40	70.00	65.00 to 87.00
No. 1 reinforced concrete, per cu. yd	11.00 to 20.00	11.00	11.00 to 15.00
No. 2 mass concrete, per cu. yd	6.50 to 11.05	10.00	7.00 to 10.00
Reinforcement, per ton	45.00 to 100.00	70.00	40.00 to 100.00
Structural steel, per ton	50.00 to 100.00	80.00	55.00 to 100.00

(The above prices are the minimum and maximum quotations received) is driven 13 ft. back from the sides of the pier. The design of the column footings inside of the rows of sheet-piling is similar to those of Type "D"—that is, concrete pedestals supported on timber piling. The center rows of column bases outside of the sheeting are supported on concrete pedestals, each one carried by five reinforced piles 18 in. square. Transverse reinforced-concrete beams 12 × 18 in., running from side to side of the pier, on 20-ft. centers, tie the construction together. The wall and sheeting across the outshore end of the pier are held in place by reinforced-concrete ties running to concrete blocks, supported and braced by vertical and inclined timber piles.

Type "D" consists of: Timber piling in transverse bays, spaced 10 ft. c. to c., cut off and clamped at about 12 ft. above mean low water. Upon these clamps a 10-in. reinforced-concrete floor slab is constructed. On this slab the deck paving is laid. In addition to the above clamps a lower set is also provided at about 2 ft. above mean low water and the piles are thoroughly braced together both longitudinally and transversely.

Type "E" consists of: Piles driven in clusters about 20 ft. apart c. to c., in transverse bays, spaced on 20-ft. centers. These piles are clamped and decked over at about 2.5 ft. above mean low water to support concrete pedestals. These pedestals are approximately 11 ft. high and from them spring the girders of a reinforced-concrete floor system of beams and slabs. On the surface of the slabs the deck paving is laid.

The ruling considerations in these designs were: First, practical permanency of construction and second, as great a degree of economy as was consistent with permanency and stability. No marine borers of any type are prevalent in the waters of the Delaware River as far up as Philadelphia and consequently no necessity existed for providing in these designs against their attacks.

All of these designs are considered to be of permanent character, except Type "D." In this the timber piles extend up to the bottom of the main deck slab, at elevation approximately 12 ft. above mean low water, and their upper ends would be subject to complete renewal in from ten to fifteen years. The portion of the structure subject to decay is readily renewable in this type, and it was thought originally that a material saving in first cost might be accomplished by this design sufficient to offset its partially temporary character. The difference in bid prices obtained, however, was not sufficient to justify the adoption of this type in the contract award.

Of the four permanent types, the "E" design, or the so-called concrete-beam type, is the most economical for the particular width of pier under consideration, and presumably for narrower ones. A comparison of the unit prices named, indicates that this type will continue to be the most economical for piers up to 200 ft. in width. For widths above this, the "C" design, or the solid earth-fill type, would be cheaper under local conditions in Philadelphia, its economy over the other designs increasing steadily with the width of the pier.

The Department of Wharves, Docks and Ferries has adopted a policy of wide-pier construction for city wharves, it being believed that structures of upwards of 300 ft. in width are necessary to properly accommodate the handling and storage of inbound and outbound cargo of large, modern ocean freightcarriers, so that the solid earth-fill type will probably be generally used for future municipal steamship piers.

Life, Maintenance and Cost of Pile Piers with Timber and Concrete Decks. Charles W. Staniford, Proc. A. S. C. E., Vol. XXXIX, gives the following (see Engineering and Contracting, June 18, 1913).

The United States Government requires that all piers constructed beyond the bulkhead line, along the entire water front of New York harbor, must be of such construction that the free flow of the tidal water shall remain uninterrupted by supporting columns.

The pier which meets these requirements, and was adopted by the city in its early history as the type of structure for berthing vessels (and also adopted by all private and corporate interests), is a wooden structure throughout, consisting of a deck resting on piles driven into the mud or hard bottom. The physical features of the harbor, the geological formation of the bottom, and the condition of the water, fortunately permit the adoption of this type of construction, which, in many other parts of the world, is not adaptable because the life of the timber itself in the water would not be permanent or fairly long. Wood-boring animals, the teredo, limnoria, etc., are very little in evidence, and, therefore, wooden piles are practically permanent below the water-line in almost all parts of New York harbor.

The prominent objectionable feature to wooden pier construction is the expense necessitated by the constant repairs of the deck sheathing and the continuous wear and tear of the fender system extending along the sides and outer ends of the piers. As to the remainder of the structure, piles, floor system, etc., its maintenance and repair is very economical and consists generally in the replacement, from time to time, here and there, of decayed portions of the timber above mean low water only, at inconsiderable expense.

Until seven or eight years ago, the piers were generally built with decks of yellow pine, 4 ins. thick, laid on a system of yellow pine floor structure of rangers and stringers. This deck plank in turn was covered with a second layer of either 3 or 4-in. plank sheathing, laid diagonally or at right angles to the deck proper, to form a wearing surface for the traffic.

Constant repairs and renewal of this deck sheathing, caused by the wear and tear of team traffic, is augmented in great measure by the moisture, horse urine, etc., which saturates the wood and eventually finds its way to the underlying deck and rangers. This forms the greatest item incident to the expense of pier maintenance, the average life of the sheathing for most busy piers being about six years, or requiring a 17 per cent renewal annually. As the cost of the deck sheathing is generally about 12 per cent of the total cost of a pier, it will be seen that these sheathing repairs would aggregate 2 per cent per annum of the cost of the entire structure.

The unit cost of construction of a pier depends in a large measure on the size of a pier. As the outer portions, the sides, and outer end of a large pier are more rigid and heavier than those of a smaller pier, and therefore, cost more in both labor and material, the relative cost per square foot of a short pier is considerably larger than that of a long one. The average cost of the old wooden deck pier of large dimensions is from \$1.00 to \$1.15 per square foot.

Notwithstanding the necessity for constant repairs to the deck sheathing of the wooden pier, the parts of the remainder of the structure—rangers, caps, stringers, piles, and bracing—give excellent service. Maintenance is economical, the average life of the structure above mean low water line being from 20 to 25 years, the repairs aggregating an entire renewal above low water in that period of time. As the life of the piles supporting the structure is practically permanent when submerged below the water, the entire structure can be rebuilt after this period and made practically new by "bench capping" such piles as may be decayed above the water line and renewing the stringers, caps, deck, and sheathing; in other words, the pier structure proper, after a

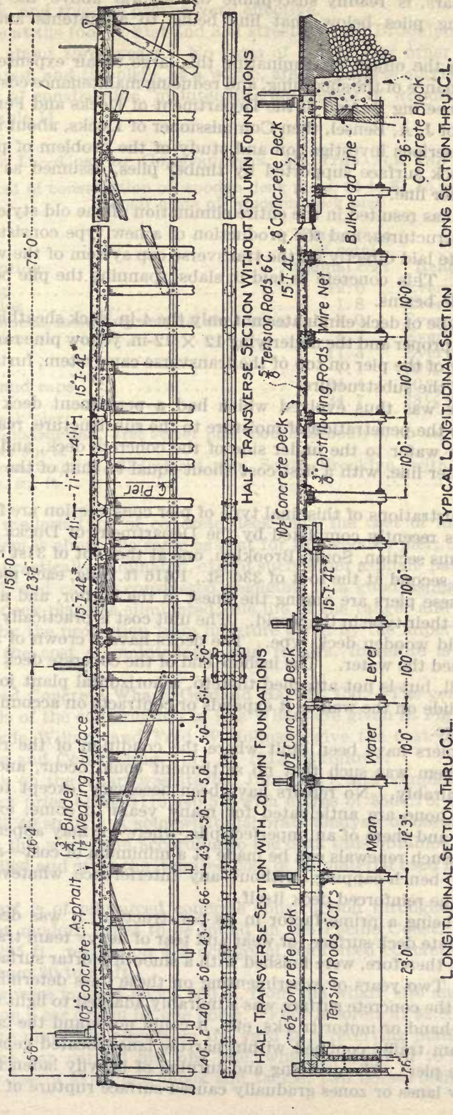


FIG. 5.—Sections of standard reinforced concrete deck for piers, New York Harbor.

life of 25 years, is readily susceptible of renewal above the water line, the supporting piles below that line being to all intents and purposes permanent.

It was with the object of eliminating this large repair expense incidental to the maintenance of the sheathing, and reducing maintenance cost generally, that the Engineering Bureau of the Department of Docks and Ferries, under the direction of J. A. Bensel, then Commissioner of Docks, about seven years ago, began a serious investigation and study of the problem of producing a permanent deck surface supported by timber piles, assumed as permanent below the water line.

This study has resulted in the entire elimination of the old style of wooden deck in new structures, and the production of a new type consisting of reinforced concrete laid directly on the transverse cap system of the wooden pier substructure. This concrete is laid in slabs, spanning the pile bents practically as simple beams.

This new type of deck eliminates not only the 4-in. deck sheathing, but also the 4-in. deck proper and the underlying 12 × 12-in. yellow pine ranger system longitudinally of the pier on top of the transverse cap system, further increasing the life of the substructure.

A structure was thus evolved which had a permanent deck practically impervious to the penetration of moisture to the substructure, readily renewable from low water to the under side of the concrete deck, and permanent below the water line, with a first cost about equal to that of the old wooden deck pier.

Definite illustrations of this final type of pier construction are found in the two new piers recently completed by the Department of Docks and Ferries at the Gowanus section, South Brooklyn, one at the foot of 31st St., 1,475 ft. long, and the second at the foot of 33d St., 1,616 ft. long, each pier being 150 ft. wide. These piers are among the finest in the harbor, and are probably the largest of their type in the world. The unit cost is practically the same as that of the old wooden deck type. The decks have a crown of about 8 ins. in order to shed the water. The inshore end of the concrete deck rests on the bulkhead wall, but is not attached thereto, a horizontal plant joint allowing the deck to slide on the wall as it expands or contracts on account of changes of temperature.

All these piers have been built where the condition of the river bottom underlying them was such that no settlement could occur, and they have behaved admirably. No repairs have been necessary, except to the fender system, and none are anticipated for many years to come, excepting the renewal here and there of an imperfect pile, where rot may appear above the water line. Such renewals can be made at a minimum of cost—a few dollars per pile—by bench-capping, without any interference whatever with the integrity of the reinforced deck itself.

Economy being a prime factor in its construction, it was decided to try out the concrete deck surface for wear and tear of heavy team traffic, and the earlier decks, therefore, were finished with a smooth mortar surface to receive this traffic. Two years of experimenting on these lines determined the fact that though the concrete surface was admirably adapted to light traffic, cargo handling by hand or motor trucks, etc., it could not stand the concentration of heavy team traffic confined within narrow lanes located generally in the center of the pier. The grinding and turning of heavily laden trucks inside these narrow lanes or zones gradually caused surface rupture of the top coat of mortar. It was decided, therefore, to place an asphalt wearing surface on the deck, and this has proven very effective.

The piers at the foot of 31st and 33d streets, South Brooklyn, have been in service for about three years. No signs of cracking or other imperfections have appeared, and the piers, as a whole, are a complete success.

The cost of construction, maintenance and repair of wooden deck piers is given in Table II.

TABLE II.—COST OF CONSTRUCTION, MAINTENANCE AND REPAIRS

(Average cost of construction of wooden deck piers, $1 to $1.15 per square foot.)
Repair costs of wooden deck pier

Description	Percentage of total original cost	Renewal required
Sheathing	12.0	Every 6 years
Backing log	1.8	Every 8 years
Fender chocks, including vertical sheathing	4.0	Every 10 years
Fender piles	4.7	Every 12 years
Decking	11.3	Every 15 years
Bracing	7.1	50% in every 20 yrs.
Rangers and caps	24.4	50% in every 20 yrs.
Piles	34.7	33⅓% every 20 yrs.

Concrete deck pier:

Cost of construction, 31st street pier, South Brooklyn, no asphalt surface, per sq. ft.	$0.87
Cost of construction, 33d street pier, South Brooklyn, with asphalt surface, sq. ft.	0.97

For the modern type of concrete deck pier, the cost of maintaining the fender system is about the same as that for the wooden pier; deck sheathing repairs are practically eliminated, except such minor asphalt patching as may be required, and can be considered negligible in a good asphalt deck under cover; the deck plank is eliminated; the life of the ranger and cap system is prolonged by the protection from moisture given by the impervious concrete deck, and the cost of maintenance and repairs, therefore is reduced to a minimum.

Reinforced Concrete Wharf, Oakland Harbor, Cal.—The general plan and some details of the construction of this Wharf are given in Fig. 6.

Wm. Clyde Willard and Fred W. Johnson give the cost of this wharf in Engineering and Contracting, July 16, 1913, as follows:

The work on the wharf was started June, 1911, and completed April, 1912 the contract price being $119,440.57, with extras of $506.76, totaling $119,-947,33 or $3.40 sq. ft. A somewhat elaborate analysis of costs was made by the city on this work, and according to the data thus obtained Table III has been compiled and gives the itemized cost of all material used in constructing the wharf.

The wharf is of reinforced concrete construction throughout, and is one of the most modern types to be found on the Pacific Coast. The wharf is 124 ft. × 295 ft., resting on 422 octagonal reinforced concrete piles varying in length from 30 to 50 ft.

The piles were molded about 800 ft. from the wharf site and were hauled to the site on a car drawn by one horse. Four laborers at $2.50 per day were employed to move the piles from the yard to a receiving platform, near the wharf. The car carried but one pile, which was rolled to it and loaded thereon by use of skids and block and tackle, two horses being used to haul the tackle. A donkey engine was at first tried for this work but proved to be too expensive. From the receiving platform the piles were loaded by the floating driver onto a barge, the barge holding about eight piles, and hauled to the desired location at the wharf.

Molding Piles.—The bottom for the pile forms was made of two 2 × 10-in. pieces cleated together, 3,000 lin. ft. of this being used. The sides were of 2-in. plank with triangular strips, having approximately a 7-in. face nailed on at top and bottom so that when the two sides were placed on the bottom a

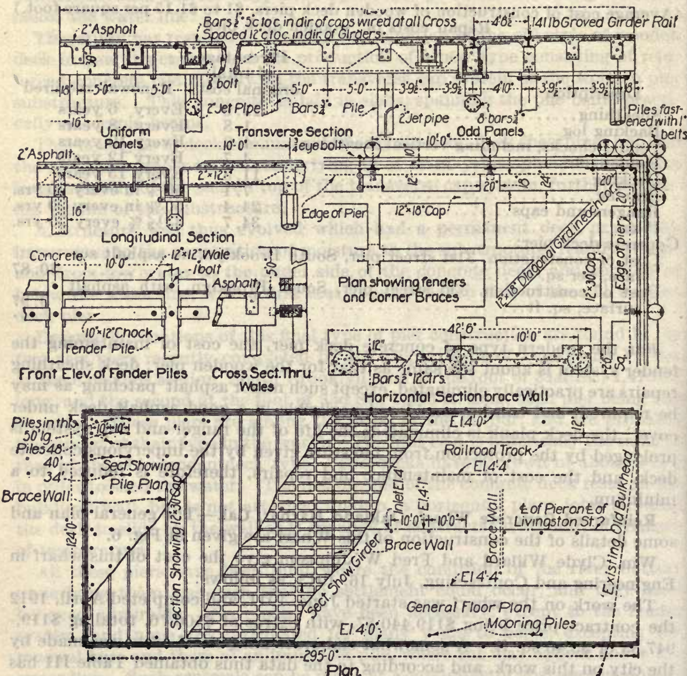


FIG. 6.—Plan and details of Livingston St. Wharf, Oakland Harbor.

cross section of the enclosed space was approximately an octagon whose diameter between faces was 16 ins. A total of 2,360 lin. ft. of sides were used. Fig. 7 shows the details of the reinforcement and jet pipe.

To make the form, a bottom of the desired length was placed on the ground, shimmed to a firm and even bearing, and the steel cage of reinforcement placed on the bottom by laborers. (The cages were built by union labor at $6 per day for foremen and $5 per day for iron workers.) The sides were put in place by carpenters at $3 to $4 per day, toe-nailed to the bottom and tied together at the top with 1 × 2-in. cleats. The steel and jet pipe were sus-

TABLE III.—COST OF MATERIALS FOR CONSTRUCTING WHARF

Items	Remarks	Prices	
Piles, concrete	73 50-ft., 97 48-ft., 63 40-ft., 59 34-ft., 130 30-ft., = 16,734 lin. ft.	$ 0.9449 per lin. ft.	$15,876.48
Piles, creosoted	95 piles = 5,593 lin. ft.	0.44 per lin. ft.	2,460.92
Piles, untreated	19 30-ft., 30 40-ft., 12 50-ft. = 2,370 lin. ft.	0.17 per lin. ft.	402.90
Lumber, untreated	184,921 B. M. O. P., assorted sizes	16.00 per M.	2,958.74
Lumber, creosoted	198 pieces 4 × 12-in. O. P. = 17,816 B. M.	39.30 per M.	700.17
Lumber, creosoted	70 pieces 10 × 12-in. O. P. = 7,000 B. M.	37.80 per M.	264.60
Cement	2,081 bbls. Portland, from Tolenas, Calif.	2.04 per bbl.	4,245.24
Rock	12,436 cu. yds., from S. F. Quarry Co., Marin County, Calif.	0.90 per cu. yd.	1,119.24
Sand	6,62 1cu. yds., from Howard & Co., pumped from Bay of San Francisco	1.05 per cu. yd.	695.21
Steel	80,565 lbs. 7/8-in. twist bar	2.30 per 100 lbs.	1,853.00
Steel	115,669 lbs. 1/2-in. twist bar	2.50 per 100 lbs.	2,891.73
Wire, tie and stretcher	6,055 lin. ft. No. 8	4.62 per 100 lbs.	80.10
Nails	6d, 8d, 20d, 40d, 60d, 7-in. spikes—45 kegs	2.85 per keg	128.25
Bolts, nuts, washers	Mixed sizes and lengths		1,066.07
Corner angles	4 1″ × 12″ × 4′, 4 1″ × 12″ × 5′ rolled iron		207.60
Sockets	69 C. I. sockets		146.77
Springs	69 3-spiral car springs		217.50
Pipe	800 lin. ft. 2-in. No. 2 galv. and C. I.	0.08 per lin. ft.	64.00
Pipe	550 lin. ft. 3-in. galv.	25.65 per 100 ft.	141.08
Rails	20 30′ 0″ 141-lb. grooved girder = 84,600 lbs.	44.00 per ton	1,861.20
Rails	2,400 ft. old street car at 5 cts. ft., 3,600 old ties at $5 per 100, old turntable, $15.00		315.00
Fuel	Lampblack from gas works, 293 tons	5.00 per ton	1,465.00
Fuel	Gasoline, 62 gals.	0.20 per gal.	12.40
Water			61.40
Rings, mooring holes	11 rings		116.85
Shingles and oakum			9.30
Total			$39,360.75

pended by wire from these cleats. Headers were then placed at each end, the form thoroughly wetted and the concrete poured. The day following the pouring of the concrete these sides were removed, cleaned and used again. Four days after pouring, the pile was rolled off the bottom, which was then cleaned and re-used. A total of 424 piles, only two in addition to the number actually used in the wharf, were molded, and at the end of the work the forms were still in good condition. The form work was not economically handled and the cost of this item was relatively high, being nearly $1 per ft. of pile.

Of the 1,047.5 bbls. of cement used in the piles, 986 bbls. were delivered f. o. b. the job at $2.05 and the balance by team at $2.20. The rock, sand and screenings were delivered by team, the haul being about one-half mile. The concrete was mixed by an old type Ransome mixer in poor condition, run by a gasoline engine which caused considerable trouble. From time to time the mixer was moved along the work so that the round trip from the mixer to forms was about 75 ft. An extra wet mixture was used and was hauled in wheelbarrows holding 3 cu. ft. The labor consisted of a crew of from 11 to 14 men, exclusive of laborers who brought the cement from the storehouse.

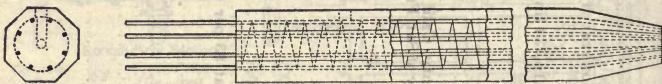


Fig. 7.—Details of reinforced concrete pile, Oakland Harbor.

The concrete mixtures specified were: For 40-ft. piles, 1:2:4; for 30 and 34-ft. piles, 1 of cement to 2 of sand to 2 of screenings to 2 of rock; for the 48 and 50 piles, 1 : 1½ : 1½ : 1½. On account of the character of the materials these mixtures were changed slightly by making an excess of grout and reducing the quantity of stone.

Driving Piles.—The piles were driven by jetting and churning, a drop of from 6 ins. to 2 ft. appearing to give the best results. The time of driving averaged from one to two hours. In using a longer drop, it was found that the material caved under the end of the pile, and also that in penetrating a layer of cemented gravel which underlaid part of the work the square edges at the end of the pile became rounded. An attempt was made to do the driving with a steam hammer by using a special iron follower so cast as not to interfere with the reinforcing rods, which projected 2 ft. beyond the top of the piles, and inserting a wooden cushion block between the pile and follower. However, the outer edge of the head of the pile chipped off during driving and the method was abandoned.

The jet was supplied by two pumps developing a pressure of about 80 lbs. per square inch. A floating driver working two shifts drove 348 piles; and 74 piles inshore were driven with a top driver on false work, the two drivers being similarly equipped. The crew consisted of a foreman at $6, engineer at $5 and four journeymen at $4 per day.

In driving the 48 and 50-ft. piles inshore, some difficulty was encountered in penetrating the layer of cemented gravel 4 to 10 ft. thick and lying at a depth of 35 to 40 ft. below mean tide. This layer inclined towards the water and only seriously interfered with the driving of the piles nearest shore. In order to get the piles through this stratum it was necessary to use a mud pump, the time of pumping averaging from two to three hours.

In order to prevent the concrete in the pile from cracking under its own weight while being hoisted into the gins, all 48 and 50-ft. piles were braced with 12 × 12-in. stiffening timber 30 ft. long, firmly clamped to the pile. The average time of placing stiffening timber and adjusting hoisting collar was about 40 minutes.

Occasionally the jet pile would become plugged by the edges of the pipe jamming together at the lower end. When this occurred the pile was hoisted into the gins and the hole drilled out. In a few cases the nipple at the upper end of the jet pipe was found plugged with concrete, in which case a hole was drilled into the jet pipe lower down the pile and a new nipple inserted and calked with lead. With the exception of the layer of cemented gravel all other material encountered in driving was compact blue clay and mud. After being driven, each pile was sprung into place and held so by 3 × 4-in. timber ribbons bolted around the pile with ¾-in. bolts. The friction of these ribbons on the piles was sufficient to carry the weight of the deck forms.

Brace Walls.—The concrete brace walls, each enclosing five of the concrete piles, were constructed as part of the substructure of the wharf, as shown by Fig. 6. A cofferdam of 2-in. T & G sheet piling, about 10 × 50 ft., was driven for each brace wall and left in place after the work was finished.

The construction of brace walls was poorly handled, the machinery almost worn out, and on brace walls Nos. 1 and 2 there was considerable overtime work at time and a half, all of which unnecessarily increased the costs, which were, for brace walls Nos. 1, 2 and 3, $1,293, $878 and $626, respectively.

Deck Forms.—All form lumber was 2-in. plank with the exception of the side pieces on the pile caps, which were 4 × 12 ins. The lumber was ordered for half of the wharf only and was re-used for the second half.

Concrete.—The rock, sand and cement for the deck structure were delivered on barges, from which they were fed directly to the mixer, a one-half yard Smith in fair condition, run by a vertical steam engine supplied by steam from a separate donkey boiler. This machinery was mounted on a 30 × 50-ft. barge. From the mixer the concrete was hoisted vertically to a hopper about 30 ft. above and poured by a 10-in. O. D. casing some 50 ft. long, a length sufficient to reach the center of the wharf. This tube was suspended from a boom, and by mooring the barge the concrete could be poured at any point on half of the wharf during any stage of the tide.

Two hinged chutes about 40 ft. long, hoisted by a gypsy, were attached to the rear of the mixer barge and extended out over the material barge. The rock and sand were shoveled into these chutes, the outer ends of which were then hoisted by the gypsy so that the contents dumped into iron dump cars, which, in turn, were run up an incline and dumped into the mixer. These chutes were 8 × 18 ins. and as each running foot of chute contained 1 cu. ft., it made a very convenient method of measuring quantities. The capacity of the dump cars was insufficient to supply the full capacity of the mixer, so that on the outer half of the wharf only ⅓ cu. yd. of mix was obtained. For the work on the other half, side boards were placed on the cars and the mixer charged to its full capacity of ½ cu. yd.

From 30 to 33 men distributed as follows were required to handle the equipment on the wharf: One foreman at $6 to direct the placing of concrete and handling of barge; one man at $4 to swing tube; three men at $4 shoveling and tamping. On the barge: One finisher at $6; one engineer at $5 hoisting skip and dump cars; one engineer at $5 on mixer engine; one man at $4 on gypsy hoist; three men at $4 to handle mooring lines; two men at $2.50 firing boilers; two men at $2.50 handling cement; one man at $4 cleaning hopper;

11 to 14 men at $4 running mixer, shoveling, etc.; 2 to 6 men at $2.50 shoveling. The mixer averaged about 25 batches per hour, as the dump cars did not deliver the material fast enough to keep it supplied.

Considerable time was lost in moving the barge to change the location of the tube, which, in reality, was too cumbersome for the work it was required to do. Had the mixer been of 1-yd. capacity the cost could have been greatly reduced, as doubling its capacity would have required only about four men in addition to the actual crew.

Fenders, Etc.—The fender piles which were treated with a 12-lb. treatment of creosote, were driven by a top driver on the wharf. The average time of trimming the head of a pile and getting it into the gins was 15 minutes. The time of driving was from 5 to 7 minutes. The waling was formed in sections and hoisted into place.

The railroad tracks on the wharf were of 141-lb. grooved rails without spacers, embedded in concrete.

Cost of Cellular Concrete Superstructures for Timber Piers.—J. A. B. Tompkins in Professional Memoirs, describes the methods and costs of repairing timber piers and jetties. The following matter is taken from an abstract of Mr. Tompkins' paper published in Engineering and Contracting, Aug. 22, 1917.

Concrete superstructures are cellular in type, consisting of two parallel walls connected at intervals of about 8 ft. by cross walls from 12 to 18 in. thick, thereby forming open pockets or "cells" which are filled with rubble stone. The superstructure is built in monolithic sections, 24 or 25 ft. in length, and is provided with a continuous walk of reinforced concrete slabs, supported by the cross walls.

In all cases where an old pier is to be provided with concrete superstructure of this type, the work has been done by hired labor and use of Government plant.

The work of building cellular superstructures on old piers does not require a large or special plant. The plant now being used in the Milwaukee District for such work consists of a floating derrick of 3 to 5 tons' capacity, two flat scows, and a small gasoline tug. A steam-driven concrete mixer, having a capacity of about two-thirds of a yard of finished concrete, is placed on one scow; the other scow is used for carrying materials. With this plant and a crew of about 15 to 20 men, from 200 to 300 lin. ft. of superstructure are built per month, including the cutting down of the old pier.

The total cost of the concrete superstructures described, including the cost of cutting down and preparing the old pier for reception of the superstructure, has been from about $12 to $15 per linear foot of pier, depending upon the width of pier, which usually varies from 14 ft. to 18 ft. center to center of parallel rows of round piles.

An adaptation of the form of superstructure described has been used for original pier construction. In this case the sides of the pier are alike, consisting of round piles spaced 4 ft. centers, with 9-in. triple-lap sheeting; 12 by 12 in. spreaders are used between round and sheet piles. The general method of construction is the same as that previously described. All work constructed according to this design has been done by contract. The timber, cement, and reinforcing steel were furnished to the contractor by the United States; all other materials were furnished by the contractor. Table IV shows the approximate cost of building 100 lin. ft. of this style of pier in this district by contract, including the cost of materials furnished by the United States.

Cost of a Timber Pleasure Pier on Pile Bents.—In Engineering and Contracting, Sept. 28, 1910, Benjamin Brooks gives the following. The site of the pier was a prospective beach resort upon the coast of California.

It was 10 miles from the nearest port, about 3 miles from the nearest broad-gage railway (which, however, did not connect with the port) had absolutely no roads leading to it, and was girt on one side by heavy surf and on the other by barren sand dunes.

After a preliminary trip, the writer decided to run the risk of beaching the materials on the spot and to ship the pile driver outfit through the port to the nearest narrow gage station—about 7 miles away—and team it from there to the beach.

An experienced freighting company was hired by the day to transport the pile driver outfit. The first four miles of road were perfectly level and good; the last three were simply trails over the deep, dry sand leading on to the hard beach, where, however, a small stream was to be crossed. A team of four horses and driver cost $6.50 per 9-hour day. For the first part of the journey the teams worked separately, but on the last three miles they doubled and trebled, the engine sinking its wagon down in the sand till it dragged. The trip required twelve team days, or $78—over $11 per mile.

Setting up the driver took three days and was done in a piecemeal manner according as the outfit arrived by team. A foreman at $5 and a crew of three men at $3 brings this setting up expense to $42.

Beaching the lumber and piles proved to be a somewhat uncertain but satisfactory method of getting them there, and much cheaper than any other way. The material comprised the deck load of a small coasting steamer. After having coaxed a few farmers in the neighborhood to appear on the beach with their teams on a certain morning to be named later, the writer left things in charge of the pile driver foreman and set out to meet the steamer at the nearest port. She was only three days late, but arrived at night so that orders could be phoned to have the farmer-teamsters on hand next morning.

On the following day the weather was so thick that the steamer sailed past the wharf site twice before it could be identified from the sea;

TABLE IV.—APPROXIMATE COST PER 100 LIN. FT. OF PILE PIER WITH CONCRETE SUPERSTRUCTURE

Materials	Unit cost	17-ft. pier—16 ft. water Quantities	Cost	14-ft. pier—12-ft. water Quantities	Cost	11-ft. pier—8-ft. water Quantities	Cost
Round piles, lin. ft.	$ 0.37	1,450	$ 536.50	1,250	$ 462.50	1,050	$ 388.50
Sheet piles, ft. B. M.	44.00	39,600	1,742.40	32,400	1,425.60	25,200	1,108.80
Timber, ft. B. M.	47.50	10,633	505.07	10,633	505.07	8,033	381.57
Bolts, spikes, etc., lbs.	0.05	3,761	188.05	3,412	170.00	3,064	153.20
Concrete superstructure, cu. yds.	10.50	98	1,029.00	93	976.50	87	913.50
Concrete slabs, cu. yds.	12.00	12	144.00	6	72.00	6	72.00
Reinforcing bars, lbs.	0.02	3,249	64.98	2,303	46.06	2,003	40.06
Stone—filling and riprap, tons	1.60	2,000	3,200.00	1,100	1,760.00	425	680.00
Cost of 100 lin. ft. of pier			$6,904.93		$5,418.33		$3,737.63

so that it was 1 p. m. before the first stick was thrown overboard. The teamsters meanwhile continued leisurely to draw their pay on the beach, as did also two expert surf boatmen in a dory hired to take lines ashore if necessary or to rescue stray timber. These latter proved unnecessary, but were a good safeguard in case of change of wind.

The first pile thrown over showed that the vessel was not anchored exactly in the right place, and she was accordingly moved. Her final position was about a mile off shore. The surf was rather heavy, the wind light and the timber took about an hour to drift in. It arrived a good deal faster than seven teams could pick it up, but the surf and wind kept it on the beach. It did not, however, all come to one place, but scattered out about 1,000 ft. wide. No attempt was made to pile it, but each piece was pulled up the beach, where it struck and left above high water mark. The last piece left the vessel about 5 p. m., and the last snaking out occupied the teams until 10 p. m. They had the advantage of a moon and free hot coffee.

The following costs are worked out without regard to the six hours lost in waiting for the vessel, for this delay is always likely to happen; and both teams and boats are counted as having worked from 7 a. m. until about 10 p. m. On this basis the landing and snaking to safety required:

0.090 boat hours per M at $2.00	$0.180
0.785 team hours per M at $0.40	.314
0.64 man hours per M at $0.20	.128
Total	$0.622

The following day at daylight a few teams were engaged to sort out and gather up the lumber from the beach and pile it at the wharf site. Owing to bruised legs and other discomforts incident to working in the surf, the price of teams had increased over night, so that the cost of stacking the material was:

1.40 man hours per M at $0.25	$0.35
1.36 team hours per M at $0.50	.68
Total	$1.03

which brought the total cost of bringing the lumber to the pier site $1.65 per M ft. B. M.

The pier was of simple construction, with bents 20 ft. apart, four piles to the bent (the two outside ones battered) under a 12 × 12 in. cap 16 ft. long, which was drifted and strapped to each pile. The deck was 2 × 12 in. on 3 × 12 in. joists. There was a light railing on each side.

The piled iver had 35 ft. swinging leads and 64 ft. gunwales, a 3,500-lb. hammer and an oil burning engine big enough to keep up steam under hard driving. The sand was so compact that piles sometimes collapsed under the hammer before they had reached the required 10 ft. penetration. After the driving was well under way the time of each operation was as follows:

BENT No. 9

	Minutes
Rigging staging for cross-cut saw men	13½
Placing battons	8
Sawing off four piles	15
Hoisting cap in position	2½
Boring and drifting cap (straps put on later)	12
Removing staging and tieing bent to previous one	5½
Pulling driver ahead	3
Placing first pile	6½
Driving first pile (81 blows)	7½
Plumbing leads	1½
Placing second pile	5
Driving second pile (83 blows)	9
Placing third pile	9
Driving third pile	6
Placing fourth pile and swing leads	5½
Driving fourth pile	6
Total for driving and capping bent	115½

BENT No. 10

	Minutes
Pulling driver in position	5½
Hoisting and placing first pile	3
Driving first pile (67 blows)	6½
Plumbing gins and placing second pile	5
Driving second pile (62 blows)	5
Placing third pile	2½
Driving third pile (58 blows)	5
Placing fourth pile	5
Driving fourth pile (63 blows)	3
Rigging staging for cut-off	10
Placing battons	8½
Sawing off four piles	12
Placing and drifting cap	13½
Tieing bent to previous one	5
Total for driving and capping bent	89½

Occasional delays brought this down to four bents per 9-hour day. The crew comprised an excellent foreman, a well drilled set of seven men and a team. The daily expenses of running the driver were:

Crew (foreman, $5.00; men, $3.00)	$26.00
Team	4.50
Extra man on beach	2.25
Fuel oil (including teaming of same)	4.00
Interest and depreciation on outfit	3.00
Engine oil (assumed)	.25
Total	$40.00

This gives a cost of $10 per bent. To sum up, we have a piledriver expense of $78 teaming and $42 setting up, and assuming an equal cost of removal brings this to $240. Since the pier was 800 ft. long, the piledriver charges would be $^{20}/_{800}$ of $240 or $6 per bent.

Pile driver expenses	$ 6.00
Beaching and stacking 3¾ M lumber at $1.65	6.19
Driving and capping	10.00
Placing joists and deck, 1½ M at $4.76	7.14
Placing railing, 0.13 M at $10	1.30
Placing cap straps (estimated)	2.00
Total	$32.63

which is equal to $1.63 per foot.

This is, with the exception of oil for the pile driver and interest on it, a strictly labor cost. The time of the writer for surveys, soundings and steamer piloting is not taken into account, nor are the railway freights, fares for the crew, rent of quarters in the "pavilion," reconnaissance, and so on.

This method of landing lumber requires a wide beach and a steady wind blowing directly or almost directly on it. If the wind blows at an angle with the beach, the lumber will drift a long way before beaching, and scatter very much. A change of wind is fatal, so that not too much lumber should be afloat at a time. Anything smaller than 2 × 10 ins. should be fastened in square bundles to avoid breakage in the surf. Too much care cannot be taken to avoid broken legs.

Cost of Driving Sheet and Bearing Piles and Placing Concrete for the Concrete and Steel Ore Dock of the Duluth and Iron Range R. R.—Leland Clapper in Engineering and Contracting, July 17, 1912, gives the following.

The concrete steel dock, erected on the site of a former one of timber, is made up of a timber approach 220 ft. long, a steel approach 329 ft. long, the dock proper 1,344 ft. long, and an end tower of 32-ft. span. The timber approach has three-pile bents and twelve-trestle bents of 15-ft. centers, with a 10-ft. span joining onto the steel approach. The steel approach has four 32-ft. towers with three spans of 63-ft. deck plate girders joining them and a 12-ft. span joining the last tower to the dock proper. In the dock proper, there are 112 spans 12 ft. long, each span supporting an ore pocket on each side of the dock. The dock proper and end span are level, the steel approach is on a 0.304 per cent grade, the timber approach on a 0.20 per cent grade and the ore yard on a 0.51 per cent grade, all being down grade away from the dock.

Foundations.—The entire area to be covered by the foundation of the dock proper was enclosed by sheet piling. The two side walls of sheet piling were 55 ft. inside to inside, while the end walls were about 1,404 ft., making the total area enclosed about 1.8 acres. The sheet piles, of which 2,350 were required, were made of 12 × 12-in. fir 32 and 34 ft. long, by spiking to these, with ⅜ × 8-in. boat spikes, 3 × 4-in. strips flatwise, to form tongues and grooves. The points were made by sawing them on a long bevel of about 2 to 1 sloping up from the groove side to the tongue. Any side beveling, necessary to hold the pile to line, was done at the drivers.

The sheet piles were handled from the framing yard to the drivers by a derrick scow. Two roller drivers were used, one on each side of the dock, each having a 2,800-lb. hammer and 35-ft. leads.

The lake bed, at this point, is red clay, so that jetting was impossible. However, little difficulty was experienced in driving. An occasional wedge was used to keep the piles plumb. These were made by ripping the 12 × 12-in. timber diagonally and then nailing on the tongue and groove. A sliding block, made with a groove to fit over the tongue of the pile being driven, and with a line passed around it to the engine, held the pile firmly to place during the driving. A hand winch was used to hold the tops of the piles tight after they were driven. A temporary inside waling or guide timber was bolted to the ends of the pile caps of the old foundation and to this about every fifth sheet pile was bolted to hold it in place and to maintain a true line until the temporary outside waling timbers could be placed. These temporary outside waling timbers were 14 × 14 in. second-hand fir and were placed 11 ins. below the sheet pile cut-off, which was 6 ins. below mean water level. The two walls were then tied together through these timbers with 1-in. × 59-ft. rods, spaced

6 ft. centers, and using a center turnbuckle. The final anchoring of the sheet piling was by placing a 1-in. bolt 4 ft. 8 ins. long through each pile at a point 8 ins. below the cut-off.

Following the sheet pile driving, a swing driver having a 4,200-lb. hammer and 65-ft. leads, drove the bearing piles, varying from 30-ft. to 60 ft. in length in the main foundation. These piles were unloaded from cars at a point where they could be easily pointed, sorted, and rolled into the water for rafting. The piles were cut off by hand at a point 1 ft. 3 ins. below mean lake level. The rows of new bearing piles are spaced 6-ft. centers with a row of the old timber dock bearing piles half way between. In each row on each half of the dock, there are seven piles spaced 2½ ft. centers, the first being 1½ ft. from inner edge of the sheet piling. The pile driving specifications called for a penetration of not over 6 ins. in six blows under a 40-ft. drop of a 3,000-lb. hammer, or its equivalent.

In Table V for sheet piling, the item "preparing and handling" includes spiking on the tongues and grooves, using about 50 ⅜ × 8-in. spikes per pile, also sharpening, loading by derrick from skidway to scow, and unloading at the drives. The item "waling and tying" covers the placing of the temporary inside guide timbers, the temporary outside waling timbers and all temporary and permanent bolts and anchors.

TABLE V.—TIME COST OF SHEET PILING (2,350 PILES)

	Hours	Hours per 100 sheet piles
Preparing and handling:		
Foreman	370	15.58
Carpenters	520	21.89
Skilled labor	1,630	70.73
Common labor	4,950	208,40
Engineer	340	14.31
Tug and crew	40	1.68
Derrick scow	250	10.53
Driving:		
Foreman	590	24.84
Skilled labor	1,890	79.57
Common labor	2,160	90.94
Engineer	830	34.94
Drivers	570	24.00
Cutting off:		
Common labor	1,700	71.57
Waling and tieing:		
Foreman	760	32.00
Carpenters	2,380	100.20
Skilled labor	6,330	266.49
Common labor	13,370	562.88
Engineer	1,960	82.52
Tug and crew	40	1.68
Derrick scow	1,040	43.78
Drivers	570	24.00

Table VI for round piles includes only those piles in the dock proper. The item "pointing and handling" includes sorting, pointing, rafting and delivering to drivers. The cutting includes the removing of the old pile heads.

TABLE VI.—TIME COST OF ROUND PILE WORK (163,500 PILES)

	Hours	Hours per 100 lin. ft.
Pointing and handling:		
Foreman	20	.0122
Engineer	350	.2135
Skilled labor	2,330	1.4213
Common labor	2,390	1.4579
Derrick scow	130	.0793
Team	350	.2135
Driving:		
Foreman	670	.4087
Engineer	670	.4087
Skilled labor	2,670	1.6287
Common labor	2,690	1.6409
Pile driver	660	.4026
Cutting off piles:		
Foreman	130	.0793
Skilled labor	600	.3660
Common labor	3,180	1.9398

The forms for all concrete work were made of 2-in. matched lumber and were set, removed and carried ahead by a small derrick scow. The outside forms, of which 19 sections 24 ft. long were used on each side of the dock, rested on the temporary waling timber 4 ins. outside the sheet piling. An expansion joint above mean water level was used every 72 ft. A key 6 ins. × 3 ft. was made in the end form at each joint so that there could be no transverse movement of sections. As soon as the outside and center core forms had been set, the reinforcing rods were bent and placed. In each 72-ft. section about 12,100 lin. ft. of 1-in. smooth circular rods and 900 lin. ft. of 1½-in. rods were used. The main slabs are 19 ft. 4 ins. wide, with an opening of 19 ft. between them and are 5½ ft. thick, extending from 2½ ft. below mean water to 3 ft. above the same. These slabs are tied together every 24 ft. by 3 × 4-ft. concrete tie walls reinforced with four 1½-in. × 36-ft. rods. Raising from the main slab by three 8-in. steps and extending from its outside edge to its center, is a parapet slab 2 ft. thick. On the main parapet and at its outer edge is a parapet walk 9 ins. thick and 2½ ft. wide. The tops of the parapets and slabs were given a slope of ⅛ in. to the foot toward the center of the dock to insure drainage. The center line of the piers, which are 4 ft. 9 ins. square on top with batters of 1 in. to 4 ins., is 18½ ft. from the center line of the dock. These piers are tied to the main slab by four 1½-in. × 9-ft. reinforcing rods.

Two scow mixers were used on this work, one on each side of the dock. The one was a ¾-cu. yd. Smith mixer with chain conveyors carrying materials from hoppers on main deck to a measuring hopper which fed into the mixer about 15 ft. above the main deck. A derrick scow supplied sand and gravel to the hoppers. The ¾-cu. yd. mixer mixed two-thirds of the total yardage: Its scow was about 80 ft. long and 25 ft. wide. A three-story tower about 16 ft. square was erected in the center of the scow. On the lower floor of the tower were the boiler, pumps and conveyor engines. On the second floor were the mixer, mixer engine and the gate controlling the measuring hopper. And on the third floor were the measuring hopper and the levers controlling the conveyors. On the deck of the scow and 6 ft. from the edge of the tower toward the one end was the sand hopper, and toward the other end was a gravel hopper. Behind the sand hopper on the end of the scow was a small cement shed holding about 200 bbls.

Conveyors handled the cement in sacks from the deck to the third story and gravel and sand from the hoppers on the main deck (holding material for about 30 cu. yds.) to the measuring hopper.

The mixer required for running, an engineer, a fireman, two laborers handling cement to the conveyor, one man at the mixer, and three men on the top floor dumping cement and operating the conveyors. The maximum day's run for this mixer was 280 cu. yds.

The second scow had two ½-cu. yd. Smith mixers mounted about 20 ft. above water level. Here the material was shoveled into a bucket on the deck of the scow, hoisted and dumped into a hopper which discharged into the mixer. With either scow, the mixers would dump to any part of the section by the use of spouts. Cement was supplied to each mixer by a small cement scow. The maximum day's run for both mixers was 438 cu. yds., while the average day's run was 245 cu. yds.

The materials used for concrete were lake gravel and sand in proportions so that when mixed with five sacks of Universal Portland cement per yard it would give the densest concrete.

In placing the concrete, every other 72-ft. section, for five sections, was filled to the top of the main slab, including the tie walls. Forms were then set and filled for the parapets in these sections. As soon as these parapets had set, the end forms were removed and the sections between filled. These end walls were painted with tar before filling the section between, the tar destroying the bond of the concrete and making a good expansion joint.

The forms for the piers were set and filled about half full of concrete, which was allowed to set before anchor bolts were placed. The anchor bolts were then set in templets and wired plumb, after which the piers were filled to within 1 in. of elevation. Triangular strips, so beveled that the tops were horizontal when placed, were nailed to exact elevation. The tops of the piers were leveled from these strips with a steel-faced straight edge by using 1 to 3 mortar. Castings were set without grout.

A fender of two timbers was used. The top timber, which was a 14 × 16-in. recessed 4 ins., was placed with its edge 1 in. below the parapet walk and bolted through pipe through this walk. The lower timber was a 12 × 12 in. recessed 2 ins. and fastened by 1-in. upset bolts threaded at both ends and placed in pipe in the main slab before concreting.

In Table VII the item for handling and placing new concrete includes unloading cars; loading on and unloading from scows, and fastening the reinforcing in place with wire. The item "forms" includes the making, placing, bracing and removing of all forms. The item "anchor bolts" includes making and placing templets and setting bolts. The item "mixing and placing" covers the handling to the mixers of the sand and gravel from a stock pile on the old foundation, or a portion of the finished new foundation; of handling cement from cars and all mixing, placing and finishing of the concrete.

The time shown in the above tables does not include the time required to get outfits to the work and in shape to run.

A top traveler with two 70-ft. steel booms was used for erection. This traveler erected all of the heavier members and sufficient bracing to allow it to proceed. A portion of the lighter bracing and the platforms were placed by a derrick car. The riveting was all done by compressed air, furnished by the railroad company from its permanent compressors. Riveting followed erection as closely as convenient, usually with about six hammers working and driving 2,500 rivets daily.

TABLE VII.—TIME COST OF HANDLING AND PLACING CONCRETE
(15,040 cu. yds. concrete, 746,000 lbs. reinforcing)

	Hours	Hours per cu. yd.
Bending reinforcing:		
Foreman	200	.0132
Skilled labor	680	.0449
Handling and placing reinforcement:		
Foreman	560	.0370
Skilled labor	3,260	.2152
Common labor	4,750	.3135
Flat scows	520	.0343
Forms:		
Foreman	1,510	.0997
Carpenters	9,340	.6164
Engineers	315	.0176
Skilled labor	5,770	.3808
Common labor	6,300	.4158
Derrick scows	320	.0211
Anchor bolts:		
Carpenters	1,135	.0749
Common labor	950	.0627
Mixing and placing:		
Foreman	1,680	.1109
Engineer	2,250	.1485
Skilled labor	6,770	.4668
Common labor	9,990	.6593
Derrick scows	620	.0409
Flat scows	640	.0422
Scow mixers	1,120	.0739

Cost of Driving Piles with a Gasoline Hoist.—Engineering Record, July 18, 1914, gives the following.

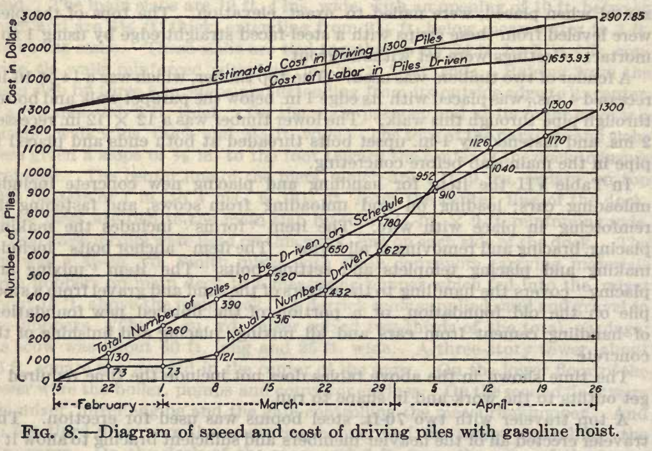


FIG. 8.—Diagram of speed and cost of driving piles with gasoline hoist.

A reversible gasoline hoist with a 6½-hp. engine and operating a 1,650-lb. drop hammer has been used for driving 1,300 piles to support a stage for 7,000 singers during the St. Louis pageant. These piles were driven from a scow about 6 ft. deep in the bottom of the Mississippi River at Forest Park.

In the accompanying diagram (Fig. 8) are shown the total number of piles to be driven on schedule and the actual number of piles driven, the estimated cost of driving 1,300 piles and the actual cost of labor on piles driven. The largest number of piles driven in one day was seventy-five. In the estimate were included 17,105 lin. ft. of piling at a cost of 17 cents, giving a total cost of $2,907.85. The average length per pile was estimated to be 13.15 ft.

Actually 1,326 piles, aggregating 19,104 lin. ft. and averaging 14.4 ft., were driven. Of this number 25 piles were driven out of line, so that the useful number was 1,301 piles, aggregating 18,735 lin. ft. Allowing 100 per cent depreciation on engine and scow, the cost of driving 18,735 lin. ft. was $2,148.38 or 11.5 cents per foot. This depreciation, of course, is excessive, and if 20 per cent is allowed on engine and scow and 15 per cent for over head charges the total cost of driving was $2,000.92 or 10.7 cents per linear foot. The cost of the piles delivered was $1,432.80 or 7.5 cents per linear foot, so that with a cost of driving of 10.7 cents the cost per linear foot of pile in place was 18.2 cents. The crew consisted of four men.

The itemized costs were as follows: Cost of piles delivered, $1,432.80; total payroll, $1,653.93; engine and hoisting outfit, $340; scow, $154.45.

On this work, union men were employed, at the following rates:

Hoisting engineer, 80 cts. per hr.; piledriver foreman, 75 cts. per hr., piledriver laborers, 40 cts. per hr.

The driver leads were 20 ft. high, built with 6 × 6-in. timbers, braced back to the rear portion of the scow. The hoisting equipment, built by the Whitman Agricultural Co., St. Louis, consisted of a 6½-hp. "Sultan" reversible gasoline-driven engine, geared into two drums with necessary controls, etc. A winch head, on the hoist, was used to pull in the piles. The weight of the drop hammer was 1,650 lb. The scow was 14 × 16 ft. and 3 ft. deep.

Cost of Driving Sheet, Foundation and Marine Piles.—In a paper presented by Victor Windett before the Western Society of Engineers and abstracted in Engineering and Contracting, June 21, 1911, the following is given.

Trench Sheeting.—A sand trench 4,017 ft. long and 10 ft. deep was sheeted with 2 × 10 in. × 14 ft. hemlock and yellow pine sheeting, to carry a steam shovel over the trench. Triple lap sheeting was made by nailing 1 × 6 in. × 12 ft. hemlock sides to give a 2 in. groove. The cost of making the sheeting ready for driving was 8.8 hours of labor at $2.63 per 1,000 ft. B. M. with labor at $0.31 per hour. The work was nailing on the side pieces, pointing the driving end, and cutting the hammer end to 8 in. in width to permit the use of a steel driving cap. The total labor cost, including the making of the sheeting in place, with labor at $0.30 per hour, was:

	Per M. ft. B. M.	Per lin. ft. of trench	Per sq. ft. of penetration trench side of sheeting
Hours of labor......................	21.9	1.4	0.12
Cost of labor........................	$ 6.56	$0.422	$0.035

A pile driver having two sets of leads complete was built for this work at a cost of about $600 for labor and material, excluding the double-drum hoisting engine. The leads and sheaves for the hammer line were fastened on the deck timbers so that when the width of the trench was reduced at a change in the size of the sewer, the leads were moved in towards the center line of the machine. This change took 1½ hours to make.

The sheet piling was pulled by a machine consisting merely of a platform to carry a hoisting engine and an A-frame carrying two sheaves. Over these sheaves two lines ran from the engine, on the free end of which was a few feet of ½-in. chain and a hook with which to pull the sheeting.

This machine would be manned by a pickup crew of engineman, fireman, and four laborers, who would pull, in 1½ hours to 2 hours' work, all of the sheeting corresponding to a day's progress of the work, which would be from 130 to 160 ft. The average rate of wages per hour was $0.30. The average of work was:

	Per M. ft. B. M.	Per lin. ft. of trench
Hours of labor	3.72	0.24
Cost of labor	$1.11	$0.07

One disadvantage of such sheeting was that the 1-in. side pieces had a short life, requiring renewing after about four times of use. The loss of the center pieces from hard driving and even though used nine times was very little. The pulling chain was rather severe upon the sheeting, as it was liable to cut into the wood. At the close of the work the sides were stripped off and half of the 2 × 10-in. pieces were sawed up for catch-basin bottom, which otherwise would have required the purchase of new lumber. The total waste of sheeting was about one-fourth and the remainder was shipped to another job.

Hand driven sheeting of 2-ins. × 10-12 ft. long is best driven in sand by a combination of hand mauling and the use of the water jet. Employing labor at $0.314 per man per hour, the expense of this work for 1,102 ft. of trench was:

	Per M. ft. B. M.	Per lin. ft. of trench	Per sq. ft. penetration
Hours of labor	11.9	0.973	0.042
Cost of labor	$ 3.70	$0.305	$0.013

Table VIII.—Foundation Piles. Chicago Drop Forge & Fdy. Co.

	Hours	Cost	Cost per lin. ft.
Erection and dismantling driver	386.5	$160.53	$0.088
Unloading and sawing piles in two	39.0	15.96	0.016
Driving piles	236.0	99.32	0.011
Sawing pile tops to grade	53.0	19.88	0.054
Total	714.5	$295.69	$0.169
Freight, supplies and piles, cost	.....	279.02	0.152
Total cost	.....	$574.71	$0.321

Soil, hard clay; hammer used, 3,000-lb. drop hammer.
Material—96 piles, 20 ft. long. Crew 10 men.

Foundation Pile Driving.—Table IX is the record of a large piece of work carried on by the contractor with great vigor. At times as many as 9 pile drivers were at work simultaneously.

In foundation pile driving, where piles are driven in clusters, the general level of the ground will be higher after driving than it was before. This swell or rise of the level will cause an extra amount of excavation for the placing of the footing concrete around the pile tops.

Careful levels were taken over an area in which 1,570 piles were driven 2½ ft. centers. The piles were 35 ft. long, having 12-in. tops and 7-in. points. The swell of the ground amounted to 1.5 ft. in height, or 8.3 cu. ft. net measurement of the earth per pile, or 0.28 cu. ft. of pile penetration. Inasmuch as the volume of the piles below the original surface averaged 14.1 cu. ft., the consolidation of the earth amounted to 5.8 cu. ft. per pile. The soil consisted for about 10 ft. of a mixture of loose sand, gravel and clay. Below this was a moderately soft blue clay.

At the job for the hammer shop, a drop hammer, weighing 3,000 lbs., was used. In fact, the same driver and crew foreman did this work as the drop-hammer driving, for which costs are given in Table IX. But in the case of Table VIII the soil was clay, whereas the first 10 to 12 ft. was sand, in the other case.

TABLE IX.—FOUNDATION PILES

	No. 1 Vulcan steam hammer	3,000-lb. drop hammer
Total number of piles	10,417	519
Total length of piles	373,715 feet	71,855 feet
Total length of pile penetration	358,090 feet	16,817 feet
Average length per pile	36.0 feet	34.4 feet
Average length of piles undriven	1.5 feet	2.0 feet
Average day's work for 1 driver	277 days	30 days
Aveiage piles driven per day	37 7 piles	17.3 piles
Average piles driven per day	1,349.2 lin. ft.	595.2 lin. ft.
Average piles penetration per day	1,296.2 lin. ft.	560.6 lin. ft.
Crew per driver	10 men	9 men
Auxiliary men per driver per day	8 men	6 men
Total crew per driver per day	18 men	15 men
Crew time 8 hr. day	2,770 days	270 days
Auxiliary time 8 hr. day	1,634 days	180 days
Total time 8 hr. day	4,786 days	450 days
Daily pay roll crew	$34.00	$30.60
Auxiliaries	19.75	15.25
Total	53.75	45.85

Unit cost	Lin. ft. of pile	Lin. ft. penetration	Lin. ft. of pile	Lin. ft. penetration
Labor	$0.04	$0.042	$0.077	$0.082
Saving pile butts	0.003	0.003	0.003	0.003
Total labor	0.043	0.045	0.08	0.085
Supplies and repairs, est	0.01	0.01	0.015	0.015
Piles	0.125	0.125	0.12	0.12
Total "field expense"	$0.178	$0.180	$0.295	$0.220

From points of view of speed, economy, and excellence of driving, the comparison between drop and steam hammers is strongly in favor of steam hammers.

In addition, a proportional share of local general office and yard expense and the general office expense, should be added.

In sawing off pile-butts two saw filers kept the saws sharp for the gang of sawyers. A pair of sawyers would cut 40 to 60 mixed wood piles per day at a cost per pile of $0.10 to $0.12.

Other men were employed in making runways and unloading piles from cars which were delivered at the edge of the work—a team and 2 men hauling piles to the more inaccessible drivers.

The ordinary pile driver crew was composed of men as follows:

Foreman, $0.58¾ per hr	$ 4.80
1 engine runner, $0.55 per hr	4.40
1 fireman, $0.37½ per hr	3.00
1 winchman, $0.45 per hr	3.60
1 leadsman, $0.45 per hr	3.60
3 groundmen or deckhands, $0.40 per hr	9.60
1 coal passer, $0.25 per hr	2.00
1 pile hooker and trimmer, $0.37½ per hr	3.00
Total labor crew	$34.00
Auxiliaries, 6 men	15.00
Proportion of pumping station labor, supplying water for jetting	2.00
Field superintendence	2.75
Total labor	$53.75

Marine Pile Driving.—The marine pile driving, as given in Table X was all within a protected harbor shielded from the heavy waves of the open lake, so but little time was lost by rough seas. In the delivering of piles from cars to scows, a large part of the labor was done by steam devices, but it is considered as being equal to the expense of six men all of the time the marine driving was going on. The soil was sandy for a few feet and below that it consisted of a moderately soft clay. The piles stood out of the water on an average of 12 ft. per pile, undriven. A tug was occupied about one-third of a day per driver in towing out and back to the yard. A drop hammer of 3,500 lbs. weight was generally used, being attached continuously to the hoisting rope. Each driver had two scows for piles, one on the work and one at the yard being loaded with piles.

TABLE X.—MARINE PILE DRIVING BY GREAT LAKES DREDGE & DOCK CO.

Number of piles driven	9,896	
Length of piles driven	326,295 lin. ft.	
Length of pile penetration	207,816 lin. ft.	
Average of piles	33 lin. ft.	
Average of piles driven	21 lin. ft.	
Total days' work and driver	137	
Piles per day work and driver	72.2	
Piles per day work and driver	2,380 lin. ft.	
Penetration per day work and driver	1,516 lin. ft.	
Crew of driver	10 men	
Auxiliaries driver	6 men	
Total men per driver	16 men	
Total crew time	1,370 days	
Total auxiliaries time	822 days	
Total	2,192 days	
Pay roll per day:		
Tug service		$15.00
Crew		34.00
Auxiliaries		19.75
Total		$68.75
Costs	Lin. ft. of piling	Lin. ft. of penetration
Labor	$0.029	$0.0453
Supplies and repairs	*0.015	*0.0235
Piles	*0.125	*0.1962
Total "field" expense	$0.169	$0.265

* Estimate.

Foundation Pits.—Triple lap sheeting was driven for three foundation pits. The upper 15 ft. of ground is sound, below which is a soft clay. Through the sand, driving was assisted by using a water jet. The expense of this work is given in Table XI.

TABLE XI.—FOUNDATION SHEET PILE DRIVING

Piling driven, pieces	405
Piling driven, lin. ft.	9,291
Piling driven, ft. B. M.	83,622
Moving out and off job, 5 days	$227.50
Driving, 19 days	679.00
Total, 24 days	$906.50

Unit cost of labor—

$ 2.24 per pile
0.098 per lin. ft.
10.84 per M. ft. B. M.

Two No. 1 Vulcan steam hammer drivers were used. Hence the item of moving on and off the work was somewhat high. The average rate of pay per man per 8-hour day was $3.50; including men nailing the sheeting planks together, the average size of crew per machine was from ten to twelve men. Including supplies and repairs, the expense per machine per day was approximately $50.00, whereas the labor as above given amounted to $37.77 per day.

At the same place 717 pieces of 9-in. by 12 in. 28 ft. triple-lap sheeting were driven. This formed a subaqueous front of a concrete-topped wharf. Table XII gives the cost of this work.

TABLE XII.—WHARF SHEET PILING—TIME OCCUPIED IN THE WORK, 29½ DAYS

Piling driven—	
405 pieces	
14,340 ft. driven in ground	
180,784 ft. B. M. of lumber	
Towing, ⅓ of cost of 30 days at $10.00	$ 300.00
Making sheeting, 75 days at $3.00	225.00
Driving, 285 days at $3.50	997.50
Pulling, 10 days at $3.50	35.00
Total, 370 days	$1,557.50
Labor cost per piece	$2.17
Labor cost per lin. ft. driven	0.109
Labor cost per 1,000 ft. B. M	8.62

Durability of Untreated Piling Above Mean Low Water.—Engineering and Contracting, April 24, 1918 publishes the following information prepared by Mabel E. Thorne, Statistical Clerk, and C. H. Teesdale, in charge Section of Wood Preservation, Forest Products Laboratory, Forest Service.

It has long been recognized that wood constantly immersed in water is not subject to decay. Instances are on record of wood being preserved in this way for centuries. Timber structures in fresh water or in water free from the various forms of marine woodborers remain sound indefinitely, unless affected by some destructive agent other than decay.

In tidal water, where marine borers are not active, portions of piles that are completely immersed at each high tide may be exposed at other times without danger of decay, for though completely immersed only part of the time, they may be practically saturated all the time. The extent of this saturation, and therefore permanent preservation against decay, is an item of considerable interest and importance in designing pile construction. The difficulties of cutting off piling at low water, as well as the extra cost and weight of the superstructure, when joints are made at low tide level, may well be avoided wherever immunity from decay exists for any distance above this level.

Because there is so little available data as to the extent of this immunity zone, the Forest Products Laboratory has recently been conducting a study of the subject by the questionnaire method. They show careful thought, and several of them contain records of actual investigations made after the questionnaire was received.

Replies received from 25 different sources were divided into two classes, those which state that for permanent foundation work piles can be safely cut off at mean tide level or above and those which state that the zone of safety does not extend to mean tide level. It is noticeable that the grouping of these replies according to their character is a geographical grouping as well. The climate of the northern states is more favorable to the long life of piling than that of the southern states. From the data at hand, it would seem that the line of demarcation between the harbors in which it is safe to cut off piling at mean tide level or above and the harbors in which it is not safe lies somewhere between New York and Baltimore.

The rate at which a pile dries is largely dependent on temperature and relative humidity. The relative humidity varies only slightly from Maine to Florida, while the temperature variation is considerable. This means that, a few hours after high tide, piles in southern waters will have a much lower percentage of moisture than those in northern waters, which, combined with the encouragement to the growth of fungi furnished by the higher temperatures, probably accounts for the variation in the extent of the zone of safety.

Life of Creosoted Piles.—From time to time as structures are demolished to make way for extensive improvements there is afforded an opportunity for observing on a large scale the behavior of treated piles. An instance of this kind is noted in Engineering and Contracting, July 23, 1919, from which the following is taken:

A wharf of the Southern Pacific Railroad on San Francisco Bay was removed to make room for port improvements. The wharf was the oldest creosoted pile structure which thus far had been dismantled on the Pacific coast and contained about 14,000 creosoted piles which had been in service for periods ranging from 18 to 29 years. Of these piles, interest centers particularly in 600 which were of Douglas fir, well seasoned before being treated with creosote by the Bethel process in the fall of 1889, and were driven in 1890. Records show that under a pressure of 200 lb. per square inch and a temperature of 260° F., the piles absorbed 14.17 lb. of creosote per cubic foot.

Of these 600 piles, 33 were selected at random for test purposes when the wharf was dismantled. Out of this number 22 (67 per cent) were entirely sound; 2 (9 per cent) had been slightly attacked by borers; 6 (18 per cent) had been severely attacked and 2 (6 per cent) were so damaged as to be unfit for further use. These percentages were typical of the entire lot, it is reported, and about 70 per cent of the 600 are to be redriven just as they are. In fact, this percentage of piles suitable for redriving, it is reported, applies approximately to the entire 14,000 piles. Those not as suitable showed damage only between mud line and high-water mark, and other portions of these piles were in good condition.

The results of this study are believed to confirm the theory that a creosoted pile is absolutely immune from attack of marine borers such as exist in Pacific Coast waters, so long as the shell or portion of the pile impregnated with creosote remains intact.

Cost of Driving Piles for the Panama-Pacific Exposition.—L. F. Lewrey in Engineering News, July 30, 1914, gives the following:

The site on which the Main Exhibit Palaces of the Exposition are located was originally a tidal flat of San Francisco Bay, with occasional deeper bights that had been dredged out for wharves and anchorage for vessels. About twenty years ago, private interests received a grant of these tidal lands and built a rock sea wall. A large sand hill that overlay the site of the Concessions District was graded and the excavated material deposited over a large portion of the submerged area but the work was not carried to completion, and an area of water about 80 acres in extent remained to be filled by the Exposition.

Hydraulic Fill; Subsidence.—The exposition company pumped 1,300,000 cu. yd. of fill into the submerged area. This brought the surface to Elev.—2.75 approximately. The fill material averages from 60% to 70% of sand, the remainder being mud and silt. Due to the superior weight and density of this material, it crushed its way 2 to 5 ft. into the soft ooze of the old bottom, to such extent that where the original soundings showed Elev.—15, the actual bottom of the dredger fill is nearer Elev.—20.

Due to the varied lines of flow of the dredger fill and its varying character, numerous "kidneys" or watery pockets were found in the fill. These kidneys often had skins of tight sand overlying them, but on driving in a long pile their presence would be indicated by a geyser of water coming up around the pile and by the corklike action of the pile in floating up when relieved of the weight of the hammer.

Test borings were made and test piles driven covering the site of each building. The results obtained were not only valuable in giving the engineers assurance in the use of short piling, but also reduced contractors' prices by furnishing them with accurate information, thus eliminating unnecessyar waste.

Table XIII gives data on the foundation piles as driven for the exposition buildings and Table XIV gives unit costs of the tests.

TABLE XIII.—QUANTITIES AND COSTS OF FOUNDATION PILES, PANAMA-PACIFIC INTERNATIONAL EXPOSITION

Buildings	No. of piles driven	Lin. ft. piling driven	Lin. ft. piling cut-off	Piling below cut-off	Percentage of waste	Average length of pile below cut-off	Approx. cost per lin. ft. of pile below cut-off
Machinery	1,577	47,573	2,487	45,086	5.2	28.6	27 cts.
Education	634	11,595	1,608	9,987	13.9	15.7	40
Manufactures	1,591	62,292	5,429	56,863	8.7	35.7	25
Agriculture	1,374	59,710	2,253	57,457	3.8	41.8	23½
Food Products	665	12,015	2,388	9,627	19.9	14.5	40
Liberal Arts	751	10,989	1,241	9,747	11.4	13.0	40
Transportation	4,541	298,674	11,849	286,915	4.0	63.2	23
Fine Arts	1,051	31,111	4,173	26,938	13.4	25.6	25
Varied Industries	1,444	52,367	2,756	49,611	5.2	34.3	22
Mines	2,026	98,463	4,609	93,461	4.6	46.1	22
Total	15,654	......	......	645,692	....	41.2	24½ cts.

NOTE.—All piles were driven with No. 1 Vulcan Steam Hammers.

Weight of moving element approximately, lb.	5,000
Fall of hammer element approximately, ft.	3½
Average cost of Douglas fir piles delivered at site, per lin. ft.	14 cts.
Approximate cost of erecting and dismantling pile driver	$500

TABLE XIV.—UNIT-COSTS OF TESTS

(Total cost, including material, labor and engineering)

Loading piles by means of 30-ton sandboxes, per test	$70
Loading platforms with sand load, per test	15
Hand borings with auger and 3-in. casing, holes 15 to 65 ft. deep in sand and clay, per lin. ft	0.26

High Records of Pile Driving.—Engineering and Contracting, July 17, 1918, gives the following:

What is probably a world's record for pile driving was made on June 12 at the Hog Island Ship Yard, when a crew of 11 negroes in charge of Edward Burwell, working for the Arthur McMullen Co., put down 220 65-ft. piles in 9 hours and 5 minutes. The best previous record at the yard was 165 62-ft. piles driven in 9 hours and 15 minutes by the Raymond Concrete Pile Co. In the construction of the foundation for the extension of the Northern Pacific Ry. ore dock at Superior, Wis., the contractors, Siems, Helmers & Schaffner, drove 168 60-ft. piles in 9 hours with a turntable device. In the ore dock work the piles were driven through holes thawed through 4 ft. of ice and in 28 ft. of water.

The equipment used in driving the 220 piles at Hog Island consisted of a

Vulcan No. 1 hammer and a skidding rolling machine, with a 3-drum 9 × 10 hoisting engine. Hammer and hoist were driven by compressed air. The log for the day follows:

7:00 a. m.—8:00 a. m.	27 piles
8:00 a. m.—9:00 a. m.	23 piles
(Delay 4½ minutes due to broken steam line; raining very hard from 8:15 a. m. to 10:00 a. m.)	
9:00 a. m.—10:00 a. m.	28 piles
10:00 a. m.—11:00 a. m.	22 piles
(Delay 8 minutes due to pile fall breaking.)	
11:00 a. m.—12:00 a. m.	27 piles
12:00 noon—12:30 p. m.	lunch
12:30 p. m.—1:30 p. m.	25 piles
(Heavy rain with electric showers from 1:25 p. m. to 2:50 p. m. 1:25 p. m. to 1:40 p. m. air pressure dropped considerably, which held up hammer.)	
1:30 p. m.—2:30 p. m.	23 piles
2:30 p. m.—3:30 p. m.	23 piles
3:30 p. m.—4:35 p. m.	22 piles
9 hours and 5 minutes	220 piles

Total linear feet piles, 14,260. Stopped driving at 4:35 p. m. as shipway No. 46 was completed and there are no remaining piles to be driven on the shipways or piers on Group No. 5. The only piles yet to be driven are fender piles, dolphins, spur piles and a few special piles for derrick footings.

The Burwell crew since it began work at Hog Island in January last has driven 4,131 piles with a total of 241,573 lin. ft. The record of this gang for 6 months follows:

Month	No. days	Piles	Lin. ft.	Average No. piles per day	Av. lin. ft. per day
January	10	190	8,531	19.0	853.1
February	11	361	20,560	32.8	1,869.1
March	23	711	42,730	30.9	1,857.8
April	23	780	47,333	33.9	2,057.9
May	27	1,470	86,173	54.4	3,191.6
June	7	619	36,246	88.4	5,178.0
	101	4,131	241,573		

Average number of piles per day (6 mos.)	42.68
Average linear feet per day (6 mos.)	2,391.82
Average length of piles	58.5

Cost of Cutting off Submerged Piles.—Arthur C. Freeman in Engineering and Contracting, Sept. 7, 1910, gives the following:

The physical conditions encountered during the building of the foundations for supporting the rails of the Old Dominion Marine Railway at Norfolk, Va., required cutting off 306 piles under water at a depth of from zero to 26 ft.

There were not enough piles to be cut to justify bringing to the job a steam outfit and diver, so it was decided to make a device for cutting by hand without the use of a diver. This was done and proved a complete success. It consists of a rectangular frame 4 ft. 3 ins. wide and with varying length, made up of 2 × 2 × ⅜-in. angles, stiffened by curved braces at the lower end and by knee braces at the upper end so bolted to the top of frame that the length from saw to the point of support is adjustable for any distance. An ordinary 4-ft. cross-cut saw was attached to the bottom by means of split bolts and tightened by nuts to the frame. The top of the frame has a small lug which fits into a saddle for support at the center of the top of the frame and free to allow a rocking motion while restrained from rising during the sawing. Two ropes were attached to the side of frame at the bottom near the saw, one pair being to supply power to produce the see-saw motion for cutting, the other to apply pressure to the saw in the line of cutting. The saddle supporting the frame rests on a "ribbon" or grade line made up of 4 × 4s placed some uniform distance above line of cut-off and to the same grade. Clamps hold the saddle to the "ribbon" and are easily detached to move the frame to the next pile for cutting. The foreman stands at the frame to steady it and give directions, two to three men were placed at each of the power lines, while one man held both of the pressure lines. The cuttings were made in three lifts, 12, 18, and 26 ft. from the point of support. The grade of cut-off was ⅜-in. to the foot descending to the water, making the cut of the last piles 26 ft. under water. After cutting the elevations were tested and showed in no case a variance over ¼ in., which was as close as could be done by hand work above surface. The maximum number of piles cut in one day was 47.

The following table shows the costs taken from the time book: Wages: Foreman $4.00, helper $2.00, labor $1.50.

75 piles at 12 ft. cutting av. cost	33⅓	cts. each
67 piles at 18 ft. cutting av. cost	32	cts. each
164 piles at 26 ft. cutting av. cost	42	cts. each

Cost of Making and Sinking Premoulded Concreted Piles.—Geo. K. Leonard, in Engineering and Contracting, July 26, 1916, gives the following:

The plans for the construction of the Lexington, Neb., State Aid Bridge, across the Platte River, called for the placing of three concrete piles 12 in. square and 45 ft. long under each of 26 piers. The bed of the Platte River, throughout its entire length, is composed of successive layers of sand and gravel, varying in size from quicksand to 5-in. stones. At this particular point, clay was struck at a depth of 40 ft. below low water, and the piles were to penetrate this 3 ft., the remaining 2 ft. projecting into the pier. The piles were reinforced, as shown in Fig. 9.

Two moulding floors 24 by 48 ft. were made and the piles cast in lots of 16, by moving the side forms from one floor to the other. Following is the material bill for the forms:

	Ft. B. M.
Sleepers, 26–4″ × 4″–24′	832
Two floors, 48–2″ × 12″–48′	4,608
Sides, 32–2″ × 12″–48′	3,072
Top braces, 14–4″ × 4″–24′	448
Miscellaneous for wedges, etc	260
Total	9,220
56–¾″ × 2′–6″ bolts.	

Cost of Material and Labor for 78 Piles

Material:	
Cement, 751 sacks @ $0.432	$ 326.51
Rods, 52,645 lb. @ $0.0275	1,084.23
Mesh, 12,166 sq. ft. @ $0.0314	382.01
Gravel, 118½ cu. yd. @ $0.75	88.88
Lumber, 9,220 ft. B. M. @ $26 per M	239.72
Bolts, 56 @ $0.15	8.40
Total	$2,129.75
Material, cost per pile	27.31
Material, cost per lin. ft	.607
Labor:	
Making, placing and removing forms	$ 148.60
Placing reinforcing	353.50
Mixing and placing concrete	97.96
Total	$ 600.06
Labor, cost per pile	7.69
Labor, cost per lin. ft	.170

Ordinarily a concrete pile will sink in the Platte River of its own weight, if properly jetted. This was tried by the contractor, but at a depth of 40 ft. a coarse layer of gravel was encountered, which carried off the water as fast as it could be pumped, and the piles would sink no further.

Not deeming it advisable to hammer on the piles, 3 ft. was cut off of each one, and the following method used in sinking them so that they would rest on the clay:

By means of a specially designed sand bucket, which will be described later, a 22-ft. length of ¼-in. steel casing, 24 in. in diameter, was sunk until the top was about 2 ft. above the water. Into this was set a 40-ft. length of casing 20 in. in diameter, which was sunk until it rested on clay. The pile was then set into the open well, and the two sections of casing pulled. The sand running in around the pile held it as firmly as if it had been driven. A steam hoist and derrick handled the casings and piles.

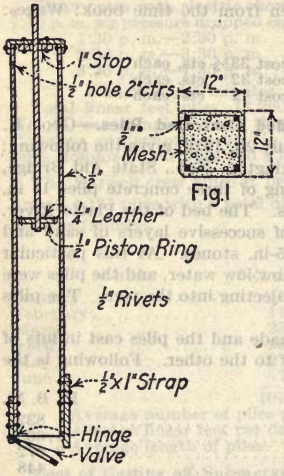


FIG. 9.—Section of pile (1) and sand bucket (2).

The bucket, which was used in excavating and sinking the casings, is shown in Fig. 9, and is described as follows: A piece of heavy steel pipe 8 in. in diameter and 6 ft. long was fitted with a hinged bottom, containing an ordinary valve opening inward. The bottom was held shut by means of a dog, which could be tripped with a hammer when the bucket was full of sand. Riveted to the top of the bucket was a steel head through the center of which the piston rod slipped. The piston was an ordinary pump piston, with leather attached. In operation, the bucket, with the bottom closed, is dropped to the bottom of the casing by means of a gasoline hoist, the hoisting line being fastened to a ring in the upper end of the piston rod. As the piston is pulled to the top, the sand is sucked in at the bottom and the bucket settles. When the piston is at the upper end of the bucket it strikes the top and bucket and all is hoisted to the top of the casing and dumped. As the sand is taken from the casing it settles, due to its own weight, and to a number of sand bags on a platform, hanging from the top of the casing. In this way, with a gang of two men at 30 cts., and one man at 20 cts. per hour, working ten hours per day, one pile could be placed per day.

The cost of sinking the piling for the job, excluding superintendence, cost of equipment, repairs, etc., is:

Labor	$634.55
Coal, 5 tons	31.50
Gas, 210 gal.	23.10
Total	$689.15
Sinking cost per pile	8.84
Sinking cost per lin. ft	.221
Total cost per pile in place	43.84
Total cost per lin. ft. in place	.998

Cost of Cutting off Concrete Piles.—Some precast concrete piles in one of the navy yards were driven to refusal while their tops were still above proper grade. The method of cutting them off is described by Civil Engineer Kirby Smith, of the United States Navy, in Bulletin 28 of the Public Works of the Navy, abstracted in Engineering News-Record, Jan. 17, 1918. The piles were 18 in. square at cutoff, reinforced with eight ¾-in. square rods tied together with ⅜-in. wire hoops 2 in. c. to c. for a distance of 3 ft. from each end and 8 in. c. to c. between these limits. They were driven 3 to 20 ft. above the required elevation, the difference being due to a varying stratum of rock. Outside the reinforcing rods there was a protective concrete covering of 2 to 2½ in. This was chipped off at the required level with a cold chisel and a sledge, leaving the rods exposed. An air drill was tried, but the chisel-and-sledge method was found to be easier. Then the rods were cut with an acetylene torch. This left the concrete core, which had a low tensile strength. Where the projecting pile was of sufficient length to give good leverage, a 1½-in. manila rope was slung around the top and four men pulling on the rope snapped the pile off at the cut. Where the projecting portion was short, the same result was accomplished by a direct pull from a stationary engine and a ⅞-in. steel cable attached to the top of the pile. Two men were employed in cutting out the concrete, and four men to snap off the piles. The average time for each pile was one hour, and the total cost per pile averaged 60 cents.

CHAPTER XXIII

BUILDING CONSTRUCTION

References.—For further data on cost of building the reader is referred to Gillette's "Handbook of Cost Data," Section X, which contains 108 pages and to Gillette and Dana's "Handbook of Mechanical and Electrical Cost Data," Chaper III which contains 70 pages.

Rapid Methods of Estimating Costs of Buildings.—In Engineering and Contracting, Nov. 28, 1917, I gave the following suggestions:

The square foot of floor area and the cubic foot of total volume are the two units in which the costs of buildings are commonly expressed by those who apply rough and ready methods of estimating. But obviously such unit costs are subject to wide variations, even in buildings of the same type. Much more satisfactory than the square foot of floor area for approximate cost estimating purposes is the square foot of wall, floor and roof, with the basement and foundation estimated separately. Then each type and class of wall, floor and roof can be estimated by itself.

To prepare unit costs for estimating a given type of wall, for example, the estimator first prepares a bill of materials for, say, 100 sq. ft. of wall, and applies unit prices, including labor, to all the materials, totals the items and divides by 100. The same is done for windows and doors, so that, knowing the total area of "openings" the cost is readily estimated.

Preferably the cost of columns is estimated by the linear foot, but, if desired, the cost of columns may be included as a part of the cost of the floors. Basements may be estimated by the cubic foot, to which may be added the cost of any special foundation work, such as piling, and the cost of the floor. The "equipment"—plumbing, heating, lighting, sprinkler system, elevators, etc.—should be estimated separately; but this, at least in part, may often be estimated by the square foot of floor area. Thus the cost of a factory heating system may be taken at 25 cts. per square foot, and the cost of a fire sprinkler system at 20 cts. per square foot of floor.

Between the very crude method of expressing the entire cost in terms of the square foot of floor area and the very refined method of detailing all quantities in a building, there stands the method above suggested, in which composite units of different types and classes are used.

How to Estimate by the Square.—I. P. Hicks gives the following in the National Builder, Oct., 1920.

It has long been the desire of carpenters and contractors to find some practical short way of estimating that would do away with the laborious job of making out bills of material in detail. We will now show how to make combinations in a safe and practical way which can be used to save a large amount of the ordinary figuring. We have arranged the items so that carpenters and contractors can fill in the prices and make the combinations to suit the job which they have on hand.

The combinations are to be made to fit the job. For example the outside walls of the house may be sided, shingled or stuccoed. Each would have to be figured at a different rate per square; consequently the different items must be combined to fit the job. The same is true with the floors; some kinds of flooring may cost much more than others both in regard to material and labor. So in every case it is necessary to consider the kind of material and labor that goes into every part of the job. What will do for one job may not answer at all for another and it always will be necessary for the contractor to use discriminating judgment in making estimates no matter how it is done or by what system. A good record of estimates showing the actual cost of work from time to time soon gives the contractor a knowledge of costs which he can rely upon. Keep a record of your work, follow the system given, watch it closely and you will soon be able to establish a rate per square, per lineal foot and per piece that you can depend upon. By this system you can shorten the work of estimating to a large extent without the usual dangerous results from short cuts in estimating. It is no guess work; you simply combine such parts of the work as you can consistently and figure them together in a lump sum. Things that can not be figured in combination, you can figure separately and add them to your estimate just the same. The combinations as given will enable one to figure the cost of the bulk of the material and labor above the foundation without making out itemized lists of material and labor.

Such items as excavating, masonry, plastering, painting, electric wiring, tin work, heating and plumbing should be figured separately and added to make the complete estimate. It is the lumber, millwork and carpenter labor mostly that the carpenter contractor seeks for a reliable and easy way out in the matter of estimating. The following is our form and system of estimating the cost of building:

Floor Cost Per Square

Floor joists, size....set....centers...............	$.........
Rough floor....................................	....
Finish floor....................................	....
Carpenter labor framing........................	....
Carpenter labor laying rough floor	....
Carpenter labor laying finish floor..............	....
Carpenter labor scraping finish floor...........	....
Nails for framing..............................	....
Nails for rough floor...........................	....
Nails for finish floor...........................	....
Floor deadening...............................	....
Total per square...............................	$.........

The above form shows how you can arrive at a correct price per square in a lump sum. In making your total you can figure according to your job. For example all floors may not have the same size joists, they may be spaced different, the finish floor and the rough floor may be different on different jobs. Some floors may not have to be deadened or scraped. In getting the total omit such parts as are not required and fill in the items such as are called for on the job you are to figure. The quantities of dimension for different size joists and the quantities of rough and finish floors for the different kinds of flooring we have given in former articles.

Outside Wall Cost Per Square

Outside studding, size....set....inch centers........	$..........
Outside sheathing....................................	....
Siding...	....
Shingles...	....
Stucco material......................................	....
Building paper.......................................	....
Labor framing..	....
Labor sheathing......................................	....
Labor siding...	....
Labor shingling outside walls........................	....
Labor applying stucco................................	....
Nails for framing....................................	....
Nails for sheathing..................................	....
Nails for siding.....................................	....
Nails for shingling..................................	....
Nails for applying stucco board or lath..............	....
Total per square.....................................	$..........

Not all of the above items will be likely to be required on any one job; in reaching a total combine such items as will be required on the job you are estimating.

Partition Cost Per Square

Studding, size......set......inch centers............	$..........
Labor, framing.......................................	....
Nails..	....
Total per square.....................................	$..........

Ceiling Cost Per Square

Joists, size......set......inch centers..............	$..........
Labor, framing.......................................	....
Nails..	....
Total per square.....................................	$..........

Roof Cost Per Square

Rafters, size......set......inch centers.............	$..........
Sheathing..	....
Shingles...	....
Asbestos shingles....................................	....
Slate roof...	....
Tile roof..	....
Tar and gravel roof..................................	....
Textile shingles.....................................	....
Rubberoid roof.......................................	....
Canvas roofing.......................................	....
Tin roof...	....
Labor framing..	....
Labor sheathing......................................	....
Labor shingling......................................	....
Labor asbestos shingles..............................	....
Labor slate roof.....................................	....
Labor tile roof......................................	....
Labor tar and gravel roof............................	....
Labor textile roof...................................	....
Labor rubberoid roof.................................	....
Labor canvas roof....................................	....
Labor tin roof.......................................	....
Nails, framing.......................................	....
Nails sheathing......................................	....
Nails shingling......................................	....
Nails for other roofings.............................	....
Total per square.....................................	$..........

Make the combinations and total according to kind of roofing used and to fit the job.

Porch Floor Cost Per Square

Joists size......set......inch centers.............. $..........
Flooring..
Labor framing...
Labor flooring..
Nails framing...
Nails flooring..

Total cost per square............................. $..........

Porch Ceiling Cost Per Square

Ceiling joists, size......set......inch centers...... $..........
Ceiling...
Labor, framing..
Putting on ceiling..
Nails ceiling...

Total cost per square............................. $..........

Cornice Cost Per Lineal Foot

Material, frieze.................................. $..........
Plancer...
Fascia..
Verge boards..
Crown mould...
Bed mould...
Labor, Frieze...
Plancer...
Fascia..
Verge boards..
Crown mould...
Bed mould...
Nails...

Total cost per lineal foot......................... $..........

In making totals figure only such items as apply to the job you are estimating.

Add for gable brackets............................ $..........
Labor for setting the same..

Total for brackets................................ $..........

Window Cost Complete in House

Frame, cost, material and labor, size............. $..........
Sash, glazed..
Inside trim for finish...
Labor cost, setting frame...
Fitting sash..
Inside finishing of, casing, etc..................................
Nails, hardware, weights, etc.....................................

Total cost per frame.............................. $..........
Add for outside or inside blinds..................................
Labor for same..
For storm sash..
Labor fitting and hanging same....................................
Screens for windows...
Labor fitting and hanging...
Hardware..

Totals.. $..........

Make totals according to requirements.

Cost Outside Doors Complete in House, Cased One Side

Frame material and labor, etc.	$..........
Cost of door	....
Casings for finishing	....
Storm door	....
Screen door	....
Labor setting door frame	....
Fitting and hanging door	....
Casing and finishing	....
Fitting and hanging storm door	....
Fitting and hanging screen door	....
Nails and hardware	....
Totals	$..........

Cost Interior Doors Complete in House, Cased Two Sides

Cost of jambs, material and labor, size	$..........
Cost casings, cased two sides, steps included	....
Labor, cost setting jambs	....
Fitting and hanging door	....
Casing and finishing	....
Nails and hardware	....
Total cost per door	....

Cost of Sliding Doors Complete

	Single	Double
Cost of jambs, size	$..........	$..........
Cost of doors	....	....
Cost of casings, two sides and steps	....	....
Labor, setting jambs	....	....
Fitting and hanging doors	....	....
Casing and finishing	....	....
Nails and hardware	....	....
Totals	$..........	$..........

Cost of Folding Doors Complete in House

Cost of jambs, size	$..........
Cost of casings, two sides including stops	....
Doors	....
Nails and hardware	....
Labor, setting jambs	....
Hanging doors	....
Casing and finishing	....
Total cost	$..........
Inside base lineal foot	$..........
Floor mould	....
Nails	....
Labor	....
Total cost	$..........

Cost of Picture Moulding Per Foot

Picture mould	$..........
Nails	....
Labor	....
Total cost	$..........

Cost of Room Cornice Per Lineal Foot

Material per foot	$..........
Nails	....
Labor	....
Total cost	$..........

Beam Ceiling Cost Per Lineal Foot

Material per foot	$..........
Nails	....
Labor	....
Total cost	$..........

Plate Rail Cost Per Lineal Foot

Material per foot	$..........
Nails	....
Labor	....
Total cost	$..........

Estimating Data.—U. M. Dustman gives the following in The National Builder, May, 1918.

First Floor Joist.—The joist can be butted together, or they can run past each other in the center and be spiked together, which is preferable. The first floor joist plan will show the number of joist required for the building; but when there is no floor joist plan, divide the length or space that the joist are to occupy by 4 and multiply the quotient by 3 and add one; then add one for each partition, to double the joist. It is safer to add another extra one, as sometimes the joist cannot be spaced equally, especially for the second floor, when it is sometimes necessary to have a joist on each side of a partition. The first floor joist are generally taken from the basement plan and the second floor joist from the first floor plan, to see where the bearing partitions are. The second floor plan must also be taken into consideration when the floor joist are being taken off, as for double joist under partitions, and extra projections are sometimes given as in a plan where the second floor extends partly over the front porch.

Partitions.—In taking off the number of studs required for inside partitions, each partition should be taken by itself. A partition 12 feet long will require 12 divided by 4 and multiplied by 3 equals 9, add 1 equals 10. No allowance should be made for openings, as the doubling of the studs on each side of an opening will take the ones left out for the opening.

Plates.—Figure a single plate at the bottom and a double plate at the top for all bearing partitions; partitions that are not bearing will only require a single plate at each end. Outside walls should be double plates at the top.

Outside Wall Studs.—Studs for outside wall should be taken on 16 inch centers, not taking out any openings unless they are 4 feet or more. Corners must be doubled.

Rafters.—If 16 inch centers, take the same figures as for the studs. If 24 inch centers, then divide the space by 2 and add 1. To get the length of rafters when figuring out a bill of material for a one-half pitch roof, add 5 inches to each foot of run. Take a building 24 feet wide with a projection of 2 feet on each side; then the starting place for the roof will be 24 feet plus 4 feet or 28 feet wide. One-half of 28 equals 14 feet run; 5 times 14 equals 70, or 70 inches to be added to 14 feet, or 19 feet 10 inches; it will then require a timber 20 feet long for the rafter. For the one-third pitch roof add 2½ inches to each foot of run.

Shiplap, Flooring and Siding.—For 8-inch and 10-inch shiplap add 15 per cent or one-seventh of the number of square feet. If there are 1,400 square feet requiring shiplap it will take one-seventh of 1,400 or 200 square feet extra to cover the same or 1,600 feet. For 6-inch flooring add one-fifth; for 4-inch flooring add one-fourth, and for 2-inch flooring add two-fifths. For 6-inch lap siding add three-tenth, for 5-inch siding add one-third, and for 4-inch siding add two-fifths.

Roof Sheathing.—Take the number of square feet in the roof.

Shingles.—If laid 4½ inches to the weather it will require about 900 shingles to the square of 100 square feet, but as there is always a waste it is safer to figure 1,000 shingles to the square.

Plastering.—Multiply the length of a partition by the height and divide it by 9; for the ceiling the same. It is safer to take each room by itself when the actual number of yards must be had. If the height of a ceiling is 9 feet then every foot of run will be 1 yard. No allowance is made for openings unless they contain more than 40 square feet. The rules are different in most cities. If the openings are taken out the contractor must figure more per yard.

Lathing.—It takes about 14 lath 4 feet long to make one square yard. The price for lathing varies in different cities, and one figuring work must figure the price figured in the city where the work is to be done. Metal lathing is also done mostly by the square yard, though sometimes by the day.

Painting.—Painting is mostly figured by the square yard. When lap siding is used, allowance must be made for the under edge of the siding. Measure the projection of the cornice. No allowance is made for windows as they take more work than if it were all solid. Inside doors generally are figured the same way, by the number of square yards they contain. A 2 feet 6 inches by 7 feet door with the jambs and casing will contain about 3 square yards on each side. Floors are very easily figured by the square yard.

Cement Work.—Some contractors figure cement work by the cubic yard and some by the cubic foot for foundation work, footings, etc. Cement floors and sidewalks are figured by the square foot of surface. Cement blocks are figured at so much a block; prices vary in different localities according to wages paid and the price of material. A cubic yard of sand and gravel contains 27 cubic feet. One sack of cement contains 1 cubic foot of cement. When water and cement are added to pit gravel it settles more solid than the loose gravel and when in place it will only measure about 25 cubic feet; so when figuring cement work obtain the actual number of cubic feet and divide it by 25, which will give the number of yards of pit gravel required. A wall containing 600 cubic feet will require 600 divided by 25 or 24 yards of sand and gravel. A mixture of 1 part of cement to 6 of gravel will require 100 sacks of cement, 4 sacks to a barrel or 25 barrels. For top dressing it will take more cement, as the mixture is sometimes in equal parts and sometimes 1 of cement to 2 of sand. For cellar floors or sidewalk work, determine the number of cubic feet of concrete by multiplying the length by the width in feet, then if 4 inches thick divide by 3. A floor 10 × 30 feet will then have 10 × 30 or

300 square feet; divide 300 by 3 and we find that there are 100 cubic feet of concrete. For the top dressing, which is generally 1 inch thick, there will be for the same floor 10 × 30 feet equals 300 square feet of dressing 1 inch thick, then by dividing 300 by 12 we have the number of cubic feet of top dressing or 25 cubic feet. One cubic yard of sand will be sufficient sand, and if mixed 1 part of cement to 2 of sand then it would require 12½ sacks of cement; if in equal parts it will take 25 sacks, 4 sacks to a barrel. When washed gravel or broken stone are used, mixed with sand, it will require more material than for pit gravel, as the sand will fill the voids in the gravel or broken stone. If it requires 600 cubic feet of solid concrete, add 15 per cent to this which will make 600 cubic feet of material. A mixture of 4 parts of gravel, 2 of sand and 1 of cement would then take 690 divided by 3 or 230 cubic feet of sand or 8½ cubic yards; 460 cubic feet gravel or 17 cubic yards; 100 sacks of cement, to do the work for 600 cubic feet of solid concrete.

Brick Work.—When figuring brick work the walls are figured solid and the corners two times. Brick are generally figured by the thousand, laid in the wall. For a 4-inch wall figure 7½ brick for each square foot of wall surface, 15 brick for an 8-in wall, 22½ for a 12-inch wall, and so on, adding 7½ brick for every 4 inch in thickness. When figuring the actual number of brick required to do a certain job, take the number of surface feet and deduct for all openings and multiply by 6½, which will give plenty of brick and allow for broken ones. For mortar to lay 1,000 brick it will take 2½ bushels or 200 pounds of lime and about ¾ yard of sand. For lime and cement mortar take 2 bushels lime, 1 barrel cement to ¾ yard of sand for 1,000 brick. The amount of mortar required depends largely on the thickness of the mortar joint. Mortar coloring requires about 50 pounds of color to the thousand brick, depending on the shade of mortar color required.

Stone Work.—Stone walls for foundation work are generally figured by the perch. While 24¾ cu. ft. contain one perch, in some localities 16½ cu. ft. are figured as one perch and the price made accordingly. Foundation walls for a residence are generally figured 18 in. thick, corners counted to times; that is, the outside measurement of the wall is taken. To find the number of perch in a wall if 18 in. thick, multiply the length by the height of the wall, then by 1½ and divide by the number of cubic feet in a perch. A wall 40 ft. long, 8 in. high, 18 in. thick, will contain 40 × 8 × 1½ or 480 cu. ft. of wall.

Interior Trim.—The interior trim is generally taken from the plans by the mill man and figured, but the contractor should be able to take off a mill bill and send it out for figures to different mill men. Give the number of doors, size and thickness, and the kind of wood; give the number and size of all windows, also the number of window frames, size of casing, kind of head casing, and whether for a wood, plastered or brick building. Give length of inside casing and number, number of feet of base, quarter round, picture mould, head mould, etc.; number and size of cupboard doors, drawers and shelving; window and door stops; stairways, size of tread and rise and length, number of feet of railing, number of balusters, cove, newels, hand rail; number of feet of chair rail, and closet strips, porch columns, balusters and railing, mantle shelf, seats, colonnade, etc.

Hardware.—Make out a list of hardware wanted and get figures on same, or let the hardware dealer give you an estimate of what he will furnish for so much money. When making out list of hardware mention the number of locks, hinges and size of same; valley tin, ridge roll, gutters, down spouts, tin roof and flashing; drawer pulls, sash lifts and locks, weights, sash cord. Figure the nails as follows: 5 lbs. of shingle nails to each 1,000 shingles, 18 lbs. siding nails to 1,000 feet siding, 20 lbs. 8d. for sheathing and 25 lbs. for 4-in. and 6-in. flooring per 1,000 ft. Dimension, 20 lbs. per 1,000 ft.

Estimating carpenter labor with labor at 50 cts. per hour. No exact method can be established to do carpenter work. Some men do more work than others in a day, which makes a difference in estimating. A very close average can be had by keeping track of work done on other buildings. The following is a very close way of estimating; it is better to make your estimate too high than too low and lose money on work. Add together the number of feet of lumber required for the framing, sheathing for outside wall, roof, and for sub floors, siding and partition studs and figure the same at $15 per thousand feet. Suppose there are 15,000 feet of lumber required for a residence; at $15 per thousand, the labor would cost $225 to put all of the lumber in place. For a one-story porch with floor, ceiling and wood shingle roof, the labor will cost about 25 cts. per square foot of floor surface. A porch 10 ft. wide by 16 ft. long contains 160 sq. ft.; thus at 25 cts. per square foot will amount to $40 for labor to build the porch. For a two-story porch 40 cts. per square foot if screened.

Hard Wood Floors.—To lay and scrape a hard wood floor is worth 5 cts. per square foot of floor laid. A room 12 × 20 ft. contains 240 sq. ft. of floor space, and at 5 cts. per square foot will amount to $12. For yellow pine floor figure at 3 cts. per square foot.

Exterior Trim.—Find the number of feet required for exterior trim and multiply by $20 per thousand feet.

Window Frames.—To set the frame, hang the sash and do the casing for ordinary windows it is worth $1.50 each for yellow pine and $1.75 for oak.

Door Frames.—To set case on outside frames, hang the door and put on lock and stops complete, $2 each. Inside Doors.—To set jamb, case, hang and put on lock and stops for yellow pine, $1.75 each; oak, $2.25. Cupboard from $8 to $10. Base 3 cts. per running foot; picture mould, 75 cts. a room.

Stairs.—Main stairs from $8 to $10, cellar stair $2, and rear stairs $4. Porch steps—front, $4; rear, $2. Screens, 40 cts. each; colonnade from $6 to $8; seat, $4 to $6. Cased openings, $2.

Component Costs of Building Construction.—At the national conference of the construction industries held in Feb., 1921 at Philadelphia, Barclay White, a contractor, of that city, gave some information on this subject that should be of interest. The following abstract of his statement is given in Engineering and Contracting, June 22, 1921.

The relative values of the various parts of the building have not been very carefully studied heretofore but we have made an attempt to fix an approximate proportion covering the whole building field in this territory. We have gone about this by taking a composite of building, which includes a reinforced concrete factory building; slow burning or heavy construction warehouse building with brick walls; the typical style of two-story dwelling; detached brick and frame residence; stone schoolhouse with wood floor construction; fire-proof institutional building; the apartment house; and the steel frame office building.

How the Costs Were Arrived At.—From our own records of cost we have taken typical instance in each of these eight types of building and have divided it up according to the actual cost figures, into labor and materials, and have then tried to proportion the various types of building as nearly as possible, in their correct relation to the total volume of business which is done in this territory. Of course, right there you will realize that there is bound to be a great deal of leeway which should be brought out, for in the course of the last few years house building has fallen off very largely in proportion to the heavier types of construction. These figures will have to be taken as the best approximation that the circumstances permit.

After arriving at a makeup of the different types, and proportioning the various types into their proper ratios, we have summarized, for instance, the main item as skilled labor on the building. It is a little difficult to say where skilled labor stops and unskilled labor begins, but we have based the calculation on the mechanics on one side as against the apprentices, helpers, hod carriers and common laborers on the other side. The result of our calculation is given in Table I.

Overhead, Expenses and Profit.—There is really a duplication of overhead expenses and profit because possibly 65 per cent of the work is sublet, and on that work sublet to the plumber, the plasterer, the painter, etc., there is really a double overhead, because the general contractor, as superintendent of the work, makes arrangements with the sub-contractor and divides the work, so that we find office rent, general expenses and overhead—but not including office wages—to be 5.8 per cent. The net compensation of the sub-contractors, assuming they do 65 per cent of the work, 3.90 per cent, and the net compensation of the general contractor, assuming he does 35 per cent of the work, directs and supervises the balance, 3.42 per cent, bringing the total up to 100 per cent.

Table I. —Percentages of Elements in Composite Building

The division of costs of an imaginary composite building has been arrived at by taking the actual cost figures on different types of buildings, including an ordinary two-story brick dwelling (row type), a detached residence, a reinforced concrete factory building, a slow burning construction warehouse building, a steel frame office building, a fireproof and wood floor school building, with stone walls, and a brick apartment house.

The relative importance of these different types of building in determining the figures for the composite whole, were determined by reference to the published lists of building permits and similar statistics as furnished by F. W. Dodge Co., so that the result as given represents as nearly as possible the exact relative importance of the various items in the make-up of the total volume of building business transacted in this territory

Analysis in percentages of cost of a composite building, showing average values of various items for each $100 worth of building work normally done in Philadelphia district:

Labor:	Per cent	
All skilled labor and supervision on the building including also stone cutting, and shop work on sheet metal and millwork only	27.55	
Unskilled labor as above	9.44	
Office, estimating, general supervision and engineering salaries.	5.60	
Liability insurance	1.41	
Total labor (no manufacturing except as stated)		44.00

	Per cent
Materials:	
Lumber for millwork, concrete forms and structure delivered at site	$ 8.86
Bricks—delivered at site	6.10
Steel—structural, miscellaneous and reinforcement, delivered at site	5.93
Boilers, heaters, piping, etc., for heating	3.05
Plumbing fixtures, piping, etc	2.76
Cement f. o. b. cars	2.60
Hardware, nails and similar misc. materials	1.78
Sand, delivered to site	1.69
Electric fixtures, conduit wire, etc	1.60
Stone, slag and pebbles for concrete	1.49
Sprinklers and fire protection apparatus and minor unclassified items	1.04
Building stone	.90
Paint	.76
Roofing and sheet metal materials	.70
Plastering materials (no sand)	.65
Lathing materials	.65
Steel sash, etc., delivered to site	.50
Lime (no plaster)	.45
Glass	.40
Cut stone (materials) and terra cotta	.38
Elevators (delivered to site)	.28
Mechanical equipment, cranes, etc	.21
Tile and marble (materials only)	.10
	42.88
Overhead expense and Profit:	
Office rent, taxes, interest, depreciation of equipment, general expense and overhead (not wages)	5.80
Net compensation of all sub-contractors (assumed as doing 65% of the work direct)	3.90
Net compensation of general contractor (assumed as doing 35% of the work direct and supervising the balance)	3.42
	100.00

Cost of College Buildings from 1851 to 1916.—Interesting information on building costs at the University of Wisconsin from the period from 1851 to 1916 is given by Arthur Peabody, State Architect of Wisconsin, in an article in the Wisconsin Engineer, from which the matter following is abstracted in Engineering and Contracting, June 26, 1918.

The original buildings at the University consisted of three halls and a residence. These buildings were completed by 1857, after which for 14 years no others were added. They were constructed of local stone, the walls being of rubble masonry with a facing of ashler. The floors, roof and partitions were of timber. The costs of these four structures were as follows:

Year built		Cubic feet, gross	Cost per cu. ft., cts.
1851	North Hall	331,655	6.0
1855	South Hall	331,650	6.4
1855	Residence of director of observatory	110,000	4.5
1857	University Hall	682,500	9.3
	Average for 4 buildings		7.5

The buildings erected between 1871 and 1887 followed the general practice of construction employed in the other buildings. The cost per cubic foot of these buildings ranged from 5.1 cts. for a structure erected in 1879 to 17.7 cts.

for one erected in 1878. The cost of the Chadbourne Hall built in 1871 was 15.2 cts. per cubic foot.

The new Science Hall built in 1888 was a departure from previous buildings. The use of fireproof construction and steel and hollow tile in this building was one of the first, if not the first, example of the use of these materials in modern public buildings. The gross contents of building of the building was 1,751,310 cu. ft. and it cost 16.3 cts. per cubic foot. The only other fireproof building erected at Wisconsin up to 1906 was the State historical library. This building was of structural steel and hollow tile with a facing of Bedford stone. It was erected in 1900, had 1,410,000 cu. ft. gross contents and cost 53.1 cts. per cubic foot.

Some comparisons of cost as between fireproof and non-fireproof buildings are interesting, as they tend to show a decrease in actual cost, if the greatly enhanced value of the buildings erected is taken into consideration.

The following buildings are of ordinary construction, having masonry walls, and wooden floors and partitions:

	Year built	Walls	Cubic feet, gross	Cost per cu. ft., cts.
Chadbourne Hall	1871–1896	Stone	775.250	17.4
Dairy building	1892	Brick	300,000	13.3
Soils physics building	1894	Brick	123,750	15.0
South wing University Hall	1895	Stone	518,320	12.5
Engineering building	1901	Brick	746,144	13.4
Agricultural Hall	1902	Brick	1,041,000	14.8
Main Chemistry building	1905	Brick*	1,420,000	8.2
North wing University Hall	1906	Stone	518,320	14.3
Average for 8 buildings	....	......	....	13.6

* Built of sand lime brick walls, except on small part of front; very plain.

The following buildings have masonry walls, concrete floors and tile partitions:

	Year built	Walls	Cubic feet, gross	Cost per cu. ft., cts.
Agronomy building	1906	Brick	193,500	14.3
Agricultural Engineering	1906	Brick	345,000	14.8
Central heating station	1908	Brick	1,011,500	10.38
Forest Products laboratory	1909	Brick	573,600	8.5
Lathrop Hall	1909	Stone	1,476,000	13.0
Dairy laboratory	1909	Brick	144,377	11.0
Biology building	1910	Stone	1,198,450	16.7
Wing on Engineering building	1910	Brick	277,000	13.6
Horticultural building	1910	Brick	325,600	15.4
Wing on Chemistry building	1912	Brick	545,200	13.2
Home Economics building	1912	Stone	746,200	15.9
Barnard Hall	1912	Stone	647,700	19.07
Wisconsin High school	1913	Brick	900,000	13.15
Agricultural Chemistry building	1913	Brick	658,250	12.66
Physics building	1915	Brick	1,323,000	13.3
Soils building	1915	Brick	333,800	15.9
Average for 16 buildings	....	.....	....	13.75

Cost of Seven School Buildings at Pittsburgh, Pa. (Engineering and Contracting, Aug. 22, 1917).—During the past five years the Board of Public Education of Pittsburgh, Pa., has completed seven new elementary schools and two new high schools at a cost of $3,168,721. The average cost of the general work has been 14.6 cts. per cubic foot. The cost of the heating and ventilating has been 2.9 cts. per cubic foot. The cost of the plumbing has been 1.2 cts. per cubic foot and the cost of the electrical work has been 0.8 cts. per cubic foot. The total cost of all buildings has been 19.5 cts. per cubic foot. Bids taken Dec., 1916 indicated an increase in the cost of construction amounting to 56 per cent above contracts let a year previous to that date.

Unit Costs of Forty-Seven School Buildings (Engineering Record, Oct. 4, 1913).—Total costs of forty-seven school buildings in Boston are given in the (1912) annual report of the Schoolhouse Department, and from these figures the cubical contents and the number of pupils accommodated, costs per cubic foot and per pupil are derived. The total costs range from $23,000 to $329,000, the number of pupils per school varying from 160 to 1832. The costs per cubic foot are very uniform, averaging between 22 and 23 cents, two running as low as 17 cents and one as high as 28 cents. The costs per pupil fluctuate more widely, ranging from $117 to $208, exclusive of several high school and normal school buildings, in which the cost per pupil is as high as $940. The figures are further divided into the building proper, heating, plumbing and electrical equipment. The buildings proper cost from 76 to 86 per cent of the whole, the heating from 6 to 15 (most of them being from 8 to 11 per cent), the plumbing 4 or 5 per cent, except in a few cases as low as 3 or as high as 9, and the electrical equipment slightly less.

Cost of Nine School Buildings in Cincinnati.—W. P. Anderson, in Engineering Record, Aug. 7, 1909 gives the following:

TABLE II.—SIZE AND COST OF NEW SCHOOLS IN CINCINNATI

Year opened	Remarks	Construction	Cubic feet contents	Cost per cubic foot	Class rooms	Auditorium	Gymnasium	Play rooms	Toilet rooms	Other rooms
1906	3 stories and basement	Joist.—Fireproof corridors	949,354	$0.151	14	1	1	2	2	..
1907	2 stories and basement	Joist.—Fireproof corridors and stairs	786,239	0.165	10	1	1	2	2	1
1908	2 stories and basement	Fireproof except attic and roof	871,796	0.159	12	..	..	2	2	5
1908	2 stories and basement	Fireproof..........	1,460,266	0.155	20	1	1	2	2	5
1908	3 stories and basement	Fireproof..........	1,475,811	0.168	28	1	2	2	2	4
1909	2 stories and basement	Fireproof..........	1,108,105	0.163	17	1	1	2	2	4
.... 1909	2 stories and basement, cage construction	Fireproof..........	778,461	0.151	10	1	1	2	2	3
....	3 stories and basement	Fireproof..........	766,176	0.180	10	1	1	..	2	5
....	3 stories, basement, subbasement and tower.	Fireproof..........	4,525,179	0.147	29	1	2	*	2*	5*

* Miscellaneous shop rooms.

Costs of Warehouses at Navy Yards.—Civil Engineer Kirby Smith, U. S. Navy in "Public Works of the Navy," and in Engineering and Contracting, Aug. 28, 1918, gives the following.

The general features of design in all the structures are the reinforced concrete columns with a flat-slab floor system, and brick curtain walls with adequate glazed areas. Buildings are equipped with extensive toilet and locker facilities, sprinkler systems, fire walls, and a sufficient number of elevators, the larger structures having both freight and passenger service. The buildings are generously provided with loading platforms and large doors for handling incoming and outgoing stores. Contracts for all these buildings were let between April and Nov., 1917.

TABLE III.—DETAILS OF GOVERNMENT STOREHOUSES

Location	Size	Stories	For soil, tons*	For piles, tons*	Rein. steel, tons†	Struc. steel, tons†	Cement, est., bbls.
New York	180 × 360	11	...	28	2,150	50	63,000
Philadelphia[1]	....	7	...	20	842	20	27,300
Boston[2]	....	6	4	..	800	20	27,300
Mare Island	64 × 404	5	6	..	418	15	12,600
Charleston	61 × 321	5	...	20	384	12	10,000
Puget Sound	120 × 240	10	4	..	1,275	20	21,000
New London	64 × 224	4	4	..	171	11	4,000
Hampton Roads	118 × 494	6	...	35	696	16	26,000
Pearl Harbor	61 × 150	4	3½	..	120	8	2,600
Newport	61 × 241	4	1½	..	172	5	4,000
Washington	100 × 250[3]	5	...	20	590	12	12,200
Brooklyn	103 × 103	7	3½	..	250	8	6,450
Mare Island	60 × 186	4	5½	..	106	5	3,306

* Allow bearing on foundations. † Steel tonnage, estimated.
[1] L-shaped, 104½ ft. and 224½ ft. on ends; 304½ ft. and 200 ft. on sides.
[2] U-shaped, 184½ ft. × 264½ ft. with court 33½ ft. wide. [3] And 50-ft. 1-story annex.

TABLE IV.—COST OF GOVERNMENT STOREHOUSES

Location	Cubic contents, cu. ft.	Total floor area, out to out of bldg., sq. ft.	Floor area, inside of walls, sq. ft.	Actual cost, per cu. ft.	Actual cost, per sq. ft.
New York	8,737,000	712,800	696,300	$0.133	$1.63
Philadelphia	3,604,300	307,900	300,300	.141	1.65
Boston	2,996,100	251,700	243,200	.173	2.04
Mare Island	1,338,400	128,700	125,600	.148	1.54
Charleston	995,000	96,600	93,100	.218	2.24
Puget Sound	2,976,700	287,800	280,600	.170	1.76
New London	665,000	57,000	54,900	.180	2.10
Hampton Roads	3,994,123	352,423	345,073	.179	2.03
Pearl Harbor	416,000	37,000	35,300	.232	2.61
Newport	731,474	59,409	56,985	.202	2.49
Washington	1,981,250	137,500	133,900	.190	2.74
Brooklyn	795,675	74,263	71,379	.250	2.69
Mare Island	473,507	39,757	38,264	.....	....

Costs of Twenty-Two Hospital Buildings.—Costs of hospital buildings are given by O. H. Bartine in a paper read before the American Hospital Association. The following data, published in Engineering and Contracting, July 26, 1916, are summarized from detailed tabulations.

For twenty-two buildings the building and equipment costs per cu. ft. were as follows:

Item	Per cu. ft., cts.
Total building	38.2
Heating and ventilating	3.3
Electric system	0.9
Electric fixtures	0.3
Plumbing	2.9
Refrigeration	1.2
Vacuum cleaner system	0.2
Elevators	0.7
Kitchen equipment	0.4
Power plant	4.7
Total	52.8

The segregated building costs per cu. ft. for thirteen hospitals were as follows:

Item	Per cu. ft., cts.
Excavation	2.6
Masonry	12.4
Structural steel	4.5
Carpentry	2.8
Roofing	1.0
Glass and glazing	3.6
Skylights and sheet metal	1.1
Painting	0.6
Lathing and plastering	1.23
Composition flooring	0.8
Tiles, mosaics and marbles	2.11
Hardware	0.5
Cast iron	2.2
Total	43.2

In determining cubical contents the author states: "Measurements should be taken from the basement or subbasement (lowest) floor level to the mean of the outside of the roof, and from outside to outside of walls. In other words, the cubic feet of air displaced by the exterior dimensions of the building should be considered, eliminating approaches, balustrades and other projections not enclosing space."

Cost of Fireproof Loft Building, Chicago.—Harold Doerr, in Engineering and Contracting, March 18, 1914, gives the following:

The building, completed in the fall of 1913, is seven stories high with provision for the addition of three stories in the future and covers an inside lot 50 × 170 ft. The foundations are of reinforced concrete having a maximum thickness of 3 ft. 1 in. and cover practically the whole building area.

The foundation and columns are stronger than are actually required to meet the present conditions. The present roof beams, which are to form the framework for a future eighth floor, have been set level. The pitch of ⅛ in. in 1 ft. required for the roof is obtained by means of a graded cinder fill, over which is built a 1-in. layer of cement mortar, mixed in the proportions of 1 part cement to 2 parts sand, on top of which was laid a tar-and-gravel roof. There are three pent houses on the roof for the tanks and two elevators in addition to a stair hatch. The building contains a large six-ton high-speed freight elevator, large enough to allow a truck to drive onto it from the alley, and a ten-passenger elevator located in the front part of the building. A sprinkler system of the wet type is installed complete, with pumps for water and air, and a 5,000-gal. pressure tank and a 25,000-gal. gravity tank being provided. The floors throughout the building are of maple, the best quality being used on the first three floors and first-grade factory maple on the upper floors. The 10-in. tile floor arches are covered with a 3-in. cinder concrete fill. All columns are fireproofed with a 1:2:4 mixture of stone concrete, the minimum protection afforded being 2½ ins.

Contract Price and Unit Cost.—The contract prices of the principal items are:

	Total	Cents per cu. ft.	Per cent
Steelwork, 703 tons at $60.00	$ 42,180.00	4.15	28.60
Foundation and sidewalk	11,300.00	1.11	7.65
Fireproofing	16,000.00	1.58	10.82
Masonry	14,000.00	1.38	9.49
Carpenter work	8,500.00	0.84	5.40
Sprinkler system	7,500.00	0.74	5.10
Elevators	7,000.00	0.69	4.75
Heating	6,575.00	0.65	4.46
Ornamental iron	4,800.00	0.47	3.25
Plastering	4,500.00	0.44	3.05
Architectural terra cotta	3,979.70	0.39	2.69
Cinder concrete	3,900.00	0.38	2.64
Excavation (15 ft.)	2,637.50	0.76	1.78
Total for above items	$132,872.20	13.08	89.68

Other contracts increase the total cost of the building to about $147,808. The cubic contents of the building, including foundations and pent houses, are 1,016,965 cu. ft., making the cost approximately 14.5 cts. per cubic foot.

Cost of Railway Buildings of Concrete and Brick.—The following examples of structures with their cost are abstracted from the report of the American Railway, Bridge and Building Ass'n. by Engineering and Contracting, Oct. 23, 1912.

On the Lehigh Valley Railroad the passenger station at Cortland, N. Y., was built with hollow tile walls with a cement-stucco finish. The foundations are of concrete. The partitions are of hollow tile. This building is a one-story structure 25 × 109 ft., with a second story over the ticket office 28 × 31 ft. The cost of the building was $19,000, exclusive of platforms, or about $6.50 per square foot. The cost per cubic foot was 24 cts.

A combined passenger and freight station on this road at Milan, Pa., was built with concrete foundations and hollow tile partitions. The floors were of concrete and the roof of timber, covered with roofing paper. The size of the building is 19.5 × 52 ft., and its cubic contents are 18,200 cu. ft. The freight house portion of the building has a raised platform of reinforced concrete, and the platforms for the passenger station are also of concrete. The cost of the building was $3,600, or $3.50 per square foot. The cost per cubic foot was 20 cts.

A freight house built by the Lehigh Valley Company at Bethlehem, Pa., cost $35,000. The office portion of the building had concrete foundations, hollow tile with stucco finish, wood floors, roof trusses and partitions. It is finished with wood trim inside and is plastered. The building is two stories high and 45 × 54 ft. in area. In the freight portion of the building the foundations, outside walls, fire walls and floors are of concrete and the roof is of timber.

The area is 59 × 254 sq. ft. and the height is one story. A raised platform is built of reinforced concrete. There are three fire walls. The building has a basement. The cost of the entire building per cubic foot was 6.7 cts. The cost of the office portion of the building was 12 cts.; of the freight house portion 5.7 cts. and of the platform was 80 cts. per square foot.

A roundhouse of 16 stalls was built by the Lehigh Valley R. R. at Coxton, Pa., at a cost of $50,000. The foundations were of 1 : 3 : 5 concrete and the columns, roof beams and roof of 1 : 2 : 4 concrete. The side curtain walls were of plastered hollow tile. The floor was also of concrete. The windows were of wood. The cost per stall was $3,125, or 8 cts. per cubic foot, or $1.87 per square foot. The cubic content of the roundhouse was 626,040 cu. ft.

Costs per Square Foot of Buildings, Panama-Pacific Exposition.—A. H. Markwart, in Engineering Record, June 6, 1914, gives the following:

TABLE V.—DIMENSIONS AND COST OF BUILDINGS, PANAMA-PACIFIC EXPOSITION

Palace	Size of building, ft.	Volume of building, cu. ft.	Average height of building, ft. and in.	Total cost	Floor area—Sq. ft.	Floor area—Cost per sq. ft.
Agriculture	579 × 639	20,634,000	62 6	$425,610	328,633	$1.30
Education	394 × 526	14,053,000	68 6	304,263	205,100	1.48
Festival Hall				270,000	57,400	4.70
Fine Arts				580,000	204,325	2.84
Food Products	424 × 579	15,609,000	66 0	342,551	236,690	1.45
Horticulture				341,000	201,000	1.70
Liberal Arts	475 × 585	16,038,000	64 0	344,180	251,300	1.37
Machinery	367 × 967	38,000,000	103 0	659,665	369,600	1.78
Manufactures	475 × 552	15,650,000	67 0	341,069	234,000	1.46
Mines and Metallurgy	451 × 579	16,199,000	64 0	359,445	252,000	1.43
Transportation	579 × 614	20,413,000	65 0	481,677	314,000	1.53
Varied Industries	414 × 541	14,648,000	67 0	312,691	219,000	1.43

Cost of a Cotton Storage Shed.—E. S. Pennebaker, Jr. (Engineering News, Jan. 2, 1913) describes a large cotton-storage shed at Mobile, Ala., to provide for the protection of cargoes of export cotton from damage by bad weather. It is a timber structure 135 by 410 ft., covering a smooth concrete floor, and fronting the Mobile River.

The building was erected and thoroughly equipped by labor contract, the railway company furnishing all materials. The work was done under the supervision of the construction department and completed in approximately 60 working days at a cost of 22.2 cts. per sq. ft. of floor area, exclusive of fire line and lighting, or at a total cost of 27.5 cts. per sq. ft. of floor area. This structure covers a floor area of nearly 1⅓ acres, and has a capacity of 7000 bales of compress cotton piled single tier. It is provided with ample fire protection, is lighted with tungsten lamps, and is served with track facilities which reduce to a minimum the cost of shipside delivery.

1921 Cost of Building Materials.—The Architect and Engineer, gives the following, based on reliable information furnished by San Francisco material houses. Date of quotations, June 20, 1921.

All prices f. o. b. cars San Francisco or Oakland. For country work add freight and cartage to prices given.

American Institute of Architects' Fees.—New work—6 per cent minimum basis. Alterations—7 to 10 per cent as a minimum basis. High class residence work—10 per cent as a minimum.

Bond—1½ % amount of contract.

Brickwork—

Common, $40.00 per 1000 laid.
Face, $90.00 per 1000 laid.
Common, f. o. b. cars, $16.50 plus cartage.
Face, f. o. b. cars, $55.00 per 1000, carload lots

HOLLOW TILE FIREPROOFING

12 × 12 × 3 in., 10¼ cts. per square foot.
12 × 12 × 4 in., 11¾ cts. per square foot.
12 × 12 × 6 in., 16¼ cts. per square foot.

Hod carriers, $7.40 per day.
Bricklayers, $9.25 per day.
Lime—$3.25 per bbl.; carload, $2.75 per bbl.

Composition Floors—30 cts. per sq. ft.

Concrete Work (material at San Francisco bunkers)—

No. 3 rock	$2.25 per yd.
No. 4 rock	2.25 per yd.
Niles pea gravel	3.25 per yd.
Niles gravel	2.50 per yd.
Niles top gravel	3.00 per yd.
City gravel	2.25 per yd.
River sand	1.50 per yd.
Bank sand	1.00 per yd.

SAND

Del Monte, $1.25 to $1.50 per ton.
Fan Shell Beach, $2.50 to $3.00 per ton.
Car lots, f. o. b. Lake Majella.

Cement (f. o. b. cars)	$ 3.69 per bbl.
Rebate for sacks, 15 cts. each.	
Atlas "White"	$12.60 per bbl.
Medusa cement	$12.60 per bbl.
Forms	$25.00 per M

WAGE—

Concrete workers	$ 7.50 per day
Cement finishers	8.35 per day
Laborers	6.95 per day

Dampproofing—

Two-coat work, 25 cts. per yard.
Membrane waterproofing—4 layers of P. B. saturated felt, $6.00 per square.
Hot coating work, $2.00 per square.
WAGE—Roofers, $8.35 per day.

Electric Wiring—$8.00 to $12.00 per outlet for conduit work (including switches)
Knob and tube average $4.50 to $6.00 per outlet.
WAGE—Electricians, $9.25 per day.

Excavation—

$1.75 per yard.
Teams, $10.00 per day.
Trucks, $28.50 to $38.50 per day.
Above figures are an average without water.
Steam shovel work in large quantities, less; hard material, such as rock, will run considerably more.

Fire Escapes—Ten-foot balcony, with stairs, $100.00 per balcony.

Glass—(Consult with manufacturers.)

21 ounce, 20 cts. per square foot.
Plate, $1.40 per square foot.
Art, $1.00 up per square foot.
Wire (for skylights), 44 cts. per square foot.
Obscure glass, 28 cts. per square foot.
Note.—Add extra for setting.
WAGE—Glaziers, $7.85 per day.

Heating—Average, $2.00 per sq. ft. of radiation, according to conditions.
WAGE—Steamfitters, $9.25 per day.

Iron—Cost of ornamental iron, cast iron, etc., depends on design.
WAGE—Iron workers, bridge and structural, $9.25 per day.
Lumber—(Prices delivered to bldg. site)
Common, $34 per M (average).
Common O. P. (select), $45 per M (average)

Flooring—

1 × 3 No. 1	$77.00 per 1000
1 × 3 No. 2	72.00 per 1000
1 × 4 No. 1	73.00 per 1000
1 × 4 No. 2	70.00 per 1000
1 × 4 No. 3	47.00 per 1000
1 × 6 No. 2 and better	73.00 per 1000
1¼ × 4 and 6 No. 2	75.00 per 1000
Slash grain, 1 × 4 No. 2	48.00 per 1000
Slash grain, 1 × 4 No. 3	39.00 per 1000
No. 1 common run to T. & G.	35.00 per 1000
Lath	6.50 per 1000

Shingles—(Add cartage to prices quoted)

Redwood, No. 1	$1.00 per bdle.
No. 2	.90 per bdle.
Red Cedar	1.10 per bdle.

Hardwood Floors—
Maple floor (laid and finished), 30cts. per foot.
Factory grade floors (laid and finished), 20cts. per foot.
Oak (quartered, finished), 40cts. per foot.
5/16 Oak (clear), 30cts. per foot (plain).
5/16 Oak (select), 28cts. per foot (plain).
5/16 Oak, quartered, sawed, clear, 35cts.
WAGE—Floor layers, $9.35 per day.

Hardwood Floors (not laid)—

		Per M ft.
5/16 × 2″ sq. edge	Clear quartered oak	$173.50
	Select quartered oak	121.50
	Clear plain oak	119.00
	Select plain oak	95.00
13/16 × 2¼″ face	Clear quartered oak	210.00
	Select quartered oak	144.00
	Clear plain oak	157.50
	Select plain oak	114.00
	Clear maple	134.50
	Clear maple—white	178.00
13/16 × 3¼″ face	Clear maple	134.50
1⅛ × 2¼″ face	Clear maple	134.50
⅜ × 2″ face	Clear quartered oak	158.00
	Select quartered oak	112.50
	Clear plain oak	112.50
	Select plain oak	78.00
	Clear maple	89.50

Millwork—
O. P., $100 and up per 1000. R. W., $120 and up per 1000.
Double hung box frame windows (average) with trim, $7.50 and up each.
Doors, including trim (single panel), $10 and up each.
Doors, including trim (five panel) .... $9.00 each
Screen doors, $3.50 each.
Window screens, $1.50 each.
Cases for kitchen pantries seven feet high, per lineal foot, $9 each.
Dining room cases, if not too elaborate, $10 each.
Labor—Rough carpentry, warehouse heavy framing, $13.00 per 1000.
For smaller work, average, $25.00 to $35.00 per 1000.
WAGE—Carpenters, $8.35 per day.
Laborers—Common, $6.00 per day.
Marble—(Not set) add 60cts. up per ft. for setting

Columbia	$2.05 sq. ft.
Alaska	2.05 sq. ft.
San Saba	3.65 sq. ft.
Tennessee	2.50 sq. ft.
Verde Antique	4.55 sq. ft.

WAGE—Marble polishers and finishers, $6.00 per day.

Painting—
Two-coat work, 35 cts. per yard.
Three-coat work, 50 cts. per yard.
Whitewashing, 5 cts. per yard.
Cold water painting, 9 cts. per yard.
Turpentine, $1.05 per gal. in cases and 90cts. per gal. in tanks.
Raw linseed oil, 94 cts. per gal. in barrels.
Boiled linseed oil, 96 cts. per gal. in bbls.
Pioneer white and red lead, 11¾ cts. lb. in one ton purchases; 12½ cts. lb. for less than 500 lbs.
WAGE—Painters, $8.35 per day.
NOTE—Accessibility and conditions cause wide variance of costs.

Patent Chimneys—

6-inch	$1.50 lineal foot
8-inch	1.75 lineal foot
10-inch	2.25 lineal foot
12-inch	3.00 lineal foot

Pipe Casings—$8.00 each.
Plastering—
Interior, on wood lath, 70 cts. per yard.
Interior, on metal lath, $1.30 per yard.
Exterior, on brick or concrete, $1.30 per yard.
Portland White, $1.75.
Interior on brick or terra cotta, 60 cts. to 70 cts. per yard.
Exterior, on metal lath, $1.85 to $2.25 per yard.
Wood lath, $6.50 at yard per 1000.
Metal studding, $1.25 to $1.50 per yard.
Suspended ceiling and walls (metal furring, lathing and plastering), $2.25 per yard.
Galv. metal lath, 33 cts. and up per yard, according to gauge and weight.
Lime, f. o. b. warehouse, $3.25 per bbl.
Hardwall plaster, $22.00 per ton, f. o. b. warehouse. (Rebate on sacks, 15 cts).
WAGE—Plasterers, $10.20 per day.
Lathers, $9.25 per day.
Hod carriers, $8.35 per day.
Plumbing—
From $70.00 per fixture up, according to grade, quantity and runs.
WAGE—Plumbers, $9.25 per day.
Reinforcing Steel—Base price for less than car load lots $3.50 per 100 lbs.
Carload lots, $3.25 per 100 lbs., f. o. b. San Francisco. (Mill delivery.)
Roofing—Five-ply tar and gravel, $6.50 per square for 30 squares or over.
Less than 30 squares, $7.00 per square.
Tile, $35.00 to $50.00 per square.
Redwood shingle, $10.00 per sq. in place.
Cedar shingle, $10.00 per square in place.
Reinforced Pabco roofing, $8.25 per square. WAGE—Roofers, $8.35 per day.
Rough Hardware—
Nails, per keg, $5.50 base.
Deafening felt, $110.00 per ton.
Building paper, P. & B.,
1 ply, $3.50 per 1000 ft. roll.
2 ply, $5.50 per 1000 ft. roll.
3 ply, $8.00 per 1000 ft. roll.
Sash cord,
(Sampson spot), $2.25 per hank 100 ft.
Common, $1.00 per hank 100 feet.
Sash weights, cast iron, $80.00 per ton.
Sheet Metal—
Windows—Metal, $2.00 a square foot.
Skylights—
Copper, $1.25 a square foot (not glazed).
Galvanized iron, 40 cts. a square foot (not glazed).
WAGE—Sheet metal workers, $9.25 per day.
Stone-granite—
WAGE—Stone cutters, $8.35 per day.
Stone setters, $8.35 and $8.80 per day

Store Fronts—
Kawneer copper bars for store fronts.
Corner, center and around sides, will average $1.35 per lin. foot.
Zouri bar, $1.25 per lin. foot.
Zouri Underwriters' Specification sash $1.60 per lin. foot.
Structural Steel—$130.00 per ton (erected).
This quotation is an average for comparatively small quantities.
Light truss work higher; plain beam and column work in large quantities, less.
Steel Sash—
Fenestra, from S. F. stock, 28 cts. to 34 cts. per sq. ft.
Fenestra, plant shipment, 28 cts. to 34 cts. per sq. ft. (Includes mullions and hardware.)
Trus-con, from San Francisco stock 27 cts. to 33 cts. per sq. ft.
Trus-con, plant shipment, 27 cts. to 33 cts. per sq. ft.
U. S. Metal Products Co., 30 cts. per sq. ft. in San Francisco.
Tile—White glazed, 80 cts. per foot.
White floor, 80 cts. per foot.
Colored floor tile, $1.00 per foot.
Promenade tile, $1.00 per sq. ft. laid.
WAGE—Tilesetters, $8.35 per day.

Comparative Costs of Small Houses for 1914, 1920, and 1921 (Engineering and Contracting, May 25, 1921.) At the national conference on the construction industries held at Philadelphia Feb. 15–18 under the auspices of the Industrial Relations Committee of the Philadelphia Chamber of Commerce and the National Federation of Construction Industries, Daniel Crawford, Jr., an operative builder of Philadelphia, gave an interesting analysis of the cost of the general construction of a typical dwelling. According to his figures a 2-story house of 6 rooms and bath, built in Philadelphia. cost $2,969 in 1914, $8,346 in 1920 and could be built for $6,676 in 1921. These figures are based on an operation of 100 houses. Mr. Crawfords' figures follow:

	1914	1920	1921
Ground	$500.00	$600.00	$600.00
STREET IMPROVEMENTS			
1. Sewer	22.50	60.00	60.00
2. Water pipe	15.00	30.00	30.00
3. Curb (plain)	6.00	16.50	16.50
4. Cartway paving	25.00	90.57	90.57
	$ 68.50	$197.07	$197.07

GENERAL CONDITIONS

	1914	1920	1921
1. Plans	$ 1.00	$ 2.00	$ 2.00
2. Survey	3.50	5.00	5.00
3. Building permits and affidavits	5.00	7.50	7.50
4. Water permit (brick and stone)	1.80	1.80	1.80
5. Electric service	....	....	....
6. Gas service	....	4.00	4.00
7. Fire insurance on building material	.10	.10	.10
8. Fire insurance on buildings	1.60	3.87	2.58
9. Plant and tools	5.00	15.00	12.00
10. Sales expense	64 00	176.00	144.00
11. Advertising	32.00	88.00	72.00
12. Office expense	29.40	78.60	65.50
13. Compensation insurance	....	7.93	6.80
14. Taxes	11.25	25.00	77.45
15. Interest	101.25	263.00	219.40
16. Title company's charges	69.75	150.25	123.75
17. Deed—Acknowledging revenue and recording	4.00	8.50	5.00
18. Expense—Placing first mortgage	20.00	220.00	108.00
19. Expense—Placing second mortgage	23.00	278.00	125.00
20. Supervision	18.00	36.00	36.00
21. Supplies	5.00	15.00	12.00
	$395.65	$1,445.55	$1,036.18

CONSTRUCTION

1. Excavation	$ 40.95	$ 99.45	$ 93.60
2. Stone masonry	145.54	408.70	354.42
3. Brick masonry	226.25	703.67	659.71
4. Rough carpentry	255.42	955.41	555.67
5. Finish carpentry	266.00	850.00	610.00
6. Plastering	104.61	385.04	269.42
7. Cement work	83.00	258.54	198.76
8. Cut stone	7.70	16.00	16.00
9. Structural steel	11.80	48.47	33.63
10. Roofing and spouting	50.00	120.00	110.00
11. Plumbing and gas fitting	167.00	545.00	442.00
12. Heating	166.00	440.00	368.00
13. Electric wiring	30.00	81.25	65.00
14. Stairwork	37.50	166.00	125.00
15. Labor—general	25.00	50.00	50.00
16. Tile work	5.50	12.00	9.90
17. Iron fence and clothes poles	17.00	30.00	25.00
18. Sheet metal work	35.00	105.00	85.00
19. Cabinet work	22.70	56.00	40.00
20. Hardware—finish	11 00	35.00	32.00
21. Hardware—rough	11.00	33.00	24.00
22. Painting and glazing	100.00	225.00	215.00
23. Art glass	8.75	15.00	15.00
24. Range and connection	21.50	65.00	65.00
25. Gas water heater and connection	12.00	35.00	26.00
26. Parquetry floor	48.60	143.75	129.60
27. Flue lining and crocks	2.10	8.85	8.85
28. Grading—general	3.15	6.65	6.30
29. Paperhanging and decorating	42.75	110.00	106.88
30. Lighting fixtures	44.25	90.00	85.00
31. Sodding and seeding	2.43	4.85	4.05
32. Numbering houses	.65	1.00	1.00
	$2,005.15	$6,103.64	$4,842.79

SUMMARY

Ground	$ 500.00	$ 600.00	$ 600.00
Street improvements	68.50	197.07	197.07
General conditions	395.65	1,445.55	1,036.18
Construction	2,003.15	6,103.64	4,842.79
	$2,969.30	$8,346.26	$6,676.04
Sale price	3,200.00	8,800.00	7,200.00
First mortgage value	2,000.00	4,000.00	3,600.00
Second mortgage value	700.00	2,500.00	2,000.00

RATES FOR LABOR USED IN COMPILING ESTIMATES

	Per hour 1914	Per hour 1920	Per hour 1921
Common labor	$0.17½	$0.50	$0.40
Carpenters	.40	1.12½	1.00
Carpenters' helpers	.20	.60	.50
Plasterers	.50	1.25	1.25
Plasterers' helpers	.35	1.10	1.10
Bricklayers	.50	1.30	1.30
Bricklayers' helpers	.35	1.10	1.10
Stone masons	.45	1.30	1.30
Painters	.40	1.00	1.00
Roofers	.40	1.10	1.10
Roofers' helpers	.25	.70	.85
Cement finishers	.50	1.00	1.00
Cement laborers	.20	.60	.60
Tile setters	.65	1.00	1.00
Tile setters' helpers	.40	.80	.68¾
Plumbers	.44	1.15	1.15
Plumbers' helpers	.20	.75	.75
Steamfitters	.36	1.10	1.10
Steamfitters' helpers	.24	.75	.75

Cost of Material

	1914	1920	1921
Foundation stone, per perch	$ 1.40	$ 4.00	$ 3.00
Bricks, per M	7.00	20.00	18.00
Cement, per bbl	1.55	5.25	2.63
Rough lumber, per M ft	20.00	70.00	46.00
Flooring, No. 1 spruce, per M ft	30.00	80.00	60.00
Lath, 4 in., per M ft	3.00	20.00	9.50
Builders' lime, per bu	.25	.70	.64
Calcine plaster, per bbl	2.00	6.25	6.25
Sand, per ton	1.30	2.96	2.30
Fibre, per bu	.25	.35	.35
Structural steel, per cwt	1.40	5.75	4.00
Tin, per box	8.20	22.00	22.50
Felt, per ton	30.00	110.00	85.00
Pitch, per cwt	.70	2.00	2.10
Nails, per keg	3.00	7.50	4.75
Sash cord, per hank	.55	1.25	.85
Tile floors, per. sq. ft	.30	1.00	.82½

Sub-contracts Shown by Percentage of Increase (above 1914)

	1914	1920	1921
Hardware (finish)	Unity	218	190
Plumbing	Unity	226	168
Heating	Unity	165	122
Painting	Unity	125	115
Paperhanging	Unity	157	150
Parquet floors	Unity	195	167
Roofing	Unity	140	120
Sheet metal work	Unity	200	150
Electric wiring	Unity	170	117
Millwork	Unity	215	121
Plastering	Unity	268	158
Gas ranges	Unity	200	200
Excavations	Unity	143	128
Rough stone foundation walls	Unity	208	170
Face stone work	Unity	126	90

Mr. Crawford comments on the above costs as follows:

In 1914 it was possible to buy small lots for dwelling house construction on 40-ft. streets for about $500. The price of the same lot today on a 50-ft. street is a little bit more. I say a 50-ft. street because there has been a general tendency in this community to develop on wider avenues, and the land has been laid out by the surveyors or engineers with a view of getting not less than a 50-ft. street, if possible, so that it is difficult today to find a piece of land that is divided up into 40-ft. streets. So that we have taken the same basic value, and merely added the land that is added. and made it $600 for 1920 and $600 for 1921.

The next item that enters into the cost of construction is utilities—the drainage, the water pipe, the curb, the paving—that the builder must pay for. In 1914 they cost him $68.50, and last year they cost him $197.07. This year the rates are the same. Some folks have said that we are going back to pre-war levels. The first important item that we find is the sales expense of 2 per cent, advertising 1 per cent, and office expense about 1 per cent. Generally, that is the total overhead charge of an operative builder. Four per cent represents his selling expense, his advertising and his office expense. The next item is taxes that amounted in 1914 to $11.25, $85 last year and $77.45 this year.

The next item is interest. You will notice that when a man starts in to build a hundred houses, it takes a lot of money. He must go to a trust company and negotiate a loan, and, of course, he must pay interest on that loan until he repays it to the trust company. We have predicated that charge on 9 months' interest on three-quarters of the cost of the house, the average operation taking anywhere from 15 to 18 months from the time it is started to the time it is disposed of. The title company charges cover title insurance and guaranteeing against mechanics' liens, and searches, recording, and all that sort of thing, which, of course, are perfectly legitimate charges. The next large item is the expense of placing first mortgages. In 1914 we had no difficulty whatever in placing a mortgage of $2,000 on a $3,200 house at an expense of 1 per cent. People were glad to take those mortgages because they were a very good investment. In 1920 the conditions had reversed themselves very much. It was necessary to pay 5 per cent in most cases to place that mortgage, so that the cost of that item jumped from $20 to $220. That condition has been changed this year, and we can place mortgages now at 3 per cent, so that there is run into the expense of building that house a charge of $108. The next item is the expense for placing second mortgages. In 1914 most of the building and loan associations which took the mortgages were in funds, and there was no difficulty in placing that second mortgage by paying the charges of the attorney who represented that association, their solicitor, for drawing the papers, and looking after the settlement, a charge that generally amounted to $23. But the conditions of 1920 changed materially. It was necessary to pay 10 per cent in 1920 for placing second mortgage loans and that amounted to $278. That has changed, and we can place them today at 5 per cent so it is $128. Supervision and so on, is estimated at $18, $36 and $36. The general conditions in the construction of the average small dwelling house rose from $395 to $1,445, and now stands at $1,036.

Relative Output and Cost of Labor in Building Trades in 1914 and 1919.—John B. Miles in a letter published in Engineering and Contracting, July 28, 1920, gives the following data which were obtained from reputable contractors.

EFFICIENCY OF LABOR IN BUILDING TRADES, NORFOLK, VA.

Trade	1914	1919
	Production per 8-hr. day	
	9 doors	5 doors
Carpenters	11 openings	6 openings
Brick masons	1900	800
Plasterers	150 sq. yds.	75 sq. yds.
Painters	1800 sq. ft.	900 sq. ft.

Cost Estimating for Reinforced Concrete Buildings.—Engineering and Contracting, March 27, 1918, gives the following abstract of a paper presented at the 14th convention of the American Concrete Institute by Clayton W. Myers.

The process of estimating various designs for comparative cost purposes is not nearly as difficult as may be supposed. After the quantities have been calculated for the various designs, unit prices are fixed and the total cost of the member estimated. It is not necessary to fix absolutely accurate unit costs to these quantities in order to obtain reasonably accurate cost comparisons. As long as the same unit costs are used for similar types of work in the various designs, the comparative costs will be surprisingly accurate. In fact, some of the unit costs may be in error 25 per cent or 30 per cent, and yet the resulting costs will show unquestionably which type of construction should be used. However, the alert engineer will soon become as interested in having his unit costs in accordance with current prices of material and labor as he is in having his design correct.

Concrete.—A list of approximate unit prices has been tabulated here which may be used to calculate the comparative costs of the principal members in a concrete building. Judicious use of these unit costs will enable the designer to incorporate in his design the most economical methods and at the same time develop a keener eye for economical construction. The following tabulation is a detailed estimate of the cost of concrete mixed in the proportion of 1:2:4.

Concrete (1:2:4 mix), per cu. yd.:		
Cement, 1⅔ bbl. at $2 per bbl. at the job		$3.33
Sand, ½ cu. yd. at $1.50 per cu. yd. at the job		.75
Crushed stone, 1³⁄₁₀ ton at $2 per ton at the job		2.60
Plant, cost per cu. yd.:		
Freight charges	$0.05	
Rental of mixer, etc	.35	
Small purchases, fuel and supplies	.45	
Labor	.40	
		1.25
Labor of mixing and placing		1.25
Total cost per cu. yd		$9.18
Total cost per cu. ft		.34

Concrete mixed in the proportion of 1:1½:3 will require about ⅓ bbl. more cement per cubic yard. This will add about 67 cts. to the cost of 1 yd. of concrete in place, making the unit price about $9.85 per cubic yard, or 36½ cts. per cubic foot. If a 1:1:2 mix of concrete is used, the cement will be increased about 1 ²⁄₁₀ bbl. over and above that used in a 1:2:4 mix. At $2 per barrel this would make the cost of 1:1:2 mix concrete about $11.58 per cu. yd. or 43 cts. per cubic foot. In large plain concrete footings it is sometimes advisable to use a concrete mixed in the proportion of 1: 2½:5. Concrete mixed in this proportion requires about ³⁄₁₀ bbl. less cement than 1:2:4 mix. Figuring cement at $2 per bbl., concrete mixed in the proportion of 1: 2½ :5 works out at approximately 32 cts. per cubic foot in place.

In calculating the amount of materials necessary to make 1 cu. yd. of concrete, it has been assumed that a cubic yard of 1:1:2 concrete will require the same quantity of sand and crushed stone as a cubic yard of 1:2:4 concrete. Theoretically this is not true, but in general practice there is some waste of material and it has been found that the small differences of aggregate used in the various mixes of concrete in a building are negligible. A very large part of the concrete in a building is a 1:2:4 concrete, therefore, the aggregate quantities of 1:2:4 mix are generally used for all concrete work and the cement alone is changed for various mixes. It will also be noted that the quantity of cement, sand and stone used here is somewhat in excess of the amount usually given in the tables published in various text-books. It must be borne in mind that the waste of materials on the job must be absorbed and the quantities in tables compiled by laboratory tests must be somewhat increased. It is actually necessary to estimate on about 1⅔ bbl. of cement to make 1 cu. yd. of 1:2:4 concrete on a job where the usual construction methods are employed and in other mixes of concrete the cement should be proportionately increased.

The prices of concrete work as tabulated here are about 30 per cent in excess of pre-war prices and 50 per cent more than the prices of 1913. These costs based on the present high cost of material and labor should be adjusted from time to time as necessary.

Plant Cost.—In making estimates for the cost of concrete in place, the most uncertain element entering into this cost is the item of "plant." At the present high cost of all building materials and labor, "plant" costs cannot be safely assumed to be less than $1 per cubic yard and will very seldom run as high as $2 per cubic yard of concrete. Owing to this wide variation in the cost of "plant," it is necessary in estimating concrete to strike an average cost which, while not accurate, will cover the usual "plant" work, and give a unit cost for concrete in which all times of material and labor have been considered. It is with this in view that a "plant" cost of $1.25 per cubic yard has been used in making up the unit cost of concrete in place as given in the foregoing tabulation.

The cost of steel reinforcement is extremely erratic in its fluctuation, but at present it may be assumed at $90 per ton exclusive of the labor of bending and placing. It will cost from $6 to $15 per ton to cut, bend and place this reinforcement, $100 per ton, or 5 cts. per pound, being a unit price which may be used to give reasonably close cost ratios. Reinforcement requiring much bending and made up of small bars should be figured about ½ ct. per pound higher than steel requiring only a small amount of bending. Spiral reinforcement for columns should be figured at an extra cost of about ½ ct. per pound over and above plain bars. In estimating the weight of spiral reinforcement it should be remembered that about 7 per cent should be added to the weight of the spirals for welding laps. Also, it will be necessary to add about 3 lb. per lin. ft. of column for spacers used to hold the spirals in proper pitch.

Forms for round columns are usually made from sheet metal and in flat slab construction it usually works out cheaper to use round interior columns formed with this material. However, the cost of forming an interior column 26 in. in diameter for flat slab construction is about the same as forming a column 20 in. in diameter designed for the same purpose. This being the case, it is not necessary to consider the difference in the cost of forms due to different diameters of round interior columns. It may be well to remember that it costs somewhat less to build an interior column having a head by using a steel form than it does to form the column of wood, as the cost of forming the head in wood is no small part of the column cost. The list of unit prices given here covers the cost of labor and material for form work for the principal operations in a concrete building, and are tabulated for use in making comparative estimates for weeding out the more expensive designs but not for making actual estimates of buildings without regard to conditions and what not. While these costs might be more or less useful in arriving at the total cost of a concrete building it should be remembered that they are only approximate units to be used for the purpose outlined.

Type of construction	Square feet cost (Surface measurement)
Forms for flat slabs, including drop panels	$ 0.09
Slab, beam and girder construction, slabs to span not less than 9 ft.	.12
Slab, beam and girder construction, slabs to span not less than 7 ft.	.13
Slab, beam and girder construction, slabs to span not less than 5 ft.	.14
Column forms	.15
Floor beams and girders, not including slabs	.16
Wall beams	.14
Partitions and wall forms	.15
Footing and foundation forms	.15
Round steel column forms, including heads, each	15.00

For making complete estimates, typical dimensioned sketch cross-sections of the building from the roof slab to the footings should be made and the work of estimating done from these sketches. In this way the extra column lengths required to obtain the same clear story heights will enter into the estimate. This is quite a factor in comparing flat slab with beam and girder designs. Estimates made from these cross-sections for a length of building equal to one bay only, is the usual practice. In this way the cost per lineal foot of building as well as the cost per square foot of floor space may be calculated. Comparisons of costs made in this manner are genuine proofs to the designer that he is giving the design proper study for economy, and will result in a conservation of building materials, save good dollars for the owner, and establish for the engineer the reputation of being a designer of economical concrete buildings.

Interior Columns.—A typical interior concrete column as used in certain types of flat slab construction is illustrated in Fig. 1. Several comparative designs have been made for this column using in each case standardized formulae and fibre stresses. The cost of the various schemes is worked out in detail in Table VI the unit prices fixed to the quantities of material and labor being taken, principally, from figures previously given.

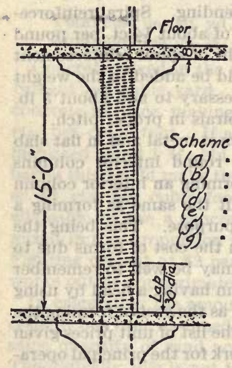


FIG. 1.—Typical interior column.

From the estimated comparative costs in Table VI perhaps the most noticeable fact is that the columns using the 1:2:4 mix of concrete are among the most expensive. Using this lean mix necessarily produces a column larger in diameter which means, also, a loss of valuable floor space. It will also be noticed that the smallest column designed is not the most economical. The column which shows the most economy in this case is one having a 1:1:2 mix and about 1 per cent of vertical reinforcement together with 1 per cent of spiral reinforcement. Hence, a rich mix of concrete and comparatively small percentages of steel reinforcement seem to show the most economicalre sults for a column carrying a fairly heavy load.

For comparative purposes, the difference in the amount of concrete in the column heads may be neglected as the top diameter of the head usually remains the same throughout the building. The cost of forming the column and its head has been estimated here at $15 each. This is done for convenience in arriving at a total cost of the column shaft Ordinarily this cost is neglected in making comparative estimates of interior columns, as it costs about the same to form a round column of small diameter as it does a column of larger diameter. Many other schemes may be designed for this particular column and the comparative costs estimated. However, the several examples, some of which are obviously too expensive to consider, will suffice to give the reader a working knowledge of the methods of calculation employed to determine the costs of the various types of interior columns. It is readily appreciated that even though a larger column were somewhat cheaper to build, the additional floor space occupied by this larger column might be worth more to the owner of the building than he would save in the construction of

TABLE VI.—COMPARATIVE ESTIMATES FOR SEVERAL DESIGNS OF INTERIOR CONCRETE COLUMNS

Design	Comparative Estimates		
Scheme (a):			
36-in. dia. column	Concrete	99 cu. ft. at 24 cts.	$ 33.66
11 1⅛-in. rd. vert. rods	Forms	Round steel	15.00
⅜-in. rd. hoops 12 in. o/c	Reinforcement	716 lb. at 5 cts.	35.80
Mix 1:2:4	Lost floor space	5 sq. ft. at $2.75	13.75
	Total		$ 98.21
Scheme (b):			
32-in. dia. column	Concrete	79 cu. ft. at 34 cts.	$ 26.86
23 1⅛-in. rd. vert. rods	Forms	Round steel	15.00
⅜-in. rd. hoops 12 in. o/c	Reinforcement	1,437 lb. at 5 cts.	71.85
Mix 1:2:4	Lost floor space	3 1/10 sq. ft. at $2.75	8.53
	Total		$122.24
Scheme (c):			
32-in. dia. column	Concrete	79 cu. ft. at 36½ cts.	$ 28.84
23 1⅛-in. rd. vert. rods	Forms	Round steel	15.00
⅜-in. rd. hoops 12 in. o/c	Reinforcement	770 lb. at 5 cts.	38.50
Mix 1:1½:3	Lost floor space	3 1/10 sq. ft. at $2.75	8.53
	Total		$ 90.87
Scheme (d):			
26-in. dia. column	Concrete	52 cu. ft. at 36½ cts.	$ 18.98
11 1-in. rd. vert. rods	Forms	Round steel	15.00
1 per cent spirals (18½ lb.) per lin. ft.	Reinforcement (vert.)	514 lb. at 5 cts.	25.70
Mix 1:1½:3	Spirals	264 lb. at 5½ cts.	14.52
	Lost floor space	7/10 sq. ft. at $2.75	1.92
	Total		$ 76.12

Table VI.—*Continued*

Design	Comparative Estimates		
Scheme (e): 28-in. dia. column; 20 1⅛-in. rd. vert. rods; ⅜-in. rd. hoops 12 in. o/c; Mix 1:1:2	Concrete	60½ cu. ft. at 43 cts.	$ 26.02
	Forms	Round steel	15.00
	Reinforcement	1,255 lb. at 5 cts.	62.75
	Lost floor space	1.45 sq. ft. at $2.75	3.99
	Total		$107.76
Scheme (f): 26-in. dia. column; 7 ⅞-in. rd. vert. rods; 1 per cent spirals (18½ lb.) per lin. ft.; Mix 1:1:2	Concrete	52 cu. ft. at 43 cts.	$ 22.36
	Forms	Round steel	15.00
	Reinforcement	245 lb. at 5 cts.	12.25
	Spirals	264 lb. at 5½ cts.	14.52
	Lost floor space	7/10 sq. ft. at $2.75	1.92
	Total		$ 66.05
Scheme (g): 24-in. dia. column; 10 1⅛-in. rd. vert. rods; 1 per cent spirals (16 lb.) per lin. ft; Mix 1:1:2	Concrete	44½ cu. ft. at 43 cts.	$ 19.14
	Forms	Round steel	15.00
	Reinforcement (vert.)	606 lb. at 5 cts.	30.30
	Spirals	229 lb. at 5½ cts.	12.60
	Total		$ 77.04

the column. Hence, it becomes necessary to consider the value of this additional floor space as a part of the cost of this larger column. It is difficult to say just what this floor space is really worth. However, a satisfactory way to deal with the situation is to consider the smallest column designed as a basis to which the other columns are to be compared. In the illustration this column is 24 in. in diameter. Consider the area of floor space occupied by a column equal to the square of the diameter of the column. The additional area occupied by any one of these larger columns is equal to the difference between the square of the diameter of the column in question and the square of the diameter of the smallest column designed. This additional or lost floor area is priced at a unit cost equal to the approximate unit cost per square foot of floor space of the completed building, including heating, lighting, sprinklers, etc. The unit cost per sq. ft. of building is calculated by dividing the approximate total cost of the building by the number of sq. ft. of floor space in the building, measurements to be taken "out to out" of the floor plan. For

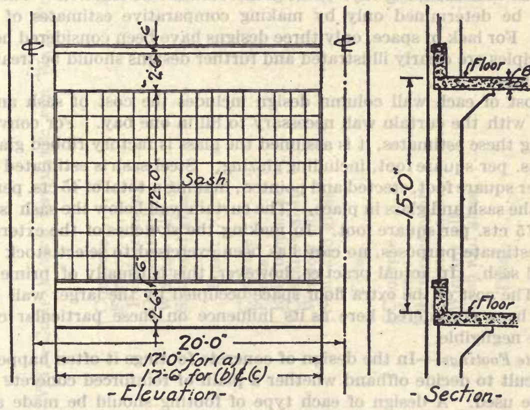


FIG. 2.—Typical wall column.

example, a building 200 ft. × 60 ft. and five stories high may cost $165,000 complete. This works out at $2.75 per square foot and for general purposes this will give fairly accurate results for the purpose described above.

In the comparative estimates of the interior column given, if we strike out of each estimate the cost of lost floor space, the relative cost of each column will remain unchanged. This is not always the case, and even in our examples it will be noticed that the columns having the leaner mixes show up much more favorably when this item of cost is excluded from the total cost of the column. Frequently, the omission of this item will result in a transposition of the economic order of the various designs. In many buildings the loss of a few feet of floor space is immaterial, but in other cases it is of great importance, as in shorehouses or in buildings where the machinery layout would be interfered with by a larger column. Where loft buildings or offices are rented by the square foot of net area the cost of this floor space should be figured at a considerably higher figure than the one given in our tables.

Wall Columns.—In determining the economical wall column, the method is very similar to that used for interior columns except that the item of the cost of wood forms enters into the estimate. It will be necessary also in designing exterior columns to consider the width carefully, as every inch added or deducted will change the corresponding dimension of wall sash a like amount.

Fig. 2 shows a typical exterior wall column for a concrete building having these columns spaced 20 ft. apart. Three designs of this column have been compared, and the respective estimates are shown worked out in detail in Table VII in an effort to determine which one of the three designs would be the most economical to use. Three different mixes of concrete have been used and again, as in the case of the interior column, the column designed to use a 1:1:2 mix concrete appears to be the least expensive to build. Generally speaking, with the present high price of reinforcement, cement is the cheapest reinforcement for a concrete column. Nevertheless, it must not be concluded that a rich mix should always be used in column construction. The proper mix can be determined only by making comparative estimates of several designs. For lack of space, only three designs have been considered here, but the principles are clearly illustrated and further designs should be treated in a like manner.

The cost of each wall column design includes the cost of sash and glass together with the curtain wall necessary to fill in one bay. For convenience in making these estimates, it is assumed the glass is factory ribbed glass costing 20 cts. per square foot, including glazing. Steel sash is estimated here at 25 cts. per square foot, erected and pointed, making a total of 45 cts. per square foot for the sash and glass in place. The curtain wall below the sash is figured here at 75 cts. per square foot. In making the sketches of the exterior wall bay for estimate purposes, no care has been exercised to select stock sizes of steel wall sash. In actual practice, however, this is usually of prime importance. The cost of the extra floor space occupied by the larger wall column has not been considered here as its influence on these particular columns would be negligible.

Concrete Footings.—In the design of concrete footings it often happens that it is difficult to decide offhand whether a plain or reinforced concrete footing should be used. A design of each type of footing should be made and the comparative costs calculated. The engineer knowing the kind of soil these footings will rest upon should price the excavation required at a proper figure. This is a very important part of the footing cost, in fact, many times the most vital part of the estimate for foundation work. In the absence of any more reliable information the unit costs of excavation per cubic yard (not over 5 ft. deep), may be assumed as follows:

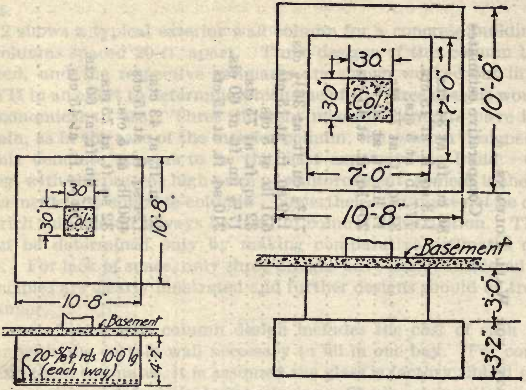
Loam or other easy excavation	$0.75 cu. yd.
Gravelly earth containing small stones	$1.00–$1.50 cu. yd.
Frozen earth	2.25– 2.50 cu. yd.
Rock or ledge excavation	3.50– 4.00 cu. yd.
Backfill	.30– .50 cu. yd.
Sheeting around excavated holes for footings	.10 sq. ft.

For excavation work over 5 ft. deep and down to 10 ft. deep, the unit cost on the yardage below the 5-ft. depth should be increased approximately 50 per cent. The unit price of excavating to a depth exceeding 10 ft. is based on the number of times the excavated material must be rehandled before it is finally deposited where it may be teamed away or disposed of in some other

Table VII.—Comparative Estimates for Wall Columns

Design	Comparative estimates		
Scheme (a):			
36 × 24 in.	Concrete	86 cu. ft. at 34 cts.	$ 29.24
12 1/8-in. rd. rods 17 ft. 6 in.	Forms	143 sq. ft. at 15 cts.	21.45
3/8-in. rd. hoops 12 in. o/c	Reinforcement	777 lb. at 5 cts.	38.85
Mix 1:2:4	Curtain walls	31 sq. ft. at 75 cts.	23.25
	Window sill	17 lin. ft. at 60 cts.	10.20
	Sash and glass	204 sq. ft. at 45 cts.	91.80
	Total		$214.79
Scheme (b):			
30 × 24 in.	Concrete	71 2/3 cu. ft. at 36 1/2 cts.	$ 26.16
10 1 1/8-in. rd. rods 17 ft. 10 in.	Forms	129 sq. ft. at 15 cts.	19.35
3/8-in. hoops 12 in. o/c	Reinforcement	651 lb. at 5 cts.	32.55
Mix 1:1 1/2:3	Curtain walls	32 sq. ft. at 75 cts.	24.00
	Window sill	17 1/2 lin. ft. at 60 cts.	10.50
	Sash and glass	210 sq. ft. at 45 cts.	94.50
	Total		$207.06
Scheme (c):			
30 × 22 in.	Concrete	66 cu. ft. at 43 cts.	$ 28.38
12 7/8-in. rd. rods 17 ft. 2 in.	Forms	124 sq. ft. at 15 cts.	18.60
3/8-in. rd. hoops 12 in. o/c	Reinforcement	460 lb. at 5 cts.	23.00
Mix 1:1:2	Curtain walls	32 sq. ft. at 75 cts.	24.00
	Window sill	17 1/2 lin. ft. at 60 cts.	10.50
	Sash and glass	210 sq. ft. at 45 cts.	94.50
	Total		$198.98

manner. An example is given in Table VIII here with comparative costs for the two types of footings, reinforced and plain, shown in Fig. 3, schemes a and b respectively. The excavation is assumed as costing \$1 per cubic yard to remove, and the excavated holes are sheeted close in order to do away with form work around the large footing block.



(Scheme a) (Scheme b).

Fig. 3.—Typical concrete footings.

Table VIII.—Comparative Estimates for Footings

Scheme (a), reinforced type (mix 1:2:4):		
Concrete 1:2:4	460 cu. ft. at 34 cts	\$156.40
Forms (none)		
Reinforcement	420 lb. at 5 cts	21.00
Excavation	19¼ cu. yd. at \$1	19.25
Backfill and level	19¼ cu. yd. at 30 cts	5.78
3-in. (close) sheeting	182 sq. ft. at 10 cts	18.20
Total		\$220.63
Scheme (b), plain type (mix 1:2½:5):		
Concrete 1:2½:5	507 cu. ft. at 32 cts	\$162.24
Forms (top block)	84 sq. ft. at 15 cts	12.60
Excavation	24 cu. yd. at \$1	24.00
Excavation below 5-ft. mark	5½ cu. yd. at \$1.50	8.25
Backfill and level	29½ cu. yd. at 30 cts	8.85
3-in. (close) sheeting	270 sq. ft. at 10 cts	27.00
Total		\$242.94

The estimates in Table III indicate that the reinforced footing is the most economical to use in this case. However, provided stones or "plums" were obtainable at a small expense, the cost of the plain footing could be considerably reduced. It will be noted in the estimates for these two footings that the excavation for the plain footing is the determining factor in its cost. The materials used in the plain footing cost somewhat less than those used in the reinforced type, but the extra depth of the excavation makes the plain type the more expensive one to use. This extra cost becomes still greater when the footings are placed in wet or frozen ground, for which excavation costs are considerably more. In case the reinforced type of footing is built with a sloping top, and a wood form is used for this top, the cost would be about the same as though the concrete were placed up to a level with the top of the footing, and the form work omitted, as above estimated. In some operations the top part of a footing is sloped and the concrete placed "dry." This necessitates a change in the batch, slows up operations and many times does not work out economically. For estimating comparative costs of footings it is not a safe procedure to assume that the top part of the footing will be placed "dry" in order to do away with forms on the slope. Either estimate a form for this sloping surface or figure on the concrete as being placed up to a level with the top of the footing.

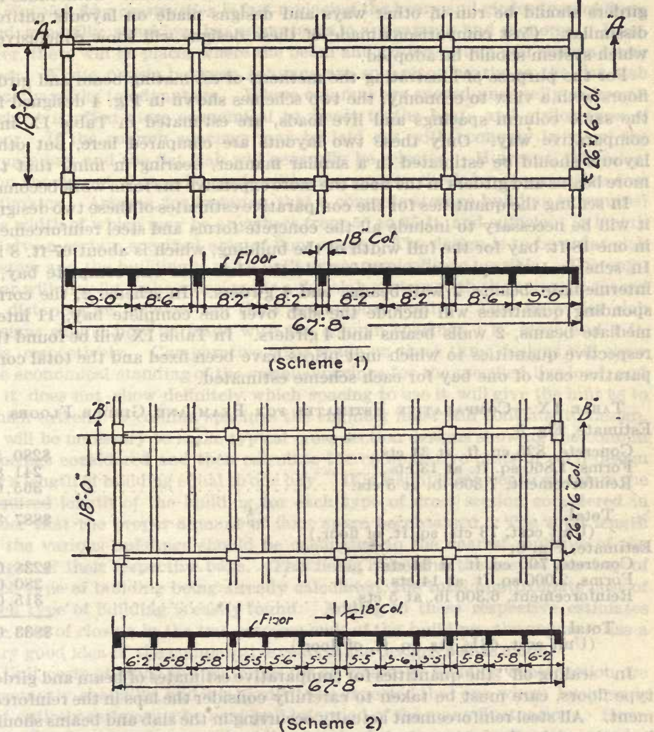


FIG. 4.—Typical beam and girder floors.

Concrete Floor.—In the design of the beam and girder type floor, the omission or addition of one intermediate beam per bay may influence the cost materially. Although this problem is usually handled economically by engineers designing concrete buildings which have usual floor loadings and column spacings, it sometimes happens that when unusual floor loadings and column spacings are required, it is necessary for the engineer to determine a layout which will show the most economy. In a proposition of this kind it is first necessary to make the design which looks most likely to be the economical one. Then, two more designs should be made, one having one more intermediate beam and the other having one less intermediate beam. Sometimes the girders should be run in other ways and designs made on layouts entirely dissimilar. Cost comparisons made of these designs will show conclusively which system should be adopted.

For the purpose of illustrating the methods of estimating beam and girder floors with a view to economy, the two schemes shown in Fig. 4 designed for the same column spacings and live loads, are estimated in Table IX in a comparative way. Only these two layouts are compared here, but other layouts should be estimated in a similar manner, bearing in mind that the more beams and girders in the floor the more expensive the form work becomes.

In scaling the quantities for the comparative estimates of these two designs, it will be necessary to include all the concrete forms and steel reinforcement in one 18-ft. bay for the full width of the building, which is about 67 ft. 8 in. In scheme 1 the quantities will include the slab over one complete bay, 7 intermediate beams, 2 wall beams, and 4 girders. In scheme 2, the corresponding quantities will include the slab over one complete bay, 11 intermediate beams, 2 walls beams and 4 girders. In Table IX will be found the respective quantities to which unit prices have been fixed and the total comparative cost of one bay for each scheme estimated.

Table IX.—Comparative Estimates for Beam and Girder Floors

Estimate, Fig. 5:	
Concrete, 825 cu. ft. at 34 cts.	$280.50
Forms, 1,860 sq. ft. at 13 cts.	241.80
Reinforcement, 7,300 lb. at 5 cts.	365.00
Total	$887.30
(Unit cost, 73 cts. sq. ft. of floor.)	
Estimate, Fig. 6:	
Concrete, 700 cu. ft. at 34 cts.	$238.00
Forms, 2,000 sq. ft. at 14 cts.	280.00
Reinforcement, 6,300 lb. at 5 cts.	315.00
Total	$833.00
(Unit cost, 68½ cts. sq. ft. of floor.)	

In "scaling off" the quantities for comparative estimates of beam and girder type floors, care must be taken to carefully consider the laps in the reinforcement. All steel reinforcement actually occurring in the slab and beams should be estimated. In taking off the quantities, also, it will be found most convenient to first get the quantity of concrete, then the square feet of forms and lastly the pounds of reinforcement. The order of scaling for the form work and reinforcement should be the same as that followed in getting the quantity of concrete; that is, if beams follow slabs in the concrete scaling, beam steel should follow slab steel in the reinforcement scaling. This method will eliminate to a large extent the liability of error, and also lessen the work of scaling dimensions since the form areas may be taken directly from the scaled dimensions of the concrete work.

The slight changes in column and footing design which might actually occur in two buildings designed with floors like those above estimated, have not been considered here. However, in buildings several stories in height this phase of the design should be carefully considered in conjunction with the cost of floor designs when the cost comparisons are made. Even though the spacing of columns remains the same for all schemes considered, the different dead loads may influence the cost of the columns and footings considerably and the different girder depths may make it possible to vary the overall height of the columns in order to get the same clear head room.

Flat slab floor construction is fast replacing the beam and girder type of floor, and generally speaking, has advantages in appearance and economy. However, there will be places where the beam and girder system will show a lower cost. Where panels between columns are square or nearly so the flat slab usually works to advantage. Where columns are spaced unequally or irregularly it is often more economical to resort to the beam and girder type of floor. If the column spacings may be laid out with economy in view, the square bay and the flat slab will generally be selected. However, this selection should not always be made without a proper check by comparative cost estimates. Assume, for instance, that a concrete storage building is required the width of which may be anywhere from 55 to 65 ft. and sufficient in length to give a certain specified area of floor space. The design is to be a flat slab system and the building is to be built as economically as possible. The engineer will usually make a design for a flat slab system with the columns spaced at distances he believes will show economical results. Two more flat slab designs should now be made with the column spacings 1 ft. more and 1 ft. less, respectively. Comparative costs made on these three designs will show the economical standing of the various spacings for the specified live load, and if it does not show definitely which spacing to use it will give the hint as to which extreme of column spacings the engineer must still continue to design. It will be necessary to make typical cross-section designs showing the column spacings considered and then calculate the comparative costs of each design for a length of building equal to one bay. It is a simple matter to calculate the required length of the building for each type of cross section considered in order that the proper amount of floor space be obtained. The total length of the various buildings should be calculated to the nearest multiple of the length of their respective bays. This being done and the cost of one bay of each type of building being already calculated, the total approximate cost of each type of building is easily found. Adding to these respective estimates the cost of closing in the two extreme ends of the building, the engineer has a very good idea of the comparative costs of the designs he has made.

Unit costs of labor and materials for all classes of building construction are constantly changing, and it is hardly to be expected that one whose business is not entirely estimating be kept well informed of the many fluctuations. However, the designer does not have to use absolute accurate unit costs in order to determine by comparative estimates, the relative economic standing of his designs. A review of the market conditions from time to time in a general way will give him enough information to revise his unit costs in order that his comparisons may show more accurately the true status of his work. The prices tabulated and used throughout this paper, as before mentioned, are much higher than the prices of two or three years ago. It is quite possible that two years hence they may undergo another change equally great, and the engineer must look out for this and act accordingly. Five years ago the ratio of cost of concrete, forms and steel in a building was roughly 2:2:1. Today it is about 2:1:1—that is to say, five years ago the total cost of the concrete about equaled the cost of the forms, and the reinforcement equaled about one-half of the cost of either. Today, the cost of the concrete in a building is slightly less than twice the cost of the forms, and the cost of the reinforcement is about equal to the form cost. It is quite probable that five years from now the ratio may be again changed.

Items Making up Cost of Concrete Building.—C. E. Patch gives the following data in Engineering and Contracting, July 28, 1920.

	Percentage referred to Structural cost of building	Percentage referred to Total cost including sub-contracts
Concrete	24.0	19.2
Reinforcing	16.0	12.76
Forms	14.6	11.8
Engineering	5.5	4.50
Cold weather	5.2	4.25
Doors and windows	5.2	4.15
Plant	4.6	3.85
Miscellaneous and extras	4.5	3.6
Excavation	3.7	3.05
Carpentry	3.7	3.05
Masonry	2.5	2.08
Fire main and roof drains	2.3	1.95
Miscellaneous iron and steel	2.2	1.85
Overhead	1.56	1.28
Superintendence, travel, etc	1.50	1.23
Roofing and flashing	1.36	1.12
Liability insurance	0.62	0.51
Watchman	0.54	0.45
Clean up job	0.42	0.35
Heating and sprinklers	59.7*	11.20
Plumbing	15.3*	2.93
Elevators	14.6*	2.86
Electrical work	10.4*	1.98

* Of total cost of equipment sub-contracts.

Cost of Reinforced Concrete Power House.—John W. Ash in Engineering Record, Jan. 25, 1913, gives the following cost of constructing a power house in connection with the waterworks plant at Dalton, Ga. The floor area of the power-house, including the filter, covers about 4,650 sq. ft.; the walls average a little over 20 ft. in height, 6 and 8 in. thick, with columns averaging about 11 ft. on centers. A beam 12 in. square runs around on top of all walls. The concrete mixture was 1 : 2½ : 5.

TABLE X.—POWER-HOUSE COSTS

	Labor	Material	Total
Excavation, 437 cu. yd	$253.80	....	$ 253.80
Forms	677.80	$ 182.50	860.30
Concrete, 315 cu. yd	417.20	1,176.60	1,593.80
Steel, 15,500 lb	93.90	316.90	410.80
Roof trusses	21.30	292.50	313.80
Lumber, floors and roof, 19,020 ft. B.M.	104.60	387.00	491.60
Wood doors and windows	87.20	178.85	266.05
Fire-doors, 302 sq. ft	29.50	201.00	230.50
Composition roof, 5,000 sq. ft	30.00	150.00	180.00
Pipe connections	25.00	....	25.00
Concrete floor, 2,340 sq. ft	65.10	145.50	210.60
Reinforced concrete floor, 80 sq. ft	6.50	14.50	21.00
Handling and placing outfit	88.90	....	88.90
Coal, oil, waste, etc	....	42.50	42.50
Depreciation, repairs	....	....	78.50
Ventilators and granite slab	7.50	109.60	117.10
Grand total			$5,184.25

Cement cost $1.35 per barrel; sand $1.05 per ton; stone $1.43 per ton. Labor was $1.35 and $1.50 per day; carpenters $2.25 to $3.50 per day. The labor item in the above table includes foremen and superintendence.

Cost of Constructing a Reinforced Concrete Storehouse.—Civil Engineer, E. R. Gayles, U. S. N., in Public Works of the Navy, June, 1916, and in Engineering and Contracting, Aug. 23, 1916, gives the following:

The structure was built by contract and consists of a six-story main building 100 × 250 ft. and of a one-story crane runway annex 50 × 250 ft. The construction is reinforced concrete except the exterior brick curtain walls of the main building and the roof of the annex which is steel frame with ferroinclave roofing.

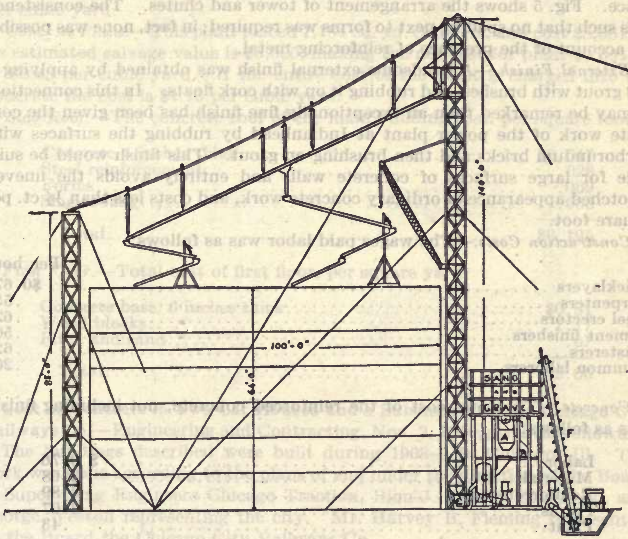


Fig. 5.—Concreting plant for storehouse.

Structural Features.—The building has pile foundations designed for a loading of 20 tons per pile, penetrating through partly consolidated filling and alluvial deposits to a fairly flat layer of gravel and sand at a depth of about 43 ft. below cut-off. The piles were driven by drop hammers weighing 2,500 lb. and the slow rate of progress, averaging only 11.4 piles per driver per day, gave a striking illustration of the inefficiency of this antiquated method of driving.

The concrete piers were 1:3:6 gravel concrete, chuted into place, the pile heads being embedded 6 in. in the concrete.

The columns were designed for the total dead load plus 75 per cent of the live load. The columns are square, 3 × 3 ft. with eight 1⅝-in. diameter round rods in the first story, diminishing uniformly at each story to 12 × 12 in. with four ¾-in. diameter round rods in the sixth story. At the first story the longitudinal reinforcement is 1.5 per cent of the effective area, and at the sixth story 2.2 per cent. One-fourth inch diameter round hoops were used spaced 12 in. apart; the percentage of hooping is as a result very small, and the columns were therefore designed as with longitudinal reinforcement only.

The floors with the exception of the first, which rests on ground, consist of slabs and T beams and were designed for loads varying from 400 lbs. per sq. ft. on the second floor to 150 lbs. per sq. ft. on the sixth floor.

Forms.—The forms were made of tongued-and-grooved pine; new lumber was provided for forms for three stories, and the same forms were altered and repaired for the upper two stories and roof.

Handling Concrete.—The concrete was hoisted by tower and chuted into place. Fig. 5 shows the arrangement of tower and chutes. The consistency was such that no spading next to forms was required; in fact, none was possible on account of the presence of reinforcing metal.

External Finish.—A handsome external finish was obtained by applying a 1:2 grout with brushes, and rubbing it on with cork floats. In this connection, it may be remarked than an exceptionally fine finish has been given the concrete work of the power plant at Indianhead by rubbing the surfaces with carborundum bricks and then brushing on grout. This finish would be suitable for large surfaces of concrete walls and entirely avoids the uneven splotched appearance of ordinary concrete work, and costs less than ½ ct. per square foot.

Construction Costs.—The wages paid labor was as follows:

	Per hour
Bricklayers	$0.67
Carpenters	.55
Steel erectors	.62
Cement finishers	.50
Plasterers	.62
Common laborers	.20

Concrete.—The total cost of the reinforced concrete, not including finish, was as follows:

Labor	$ 0.76
Materials	3.08
Reinforcement	3.89
Forms	3.07
Plant	.43
Total	$11.23

The cost of 1:3:6 foundation concrete was as follows:

Labor	$0.78
Materials	2.65
Reinforcement	.60
Forms	.20
Plant	.43
Total	$4.66

Materials were received in bottom dump wagons. Labor cost includes dumping materials into receiving hopper, handling by bucket conveyor to bins, mixing, hoisting into tower, chuting, distributing and working into place, setting anchor bolts and column dowels.

The concrete of the first floor was handled by industrial track and tip cars;

including placing track, etc., 2,670 sq. yd. cost $0.81 per square yard for labor and material for 6-in. floor without cement finish.

Reinforcing steel for 5,264 cu. yd. reinforced concrete weighed 1,170,000 lb., corresponding to an average throughout the building of 8.2 lb. reinforcement per cubic foot of concrete, or 1.7 per cent, and cost $3.89 per cubic yard of concrete, at the rate of $0.475 per pound in place.

Forms were generally used twice. Forms per 5,264 cu. yd. reinforced concrete cost $17,200, or $3.07 per cu. yd. There were 247,500 sq. ft. of forms used in the entire building, costing $0.024 per square foot for labor and $0.045 per square foot for materials, total $0.069 per square foot of forms in contact with concrete. Cement cost $1.10 per barrel net; sand $0.98, and gravel $1.20, per cubic yard.

Concrete Plant.—This plant placed 7,184 cu. yd. concrete, and cost $8,061.92 its estimated salvage value is $5,000, making the net cost for plant $3,061.92 or $0.43 per cubic yard. If the entire cost of the plant is charged into the concrete the cost is $1.13 per cubic yard.

Slab Roof.—The concrete roof of the main building cost, per square foot:

Concrete 4 inches thick	$0.047
Steel reinforcement	.026
Forms	.069
Slag roofing	.053
Total	$0.195

First Floor.—Total cost of first floor, per square yard:

Concrete base, 6 inches thick	$0.81
Wood blocks	1.17
Pitch and sand	.07
Total	$2.05

Cost of Concrete in Two Car Houses and a Substation for the Chicago City Railways Co.—Engineering and Contracting, Nov. 2, 1910, gives the following:

The buildings described were built during 1908–9 in Chicago, Ill. The work was done according to the plans of and under the direction of the Board of Supervising Engineers Chicago Traction, Bion J. Arnold, Chairman, and George Weston representing the city. Mr. Harvey B. Fleming represented on the Board the Chicago City Railways Co.

The general plans of the Board of Supervising Engineers call for double ended car houses divided into longitudinal bays by fireproof partitions. The exterior walls are of brick. The columns and walls have concrete footings and the floors are of concrete. The pits are open and have concrete walls and floors. Between pits the floors are reinforced concrete and the roof is reinforced concrete slab and girder construction with skylights along the center of each bay nearly the whole length.

Sixty-Ninth St. and Ashland Avenue House.—This car house was built during 1908. It is 485 × 265¼ ft., divided into six car storage bays and one repair bay by six longitudinal partitions. Each bay has three tracks with a pit under each track. In the storage bays the pits are all 288 ft. long and in the repair bay they are 176 ft. long. The roof construction is shown in detail by Fig. 6. The concrete work comprised foundation footings and walls, floors, pits, wells and floor and roof slabs and girders. The cost of the concrete work was as follows:

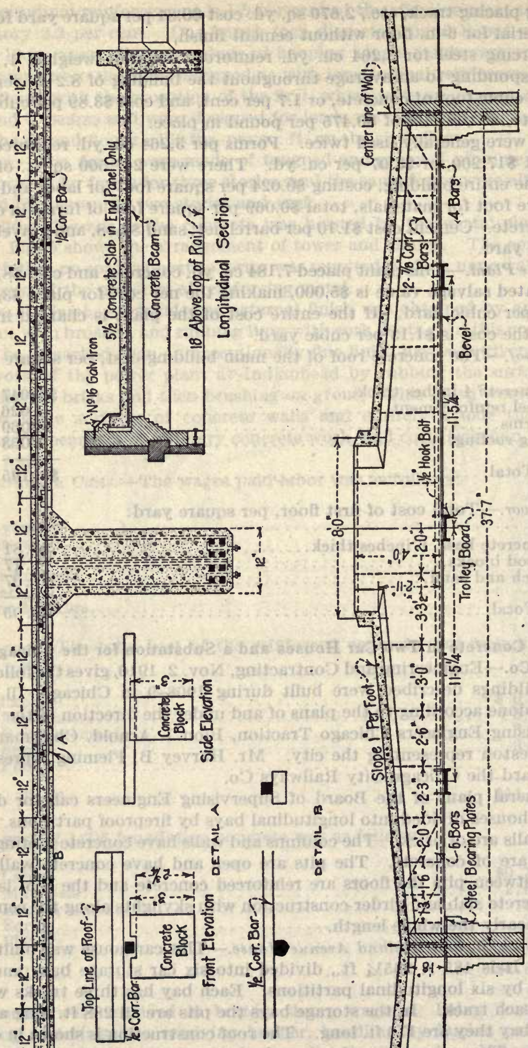


FIG. 6.—Reinforced concrete car barn roof.

For 1,776 ft. of 1:3:6 plain concrete in footings and foundation walls the cost including forms was $11,181 or $6.30 per cu. yd. The cost of 380 cu. yds. of 1:3:6 concrete in pit walls, including form work, was $3,026, or $7.96 per cu. yd. The pit floors, containing 1,287 cu. yds,. cost $9,515 or $7.40 per cu. yd. The cost of pit floors per square foot was 13.6 cts. There were also 12,200 sq. ft. of cement walk and 1,186 ft. of curb. The walks were 4½ ins. thick, of 1:2½:5 concrete, with a ¾-in. top coat of cement and granite screenings; the cost was as follows:

Item	Per sq. ft.
Materials	$0.056
Labor	0.123
Total	$0.179

The curbing was 2 ft. deep by 6 in. thick and the cost of 1,186 lin. ft. or 43.9 cu. yds. was:

Item	Per lin. ft.	Per cu. ft.
Material	$0.127	$ 3.44
Labor	0.390	10.54
Total	$0.517	$13.98

The cost of 89,935 sq. ft. of roof, including 168 girders, of the construction shown by Fig. 6 can be given in more detail. There were in this roof 2,365 cu. yds. of 1:2½:5 concrete. The cost of concrete materials and labor concreting was as follows:

Item	Per cu. yd.
5,075 bbls. cement at $1.21	$1.57
1,675 cu. yds. sand at $1.60	1.14
1,635 cu. yds. stone at $1.40	0.96
Labor concreting	3.06
Total	$6.73

The cost of reinforcing rods and labor placing was as follows:

Item	Per cu. yd.
329,900 ft. ½-in. bar at 1.62 cts	$2.22
14,629 ft. ½-in. stirrup at 1.84 cts	0.12
153,605 ft. ⅞-in. stirrup at 1.75 cts	1.14
Labor on reinforcements	1.18
Total	$4.66

The cost of incidentals and labor for forms was as follows:

Item	Per cu. yd.
91 M. ft. B. M. hemlock at $18	$0.69
149 M. ft. B. M. pine at $20	1.26
Spikes, bolts and wire	0.21
Labor on forms	5.34
Total	$7.50

Summarizing the above figures and extending them to include cost per square foot we have the following:

Item	Per cu. yd.	Per sq. ft.
Concrete	$ 6.73	$0.177
Reinforcement	4.66	0.123
Forms	7.50	0.197
Total	$18.89	$0.497

Archer Ave. and Rockwell St. House.—The dimensions of this house are 309 × 490 ft. and it is divided into seven bays by longitudinal fireproof walls. The concrete construction comprises foundation walls, pits and roof of the design shown by Fig. 6.

The foundation walls of 1:3:7 concrete cost for 1,953 cu. yds. as follows:

Concrete	Per cu. yd.
1,894.41 bbls. cement at $1.22	$1.183
839.79 cu. yds. sand at $1.43	0.614
1,972.53 cu. yds. stone at $1.54	1.555
Labor, mixing and placing	1.471
Total concrete	$4.823
Forms	
Lumber	$0.321
2 rolls No. 10 wire at $2.23	......
2,000 18-in. form clamps at 4¾ cts	......
500 26-in. form clamps at 5¾ cts	......
125 25-in. form clamps at 5½ cts	0.134
500 keys for form clamps at 3 cts	......
48 kegs of nails at $2.36	......
Labor building and removing	1.321
Total forms	$1.776
Supplies	
7.65 tons coal at $4.15	......
5 gals. cyl. oil at 48 cts	......
10 gals. eng. oil at 23 cts	......
10 lbs. lubricant at 12 cts	......
Total supplies	$0.019
Grand total	$6.618

The pit tracks are supported by cast iron columns on each side and these columns have concrete footings. The cost of these footings which are of the usual stepped pedestal type was as follows:

Item	Per cu. yd.
270 bbls. cement at $1.22	$1.355
118 cu. yds. sand at $1.40	0.694
241 cu. yds. stone at $1.54	1.525
Labor mixing and placing	1.867
Coal and oil	0.007
Total	$5.448

The following was the cost of 211 cu. yds. of concrete in the side and end walls of the pits:

Concrete	Per cu. yd.
235 bbls. cement at $1.22	$1.35
105 cu. yds. sand at $1.43	0.72
209 cu. yds. stone at $1.54	1.52
Labor mixing and placing	1.02
Total	$4.61
Forms	
16 kegs nails at $2.40	$0.18
½ roll wire	0.05
Lumber	0.51
Labor erecting	3.06
Labor removing	0.57
Total	$4.37
Grand total	$8.98

The floor work of the building comprised the floors between tracks for the end sections of each bay not occupied by the pits; the floors for store room, shops and other service rooms; the pit floors and the reinforced concrete floors between pits. All these floors except the reinforced concrete floors between pits are the usual concrete basement floor construction:

End floors (63,630 sq. ft.)	Per sq. ft.
1,684 bbls. cement at $1.22	$0.03
744 cu. yds. sand at $1.43	0.01
1,190 cu. yds. stone at $1.54	0.02
Labor	0.06
8.45 tons coal at $4.15	0.0005
32 tons coke at $5.25	0.02
38 loads manure at $2	0.001
Oil	0.00006
Total	$0.14156

Service floors (11,921 sq. ft.)	Per sq. ft.
239 bbls. cement at $1.22	$0.025
105 cu. yds. sand at $1.43	0.015
155 cu. yds. stone at $1.54	0.015
Labor	0.095
1,380 cu. yds. cinders at 30 cts	0.032
1 ton coal at $4.15 and oil	0.0003
Total	$0.1823

Excluding the cost of cinders we have a cost of 11.33 cts. per sq. ft.

Office floors (8,793 sq. ft.)	Per sq. ft.
120 bbls. cement at $1.22	$0.016
53 cu. yds. sand at $1.43	0.008
107 cu. yds. stone at $1.54	0.018
Labor	0.095
1,010 cu. yds. cinders at 30 cts	0.035
Coal and oil	0.0004
Total	$0.1724

Excluding the charge for cinders we have a cost of 10.58 cts. per sq. ft.

Pit floors (58,559 sq. ft)	Per sq. ft.
1,377 bbls. cement at $1.22	$0.028
609 cu. yds. sand at $1.43	0.014
940 cu. yds. stone at $1.54	0.024
Labor	0.069
6.675 tons coal at $4.15	....
28 tons coke at $5.25	0.002
43 loads manure at $2	0.001
56 gals. gasoline at 12½ cts	....
Oil	....
Total	$0.1422

Reinforced concrete floors (37,048 sq. ft.)	Per sq. ft.
1,126 bbls cement at $1.22	$0.037
497 cu. yds. sand at $1.43	0.019
822 cu. yds. stone at $1.54	0.034
37,048 sq. ft. wire netting at 17 cts	0.017
Labor on concrete	0.061
Form lumber	0.007
Labor erecting forms	0.061
Labor removing forms	0.010
7.05 tons coal at $4.15	0.001
18.05 tons coke at $5.25	0.002
23 loads manure at $2	0.001
Oil	0.0001
Total	$0.2501

The roof construction, as previously stated, was substantially that shown by Fig. 1. The cost of 121, 881 sq. ft. or 2,869 sq. yds. was as follows:

Item	Per cu. yd.
Concrete materials	$ 4.11
Labor on concrete	3.58
Small concrete blocks	0.02
Total concrete	$ 7.71
Form lumber ($9,531.04–$3.321.25 salvage)	$ 2.16
Butts, washers and nails	0.15
Labor erecting forms	6.69
Labor removing forms	1.64
Labor moving forms to storage	0.21
Total forms	$10.85
Reinforcement	$ 2.74
Wire	$ 0.01
4 kegs round rods	0.004
Labor on reinforcement	1.37
Total reinforcement	$ 4.13
Coal	$ 0.02
Cylinder oil	0.001
Engine oil	0.001
Imperial lubricant	0.001
Tar paper	0.01
Manure	0.008
Total supplies	$ 0.05
Grand total	$22.74

This gives a cost per square foot of roof of 53.7 cts. Neglecting the salvage in lumber the cost is 56.42 cts. per sq. ft.

Substation.—The substation was built during the fall and winter of 1908–9. The building is of dark pressed brick so designed as to be an ornament to the neighborhood in which it is located. The construction is fireproof throughout, with tile roof carried on structural steel trusses.

The building is 60 ft. wide by 120 ft. 7 ins. long over all, and the operating room has a clear height of 32 ft. to the under side of the steel roof trusses.

The concrete work comprises footings for walls and piers, building walls, rotary converter walls, basement floor and drives, station floors, partition walls and battery shelves. The costs of these various items of work were as follows:

Wall and Pier Footings	Per cu. yd.
234 bbls. cement at $1.21	$ 1.32
110 cu. yds. sand at $1.60	0.82
197 cu. yds. stone at $1.55	1.42
Labor placing concrete	3.01
Total concrete	$ 6.57
Form lumber	$ 0.28
Labor on forms	0.25
Total forms	$ 0.53
Grand total	$ 7.10

Building Walls	Per cu. yd.
272 bbls. cement at $1.21	$ 1.45
116 cu. yds. sand at $1.60	0.83
187 cu. yds. crushed stone at $1.55	1.28
Labor on concrete	2.08
Total concrete	$ 5.64
Lumber for forms	$ 1.48
Nails, etc	0.18
Carpenter work on forms	2.04
Removing forms	0.63
Total forms	$ 4.33
Miscellaneous labor	$ 0.24
Grand total	$10.21

Basement Floor and Drive	Per sq. ft.
353 bbls. cement at $1.21	$ 0.08
146 cu. yds. sand at $1.60	0.04
91 cu. yds. stone at $1.55	0.03
Labor placing concrete	0.21
Labor finishing floor	0.05
Total concrete	$ 0.04
170 cu. yds. cinders at 25 cts	$ 0.008
Manure	0.0019
Miscellaneous materials	0.012
Carpenter labor	0.029
Labor placing cinders, etc	0.11
Total	$ 0.165
Grand total	$ 0.576

Station Floor	Per sq. ft.
286 bbls. cement at $1.21	$ 0.079
121½ cu. yds. sand at $1.60	0.045
108 cu. yds. stone at $1.55	0.038
Labor placing concrete	0.160
Patching floor	0.008
Total concrete	$ 0.33
Lumber for forms	$ 0.045
Beam clips	0.007
Bolts	0.010
Miscellaneous	0.010
Labor building forms	0.460
Labor erecting forms	0.063
Labor cleaning forms	0.026
Labor removing forms	0.065
Total forms	$ 0.686
Grand total	$ 1.016

The cost of water-proofing 1,040 sq. yds. of foundation walls, footings and floors was as follows:

Item	Total	Per sq. yd.
177 rolls felt at $1.30	$ 230.10	$ 0.221
39 bbls. tar at $3.80	128.70	0.123
Mops, etc	16.87	0.016
Labor	359.90	0.346
Total	$ 735.57	$ 0.706

None of the above costs include engineering, superintendence or overhead charges.

Labor rates were the union wage for 1908, which ran about as follows per hour: Enginemen, 70 cts.; carpenters, 60 cts.; finishers, 56¼ cts., and common labor, 37½ cts.

Perhaps the most interesting of the various costs given are those of roof work. The character of this work is indicated clearly by the drawings of Fig. 6. In one case the unit cost was $18.89 per cu. yd. and in the other case $22.74 per cu. yd., and of the total cost about 70 per cent and 50 per cent, respectively, and chargeable to form work.

Labor Cost of Placing Concrete with Tower and Chutes.—W. D. Jones in Engineering and Contracting, Dec. 27, 1916, gives the following:

The work consisted in building a six story and basement warehouse for the Harbor Commission of Los Angeles. The structure was 152 ft. wide and 484 ft. long. The basement was 7 ft. 9 in. high, first story, 14 ft. 6 in. high and upper stories 10 ft. high. All materials were furnished by the city f. o. b. cars at building site, and contractor was required to unload, sort and shelter these in a building provided by the city and be responsible for their incorporation in the structure in good condition.

In the call for bids the approximate quantities were given as follows. Opposite each of these approximate quantities is set the unit price bid for the performance of this work.

27,000 cu. yds. of concrete in place	$ 3.25 cu. yd.
1,290 tons of reinforcing steel in place	12.05 tn.
75 tons of structural steel in place	11.20 tn.
475,000 sq. ft. floor finish	0.01⅞ sq. ft.
Excavating, grading and cleaning up	4,098.00 lump sum

Concrete.—The materials used for concrete Portland cement, sand and gravel, the latter from ¼ in. to 1 in. in size, in order to work readily through the reinforcement, etc. The most of the concrete was a 1:2:4 mixture, though some columns in the lower floors were of a richer mixture in order to reduce the size.

For the concrete pouring two Insley steel towers 160 ft. high were placed on one side of the building and were provided with hoisting buckets of 24 cu. ft. capacity water measure. These were hoisted by 50 h. p. Crocker-Wheeler motor driven hoists with a line speed of 150 ft. per minute when pouring the lower floors, but when upper floors were reached it was found expedient to increase the speed of the hoisting buckets in order that the mixer not be forced to wait on the hoist. This was accomplished by rigging hoisting lines in such a manner as to connect directly to hoisting bucket with a single line instead of passing the line through a pulley on a bucket and fastening the end in the top of the tower. This worked a hardship on the hoist, especially the friction blocks, but these were watched closely and renewed often and no serious consequences were encountered.

Each tower was equipped with a Bremer mixer having a capacity of 32 cu. ft. of loose material, a hoisting bucket of 22 cu. ft. capacity and a 50-ft. boom supporting 100 ft. of gravity spout. One extra piece of spout 50 ft. long and one about 20 ft. long were also provided and used at each plant when that plant was working.

On either side of the mixer was placed a rock bin and a sand bin each holding about 4 carloads of material and dumping directly by gravity into measuring bins which in turn dumped by gravity into mixer charging hopper. Directly over the charging hopper and between the sand and gravel bins was placed a cement bin. Into this the cement was dumped from sacks and passed by gravity through measuring bins as in case of sand and gravel, to the mixer. This method of handling the cement was not found to be as cheap as the old method of loading the mixer by cheap labor and was consequently later abandoned. There is no reason, however, that it should not have been successful had it been properly operated.

The sand and gravel bins, as well as the cement bin, when it was used, were loaded with an industrial traveling crane equipped with a 1¼-cu. yd. bucket.

The floor finish consisted of equal parts of cement, sand and fine crushed rock taken from the ledge and was put on the base before this was thoroughly set. This necessitated several changes of system at the mixer during the day but by a systematic arrangement of the necessary materials the changes were made with hardly a perceptible interruption and the system of pouring top and base practically as one monolithic mass worked out as cheaply, if not cheaper, than the system of pouring for a day or for a day and a half and then topping this out.

A fair day's work with the above concrete plant on slabs was about 300 cu. yd. and on walls and columns was about 200 yd. This varied of course a great deal with conditions. In pouring walls and columns it was found expedient to run concrete with gravity plant to a hopper centrally located with reference to the day's work and distribute from this with carts. On slab pouring, however, the gravity chute was used to pour the concrete directly into place and very good results obtained. The gravity system was also used to spout the floor finish to place.

Costs.—The actual pouring costs observed on several different occasions including labor only and taking materials from bins by gravity, measuring, mixing and placing were as follows:

On slab	30 cts. per cu. yd.
On walls	39 cts. per cu. yd.

Scale of wages was as follows:

Foremen, $6; sub foreman, $4; steel men, $2.25; steel men, $3; carpenters, $3; laborers, $2.25; laborers, $2.

Cost of Placing Concrete and Installing Equipment.—In planning for the construction of the Austin Nichols Building, Brooklyn, N. Y., according to a paper by T. Arthur Smith before the American Concrete Institute, the method for placing concrete was carefully considered by the Turner Construction Co. who executed the general contract. The following is taken from an abstract of Mr. Smith's paper published in Engineering and Contracting, March 31, 1915.

The building is 439 ft. 11½ ins. by 178 ft. 8 ins., and is 6 stories high with basement, and required about 19,620 cu. yds. of concrete.

Records of the cost of wheeling concrete on similar buildings showed that its cost did not exceed 9 cts. per cubic yard, cost being based on labor at 37½ cts. per hour. Assuming that, of the total 19,620 cu. yds. of concrete to be placed, 16,000 cu. yds. could be placed by spouting, the cost of wheeling would be $0.09 × 16,000 = $1,440. Hence $1,440 would have to cover both the cost of installing two spouting outfits and the following additional installations incidental to placing concrete in this manner: raising tower additional height; guying tower; and moving spouts.

This analysis showed conclusively that, for this building, the cost of the spouting equipments plus the additional installation cost, would materially exceed the cost of wheeling concrete.

Unloading and Concreting Equipment.—The layout of the unloading derrick, storage bins, concrete mixers and hoists is shown in Fig. 7. Sand and gravel were delivered alongside the bulkhead, adjacent to the storage bins, on scows — about 400 cu. yds. capacity. A derrick equipped with a clam-shell bucket of 1⅝ cu. yds. capacity unloaded the contents of these scows into storage bins holding 100 cu. yds. of sand and 200 cu. yds. of gravel.

The derrick was operated by a Meade-Morrison three-drum standard hoisting engine having 9 × 10-in. cylinders and a rated capacity of 35 h. p. For swinging the derrick a separate engine was installed. Power was supplied by a 50-h. p. horizontal boiler.

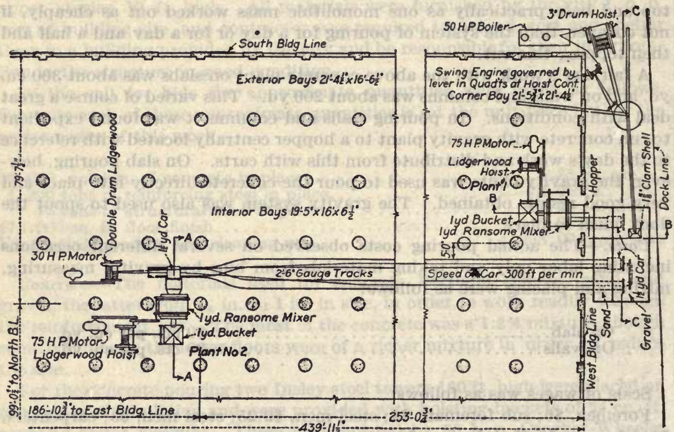


FIG. 7.—Plan showing unloading, mixing and hoisting equipment—Austin Nichols Building.

The sand and gravel were discharged from the bins through "Ransome" gates, into "V" bottom, two-way dump cars for delivery to the mixers. Each car was loaded with 12 cu. ft. of sand and 24 cu. ft. of gravel, a steel partition separating these materials.

One car was used to convey the materials to mixer No. 1, and was pushed by hand from the storage bin to the mixer. For charging mixer No. 2 a 2-ft. 6-in. gage double track was laid from the bin to the mixer, on which two cars were operated, one on each track. These tracks were laid on the first floor, which, in order to follow the grade of North Third St., sloped down 8 ft. from Kent Ave. to the river. A double-drum, motor-driven "Lidgerwood" hoist pulled the cars from the bin to the mixer. These cars were connected by a tail line operating around a sheave at the bin, so that the loaded car going toward the mixer would pull back the empty car to the bin.

Owing to the limited bulkhead space at the building it was necessary to dock the cement lighters one block away and to truck the cement to the building. The cement was stored adjacent to each mixer, six bags being used in each batch.

Two 1-cu. yd. "Ransome" mixers were installed in the locations shown in Fig. 7. Each mixer discharged into a 1-cu. yd. "Ransome" bucket, which was hoisted by a single-drum "Lidgerwood" hoist. Power for the operation of each concrete plant was furnished by a 75-h. p. motor. The concrete was dumped from the bucket into a 2-cu. yd. box on each floor, from which it was wheeled in carts.

The derrick used was capable of unloading 700 cu. yds. of material per day of eight hours. The average capacity of each concrete plant was 45 cu. yds. of concrete per hour. The largest quantity of concrete placed in one day of 8½ hours was 640 cu. yds. In 62 working days, 17,510 cu. yds. were placed an average daily output of 282 cu. yds.

The efficiency of the equipment for conveying materials from the bins to the mixer was demonstrated when, due to a slight breakdown, the derrick was idle for one day. In order to keep one mixing plant in operation, the sand and gravel were wheeled from emergency storage piles on North Third St. Charging one mixer in this manner required 22 additional men, and reduced the output of the plant to about 30 cu. yds. per hour.

In order not to delay the progress of the work it was necessary that the reinforcing steel be placed immediately after the completion of the forms. This required that work in the steel yard be so systematized that the bending and fabrication of steel would be sufficiently in advance of requirements to prevent any delay in the work.

Beam and girder bars were bent in the "Wilson" bender at an average rate of 125 per hour, while the capacity of the "Wilson" stirrup bender was 4,000 stirrups per day.

The total labor cost for installing all equipment used in the erection of the building was 20 cts. per cubic yard of concrete. It must be borne in mind, however, that this cost does not cover any charge either for materials or for the use of plant, depreciation or interest on equipment investment.

Cost of Mixing and Placing Concrete by Hand.—Concrete mixed and placed by hand in a 6-in. wall, with experienced labor, in Riverside, Cal., during 1909 cost $1.19 per cu. yd. An itemized account of the cost of the work is given by C. W. Gaylord in "Cement and Engineering News." The crew was as follows:

1 foreman at $3 per day	$ 3.00
2 men at $2.25 per day	4.50
8 men at $2 per day	16.00
Total	$23.50

This crew averaged 12 batches per 9-hour day, each batch containing 1.7 cu. yds., or 20.4 cu. yds. per day. This amount included 84 sacks of cement, 9.8 cu. yds. of sand and 19.6 cu. yds. of 1½-in. stone. This is over 2 cu. yds. per man per day and is above the average. The work was divided as follows:

	Per cu. yd.
Loading on wheelbarrows:	
Sand, 0.46 cu. yds. at 10 cts	$0.05
Stone, 0.92 cu. yds. at 15 cts	0.14
Total	$0.19

	Per cu. yd.
Wheeling to mixing board and dumping in measuring box:	
Cement (all handling)	$0.04
Sand, average haul 30 ft	0.02
Stone, average haul 50 ft	0.05
Total	$0.11
Mixing:	
Sand and cement (2 turnings)	$0.12
Mortar and stone (3 turnings)	.27
Total	$0.39
Loading into wheelbarrows	$0.17
Wheeling to place (av. haul 55 ft.)	0.06
Dumping, spreading and ramming	0.11
Supervision (⅓ foreman's time)	0.10
Care for water	0.02
Total	$0.46
Grand total	1.15

Adding cost of mixing boards and divided by number of yards mixed with each board gives: 16 × 16 ft. boards 500 ft. B. M. at $40 per M. divided by 500 equals $0.04. Adding this we get a total cost of $1.19.

Cost of Stucco Finish for Concrete House (Engineering and Contracting, Sept. 25, 1918.)—Data on the stucco finish for the walls of a concrete house built in 1917 in Darien, Conn., are given as follows by M. D. Morrill in Concrete:

The stucco finish was put on in a single coat about ¼ in. thick, applied with a plasterer's trowel. The walls were not wet down, but all dry dust was removed. The wall surface was left smooth by the steel forms, and it was at first questioned if there was not danger that this thin coat of stucco would eventually peel off. Experience, however, seems to prove the contrary, and on a considerable number of buildings finished in this way six years ago there is no sign of the separation of the stucco. It appears to be a permanent as well as a rather inexpensive way to finish these steel molded concrete walls. After this stucco was troweled on and had been allowed to stand a few minutes, the surface was gone over lightly with a cork float. A little water was thrown on with a brush, as needed, while the surface was being floated.

In order to get at the exact cost of this wall finish, the time and material used on finishing a surface of 142 sq. yds. was kept, no allowance being made for openings.

Labor and Material, 142 Sq. Yd. of Stucco

½ day, 3 masons, at $4.80 for 8 hours	$7.20	
½ day, 2 helpers, at $3.00 for 8 hours	3.00	
½ day, 2 carpenters, at $4.50, scaffolding	4.50	
Total labor		$14.70
2 bbls. cement at $1.92	$3.82	
1 yd. sifted sand at $3.00	3.00	
Total materials		$ 6.82
Total		$21.52

The total cost of finishing these walls was thus between 15 cts. and 16 cts. per square yard.

Relative Cost of Different Slab Designs.—The following studies relate to different systems proposed for the floors of the buildings of the Massachusetts Institute of Technology, as abstracted in Engineering and Contracting, June

9, 1915, from a paper by Sanford E. Thompson presented before the annual meeting (1915) of the American Concrete Institute. The long-span concrete slab construction proved most economical, when the total cost of concrete, steel, and making of forms was considered. Designs and estimates were made for the following cases:

Case I. Panel with no intermediate beam; slab 15 ft. 6 ins., solid concrete construction.

Case II. Panel with one intermediate beam; slab 7 ft. 9 ins.

Case III. Panel with no intermediate beam; slab 15 ft. 6 ins., with tile.

In Table XI there is summed up the relative costs for the three cases. It is evident that the cost of forms is the important factor, completely upsetting the conclusions that would be drawn from the relative costs of materials actually used in the slab.

Economics of Concrete Columns (Engineering and Contracting, June 19, 1912).—Leonard C. Wason, President of the Aberthaw Construction Co., Boston, states that in one case the saving of concrete by reducing the size of columns on successive floors was $2.30 per column. On the other hand, the increase in form cost was $5.70 per column, entailing a loss of $3.40 per column. This is a very good example of why it is cheaper to use the same size columns on successive floors than to reduce the dimensions. To avoid fre uent changes in column sizes the column reinforcement may be varied in successive stories.

Unit Costs of a Brick and Concrete Building (Engineering and Contracting, Nov. 16, 1910).—The Sanitarium at Battle Creek, Mich., was built in 1902 at a cost of about $1,000,000. It is a fireproof building with brick walls and reinforced concrete floors. The building is 600 ft. long and 400 ft. deep. It is seven stories high at one end, but the slope of the ground makes it only six stories at the other end. The accompanying tables of costs were furnished by John McMichael, who did the work on a percentage basis.

The material for construction was hauled in wagons from switch tracks about four blocks distant. Teams for this purpose were hired at $4 per day.

The following table gives the cost per cubic yard of concrete footings. The concrete was mixed by hand on a board which was shifted along to save wheeling of the mixed concrete. The sand and gravel was bought by the load, mixed, and was dumped at various points convenient to the board.

	Per cu. yd.
Materials:	
Cement, 1.1 bbls.	$1.40
Gravel and sand	0.07½
Gravel and sand hauling	0.50
Total materials	$1.975
Labor:	
Carpenters	$0.18
Common labor	0.68
Total cost of labor	$0.86
Total cost of labor and material	$2.83½

This does not include superintendence. Carpenters received 35 cts. per hour and laborers 20 cts.

Rubble Stone Masonry.—The foundation walls were laid up with boulder stones taken from the old buildings. These are much harder to lay in foundation walls than any other class of stone masonry. The item $6.42 is the cost of wrecking the foundations of the old buildings to get the stone from them.

TABLE XI.—RELATIVE COSTS OF DIFFERENT SLAB DESIGNS

Item	Unit cost	Concrete slab; span, 15 ft. 6 ins.		Concrete slab; span, 7 ft. 9 ins.; 1 intermediate beam		Hollow tile; span, 15 ft. 6 ins.	
		Amt.	Cost	Amt.	Cost	Amt.	Cost
Concrete, per panel:							
Slab, cu. yds.		10.7		6.1		6.6	
Beam, cu. yds.		2.8		2.6		2.2	
Girder, cu. yds.		....		0.65		....	
Total	$ 5.82	13.5	$ 78.50	9.35	$ 55.00	8.8	$ 51.22
Steel, per panel:							
Slab, lbs.		1,080		435		670	
Beams, lbs.		944		1,620		944	
Girder, lbs.		....		690		....	
Total	$ 0.027	2,024	$ 55.60	2,745	$ 75.00	1,551	$ 41.88
Tile, per panel:							
Slab, piece	$ 0.200	....		....		286	57.20
Total cost of materials			$134.10		$130.00		$150.30
Form lumber:							
Slab, 1¼-in. stock, ft. B. M.		1,772		1,435		1,772	
Beam, 1¼-in. stock, ft. B. M.		496		680		429	
Girder, 1¼-in. stock, ft. B. M.		....		267		....	
Total for 4 floors		2,268		2,382		2,201	
Total per floor per panel	$30.00	567	$ 17.00	596	$ 17.86	550	$ 16.50

per M.

Carpenter labor .... 50 cts. per hour.
Ordinary labor .... 25 cts. per hour.

Form labor:						
Slab:						
Make	$ 4.39		$ 3.78		$ 4.39	
Place and remove first floor	12.88		11.48		12.88	
Place and remove second floor	9.88		8.57		9.88	
Place and remove, third floor	11.02		9.31		11.02	
Place and remove, fourth floor	11.02		9.31		11.02	
Total cost 4 floors	$49.19		$42.45		$49.19	
Cost per panel per floor		$ 12.30		$ 10.61		$ 12.30
Beams:						
Make	$ 3.00		$ 2.10		$ 2.70	
Place and remove first floor	5.79		4.40		5.10	
Place and remove second floor	5.20		3.90		4.60	
Place and remove third floor	6.92		5.10		6.80	
Place and remove fourth floor	6.92		5.10		6.80	
Total cost per beam 4 floors	$27.83		$20.60		$26.00	
Cost per panel per floor		$ 6.95		$ 10.30		$ 6.40
Girders:						
Make	......		$ 2.30		......	
Place and remove first floor	......		4.80		......	
Place and remove second floor	......		4.10		......	
Place and remove third floor	......		6.20		......	
Place and remove fourth floor	......		6.20		......	
Total cost 4 floors	......		$23.60		......	
Cost per panel per floor		......		$ 9.50†		......
Total cost forms		$ 36.25		$ 48.27		$ 35.20
Total cost		$170.35		$178.27		$185.50

Costs are from "Concrete Costs," by Taylor and Thompson.

† Multiply cost per panel per floor by 1.6 instead of 2.0 to allow for spandrel beams.

NOTES.—Forms assumed to be used four times and remade once for a change in size of columns. Size of beam below slab, 12 × 19 ins.; size of girder below slab, 14 × 19 ins. Note that cost of forms and not cost of materials used in beams and slab determines relative cost of the three alternate designs.

The costs are given per cord of masonry in place. One cord is equal to 100 cu. ft. as here considered.

	Per cord
Materials:	
Stone	$ 6.42
Sand	0.57½
Cement, 1⁹⁄₁₆ bbls	2.25
Total material	$ 9.245
Labor:	
Masons	$ 1.82½
Common	3.04
Total labor	$ 4.865
Total labor and material	$14.11

Masons received 40 cts. per hour and laborers 20 cts. The amount of stone laid per mason per 8 hours was 1¾ cords.

Brick Work.—The total amount of brick in the building is about 5,250,000, of which about 1,250,000 are pressed brick used for the exterior and for trimmings. About 60 bricklayers were employed during the main part of the work. Three of the Thomas Elevator Co.'s double brick hoists were used for elevating brick and mortar. The costs given are per thousand of brick laid. The number of common brick laid per 8-hour day per man was 2,400.

	Per M brick
Materials:	
Common brick f. o. b. Chicago	$ 4.00
Freight	2.68
Hauling	0.78
Sand	0.57½
Lime (4 bu.)	1.06
Hauling lime	0.16
Total materials	$ 9.25½
Labor:	
Masons	$ 1.65
Common labor	1.82
Total labor	$ 3.47
Total labor and material	$12.72½

Masons received 50 cts. per hour and common labor 20 cts.

Shawnee Buff Pressed Brick were used for the exterior. The number of pressed brick laid by each mason per 8-hour day was 480. The cost of pressed brick work was as follows:

	Per M brick
Materials:	
Pressed brick per M f.o.b	$11.00
Freight	5.50
Hauling	0.95
Sand	0.57½
Lime (3 bu.)	0.91½
Mortar color (buff)	1.82
Cement	0.45
Bonds (wire cloth)	0.57
Total material per M	$21.78
Labor:	
Masons	$ 9.43
Common	6.40
Total labor	$15.83
Total labor and material	$37.61

Masons for pressed brick work received 55 cts. per hour and common laborers 20 cts.

For trimmings, Gray pressed brick were used. The cost of this work was as follows:

Material:	Per M brick
Cost of gray pressed brick f.o.b	$14.00
Freight	6.50
Hauling	0.95
Sand	0.57½
Lime (3 bu.)	0.91½
Cement	0.45
Mortar color (lampblack)	0.18
Bonds (wire cloth)	0.85
Total material	$24.42
Labor:	
Masons	$ 9.45
Common	6.41
Total labor	$15.86
Total labor and material per M	$40.28

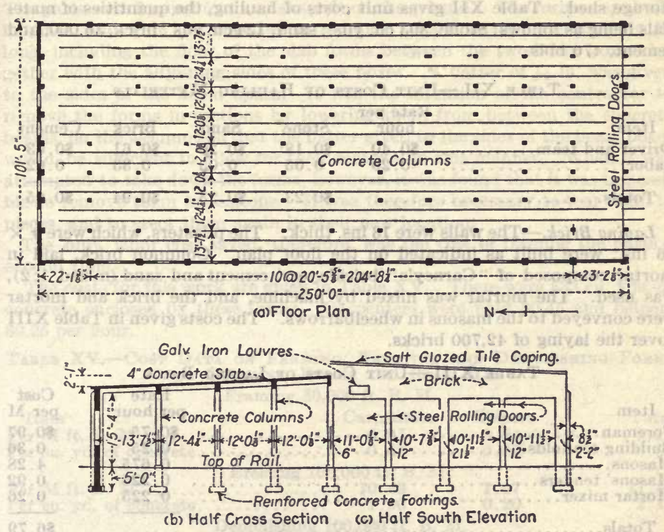


FIG. 8.—Floor plan, half cross section and half south elevation of car storage house of Omaha & Council Bluffs Street Railway Co.

The time required for executing the entire work was about six months.

Costs of a Reinforced Concrete and Brick Car Storage House.—W. L. Fulton in Engineering and Contracting, July 14, 1915, gives following:

The structure, an extension of the existing car house, was built to provide additional storage space required by the Council Bluffs lines. The outside dimensions of the building are 101 ft. 5 ins. by 250 ft. The offices, lobbies, club rooms, repair pit, etc., were provided for in the original building.

Brick and reinforced concrete were adopted as materials of construction. As the building was to be used only for the storage of cars, and therefore the usual clear space between cars not required, a row of columns was placed in each space between tracks, the resulting short spans effecting a considerable saving in cost. Fig. 8 gives the general dimensions and indicates the type of construction used.

Excavation.—The earth excavated from the footing trenches and pits was either back-filled or was distributed over the surface of the ground; no earth was hauled away. The total amount excavated was 233 cu. yds., and the total cost was $51.70, or 22.2 cts. per cubic yard. Laborers were paid 20 cts. per hour.

Hauling Materials.—The cars of building materials were set on a steam railway siding about ¼ mile from the building site. Materials were hauled to the site in flat-bottom wagons of about 1-cu. yd. capacity. The teams stood idle while wagons were being loaded and unloaded, and the drivers helped in loading and unloading. At the building, the sand and stone were dumped on the ground, the brick was piled, and the cement was carried by hand into the storage shed. Table XII gives unit costs of hauling, the quantities of materials being as follows: Stone, 393 cu. yds.; sand, 124 cu. yds.; brick, 36,000, and cement, 470 bbls.

TABLE XII.—UNIT COSTS OF HAULING MATERIALS

Item	Rate per hour	Stone	Sand	Brick	Cement
Driver and team	$0.40	$0.18	$0.20	$0.61	$0.03
Labor	0.20	0.05	0.03	0.33	0.02
Totals	.....	$0.23	$0.23	$0.94	$0.05

Laying Brick.—The walls were 13 ins. thick. The pilasters, which were 9 × 26 ins., were built as indicated on the floor plan. Common brick, laid in mortar composed of "Carney's" bricklayers' cement and sand (mixed 1:2), was used. The mortar was mixed by machine, and the brick and mortar were conveyed to the masons in wheelbarrows. The costs given in Table XIII cover the laying of 42,700 bricks.

TABLE XIII.—UNIT COSTS OF LAYING BRICK

Item	Rate per hour	Cost per M
Foreman	$0.75	$0.97
Building scaffolds	0.25	0.36
Masons	0.675	4.28
Masons' tenders	0.225	0.92
Mortar mixer	0.225	0.26
Totals	......	$6.79

Form Building and Demolition.—(a) *Forms for Walls Below Grade.*—The total length of these walls was 600 ft. and their height 4 ft. 6 ins. Pilasters 9 × 26 ins. were built, as indicated.

The forms were built in sections and were used three times. They contained 5,000 ft. B. M. of lumber. The forms for the pilasters were made of 1-in. lumber, and the remainder of these forms was built of 2-in. lumber, cleated together into sections.

The unit costs of the forms for walls below grade are given in Table XIV.

TABLE XIV.—COST DATA ON BUILDING AND MOVING FORMS FOR WALLS BELOW GRADE

Item	Ft. B. M.	Cost per M ft. B. M.	Cost per cu. yd of concrete
Form building	5,000	$ 6.20	$0.25
Moving forms	15,000	8.10	0.98
Totals	......	$14.30	$1.23

Form Building and Demolition.—(b) *Forms for Columns, Beams and Roof Slab.*—The column boxes were built of 2-in. planks, set vertically and clamped together. In the beam boxes the bottoms were of 2-in. planks, and the sides were of 1-in. shiplap. The floor of the slab forms was also of 1 × 8-in. shiplap. The forms were supported by the column boxes and by 4 × 4-in. shores set below the beam boxes and about 5 ft. apart. The joists under the slab forms were 2 × 6 ins , 16 ins. center to center, and they extended from beam box to beam box. The ends of these joists were supported by 2 × 4-in. cleats extending down the sides of the beam boxes to the bottom of the same, from whence the load was carried directly to the shores.

The forms were used twice, and they contained 50,000 ft. B. M. of lumber. The parts were framed (cut and shaped) on the ground. The forms were built in place, and were put together in sections. Each section was about 6 ft. long, including the floor of the slab forms between the two-beam boxes, together with the adjoining sides of these boxes. A batter of ½ in. was given to the sides of the beam boxes. It was the intention of the contractor to remove the forms in sections by lowering them from between the concrete beams, on the assumption that the batter given to the sides of the beam boxes would be sufficient to allow for their removal in this manner. When it was attempted to take down the forms, however, it was found that it was impossible to remove them in sections. It was therefore necessary to tear them to pieces, and to erect them again in their new location.

The only labor cost saved, therefore, was the cost of framing the parts a second time.

The costs for this work are given in Table XV. There were 533 cu. yds. of concrete enclosed by these forms. Carpenters were paid $0.45 and helpers $0.25 per hour.

TABLE XV.—COST DATA ON FRAMING, ERECTING AND DEMOLISHING FORMS OF COLUMNS, BEAMS AND ROOF SLAB

Item	Carpenters	Helpers	Total
Framing 50,000 ft. B. M.			
Per M ft. B. M.	6.95	0.24	7.19
Per cu. yd. of concrete	0.65	0.02	0.67
Erecting 100,000 ft. B. M.			
Per M ft. B. M.	10.43	1.07	11.50
Per cu. yd. of concrete	1.96	0.20	2.16
Demolishing 100,000 ft. B. M.			
Per M ft. B. M.	3.35	2.78	6.13
Per cu. yd. of concrete	0.63	0.52	1.15

Assembling and Placing Steel Reinforcement.—All of the steel reinforcement was shipped to the job already bent and cut to length. Beam reinforcement was assembled into units, one per beam, before shipping. Column reinforcement was assembled on the job. All reinforcement, except the top reinforcing bars in the roof slab, was put in place and wired before any concrete was placed. The top reinforcing bars in the roof slab and the reinforcing bars in the column footings were placed by the concrete workers, and the cost of same is included in the cost of the concrete work.

The quantity of reinforcing steel in the various portions of the building is as follows:

	Pounds
In column footings	3,000
In columns	12,500
In roof slab, main reinforcement	52,000
In roof slab, top reinforcement	26,000
In beams	27,000

The costs of assembling and placing the steel reinforcement (except as noted above) are given in Table XVI these costs covering 91,500 lbs. of steel and 533 cu. yds. of concrete:

TABLE XVI.—COSTS OF ASSEMBLING AND PLACING STEEL REINFORCEMENT

	Rate per hour	Cost per 100 lbs.	Cost per cu. yd. of concrete
Foreman	$0.45	$0.096	$0.166
Laborers	0.25	0.137	0.235
Totals	.....	$0.233	$0.401

Mixing and Placing Concrete.—The concrete in the floors and walls up to the floor level (including footings) was wheeled from the mixer to the forms in wheelbarrows and poured at the floor level. The concrete in the roof and in the portion of the columns above the floor level was discharged from the mixer into wheelbarrows, which were hoisted to the roof level in a double-cage building elevator and wheeled to place over runways laid on the roof forms. All concrete was mixed in mixers of the batch type. All stone and sand were wheeled to the mixer in wheelbarrows loaded by hand. The costs of this work are given in Table XVII.

TABLE XVII.—COST DATA ON MIXING AND PLACING CONCRETE IN VARIOUS PARTS OF STRUCTURE

Item	Rate per hour	Cost per cu. yd.
Walls and Footings; 163 Cu. Yds.; Dist. Wheeled 75 ft.		
Foreman	$0.40	$0.04
Wheeling sand, stone, concrete	0.20	0.63
Placing concrete	0.25	0.06
Attending mixer	0.25	0.08
Totals	.....	$0.81
Column Footings and Columns Up to Floor Level; 66 Cu. Yds.; Av. Dist. Wheeled, 85 ft.		
Foreman	$0.40	$0.22
Wheeling sand, stone, concrete	0.20	0.70
Placing concrete	0.35	0.21
Attending mixer	0.25	0.20
Totals	.....	$1.33
Columns Above Floor Level, Beams and Roof Slab; 467 Cu. Yds.; Av. Dist. Wheeled, 90 ft.		
Foreman	$0.40	$0.21
Wheeling sand, stone, concrete	0.20	0.67
Placing concrete	0.35	0.17
Attending mixer	0.25	0.12
Operating elevator	0.20	0.10
Totals	.....	$1.27

Estimating Brick Work.—The following is given by I. P. Hicks in the National Builder.

Brick, as made by different manufacturers, vary in size, and, of course, there is sure to be more or less variations in the actual quantities required for certain jobs; the variations depending upon the size of the brick and the size of the mortar joints made in laying the brick. For common brick we will assume the average size to measure 8¼ × 4 × 2½ inches and that the wall is to be laid up with a ⅜-in. mortar joint.

For this kind of a wall figure 6 brick to each square foot for every 4-in. thickness of wall. Thus, for a wall 4 inches thick, figure 6 brick per square foot; for an 8-inch to 9-inch wall, figure 12 brick per square foot; for a 12 to 13-inch wall, figure 18 brick per square foot; for a 16 to 17-inch wall, figure 24 brick per square foot and so on, adding 6 brick for each 4-inch thickness of wall.

To be very accurate in the number of brick required, deduct the brick required for all openings. In small foundation work, where there are only a few small cellar window openings, it is hardly worth while to deduct the openings, but for the main windows and doors in a brick building, it becomes necessary to deduct the brick for the openings, otherwise the result would be far too many brick.

Brick Footings.—Brick footings, based on steps or offsets of 2 inches, may be estimated by the lineal foot, as follows: For a 9-inch wall, 2-course footing, 10½ brick; 13-inch wall, 3-course footing, 22½ brick; 18-inch wall, 4-course footing, 39 brick; 22-inch wall, 5-course footing, 60 brick; 26-inch wall, 6-course footing, 85½ brick.

Press Brick.—For a standard size of press brick we will assume the following dimensions: 8¼ × 4 × 2¼ inches, and the mortar joint to be ¼ inch. This will require 7 brick per square foot for every 4-inch thickness of wall.

Lump Lime Mortar.—The quantity of material required to lay 1,000 brick with a ⅜-inch joint, using 1 to 2 lime mortar, composed of 1 part lime putty to 2 parts sand, will be 1¾ barrels of lump lime and ⅝-cubic yard of sand.

Hydrated Lime Mortar.—For mortar composed of 1 part hydrated lime and 2 parts sand, figure 6½ 50-pound sacks of hydrated lime and ⅝-cubic yard sand per 1,000 brick.

Cement Mortar.—For 1 to 3 cement mortar composed of 1 part Portland cement and 3 parts sand, figure 5 sacks of cement and ⅝-cubic yard of sand per 1,000 brick, with a ⅜-inch mortar joint. Approximately 2½ bags of cement and ½ of a cubic yard of sand will be required if laid with about a ¼-inch joint.

Cement and Lime Mortar.—Figure 1 sack of Portland cement, ¾-barrel of lump lime and ⅝-cubic yard of sand per 1,000 brick laid in the wall with a ⅜-inch mortar joint.

Estimating Brick for Chimneys (The sizes given are inside of flue measure.)

8 × 8 flue, 24 brick per lineal foot.
8 × 12 flue, 28 brick per lineal foot.
12 × 12 flue, 32 brick per lineal foot.
12 × 16 flue, 36 brick per lineal foot.
16 × 16 flue, 40 brick per lineal foot.
8 × 8 double flue, 40 brick per lineal foot.
8 × 8 and 8 × 12, two flues, 44 brick per lineal foot.
8 × 12 double flue, 48 brick per lineal foot.
8 × 12 and 12 × 12 two flues, 52 to 56 brick per lineal foot.

Chimney breasts for fireplaces and mantels require 90 to 110 bricks per lineal foot the height of the chimney breast. Where the chimney is reduced in size above the breast, figure according to the size and number of flues from there to the top as given above. These figures should enable one to arrive at a very close figure as regards the number of brick required. In the above figures no allowance has been made for any waste in brick and it would be proper to allow a small percentage for broken and wasted brick. If the brick are of good quality, 3 to 5 per cent ought to cover all the waste in handling and laying.

Labor Cost of Laying Brick.—The labor cost of laying brick varies according to the wall, the bond and the kind of mortar joint made. Common brick laid with common bond and plain cut joints: a bricklayer, with one tender, should lay 1,100 brick per 8-hour day, using cement mortar, and 1,350, using lime mortar.

For walls laid in common bond with struck joint one side and plain cut joint on the other side, figure 1,000 brick per 8-hour day, using cement mortar, and 1,200, using lime mortar.

For face walls laid up with selected common brick in common bond and struck joints, figure 950 brick per 8-hour day, using cement mortar, and 1,000 for lime mortar.

For face walls laid with selected common brick in common bond with V-shaped mortar joints, or with joints raked out, figure per 8-hour day, 900 brick, using cement mortar, and 950, using lime mortar.

Face walls laid up with press brick or face brick where there are panels and pilasters, figure 350 to 400 brick per 8-hour day.

For plain walls laid up with press or face brick, figure 700 to 800 brick per 8-hour day.

Figure laborer's time same as bricklayer's time where there is but one bricklayer working; if two bricklayers are working, figure ½ hour laborer's time to 1 hour of bricklayer's time.

Costs of Masonry and Carpenter Work for a Church Building.—Engineering and Contracting, Nov. 30, 1910, gives the following costs taken from the records of the contractor, John McMichaels.

The building was a brick masonry and timber structure constructed at Oak Park, Ill. The work involved rubble masonry foundation walls; concrete footings, brick masonry and timber roof, floors and finish.

Rubble Masonry.—The foundation walls were of rubble masonry about one-fifth of the stone from which were taken from the walls of the old church. The cost per cord of masonry (100 cu. ft.) was as follows:

	Total	per cord
Materials:		
81 cords	$ 619.08	
100 bbls. Portland cement	170.37	
Total material	$ 789.45	$ 9.734
Labor:		
841¾ hrs. masons at 50 cts	$ 420.58	
525¼ hrs. helper at 30 cts	157.55	
296 hrs. helper at 25 cts	73.97	
103 hrs. helper at 20 cts	20.60	
16 hrs. helper at 15 cts	2.40	
Foreman	75.80	
Timekeeper	21.69	
Water boy	12.37	
Night watchman	0.60	
Total labor	$ 785.56	$ 9.698
Grand total	$1,575.01	$19.432

Assuming 5 cu. yds. to the cord of masonry the cost was $3.886 per cu. yd. About 1 2-5 bbls. of cement were used per cord and 1 cu. yd. of sand. Sand was taken from the excavation and is included in labor. It required 105.25 man days to lay 81 cords which is a rate of nearly 0.77 cords per man per day.

Concrete Footings.—A number of small concrete footings in the basement cost for mixing and placing as follows:

395 hrs. labor	$103.49
Foreman	39.20
Water boy	7.16
Timekeeper	6.36
Night watchman	0.15
Total	$156.36

There were 2,400 cu. ft. or 88.9 cu. yds. of concrete in the footings; this gives a cost per cubic yard for mixing and placing of $1.77.

Brick Walls.—The brick building walls averaged 30 ft. in height. All material was carried in hods. The cost of common brick work was as follows per 1,000 brick:

290½ M common brick at $5.70	$1,653.30
340¾ bbls. lime at 45 cts	153.63
42¾ bbls. Louisville cement	24.95
23 bbls. Portland cement	40.00
200 cu. yds. sand	100.00
Total material	$1,971.88
1,328½ hrs. masons at 50 cts	$ 664.25
1,837¼ hrs. helpers at 30 cts	551.21
1,628¼ hrs. helpers at 25 cts	407.06
51 hrs. helpers at 20 cts	10.20
10 hrs. helpers at 17½ cts	1.75
652 hrs. apprentice at $9 per week	122.40
Water boy	3.34
Foreman	176.43
Timekeeper	47.65
Night watchman	43.75
Total labor	$2,028.04

From these figures the cost per 1,000 brick was as follows:

Materials	$ 6.99
Labor	6.79
Total	$13.78

The number of bricks laid per man per day was 800; the rates of helpers' labor to masons' labor was 2⅛ hours to 1 hour; 1⅙ bbls. of cement were used per 1,000 brick.

Nailing Strips.—The cost of placing nailing strips in cinder concrete floor was as follows:

2, 915 ft. B. M. 2 × 4 in. by 16 ft. at $15.50 per M	$45.74
42½ hrs. labor at 42½ cts	8.29
36 hrs. labor at 25 cts	9.12
Foreman	2.75
Timekeeper	0.50
Total	$66.40

The cost per M. ft B. M. was $22.77. One man laid 149 ft. B. M. per hour. The cost per 100 sq. ft. of floor was as follows:

Material	$1.50
Labor	0.70
Total	$2.25

First Floor Girders.—The costs of the first floor girders was as follows:

3, 147 ft. B. M. 10 × 10 in. Y. P. at $20	$62.94
66 hrs. carpenters at 42¼ cts	28.04
Foreman	1.50
Timekeeper	1.50
Watchman	1.00
Total	$94.98

These girders were pitched for an inclined auditorium floor and one man laid 48 sq. ft. per hour. The cost per M. ft. B. M. was as follows:

Material	$20.00
Labor	10.18
Total	$30.18

First Floor Joists.—The cost of laying 2 × 10-in. and 2 × 12-in. joists pitched to an incline for an auditorium floor was as follows:

15, 062 ft. B. M. yellow pine joists	$247.49
239¼ hrs. carpenters at 42½ cts	101.54
4 hrs. labor at 25 cts	1.00
Foreman	22.92
Total	$372.95

One man laid 63 sq. ft. per hour. The cost per M. ft. B. M. was as follows:

Material	$16.50
Labor	8.33
Total	$24.83

Timber Roof.—The timber roof comprised trusses, valley rafters and purlins.

Lumber:	
15, 428 ft. B. M. lumber	$332.14
20 hrs. unloading at 45 cts	9.00
34 hrs. unloading at 25 cts	8.50
1½ hrs. unloading at 30 cts	0.45
Total	$350.09
Framing Trusses:	
333 hrs. carpenters at 42½ cts	$141.39
Foreman	62.40
Timekeeper	7.08
Night watchman	7.00
Total	$217.87
Raising Trusses:	
132½ hrs. at 50 cts	$ 66.25
30 hrs. at 30 cts	9.00
35¼ hrs. at 25 cts	17.82
48 hrs. at 42½ cts	20.37
Iron foreman	36.00
Foreman	9.00
Timekeeper	1.00
Total	$159.44
Valley Rafters:	
54½ hrs. labor at 42½ cts	$ 23.16
Waterboy	1.45
Total	$ 24.61
Purlins:	
136½ hrs. at 42½ cts	$ 57.18
Foreman	4.40
Timekeeper	1.00
Watchman	1.00
Total	$ 63.58
Grand total labor	$483.45

Summarizing we have the following cost per M ft. B. M.:

Material	$21.53
Labor	31.34
Total	$52.87

The cost of material and labor for rafters was as follows:

13, 674 ft. B. M. at $16.85	$229.45
339½ hrs. carpenter at 42½ cts	143.84
Foreman	20.05
Timekeeper	5.50
Night watchman	4.60
62½ hrs. labor at 25 cts	15.62
Total	$419.06

These totals give the following cost per M ft. B. M.

Material	$16.85
Labor	13.86
Total	$30.71

The work amounted to 40 ft. B. M. per man per hour.

Bridging costs for materials and labor $3 per M ft. B. M. of joists.

Boarding Roof.—The cost of covering the roof with 1 × 6-in. D. & M. flooring was as follows:

15, 400 ft. B. M. lumber	$252.80
228 hrs. carpenters at 42½ cts	97.88
12 hrs. labor at 25 cts	3.00
Foreman	18.64
Timekeeper	4.00
Watchman	3.75
Total	$380.07

This gives a cost per M. ft. B. M. as follows:

Material	$16.00
Labor	8.26
Total	$24.26

Ceiling in Rafters.—The cost of beaded out circling securing rafters was as follows:

9 000 sq. ft. ceiling	$315.00
235½ hrs. carpenters at 42½ cts	100.07
35 hrs. labor at 30 cts	10.50
Foreman	13.20
Timekeeper	2.00
Watchman	2.00
Total	$442.77

These totals give the following costs per M ft. B. M.:

Material	$41.00
Labor	14.20
Total	$55.20

The amount of ceiling placed was 38 sq. ft. per man per hour.

Flooring.—The cost of 2 × 6-in. D. & M. flooring was as follows:

14, 414 ft. B. M. lumber	$227.58
101¼ hrs. carpenters at 42½ cts	43.05
56 hrs. labor at 25 cts	14.00
Foreman	19.00
Timekeeper	2.00
Total	$305.63

These totals give the following costs per M ft. B. M.:

Materials	$15.50
Labor	5.42
Total	$20.92

About 143 sq. ft. of flooring was laid per man per hour.

Summarizing the cost of carpenter work per unit we have the following:

Floor strips in cinder concrete	$ 7.00 per M. ft.
First floor girders	10.18 per M. ft.
First floor joists	8.33 per M. ft.
Truss timbers and valley rafters	31.34 per M. ft.
Rafters	13.86 per M. ft.
Roof boarding	8.26 per M. ft.
Flooring	5.42 per M. ft.
Ceiling	14.20 per M. ft.

Cost of Carpenter Work on a Frame Residence.—Engineering and Contracting, Nov. 30, 1910, publishes the following data furnished by the contractor John McMichaels.

The costs are calculated per thousand ft. board measure of lumber used in the construction of a residence at Chicago Heights, Ill., in 1905. Union labor, at 60 cts. per hour for carpenters, was used:

Frame timber	$ 6.00
Bridging (per M. ft. of joists)	3.00
Rough floor and roof boards	6.32
Sheathing	10.40
Siding	20.00
Floors maple 3-in	14.00
Floors Y. P., 3-in	12.00
Ceiling Y. P., 3-in	14.00

Erecting the millwork cost 50 per cent of the value of the material.

Unit Costs of Carpenter Labor on Four Two-Story Frame Flats.—In Engineering and Contracting, Dec. 14, 1910, John McMichaels gives the following. The costs are for labor per thousand feet board measure of lumber with union labor at 60 cts. per hour. The buildings were each two stories in height and were 21 ft. 6 ins. wide by 34 ft. in depth:

Frame timber	$10.90
Bridging (per M ft. of joists)	3.00
Sheathing	8.36
Shingles	2.22
Siding	14.57
Flooring, Y. P	15.00
Flooring, maple	15.00

The millwork was bought by board measurement and was made up on the job. The carpenter work for making up and setting the millwork cost 58 per cent of the cost of the material.

Labor in Different Types of Work in Constructing Frame Houses.—The data given in Table XVIII are derived from a table given by Leroy K. Sherman, President of the U. S. Housing Corporation in Engineering News-Record Feb. 5, 1920.

Table XVIII.—Hourly Labor Output for Building Construction

Item	Kind of labor	Unit Quantity	Labor Output Unit Quantities Per Hour
Excavation (general)	Common	Cu. yd.	0.50
Excavation (trench)	Common	Cu. yd.	0.333
Backfill and grading	Common	Cu. yd.	1.47
Cinder fill, no cement	Common	Cu. yd.	0.625
Plain concrete	Common	Cu. yd.	0.20
Forms for concrete Laborer's time 1½ carpenters	Carpenter and common	Sq. ft.	10.00
Concrete floor, cellar	....	Cu. yd.	0.167
Top dressing	Common	Sq. ft.	31.25
Waterproof painting	Mason	Sq. ft.	50.00
Drainage cellar floor	Common	Cu. ft.	5.00
Flue lining	Mason	Lin. ft.	12.50
Plastering (interior) Laborer's time ⅞ plasterers	Mason and common	Sq. yd.	2.666
Lathing	Lathers	Sq. yd.	11.3
Corner beads	Lathers	Lin. ft.	28.3
Plastering (exterior) Laborer's time ½ plasterers	Mason and common	Sq. yd.	1.693
Plaster board	Carpenter.	....	25.00
Lumber and carpentry Laborers time equal carpenters	Carpenter and common	1000 B. M.	0.0219
Roofing, slate Laborer's time ¼ roofers	Roofer and common	100 sq. ft.	2.75

The rates given above are based upon the experience gained in constructing a large number of houses.

Unit Hour Basis for Estimating Carpenter Work (Engineering and Contracting, Sept. 28, 1921.)—The Quantity Survey Bureau of the Master Carpenters' Association, with the co-operation of several members, has compiled the following tables for use in figuring the cost of carpenter work.

Size	Material	Unit Working Hours per M ft.	Size	Material	Unit Working Hours per M ft.
2 × 4″	Studs	32	1 × 6″	Boards	16
2 × 4″	Rafters	39	1 × 8′	do.	14
2 × 4″	Partitions	54	1 × 8′	Cut betw. Joists.	24
2 × 5″	Studs	31	1 × 4″	D & M Floor	25
2 × 5″	Rafters	37	1 × 6″	Sheathing	18
2 × 5″	Partitions	48	1 × 4″	Siding	46
2 × 6′	Studs	30	1 × 6″	do.	33
2 × 6″	Rafters	36	1 × 4″	Mitered	50
2 × 6″	Partitions	46	1 × 6″	Siding	37
2 × 6″	Joists	26	1¼″	D & M Floor	30
2 × 8″	do.	24	2 × 4′	D & M Floor	25
2 × 10″	do.	21	2 × 6″	D & M Floor	20
2 × 12″	do.	19	1 × 6″	Drop Sidg.	28
2 × 14″	do.	17	1 × 8″	Drop Sidg.	25
3 × 8″	do.	19	1⅛″	Face Maple or Oak Flooring	80
3 × 10″	do.	18			
3 × 12″	do.	17	2″	Face Maple or Oak Flooring	45
3 × 14″	do.	16			
3 × 4″	Sleepers	40	2¼′	Face Maple or Oak Flooring.	40
Furring	On wood	110			
	Brick	240	1¼ × 3″	Bridging	60
1 × 2″	Tile	360		Add for Planing or Scraping Flg.	
	Concrete	600			
1 × 3′	Bridging	75		Maple	50 %
4 × 6—8 × 8	Timbers	24		Oak	80 %
8 × 10—12 × 12	do.	22			

The "unit hours" shown in the third and last columns represent the number of working hours which in the opinion of the committee are required to frame, put in place and finish 1,000 ft. of the various kinds of lumber shown in other columns. By multiplying the actual quantities required for a job by the number of "unit hours" the total number of "work hours" are obtained and the latter are then multiplied by the current wage rate.

Relative Cost Types of Deep Foundations.—I am indebted to J. H. Thornley for the following matter.

Where loads are excessively heavy or the bearing value of the surface soil unusually low, spread footings must be replaced by one of the following types of deep foundation.

The table indicates the effect of various governing factors on the comparative economy of the different types.

The types are given approximately in order of cost per ton of bearing value. That is, if the nature of the proposed work is such that the "Conditions indicating use" would show either type "A" or type "B" to be applicable, then type "B" would *usually* give the cheaper foundation.

Type	Conditions Indicating Use	Objections to Use
"A" Compressed Air Caissons.	1. Very heavy concentrated loads.	1. Extremely high cost.
	2. Water or water bearing material to be penetrated.	2. Slowness.
	3. Rock or material of almost equal bearing value within 100 feet approximately.	
	4. Work sufficiently extensive to warrant heavy installation costs of the necessarily elaborate plant.	

Remarks: Load capacity of finished pier calculated on basis of column to rock.

Type	Conditions Indicating Use	Objections to Use
"B" Open Ended Steel Pipe Concrete Filled Piles.	1. Rock within 40 pile diameter (60′ for an 18″ pile).	1. Danger of occurrence of large boulders or other obstacles which may make blowing out of pile impossible.
	2. Material to be penetrated of low bearing value.	
	3. Pile to be entirely below finished ground level.	
	4. Loads fairly heavy and concentrated, 50 tons or more per column.	
	5. Piles to be placed in cramped quarters, *e.g.*, between shorings.	
	6. Material to be penetrated easily jetted; sand silt or muck.	
	7. Work sufficiently extensive to warrant the installation of the compressor plant necessary for blowing out of piles.	

Remarks: Load capacity calculated on basis of supported column to rock. Within forty diameters (New York building code allows 500 pounds per square inch on concrete section and 7500 pounds per square inch on steel section, less $\frac{1}{16}$ inch steel allowed off for rust).

"C" Closed Ended Steel Pipe Concrete Filled Piles.	1. Load fairly heavy and concentrated 40 tons or more per column. 2. Permissible load per pile not arbitrarily restricted by local building code. Load allowed according to test or formula. 3. Material to be penetrated of some frictional bearing value. 4. Length of piles uncertain. 5. Heavy boulders or other debris liable to be encountered before reaching desired penetration. 6. Small number of piles only required necessitating low plant installation charge. 7. Limited headroom for driving. 8. Enclosed quarters in which driving must be done making blowing dangerous.	1. Larger sizes of pipe only available at a few places in the country. Pipe is bulky to ship and heavy to handle.
"D" Pre-cast Concrete Piles.	1. Site covered by water.	1. Difficulty of ascertaining the lengths of pile which will be required to develop a given refusal and, therefore, a given load capacity. In case of driven piles the last piles of a large pier will sometimes be only half the length of the first piles when driven to the same refusal. Piles in different parts of the foundations of the same building often vary from one half to double the length of the average pile. Except where borings show a level strata of rock or other firm bearing material, borings form only an approximate method of ascertaining the probable length of a pile. The wastage due to cut off of precast piles often makes this system of piling extremely expensive.
	2. Ground through which piles driven such as to permit of jetting,—sand, silt or muck.	2. It is necessary to cast the pile at least 28 days before it is driven which means a serious delay in starting work on a rush job.
	3. Accurate advance knowledge as to the driven depth of piles required to support load.	3. The percentage of breakage in handling and driving precast piles is sometimes high. 4. Piles fractured in driving may not show up until they are under load.

"E" Open Caissons or Caisson Piles.	1. Large concentrated loads. 2. Little or no water in material to be penetrated. 3. Rock or material of high bearing value within thirty feet.	1. Danger of striking quicksand or unexpected springs. 2. Slower method than driven piles.

Remarks: Load capacity of finished pier or pile calculated either on basis of column to rock or on basis of bearing value of bottom material if not rock.

"F" Float Foundations.	1. No safe bearing strata within economical reach of piling. 2. Surface material liable to flow but practically non-compressible when contained. 3. No danger of future excavation occurring in close enough proximity to the foundation to cause flow of the sub soil. 4. No likelihood of change in the local water table which might result in drying out and consequent shrinkage of sub soil. 5. A uniformly distributed load. 6. A surface sub soil of homogeneous material giving uniform bearing value.	1. Uncertainty.

Note: So called float foundations are often merely cases of a spread footing extending under the entire building. The term "float foundation" as here used means a foundation on material which would flow under the building load if not contained.

"G" Wooden Piling.	1. Piles to be wholly below ground water level, or if in open water to extend above the low water level only to such an extent that the part above water level will not become dried out. (This extension above low water level will vary according to climatic conditions.) 2. Comparatively light loads or uniformly distributed loads. 3. Water conditions such as to permit of cut off at time of driving without sheeting and pumping. 4. Assurance that the water table will not be lowered either by climatic changes over a period of years or by artificial changes such as sewers, subways or canals.	1. Where piles are driven through strata of small bearing value to hard pan or rock practically all of the load must be taken in end bearing which may result in end crushing or column failure. The liability to column failure becomes serious in long piles if they are not absolutely straight. 2. In driving in soil containing boulders or in driving to a rock bearing there is always danger of cracking and end booming.
"H" Cast-in-place Concrete Piling.	1. Load sufficiently concentrated to give 20 tons or more per pile. 2. Surface soil of sufficient bearing load value to carry a land pile driving rig. 3. Probable length of pile under 50′. 4. Speed required. 5. Load concentration not in excess of 6½ tons per square foot.	1. Cannot be driven through water.

Note: Where the water table coincides closely with the bottom of the column bases avoiding either expense for pumping and sheeting or the building of a deep cap from cut off to column base, wooden piles will usually be cheaper than cast-in-place concrete piles unless the loads are large and concentrated.

There are numerous other special types of piles and caissons which have been designed to meet unusual conditions. Such, for example, are the steel screw piles and automatic caissons in which the digging is done by water jets or other purely mechanical means.

It is not intended to be understood that *all* conditions shown in the "Conditions Indicating Use" column should be expected in any particular instance. Sometimes the importance of one condition may overshadow all others. For example, where cast-in-place piles may be otherwise the obvious solution a lack of head room for a driver and apparatus may force the use of steel pipe pile.

Cost of Caisson Foundation for a Building in Chicago.—The following is given in Engineering and Contracting, Oct. 22, 1913.

The foundations were built during the summer of 1913 and consisted of 40 wells sunk to rock. Owing to the nature of the sub-soil it is unnecessary to use compressed air and the small amount of water encountered was removed by buckets.

The usual crew for a 5-ft. well was one digger, one man at the niggerhead, one dumper and enough wheelers to remove the excavated material. Usually one wheeler could handle the excavation from two wells, where the haul did not exceed 100 ft. and the runway was in good condition.

The first set of lagging placed consisted of 3 × 3-in. pieces, 6 ft. long, three rings being used for the initial set. After the caissons were topped, platforms were built of 2-in. plank, with a 2-ft. square hole at the center of each caisson, and on these platforms the tripods were erected. Each tripod carries a shaft, on one end of which was an 18-in. sheave and on the other end an 8 × 10-in. niggerhead. Directly over the center of the caisson was placed a block, suitable for a 1-in. Manila rope. This rope supported an iron bucket, 22 ins. in diameter and 24 ins. deep, which was used for hoisting the excavated material. Power was supplied by a hoisting engine, conveniently located, having a bull wheel on a stub shaft. A 5/8-in. cable passed over this wheel and also over each of the sheaves at the caissons. Ten wells were operated from one hoisting engine, and the cable would last on an average for two set-ups.

Progress of Caisson Work.—The caisson work was carried on continuously in three shifts of eight hours each, except for a four weeks' lockout. During the lockout, the only men employed were two foremen, two timekeepers, a superintendent, an assistant superintendent, and a night watchman. The excavated material for a depth of from 50 to 55 ft. below city datum consisted of the typical soft blue clay which could be excavated with a spade. For the next 10 to 15 ft. the material was dry and required grubbing; the following 15 ft. was hard-pan, which was removed with some difficulty; while the last 3 to 5 ft. consisted of water-bearing sand and gravel. In most cases it was necessary to remove some disintegrated rock from the surface of the bed-rock. Large boulders, which required blasting, were often encountered. For about the first 56 ft., 3 × 6-in. lagging, 4 ft. long, was used, and for the remaining distance, about 26 ft., 2 × 6-in. lagging, 5 ft. 4 ins. long was used. The wrought iron rings were 3 × 3¾ ins. in section, made in two parts, with flanges for the connecting bolts.

Arrangements were made with the Chicago Tunnel Co. to receive the excavated material, which was discharged through its station at Madison St. and the river. A chute was dug from the tunnel to the basement level of the site, into which the material was dumped, and by it was conveyed by gravity to the cars.

Table XIX shows the actual progress made by each eight-hour shift for two 5-ft. diameter caissons. It is seen that the progress for each caisson was practically the same for each shift.

TABLE XIX

Shift (8 hrs.)	Caisson No. 14. Depth each shift Ft.	Ins.	Caisson No. 15. Depth each shift Ft.	Ins.
1	6	0	6	0
2	14	0	13	10
3	21	2	20	10
4	27	4	27	4
5	35	7	35	7
6	41	5	41	5
7	46	7	46	7
8	50	10	50	10
9	54	8	53	3
10	55	8	55	4
11	57	8	58	7
12	59	8	58	7
13	62	5	60	4
14	65	5	64	2
15	68	8	66	3
16	72	11	69	10
17	77	4	76	2
18	80	2	80	9
19	81	8	82	3

Cost Data.—The total excavation for caisson No. 14 was 59.4 cu. yds., the total labor cost for excavating and for placing the lagging was $328.70, making a cost per cubic yard of $5.53. For caisson No. 15 the excavation was 59.8 cu. yds., the total labor cost was $328.70, and the labor cost per cubic yard was $5.50.

The total pay roll for all work done in connection with the excavation of the site and the digging and concrete of the wells was $23,468.50. This did not include the cost for shoring materials, for electrical work, or for the engineering work, which required the services of three men two days out of every three. The following scale of wages per hour was paid: Common laborers, 40 cts., niggerhead men, 50 cts.; diggers, 57½ cts.; lagging boss, 60 to 70 cts.; rigging foreman, 65 to 75 cts.; foreman, 75 cts.; and engineers, 75 cts.

With conditions such that the excavating operations consisted of excavating, pulling and wheeling, the cost per shift (with the overhead charges properly distributed), when ten wells were being excavated at the same time, averaged about $17.30 per well. This gives a cost of $51.90 per day per well, or $519.00 per day for the ten wells. These costs include the necessary labor for unloading and piling the lagging and rings, and practically all items connected with the actual work done on the caissons. It does not, however, include the disposal of the excavated material (after dumping into the chute), the cost of shoring materials, or the concreting of the caissons.

Concreting of Caissons.—The ¼-yd. motor-driven mixer was mounted on a platform, placed at the level of the street. The concrete materials were stored in the street, and the concrete was, in most cases, spouted to the caissons. For some of the more distant wells, however, the concrete was wheeled in buggies. When it was possible to keep the mixer in continuous operation, a gang of 22 men could mix and place about 100 cu. yds. per shift of eight hours, at a labor cost of slightly less than $1.00 per cubic yard. The labor cost, even with intermittent running seldom reached $1.25 per cubic yard. The concrete was poured in at the top of the caisson and was permitted to fall to the bottom. A mixture of one part Portland cement, three parts torpedo sand and five parts 1-in. crushed stone was used for the caissons.

A Comparison of the Cost of Concrete and Wood Piling.—Philip J. Kealy, in Engineering and Contracting, Jan. 25, 1911, gives the following:

In the erection of a large industrial shop in the Chicago district during the summer of 1910, a pile foundation was necessary and the question as to the kind of piling arose. The building site was on filled ground, near a river, with the ground water line approximately 14 ft. below grade, and the piling depended largely on skin friction for bearing power.

A proposal was made to furnish concrete piles at $1 per ft. but wood piles were selected because they could be secured at 23½ cts. per ft. in place. The piles were designed to carry 20 tons each and the number of piles varied from 4 to 9 under each pier. The contractor was allowed 12 cts. per ft. for each foot followed.

Driving.—The following is the cost data on the pile driving operation:

Total piles driven, approximately	1,250
Total linear ft. driven, approximately	50,000
Total linear ft. followed, approximately	6,000
Actual cost of pile (to company) per foot driven	25.15 cts.
Actual cost of one pile (driven)	$10.21

The piles were driven during July and August.

Sawing Off Heads.—The piles were cut with a cross cut saw about 4 ft. long worked by two men who received 35 cts. per hour each. The heads were hoisted out by a three-leg derrick and single block, six men being required to hoist up and dispose of them. These laborers received 25 cts. per hour. Water existed in many of the holes which varied from 12 to 15 ft. in depth. The average cost to cut off each head, get it out of the hole and dispose of it was 38 cts. The unit cost varied from 17½ cts. to $1.35.

Excavation.—The cost per cubic yard for excavation was $2, which price included backfilling. The pier holes were in many instances full of water, entailing pumping, sheeting was necessary to prevent caving, double and triple casting of dirt was frequently required and much of the material handled was slush, so that the price per yard was not excessive. The amount of excavation required for various size piers and the cost per pile was as follows:

4 piles 6 × 6 × 14.5 = 19.3 cu. yds. at $2 = $38.60, or $9.65 per pile.
5 piles 6.5 × 6.6 × 14.5 = 22.7 cu. yds. at $2 = $45.40, or $9.08 per pile.
7 piles 7 × 7 × 14.5 = 26.3 cu. yds. at $2 = $52.60, or $7.51 per pile.
9 piles 7.5 × 7.5 × 14.5 = 30.2 cu. yds. at $2 = $60.40, or $6.71 per pile.

The majority of the piers rested on the smaller number of piles so that the average cost of excavation per pile was $8.61.

Concrete Caps and Piers.—The coat of the concrete work in the piers was $5.40 per cu. yd., the contractor furnishing all materials and forms. From the detail drawings the cubical contents of the piers are found to be as follows: 4 pile, 6.3 cu. yds.; 5 pile, 6.8 cu. yds.; 7 pile, 8.0 cu. yds.; and 9 pile, 8.7 cu. yds. At $5.40 per yd. the cost of the concrete work in place was as follows:

4 pile 6.3 cu. yds. at $5.40 = $34.02 or $8.50 per pile.
5 pile 6.8 cu. yds. at $5.40 = $36.72 or $7.34 per pile.
7 pile 8.0 cu. yds. at $5.40 = $43.20 or $6.17 per pile.
9 pile 8.7 cu. yds. at $5.40 = $46.98 or $5.22 per pile.

The average price per pile for the concrete cap and the pier from cap to footing grade, was $7.15.

Recapitulation.—From the foregoing figures the following table summarizing the cost of a pile in the various size piers is obtained:

Item	Cost per mile 4 pile	5 pile	7 pile	9 pile
Driving and following	$ 10.21	$ 10.21	$ 10.21	$ 10.21
Sawing heads	0.38	0.38	0.38	0.38
Excavating and backfill	9.65	9.08	7.51	6.71
Concrete	8.505	7.34	6.17	5.22
	$28.745	$ 27.01	$ 24.27	$ 22.52
	4	5	7	9
Cost of completed pier	$114.98	$136.05	$169.89	$202.68

Concrete Piles.—Numerous tests have shown that where the loading is supported by skin friction, a short tapering concrete pile will sustain as great or greater a load than a long wood pile and for that reason it was proposed to use 24 ft. piles on this work had concrete piles been selected. In tests made in just such soil conditions as existed in this case, it was demonstrated that the concrete piles could stand from two to three times the loading, without settlement, that the wood piles could carry, but in order to be conservative 50 per cent greater loading is assumed for a comparative basis of cost. The cost of a 4 pile cluster (assuming same loading as on wood piles) of concrete piles would be:

Piling, 4 at $24	$ 96.00
Excavation for cap at 2 cu. yds. at $1.00	2.00
Concrete in cap 2 cu. yds. at $5.40	10.80
	$108.80

Assuming 50 per cent greater bearing power, piles to be driven on 2 ft. centers, the cost of a 4 pile cluster would have been:

Piles, 3 at $24.00	$72.00
Excavation, 2 cu. yds. at $1.00	2.00
Concrete cap, 2 at $5.40	10.80
	$84.80

This is a saving of approximately 26.5 per cent of the initial cost of the wood piles. Upon the same premises, the cost of the different size piers would have been as follows:

COST OF CONCRETE PILE PIERS

Number of wood piles	4	5	7	9
Cost of concrete piles	$72.00	$ 96.00	$120.00	$144.00
Cost of excavation	2.00	2.00	3.00	3.00
Cost of cap	10.80	10.80	16.20	16.20
Total cost	$84.80	$108.80	$139.20	$163.20

A comparison of the cost of the complete wood pile piers necessary to take care of the same loading, with the concrete piles and the per cent saving in initial cost in favor of the latter is shown in the following table:

SIZE OF WOOD PILE PIERS

	4-pile	5-pile	7-pile	9-pile
Concrete	84.40	108.80	139.20	163.20
Wood	114.98	135.05	159.89	202.68
Per cent saving in initial cost	26.4	19.45	18.1	19.5

It is evident from the above figures that a saving of over 20 per cent of the initial cost of the foundation work would have been effected by the use of concrete piles, under the conditions which existed on this job. This saving is brought about by avoidance of expensive excavation and deep concrete piers necessitated by the wood piling and would be approximately the same percentage in the nine-pile cluster, as it is in the four-pile.

On further analysis, it would appear that where the ground-water line is 8 ft. or more below grade, the initial cost of the foundation work below grade would be less if concrete piles were selected in preference to wood, although the cost of concrete piles would be $1 per foot and wood piles 25 cts. per foot driven.

Output of Steam Pile Drivers on Foundations of the Field Museum of Natural History.—Engineering and Contracting, Nov. 24, 1915, gives the following:

The concrete piers of this building are supported on clusters of wood piles. These piles are 60 ft. long, of Georgia pine, and are almost perfectly straight. They are 9 ins. in diameter at the tip, and vary from 15 to 22 ins. in diameter at the butt, averaging about 18 ins. The total number of piles required is 9,320. Pile driving was begun July 29, 1915, and 8,100 piles had been driven up to Nov. 10. Three steam drivers, equipped with 70-ft. leads, are being used for this work. As the piles are cut off at elevation—1 ft. 9 ins. (the elevation of the pier bases being—2 ft. 6 ins.) it is necessary to use followers in all cases. The piles are driven through from about 16 to 25 ft. of clay fill, through a thin stratum of wet sand, then through from 20 to 30 ft. of soft blue clay, into strata of stiff to hard blue clay and gravel. All piles are driven practically to refusal at these depths. With the exception of about two weeks, during which time it was impossible to secure delivery of piles on account of floods in the South, pile driving has continued without interruption.

Each driver has averaged from 30 to 35 piles per day of ten hours, the pile driving crew consisting of 7 men, in addition to those whose duty it is to prepare the piles for driving and to bring them to the driver.

Cost of Pedestal Concrete Piles.—Fig. 9, and the following explanation, describing the method of forming pedestal piles, are given in the official Bulletin, Investigating Committees of Architects and Engineers.

1. A core and cylindrical casing are first driven to the required depth.

2. The core is now removed and a charge of concrete dumped to the bottom of the casing.

3. The core is now placed on the charge of concrete and the casing is raised to permit the forming of the pedestal.

4. The core is now used as a rammer, to compress this concrete into the surrounding soil. The process is repeated until the base is as large as can be formed under the compression caused by the action of a Vulcan steam hammer.

5. The enlarged base being completed, the casing is filled to the top with concrete and is then removed with the core and hammer (approximately 6 tons) resting on the concrete.

6. The final step is to withdraw the cylindrical casing from the ground. The completed pedestal pile, consisting of a monolithic concrete column 16

inches in diameter surmounting a broad base or pedestal, is thus left in the ground.

The following summaries, of cost and working conditions on two typical jobs where pedestal concrete piles were used, were prepared by J. H. Thornley, chief engineer, MacArthur Concrete Pile & Foundation Co.

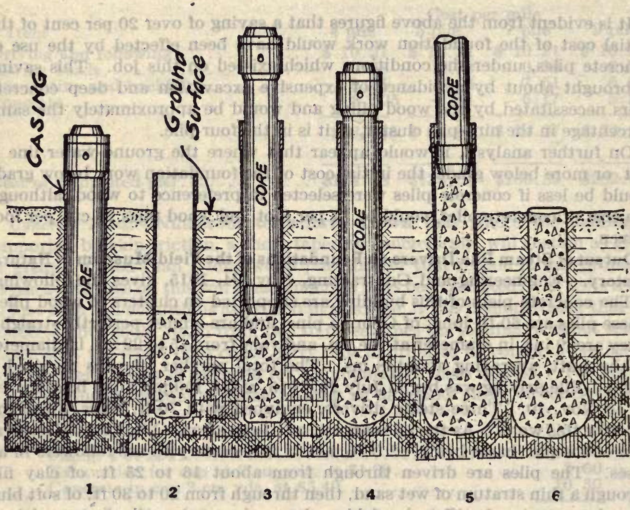


FIG. 9.—Sections showing steps in forming pedestal piles.

1. Location of Job: West Orange N. J.
2. Owners: Ward Baking Company
3. Contractors for whom work was done: John W. Ferguson Company, Paterson N. J.
4. Number of piles in job: 463
5. Average length: 12 feet
6. Piles in groups of: 7 and 8
7. Distance between piers: 16 feet one way—23 feet one way
8. Pile centres: 3 foot 0 inches
9. Soil conditions: Sand and large boulders
10. Remarks: Very hard driving—worst possible conditions
11. Total footage: 5,563
12. Total Cost: $9 503.00
13. Cost per foot of pile: $1.71
14. Wages paid:

Foreman	$52.25	a week
Engineers	52.25	a week
Pile driver Men	1.00	an hour
Concrete Labor	.72	an hour

15. Cost of Material: $2.93 per barrel of cement
    2.75 per cu. yd. of sand and gravel aggregate.

1. Location: of Job: Clifton, Staten Island
2. Owners: Pouch Terminal Company
3. Contractors for whom work was done: Turner Construction Company of New York
4. Number of piles in job: 757
5. Average length: 22.8 feet
6. Piles in groups of: 10 to 21

7. Distance between piers: 20 feet both ways
8. Pile centres: 2 foot six inches
9. Soil conditions: Clay and sand
10. Remarks: Moderate to hard driving.
11. Total footage: 17,282
12. Total Cost: $24 140.00
13. Cost per foot of pile: $1.40
14. Wages paid: Foreman.......................... $52.25 a week
    Engineers.......................... 52.25 a week
    Pile driver men.......................... 1.00 an hour
    Concrete labor.......................... .78 an hour
15. Cost of Material: $2.85 per barrel of cement
    2.75 per cu. yd. of sand and gravel aggregate

Mr. Thornley states, that under average conditions and with wage rates as shown, the average price per foot, for driving and forming complete approximately 500 pedestal piles, would be as follows:

	Wages per 8-hr. day
Foreman	$10.00
Engineer	9.00
Pile driver men	7.00
Concrete labor	3.60

Length of pile, ft.	Price per ft.
10 to 20	$1.60
20 to 30	1.30
30 to 42	1.20
42 to 50	1.25

Rapid Driving of Raymond Concrete Foundation Piles.—Engineering News-Record, July 12, 1917, gives data regarding the speed developed in driving 3776 Raymond Concrete Piles for the footings of the large storage building constructed at the beginning of the war at the Brooklyn Navy yard. Four pile drivers were used and were operated continuously with the exception of Sundays, three 8-hr. shifts being run on week days and three 4-hr. shifts on Saturday.

The average penetration of the piles was 22.85 ft. and the average number of piles driven by each driven crew per 8-hr. shift was 21.

The piledrivers used by the contractor were steel-frame turntable machines, equipped with two-drum hoists and No. 1 Raymond steam hammers. They travel on a nest of rollers under the base of the turntable. A timber runway has to be laid for them. This type of rig is considered the most rapid ever developed, and this in spite of the fact that Raymond piles are more difficult to drive, on account of the process involved, than wood piles. The core on which the shells are assembled before driving weighs about 8800 lb. and, furthermore, must be withdrawn after each pile is driven. A record for the number of piles driven in a single shift, which it is thought has never been approached under similar conditions, was established in 1916, when one of these machines drove 119 twenty-foot piles in 10 hours at the plant of the Chevrolet Motor Co. in Flint, Michigan.

Cost of a Damp-Proof Timber Floor.—In Engineering News, Aug. 27, 1914, J. Albert Holmes gives the following:

The floor was laid in the basement of a manufacturing building on the natural earth, hardpan and sand, without underdrains, and carrying machinery, round steel in racks and square steel piled solid in storage.

The owner, wishing to secure a long-lived floor, purchased kyanized hemlock for the 3-in. underfloor and had two-ply felt and a layer of pitch placed between the plank and top flooring. The ground was prepared by the contractor for the building by rolling or puddling, therefore, the costs given in the accompanying table are for materials and labor above the ground.

The soft-coal cinders used for the foundation course were purchased from the railroad and delivered in cars on a siding from which they were shoveled directly into the basement where used. Materials were delivered and the work performed in the winter, so that storage in the basement obviated the necessity of heating the cinders when mixed with the tar. Tar was purchased from the local gas works and 14 gal. used per cu. yd. of cinders.

The cinders were spread, rolled and tamped to a thickness of 4 in.; the shrinkage from measurement in cars to place was 36%. Sand and tar were heated outside the building and mixed in the basement. This mixture, while warm, was spread over the cinders and screeded off ⅜ in. above the bottom of the plank; planks being laid to grade for screeding. Into the sand while still warm, the 3-in. planks were firmly bedded by ramming.

For specially prepared tars, 50 to 60 gal. per yd. of sand are specified. On this work the greatest amount of tar that the sand could be made to contain, without making a soft, wet mixture, was 35 gal. per cu. yd., the same kind of tar being used in both cinders and sand. The writer has knowledge of floors where the tar has come up through the joints in both plank and top floor due, no doubt, to an excess of tar in the sand.

The difference in volume of sand in place and in carts, due to compression and to inequalities of surface of cinder layer was 68%. The plank was 3-in. kyanized hemlock, planed one side to a uniform thickness of 2¾ in. and not less than 6 in. wide, random lengths, square edged and saw butted; laid to break joints and toe nailed but not driven tightly together. There was no loss of plank by cutting.

Over the plank were placed two layers of felt and one of pitch. The felt weighed 14 lb. per 100 sq. ft. and was laid to break joints one-half the width of the sheet; no pitch was allowed to come in contact with either plank or top floor. The loss in area of felt due to lapping was 21%.

Over the felt and at right angles to the plank was laid a maple-top floor 1$\frac{1}{16}$ in. thick. This flooring was square edge, 3 in. wide, and nailed with 10-penny finish nails through the top every 8 in. on alternate sides.

The waste and shrinkage due partly to laying, but mostly to manufacture, was 40%; in other words, while the market price of the flooring was $45 per M, the shrinkage in manufacturing that must be paid for, plus a small loss by waste in laying, brought the cost up to $63 per M. Builders are familiar with shrinkages in manufactured lumber, but engineers, not having occasion to use it so frequently, are not so familiar and are surprised when as for instance, they purchase 5-in. V-sheathing for building a field office, to find that it covers a width of only 3¼ in. and that the Western rules for inspection of hard pine allow ⅛ in. less than the Eastern, which in turn allow an ⅛-in. or more, less than full dimension for square timber and plank.

Referring to the accompanying table, the quantities are the quantities purchased in the market, as for instance, 4 in. of cinders in place amount to 0.151 cu. yd. measured in cars, or 36% more than the place measurement and similarly for sand, felt and top floor, there being no loss in laying the 3-in. plank.

In this work, two distinct classes of labor or trades were employed, roofers in this case and carpenters, and though they worked together, their organizations were separate. For this reason, the combined items for superintendence

Cost of Damp-Proof Floor

Materials and labor	Thickness of material in place	Quantity per sq. yd.	Unit cost	Cost per sq. yd.	Per cent of waste and shrinkage	Cost* per sq. yd.
Cinders	4 in.	0.151 cu. yd.	$ 0.50 per cu. yd.	$0.076	36	$0.076
Tar in cinders	......	0.0381 bbl.	2.00 per bbl. (57 gal.)	0.076	..	0.076
Sand	1 in.	0.045 cu. yd.	1.00 per cu. yd.	0.045	68	0.045
Tar in sand	......	0.0276 gal.	2.00 per bbl. (57 gal.)	0.055	..	0.055
Felt	2 ply	3.10 lb.	35.00 per ton	0.054	21	......
Pitch on felt	......	3.32 lb.	17.00 per ton	0.028	..	......
Teaming, tar	......	....	0.50 per hr.	0.039	..	0.039
Laborer, roofers	......	....	0.375 per hr.	0.433	..	0.358
Supt., roofers	......	....	0.50 per hr.	0.100	..	0.078
Kyanized plank	2¾ in.	0.027 M.	33.50 per M.	0.905	00	0.756
Maple top floor	1 1/16 in.	0.0134 M.	45.00 per M.	0.603	40	0.603
Nails	......	1.2 lb.	2.10 per cwt.	0.027	..	0.027
Carpenters	......	....	0.41 per hr.	0.475	..	0.475
Labor	......	....	1.75 per day	0.230	..	0.230
Supt	......	....	0.50 per hr.	0.080	..	0.080
Totals	9 in.	....	....	3.226	..	2.898
			Materials	1.869	..	1.638
			Labor	1.357	..	1.260

* Cost omitting felt, pitch on felt, labor placing felt and pitch and using untreated Hemlock plank @ $28.00 per M.

is high and that for superintendence of roofers unnecessarily so. Reducing the item for superintendence of roofers and using untreated plank and leaving out the felt and pitch between plank and top floor, the cost would be reduced as shown in the last column of the table.

Cost of Granolithic Floor.—John T. Sullivan in Engineering News-Record, April 4, 1918, gives the following:

A unit cost on concrete floor finishing of 58c. for 100 sq. ft. was recently attained on the first floor of the new Charles Shannon Building in Cincinnati. The entire job, consisting of 3325 sq. ft. was cleaned up by four laborers and two finishers within nine hours. Work started at 7 a. m. Two laborers mixed the finishing material—one wet batch and another dry batch—using iron mortar boxes. Two other laborers roughened the floor with wire brooms, the floor having been poured the previous day. As soon as the first batch was ready, one of the laborers was used to wheel the finish in on the floor.

One finisher spread the batch while the second finisher leveled it off with a 6-ft. screed. The first finisher then floated the surface with a long home-made float and with a hand-float. The second finisher then spread and screeded continuously while his partner worked on floating. At 2 o'clock the whole floor was spread and screeded, so both finishers worked with the floats until the floor was finished at 4:30 p. m. The laborers used on mixing and wheeling were put on other work as soon as their task was completed. Here is a summary of the costs:

Two laborers to mix, 7 a. m. to 2 p. m., 6½ hr. each at 30 cts. per hr. =	$ 3.90
One laborer to wheel finish onto floor, 6½ hr. at 30 cts. per hr. = ...	1.95
One laborer to broom and use big float, 8½ hr. at 30 cts. per hr- = ...	2.55
Two finishers, 9 hr. each at 60 cts. per hr. = ...	10.80
Total labor cost...	$19.20
Total area .... = 35 × 95 ft. = 3, 325 sq. ft.	
Unit cost .... = $\frac{\$19.20}{3,325}$ = 58 cts. per 100 sq. ft.	

One-half hour was taken for lunch.

Cost of Resurfacing Concrete Floors.—C. L. Samson, gives the following data in Engineering and Contracting, Nov. 29, 1911.

Both floors as originally laid consisted of 13/16 in. maple flooring nailed to 2 × 4 in. pine nailing strips laid in concrete. Concrete was flush with the top of nailing strips. In seven years time the nailing strips rotted out and the maple came loose. It was decided to remove the maple flooring and surface the underlying concrete.

The item "cleaning floor," consisted of removing the maple, picking out remains of nailing strips and scrubbing surface of old concrete to receive the finish. It was the intention to make the finish 1 in. thick but the old floor was uneven so that in some cases the finish was 1¾ ins. thick, while in other places the old concrete had to be picked out and renewed. The amount of crushed stone used will serve as a rough indication of the amount of concrete removed and replaced.

The form work mentioned was over a tunnel and formed a slab 4 × 16 ft. which was reinforced by ¼ in. round rods.

The first floor was finished with what was sold to us as Wisconsin Granite chips. It proved to be little more than sand stone and did not make a satisfactory floor. It finished beautifully but the floor was so soft that the glaze soon wore rough under trucking. The mixture of finish was 1 of Portland cement to 1½ "Wisconsin Granite."

The same mixture was used on the second floor excepting that common sand was used instead of the granite. No trouble was experienced in either case in getting the finish to stick to the old concrete. The old concrete was slushed with a neat cement grout before applying the finish.

The first floor was laid in February and the second in June while the weather was very warm. The intense heat is largely responsible for higher cost per square foot of the second floor. The second floor also contained one reinforced concrete slab 13 ft. square and 7 in. thick. The cost of the first floor was as follows:

Labor:	
Cost of cleaning old floor for concrete	$ 89.93
Cost of bringing in material	36.53
Cost of mixing board, floats and straightedge	1.43
Cost of setting screeds	7.15
Cost of forms around two tunnel doors	12.20
Cost of finishing	45.59
Total cost of labor	$192.73
Material:	
82¾ barrels Portland cement	$ 74.47
15 yds. crushed granite	58.50
5 yds. sand	6.25
10 yds. crushed stone	13.00
Cartage	21.12
Total cost of material	$173.34
Grand total	$366.07

The rates of wages paid were: Common labor, 25 cts. per hour, and carpenter labor, 30 cts. per hour. The area of floor laid was 5,120 sq. ft., and the cost per square foot was $0.0710. The cost of the second floor similar to above was as follows:

Total cost of labor at 25 cts	$203.31
Cost of material:	
68¾ barrels Portland cement	61.88
25 yds. sand	37.50
16 yds. stone	24.00
1140 lbs. twisted steel	29.64
Total cost of material	$153.02
Total cost of floor	$356.33

The area of floor laid was 4,217 sq. ft. and the cost per square foot was $0.084.

Labor Cost of Laying Concrete Basement Floor, Columbus, Miss.—C. L. Wood, in Engineering and Contracting, Sept. 14, 1910, gives the following:

The floor covered a 12 × 200 ft. hallway and nine side rooms ranging in area from 759 to 2,069 sq. ft. the total area being 12,952.2 sq. ft. The total thickness of the floor was 6 ins., composed of 4-in. base of 1:3:5 concrete, and a 2-in. surface of 1:2 mortar. The aggregates were sand and gravel. The foundation was 4 ins. of screened coal cinders, wet and tamped. The sand and gravel was delivered in piles opposite the windows of the basement; cement was stored in one room and lumber was delivered in piles opposite the doors. The contract for laying included all labor and supervision necessary to the finished floor, with materials purchased and delivered as mentioned, and with free use of shovels and wheelbarrows, and of water.

The unscreened sand and gravel was shoveled into the rooms through the basement windows, screened and moved with wheelbarrows to the mixing boards, which were set in the hall at two points of which there were water connections. The mixing was done by hand, working 4 men on the mixing board and 1 man at the mortar box. Lights were necessary, but as all work was under cover, no delays were caused by rain. The gang consisted of 1 foreman, who was the contractor and form setter, 1 finisher, 1 mortar mixer, and from 7 to 12 laborers. A 10-hour day was worked, the finisher requiring extra time, since all work was completed the same day that it was begun. The job was completed in 5 calendar weeks and 2 days. The work of electric wiring, steam piping, laying drain, etc., was in progress at the same time as the floor construction, which greatly hindered the progress of the concrete work and in the narrow quarters made necessary a small working party. The following was the cost of the work:

2,010½ hrs. common labor at 10 cts	$201.05
276.4 hrs. mortar mixer at 12½ cts	34.95
296.36 hrs. finisher at 27½ cts	81.50
32 days foreman at $5	160.00
Total	$477.50
Profit	$ 50.00
Contract price	$527.84

The cost per square foot of floor was 3.71 cts. and the contract price was 3¾ cts.

Cost of Concrete Arch and I-Beam Power House Floor.—The following itemized account of the cost of a floor built in a power house in Lincoln Park, Chicago, in 1909 is taken from Engineering and Contracting, March 15, 1911.

The floor was 20 × 25 ft. in area and was made of 10-in. I-beams, spaced 5 ft. on centers. The concrete was 11 ins. thick at the beams and was arched between the beams so that the thickness of the concrete was 5 ins. at the crown of the arch. The area of the floor was 500 sq. ft., but a stair space reduced the area of concrete placed to 475 ft. The total cost was $208.

	Per sq. ft.
Labor:	
2 days engineering at $3.70	$0.0156
1 day superintendent at $3.25	0.0069
15 days labor at $2	0.0631
13½ hrs. finishers at 28 cts	0.0079
64 hrs. carpenters at 60 cts	0.0808
4 hrs. mason	0.0053
Total	$0.1796
Materials:	
Lumber	$0.0526
10-in. I-beams	0.1053
17½ bbls. cement at $1.35	0.0479
10 cu. yds. gravel at $1.65	0.0347
6 cu. yds. torpedo sand at $1.35	0.0170
Total	$0.2575
Grand total	$0.4371

Cost of Concrete Balcony Floors of the Lockport Power House, Chicago Drainage Canal.—In Engineering and Contracting, May 25, 1910, L. K. Sherman gives the following.

The work was done by day labor and consisted of placing the concrete in two balconies, one above the other, 359 ft. long by 26.5 wide. The steel frame and columns of the balcony floors was erected by contract.

Fig. 10 shows a section of the floor, which is composed of concrete arches covering the spans between the 18-in. I-beams and supported by the lower flanges of the I-beams. The floor arches were 5 ins. thick at the crown, with elliptical intrados. The concrete was mixed in the proportion of 1 part Portland cement, 2½ parts limestone screenings under ⅛-in. size, and 4½ parts crushed stone ranging from ¼ to 1¼ ins. The floor surface was made with a "granolithic" finish of mortar composed of 1 part cement to 2 parts torpedo sand, placed from 1 in. to 1½ ins. thick. The granolithic surface was invariably placed before the concrete had an initial set, although this required night work of the finishers at times. Contraction grooves were cut in the floor above each I-beam.

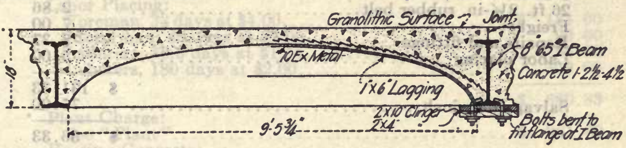


FIG. 10.—Section of balcony floor showing forms, Lockport Power House.

Concrete and Finishing.—The mixed concrete (1-2½-4½) was purchased from the general contractor for the power house at $5 per cu. yd. at the mixer.

The concrete was hauled from the mixer to the elevator in a 1½ cu. yd. Western dump car. The car was hoisted to the balcony floor, run out on a short piece of track and dumped on a receiving platform. The empty car then returned to the mixer. Concrete was carried from the receiving platform and placed in the work with wheelbarrows.

The mortar for granolithic surface was mixed in a box near the receiving platform. The cement finishers followed immediately after the concrete gang. The expanded metal reinforcement was placed on the forms and covered uniformly with about 2 ins. of soft concrete. The expanded metal was then pulled up from the form with hooks and shaken slightly, so that the mortar ran through the mesh and kept the reinforcing about 1 in. away from the lower surface.

The remaining concrete was then tamped in place. Some reinforcing bars were used about the floor openings. The work was done in February, March and April, 1907. Common labor received 17½ cts. per hour in February and March and 20 cts. per hour in April. During freezing weather heat was supplied with four salamanders burning coke. These fires were placed under the section of new concrete floor and canvas curtains were hung around, so as to confine the heat to the required section.

A typical force during the period of placing concrete work was as follows:

1 Foreman.
1 Motor man.
1 Car man.
1 Carpenter on reinforcing and minor form fitting.
1 Laborer on reinforcing and minor form fitting.
12 Laborers, wheeling and placing concrete.
2 Cement finishers on granolithic surface.
1 Mortar mixer on granolithic surface.
2 Mortar wheelers on granolithic surface.

Cost.—The cost of the work is given in the accompanying itemized tabulation. The total cost was \$7,827.50, or 42¾ cts. per square foot. The engineer's estimate was \$8,128. The only bid received was \$11,000.

PLANT

Elevator:	
Cage	\$ 44.00
Guides, lumber	37.62
400 ft. ½-in. wire rope and fittings	26.25
3 16-in. sheaves	26.40
1 ½-in. snatch block	12.00
Labor	43.55
	\$ 189.82
Hoisting winch:	
1 Shannon double purchase winch	\$ 100.00
1 42-in. wood pulley	8.10
26 ft. 2½-in. rubber belt	2.86
Freight	7.00
Repairs and fittings	8.37
Labor placing	5.00
	\$ 131.33
Salvage on winch	75.00
	\$ 56.33
Electric motor:	
Rent of motor 2 hp. 220-volt D. C.	\$ 25.94
Labor placing	5.71
Labor electrician	20.00
	\$ 51.65
Electric Current: 6 cts. hp. hour	76.58
Track:	
Rent of 300 lin. ft. rail 30-lb	\$ 25.00
Labor on track	28.38
	\$ 53.38
Grand total	427.76
Distribution of plant charge:	
To concrete \$427.76 × 85 % =	\$ 361.60
To granolithic surface \$427.76 × 15 % =	66.16
Total	\$ 427.76

COST OF BALCONY FLOORS

Forms:	
Lumber:	
11,000 B. M. 1 × 6-in. D. & M. lagging at \$25.00	\$ 275.00
2,220 B. M. 2 × 10-in. S. I. S. stringers at \$30.00	66.60
1,500 B. M. misc. rough lumber	28.19
316 ribs for 10-ft. span at 66 cts	208.56
99 ribs for 8-ft. span at 62 cts	61.38
48 ribs for 4-ft. span at 50.9 cts	24.42
	\$ 664.15
Bolts, tools etc.:	
1,000 ¾-in. hook bolts at 8 cts	\$ 80.00
9 kegs nails	24.58
Sheet iron	15.15
Tools	9.85
	\$ 129.58
Total form materials	\$ 793.73

Labor:	
Building and Moving Forms:	
Foreman, 29 days at $4.00	$ 116.00
Carpenters, 39.5 days at $4.50	177.75
Carpenters, 51.1 days at $3.50	178.85
Carpenters, 110.2 days at $3.00	330.60
Laborers, 66 days at $1.75	115.49
Laborers, 17.3 days at $2.00	34.60
Craneman, 1 day at $2.50	2.50
	$ 955.79
Total, Forms	$1,749.52
Concrete:	
470 cu. yds. concrete mixed material in car at mixer at $5.00	$2,350.00
Tools	56.61
	$2,406.61
Labor Placing:	
Foreman, 33 days at $4.00	$ 132.00
Motorman, 45 days at $2.00	90.00
Laborers, 56.5 days at $1.75	98.83
Laborers, 180 days at $2.00	360.00
	$ 680.83
Plant Charge:	
See "Plant"	$ 361.60
Heating Concrete:	
4 Salamanders	$ 11.00
2,450 lbs. coke	12.24
6 12 × 30-ft. tarpaulins	54.60
	$ 77.84
Concrete total	$3,526.88
Reinforcing:	
19,734 sq. ft. 3-in. No. 10 expanded metal at 3 cts.	$ 592.02
330 lbs. ½-in. cor. bars at 3 cts.	10.51
585 lbs. ¾-in. rods at 2½ cts.	14.63
Cutter and sledge	1.89
	$ 619.05
Labor:	
1 day, cement foreman at $5.00	5.00
11 days, cement foreman at $3.50	38.50
2 days, motorman at $2.00	4.00
7.6 days, laborer at $2.00	15.28
	$ 62.78
Reinforcing total	$ 681.83
Granolithic surface:	
Materials:	
260 bbls. cement at $1.72	$ 447.20
Cement hauling	21.33
90 cu. yds. sand torpedo	56.90
Sand freight	149.17
Tools	8.24
	$ 682.84
Labor:	
Cement finisher, 25.1 days at $5.00	$ 125.50
Cement finisher, 38.35 days at $3.50	134.22
Cement finisher, 20.05 days at $3.00	60.15
Cement finisher, 33.00 days at $2.25	74.25
Motorman, 11 days at $2.00	22.00
Laborers, 82 days at $2.00	169.00
Laborers, 46.4 days at $1.75	81.15
	$ 661.27

Plant charge:	
See "Plant"	$ 66.16
Granolithic total	$1,410.27
Finishing Ceiling.	
Labor:	
Cement finisher, 49 days at $5.00	$ 245.00
Cement finisher, 57 days at $3.50	199.50
Cement and brushes	14.50
	$ 459.00

SUMMARY

	Total cost		Cost in cents per sq. ft. of floor	
Forms, material	$ 793.73	....	4.36	......
Forms, labor	955.79	$1,749.52	5.21	9.57
Concrete, material and mixing	2,350.00	....	12.82	......
Concrete, placing	1,176.88	3,526.88	6.42	19.24
Reinforcing	....	681.81	3.73	3.73
Granolithic surface, plant and materials	749.00	....	4.08	......
Granolithic surface labor	661.27	1,410.27	3.62	7.70
Finishing ceiling	....	459.00	2.51	2.51
Total, 18,317 sq. ft	....	$7,827.50	.....	*42.75

* Cents.

Cost of 2-In. Solid Metal Lath Partitions.—The following data by A. Dixon are given in Engineering and Contracting, Jan. 18, 1911.

The figures on plastering are the amount of completed three coat work which one man can do in one hour and are based on the average of a gang of men and the total time required to apply three coats on a given area.

	12-in. stud centers	16-in stud centers
Steel channels, weight lb. per sq. yd	4.25	3.00
Erecting channels, sq. yds. per hour	6.0	9.0
Metal lath, applying, sq. yds. per hour	6.5	8.25
Plastering, three coats, sq. yds. covered per hour	1.25	1.25

Cost of Metal Lathing and Plastering.—The following data are published by A. Dixon in Engineering and Contracting, Feb. 1, 1911.

Applying metal lath on wooden studs: An expert on straight work will put on 12.5 to 17.0 sq. yds. per hour. On crooked or complicated work the same man will put on 5 to 7 sq. yds. per hour.

Applying metal lath on steel studding: One man will put on from 5 to 9 sq. yds. per hour.

Plastering on metal lath: First coat, from 9 to 14 sq. yds. per hour; second or scratch coat, 6 to 9 sq. yds. per hour; finishing coat, 11 to 14 sq. yds. per hour.

Cost of Laying Composition and Gravel Roofs.—H. Lundt, a roofing contractor (*Engineering and Contracting*, Apr. 12, 1911), states that the cheapest composition roof is 3-ply tar and gravel, using 45 lbs. of saturated felt, 70 lbs. of tar and pitch, ⅛ yd. of screened gravel, and lath and nails at a total cost for material of $1.50 per square, (10 × 10 ft.). The labor cost of the work varied from $0.40 to $1 per square, depending upon the number of squares in each job. It requires 4 men to each gang of roofers, common labor receiving 25 cts. and skilled labor 50 cts. per hour. This would make the total cost of a 3-ply composition roof with tar and gravel from $1.90 to $2.50 per square. This roof, for ordinary uses, will last from 5 to 8 years.

A better roof is a 4-ply composition roof laid in the same manner as a 3-ply, but having one extra ply or 15 lbs. more of saturated felt and 30 lbs. more of composition which will make the total cost from $2.50 to $3.00 per square. This class of roof will easily last 10 years.

The next better roof is the solid mopped roof with a cap sheet over the 4-ply, laid as follows: Each of the 4 layers of felt is mopped over the entire surface and laid 8 ins. to the weather. The entire surface is then covered with a cap sheet which is coated with the hot pitch compound. In this way every seam of the four layers is covered. Over all, the pitch and tar and screened gravel is laid. I have one of these roofs which has been laid 14 years without recoating. The cost of labor and material on this class of roof is $4 per square. The material used per square is 75 lbs. of saturated felt, 150 lbs. of composition, ⅛ cu. yd. of screened gravel and lath and nails.

Any of the foregoing roofs can be laid with asphalt in the same way that the tar and pitch composition is used. This will increase the cost from $0.75 to $1 per square. I put on some of these roofs 10 years ago and they are in good condition today. Asphalt retains its life, but the tar and pitch crumble to dust and require a recoating after about 5 years. The cost of recoating is about $1.50 per square. In recoating, all the loose gravel is swept off and the felt is cleaned of dirt and dust. Then the composition is placed with not less than 60 lbs. to the square.

Unit Costs of Factory Buildings.—A paper by W. E. King before the Civil Engineers Society of St. Paul (Engineering and Contracting, Aug. 5, 1914) gives the following:

One story shop building in fireproof construction will cost from $1.25 to $2.00 per sq. ft. depending upon the height of the story, depth of footings, length of spans and kinds of exterior finish used. Fireproof buildings of more than one story may be built for as little as 50 cts. per sq. ft. of floor area.

TABLE XX.—SOME COSTS OF DIFFERENT TYPES OF CONSTRUCTION

Item	Description	Approximate cost per sq. ft. in place
Roofs*		
Fireproof:		
	1. 3-in. hollow book-tiles laid on steel T-beams, covered with good prepared roofing; including supports	$0.30
	2. Corrugated iron on steel purlins including supports	0.12
Non Fireproof:		
	3. 2-in. matched and dressed sheathing laid on wood or steel purlins, covered with good prepared roofing, including supports	0.20
Walls	12-in. common brick	0.38
	12-in. with facing brick and some architectural decorations	0.40–0.60
Sash	Underwriters, glazed with ¼-in. wire glass	1.00
	Rolled steel sash glazed with double strength glass	0.40–0.45
	Double hung wooden sash	0.25–0.50
Sprinkler Protection		
	Cost per sq. ft. of floor area covered	0.05–0.15

* Types 1 and 3 suitable for heated buildings; type 2 suitable for unheated buildings.

Formulas for Weights of Steel Roof Trusses.—R. Fleming (Engineering News-Record, March 20, 1919) has brought to a common notation many of the empiric formulas for determining the weights of steel roof trusses.

The notations used follow:

T = weight of truss = WSD;

W = weight of truss in pounds per square foot of the horizontal projection of that portion of the roof supported by one truss;

S = span or distance between centers of supports in feet;

D = distance between centers of adjacent trusses in feet;

P = loading of truss in pounds per square feet of horizontal projection of roof;

U = allowable average direct stress in pounds per square inch (found only in the Thayer formula).

The following list includes the formulas most commonly quoted:

Cambria Steel Co., "Cambria Steel," 11th edition, 1914, for spans of 75 ft. or less.

$$T = 5SD$$

Carnegie Steel Co., "Pocket Companion," 19th edition, 1917, for loads of 40 lb. or more per square foot of ground area:

$$W = \frac{P}{40} \times \frac{1}{5}\left(\sqrt{S} + \frac{S}{8}\right)$$

Fowler, "Specifications for Steel Roofs and Buildings," 5th edition, 1909, for Fink trusses up to 200-ft. span:

$$W = 0.06S + 0.6 \text{ for heavy loads}$$
$$W = 0.04S + 0.4 \text{ for light loads}$$

Johnson, Bryan and Turnure, "Modern Framed Structures," early editions: $W = S/25 + 4.0$. In the latest edition, 1916, the Ricker, 1907, formula is used for trusses resting on brick walls, and the Ketchum formula for trusses of steel-frame buildings.

Jones & Laughlin, "Standard Steel Construction," 1916:

$$W = \frac{P}{40}\left(\frac{S}{20} + \frac{12}{D}\right)$$

Ketchum, "Specifications for Steel-Frame Buildings," 3rd edition, 1916 for trusses up to 150-ft. span:

$$W = \frac{P}{45}\left(1 + \frac{S}{5\sqrt{D}}\right)$$

Maurer, "Cyclopedia of Civil Engineering," 1908:

$$W = S/25 + 1$$

Merriman, "Roofs and Bridges," 1888, 1911:

$$T = \frac{3}{4}DS\left(1 + \frac{S}{10}\right)$$

Ricker, "A Study of Roof Trusses," University of Illinois Bulletin, No. 16, August, 1907:

$$W = \frac{S}{25} + \frac{S^2}{6000}$$

Ricker, "Design and Construction of Roofs," 1912:

$$W = \frac{S}{25} + \frac{S^2}{12,600}$$

Thayer, "Structural Design," Vol. II, 1914:

$$T = \sqrt{\frac{PD}{U}} (4S^2 + 60S)$$

Trautwine, "Engineer's Pocket Book," 1911:

$$W = (0.05 \text{ to } 0.08)S$$

Tyrrell, "Mill Buildings," 1911, for roof load of 40 lbs. per square foot of ground area, bays 10 to 20 ft., rafter slope 6 ins. to 1 ft. and unit stresses of 12,000 compression, 15,000 tension:

$$W = \frac{S}{20} + \frac{12}{D}$$

The weights of trusses for other loadings and rafter slopes are obtained from a series of curves.

Conclusions regarding empirical formulas drawn from estimated weights of several hundred trusses may prove interesting. Three light Fink trusses resting on brick walls of 40-, 60- and 80-ft. spans, bays 16 ft., load equivalent to 40 lbs. per square foot of horizontal area uniformly distributed on the top chord, roof slope 6 ins. per foot, weighed 1,370, 2,550 and 4,320 lbs., respectively. The estimated weights of three trusses of the Warren type, same span and loading, but roof slope of 1 in. per foot, were 1,500, 2,900 and 4,800 lbs. The weights, according to the formulas quoted, for trusses with same spans and loading, are given in Table XXI.

Table XXI.—Weights of Roof Trusses—16-foot Bays; Load, 40 Lbs. Per Square Foot of Horizontal Area

W = Weight per square foot of area; T = Weight of truss

Formula	40-ft. span W	40-ft. span T	60-ft. span W	60-ft. span T	80-ft. span W	80-ft. span T
Cambria	5.00	3,200	5.00	4,800	5.00	6,400
Carnegie	2.26	1,446	3.05	2,928	3.79	4,851
Fowler	2.00	1,280	2.80	2,688	3.60	4,608
Johnson B. & T.	5.60	3,584	6.40	6,144	7.20	9,216
Jones & Laughlin	2.75	1,760	3.75	3,600	4.75	6,080
Ketchum	2.67	1,709	3.56	3,417	4.44	5,683
Maurer	2.60	1,664	3.40	3,264	4.20	5,376
Merriman	3.75	2,400	5.25	5,040	6.75	8,640
Ricker 1907	1.87	1,197	3.00	2,880	4.27	5,466
Ricker 1912	1.73	1,107	2.68	2,573	3.71	4,749
Thayer	2.75	1,760	3.75	3,600	4.75	6,080
Trautwine	2.00	1,280	3.00	2,880	4.00	5,120
Tyrrell	2.75	1,760	3.75	3,600	4.75	6,080

Again, three Fink trusses of the same span, spacing and slope as before, but with load of 56 lbs. per square foot of horizontal projection, an increase of 40%, weighted 1,670, 3,200 and 5,500 lbs., respectively. Trusses of the Warren type, roof slope of 1 in. to 1 ft., weighted 1,900, 3,750 and 6,000 lbs. The formulas give weights for this loading as in Table XXII.

The variation—in some cases more than 100 per cent—of weights obtained from the different formulas will at once be noted. The values obtained from a number of the formulas depend upon the span length alone, and are the same for all loadings. Other formulas make the weight of the truss vary directly as the load, which actual weights show to be an error. DuBois, in "The Strains in Framed Structures," gives a formula taking into account the load, span, slope and unit stresses, but it is too cumbersome for use. Moreover, it supposes the chords to be of constant section, and neglects the web members, assuming that these two errors compensate.

TABLE XXII.—WEIGHTS OF ROOF TRUSSES—16-FOOT BAYS; LOAD, 56 LBS. PER SQUARE FOOT OF HORIZONTAL AREA

W = Weight per square foot of area; *T* = Weight of truss

Formula	40-ft. span *W*	40-ft. span *T*	60-ft. span *W*	60-ft. span *T*	80-ft. span *W*	80-ft. span *T*
Cambria	5.00	3,200	5.00	4,800	5.00	6,400
Carnegie	3.16	2,024	4.27	4,100	5.31	6,791
Fowler	3.00	1,920	4.20	4,032	5.40	6,912
Johnson, B. & T.	5.60	3,584	6.40	6,144	7.20	9,216
Jones & Laughlin	3.85	2,464	5.25	5,040	6.65	8,512
Ketchum	3.73	2,393	4.97	4,784	6.21	7,956
Maurer	2.60	1,664	3.40	3,264	4.20	5,376
Merriman	3.75	2,400	5.25	5,040	6.75	8,640
Ricker, 1907	1.87	1,197	3.00	2,880	4.27	5,465
Ricker, 1912	1.73	1,107	2.68	2,573	3.71	4,749
Thayer	3.26	2,082	4.44	4,259	5.62	7,193
Trautwine	2.60	1,664	3.90	3,744	5.20	6,656

In fact, as stated by Marburg, in "Framed Structures and Girders," the variables are so numerous that no formula, for the weights of roof trusses which is at once simple, accurate and generally applicable, can be devised. Such a formula is not necessary. In calculating stresses the weight of the truss is usually so small compared with the weight of the covering, the snow and the wind, that an error in its assumption is negligible.

Ordinary steel roof trusses on brick walls with roof slope of 6 in. to 1 ft. and an assumed load of 800 lbs. per linear foot of top chord, uniformly distributed, weigh from 30 to 75 lbs. per linear foot of span for spans up to 85 ft. For less slopes the weight may be from 5 to 25% more. For different loadings the variation in weight is usually from 25 to 75% of the variation in loading. It should be noted that the personal equation of the designer and the many factors entering into the weights of roof trusses may cause a variation of 5 to 25% in the same truss.

Formula and Table of Weights Steel Roof Trusses.—Marshall L. Murray gives the following data in Engineering and Contracting, June 25, 1919.

In the preparation of designs for steel-roof trusses for preliminary estimates for factory buildings, after several designs had been prepared and lists of material and estimates of cost had been made, the data on hand were used in several formulas for giving the weights of steel-roof trusses, in order to find one which would give results closely agreeing with the figured weights. If such a formula could be found it was intended to use it for purposes of preliminary estimates instead of taking time to prepare a design. But no one formula gave results which were considered satisfactory. It was observed that the Ricker formula

$$W = \left(\frac{S}{25} + \frac{S^2}{6{,}000}\right) SA,$$

gave results which were too low and the Ketchum formula,

$$W = \frac{P}{45}\left(1 + \frac{S}{5\sqrt{A}}\right) SA,$$

gave results too high to agree closely with our design data. In these formulas W equals total weight of truss; S equals span of truss in feet; A equals distance center to center of trusses in feet; P equals carrying capacity of truss in pounds per square foot of horizontal projection of roof.

After carefully studying the formulas and reading the explanation of the Ricker formula in University of Illinois Bulletin No. 16, and that of the Ketchum formula in the author's text book on Steel Mill Buildings, it occurred to the writer to combine the two formulas, thereby making use of the span factors in the Ricker formula and the center to center of truss factor and the variable load factor in the Ketchum formula. From the bulletin it seemed the carrying capacity of the trusses upon which the Ricker formula was based was about 50. Therefore the results obtained by using the data on hand with the Ricker formula were increased in the ratio of $\frac{P}{50}$, since the Ricker formula does not take into account the variable load P. These weights were then averaged with those obtained by the Ketchum formula, which considers the variable load P, and the final results agreed quite closely with the data on hand. The tentative formula then became

$$W = \left[\frac{\frac{P}{50}\left(\frac{S}{25} + \frac{S^2}{6{,}000}\right) + \frac{P}{45}\left(1 + \frac{S}{5\sqrt{A}}\right)}{2}\right]SA$$

For trial calculation the two factors $\frac{P}{50}$ and $\frac{P}{45}$ were averaged and made the same for both formulas. Then

$$W = \frac{1}{2} \times \frac{P}{47.5}\left(\frac{S}{25} + \frac{S^2}{6{,}000} + 1 + \frac{S}{5\sqrt{A}}\right)SA$$

After several trials with the slide rule the variable load factor was made $\frac{P}{92}$ instead of $\frac{P}{2 \times 47.5}$ or $\frac{P}{95}$, so as to agree with the figured weights. Therefore the formula finally derived was,

$$W = \frac{P}{92}\left(1 + \frac{S}{25} + \frac{S^2}{6{,}000} + \frac{S}{5\sqrt{A}}\right)SA$$

In order to try out the above formula it was applied to all trusses upon which we had the necessary data, and to others used as examples in text books and the results were remarkably close to the weights obtained from material lists. After finding that the formula was worth while the writer prepared the accompanying table to simplify its use. This was done by making P equal to unity and calculating the value of W for a series of values given to S and A. It will be noted this reduced to a simple multiplication the calculation necessary to find the weight of the steel roof truss, having given the span, distance center to center of trusses, and the carrying capacity of truss. The writer has found this table to be very useful and quite reliable in preparing preliminary estimates, and even as a check on weights figured from a design.

WEIGHTS OF STEEL ROOF TRUSSES

The table gives weight of truss for a capacity of 1 lb. To find total weight of truss, multiply value in table by capacity of truss in pounds = P.

	Span of truss in feet: Out to out of bearings = S																		
A*	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	110	120
6	4.6	6.8	9.4	12.5															
8	5.7	8.4	11.7	15.5	19.8	24.7	30.2												
10	6.8	10.2	13.9	18.3	23.5	29.3	35.8	42.9	50.8	59.4									
12			16.0	21.1	27.0	33.6	41.1	49.3	58.4	68.3	79.0	90.5							
14				23.8	30.5	37.9	45.6	55.6	65.8	76.9	89.0	102.0	116.0	131.3					
16					33.9	42.1	51.4	61.7	73.0	85.4	98.8	113.2	128.9	145.7	163.6	182.6	202.7		
18						46.3	55.4	67.7	80.1	93.7	108.5	124.1	141.4	160.2	179.5	200.4	222.5	271.1	
20							61.4	73.6	87.1	101.9	117.9	135.0	153.8	173.7	195.3	218.1	242.1	295.0	353.8
22								78.8	94.7	110.0	127.2	145.7	166.0	187.6	210.7	235.1	261.4	318.5	382.0
24										117.8	136.4	156.1	178.0	201.1	226.2	252.2	280.3	341.6	409.5
26												166.9	189.9	214.6	241.1	269.3	299.8	364.7	437.7
28														228.5	256.0	286.0	317.8	387.2	465.0
30															271.1	302.7	336.3	410.2	492.1

For general purposes, P = 60 lb.

* Distance C. to C. of trusses in feet = A.

Cost of Private Fire Protection Installations for Industrial Plants.—The following data are given by Leonard Metcalf in a paper before the American Water Works Ass'n. in 1913, abstracted in Engineering and Contracting, July 23, 1913.

A cotton mill having a value in buildings and machinery as follows:

Buildings, including foundations	$ 400,000
Machinery, engines, boilers, shafting, electrical and steam fittings, elevators, etc	900,000
Cost of mill	$1,300,000
Cost of fire protection equipment for this mill:	
Underground piping	2,600
Indicator post gates, valves, check valves, hydrants, etc	1,000
Fire pumps (2)	2,500
Suction supplies	1,000
Hose, hose houses, watchman's system and fire alarm	1,700
Automatic sprinklers and all inside piping	16,000
	$ 24,800
If suction reservoir has to be built, add	3,000
Total cost of fire protection equipment	$ 27,800

This is equivalent to 2.1 per cent of cost of buildings and machinery.

2nd: A smaller plant, where cost of protection is of necessity larger in proportion to cost of mill equipment:

Buildings, excluding foundations	$ 70,000
Machinery, etc., same as above	100,000
	$ 170,000
Cost of fire protection, as items above	6,200

This is equivalent to 3.7 per cent of cost of the buildings and machinery.

In these examples, if elevated tanks or reservoirs had been necessary, the fire protection would have been increased in cost correspondingly. They represent, however, fairly typical cases, but oftentimes difficult conditions add to the estimated cost further amounts from 15 to 20 per cent.

In general the cost of the fire protection equipment will be from 3 to 5 per cent of cost of the mill property.

The operating charges upon such an installation as that cited in the first illustration given above might be as follows:

	Per cent
Interest	6
Depreciation	2
Repairs	3
Supplies and miscellaneous	1½
Coal for use on Sundays and holidays	½
Extra labor on Sundays and holidays	½
Total	13½
Add administration and overhead charges	1½
Grand total upon the cost of the fire protection system	15

This would upon the cost of the fire equipment amount to approximately $4,170. If now the mutual insurance rate upon this property be added amounting to approximately 7 cts. per $100 of risk, or $910 per year, the total cost of the fire protection service and insurance, excluding the payment to be

TABLE XXIII.—DATA ON SAVING EFFECTED IN INSURANCE FOLLOWING THE INSTALLATION OF SPRINKLER SYSTEM

	A	B	C	D	E	F
Type of construction	Mill	Mill	Mill	Mill	Joisted brick	Fireproof
Occupancy	Leather storage	Mfg. of air products	Metal workers	Metal workers	Storage warehouse (merchandise)	Loft
Total floor area	144,000	25,000	72,000	48,000	23,800	42,800
Cost of sprinkler installation	$ 13,000	$ 2,550	$ 13,400	$ 6,000	....	$ 6,600
Cost of water supplies	1,650	2,450	4,600	2,000	....	2,500
Total cost	14,650	5,000	18,000	8,000	$ 4,700	9,100
Yearly charges—						
Interest and depreciation at 7¼ per cent	1,060	360	1,300	580	340	660
Maintenance	600*	600*	900*	900*	150	200
Total	1,660	960	2,200	1,480	490	860
Insurance carried on building and contents	460,000	285,000	500,000	200,000	80,000 (B) 1,000,000 (C)	200,000 (B) 250,000 (C)
Rate in dollars and cents per $100 per year—						
Before installing sprinklers in building	$ 0.71	$ 0.53	$ 0.71	$ 0.75	$ 0.17 (B) 0.20 (C)	$ 0.20 (B) 0.55 (C)
After installing sprinklers in building	0.17	0.09	0.12	0.07	0.11 (B) 0.8 (C)	0.084 (B) 0.22 (C)
Total insurance premiums—						
Before	3,260	$ 1,510	$ 3,550	$ 1,500	$ 136 (B) 2,000 (C)	$ 400 (B) 1,375 (C)
After	780	256	600	140	88 (B) 800 (C)	168 (B) 500 (C)
Saving—						
Amount	$ 2,480	$ 1,254	$ 2,950	$ 1,360	$ 1,248	$ 1,057
In per cent of cost of equipment	17 %	25 %	16 %	17 %	27 %	12 %
Cost of alternate water supply (1,500-gal. pump installed in separate pump house, also suction reservoir)	$ 3,500	$ 3,500	$ 3,500	$ 3,500	No city water	No city water

* Maintenance includes cost of night watchman; this service is taken in consideration in fixed final rate. Average yearly cost of maintenance, excluding watchman, is from 2 to 4 per cent of cost of system. (B) Stands for Building, (C) for Contents.

made to the waterworks for the water service, would amount to $5,080. Without the sprinkler service the rate upon such property in the stock insurance companies might be $1 per $100 of risk, in which case the saving effected would amount to approximately $8,000 per year. If the rate given by the stock companies were less than $1 per $100 of risk, the saving would be correspondingly reduced. It is probably safe to say, however, that the equipment would be paid for by the saving in insurance in a period of not over five to six years, if nominal charge only be made by the waterworks for the service rendered by it to the mill.

Data on Erection of Cantonment Buildings.—The following data on the construction of buildings at Camp Meade, Md., are abstracted in Engineering and Contracting, June 26, 1918, from a paper presented to Western Society of Engineers by N. B. Garver.

The construction of the buildings for training battalions designated as Regiment AA was determined upon Friday, Sept. 21. They consisted of:

32 2-story barracks, 30 by 60 feet.
8 1-story mess halls, 20 by 147 feet.
4 1-story officers' quarters, 20 by 133 feet.
1 2-story medical building, 20 by 119 feet.
2 1-stoıy store houses, 20 by 98 feet.
2 stables, 29 by 40 feet.
2 wagon sheds, 29 by 18 feet.
A total of 51 buildings.
The material required was:
2,108 posts.
1,490,000 ft. of yellow pine lumber
321,000 sq. ft. of building paper.
152,000 sq. ft. of roofing.
3,838 window sash.
304 doors.
136,400 sq. ft. of wall board.
782 sq. ft. of brick hearth.
30,514 pounds of nails.
2,184 lin. ft. of mess tables with seats were constructed.
1,600 lin. ft. of fire ladders were erected.

The hauling of posts, lumber, and other materials was begun on Saturday, Sept. 22. Actual construction began on Sunday, Sept. 23. A 10-hour workday was observed. Lumber erection was completed and the buildings were finished at 6 p. m., Oct. 2. Ten days, or 100 hours, was required to complete the 51 buildings of this regiment. Fifteen thousand feet of lumber was erected each working hour, and a building was completed every two hours.

The number of carpenter and labor hours required to complete each stage of construction of a 200-man barrack is as follows:

			Lumber ft. B. M.
Foundation posts	Carpenters	20 hrs.	
	Laborers	60 hrs.	1,000
Framing complete	Carpenters	375 hrs.	
	Laborers	72 hrs.	20,700
Sub-floors and roof	Carpenters	390 hrs.	
	Laborers	50 hrs.	19,400

Trim—			
Finished floors.			
Wainscoting.			
Inside and outside stairs.			
Doors	Carpenters	530 hrs.	
Sash	Laborers	85 hrs.	25,000
Partitions.			
Tables.			
Counters.			
Screening.			
Outside sheathing	Carpenters	450 hrs.	
	Laborers	40 hrs.	5,900
Wall board	Carpenters	320 hrs.	
	Laborers	40 hrs.	
Roofing felt	Carpenters	70 hrs.	
	Laborers	20 hrs.	
Undersheathing and ladders	Carpenters	60 hrs.	2,000
	Laborers	15 hrs.	
Total			74,000

Total carpenter hours on lumber erection, 1,825.
Total labor hours on lumber erection, 322.
Lumber erected per carpenter per day, 407 ft. B. M.
Carpenters received 62½ cts. per hour and laborers 30 cts. per hour.

Cost of Constructing a Camp to Accommodate Forty Laborers.—In Engineering and Contracting, July 2, 1913, Clark A. Bryan gives the following. The camp was built during the summer of 1912, to accommodate laborers employed on the construction of sewerage system and disposal plant at Ridgely, Md., and consisted of store and dining room, bunk house, cook shed, toilet and well. The following matter is taken from Mr. Bryan's article.

Store and Dining Room.—The building itself is 36 × 16 ft. in plan and is built with a gabled roof. The height from the top of the floor to the top of the plates is 7 ft. 3 ins. and the height of the gable is 4 ft. 6 ins., making the total height of the ridge 11 ft. 9 ins. above the floor. This building is divided into two rooms sized 11 ft. 6 ins. and 24 ft. 6 ins. respectively, the former being used as a store and the latter for a dining room. The sills were made of 4 × 6 in. lumber. The four corner posts were made of 3 × 4 in. material and the intermediate posts, of which there were two on each of the long sides, were spaced 11 ft. 6 ins. from each end of the building and were made of the same sized material. These upright 3 × 4 in. posts were all mortised into the plate, which was made of 4 × 4 in. material. To further brace the building a piece of 2 × 4 in. was run completely around the building between the uprights at a height of 3 ft. above the floor. The building was braced in the direction of its short dimension by running a piece of 2 × 4 in. material from the top of one of the intermediate posts to the top of the opposite post, these braces being set flush with the top of the plate. The rafters were nailed to the plate and were made of 2 × 4 in. material. There were 19 rafters on each side of the ridge and they were 10 ft. long, thereby overhanging the sides of the building by about 8 ins. To finish off the exposed ends of the rafters a piece of 1 × 5 in. material was nailed over their ends as a sort of trim. The purlins were laid at right angles to the rafters and nailed to them. They were spaced 1 ft. 6 in. on centers and a 1 × 3 in. lathing was used for this purpose; at the ridge four of these laths were used. For a roof corrugated iron weighing 115 lbs. per square was used and this was nailed directly to the purlins. By this method of construction a roof was built which provided plenty of ventilation, inasmuch as it was not tightly sheathed at the sides of the building, and yet rain could not enter the building through this space. The joists were 16 ft.

long and were made of 2 × 8 in. material; they were notched 3 ins. on the sills and a 1-in. floor was laid on them. The joists were spaced 1 ft. 6 ins. on centers. The sides were built of 1-in. rabbeted barn boards 10 ins. wide. A solid partition of this same material was built across the building, dividing it into two rooms 11 ft. 6 ins. and 25 ft. 6 ins., respectively. There were five windows each 2 ft. 6 ins. × 2 ft., and having six lights; four of these windows were in the dining-room or larger compartment and one in the store room. Three doors, each 2 ft. 9 ins. × 7 ft., were built, one being in the dining room and two in the store room. Table XXIV gives the bill of materials and cost of constructing this building.

Table XXIV.—Bill of Materials and Cost of Constructing Dining and Store Building for Workman's Camp

Items and size	Rate	Cost
104 lin. ft. sills, 4 × 6 ins.	$0.05	$ 5.70
100 lin. ft. posts, 3 × 4 ins.	0.0275	2.75
16 lin. ft. frames for doors, etc., 3 × 4 ins.	0.0275	0.56
104 lin. ft. plates, 4 × 4 ins.	0.03	3.12
104 lin. ft. braces, 2 × 4 ins.	0.015	1.56
32 lin. ft. braces at plate, 2 × 4 ins.	0.015	0.48
380 lin. ft. rafters, 2 × 4 ins.	0.015	5.70
432 lin. ft. purlins, 1 × 3 ins.	0.005	2.16
144 lin. ft. ridge, 1 × 3 ins.	0.005	0.72
36 lin. ft. ridge pole, 3 × 4 ins.	0.0275	1.00
416 lin. ft. joists (26 pieces 16-ft.), 2 × 8 ins.	0.028	11.70
576 sq. ft. flooring, 1-in.	0.025	14.40
782 sq. ft. barn boards in sides, 1 × 10 ins.	0.025	19.55
72 sq. ft. barn boards in gables, 1 × 10 ins.	0.03	2.16
150 sq. ft. barn boards in partition, 1 × 10 ins.	0.025	3.75
40 lin. ft. tin ridge	0.06	2.40
5 windows (six 8 × 10-in. lights), 2 ft. 6 ins. by 2 ft.	1.25	6.25
3 doors, 2 ft. 9 ins. by 7 ft.	0.90	2.70
2 mess tables, 16 ft. by 3 ft.	2.50	5.00
4 benches, 18 ft.	0.40	1.60
720 sq. ft. corrugated iron roof	0.046	33.85
90 lbs. wire nails	0.035	3.85
7 lbs. galvanized nails	0.06	0.42
3 pairs hinges (10-in. strap)	0.25	0.75
3 hooks and staples	0.05	0.15
2 hasps and staples	0.10	0.20
1 padlock	0.28	0.28
112 lin. ft. trim. 1 × 5 ins.	0.035	3.92
Total cost of materials		$135.28
Labor:		
14 hrs. foreman carpenter	$0.275	$ 3.85
66 hrs. carpenter	0.22	14.52
41.5 hrs. carpenter's helper	0.17	7.06
Total cost of labor		$ 25.45
Total cost of building		160.73

Bunk House.—This building is 50 × 14 ft. in plan and is built with a sloping roof. The building is placed with the long dimension parallel to the road leading to Ridgely and the height of the side facing this road is 9 ft. 6 ins., while the height of the rear is 6 ft. 6 ins. The house is divided into five compartments, each of which was designed to accommodate eight men. The sills were made out of 4 × 6-in. lumber, the four corner posts were made out of 3 × 4-in. material. The upright posts along the front and rear of the building were spaced 10 ft. on centers and made of the same sized material. The plate, which consisted of 2 × 4 in. material, was spiked to the tops of these uprights. The rafters rested on the plate and were spiked to it and were of 3 × 4-in. material. They were 16 ft. long and were spaced 2 ft. on centers, and overhung the sides of the building about 8 ins. As in the other building 1 × 3-in. lathing was used for purlins and spaced 1 ft. 6 ins. on centers. The roof was of corrugated iron weighing 115 lbs. per square and was nailed directly to the lathing. To finish off the ends of the rafters they were covered on the front and rear of the building by 5-in. dressed boards. By this method of construction a fresh air inlet 4 ins. high was provided along both front and rear of the building, yet rain could not enter through this space. This building was braced in a manner similar to that employed in the construction of the building previously described with the exception that the 2 × 4-in. braces running from the top of the plates were run level from the top of the rear plate and were spiked at the front to a piece of 2 × 4-in. material. The joists, floors and sides of this building were constructed as in the other and need no further comment. As stated, this building was divided into five compartments, each of which was 10 ft. wide, the compartments being separated by partitions of barn boards and each partition 6 ft. high. Each compartment was provided with a door placed at the front of the building, also with two windows, one in front and over the door, and the other at the rear. In this way complete ventilation of the building was obtained. Against each side of each compartment two tiers of bunks were built. The bunks were 3 ft. wide and extended the 14-ft. dimension of the building. The bottom tier of bunks

TABLE XXV.—BILL OF MATERIAL AND COST OF CONSTRUCTING BUNK HOUSE FOR WORKMAN'S CAMP

Items and siz	Rate	Cost
128 lin. ft. sills, 4 × 6 ins.	$0.05	$ 6.40
93 lin. ft. posts, 3 × 4 ins.	0.0275	2.56
65 lin. ft. frames for doors, etc. 3 × 4 ins.	0.0275	1.78
132 lin. ft. plates, 2 × 4 ins.	0.015	1.93
128 lin. ft. braces, 2 × 4 ins.	0.015	1.92
224 lin. ft. braces, at plate 2 × 4 ins.	0.015	3.36
416 lin. ft. rafters, 3 × 4 ins.	0.0275	11.44
650 lin. ft. purlins, 1 × 3 ins.	0.005	3.25
405 lin. ft. joists (27 pieces 16-ft.), 2 × 8 ins.	0.028	11.34
75 lin. ft. braces foot of posts, 3 × 4 ins.	0.0275	2.07
800 sq. ft. flooring, 1-in.	0.025	20.00
1,000 sq. ft. barn boards in sides, 1 × 10 ins.	0.025	25.00
336 sq. ft. barn boards in partitions, 1 × 10 ins.	0.025	8.40
500 sq. ft. barn boards in bunks proper, 1 × 10 ins.	0.025	12.50
60 lin. ft. 2 × 4-in. supports for bunks	0.015	0.90
50 lin. ft. braces, 2 × 4 ins., for bunks	0.015	0.75
132 lin. ft. trim, 1 × 5 ins.	0.035	4.62
10 windows (six 8, × 10-in. lights), 2 ft. 6 in. by 2 ft.	1.25	12.50
5 doors, (2 ft. 9 ins. by 6 ft.)	0.54	2.70
800 sq. ft. corrugated iron roof	0.046	36.80
108 lbs. wire nails	0.035	4.46
7 lbs. galvanized nails	0.06	0.42
6 prs. hinges (8-in. strap)	0.16	1.08
6 prs. hooks and staples	0.05	0.30
6 prs. hasps and staples	0.10	0.60
Total cost of materials		$177.28
Labor:		
24 hours foreman carpenter	$0.275	$ 6.60
95 hours carpenter	0.22	20.90
34 hours carpenter helper	0.17	5.95
Total cost of labor		$ 33.45
Total cost of building		210.73

was about 1 ft. above the floor, while the upper tier rested on the 2 × 4-in. brace that extended around the building. The bunks were supported at the center by means of a trestle consisting of two 2 × 4-in. posts 6 ft. long and spaced 6 ft. apart. The tops of these posts were connected by a piece of 2 × 4-in. material running longitudinally of the building, and were further braced by running 2 × 4-in. braces from the top of the rear plate over each post and spiking this brace to a piece of 2 × 4-in. material that ran across the front of the building. Nailed to these 2 × 4-in. posts and at heights of about 1 ft. and 3 ft. above the floor, respectively, were two pieces of 2 × 4-in. material 6 ft. long and upon these the bunks rested. The bunks were made of 1-in. barn board. Table XXV gives the bill of material used in the construction of this building and the cost of construction.

Cook Shed.—The shed provided for cooking purposes consisted simply of four upright posts about 7 ft. high, supporting a corrugated iron roof 12 ft. square. Under this shed the brick ovens used by the men to cook their food were prepared. The cost of constructing this shed is shown by Table XXVI.

TABLE XXVI.—COST OF COOK SHED

Items and size	Rate	Cost
40 lin. ft. corner posts 4 × 6 ins	$0.05	$ 2.00
Other lumber	......	1.00
144 sq. ft. corrugated iron roofing	0.046	6.63
Total cost of materials		$ 9.63
Labor:		
7 hours carpenter	$0.22	$ 1.54
Total cost of shed		$11.17

The toilet was built along lines typical of out-of-door toilets. It was 4 ft. square and was not roofed over. The total cost of the closet was $2.85. The following is a summary of the total cost of camp:

Combined dining room and store	$160.73
Bunk house or sleeping quarters	210.73
Cooking shed	11.17
Toilet	2.85
Well	10.55
Straw for bedding	5.00
Total cost of camp	$401.03

After the construction work on the sewer system had been finished the town of Ridgely purchased the building used as dining-room and store and remodeled it and made it into a barn. The bunk house and also the well were sold, the total amount received from these sales being $312.98 making the net cost of building the camp $88.05. As the camp was in use for a period of about eight months the net cost per month amounted to about $11.

The first cost of the camp, including a well for water supply and other accessories was $10 per man accommodated. The dining and store building cost just under 30 cts. and the bunk house just over 30 cts. per square foot of area.

Data on the Erection of Steel Work of the Shops of the Lima Locomotive Corp., Lima, Ohio.—Engineering News, May 7, 1914, gives the following:

The steelwork conforms in the Manufacturers Standard Specifications. It was given two coats of graphite paint, one applied in the shop and the other after erection.

All steel erection was done with four traveling stiff-leg derricks of 50 tons hoisting capacity, carrying booms 100 ft. long. These were of steel construction and the booms were long enough to place the roof trusses and monitor roof framing. The book tile for the roof of the erecting shop were handled by a platform elevator in the timber tower at the middle of the building. The steel gang numbered about 85 men. Work was commenced on Jan. 12 and completed Mar. 8, 1913. The tonnage and time of erection of the several steel buildings were as follows:

Building	Tons	Time of erection
Erecting shop	1200	26 days
Boiler shop	225	10 days
Smith shop	260	8 days
Hammer shop	253	6 days
Tank shop	300	7 days
Coal-pulverizing plant	20	10 days
Riveting tower	12	7 days

Cost of Erecting a Large Steel Dome.—In Engineering News, Mar. 8, 1917, M. Van Meter gives the following:

The 92-ft. dome of the Wealthy St. Baptist Church, Grand Rapids, Mich., has a steel frame formed by eight main arch members 35 ft. in span, with 19-ft. rise, framing into an octagonal crown diaphragm, 22 ft. wide across the points. The arches are tied together at the heel by four trusses and four sets of angle ties. This is because that portion of the building under the dome is square, and a part of the roof load is carried by the ties in alternate bays.

The arches are 2 ft. deep at the top and 5 ft. at the outer extremity. Three lines of beams parallel to the base ties carry the wooden ceiling and roof joists. The lateral bracing consists of a system of rods together with a line of struts in the center of each bay at right angles to the roof beams. A steel monitor frame 8 ft. high surmounts the structure.

The erection procedure was as follows: A derrick of the required height was raised, and the eight sides of the diaphragm were riveted up around its base. With two sets of blocks, the ring was raised to the final elevation, 45 ft. above the floor, and light timber falsework placed underneath. The arches were raised with a gin pole, bolted in place, and the base ties erected. The roof beams, struts and rods were then placed, rivets driven and supports removed. The entire job was completed without a mishap, the one anxiety being caused by the extraordinarily high winds that prevailed after the diaphragm was raised and before the timber falsework was finished.

The shop cost of this contract was $25 and the erection cost $28 per ton, with labor at 50 cts. per hour in each case.

Cost of Erecting Steelwork for an Armory Having Three-Hinged Arches.—The following data, taken from an article in Engineering and Contracting, Aug. 6, 1913, refer to the armory building of the University of Illinois.

When completed, this structure will have a clear drilling space of about 200 ft. by 390 ft. In 1913 the two end bays were not built, owing to a lack of appropriations. The width of the portion built is 206 ft., center to center of end pins, the length is 338 ft. center to center of end arches, and the height is 94 ft. 3 ins. from center of pin at the crown to a line connecting the end pins. The present structure has 13 bays, each 26 ft. long. The two future bays are each 26 ft. 6 ins. long.

The arches rest on masonry piers, and the horizontal thrust is taken up by tie rods which connect the end pins. These tie rods are encased in concrete to prevent corrosion.

Although the balcony was not provided at the time of erection the balcony girders were put in and provision made for connecting the future steelwork to them. Lateral bracing is placed in the end panels and in every alternate panel. The bracing in the sides of the building consists of 6 × 3½ × ⅜-in. angles, this bracing being omitted in the three center bays on account of the entrances.

The total weight of the steelwork for this armory was 985 tons. The weight of one three-hinged arch, complete with pins but exclusive of the eye-bar ties and the bases, was 37 tons. Each segment of the arch was shipped in four sections, the weights of these sections, beginning at the bottom, being 5¼ tons, 4¼ tons, 4 tons, and 5 tons. The arches rested on cast bases, each base being anchored to its footing with two 1¼-in. rods 2 ft. long. There are 15,400 ⅞-in. diameter field rivets and 14,900 ¾-in. diameter field rivets in the structure.

Contractor's Equipment.—The contractor's equipment included a large traveling derrick, two riveting outfits, an air compressor plant, an office, block-and-tackle apparatus and ropes for guiding the arches during erection, etc.

On account of the size and weight of the arches, a special traveling derrick was used. It was formed by mounting parts of two stiff-leg derricks on a steel tower, which in turn rested on rollers. One of the legs was taken off of each stiff-leg derrick, and the remaining portion was braced together as shown in the drawing. Heavy bracing was required to give the required rigidity to the tower. The tower was 37 ft. 6¼ ins. by 38 ft. 4 ins. by 32 ft. high. A platform placed on the lower sills of the tower carried the two hoisting engines. These engines were placed at the rear to assist in anchoring the tower, although considerable additional anchorage was required. One hoisting engine was used to operate each boom. The booms could be moved independently, or both could be moved at the same time. The height of the masts was 40 ft., the length of each stiff-leg was 56 ft., and the length of each boom was 90 ft., thus the height and reach of the booms was sufficient to reach any part of an erected arch. The boom had a 17-in. sheave and a 2-in. shaft at the top. Quadruple blocks were used. The masts were fitted with 13-in. sheaves and 1½-in. shafts at both top and bottom. The booms used on this work had three 30-ft. sections, although their total lengths could be changed by substituting sections of different lengths. The total weight of the traveler was about 26 tons, and each hoisting engine had a capacity of about 35 tons.

Method of Erection.—The footings were first put in place, and trenches were dug for the tie rods. The traveler was then shipped to the site and erected. As has been previously mentioned, each segment of the arch was shipped in four parts. These sections were hauled to the site on wagons. The derrick then picked up these parts and placed them on the ground in their proper positions. They were then assembled and riveted together. In the meantime, the cast bases were set on the footings, and the tie rods were laid in the trenches.

Time Account and Cost Data.—About two weeks were required to erect the traveler and to get the equipment in good order. On an average two arches were erected per week. Sometimes as many as three arches were erected in a week, but it was necessary to assemble a segment and rivet the four parts together before it could be erected and this required considerable time. Work was started putting up the traveler on Jan. 20, 1913, and about two weeks later the erection of the steelwork was started. One riveting gang started on Feb. 17 and another on Feb. 24. They finished riveting the first panel on March 1. The men started to take down the traveler on March 22.

The superintendent and the two foremen of the riveting gangs, each received 80½ cts. per hour, the two engineers for the hoisting engines and the engineer for the air compressor received 72½ cts. per hour, the men working on the steel erection 68 cts. per hour, several laborers 25 cts. per hour, and one boy received 20 cts. per hour.

Although the greatest number of men at work at any time was 44, about 75 different ones were employed by the contractor before the work was completed.

The following is a summary of costs and weights:

Total cost of erecting traveler (labor)	$ 634.63
Total cost of erecting steelwork (labor)	4,379.84
Total cost of taking down traveler (labor)	422.47
Total cost of field riveting (labor)	3,969.38
Total cost for erecting and field riveting	9,406.32
Total weight of steel in structure (tons)	985
There were 15, 400 ⅞-in. and 14, 900 ¾-in. field rivets driven, a total of	30,300
Cost of erecting steel (per ton)	$ 9.55
Cost of driving field rivets (cents each)	13.1

Prices of Water for Building Purposes.—Engineering and Contracting, April 11, 1917, gives the following data. The following schedule of rates is in force at Johnstown, N. Y., for water used for construction purposes:

Plastering per 100 yd	25 cts.
Brick per 1, 000	4 cts.
Stone per cu. yd	2 cts.

The supply must be specially applied for, and permission obtained from City Clerk for each separate building, job or piece of work, and paid for at the time application is made for the permit.

The rates at Detroit, Mich., are:

Brick per 1, 000	$0.05
Plaster per 100 sq. yd	.07
Concrete per 100 cu. yd	1.00
Concrete 6 in. thick or less per 100 sq. yd	.20
Tile per 100 cu. ft	.05
Each perch stone	.01

Cost of Manufacturing Concrete Roof Tile.—D. Helmuth (Concrete, Oct., 1919) gives the following:

The size of the tile is 9-in. by 14¾ in. By concentrating efforts on labor saving devices the output of the machines was increased from 250 tiles each man per day to 600.

To quote Mr. Helmuth:

We make our tile on the well-known hand-operated type of machine. We figure a profit of 8% on our entire investment, and from June and July, 1919, figures, it works out as follows:

Cement, per bbl., $2.32, at the mixer.

Washed sand, either river or bank—that is, practically free from loam—at $1.33 per ton, at the mixer.

Pure red and brown color, $0.17 per lb., unmixed.

Tile made on a piece-work basis, at 1 ct. per tile.

The operators have the mix brought to the machine, as well as the pallets, all ready and oiled, and the tile removed from the pallets, for the tile operator, by a laborer that costs us 60 cts. per hour.

A first-class man to make special pieces, at 70 cts. per hour.

Figure 8% as a charge on a capital investment of $50,000.

Water, light, power, heat, factory and office rentals, and every conceivable overhead necessary today in the operation of a modern business that requires about this amount of capital are charged up.

Everybody in the unit is an expert man.

Results—Tile produced and stacked in the yard for 4 cts a piece, or $6.00 per square, counting 150 pieces to a square.

Cost of Concrete Block Manufacture.—S. H. Wightman, in Engineering World, Sept., 1920, gives the following cost analysis made by him in March, 1920.

Quality of block which will stand 1500 lbs. per sq. in. in 28 days

Average capacity per day, 1000 8 by 8 by 16—300 days = 300,000 per year.

Average cost of factory building, $5000. Wood. (For modern plant add $10,000.)

Average cost of equipment, $10,000. (See schedule "A.")

Average cost working capital, $10,000.

FACTORY PRODUCTION COSTS

	Day	Cost per block
Cement—12 blocks to a bag at $2.40 per bbl. net		$0.0505
Loss on cement bags .06 cts. bbl.		
Sand and gravel—50 blocks per cu. yd. at $3 yd		.06
Productive labor—1 Machine operator	$ 8.50	
1 Off bearer	8.00	
1 Mixer man	8.00	
2 Men stocking, etc.	7.50	
	7.50	
1 Cement and gravel	7.00	
	$46.50	.0465
Total per block		.01570

FACTORY OVERHEAD

Non-productive (indirect labor)	Day	
Supt. and general overseer	$10.00	
Extra all around man	8.00	
Night man	7.00	
	$25.00	$0.023
Coal, 1 ton per week @ $8.40 per ton		.0014
Oil, water and light, $1.70 per day		.0017
Power, $2.50 per day		.0025
Repairs and maintenance, materials $9 per week		.0015
Factory expenses, freight & cartage $6 per week		.001
Depreciation on equipment (15% on $10,000 = $5 per day)		.005
Depreciation on buildings (5% on $5,000 = .833 per day)		.00083
Breakage in manufacturing blocks per day at .28 cts. = $5.60 per day		.0056
Workingmen's compensation, 4% of $72.50 per day = $2.90		.0029
Total per block		$0.04542

DELIVERY AND SALES

Loading blocks	$0.008
Freight and cartage out	.035
Extra cartage, Delivery breakage, Commission, Adjustments, Service, Estimates, Advertising	.001
Net discounts on sales 2 % = $7 per day	.007
Total per block	$0.051

EXECUTIVE OVERHEAD

General manager (owner) $5000 year = $16.66 per day	$0.01666
Office expense, $1 per day	.001
Taxes	.0005
Insurance, building equipments and materials	.0005
Interest on loans, $5000 at 6 %	.001
Loss on bad accounts, $300 per year	.001
Rent on land, $100 month	.004
Total per block	$0.02466

SCHEDULE "A"

EQUIPMENT TO MAKE 300,000 BLOCKS PER YEAR

Block machines and attachments	$ 3,200.00
40 Block cars	1,600.00
Tracks, ties and transfers	500.00
Pallets	1,000.00
2 Mixers	500.00
Gravity conveyor	100.00
Boiler	400.00
Piping and heating	200.00
Motor, 10 horsepower	250.00
Wiring	200.00
Millwright installation material	480.00
Office equipment	185.00
Tool and factory supplies	400.00
Bag bundling machine	35.00
Drawings	350.00
General expense	600.00
Total	$10,000.00

From this analysis it may be assumed that good block will cost 29 cts. to manufacture and if sold at 35 cts. each will yield a profit of 17% on the gross sales. As the quantities of materials are stated and other units of labor given any one can substitute local prices for those given, change the total accordingly and arrive at what should be the cost prices in any district. Needless to say, a fair profit should be added to total manufacturing and selling costs.

Costs of Upkeep and Repairs on a Large Building.—Walter R. Metz in Engineering News-Record, Aug. 5, 1920, gives the following:

The costs as given cover a group of ten buildings all connected together but not all under one roof. The main building is seven stories high and the other buildings are from four to six stories high. All of the buildings were designed for heavy loads and heavy machinery and are used for a printing plant. The floors in the main building were designed for loads of 300 lb. per sq. ft. and in the other buildings 200 lb. per sq. ft.

Costs have been given for each year from 1912 to 1919 inclusive and indicates the gradually increased cost of both labor and materials.

Floors.—All floors were leveled up with concrete and finished with hard maple blocks 2½ × 12 × ⅞ in., cut with interlocking grooves and projections on the sides and near the lower faces of the blocks. These blocks were dipped so as to coat the under side with hot bituminous mastic and applied to the concrete, which had been previously prepared by giving it a coat of bituminous varnish. The total area of the floors, in round numbers, is 250,600 sq. ft.

Year	Labor	Material	Total	Cost per square
1919	$2,387.69	$267.48	$2,655.17	$1.06
1918	2,787.91	132.57	2,920.48	1.16
1917	2,454.53	202.30	2,656.83	1.06
1916	1,178.37	125.31	1,303.68	.52
1915	1,058.33	99.01	1,167.34	.46
1914	1,005.17	57.86	1,063.03	.42
1913	1,336.54	95.87	1,432.41	.57
1912	1,055.09	121.59	1,176.68	.47

Roof.—The roof is of reinforced-concrete slabs supported by steel beams. It was finished with flat vitrified tiles, laid on a base of Neufchatel asphalt mastic. The mastic was applied in two coats with a layer of fine wire netting between to serve as a bond. Each tile was stuck fast to the mastic with a spoonful of bituminous cement. The inclination of the roof is about 1 to 7. This is rather steep for tiles on an asphalt base but the whole roof has stood up remarkably well. The total area of the tile roofing is 50,700 sq. ft.

Year	Labor	Materials	Total	Cost per square
1919	$ 726.91	$ 16.20	$ 743.11	$1.46
1918	2,038.80	459.96	2,478.76	4.88
1917	392.38	12.82	405.20	.79
1916	643.78	166.03	809.81	1.59
1915	102.13	4.95	107.08	.21
1914	657.96	89.33	747.29	1.47
1913	493.70	36.94	476.64	.94
1912	239.11	28.54	267.65	.52

Steam Heating.—The total volume of the main building is 7,600,000 cu. ft. The system of heating is the direct-indirect, the coils being placed in pockets under the windows with dampers for admitting fresh air and baffles for deflecting the air to the floor, whence it would have to rise through the coils. The total radiation is 70,000 sq. ft., consisting of 694 steam coils and 35 cast-iron radiators. The ratio of heating surface to the volume of the building is 108.

In addition to this there is approximately 30,000 sq. ft. of radiation in coils in the other buildings, making the total radiation approximately 100,000 sq. ft.

Year	Labor	Material	Total	Cost per 100 sq. ft. of radiation
1919	$3,928.23	$ 601.46	$4,529.69	$4.53
1918	2,631.21	2,000.38	4,631.59	4.63
1917	3,823.02	523.04	4,346.06	4.34
1916	3,183.45	694.11	3,877.56	3.87
1915	2,635.52	222.35	2,857.87	2.85
1914	2,643.43	399.83	3,043.26	3.04
1913	2,870.56	480.71	3,351.27	3.35
1912	2,436.34	343.97	2,780.31	2.78

Plaster.—Plaster on ceilings was applied to a concrete surface and three coats of plaster were applied. The first and second coats were heavily gaged with portland cement, the idea being to secure a hard plaster. Around beams the plaster was applied to wire mesh. The plaster was rather thick and it is believed it would have lasted better if it had been applied thinner, say about ¾ in. thick. The plaster on practically every beam either fell or had to be removed after about eight or ten years' use, but that on the ceilings is still in good shape although about 18 years old. The total area of plastered surface is approximately 360,000 sq. ft.

Year	Labor	Material	Total	Cost per square
1919	$ 993.63	$ 21.83	$1,015.46	$0.28
1918	62.61	......	62.61	.017
1917	9,026.52	956.49	9,983.01	2.77
1916	2,659.62	409.81	3,069.43	.85
1915	681.68	51.66	733.34	.20
1914	466.66	3.59	470.25	.13
1913	858.77	38.44	897.21	.24
1912	578.42	96.47	674.89	.18

Doors.—There are 223 doors of all sizes and types in the buildings, single-acting hinged office doors, double-acting, plain sliding, and automatic sliding fire doors. These doors receive very hard usage and need constant attention. Practically all of the double-acting doors have wire glass in the upper panels.

Year	Labor	Material	Total	Cost per door
1919	$564.58	$109.18	$ 673.76	$3.02
1918	883.44	182.91	1,066.35	4.78
1917	598.88	185.03	783.91	3.51
1916	910.38	224.22	1,134.60	5 08
1915	691.04	148.46	839.50	3.76
1914	855.72	143.85	1,099.57	4.93
1913	440.42	130.28	570.70	2.56
1912	435.80	142.81	578.61	2.59

Windows.—There are 2,290 windows in the buildings, most of them of the double-hung sliding type with a few of the hinged type. Glass sizes vary from 12 × 18 in. to 36 × 50 in.

Year	Labor	Material	Total	Cost per window
1919	$593.67	$220.26	$ 713.93	$0.31
1918	794.70	294.87	1,089.57	.47
1917	486.97	161.72	648.69	.28
1916	729.51	191.99	921.50	.40
1915	421.47	76.46	497.93	.21
1914	758.72	168.70	927.42	.40
1913	474.50	108.95	583.45	.25
1912	564.12	174.40	738.52	.32

Plumbing.—Fixtures in the building consist of 240 water closets, 338 wash-basins, 90 urinals, 21 slop sinks, 120 drinking fountains, 80 fire hose and racks. The repairs includes, of course, repairs to the necessary piping as well as to repairs to fixtures. It is difficult to find any unit basis so total amounts only are given.

Year	Labor	Material	Total
1919	$5,304.63	$406.08	$5,810.71
1918	5,309.31	352.87	5,662.18
1917	4,530.09	556 05	5,086.14
1916	3,291.66	464.90	3,756.56
1915	2,974.87	237.93	3,212.80
1914	2,941.40	238.95	3,180.35
1913	2,738.26	395.26	3,133.52
1912	2,250.82	160.36	2,411.18

Depreciation of Office Buildings.—(Engineering and Contracting, Dec. 25, 1918.) After much research work in many leading cities the committee on Taxation of the National Association of Building Owners and Managers has reached the conclusion that the minimum annual depreciation of normal office buildings is 3 per cent of actual building cost for each of the first ten years, 2.5 per cent for the second 10 years, 2 per cent for the third 10 years, and thereafter doubtful. These figures are given by H. J. Burton, chairman of the committee, in a report to the Government Advisory Council of Real Estate Interests. The report also states:

"The best authorities consider that there is a steady and inevitable annual depreciation ranging from 1.5 to 2 per cent for the structural portion of the average modern office building, and from 7 to 10 per cent per annum for the mechanical plant and equipment. This makes the annual depreciation of the combined structure and plant 3.2 per cent per annum.

"The obsolescence of the ornamental and finishing work and of the architectural plan, which reduces the competitive earning capacity of the building, should also be allowed, and should be differentiated from the obsolescence or decadence of the location, which is reflected in the reduced land values."

CHAPTER XXIV

ENGINEERING, SURVEYING AND OVERHEAD COSTS

References.—Further data on cost of surveying are given in Gillette's "Handbook of Cost Data." Chapter I of "Mechanical and Electrical Cost Data" by Gillette and Dana contains many data on overhead and engineering costs.

Schedule of Charges for Engineering Services.—Engineering and Contracting, March 13, 1918, gives the following abstract of a paper by Edmund T. Perkins presented at the 1918 annual meeting of Illinois Society of Engineers.

The various services rendered are classified as follows, and are generally charged for on a percentage basis, except surveying which should be per diem.

1—Reconnaissance.
2—Preliminary reports.
3—Surveying.
4—Plans and specifications.
5—Details.
6—Supervision and progress estimates.
7—Superintendence.
8—Alterations.
9—Professional advice.
10—Consultation.
11—Court work or arbitration.

Reconnaissance work is necessary when no data, or incomplete data, have been secured, and is preliminary to general planning of project and securing of data.

Preliminary reports are made when the necessary data on which the report is based have been secured of such detail and accuracy as to permit of proper advice being given or design made.

Surveying covers every class of field work which is not a part of reconnaissance work. It includes all location lines for roads, canals, railroads, etc., all level lines, all sinking of wells or experiment work, besides all classes of land surveying and land subdivision, and compensation therefore should be on a salary or per diem basis with expenses paid.

Plans and specifications are required as the basis for letting of contracts or for the information of the owner, employer or consulting engineer, and afford a full description of the work. They are implied by the necessities of the work even when not required by the owner, and include an estimate of the cost of the work. Plans, when adopted and approved, must be so endorsed by both owner and engineer.

Details are not always an essential of the construction work, and the rate charged, therefore, is flexible, varying with the amount of detail work.

Supervision and the making of progress estimates should always be required, that the engineer responsible for the plans and specifications should be satisfied, by personal inspection that the specifications are fully complied with and satisfactory progress made. When superintendence is paid for, as defined in the next section, there is no additional charge for supervision.

Superintendence of construction must be had by a superintendent mutually acceptable to owner and engineer. The schedule rate for superintendence applies when the engineer who has designed and planned the work, or his assistant, superintends construction. All other employes than such assistant or assistants are to be paid by the owner.

Alterations may be required at any time by the owner, or become necessary by reason of unforeseen conditions or changes in the size of projects. The schedule rate applies to such alterations as may be required by the owner—alterations becoming necessary by reason of unforeseen condition or accidents are covered by percentage charges on the aggregate costs.

Professional advice is always charged for according to interests involved, charges being based on value of services rendered, not on time required in arriving at conclusions or opinions.

Consultation with engineers who have made certain branches of professional work a specialty may be requested by the engineer having general charge of the work, or may be required by the owner. Charges for consultation work being based on value of services rendered, not on time required in arriving at conclusion or opinion.

Court work as an expert or as arbitrator in settlement of controversies, condemnation proceedings, etc., in the interest of the owner, is entitled to additional pay at a rate to be agreed upon.

Schedule rates cover compensation only for engineering services: that is, the services of the engineer and his engineer assistants.

All expenses incurred for materials, blue prints, or for transportation, hire of helpers, rodmen, chainmen, teamsters, conveyances, and living expenses when away from regular place of business, are a separate and additional charge against the owner, as is a reasonable charge for general office expenses.

Time of payment is according to agreement; but usually is arranged on the basis of a preliminary payment, or retainer, and an advance for traveling or other expenses aside from services; and further payments on account, if the commission extends over considerable time.

Final pay for preliminary reports is due upon presentation of report.

Final pay for reconnaissance work is due upon completion of same.

Pay for supervision or superintendence becomes due on progress estimates made for payments to contractors, or, if work is done by day labor, on monthly appraisements of work done.

All percentages are computed on the contract price or actual cost of work.

When construction covered by plans and specifications is not carried out, pay for these plans and specifications is due upon completion of the estimate of cost of work.

The several items of payment on the percentage basis become due from time to time when the class of service has been rendered.

Per diem rates apply to an 8-hour day. Extra time is charged for on a basis of 1½ time on week days, and twice time on Sundays and legal holidays.

TABLE OF CHARGES—ON PERCENTAGE BASIS

	Less than $5,000	$5,000 to $10,000	$10,000 to $20,000	$20,000 to $50,000	$50,000 to $100,000	$100,000 to $200,000	$200,000 to $500,000	Over $500,000
	%	%	%	%	%	%	%	%
Reconnaissance	2.0	1.75	1.5	1.0	0.75	0.5	0.4	0.3
Preliminaries	1.5	1.0	0.8	0.6	0.5	0.4	0.3	0.2
Plans and specifications	4.0	3.5	3.0	2.5	2.0	1.5	1.3	1.2
* Supervision	2.0	1.8	1.5	1.3	1.1	1.0	0.8	0.6
* Superintendence	5.0	4.5	4.0	3.5	3.5	3.0	2.8	2.4
† Alterations	7.0	6.5	6.0	5.5	5.0	4.5	4.0	3.5
Everything from beginning to completion of job	12.5	10.75	9.3	7.9	7.4	6.0	5.3	4.2

* Supervision not charged for when superintendence is.

† Alteration relates only to value of work involved in the alteration.

NOTE.—Percentages are computed upon the entire cost of the completed work, exclusive of engineering, or upon the estimated cost pending execution or completion of same. "Cost" refers only to such part or parts of the whole work or project as the engineer may deal with.

TABLE OF CHARGES—ON PER DIEM BASIS

Chief engineer—$500 retaining fee, $100 per day while absent from office and expenses.

Assistant chief engineer—$50 a day while absent from office and expenses.

Topographers, assistant engineers and chiefs of parties—$15 to $25 a day while absent from office and expenses.

Designers—$12.50 a day while absent from office and expenses.

Instrument men, draftsmen, computers—$7.50 a day while absent from office and expenses.

Stenographers, chainmen, axmen—$3.50 a day.

NOTE.—Attendance at court or expert testimony for any fraction of a day is considered as a full day.

Charges on Other Bases.—A fixed fee for services rendered may be charged by agreement where a long engagement for professional services is contemplated; the engineer may accept such retainers on a yearly basis, at a compensation not less than that of the permanently employed engineer of the client. Except in cases where the compensation of the engineer is in the form of an annual retainer, the agreement between the engineer and his client should specify the period of time during which the compensation of the engineer, as determined by per diem charges, fixed fee, or agreed percentages, shall apply. If, through no fault of the engineer, the work should not be completed within the time so specified, an additional charge may be made, the basis for which, if practicable, should be agreed upon in advance.

Mahoning Valley Engineers' Schedule of Fees.—The Mahoning Valley, Ohio, engineers, have a standard fee schedule. The schedule, as given in the 1918 report of the Committee of Standard Fees of the Iowa Engineering Society is abstracted in Engineering and Contracting, Jan. 22, 1918, as follows:

Per Diem Rate.—Consultation, opinion, testimony, preliminary investigation, reports, and consulting capacity upon design, minimum, $25 per day. (While absent from city, attending court, or similar duties, or traveling, each day of 24 hours, or fraction thereof shall be considered as one day irrespective of the actual time spent on the case. Otherwise seven hours shall constitute one day.) For examination or reports of an extensive nature covering several days, minimum, $15 per day. Engineer in charge of field work, minimum,

$10 per day. Assistants, classed as instrumentman of party, minimum, $5 per day. Assistants, classed as rodmen, chainmen, etc., minimum $3.50 per day. Inspector on paving, sewer, etc., minimum, $3.50 per day. Minimum charge for field work, $10. To all the above an additional charge will be made to cover actual expense, including $10. Residence lot, minimum charge, $10.

Office Work.—Calculating, draughting, etc., $10 per day. Minimum charge, $2.50. Minimum charge for one map, $5. Engineer to retain original drawings, but to furnish one print copy to client and if plat is for public record one copy on tracing cloth in addition. Additional copies to be furnished client at cost.

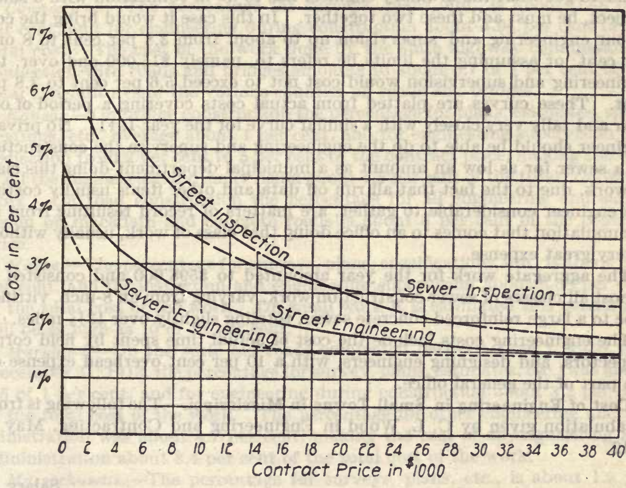


FIG. 1.

Percentage of Cost.—Engineering and supervision for sewer district or system, or disposal plant, minimum:

Contracts under $3,000, per diem rate. Contracts under $30,000: First $15,000, 8 per cent of estimate. Second $15,000, 7½ per cent of estimate.

For Paving.—Contracts under $3,000, per diem rate. Contracts under $30,000: First $15,000, 7 per cent of cost. Second $15,000, 6½ per cent of cost. Client to pay for one inspector on percentage work.

The above rates are a base for contracts with a reasonable time limit in the contract and all overtime to be based on the per diem rate.

Cost of Engineering and Inspection on Street and Sewer Construction in Spokane, Wash.—Fig. 1, given in Engineering and Contracting, July 9, 1913, shows the cost of engineering and inspection on sewer construction and street improvement work in Spokane, Wash., during the year 1912. It will be noted that four curves are given on the diagram showing, respectively, the cost of street engineering, street inspection, sewer engineering and sewer inspection.

The cost of the engineering and inspection is stated as a percentage of the contract price.

In Engineering and Contracting, Aug. 20, 1913, a letter from Alexander Potter commenting on Fig. 1 and a reply by Morton Macartney, City Engineer of Spokane, Wash. are given. The following is taken from Mr. Macartney's reply.

Relative to the diagram giving engineering costs on sewer and street work in Spokane during 1912, I beg to state that, while I agree thoroughly with Mr. Potter, that no engineer in private practice can afford to do sewer engineering and supervision for much less than from 5 to 7 per cent, you will notice that (in Fig. 1) we have segregated our inspection from our engineering, and in order to get what the ordinary engineer has to do in connection with a sewer project, he must add these two together. In this case it would bring the cost of our engineering and supervision up to about from 3.8 per cent to 8 or 9 per cent; or assuming the limits he refers to, namely $15,000 and over, the engineering and supervision would cost not to exceed 5.6 per cent to 3.8 per cent. These curves are platted from actual costs covering a period of one year and tally very closely with a similar curve for the year 1911. No private engineer should be able to do the engineering and supervise the construction of a sewer for as low an amount as a municipal department doing this class of work, due to the fact that all run off data and other items usually costing the engineer considerable to gather, are matters of record resulting from an accumulation that comes to an office doing that class of work, usually without a very great expense.

The aggregate work for the year amounted to $598,000 and consisted of almost all classes of sewer construction work, varying from an 8-inch, vitrified pipe to a large reinforced concrete sewer, totaling slightly over 13½ miles.

The engineering costs include the cost of actual time spent by field corps, inspectors, and designing engineers, with a 10 per cent overhead expense on the part of the general office.

Cost of Engineering in Small Towns in Mississippi.—The following is from a tabulation given by C. L. Wood in Engineering and Contracting, May 1, 1912.

Type of work	Town	Amount of Contract	Engineering Cost, %	Salary Equivalent of Percentage
Street grading, storm drains and brick gutters.........	Newton	$ 8,000	6.6	$125.00
Macadam and storm sewers and sidewalks............	West Point	35,000	4.0	166.67
Storm sewers, concrete curb and gutter................	Columbus	8,000	7.0	166.67
Concrete sidewalk............	Booneville	15,000	3.5	150.00
Macadam paving...........	West Point	6,200	7.3	....

Cost of Engineering on Sewage Disposal Plant.—Richard Gould in giving the costs of the Dallas Sewage Disposal Plant, Engineering News-Record July 5th, 1917, states that the total cost of the plant was $571,575 of which $36,962 was for engineering, or about 6.48%.

Cost of Engineering Supervision in Road Work.—Engineering and Contracting, May 17, 1916, gives the following abstract from a paper before the Pan American Road Congress by Lamar Cobb.

Based on inquiries addressed to state road officials the following data were amassed relating to cost of engineering supervision:

Alabama.—Bulletin No. 4 shows that in twenty counties the percentage for plans and surveys was about 3 per cent and for engineering during construction the percentage was about 5.9 per cent of the total cost of construction. The cost of all engineering work would be, therefore, about 8.9 per cent of the total cost of construction. The administrative charges are not shown.

Arizona.—The percentage for plans and surveys is 4.6 per cent and for engineering and inspection during construction 4 per cent, or total engineering and inspection, 8.6 per cent, based on total cost of construction and engineering. The cost of executive and administration is 3.6 per cent, making grand total overhead expenses 12.2 per cent.

Connecticut.—The percentage for surveys, plans, etc., is about 0.88 of 1 per cent, and for engineering during construction about 4.94 per cent of the total cost. The cost of the work done by the state highway commission in connection with roads and bridges amounts to about 0.7 of 1 per cent of the total expenditures of the various counties on roads and bridges.

Kansas.—On bridge construction the percentage for plans, estimates, specifications, etc., average about 1 per cent, and for engineering supervision and inspection from 2 per cent to 5 per cent of the contract price, making the cost of all the engineering and supervision about 4.5 per cent of the total cost of the work. On road construction the percentage for all engineering and supervision on macadam and concrete roads is about 8 per cent of the contract price.

Maine.—The percentage for surveys, plans, specifications, etc., is about 2.27 per cent, and for inspection and engineering supervision about 3.58 per cent of the total cost of the work. On small work it is estimated this percentage will be as high as 10 or 11 per cent.

Maryland.—On the state aid roads completed between June 1, 1910, and December 31, 1913, the percentage for survey, plans, estimates, etc., was about 0.5 of 1 per cent, and for engineering during construction about 3.2 per cent of the total cost of the work. The percentage for other engineering and administration was about 4.7 per cent, making the cost of all engineering and administration about 8.4 per cent of the total cost of the work.

Massachusetts.—The percentage for surveys, plans, etc., is about 1.9 per cent, and for engineering during construction about 4.5 per cent of the total cost of the work. The cost of administration is about 1.2 per cent, making the cost of all engineering and administration about 7.6 per cent of the total cost of the work.

Minnesota.—For the year 1914 all the expenditures for engineering and supervision amounted to about 5½ per cent of the total cost of the work done. Mr. Geo. W. Cooley, state engineer, states that he believes this amount to be smaller than is desirable. He believes very nearly 10 per cent is necessary for actual close supervision.

New Jersey.—On twenty pieces of work the average percentage for surveys, plans, etc., was 1.8 per cent and for other engineering was 4.1 per cent, making the cost of all engineering about 5.9 per cent of the total cost of the work. The cost of administration was not given.

New Mexico.—On bridge construction the expenditures for engineering and inspection amount to about 3 per cent of the total cost. On road construction the expenditure for engineering and inspection amount to about 5.2 per cent, and for administration and office engineering about 7.42 per cent of the total cost of the work. The cost of all engineering and administration on road construction would be about 12.62 per cent of the total cost of the work.

New York.—The report of the Commissioner of Highways for 1914 shows about 11.2 per cent of the total expenditures to be for engineering and inspection and about 3 per cent for administration, making the cost of all engineering and administration about 14.2 per cent of the total expenditures.

North Carolina.—The information available covers a few roads only and shows that about 4.06 per cent of the total cost of the work was expended for engineering and inspection. The administration charges appear to be in addition to the above.

Ohio.—Bulletin No. 22 shows that about 5.71 per cent of the total cost of road construction was expended for engineering. The cost of administration appears to be in addition to the above.

Oregon.—Upon various pieces of work reported for year ending November 30, 1914, the cost of engineering varies from about 4 per cent to about 9.4 per cent of the total cost of the work. The cost of administration is not shown separately.

Pennsylvania.—The report for the year 1913–14 shows the expenditures for engineering and inspection on completed contracts to be about 5.6 per cent of the total cost and for administration about 1.4 per cent, making the cost of all engineering and administration about 7 per cent of the total cost of the work.

Rhode Island.—On paved roads the expenditures for surveys, plans, specifications, etc., amount to about 2 per cent and for engineering and inspection about 2 per cent of the total cost of the work. The percentage for administration amounts to about 5 per cent, making the cost of all engineering and administration about 9 per cent of the cost of the work.

Virginia.—The expenditures for all engineering and inspection amounted to about 5 per cent of the total cost of construction in 1914. The commissioner states, however, that in his opinion a larger percentage would result in a substantial saving to the state.

Wisconsin.—In 1914 all overhead charges, including engineering and administration were slightly under 5 per cent on road construction. The inspector on the work is, however, charged to construction. The cost of preparing plans etc., for bridge construction was about 2.8 per cent of the cost of construction.

Engineering Cost of County Road and Bridge Work, Iowa (Engineering and Contracting, Sept. 4, 1918).—The total expenditure for road and bridge work in Iowa in 1917, according to County Engineers' reports, was $15,165,476, an increase of $828,420 over the amount for the previous year. Of the total, $7,466,797 was for bridges, $3,588,338 for county roads and $4,140,340 for township roads. The total expenditures for the three previous years were: 1916, $14,337,056; 1915, $13,525,617; 1914, $11,601,000. The percentage of engineering cost for the four years, according to the Service Bulletin of the Iowa Highway Commission, was as follows:

	Per cent			
	1914	1915	1916	1917
County engineering	2.85	2.75	2.53	2.58
Highway commission	.64	.60	.63	.59
Total all engineering	3.49	3.35	3.10	3.17

Cost of Engineering Supervision, Ohio Highway Department (Engineering and Contracting, Nov. 18, 1914.)—A publication of the Ohio Highway Department states that the cost of engineering supervision of road and bridge construction work by the department has been as follows:

Year	Percentage of total cost
1914	4.03
1912 and 1913	5.71
1911 and 1912	6.18
1910 and 1911	6.40
1909 and 1910	5.39
1908 and 1909	5.43
1907 and 1908	5.28
1906 and 1907	7.55

During the current year the state will have expended $3,150,000 and the counties $3,450,000, a total of $6,600,000 in the construction of their system.

Cost of Engineering on Maine Highway Work (Engineering and Contracting, Feb. 7, 1917.)—The cost of engineering by the Maine State Highway Department for 23 gravel road contracts let in 1914 was 6.10 per cent, according to an article by Irwin W. Barbour, assistant engineer, in the December Cornell Civil Engineer. This percentage does not include office administration. Itemized the percentage is:

	Per cent
Surveys	1.02
Plans and computations	.96
Advertising	.04
Engineering during construction	4.11

The roads were located in 16 towns and aggregated 80.11 miles. The total cost was $525,383, the percentages for the various class of work being:

	Per cent
Grading	33.77
Drainage	10.35
Surfacing	39.77
Culverts	8.43
Guard rails	1.55

Division of Costs of $18,000,000 Worth of Highways.—Engineering Record, Oct. 28, 1916 gives the following:

With the expenditure of the last of the $18,000,000 which was authorized in California in 1909 for the construction of trunk highways, the highway commission has been able to show a road system laid out in complete detail with finished roads in every part of the state on those routes where the immediate need was the most urgent. The aggregate mileage completed includes 966 miles of oil-surfaced concrete pavement, 129 miles of oiled macadam and 395 miles of graded dirt road.

Costs Summarized.—A review of the costs and notable features of the work accomplished by the commission, from which the following has been taken, was recently prepared for California Automobile Association by Eric Wold, who was retained for that purpose. His résumé of the commission's statement of expenses shows the following figures:

Construction cost:	
Payments on contracts, materials and day labor work........	$14,284,552.11
Equipment (1.15 per cent of construction cost):	
Expenditures of all classes of equipment and furniture......	164,394.46
Expenses (16.64 per cent of construction cost):	
Expenditures for engineering, legal accounting, purchasing, laboratory, services and expenses incidental thereto.......	2,372,757.41
Total expenditure to June 15, 1916..................	$16,821,703.98
Total amount available from state highway fund......	18,000,000.00
Unexpended balance June 15, 1916..................	$ 1,178,296.02

Since June 15, 1916, at which time the foregoing figures were brought up to date, the commission has obligated itself for the expenditure of approximately the entire balance remaining out of the original $18,000,000.

A general survey of 175 contracts under which the commission has let highway construction work developed the following average prices, which include the cost of material:

Excavation, including clearing right-of-way, shaping and finishing of roadbed, watering and rolling, per cu. yd..........................	$0.41
4-in. concrete pavement, per sq. yd..............................	.738
1½-in. asphalt wearing surface, per sq. yd..........................	.45
⅜-in. oil top, per sq. yd..................................	.054

A total of 2,350 miles of road was surveyed at a cost of $744,957, or $317 per mile. Of this total only 1,490 miles have been constructed, as before stated, so that the cost of locating ready for construction about 860 miles of highway is included in the expenditures made to date. This mileage of survey on which construction was not undertaken was necessary because of the difficulty and delay in securing certain necessary rights-of-way which forced the commission to construct disconnected lengths of road.

The handling and delivery of all materials used on construction were undertaken by the commission, and the overhead charge of 10 to 20 per cent of the net cost of the contract, which is usually allowed for this item, was borne by the commission and is included in the commission's expenses. A summary of the equipment which the commission purchased to carry on this work is as follows:

CALIFORNIA ROAD-BUILDING EQUIPMENT

Equipment	Cost	Per cent salvage	Salvage
Sand plants..........................	$ 27,259.19	100	$ 27,259.19
Construction equipment...............	21,257.49	100	21,257.49
Engineering equipment................	25,716.10	50	12,858.05
Furniture............................	21,328.05	40	8,531.22
Stable...............................	17,070.99	100	17,070.99
Auto.................................	41,380.55	40	16,552.22
Camp.................................	6,429.32	20	1,285.87
Laboratory...........................	3,952.74	50	1,976.35
	$164,394.43		$106,791.38

Therefore the 17.79 per cent of the total expenditure, which is shown in the first table as gross overhead, includes in reality salvable equipment, surveys (the advantage of which has not yet been realized), and other minor items, such as designs, supervision, etc., given gratis to counties undertaking independent road work. The net overhead chargeable to the construction work on the roads actually built, including allowance for these items, amounts to 12.75 per cent of the gross construction costs, which is considered a very reasonable allowance for net overhead on public work of this character.

Cost of Engineering on a Million Dollar Road Project (Engineering and Contracting, April 3, 1918).—The building of 178 miles of roads for McClennan County, Texas, cost $1,075,000 for construction and engineering, of which $35,156, or about 4.6 per cent, was for engineering. This is slightly less than $200 per mile. There were 110 miles of gravel roads, 63 miles of macadam (waterbound) and 5 miles of concrete. The work was done by contract under the direction of the county engineer, Rollen J. Windrow, of Waco, Texas.

The following are the itemized percentages of the total cost of the engineering:

	Per cent
Preliminary surveys	0.28
Office expense	0.61
Transportation (including first cost of motor cars)	0.39
Field engineering and inspection on construction	2.04
Checking gravel and stone	0.85
County engineer's salary	0.41
Total engineering	4.58

The preliminary surveys, inclusive of making plans and estimates, involved surveying 20.3 miles of line, which was done at a cost of less than $15 a mile, inclusive of expense accounts. The salaries, however, were low, being only $90 a month for transitman, $75 for levelman and $50 for the other men.

The office expense covered office supplies and the salaries of a bridge designer at $125, a chief clerk (who was an engineer) at $100, an assistant clerk (also an engineer) at $75 and a stenographer at $50.

More than half a million tons of gravel and stone were used, and, as they were furnished by the county to the contractors, the cost of checking the quantities was treated as an engineering expense, which amounted to 0.85 per cent of the total cost, or 1.8 cts. per ton.

The cost of engineering on this road project was unusually low, perhaps half what such costs average in northern states; but the salaries were low and the construction was fairly continuous, the project being completed within two years.

The Cost of Measuring Base Lines.—In Engineering News, Mar. 16, 1911, a paper by Wm. Bowie, Inspector of Geodetic Work for the Coast and Geodetic Survey, and Chief of its Computing Division, read before the Washington Philosophical Society, explains the changes which have been made on the Coast Survey in the substitution of tapes and wires in place of bars. At the 1914 annual meeting of the American Association for the Advancement of Science, at Atlanta, a paper was again presented by Mr. Bowie in which he more fully covered this subject. The following is from Engineering News, Feb. 19, 1914.

According to Mr. Bowie, not since the beginning of the present century has the Survey made use of the old bar method for measuring its base lines. This change of practice, however, has not been fully appreciated by the textbook writers at least, as treatises on surveying published in recent years describe the use of bars as if they were still a practical tool of the engineer. Mr. Bowie concludes his paper with the remark that base-line measurement bars from now on should be found only in museums and deserve a prominent place only in the history of geodetic surveying.

Cost.—With the modern invar tapes or wires the cost of base-line measurements by a survey party averages only about $50 per kilometer. The work is of a high degree of accuracy, quite comparable with that obtained by bar measurement. This means that in any geodetic triangulation net, base lines can be introduced with much greater frequency, so that in order to secure a given degree of accuracy it is not necessary to introduce so much refinement in measuring the angles of the triangles.

The invar tapes used by the Coast Survey have proved to be much less susceptible to injury in the course of use, resulting in change of length, than was at first anticipated. Mr. Bowie gives values for the constancy of length of four invar tapes used on the Coast Survey, showing that the total range in value during four years for the four tapes varied from one part in 170,000 to one part in 410,000. The difference in length between the values resulting from the length when first standardized and when last standardized varied from one part in 170,000 to one part in 1,110,000. Another great advantage in the use of tapes over bars is that they can be handled by comparatively unskilled persons. In a party of six assigned to base-line measurements, only one or two of its members need to be experts in base-line work, a very different condition from that prevailing with the micrometer bars formerly used.

Cost of Surveys for Federal Aid Roads Project in Kansas.—The following figures, given by E. L. Hageman in Engineering and Contracting, Sept. 3, 1919, relate to surveys made in the early part of 1918 for a Federal Aid road project in Labette county, Kansas. The work covered approximately 44 miles of highway, divided into four sections, as follows: Section A, 9.25 miles; B, 10.1 miles; C, 10.83 miles; D, 13.91 miles.

The transitman received $100 per month until May 1st, excepting two days due to a change of transitmen. From June 12th to June 27th, the transitman received $150 per month. The helpers received $2 per day until March 1st, when they were paid $3 per day. The time was derived from the actual number of days worked, as the helpers were working by the day and the transitman worked in the office during inclement weather.

A cheap cloth tape which had been removed from its case and the free end allowed to drag on the ground was used in measuring, it being impractical to be continually rolling and unrolling the tape. The tape was much easier to handle in this way and being inexpensive the time saved more than offset the additional cost.

Bench levels for Section A were started on Jan. 23 and completed on Feb. 5. The following is a summary of the work for the four sections:

Section	Error of closure	Error of closure-mile	Distance between B. M's., ft.	Length of shots, ft.	Miles-day	Miles of road checked, day	Length of circuit
"A"	0.032	0.0060	1,113	324	2.11	1.85	2.31
"B"	0.036	0.0059	1.532	513	2.66	2.34	2.90
"C"	0.026	0.0059	1.196	352	2.32	2.32	2.17
"D"	0.047	0.0241	1,677	331	2.20	2.02	1.60
	0.141	0.0419	5,518	1,520	9.29	8.53	8.98
Average	0.036	0.0105	1,380	380	2.32	2.15	2.245

The result of inexperienced help is clearly shown in Section "A" under miles per day. The effect of rough, hilly country is also shown in Section "D" under miles per day, and error of closure. The slower progress made on Section "A" was due in part to disagreeable weather. Sections "B" and "C," over which progress was more rapid, are similar in topography to "A." Three circuits were re-run, and two additional circuits have poor closures but were not rechecked, owing to the limited time in which to finish the survey, this being another cause of the poor closures in Section "D."

Center line surveys on Section A were started on Feb. 6 and completed Feb. 15. A summary of this work for the four sections follows:

Section	No. of miles/day	Length of shots, ft.
"A"	1.16	1,815
"B"	1.44	1,624
"C"	1.67	1,518
"D"	1.46	1,295
	5.73	6,352
Average	1.43	1,588

Section "A" shows the least number of miles per day as in bench levels and for the same reasons as stated before; the rate would have been proportionately smaller had it not been for the longer shots. In the same manner the shorter shots in Section "D" retarded the work.

Cross sectioning was started on Section A on Feb. 11 and finished Feb. 28. The following is a summary for all the sections:

Section	Error of closure	Length of foresights and back-sights	No. of miles / day	No. of shots / day
"A"	0.033	272	1.23	570
"B"	0.066	327	1.56	732
"C"	0.027	302	1.48	713
"D"	0.063	298	1.66	639
	0.189	1,199	5.93	2,654
Average	0.047	300	1.48	664

As before, Section "A" indicates a slower rate of progress, while Section "D" shows the best progress, which can be partly attributed to the fact that less shots were taken per distance traveled than upon the other sections. Rainy weather retarded progress appreciably on Section "C." The closures on Sections "A" and "C" compare very well with the bench level closures for the same sections. This would seem to indicate that an accurate line of levels can be run in connection with the cross sectioning by using the necessary precautions. The larger errors accumulated in Sections "B" and "D" are attributed to inaccuracies resulting from too fast work.

The labor cost of the surveys was as follows:

BENCH LEVELS

Section	No. of days	No. of men	Rate	Total	Cost per mile
"A"	5	1	$3.85	$19.25	.....
		1	2.00	10.00	$3.16
"B"	4⅓	1	3.85	16.68	.....
		1	3.00	13.00	2.94
"C"	4.66	1	3.85	17.94	.....
	2.0	1	2.00	4.00	.....
	3.66	1	3.00	7.98	2.76
"D"	2.0	1	3.85	7.70	.....
	4.87	1	4.81	23.42	.....
	6.87	1	3.00	20.61	3.00

CENTERLINE

Section	No. of days	No. of men	Rate	Total	Cost per mile
"A"	8	1	$3.85	$30.80	.....
		2	2.00	32.00	$7.01
"B"	7	1	3.85	26.95	
		2	3.00	42.00	6.83
"C"	6½	1	3.85	25.03	
		2	3.00	39.00	5.91
"D"	9½	1	4.81	45.70	
		2	3.00	57.00	7.38

CROSS SECTIONS

Section	No. of days	No. of men	Rate	Total	Cost per mile
"A"	7½	1	$3.85	$28.88	.....
		2	2.00	30.00	$6.37
"B"	6½	1	3.85	25.03	.....
		2	3.00	39.00	6.34
"C"	7⅓	2	3.00	34.00	.....
	1	1	4.81	4.81	.....
	6⅓	1	3.85	24.38	5.83
"D"	7.79	1	5.77	44.93	.....
		2	3.00	46.74	7.08

An automobile was used on the survey for five months. The total miles traveled in the survey was estimated at 2,187. This number was arrived at by taking the distance to the center of the road and multiplying it by twice the number of trips, some days there being two trips out and back when the party came in at noon.

The total expense of running the car for the five months was $133.89, less one-eighth the amount the car was used for other purposes, = $133.89 − $16.74 = $116.95. Depreciation = $385 (cost price) − $200 (selling price) = $185. The car had been out nine months when the survey began, was used on the survey five months and had been in use 21 months when sold. The amount of the total depreciation charged to the use of the car during the survey was one-third, or $61.66. The total expense of car was $178.61 for 2,187 miles or $0.082 per mile.

The instruments and materials used on the surveys were as follows:

BENCH LEVELS

	Cost	Depreciation	Amount
Level and rod	$ 50.00	2½ %	$ 1.25
Field books and pencils	....	.....	1.15
			2.40

CENTER LINES

	Cost	Depreciation	Amount
Stakes	$ 57.15	.....	$57.15
Transit	150.00	5 %	7.50
Axe	1.00	50 %	.50
Tape	5.44	15 %	.82
2 cloth tapes	5.00	25 %	1.25
Field books and pencils	2.25	....	2.25
Flag poles	6.00	5 %	.25
Kiel	1.00	....	1.00
Nails	.25	....	.25
			$70.97

CROSS SECTIONS

	Cost	Depreciation	Amount
Level and rod	$ 50.00	2½ %	$ 1.25
Field books and pencils	2.25	.....	2.25
4 cloth tapes	4.00	.....	4.00
			$ 7.50

This gives a total of $80.37 or 3.697 cts. per mile.

Allowing for one-fourth time of the County Engineer for 5 months at $166.66 per month gives a cost of $208.33 divided by 2,187 miles or 9.5 cts. per mile. Figuring in this cost the totals for the surveys were:

	Bench levels	Center lines	Cross sections
Labor	$130.58	$300.48	$277.77
Car	47.64	67.24	46.50
Instruments and materials	2.40	70.97	7.50
County engineer	55.20	77.90	44.02
Totals	$235.82	$516.59	$424.44
Cost per mile	$ 5.35	$ 11.72	$ 9.84

The labor cost of preparing the plans follows:

County engineer, ¼th time from Feb. 1 to July 1, 1918 at $833.33	$ 208.33
County engineer, ⅐th time from Jan. 1 to July 1 1919	142.86
County engineer, ½ time from July 1 to Aug. 15 1919	125.00
Assistant engineer, 45½ days at $3.80	157.64
Assistant engineer, 2 months at $125	250.00
Assistant engineer, 1 month a $125	125.00
Assistant, 7 weeks, at $150 per month	258.61
Assistant, 4 days at $4.17	16.88
Assistant, 6 days at $3.70	33.50
Assistant, 9 days at $5	45.00
Assistant, 3 months at $150	450.00
Assistant, ¼th time for 3 months at	131.25
Miscellaneous help	55.22
Total	$1,999.89

As the surveys covered 44.09 miles of highway, the labor cost of preparing the plans was $45.36 per mile.

The cost of supplies and use of office equipment for plans was as follows:

Ink, pencils, erasers, etc.	$ 5.00
Value of office fixtures, drawing instruments, etc., $300.30; depreciation at 4 % or	12.01
Total	$17.07

On the basis of 44.09 miles of road this gives a cost of $0.39 per mile.

The cost of blue print paper was 11 cts. per sheet; the cost of printing, trimming and binding was 14 cts., making the total cost per sheet 25 cts. Materials as follows were used in preparing the plans for the four sections:

216 sheets blue print paper at 25 cts.	$ 54.00
90 sq. yds. plain profile cloth at 70 cts.	63.00
90 sq. yds. cross section paper at 20 cts.	18.00
11.7 sq. yds. tracing cloth at 37 cts.	43.29
Total 44.09 miles of road at $4.05	$178.29

This gives a cost of $4.05 per mile of road for the blue prints.

The cost of the plans was $48.22 per mile, and the cost of the surveys was $26.69 per mile, giving a total cost of $74.91 per mile.

Cost of Road Surveys, Missouri.—In Engineering and Contracting, March 3, 1920, C. O. Sandstrom, in commenting on the law of Missouri fixing the price of road surveys and plans at $100 per mile, says that in one instance on a 22-mile job an engineering firm broke even at $225 a mile and on another job of 29 miles a small profit was made at $175 a mile. The high cost in the first case was caused by breakage in an organization. In both jobs, the design of culverts and bridges up to 20-ft. span were included.

Cost of Highway Surveys, Pennsylvania.—Engineering and Contracting, Aug. 19, 1914 gives the following record of the State Highway Department of Pennsylvania.

Cost of Surveying About 9, 000 Miles of Highway in Pennsylvania

Item	Total	Cost per mile
Surveying main line	$442,597.98	$ 47.87
Plotting main line	72,432.79	11.36
Checking and tracing main line	8,717.79	7.97
Surveying alternate line	15,461.22	50.45
Miles surveyed, main line		8,827.91
Miles plotted, main line		6,373.81
Miles checked and traced, main line		1,094.40
Miles surveyed, alternate line		306.36

Cost of Road Surveys and Plans (Engineering and Contracting, March 7, 1917).—The cost of road surveys and plans made by the forces of the Wisconsin Highway Commission between Aug. 15, 1915, and July 1, 1916, under survey contracts with counties averaged $24.79 per mile. The figures in more detail, according to the Third Biennial Report of the Commission, are as follows:

	Surveys made	Plans completed
Miles	894.27	706.69
Cost per mile	$ 7.98	$ 16.81

The cost of Isolated Road Surveys (Engineering News-Record, Oct. 4, 1917).—Since 1913 the State Highway Department of Illinois has made more than 400 preliminary surveys of roads under conditions which have made the comparative cost rather high, although the actual cost of $26.40 is but a small item of the final cost of the road and insignificant in comparison to the cost of errors that might have resulted from less careful surveys—or no surveys at all. This work was done on roads in short and entirely disconnected sections. As a result the cost of transporting men to and from the intersections was large in proportion to the amount of work accomplished after they had arrived at the work.

All of this work was preliminary in its nature, some of the surveys being made in prairie land and some in rough country. Altogether nearly 1,100 miles of road were surveyed at an average cost of $26.40 per mile. The average rate was 0.84 miles per day and the average length surveyed was 2.66 miles.

A typical party consisted of two engineers at $4 a day, three helpers at $2.50, and a team at $3. Such incidentals as transportation, board, lodging and supplies brought the total cost per day to nearly $25, and while this figure is less than the cost for similar work done by a private engineer, it does not include such charges as office expenses and profits.

Cost of Location of Mountain Roads.—Will R. White, Chief Engineer of the State Highway Department of Washington, in a paper before the 1912 American Road Congress, abstracted in Engineering and Contracting, Oct. 30, 1912, gives the following:

Costs.—Our location for mountain work should cost us from $150 to $300 per mile. These prices are for work in charge of competent engineers. Some of the work has cost us more, due to inexperienced engineers. Those not familiar with our mountains will think this cost excessive, but when you stop to consider that it is so brushy that it is necessary to have three or more axmen to average a mile of preliminary line a day, the same party averaging a half mile of location a day, you can get some idea of the expense.

Our location parties usually consist of complete transit, level and topographical crews. The camp outfit with the cook make 15 men to the party. In most cases the provisions can be hauled to them, but in some instances pack trains are required. Our final locations are usually made from contours taken from preliminary lines. In the settled districts and in the open country of Eastern Washington the cost of location will range as low as $50 per mile.

Methods and Costs of Some Extensive Railroad Surveys.—Early in 1902 the Little Kanawha Railroad began surveys for extensions eastward from Palestine to Belington, W. Va., and westward from Parkersburg, W. Va., to Zanesville, Ohio, and about a year and a half later for a line northward from Belington to the Pennsylvania-West Virginia State line. These surveys required the running of 1,400 miles of preliminary and 600 miles of located lines, and the methods used and the cost of the work were presented by W. S. McFetridge in a paper before the A. S. C. E., on May 19, 1909. The following notes are taken from an abstract of the paper in Engineering Record, June 5, 1909.

The surveys were conducted under the following charters: Zanesville, Marietta & Parkersburg Railroad, in Ohio; Parkersburg Bridge & Terminal Railroad, from the Ohio-West Virginia State line to Parkersburg (this division included a bridge over the Ohio River a few miles below Parkersburg); Little Kanawha Railroad, from Parkersburg to Burnsville; Burnsville & Eastern Railroad, from Burnsville to Belington; Buckhannon & Northern Railroad from Belington to the Pennsylvania-West Virginia State line; in all, some 328 miles of main-line location, exclusive of branch lines.

The termini, as usual, were fixed; physical conditions also fixed the Little

Kanawha River as the only outlet to the Ohio. Owing to local conditions, it was believed that the heavier traffic would be westbound, and therefore that every effort should be made to get as low a ruling grade as possible for this traffic. All roads previously built through the adjoining regions have long stretches of 1.5 per cent grades, and curves up to 12 and 14 deg. The first surveys, therefore, were of a preliminary nature, in order to determine what grades and curves could be secured.

After a number of surveys, locations and explorations had been made, it was found that the following grades and curves were possible: In Ohio, 0.5 per cent grades, 4 deg. maximum curve; Little Kanawha Division, 0.3 per cent grades, 8 deg. maximum curve; Burnsville and Eastern Division, 1.0 per cent grades against eastbound and 0.5 per cent grades against westbound traffic, 8 deg. maximum curves; all grades compensated for curvature at the rate of 0.04 min. per degree. These results were obtained in each case, and though very easy for parts of the country, required some rather long continuous grade lines, the longest being on the Burnsville and Eastern division, where there are 1.0 per cent grades, 7 miles and 7½ miles long, respectively, and a 0.6 per cent grade 14 miles long, all against eastbound traffic.

The topographical sheets of the United States Geological Survey were found of great value in making a broad, general study of the country. A large number of maps of small scale (1 in. to 1 mile or even smaller) were compiled and traced from various State, county and road maps, on which the several survey lines could be indicated.

The general direction of the survey, except along the Little Kanawha Division, was almost directly across the general drainage of the country.

In Ohio a direct line between termini was first examined, but was found to be impracticable. A systematic examination toward the southwest was then made, and a satisfactory line developed. All the streams here lie in deep, narrow valleys, and are exceptionally crooked. The only feasible way to traverse much of the country was to get up out of the valleys and stay out. Such a method necessitated crossing about 100 ft. above several streams, and running short tunnels between the watersheds; it also gave the shortest line, the easiest grades, and the lightest curvature.

The main problem on the Parkersburg Bridge & Terminal Railroad was the determination of the location for a bridge over the Ohio River. The Government regulations required 90 ft. clear head-room above low water and no piers in the main channel, which necessitated a 700-ft. span. The location finally adopted is about 5 miles below Parkersburg, and is believed, Mr. McFetridge stated, to be the shortest and cheapest railroad bridge crossing the Ohio between Pittsburgh and the Mississippi, the 700-ft. span practically clearing the entire channel.

The Little Kanawha Division, in general, followed the Little Kanawha River. The hills rise abruptly from the river banks. The river is very crooked, and to follow it gave a long line with much curvature. Much distance could be saved by cutting through the country at various points, but the work was very heavy. The line, as finally located, is a combination of river and cross country line. It is 31 miles shorter than the river, in a total distance of 100 miles. There are eight tunnels, usually short, the longest being 4,000 ft. There are seven river crossings, with main spans from 100 to 300 ft.

The Burnsville and Eastern Division is in the central mountain part of the State. The highest altitude reached is 1,725 ft. above sea level. The country was very rough and broken, and supporting ground for grades could not be found. The Buckhannon and Northern Division followed the river for about two-thirds of its length, the other third being cross-country.

Field parties were made up as follows: Assistant Engineer in charge, $125 to $150 per month; transitman, $85 to $100 per month; levelman, $75 per month; rodman, $65 per month; head chainman, $50 per month; rear chainman, $45 per month; rear flagman, $40 per month; stakeman, $35 per month; axemen (from two to five), $30 each; topographer, $65 per month; tapemen (two), $45 each; draftsman (part time), $60 per month. Camp outfits were not used. The parties boarded at houses along the line. Each party was given from 40 to 60 miles of line to cover, depending on local conditions.

After the first route to be examined had been chosen, a preliminary line was run through; then the alternate routes were run, all surveys being tied together; and finally the lines required for a thorough development of all possible routes were run. In locating long grades, it was preferable to start at a summit and run down hill. With a little experience, the assistant engineer could make a sufficiently close estimate of the amount to allow for compensation for curvature, and could run his line accordingly. In the mountainous part of the country here described this compensation amounts to about 6 ft. per mile, equal to 0.12 per cent grade, and preliminaries, for a 1.0 per cent compensated grade, run on an 0.88 per cent straight grade gave the desired information

In following the larger watercourses, it was usual to locate a line on either side for purposes of comparison, and in order to determine the advisability of crossing from one side to the other either to get a better line or to block the country against rivals.

It may appaer to some that there was much unnecessary location and running of preliminary lines, but in rough country like this, and on work of this magnitude (in 220 miles of this line there were twenty-one tunnels, the longest being 4,000 ft., five viaducts from 400 to 1,000 ft. long, and more than 100 ft. in height, besides numerous other bridges), it is, in Mr. McFetridge's opinion, time and money well spent.

Topography, showing contours, houses, roads, and similar features, was taken on practically all lines. This was taken on 12 × 18-in. sheets to a scale of 200 ft. to 1 in. The topography was plotted in the field. This method was preferred to any other; it is quicker; saves much copying and plotting; the work can be plotted better in the field, where everything can be seen at the time of plotting; and at night the assistant engineer has a finished map to look over and study. The topography was taken accurately by using a metallic cloth tape for distances and a hand-level for elevations. The topography was ordinarily taken for 300 ft. on each side of the center line. The sheets were inked in each night.

To obtain a large general map showing all lines, the lines were carefully plotted on tracing cloth, the small sheets were fitted so as to make the center line on each sheet fit the center line on the tracing, and then the topography was traced. By this method any error in plotting or joining the small sheets was eliminated from the large map. The location was projected in pencil on sheets in the usual manner.

In staking out the location, the aim was to get a profile to correspond with the projection, and not to get the lines in exactly the same relative positions shown by the projections. Also, it was often found desirable to change the location at places, giving a corresponding change in the profile. After the first location had been made, it was studied further in the chief engineer's office; if any changes were desired they were taken up with the assistant engineer, usually by the assistant chief engineer and the assistant engineer going over the ground together and there studying the question.

All curves of 3 deg. or more had spiral approaches. These were allowed for in cross-sectioning by offsetting the slope stakes the required distance. For simplicity and ease, all records, profiles, etc., were kept on simple curve data. When spiral curves came in tunnels, a special plan was made for each case, showing the offsets from the tangent and the simple curve to every 10 ft. on the spiral, the alignment being kept on the tangent and the simple curve, and allowing the required offset in giving the widths for the tunnels. Vertical curves were inserted at all places when the change of grade was more than 0.1 ft. in 100 ft. Standard forms were used for all notes, maps, profiles, plans, and reports, and were found to save much work and time in the chief engineer's office.

The greatest number of miles of preliminary line run in one day by one party was 7, and of location, 4½. The location averaged slightly more than one mile per day per party, except on the Burnsville and Eastern and on the Buckhannon and Northern lines, where it averaged ¾ mile. Stakes were set every 100 ft. on tangents, and every 50 ft. on curves. The speed of location parties was usually limited by the amount of clearing that could be done, but the number of curves and the rough character of the ground were also large factors in limiting the speed.

Each party cost from $35 to $40 per day, being allowed all expenses in addition to salaries.

Table I gives the total cost per mile of the completed surveys. It includes office rent, purchase of instruments and supplies, general expenses, all salaries, field expenses, and the preparation of final maps, plans, profiles, and estimates, with everything in readiness to make contracts for the line.

TABLE I.—TOTAL COST OF SURVEYS

Company	Amount spent	Miles of surveys: Preliminary	Miles of surveys: Location	Miles of surveys: Total	Av. cost per mile	Av. cost per mile of location
L. K. R. R.	$25,076.83	428.19	193.85	622.04	$40.31	$129.36
Z. M. & P.	19,812.77	509.03	105.23	614.26	32.25	188.28
B. & E. R. R. . . .	20,466.68	241.75	113.70	355.45	57.58	180.00
P. B. & T. R. R. .	6,651.98	84.56	38.17	122.73	54.20	174.28
B. & N. R. R.	19,249.94	162.51	151.29	313.80	61.34	127.23
Totals.	$91,258.20	1,426.04	602.24	2,028.28	$45.00	$151.53

The last column gives the cost per mile of actual location, including preliminary lines. The third and fourth columns show that there were from 2 to 5 miles of preliminary lines run for each mile of location, except on the Buckhannon and Northern line. Table I also includes 302 miles of check levels, the cost being distributed among the various accounts. The data for the Parkersburg Bridge and Terminal line include surveys and soundings for the Ohio River Bridge. The cost per mile includes the topography on practically all lines, except on the Zanesville, Marietta and Parkersburg line, where it was taken only on the located lines.

The cost shown, being the total charge against engineering from the inception of the project to the beginning of construction, contains a few items which might well be charged to other accounts than location. Instruments purchased could be a credit; some elaborate property surveys and bridge surveys could be charged to construction, but they probably are not large enough to have much effect on the cost per mile. The cost on the Little Kanawha and on the Burnsville and Eastern Division was increased considerably owing to much work being done during a bad winter. The cost on the Parkersburg Bridge and Terminal line was increased by a large amount of property surveying in the city, and by the surveys for the bridge.

The cost on all the West Virginia lines was increased by the immense amount of chopping and clearing necessary. When mountain laurel was encountered, all the axemen that could be worked could not keep a location party moving.

The average cost, including all expenses, of one mile of preliminary or location survey, determined from a detailed study of the daily reports of field parties, or office work done, and similar data, is shown by Table II.

Table II.—Average Cost of One Mile of Surveys

Company	Of preliminary	Of location	Of location, including preliminary
L. K. R. R.	$25	$ 74	$ 99
Z. M. & P. R. R.	23	79	102
B. & E. R. R.	35	105	140
B. & N. R. R.	31	94	125

Table I shows a large variation in the cost of surveys on different divisions, the cost varying from $128 to $188 per mile, with an average of $151. On the assumption that lines located for comparison or similar purposes should be included in the average, one-third should be added in these amounts, as previously noted; the cost per mile would then be as follows: Low, $171; high, $251; average, $202.

Throwing out of account abandoned lines, branch lines, etc., and charging the entire cost to the main line, terminus to terminus, would give $91,258.20 ÷ 328 = $278.23 per mile, which Mr. McFetridge believes would be rather expensive. This, however, is not a fair assumption, because many miles of lines not needed to determine the main line were located for other reasons. Therefore, the plan of throwing out only duplications, for comparisons, as shown in the preceding paragraph, gives the correct average cost per mile, including actual comparative locations where needed. A large proportion of this duplication was necessary, owing to the laws of West Virginia, which require an actual line, located on the ground, and a complete map and profile of that line to be filed with the secretary of state, and at the county seat, before a railroad company has any rights, or priority or otherwise, to that route or line.

On the basis of Table II, it may be assumed that, where the route has been previously determined within such narrow limits that the preliminary and location lines are of equal length, the surveys will cost from $100 to $140 per mile. This is borne out by the results on the Buckhannon and Northern line where the location and preliminary lines were practically equal and the cost was $127 per mile.

These two statements may be combined and put in the following form: To locate one mile, including an equal length of preliminary lines, cost from

$100 to $140, or an average of $115; to locate one mile, final location, including from two to five times as great a length of preliminary lines, cost from $128 to $188, or an average of $151; to locate one mile, final location, including from two to five times as great a length of preliminary lines, and one-third of a mile of location for comparison, cost from $171 to $251, or an average of $202.

A tabulation of the mileage of the Buckhannon and Northern line, with reference to the actual length of line to be built, and showing how the results agree with the averages deduced from Table I is as follows, the Buckhannon and Northern line being used because the conditions there make it the best average of "all conditions" encountered on the various lines: Total miles located, 151.29; miles of main line contracted for, 80; miles of main line not contracted for, 4; miles of connecting line located, but which may or may not be built, about 26. This gives 110 miles of main and connecting lines, leaving 41.29 miles of duplications and comparisons. The cost is then $19,249.94 ÷ 110 = $175 per mile.

Cost of a Triangulation Survey with 48 signals, controlling about 150 square miles of the Grand Valley project of the U. S. Reclamation Survey was made at a cost of $3.63 per square mile, and a plane table survey of 127 square miles, with maps on a 1:12,000 scale with 10-ft. contours, was made at a cost of $57.79 per square mile. The cost of the triangulation survey included that of measuring base lines and making Polaris observations.

Cost of Railroad Surveys in Bolivia.—The following data are from an article in Engineering Record, June 25, 1910, by C. A. Bock.

The model organization of a locating party is given in Table III.

TABLE III.—ORGANIZATION OF BOLIVIAN LOCATION PARTY

Foreigners		Natives	
Title	Monthly salary	Title	Monthly salary
Locating engineer	$200.00	Cook	55.00
Assistant engineer	150.00	Assistant cook	22.00
Transitman	125.00	Camp boy	15.00
Levelman	100.00	Corral boy	15.00
Topographer	100.00	Lunch boy	15.00
Draftsman	100.00	Muleteers, 2, ea	30.00
Head chainman	60.00	General helpers, 2, ea	15.00
Rear chainman	60.00	Rear flag	19.00
Level rodman	60.00	Axeman, 1 to 4, ea	19.00
Topog. rodman	50.00	Stake man	26.00
Commissary	80.00	Tape man	26.00
Doctor	150.00	Inst. carriers, 2, ea	19.00

Tables IV and V show the cost and time of three different surveys, made by different parties in more or less similar country and on the most difficult of the work thus far located. It should be noted, however, that while the work is located in mountain country, and most of it on difficult ground (an average of almost 50 per cent of the entire located line is curves) there is no cutting or clearing to be done, since the plateau portion of Bolivia lies above the timber line. The cost per kilometer of location as given includes preliminary lines, topography and all extra work necessary to accomplish the location, besides completed maps, profiles and estimates. The figures are for the total cost, and include all office and administration expenses, instruments and supplies.

TABLE IV.—DATA OF THREE SURVEYING PARTIES

	Camp 1	Camp 2	Camp 3
Total number of days in field....	593.0	480.0	240.0
Number holidays and Sundays....	86.0	69.0	33.0
Number days lost, bad weather...	23.0	7.0	8.0
Number days lost, moving camp...	16.0	44.0	17.0
Total number of working days.....	468.0	360.0	182.0
Kiloms. prelim. line run..........	500.2	293.0	181.0
Kiloms. located line run..........	242.3	237.4	137.4
Kiloms. completed location per day (av.)........................	.409	.495	.573
Total cost lo'tion (incl. all prelim.).	$53,389.41	$41,962.90	$20,339.26
Average cost location, per kilom...	220.34	176.76	148.03
Average cost location, per mile.....	354.62	284.48	238.24
Average cost of surveys, per day...	90.03	87.42	84.74

TABLE V.—DISTRIBUTION OF EXPENSES, IN PERCENTAGES

	Camp 1	Camp 2	Camp 3
Salaries..................................	46.4	47.5	47.1
Provisions................................	13.0	13.9	13.1
Traveling expense.........................	6.7	6.8	6.8
Instruments and supplies..................	5.8	2.2	4.0
Transportation of contract men............	3.6	5.2	4.3
Maintenance of animals....................	12.0	11.2	11.8
Indian labor (not on pay-roll)............	.3	.3	.3
Freight on supplies, etc..................	1.7	3.5	2.7
General expenses..........................	9.1	7.8	8.3
Miscellaneous charges.....................	1.4	1.6	1.6

The record run in a single day, of preliminary line, is 11.5 km; of located line, 5 km (containing two curves). The best single day's work is nine curves of located line run, including referencing of two points on each tangent. The largest amount of work done in one month by a single camp is 59.2 km. preliminary line, 25 km. of topography and 35.6 km. of located line, including referencing. This work was accomplished on a section of the survey where 53 per cent of the located line is curves.

Cost of Location Survey for a Short Railway Line.—Engineering and Contracting, Feb. 18, 1914, gives the following:

Location surveys for a railroad were made in 1912, in one of the eastern states, during which accurate records were kept for the purpose of producing authentic cost data.

The survey was for a branch 30.75 miles long, from an already established line to a manufacturing city; with a branch survey, to another city, 12 miles in length. Topographical considerations, aside from large bodies of water and high hills, were found to be of minor importance, the chief concern being so to approach the intersected streets that grade crossings might be cheaply avoided. Most of the distance was through a light growth of timber, requiring much chopping and trimming. No topography was taken, but all streets and water courses along the line were carefully surveyed and the boundaries of private lands were run out.

For three weeks the men were boarded in hotels in the two terminal cities; during nine weeks they were carried by team or railroad to the work from headquarters on the main line; and for twenty weeks and two days they lived in camp. From the camp, which occupied three different sites, about 26 miles of location were made, teams being kept with the camp for transportation.

TABLE VI.—DISTRIBUTION OF LABOR

Description of work	Cost	Cost per mile	Pct. of labor total	Pct. of grand total
Running the line finally adopted	$1,500	$35.10	39.7	20.8
Running lines afterwards abandoned	432	10.10	11.4	6.0
Surveys of intersected streets	666	15.60	17.6	9.3
Leveling on line finally adopted	156	3.65	4.1	2.2
Leveling on lines afterward abandoned	65	1.52	1.7	0.9
Leveling on intersected streets	20	0.47	0.5	0.3
Meandering ponds and streams	57	1.33	1.5	0.8
Surveying private boundaries	382	8.95	10.0	5.3
Triangulation and traverse lines	146	3.42	3.9	2.0
Exploration	10	0.23	0.3	0.15
Check levels	10	0.23	0.3	0.15
Office work by field men	61	1.43	1.6	0.8
Holidays, absences and rainy days	279	6.55	7.4	3.8
Totals	$3,784	$88.58	100.0	52.50

Table VI of labor distribution does not include any general officers' salaries nor that of the chief engineer. The map drawing was done in the general office and does not figure in these tabulations.

Surveying instruments were supplied from those previously in use by the company, and interest on their cost is charged under "Field and Office Equipment." The camp equipment consisting of seven tents, complete mess outfit, cot beds, blankets and quilts, was purchased second-hand at a discount of 50 per cent.

During the nine weeks above mentioned many days were lost on account of rain for which the men, being at home, were not paid. The pay of the party was as follows:

Position	Pay per day
Assistant engineer in charge	$ 4.50
Transitman	3.33
Leveler	2.50
Axman and teamster, 7 days per week	2.25
Chainmen	2.00
Rodman	1.75
Axmen	1.50
Cook, per week	15.00

A study of the tables does not suggest much resemblance to similar ones previously published, the most marked difference appearing in the matter of camp maintenance, Table VIII. Much of the higher cost shown here is doubtless due to the high cost of living prevailing. Also much may be due to the fact that all the men were accustomed to a pretty good table and an effort was made to provide them with home comforts.

The total cost per mile given, $168.08, Table VII is the cost per mile of final location, and will be seen to include the cost of preliminary lines, and all the detail surveying necessary for complete land plans.

TABLE VII.—DISTRIBUTION OF EXPENSES

	Cost	Cost per mile	Pct. of exp. total	Pct. of grand total
Field and office equipment	$ 160.49	$ 3.75	4.7	2.2
Railroad and street car fares and expenses	453.73	10.60	13.3	6.4
Board and lodging	167.00	3.90	4.9	2.3
Team transportation	836.32	19.50	24.6	11.6
Camp equipment	209.16	4.90	6.2	2.9
Camp maintenance	1,488.92	34.82	43.9	20.7
Purchased information	81.38	1.90	2.4	1.4
Mail, telegraph and telephone	5.56	0.13	.....	......
Totals	$3,402.56	$ 79.50	100.0	47.50
Grand totals	$7,186.56	$168.08	.....	100.00

TABLE VIII.—ANALYSIS OF CAMP MAINTENANCE

Commodity—	Cost	Cost per meal—4,047 meals	Cost per man per day	Pct. of total cost
Meat, fresh and canned	$ 373.72	$0.092	$0.239	25.1
Fish, fresh and canned	51.93	0.013	0.033	3.5
Potatoes	29.84	0.007	0.019	2.0
Other vegetables	53.93	0.013	0.034	3.6
Fruit, fresh and canned	120.58	0.030	0.077	8.1
Groceries	108.56	0.027	0.069	7.3
Flour	31.92	0.008	0.020	2.1
Eggs	59.39	0.015	0.038	4.0
Sugar	27.49	0.007	0.018	1.9
Coffee	26.50	0.006	0.017	1.8
Tea	9.06	0.002	0.006	0.6
Butter	37.27	0.009	0.024	2.5
Milk	73.03	0.018	0.047	4.9
Ice	18.61	0.005	0.012	1.3
Fuel	36.23	0.009	0.023	2.4
Light	6.50	0.002	0.004	0.4
Water—6 weeks from city main	5.00	0.001	0.003	0.3
Land rentals	10.00	0.002	0.006	0.7
Cook's wages	305.34	0.076	0.196	20.5
Labor moving camp	104.02	0.026	0.067	7.0
Totals	$1,488.92	$0.368	$0.952	100.0

Cost of Making a Relocation Survey of Underground Pipe Lines, Cincinnati, Ohio.—Engineering and Contracting, Aug. 12, 1914, describes in detail the methods used in this survey and gives the following costs.

A typical field party, together with rates of pay, as they were organized in 1913, is here given:

Position	Rate per month
Chief of party	$90
Instrumentman	60
Rodman	50
Rodman	50

The number of field parties was gradually increased from one on May 1, 1912, to five on Aug. 23, 1912, this number was continued until Jan. 16, 1913, when the sixth party was put in the field. The number of field parties was increased to eight in May, 1913, and with this field force of 32 men working during the summer, the field work was completed. The last field party was disbanded on Nov. 22, 1913.

The accompanying cost report, see Table IX, shows a decrease in the average cost per mile during this time from $77.53 for March to $61.20 for November or a decrease of $16.33 in the average cost. There is also a decrease of $8,166.80 in the estimated cost to complete the work. During this same time 283.5 miles of sewers were measured at a cost of $13,880.52, which gives an average per mile cost for this period of $48.96. The average costs are based on payroll charges only.

Complete information, as called for in Instructions to Field Parties was obtained on 496 miles of sewers, together with other information pertaining to the streets of the city. This includes 42 miles of sewers within the city limits for which there were no records.

The increase in the cost of the field work at the end of the season is due wholly to vacation time and the locality in which most of this work was done.

Field Work.—The work consisted of: Running bench levels, to establish elevations; Location of pipes by traverse including the following: Street and curb lines, corners, etc. Sewer center lines. Manholes, sewer, electric, telephone, etc. Inlets and catch basins. Valves, water and gas. Fire hydrants and fire cisterns. Culverts (obtain size). Bridges. Electric and steam railroad tracks.

The size and shape and condition of all pipes and appurtenances was also determined and reported.

Sewer Record Plats.—The primary purpose of these plats is to show correctly all information regarding the sewers: Their sizes, grades, location, inlets and branches. They include all improved portions of the city. These sheets also give information regarding all other underground structure. They show, therefore, the best location for new sewers or pipes. Formerly, it has been necessary to visit the various corporations having pipes or conduits in the streets in order to get this information.

These record plans are 23 × 32 ins. within the border and a binding edge of 1½ ins. is left on the left hand end of the sheet. One portion of the city is platted on a scale of 40 ft. to the inch; all other parts of the city are platted on a scale of 50 ft. to the inch.

Methods of Making Topographical Surveys and Their Cost.—The following discussion and data by D. L. Reaburn, Division Engineer, Los Angeles Aqueduct, are taken from an article in Engineering News, Aug. 10, 1911.

Two methods are in common use in this country for making topographic surveys. The older one, known as the plane-table method, has been used more extensively than any other. It is used either with or without stadia. The other, known as the transit stadia method, has been in use about 50 years.

The plane-table is used by the U. S. Coast and Geodetic Survey, the U. S. Geological Survey and the U. S. Reclamation Service; while the transit stadia has been used exclusively by the U. S. Lake, Mississippi River, Missouri River and other surveys conducted by the Corps of Engineers, U. S. A. It is also used, more or less, by engineers in general practice.

The plane-table is indispensable for geographical surveys, especially in mountainous regions of large relief. When provided with a micrometer eyepiece to the alidade, it can be used to great advantage on reconnaissance and exploratory surveys.

When used with stadia rods the plane-table is adapted to mapping on scales up to about 500 ft. to the inch; on larger scales than this the problem becomes

TABLE IX.—COST DATA OF CINCINNATI UNDERGROUND SURVEY FOR FIELD AND OFFICE WORK

Month	Field work					Platting record plans					
	Progress in miles	Cost per mile for month	Mileage sewers surveyed	Av. cost per mile	Estimated cost based on 500 miles	Progress in miles	Cost per mile for month	Mileage sewers platted	Av. cost per mile	Estimated cost based on 500 miles	Total estimated cost, field and platting
1912—											
December	11.1	$150.17	149.7	......	....	27.4	$39.14	87.4	......	....	....
1913—											
January	19.4	86.05	169.1	$75.74	$37,869.40	27.5	40.06	114.9	$52.93	$26,359.84	$64,229.24
February	22.5	84.72	191.6	76.79	38,395.38	25.1	42.80	140.0	51.12	2,550.00	63,955.33
March	20.9	84.38	212.5	77.53	38,766.80	33.5	36.21	173.5	48.23	25,500.00	63,889.69
April	26.5	64.62	239.0	76.10	38,051.38	28.5	36.94	202.0	46.64	23,321.42	61,372.80
May	43.0	45.17	282.0	71.39	35,694.61	17.7	50.99	219.7	47.00	23,499.29	59,193.90
June	47.9	43.37	329.9	67.32	33,660.11	22.5	47.20	242.2	47.02	23,510.93	57,171.04
July	49.3	43.88	379.2	64.27	32,136.03	33.8	37.63	276.0	45.87	22,935.94	55,071.97
August	44.7	48.87	423.9	62.65	31,324.40	31.5	36.87	307.5	44.95	22,475.76	53,799.66
September	47.0	43.77	470.9	60.77	30,382.59	29.4	38.01	336.9	44.34	22,171.76	52,554.35
October	17.6	69.52	488.6	61.07	30,534.04	16.9	65.05	353.8	45.33	22,666.67	53,200.71
November	7.4	87.47	496.0	61.46	30,730.92	20.3	53.00	374.1	46.02	23,010.8	53,741.79

NOTE.—Costs based on payroll expenses only.

a mechanical one of locating points rather than sketching, and compared to the more rapid transit stadia method, the plane-table is decidedly at a disadvantage.

The three-point method cannot be used to advantage on large scale work with the plane-table. A chained traverse line is generally required for control. In rough and brushy country this traverse work is slow, laborious and expensive. In rough country the hand level method is also very slow and expensive, and it is difficult to delineate accurately the character of the ground surface. The transit stadia method, on the other hand, is not adapted to small scale mapping of extended areas.

The writer has, however, used the transit to advantage in connection with the plane-table on 2,000 ft. to the inch work, where it was desirable to do the sketching in the field. The points were located by transit and plotted on the plane-table sheet with a small protractor.

The transit stadia is well adapted to large scale detail surveys. On such surveys the location and plotting of the detail points constitutes the major portion of the work. The transit in the hands of a skilled observer is capable of locating these points with more ease and rapidity than any other instrument. The transit is better adapted to work in brush than the plane-table, and there is not so much lost time from adverse weather conditions.

The *fundamental principles* governing the execution of such work along economic lines may be stated as follows: There should be a rigid horizontal and vertical control, supplemented by a less precise secondary control, upon which to base the details of the work. These principles are fully realized by the transit stadia method. The rigid control being the triangulation and precise levels, and the secondary control the stadia line. In flat country a traverse line control will sometimes be found more economical than a triangulation system.

The question of economical methods of conducting location surveys does not, as a rule, receive much consideration. The writer has observed a number of instances where money has been unnecessarily expended by not adopting methods suited to the country. In one instance, where the hand level method was in use for topography along steep brushy mountain slopes, it required the services of a transitman, levelman, topographer and nine men to make a progress of 2,000 ft. per day. A transit stadia party of six men was substituted and the progress increased to a mile per day.

During the past six years the writer has given much time and thought to the subject and tried out several of the methods in use. The transit stadia method has given the best results. A description of the methods employed, the results obtained and the cost on several pieces of work is given below.

Irrigation Canal Location.—During the summer of 1905, about 100 miles of canal location surveys on the Klamath Project of the U. S. Reclamation Service were made by the transit stadia method. Before the work of canal location was started, topographic maps of all the irrigable lands under the project had been made. About 300 square miles of this work was done. This survey was based on a triangulation and primary level control and was executed by the plane-table and stadia method on a scale of 2,000 ft. to the inch, with a contour interval of 5 ft. The cost of this plane-table work was from $15 to $30 per square mile.

Maps drawn from this survey determined the approximate location and grade of the main canals and from these data the transit stadia survey for final location was made.

Stakes were set along the grade contour from 400 to 800 ft. apart. Azimuths were observed in the forward direction, and distances to feet and differences of level to hundredths were read from each end of the line.

At intervals of every few miles a check in elevation was obtained by a spur line of levels to a nearly B. M. of the primary level system. The errors of closure were never more than 0.2 or 0.3 ft. for the distance of five or six miles between checks. Azimuth checks were obtained by lining in between two triangulation stations or by long sights to prominent points.

The belt of topography developed varied from 200 to 400 ft. in width on flat ground to 50 ft. difference of elevation on steep slopes.

Progress and Cost.—The field party consisted of an observer, recorder and four stadia rodmen. The average number of stadia shots was about 250 per mile. The maximum day's run was four miles with 1,000 stadia shots. The average days run was about three miles.

In plotting, vertical angle readings were reduced by stadia slide rule and the notes were plotted on a scale of 200 ft. to the inch. Stadia readings can be plotted fast as they can be called off from a field book. A good draftsman can usually do all the drafting, including the inking of the sheets. If there are many vertical angles to be reduced an assistant will be required.

No accurate cost data was kept of the work, but an approximation can be arrived at by taking the average daily progress (3 mi.) and the monthly cost of the party, as follows:

1 Transitman at $150	$150.00
1 Draftsman at $125	125.00
1 Recorder at $50	50.00
1 Stadia man at $45	45.00
3 Stadia men at $40	120.00
1 Teamster at $40	40.00
1 Cook at $40	40.00
Total monthly salaries	$570.00
Subsistence 9 men at $20	180.00
Feed for two-horse team	30.00
Total monthly expense exclusive of equipment cost	$780.00

Assuming 26 working days in a month, we have a daily expense of $30, or $10 per mile for the preliminary line.

Los Angeles Aqueduct Surveys.—A triangulation system of simple triangles having sides from one-half to two miles in length, furnished the horizontal control, and a line of precise levels the vertical control for this survey.

The country surveyed was for the most part along steep mountain slopes, in many places covered with brush. The belt of topography developed had a range in elevation of from 50 to 75 ft. The final grade adjustment raised the grade elevation in the Little Lake, Grape Vine and Freeman Divisions above the limits of the first survey, which necessitated a second one on the higher level.

The field party consisted of a party chief, transit stadia observer, recorder, four rodmen, draftsman, assistant draftsman, teamster and cook; a total of eleven men.

The assistant draftsman reduced the vertical angle stadia readings with slide rule and called off the notes to the draftsman. The party chief did the triangulation and sketched the topography after the shots were plotted.

TABLE X.—COST OF TRANSIT STADIA SURVEY, LOS ANGELES AQUEDUCT
(Including Office Work, of 40-ft. Belt of Topography, 5-ft. Contours, Plotted 200 ft. to the Inch)

Month	Feb.	March	April	May	June	Total
Total pay-roll	$200.63	$740.52	$787.25	$794.00	$785.00	$3,307.40
Livery and other expenses	18.68	59.51	80.54	81.40	71.09	311.22
Total cost	219.31	800.03	867.79	875.40	856.09	3,618.62
Miles run	11.0	38.0	43.6	48.1	55.3	196.0
Days worked	9.0	27.0	26.0	27.0	26.0	115.50
Miles run	11.0	1.41	1.68	1.78	2.13	1.70
Cost per day	21.93	25.81	28.43	28.24	28.53	27.41
Cost per mile	19.94	21.05	19.87	18.21	15.48	18.46

The topographic maps were on sheets 22 ins. × 30 ins. in size, drawn to a scale of 100 ft. = 1 in. Rectangular coordinate lines 10 ins. apart were projected on them and the control points plotted by coordinates.

The stadia line was first plotted to a closure between tie points, and the closure error distributed before any topography was plotted. This error was from 1 in 500 to 1 in 1,000 for lines along the grade contour, but where vertical angles entered into the line the results were not so good.

Where the ground was badly broken and for siphon crossings over deep canyons, the sheets were mounted on a plane table, after the transit notes were plotted, and the contours sketched in the field.

Progress and Cost.—The average day's run was about 1¼ miles. The number of stadia shots was from 500 to 750 per day, or about 400 to 600 per mile. The cost, including the triangulation and location of section corners was from $30 to $60 per mile.

During the spring of 1910 about 200 miles of transit stadia location surveys were made in the San Fernando Valley for the Los Angeles Aqueduct distribution system by a party in charge of Mr. J. G. Morgan.

The work was plotted on sheets 22 ins. × 30 ins. on a scale of 200 ft. to the inch, with a contour interval of 5 ft. The contours were followed out on the ground. (See Table X.)

The field party was composed of a transit man, recorder, levelman, four rodmen, draftsman and teamster. Each rodman carried a Locke hand level, for placing his rod on contours above or below the range of the transit or level, by sighting on another rod. As part of the work of spotting the rods was done by the levelman and by the rodmen themselves, the observer was able to keep four rodmen busy.

A belt of topography having a vertical width of 40 ft. was developed from one stadia line which corresponded to a horizontal width of from 100 to 1,500 ft. In some instances several adjacent 40-ft. belts were developed.

The minimum number of stadia shots per day was	240
The maximum number of stadia shots per day was	845
The average number of stadia shots per day was	520
The average number of stadia shots per mile was	300

Level control was obtained from the U. S. Geological Survey B. M.'s.

Two men were occupied 43 days in building signals and observing the angles of the triangulation system, which started from a side of the U. S. Geological Survey primary triangulation. Station marks were made of iron pipes 2 ins. × 4 ft., spread at bottom, set 2½ ft. in the ground and with a flag pole set in them.

DATA AND COST OF TRIANGULATION

No. of stations set and observed	50
Approximate area controlled	400 sq. miles
Total salaries	$463.34
Livery and other expenses	67.43
Total cost including computations	$530.77
Cost per station	10.61
Cost per square mile controlled	1.33

Topographical Survey for Industrial Development.—During the spring of 1909 a topographic survey was made by parties in charge of Mr. A. J. Ford of a large tract of land near Riverside, Cal., for the purposes of industrial development. The work was plotted on a scale of 100 ft. to the inch with a contour interval of 2 ft. The contours were followed out. No stadia readings for elevations of the contours were taken except to an occasional saddle or knoll. The ground was rolling; had a total rise of about 300 ft.; was mostly under cultivation, and the conditions were favorable. All buildings, fences, roads, etc., were located.

This work was executed by both transit and plane-table parties composed of five men each as follows: Transit party: observer, recorder and three rodmen; Plane-table party; plane-table man, levelman, recorder and two rodmen.

The rods were placed on the contour by the transitman in the transit party, and by the levelman in the plane-table party by sighting the target with which the rods were provided. After a contour was followed as far as could be reached from the setup, the rodman moved his target up or down 2 ft. and returned on another contour.

The control work was done before the writer took charge and no data can be given for it. The number of points located by the transit parties was from 500 to 600 per day, or about 7 or 8 per acre.

Table XI gives the total costs of the topographic work for each of the three parties. This includes the salary of the topographer in charge of parties and the cost of supervision.

TABLE XI.—COST OF TOPOGRAPHIC SURVEYS, RIVERSIDE, CAL.

(2-ft. contours, plotted 100 ft. to the inch)

	Party No. 1 Transit stadia	Party No. 2 Plane-table	Party No. 3 Transit stadia	Totals
Field and office labor	$1,644.62	$1,123.73	$ 313.54	$ 3,081.89
Subsistence	414.05	285.51	71.44	771.00
Transportation and supplies	164.00	134.70	38.00	336.70
Total cost	2,222.67	1,543.94	422.98	4,189.59
Acres surveyed	7,448.8	1,716.2	1,695.0	10,860.0
Cost per acre	$0.298	$0.90	$0.25	$0.386
No. days in field	100.0	78.0	18.0	196.0
Average progress in acres per day	74.49	21.95	94.17	55.41
Cost per day	$ 22.23	$ 19.79	$ 23.50	$ 21.38

REMARKS.—The cost of draftsman's work was apportioned between the two transit parties. The cost of supervision was apportioned to the three field parties.

In comparing the costs in the table it should be noted that it was necessary in addition to the main control system to establish two points by triangulation upon each plane-table shot, the cost of which is not included for Party No. 2.

All men employed in the work except the topographer in charge were inexperienced in topographic work. The increased efficiency of Party No. 1 is shown in the table below for a period of three months.

Month	Progress acres per day	Cost per acre
April	40	$0.54
May	99	0.23
June	122	0.18

Stadia Survey for Irrigation Project.—The survey, of the Preston Beck, Jr. Grant in New Mexico, formed the basis of a preliminary design and report for the reclamation of this property. The survey was made during the period from Sept., 1910 to May, 1911. The following is abstracted from an article by Mr. Vincent K. Jones in Engineering and Contracting, July 31, 1912.

Owing to the broken character of the country and the many ridges over which the water in the canals must pass a topographical map was necessary to determine the controlling points of the canal system and to enable a sufficiently close preliminary design and estimate of cost to be made. For this purpose extreme accuracy is not essential and the extra work necessary to obtain a high degree of accuracy would be wasted. The results proved to be sufficiently accurate, the errors of traverse by stadia varying from 1 in 400 to 1 in 600 and the errors in elevation when carried by transit-stadia about 1 ft. in 6 miles of horizontal distance.

The general location of the main canal was first obtained by running several rough level "fly-lines." These showed the only practical line for a main canal to lie somewhere in a strip of land whose outer limits were contours approximately 100 ft. apart vertically.

Starting at one of the controlling points the main canal known as El Paso Gap a line of topography was carried towards the Pecos River covering a strip lying approximately between the 5,200 and 5,300 ft. contours. About 2 ft. per mile of line were allowed for the rise of the canal as the line approached the river. This line, afterward used as a base line on which the topography of the land under the canal was hung, was run as a stadia traverse with elevations carried by an 18-in. wye level and checked by taking vertical angles with the transit.

From this base line the topography of the strip of land mentioned above was taken, sufficient side shots being made to enable 5 ft. contours to be interpolated on a scale of 600 ft. to the inch. The shots between stations varied from 200 ft. to 1,800 ft. in length and the number of side shots from each station from 2 to 200, depending on the roughness of the country covered and the position of the instrument station. The length of this line was 41 miles.

When the Pecos River was reached a stadia traverse was carried up the river for 12 miles to form a connecting link between the canal topography and the survey of a reservoir situated near the town of El Cerrito. The river runs in precipitous box canon between the reservoir and the point of diversion near Tecolotito, which required 2½ days to traverse. Side shots were taken along the sides of the cànon to determine the width and general topography of the river bed. Elevations throughout the base line and river traverse were carried by the wye level.

The same general methods were followed in the survey of the reservoir, the topography being hung on closed stadia traverses and elevations being by level. The high water line of the reservoir covers 401 acres, but the topography covered 20 acres. This job required 3½ days and the topography was taken sufficiently close to enable 1 ft. contours to be plotted on a scale of 200 ft. to the inch.

The "Borrow Pit" method of reservoir surveying is in general use in Southern Colorado, but the results obtained by the method described above, especially in broken country, proved to be as accurate and much better from an economical standpoint.

Cost of Base Line.—The cost of the 41 miles of stadia base line, topography, 12 miles of river traverse and the survey of the reservoir is as follows:

General expense	18.33
Salaries	1,107.60
Board (including cook's wages)	467.75
Team feed and shoeing	51.53
Depreciation of equipment and horses	47.65
Office supplies	42.35
Total	$1,735.21

The salaries paid as follows:

1 Engineer and draftsman	$150.00
1 Transitman and chief of party	90.00
1 Levelman and recorder	60.00
1 Level rodman and head topography rodman	45.00
1 Topography rodman	45.00
1 Topography rodman	35.00
1 Cook	45.00
1 Teamster and camp man	30.00

Board was in each case included in addition to the above salaries. Interest and depreciation were charged on live stock at a rate of 1½ per cent of value at start of survey per month. On the other camp equipment and instruments, interest and depreciation charged at a rate of 3 per cent per month. These percentages were figured to pay 10 per cent interest per annum on the outlay for equipment and to pay for the equipment in the probable active life of the outfit as a whole.

In the above no overhead expense has been charged to the work. Overhead charges vary so greatly on different projects that this expense should not have a place in cost data for engineer's use. These costs must be estimated according to the size of the project, office organization, and intricacies of the general organization and are generally beyond the control of the engineer.

The work was carried on at a distance of from 25 to 50 miles from the base of supplies and shipping point on the railroad and therefore a great deal of hauling was necessary which would not be if operations were carried on near the base of supplies. Two teams and one saddle horse were used. The teams were driven alternately in the field except when one team was hauling supplies or moving camp.

Progress of Work.—With three stadia rodmen and a recorder who drove the team and also acted as rear flagman, the work progressed rapidly. Six to eight miles of traverse line with all side shots were frequently made when in fairly open country. When in the breaks near the river or in close proximity to the large mesas, 2 to 4 miles of traverse was the general average. As the traverse lines were generally a half mile apart the area covered varied from 640 acres in rough country to 2,560 acres per day in open prairie.

The stadia-transit notes were worked up in camp every night and generally plotted the next day, so that if any errors were picked up they could be corrected before moving camp.

The notes were plotted to a scale of 1 in. = 600 ft. on detail paper in the camp. The sheets were not traced.

It was necessary to camp where water was available. The moves between water holes or springs averaged about eight miles. The distance from the camp to the work was frequently as far as 10 miles, which made the job cost more than it would if more camps could have been found.

The total area covered by topography was approximately 200,000 acres, of which 145,000 acres were classed as tillable land and 55,000 acres classed as rough. The topography of the rough land was not taken as closely as that of the tillable land except in places where a canal will be built or in a prospective reservoir site. The total length of traverses averaged one mile for each 300 acres.

Cost of the work, exclusive of the first base line, river traverse, and Pecos Reservoir survey, the cost of which was given above, was as follows:

Salaries	$3,133.00
Board expense (including cook's wages)	768.11
Corral expense	206.04
General expense	155.10
Depreciation equipment and horses	149.40
Office and field supplies	71.43
Total	$4,483.08

The total cost figured on a unit basis is $.0311 per acre, $9.33 per mile of traverse line, including maps and the classification of the land, but not including overhead charges.

The cost of team feed and shoeing averaged $0.214 per head per day. The cost of board, including cook's wages, but not including cartage of supplies, averaged $0.247 per meal. This cost varied from 18 cts. in the winter, when fresh beef could be kept in camp, to 32 cts. in summer.

Cost of Making Topographic Resurvey on the Truckee-Carson Project, Nevada.—L. E. Gale gives the following data in Engineering and Contracting, Feb. 25, 1914.

A portion of the country lying north and west of Fallon being irrigable and water for irrigation being available upon the completion of the Lahontan Dam, it was found necessary to make a topographic resurvey before deciding on a system of irrigation. The country had previously been mapped on a scale of 4 ins. to the mile and 5 ft. contour interval by plane table parties in 1907. This scale and contour interval was inadequate in detail and the resurvey was made on a scale of 400 ft. to the inch with a 2-ft. contours.

The wages paid were as follows: Instrumentmen $100 per month, rodmen $60 to $70 per month, recorders $70 per month, teamster $60 per month, cook $60 per month. Each man was deducted 25 cts. per meal and the mess-house was intended to be self-supporting, including the wages of the cook. The mess-house was on wheels with walls and roof of heavy canvas stretched over a light wooden frame, the whole being easily moved from camp to camp by four mules.

Attached is a detailed cost summary, showing cost per acre of the work in both districts, which includes the cost of moving the camps a total distance of 35 miles.

TABLE XIII.—COST OF TOPOGRAPHIC RESURVEY FOR DISTRICT NO. 2 TRUCKEE-CARSON IRRIGATION PROJECT

Classification	Amount	Cost per sq. mile
Horizontal Control:		
Labor	$ 294.86	$ 11.84
Corral expense	36.00	1.45
Supplies	25.98	1.04
Miscellaneous expense	94.90	3.81
Total for horizontal control	$ 451.74	$ 18.14
Vertical Control:		
Labor	$ 122.15	$ 4.90
Corral expense	18.50	.74
Supplies	9.77	.39
Miscellaneous expense	42.50	1.71
Total for vertical control	$ 192.92	$ 7.74
Plane Table Development:		
Labor	$1,294.77	$ 52.00
Corral expense	114.0	4.58
Supplies	19.14	.77
Miscellaneous expense	389.83	15.65
Total for plane table development	$1,817.74	$ 73.00
Draughting	$ 162.05	6.50
General expense	252.71	10.15
Summary by Items:		
Labor	$1,711.78	$ 68.74
Corral expense	168.50	6.76
Supplies	54.89	2.20
Miscellaneous expense	527.23	21.18
Draughting	162.05	6.50
Total field cost	$2,624.45	$105.38
General expense	252.71	10.15
Totals	$2,877.16	$115.53

The item "Miscellaneous expense," consists of idle time for men and teams, moving camp, equipment depreciation and miscellaneous labor and supplies which could not be charged directly to any of the classes of work shown on sheet. Location of work—Townships 19 and 20 N., R. 27 and 28 E., north of Carson River, in District 2. Area mapped, 24.9 square miles; rough sandy country; scale, 1 in. equals 400 ft.; contour interval, 2 ft. Horizontal control developed from geodetic co-ordinates and maps projected from polyconic projection 41 linear miles of vertical control; 26 triangulation stations calculated and plotted; 15 permanent triangulation station marks placed 4 P. B. M.'s placed. Mess loss of $90.79 is not included in the cost report. Average unit performance in square miles per plane table day 24.9, plane table days 94, unit performance 255.

Plane Table Development.—Relative to the plane table work, Mr. Gale says: Two plane tables were operated, the party for each consisting of plane table man, recorder and two rodmen. The recorder entered the distances and rod readings in the notebook and calculated the elevations, calling the same to the

TABLE XIV.—COST OF TOPOGRAPHIC RESURVEY FOR DISTRICT NO. 3 TRUCKEE-CARSON IRRIGATION PROJECT

Classification	Amount	Cost per sq. mile
Horizontal Control:		
Labor	$ 285.51	$ 6.86
Corral Expense	44.50	1.07
Supplies	23.53	.57
* Miscellaneous expense	114.00	2.74
Total for horizontal control	$ 467.54	$11.24
Vertical Control:		
Labor	$ 124.89	$ 3.00
Corral expense	28.00	.67
Supplies	12.52	.30
* Miscellaneous expense	53.98	1.30
Total for vertical control	$ 219.39	$ 5.27
Plane Table Development:		
Labor	$1,643.46	$39.51
Corral expense	65.00	1.56
Supplies	52.96	1.27
* Miscellaneous expense	556.00	13.61
Total for plane table development	$2,327.42	$55.95
Draughting	204.14	4.90
General expense	323.25	7.76
Summary by Items:		
Labor	$2,053.86	$49.37
Corral expense	137.50	3.30
Supplies	89.01	2.14
* Miscellaneous expense	733.98	17.65
Draughting	204.14	4.90
Total field cost	$3,218.49	$77.36
General expense	323.25	7.76
Total cost		$85.12

* The item "Miscellaneous expense" consists of idle time for men and teams, moving camp, equipment depreciation and miscellaneous labor and supplies which could not be charged directly to any of the classes of work shown. General expense is administration Washington D. C., Portland, etc. Corral expense is time of teams. Location of work: Townships 18 and 19 N., R. 27 and 28 south of Carson River, in District 3. Area mapped 41.6 square miles; rough sandy country; scale 1 in. equals 400 ft.; contour interval 2 ft. Horizontal control developed from geodetic co-ordinates, and maps projected from polyconic projection; 61 linear miles of vertical control; 36 triangulation stations calculated and plotted; 36 permanent triangulation station marks placed; 8 B. M.'s placed (bronze); 2 camps. Mess house loss of $106.66 is not included with cost report. Average unit performance in square miles per plane table day. 41.6 plane table days, 132 unit performance, .315.

instrumentman who plotted the position of each point and wrote the elevation by it. The two rodmen worked out the country in strips about 300 ft. wide, the width depending on the roughness of the country and varying in length or distance from the table with the visibility of the rod. In this work the contours were not directly located, but a sort of cross-section of the country was taken, the rodmen giving the high and low points, general outlines of hills and pot holes, changes in slopes, low points in saddles and breaks in the contours in general. Each set-up of the table took in an area approximately 2,000 ft. square or 1,000 ft. on each side of the table.

After all shots necessary in each set-up were taken, the plane table man walked over the ground and drew in the contours from the plotted elevations combined with personal observation; verifying doubtful contours by three-pointing at the spot and getting additional elevations where necessary.

The rodmen soon became proficient in their work, after a period of instruction, and when they understood just what was desired very excellent results were obtained. A great deal depended, of course, upon the topographical eye of the topographer.

The average area covered each day by each party was 0.3 square mile. The topographers set a standard for their work of 400 shots per diem and always tried to exceed this standard if possible; 400 shots in one day, in addition to sketching all contours in the field, locating section corners and moving between set-ups, was usually a pretty fair day's work, but this mark was frequently exceeded. It can readily be seen that the number of shots taken indicates much better than the area covered how hard the parties worked during the day.

Cost of Stadia Surveys of 50,000 Acre Flood-Control Basin.—L. R. Howson gives the following in Engineering News-Record, Sept. 27, 1917.

Planning the flood-control system for the protection of Columbus, Ohio, necessitated the survey of an area of 50,000 acres for three reservoir sites of respectively 23,000, 18,000 and 9000 acres. This work is for the Franklin County Conservancy District, of which Alvord & Burdick, of Chicago, are the engineers. It was necessary that the survey information should be available for office computations as soon as possible, and that the surveys should be completed before winter. The stadia method was selected as combining speed with accuracy for the class of survey to be made. The methods of procedure, with instructions to parties and a system of reports for comparing the progress of the three parties, were devised by the writer. The survey was in charge of John C. Prior, resident engineer for the district.

The areas surveyed differ greatly in shape, steepness of slopes, percentage of wooded area and regularity of width or freedom from side ravines. The Delaware basin is the largest and has the most favorable topography for rapid stadia work. The survey covered 23,000 acres on a site about 14 miles long and from ½ to 2½ miles wide. The maximum difference in elevation is about 90 ft. There are only three large side ravines or creek channels.

The Dublin-basin survey covered 18,000 acres, of which about 20% is wooded. The area is 25 miles long, with an average width of about one mile and a maximum of about 2½ miles. The country is somewhat rougher than that in the Delaware basin, and has a range of 150 ft. in elevation. More numerous side ravines, some of which are virtually gorges, cut into the stratified limestone to depths of from 50 to 75 ft., with a scarcely greater width.

The Flint basin, though containing only about 9000 acres, has very rough topography and is largely wooded. Steep side ravines enter the river channel at frequent intervals, one every 600 ft. on each side of the river not being unusual. The basin is about 11 × 1½ miles.

Each party consisted of four field men and one office man, with salaries as follows: Chief of party, $115 to $125 per month; instrumentman, $75 to $85; draftsman (office), $85; two rodmen, $2 per day. All expenses were paid for the first three men. The rodmen received all expenses when away from home, which averaged about half the time. The work of the instrumentman and the draftsman was considered of equal importance. Rodmen were picked up locally, being selected for willingness, agility and physique. A bright country boy under a good chief or instrumentman soon becomes a first-class stadia rodman. For each party there was a Ford automobile with special body.

About nine hours per day were spent in the field. Primary traverse lines for several days' topography were run and closed before topography was started in that area. Primary traverse points were marked with oak stakes, and levels were taken on them. Secondary traverses were run as topography was taken. All these were closed in each night, so as to catch any errors. Two field books were used. The primary traverse line was carried in both books. The draftsman each day plotted the notes taken in the field on the preceding day. Bench marks were established at about ½-mile intervals. All available data were gathered as to adequacy of bridge and culvert openings.

Special rods were made to permit of rapid long-distance reading without eye-strain. The rods were of 1 × 4-in. clear poplar, 15 ft. long, painted in black and white and could be read for 3000 ft. as easily as the ordinary rod at only a fraction of that distance.

The instrumentman recorded his own notes. For the country surveyed a recorder's services were not warranted. For each set-up only about 15 shots could be taken.

The draftsman reduced all stadia notes with the aid of a K. & E. stadia computer. The notes were plotted with the use of an 8-in. full-circle paper protractor, which carried a scale. Both the elevation of the ground and the instrumentman's shot number were marked on the drawing for identification by the instrumentman in his daily checking of the map. The scale was 1 in. to 400 ft. for the Delaware and Flint maps, and 1 in. to 600 ft. for the Dublin map.

Each chief-of-party made a daily report on a post-card blank form. This gave the weather conditions, hours spent in the field, number of transit set-ups, number of readings taken and number of acres covered, with notes or remarks. These were compiled into weekly reports, as shown. Copies of these weekly reports were given to each party. While the figures therein were interpreted in the light of the conditions influencing them, they created an added impetus to make a good showing.

The form of the report was so arranged as to indicate the differences in the character of the topography of the three areas, which has been noted above. It is evident that where few shots per acre are taken, the topography is comparatively uniform. Where few shots per set-up are possible, the country is either wooded or rough.

The greatest area covered in any one week was 2190 acres. The greatest number of shots in any week was 1902, or an average of 317 per day. The average number of shots per day for all parties was slightly over 200, counting all time occupied in running level and traverse lines.

Table XV shows the summarized performance and costs of the three survey parties on this work. Table XVI has been prepared to show the costs of these and other stadia surveys where some details of execution, cost and character of land surveyed were available.

TABLE XV.—STADIA SURVEYS OF RESERVOIR AREAS AT COLUMBUS, OHIO

	Dublin	Delaware	Flint
Total acres surveyed	18,000	23,000	9,000
Av. acres surveyed per day	182	274	105
Av. hours in field per day*	9.1	9.5	9.1
Transit set-ups per day	11	6¾	8½
Shots per set-up	13.1	48.5	17.8
Shots per acre	0.78	1.19	1.44
Shots per hour	15.8	34.5	16.8
Cost, field work per acre	8.5cts.	6.35cts.	12.95cts.
Cost, map work per acre	2.3cts.	1.72cts.	4.40cts.
Total cost, field and map work per acre	10.8cts.	8.07cts.	17.35cts.

* No deductions for inclement weather.

TABLE XVI.—COST OF TOPOGRAPHIC SURVEYS MADE BY STADIA

Location	Acres surveyed	No. in field party	Purpose of survey	Contour Interval ft	Av. Acres per day	Av. shots per day	—Cost per acre— Field work cents	Total including map, cents	Remarks
St. Louis	15,000	7	....	3	60.6	300	40.07	82.5	....
Connellsville, Pa	107,500	...	Coal areas	10	....	...	6¼	18.1	....
Sunnyside, Wash	83,610	3 to 5	Irrigation	1	....	...	16.0	27.6	Land partly developed by orchard and canals, partly sage brush.
Riverside, Cal	7,450	5	Industrial dev.	2	74½	550	22.0	29.8	Rolling cultivated, 300 ft. range in elevation.
Iron Mountain, Mich	1,080	3	Sewer design	2	77	170	14.3	.....	Rolling no trees
Salmon River, N. Y	9,600	6–8	Reservoir sites	10	205	82	10	12½	Rough country about one-third wooded; maps to scale of 400 to 800 ft. per inch.
Fish Creek, N. Y	12,150	6–8	Reservoir sites	5	288	268	8½	12½	
Black River, N. Y	54,300	6–8	Reservoir sites	10	1,160	239	2.6	3.6	
Columbus, Ohio	......	...	....	..	....	...	.....	.....	....
Dublin Res	18,000	4	Reservoir sites	5	200	143	8.5	10.8	....
Delaware Res	23,000	4	Reservoir sites	5	250	328	6.35	8.07	....
Flint Res	9,000	4	Reservoir sites	5	100	153	12.95	17.35	....

Topographic Surveys.—The accompanying tables, compiled by Franklin & Co., Civil Engineers, Philadelphia, Pa., and published in Engineering News, May 28, 1914, give cost data for a number of different surveys. Under "Remarks" is briefly stated the character of the country, the method of doing work, the time of year, and any notes which affect the cost.

TABLE XVII.—COST OF TOPOGRAPHICAL SURVEYS

	Size	Unit day in hr.	Time		Cost			
			Field	Office (one man)	Field	Office	Total cost	Unit cost per acre
1.	308 acres	6½	40 days 3 men	10 days	$327	$45	$ 372	$1.20 per acre
2.	190 acres	7	22 days 3 men	9 days	$194	$38	$ 232	$1.22 per acre
3.	104 acres	7½	8 days 3 men	1 day	$74	$ 4	$ 78	$0.75 per acre
4.	300 acres	8	40 days 3 men	22 days	$480*	$92	$ 572	$1.90 per acre
5.	99 acres	7½	12 days 3 men	4½ days	$ 115	$23	$138	$1.20 per acre
6.	1,464 acres	8½	87 days 3 men	18 days	$ 1052	$92	$1144	$0.78 per acre
7.	11,264 acres (259 mi. of stadia)	8	222 days 4 men	65 days	$ 3791*	$386	$4177	$0.37 per acre (Topography $14.63 per mi. (stadia lines)

* Field cost includes subsistence.

REMARKS

1. 95 % = points established on 5-ft. contours with Y-level, and located with plane-table. 5 % = points established on 5-ft. contours by, and located with stadia traverse = (woods). Land hilly with rise of 120 ft. Survey made Aug. to Oct. Scale of map—1 in. = 100 ft.

2. 80 % = points established on 5-ft. contours with Y-level, and located with plane-table. 40 % = points established on 2½-ft. contours with Y-level, and located with plane table. 20 % = woods = points on 5-ft. contours established and located with stadia traverse. Land hilly with rise of 180 ft. Survey made in Dec. and Jan. Scale of map—60 in. = 1 ft.

3. 70 % = points established on 5-ft. contours with Y-level, and located with plane-table. 30 % = woods = points on 5-ft. contours established and located with stadia traverse. Land = rolling = rise of 80 ft. Finished plan not made. Survey made in June. Scale of map—1 in. = 100 ft.

4. 70 % = points established on 6-ft. contours with Y-level, and located with plane-table. 40 % = points established on 3-ft. contours with Y-level, and located with plane-table. 30 % = woods = elevations obtained by stadia and vertical angles-contours interpolated. Extra large number of buildings, railroads, etc. were located. Scale—1 in. = 100 ft. Land = rough and mountainous = rise of 430 ft. Survey made Nov. and Dec.

5. Points established on 5-ft. contours with Y-level, and located with plane-table. Land = rolling = rise of 60 ft. Survey made in Feb. and March. Scale of map—1 in. = 100 ft.

6. 90 % = points established on 10-ft. contours with Y-level, and located with plane-table. 10 % = woods = points on 10-ft contours established and located with stadia traverse. All roads traversed and chained.

Land = hilly = rise of 150 ft. Survey made Sept. to Dec. Scale of map—1 in. = 200 ft.

7. Survey made entirely with stadia. Tape never used. Rough and mountainous, streams, ridges, and 2 coal outcrop lines traversed and topography taken by stadia and vertical angles. Contours interpolated. Levels on transit lines carried along by stadia and vertical angles. Survey made Oct. to Feb. Rise in elev. = 1,150 ft. Stadia lines tied on to outline. Survey made 3 months previous. Scale—1 in. = 500 ft.

Location: 1 to 6 inclusive—, in Pennsylvania. 7, in West Va.

TABLE XVIII.—RAILROAD PRELIMINARY SURVEYS AND ESTIMATES

Size	Unit day in hrs.	Time — Field	Time — Office (one man)	Cost — Field	Cost — Office	Total	Unit cost per mile
1. 26 mi.	8½	74 days 4 men	24 days	$1450*	$144	$1594	$66.30
2. 27.5 mi.	8½	75 days 4 men	25 days	$1400*	$150	$1550	$56.40
3. 12 mi.	8½	50 days 4 men	35 days	$1011*	$165	$1176	$98.0
4. 5.1 mi.	8½	14 days 4 men	14 days	$ 236*	$43	$279	$54.60
5. 34 mi.	8	43 days 9 men (inc. axemen)	54 days	$ 848	$238	$1086	$32

NOTE.—Field cost includes transportation (except to Cuba). * Field cost includes subsistence.

REMARKS

1. Transit line chained. Topography taken with Y-level and cross-sections. Land = hilly and wooded. Projected line = 21 miles. Survey made June to Aug. Scale of map—1 in. = 200 ft.

2. Transit line chained. Topography taken with Y-level and cross-sections. Land = 50 % woods and mountainous and 50 % open. Scale of map—1 in. = 200 ft. Projected line = 27½ mi. Survey made Aug. to Nov.

3. Transit line chained. Extra large number of locations of towns, railroads, etc., were made. Land = rolling and open. Projected line = 9 mi. Topography with transit (stadia and vertical angles) and plane-table. Made in Feb. and Mar. Scale of map—1 in. = 200 ft.

4. Transit line chained. Large number of extra locations were made. Topography with transit (stadia and vertical angles) and plane-table. Land = rolling and open. Projected line = 3.6 mi. Made in May-June. Scale of map—1 in. = 200 ft.

5. Transit line partly chained and partly stadia. Scale of map—1 in. = 200 ft. Topography with Y-level and transit (stadia and vertical angles). Land = mountainous and heavily wooded. Survey made Nov. to Jan. No maps of country. Cost of reconnaissance therefore was greatly increased. Subsistence amounted to $18 per mile; was paid for by owner.

Location: No. 1—N. Carolina
No. 2—Virginia
No. 3 & 4—Pennsylvania
No. 5—Cuba.

In taking the Pennsylvania topography each 5-ft. contour was traversed by the rodman along points established by the Y-level and located by plane-table. The excessive cost of the fourth item was due to the extra large number of railroad tracks, buildings, etc., that were located.

The topography in West Virginia was taken by running stadia and vertical-angle transit lines along all streams, ridges and two coal outcrop lines, one of which was about one-third and the other two-thirds of the distance up the mountainside. Elevations were taken from all these lines (which formed a gridiron system) and the 50-ft. contour lines were interpolated.

The railroad preliminaries (with the exception of the Cuban work) were all tape-measured transit lines, with topography taken either with cross-sections, stadia and vertical angles or the plane-table.

In Cuba, the transit line was partly measured with tape and partly by stadia and vertical angles. No maps of the country could be found so that the reconnaissance was necessarily much more extensive than usual, thus increasing the cost. The owner provided subsistence of the men, which amounted to about $18 per mile.

Weekly Report, Week Ending October 23, 1915

	Weather	No. hours in field	No. transit set-ups	No. stadia readings	Acres surveyed	Unit cost field work	Unit cost including map	Av. cost to date
Dublin reservoir								
Monday	Rain	8½	16	216	250	......	......	.....
Tuesday	Fair	9½	14	98	50	......	......	.....
Wednesday	Fog and fair	8½	18	108	50	......	......	.....
Thursday	Fair	9½	13	160	200	......	......	.....
Friday	Fair	10	14	220	250	......	......	.....
Saturday	Fair	10	17	153	220	......	......	.....
Total		56	92	955	1,020 10,190 to date	$0.093	$0.126	$0.16
Delaware reservoir:								
Monday	Rain 3 hrs.	10	8	229	275	......	......	.....
Tuesday	Fair	10	6	338	350	......	......	.....
Wednesday	Fog	10	9	190	120	......	......	.....
Thursday	Fair	10	6	336	275	......	......	.....
Friday	Fair	10	7	314	250	......	......	.....
Saturday	Fair	10	7	258	350	......	......	.....
Total		60	43	1,665	1,620 11,975 to date	$0.058	$0.074	$0.09
Flint reservoir:								
Monday	Rain	7	10	99	70	......	......	.....
Tuesday	Cloudy	10	10	74	140	......	......	.....
Wednesday	Fair	10	15	205	160	......	......	.....
Thursday	Fair	11	12	115	70	......	......	.....
Friday	Fair	10	16	229	200	......	......	.....
Saturday	Fair	10	19	250	200	......	......	.....
Total		58	82	972	840 3,428 to date	$0.100	$0.134	$0.24

Remarks.—Dublin Delayed 2½ hrs. rain and fog, 6.7 mi. Secondary Traverse Delaware. Delayed 3 hrs. fog; 10.2 mi. Secondary Traverse Flint Delayed 3 hrs. rain 8 mi. Secondary Traverse.

"Financial Costs," Frequently Underestimated.—Engineering and Contracting, March 6, 1912, gives the following.

It is rare that an engineer's estimate of the cost of a project contains an adequate allowance for what may be called "financial costs." In fact, even the most self-evident of these "financial costs," interest during construction, is often omitted from cost estimates. Sometimes such omissions are purposely made by engineers, especially when it is known that the owners or promoters will themselves make an estimate of the "financial costs." We question, however, whether it is ever wise for an engineer to omit any element of cost that he is capable of making, unless he is specifically instructed to return an estimate of the physical property only.

What are the "financial costs" of a project? They may be classified as follows:

1. Organization cost; i.e., legal and administrative costs (other than engineering and superintendence), general office expenses, etc.
2. Taxes during the construction period.
3. Brokerage fee or discount involved in marketing securities.
4. Interest on the capital tied up during the construction period.
5. Development cost (being the sequel to interest during construction) or the accumulated deficit below a "fair return" on the invested capital up to the time that a "fair return" begins to be earned.

This last element of "financial cost" is one whose existence has always been recognized by experienced promoters, but one that, until quite recently, has never appeared in any engineer's estimate that we have seen. *Yet failure to provide capital with which to meet the development cost of a project has been the cause of innumerable receiverships.*

During the past year we have published several articles discussing the development cost, or "going value," of public utilities, such as railways; and the method of deducing the development cost by the aid of the ledgers of a company has been illustrated by several examples. It may be added that the writer has appraised the property of about a dozen public utility companies within the last year, and has deduced the development cost in each case. It is rare that the development cost has been less than 25 per cent of the cost of the physical plant.

In Engineering and Contracting Feb. 14, 1912, Norman E. Webster, Jr., discusses "Methods of Financing Irrigation Developments." Mr. Webster gives estimates of the "financial costs" of irrigation projects, expressed as percentages of the cost of the physical plant. The following is a summary of his estimate of these cost items:

	Per cent
Organization and promotion	10
General administration	10
Interest and development cost	21 to 30
Total, exclusive of bond discount	41 to 50

Mr. Webster does not use the expression development cost, but classes it under interest lost on the investment up to the time that the property begins to make sufficient net earnings to meet the interest charges. He estimates 6 per cent per annum on the entire cost of the plant for a period of 3½ to 5 years, making a total of 21 to 30 per cent to cover the interest lost on the investment. He also points out that all the bonds must usually be sold in advance of the first construction work, which results in a long nonremunerative period. For the comparative purposes the following percentages used by the writer in recent estimates of electric railway properties may be of interest.

	Per cent
Engineering and supt. (5 %) and business administration (5 %)	10
Legal, taxes and other general expenses	1½
Interest during construction	5
Brokerage fee (cost of selling bonds)	5
Development cost	30

Calling the cost of the physical plant unity (1), we have the following;

	Cost
Physical plant (incl. 5 % for contingencies)	1.000
Add eng., supt. and adm. (11½ %)	0.115
Total	1.115
Add 5 % of 1.115 for interest	0.056
Total	1.171
Add 5 % of 1.171 for brokerage	0.059
Total	1.230
Add 30 % of 1.23 for development cost	0.369
Grand total	1.599

It is difficult for some people to look upon the development cost—the accumulated deficit below a fair return on the investment—as being a real cost. They argue that a deficit can not be a source of value, but is the reverse. Yet, curiously enough, they concede that interest during construction is an element of the cost of a property. When it is pointed out that the development cost is merely a sequel to interest during construction, it becomes more apparent that the development cost is an essential element of the cost of the going concern.

Can a deficit be a cause of value? Yes, if it is not a deficit that connotes a *permanent* loss. A deficit arising from a fire or a burglary can not be an asset in the absence of insurance. But a deficit arising from a necessary expenditure, either to create a physical plant or to create the business of a going concern, is a wholly different sort of deficit. Such a deficit is, in fact, an investment, which, in all probability, will ultimately yield an adequate return if the project is one that is well managed and is not begun too far ahead of the times. Perhaps no better example can be found to illustrate the confusion that a word can cause than is to be found in this word deficit. Since deficit often denotes a permanent loss, it impresses the mind that there is an incongruity in the argument that any deficit can be the measure of an asset. The word deficit is merely a symbol to denote an outlay of cash. If the outlay is irrecoverable—as in the case of loss of uninsured property by fire—the deficit decreases the assets. But if the outlay is recoverable—as in the case of money reasonably spent for advertising an article or promoting an irrigation project—the deficit increases the assets.

Honest promoters never incur temporary deficits in fair return upon their investments without belief in the ultimate recovery of the deficits. But many an honest promoter is too sanguine as to the short duration of the deficit period—the development period. It is clearly the function of the modern engineer to study the development cost of all sorts of projects of an engineering nature, with a view to estimating development costs with some degree of accuracy. Protection of his clients, and of the public whom his clients seek to interest in a project, should be the prime consideration of every engineer who is called upon to design a plant and estimate the cost. Full protection can only be given by a correct and full estimate of cost up to the time that the project will begin to yield an adequate return on the invested capital.

Contractor Analyzes Overhead Costs from Five-Year Records.—The following is given in Engineering News-Record, April 11, 1918.

Overhead is the deceptive part of a contractor's costs on a sewer contract. So stated Stanley D. Moore, president of the Moore-Seig Construction Co., Waterloo, Ia., at the 1918 annual meeting of the Iowa Engineering Society. Less than 10% of the contractors of the country are successful or even solvent, in his opinion. Further notes from his paper follow: "In this age of production we have kept our eyes only on the lessened cost of the actual operation and have forgotten that much of this saving is taken up in overhead charges that did not exist formerly. The unit basis for moving earth by hand may be 25 cents per yard. The same operation by machine may be performed for 10 cents per yard, but the overhead charges on the machine may equal, if not exceed the 15 cents saved. The only advantage of the machine is a gain in time and escape from labor shortage."

An analysis of overhead charges, taken from records of Mr. Moore's company over a period of five years, represents $500,000 worth of sewer work. It was done in better than average soil, at better than average price, handled with better than average efficiency by a well-equipped, well-financed and well-organized concern. Figures for 1917 were omitted purposely because of the unusual conditions under which the firm sustained a loss.

Contract prices in this analysis were distributed as follows: Profit, 1.6%; overhead, 18.4%; material, 18.0% and labor, 62.0%.

In the table, job expense includes freight on tools, drayage, transportation, straight time men, bunk houses and storage. In the consumed material item are such things as lumber, jute, dynamite, coal, gasoline, kerosene, cement bags and boots.

Figured on the basis of net instead of gross cost the 24% becomes 31.7% and to yield 10% on one's money the total bid should be 146.4% of the net cost made up of net cost 100%, overhead 31.7%; and profit 14.7%. To yield 15% the overhead is the same, 31.7%; but profit is raised to 22.8%, making the total bid 154.5%.

Segregated Overhead Charges

Item	Five-yr. average 1911–16	Estimate for 1918	Item	Five-yr. average 1911–16	Estimate for 1918
Job expense	1.4 %	1.7 %	Dues contractors' association	1.8 %	1.8 %
Maintenance	0.6	0.6	Office expense	0.6	0.7
Plant repairs	1.5	1.8	Salaries	2.3	2.3
Small tools	1.1	1.3	Traveling	1.3	1.5
Depreciation	1.0	2.0	War tax	......	0.5
Consumed material	2.4	2.4	Interest on investment	......	0.5
Bonds	0.7	1.7			
Insurance	1.6	1.9			
Interest	1.1	1.3			
Discount	1.0	2.0		18.4 %	24.0 %

The items of cost for which money was actually paid out compared with those for which the engineer usually allows are listed as follows: Engineer's costs usually cover only sewer pipe, bonds, insurance, labor, discount and association dues, but he forgets, said Mr. Moore, jute, city councils' special requests, cement, tools, inefficiency, depreciation, interest, errors, salaries, bad work, attorney's fees, taxes, transportation, engineer's errors, engineer's delays, engineer's estimate, maintenance, bad weather, freight on tools, straight time, storage, lumber, repairs, shipping delays, office expense, manholes, drayage, bad luck, traveling expense, water pipe and gas mains.

Finally, said Mr. Moore, there has been too much secrecy on the part of the contractor, too little information given by the engineer and too much suspicion on the part of the communities, also a regrettable lack of consideration of the rights of the contractor by engineers. Both engineers and contractors guess too much.

Fixed Plant Charges.—The ordinary "fixed charges" on a plant are (1) interest, (2) depreciation (exclusive of current repairs), (3) insurance, and (4) taxes. Often to these items should be added the cost of housing the plant when idle.

Depreciation is the loss in value that occurs in spite of current expenditures for maintenance. Depreciation may be due to the forces of nature or to the "progress of the art" which renders a plant obsolete. Excavating plant is commonly estimated to suffer a depreciation of 10 to 20% per annum. Sometimes the entire first cost of a special plant is charged up against one job, if there is not a strong likelihood of using it again.

Insurance and taxes are usually so small relative to depreciation that they are not separately estimated, but a liberal allowance is then made for depreciation.

Repairs should be estimated as an operating expense item entirely separate from depreciation, for repair costs depend more upon the activity of the plant than upon the lapse of time, whereas depreciation usually progresses with the lapse of time even in the absence of any use of the plant.

The annual "fixed charges" should be divided by the probable number of days actually to be worked per annum. As previously stated, the average is 150 days or less, for most excavating plants in America.

Fixed charges, repairs, the cost of plant installation and shifting, and time lost through delays from breakdowns, etc., are commonly underestimated. In addition, the cost of surplus or standby plant is seldom included in estimates of cost, yet there are few jobs where it does not pay to have a considerable investment in plant that is on hand for emergencies. Extra cars, wagons, scrapers, plows, pumps, etc. are nearly always necessary.

Operating Expense.—Operating expenses may be divided into direct expense and joint, general overhead expense, which together embrace all costs except the "fixed charges" already discussed.

Direct expenses are those directly assignable to a given number of yards of excavation in a given place.

Joint, or general, or overhead expenses are those that must be allocated or prorated because they are not directly assignable to a given yardage.

Preparatory expense is the expense incurred in installing the plant, building construction trails and roads.

Dismantling expense is the cost of dismantling and removing the plant and outfit.

Shifting expense is the expense of moving the plant and outfit from one part of the job to another part of the same job.

Idleness expense is the expense incurred when the plant is not engaged in excavating, preparing, shifting or dismantling.

Productive expense is the expense incurred when the plant is actually working.

Although it is not customary to analyze expenses in this manner, it is wise to do so at least occasionally on every job, not only to be able to estimate costs of future work with greater accuracy but to effect reductions in the cost of the work in hand.

Schedule of Contractors Fees on Government Work.—The following matter, given in Engineering and Contracting, April 17, 1918, is a revision of the percentage fees on Government contracts made by the Emergency Construction Committee of the Council of National Defense. Under the old schedule the fee for work costing under \$100,000 was 10 per cent; 8 per cent for work costing over \$100,000 and under \$125,000, 8 per cent for work over \$125,000 and under \$250,000, \$20,000 for work over \$250,000 and under \$266,666.67 and 7½ per cent for work costing more than the latter figure and under \$500,000. For work costing over \$535,714 and under \$3,000,000 the old fee was 7 per cent; and for work costing over \$3,250,000 and under \$3,500,000 it was \$210,000 and for work costing over \$3,500,000 the old fee was 6 per cent.

Under the revised schedule no fee is to be in excess of \$250,000. The revised schedule follows:

Cost of work	New fee
Under \$100,000	7 %
Over \$100,000 and under \$125,000	\$ 7,000.00
Over \$125,000 and under \$250,000	
Over \$125,000 and under \$450,000	6½ %
Over \$250,000 and under \$266,666	
Over \$266,666 and under \$500,000	
Over \$450,000 and under \$500,000	29,250.00
Over \$500,000 and under \$535,714	
Over \$500,000 and under \$1,000,000	6 %
Over \$535,714 and under \$3,000,000	
Over \$1,000,000 and under \$1,100,000	60,000.00
Over \$1,100,000 and under \$1,500,000	5½ %
Over \$1,500,000 and under \$1,650,000	82,500.00
Over \$1,650,000 and under \$2,200,000	5 %
Over \$2,200,000 and under \$2,450,000	110,000.00
Over \$2,450,000 and under \$2,850,000	4½ %
Over \$2,850,000 and under \$3,250,000	128,250.00
Over \$3,000,000 and under \$3,500,000	
Over \$3,250,000 and under \$4,000,000	4 %
Over \$3,500,000	
Over \$4,000,000 and under \$4,250,000	160,000.00
Over \$4,250,000 and under \$4,775,000	3¾ %
Over \$4,775,000 and under \$5,175,000	179,062.50
Over \$5,175,000 and under \$5,725,000	3½ %
Over \$5,725,000 and under \$6,225,000	200,375.00
Over \$6,225,000 and under \$6,825,000	3¼ %
Over \$6,825,000 and under \$7,400,000	221,812.50
Over \$7,400,000 and under \$7,750,000	3 %
Over \$7,750,000 and under \$8,350,000	235,500.00
Over \$8,350,000 and under \$8,800,000	2¾ %
Over \$8,800,000 and under \$9,650,000	242,000.00
Over \$9,650,000 and under \$10,000,000	2½ %
Over \$10,000,000	250,000.00

CHAPTER XXV

MISCELLANEOUS COSTS

References.—Further costs, of a nature similar to those included in this chapter, are given in Section XV of Gillette's Handbook of Cost Data.

Cost of Bath House, Lincoln Park Bathing Beach, Chicago.—Engineering and Contracting, May 10, 1911, describes an attractive and economical building for the accommodation of the bathers at Lincoln Park, Chicago. The idea of supplying several lockers for each dressing room or booth is unusual and in this way less booths are required to serve a given number of persons. Clothing is not left in the booths, but is placed in one of the lockers.

The space covered by the buildings is 264 ft. long by 54 ft. wide. This area is enclosed by a fence about 7 ft. in height. The fence is built of stained rough plank laid horizontally on edge, the cracks being closed with battens. The low roof of the enclosed houses, projecting somewhat above the fence line, gives a pleasing effect. The structures are all frame and are built of rough lumber with concrete floors 6 ins. thick.

The 4 × 4 in. posts in the buildings were supported on concrete pedestals carried down 4 or 5 ft. into the sand.

The work was done by the Park Commissioners by day labor and the costs are given below. These costs include everything except electric wiring and lights.

Labor:	
Engineering	$ 158.55
Foreman, 95 hrs	41.31
Teams, 94 hrs	27.50
Teamsters, 107 hrs	28.51
Common labor, 5,491 hrs	1,384.63
Carpenter labor, 8,716 hrs	4,986.56
Plumbers, 240 hrs	68.97
Total labor	$ 6,696.03
Material:	
Lumber	$ 4,506.68
Paint, etc	255.19
Hardware	1,262.22
Plumbing fixtures	1,086.34
Water system	142.57
Sewer system	994.55
Foundations and concrete floors	264.36
Tools	3.69
Total materials	$ 8,515.60
Grand total	$15,211.63
Cost per booth	$ 48.75
Cost per locker	7.41

The above labor was paid at various rates of wages. The carpenters and helpers rates varied from $2.50 to $5 per 8 hour day. The teamsters were paid about $60 per month. The common labor rate was 25 and 30 cts. per hour. Plumbers received from $2.25 to $2.75 per day. The foremen's time is distributed between this work and other work upon which they were engaged at the same time.

Cost of a Reinforced-Concrete Stadium, Brooklyn, N. Y. (Engineering News, May 21, 1914).—The construction of a large reinforced-concrete baseball stadium at the Federal League Grounds, Fourth Ave. and 3rd St., Brooklyn, N. Y., was commenced Mar. 9, 1914. On Apr. 20, the last concrete was placed for the structure. On May 5, all forms were stripped and on May 11 the completed stand was turned over to an audience of 15,000 people viewing the first game of the season. The work cost about $275,000. The rate of erection is shown in the accompanying tabulation.

The plans and specifications for the stadium are the same as those prepared for the Federal League Baseball Grounds in Chicago. The principal modifications were as to grades and code regulations. The Chicago contract was signed on Feb. 27 and completed on Apr. 23; the time elapsed being the same as on the Brooklyn stands. The work was carried out in Brooklyn in accordance with specifications, but in Chicago the contractors were obliged to substitute steelwork for the reinforced-concrete work specified, because the Chicago Building Department would not permit such a concrete structure to be used until the concrete had set 40 days. It will be noted that at Brooklyn only 23 days elapsed from the last pouring of concrete to the loading of the stands.

The Contract.—The contract comprised all work necessary for the erection of a curved-plan grandstand 865 × 119 ft. in area and about 55 ft. high; a bleacher, and a 20-ft. brick wall 1100 ft. long, 12 in. thick, with 20-in. brick piers spaced on 20-ft. centers. Each pier of the brick wall was reinforced against wind pressure by two 8-in. channel uprights, 14 ft. high and kneebraced at the bottom. The channels were fastened to the wall by connecting rods embedded in the brickwork. The grandstand is of reinforced concrete from the ground to the top seat-steps. It is supported on eight reinforced-concrete columns of length decreasing from 29 ft. at the rear or outer chord to 3 ft. at the front or inner. The seat-steps rest on concrete girders 12 in. wide spanning these columns.

The steel roof of the grandstand is carried on two lines of steel columns—numbers 1 and 5, counting the outer chord as number 1. The roof slopes upward from the outer chord to the other support,

PROGRESS SCHEDULE

Grandstand and pavilion	Progress schedule proposed Start	Progress schedule proposed Finish	Actual finish date	Average number of men Laborers	Average number of men Mechanics
Excavation 4,000 cu. yds.	Mar. 9	Mar. 21	Mar. 27	80	5
Concrete footings, 1,500 cu. yds	Mar. 12	Mar. 24	Mar. 29	70	5
Backfilling, 2,500 cu. yds	Mar. 18	Mar. 26	Mar. 30	25	1
Grading and removing 1,500 cu. yds, earth with 5 teams	Mar. 18	Mar. 28	May 1	20	1
Three concreting towers completely equipped	Mar. 11	Mar. 19	Mar. 19	10	12
All forms set	Mar. 13	Apr. 27	Apr. 6	4	25
Pouring 5,000 cu. yds. concrete	Mar. 25	Apr. 25	Apr. 20	72	6
All forms removed	. . . . . .	. . . . . .	May 5	. .	. .

a distance of about 66 ft. and a slope of about 1:5. From the second point of support, it cantilevers out 24 ft. 9⅛ in., the upper chords of the trusses declining toward the lower throughout this distance and joining at the end. This whole grandstand structure is designed with the idea of eventually adding another tier (steel) of seats. When this is done, the roof, with the exception of the cantilevered portion, will be raised. The cantilevered section will form the inside of the new tier which will continue rising to the outer chord.

The Chicago footings were designed to carry 5000 lb. per sq. ft.; but borings in Brooklyn showed that the soil was only good for 2000 lb. per sq. ft. This necessitated the enlarging in plan of 380 footings in order to obtain sufficient carrying capacity. All footings over 8 × 8 ft. in plan were made reinforced-concrete footings; those larger were made of plain concrete stepped up from the base to the column.

Construction.—In addition to the feature of speed, that of efficient organization should be noted. The timber was cut to size by two electric saws. The lumber and reinforcing rods were trucked to the field and distributed where needed. The plant comprised three 90-ft. towers, equipped with concrete chutes, 96 ft. long; ¾-cu. yd. electric-driven mixers, and electric hoists. The plant was erected at the exterior chord of the work and all concreting materials were delivered at the plant.

The concrete was mixed steadily and from the tower was conveyed by chute to a central wood distributing-hopper of about 5-tons capacity. From this hopper, smaller chutes radiated. The hopper acted as a reducing valve.

The main chutes were set at an inclination of 1:4 and worked satisfactorily at this angle. The wetness of the mix was varied with temperature in order to secure uniform flow. The slope of the stand was also about 1:4 and it was feared that the wet concrete would bulge up the lower steps from the upper; but by pouring the concrete in the upper-step forms, it had set sufficiently when it reached the lower step to prevent the expected bulging.

The average total number of men engaged in the work was about 875, divided as follows: carpenters, 250; carpenter's helpers, 60; metal lathers, 75; concrete laborers, 150. In addition to these, there were about 15 timekeepers, foremen and draftsmen. The men engaged in concrete work numbered 550. The balance, about 325, were bricklayers, structural-steel men, painters, plumbers, sheet-metal men, plasterers and laborers.

Cost of the Concrete Palmer Memorial Stadium, Princeton, N. J.—Engineering and Contracting, May 26, 1915, gives the following:

In plan the Princeton stadium is horseshoe-shaped, with two straight parallel sides, each about 454 ft. long, connected at one end by a three-centered curved portion. The total length of the structure is about 652 ft., its width, center to center of outside columns, is 520 ft., and its height, to the top of the main entrance towers, is 72 ft. At the lower, or inside, face of the stadium there is a 3-ft. passageway around the entire structure. The clear playing field is about 250 ft. wide by 510 ft. long. The structure is surrounded by a high iron picket fence forming an enclosure into which the spectators are admitted through turnstiles located opposite to the main entrance at the curved end. From this enclosure the people enter the stadium through 26 runways located at uniform distances around the structure. These runways are inclines and extend from the exterior ground level to openings located at about mid-height of the stadium.

Construction Features.—In leveling the field steam shovels and carts were used, about 40,000 cu. yds. of earth being moved in this way. After the area was excavated to the proper level, the playing field was covered with a 30-in. fill consisting of successive layers of broken stone and cinders, with open-joint drain tiles along the bottom. This base was then surfaced with new turf.

The concreting work was carried on by two separate gangs, each having an organization complete in itself. The work was started at the open end of the stand, one gang operating on each wing. The keen competition which developed between the two gangs resulted in exceedingly rapid progress.

The concrete was hoisted in 160-ft. steel towers and was chuted into place through long flexible chutes suspended from a cableway. These towers were placed back of the stand, being so located that it was possible to pour about two-thirds of one straight side in these positions. They were then moved to points near the curved end, and the structure completed.

The hoisting bucket in each tower was charged from a ¾-cu. yd. motor-driven mixer, the materials being delivered to the mixer in wheelbarrows, from storage piles located near by. With the use of a double set of three-bay forms for each wing the concreting operations were made continuous, the first set of forms being moved and re-erected while the concrete in the second set was being poured.

The first concrete was poured on June 29, 1914, and the two wings were joined together on Oct. 3, 1914, the best day's run being 227 cu. yds. of concrete poured by one gang in 10 hours. The entire structure was completed in 178 working days.

There were used in the construction of the stadium 78,000 bags of cement, 6,000 cu. yds. of sand, 11,000 cu. yds. of stone, 450 tons of reinforcing rods, 375,000 sq. ft. of "Clinton" wire mesh, and 1,670,000 ft. B. M. of lumber.

The stadium was completed during the latter part of 1914 at a cost of about $300,000. This makes the cost per seat about $7.25. This figure compares favorably with the cost of other stadia as given in Engineering Record, March 28, 1914 as follows:

	Cost per seat
Harvard Stadium	$13
Boston Baseball Club	24

Cost of a Reinforced Concrete Sand Bin.—G. A. Flink, in Engineering and Contracting, March 12, 1913, describes a reinforced concrete sand bin built by common labor in the employ of the Lewistown Foundry & Machine Co., of Lewistown, Pa., in conjunction with a sand mill erected for the Berkeley Springs Sand Co., at Berkeley Springs, W. Va.

Bids were invited for this work, and ranged from $12,000 to $6,900; this being considered too high, the Foundry and Machine company decided to build the bin themselves. A good superintendent was employed, material ordered and work started, the engineer who prepared the design assuming charge of the work, and keeping in touch with it by means of daily reports, and an occasional visit.

Shoring had to be erected to keep the railroad track in place while excavating for the footings. These latter were under water at times, and 62 hours' labor was spent at the pump. The concrete was a 1:2:4 mixture turned out by a batch mixer, and hoisted to the top on an elevator, from where it was wheeled to the place desired in barrows. Careful spading was kept up at all times. Work was broken on top of the column-footings while the forms for the columns were being placed, and at top of columns while building beam forms and placing the reinforcement. No surface finish was considered needed, the concrete filling the planed forms to perfection, and no objection being advanced to the appearance of the grain of the wood on the concrete surfaces, or to the ridges caused by the joints between the boards.

The bin, 100 by 16 ft. in plan, is divided into four compartments, the interior dimensions of which were 14 ft. 4 ins. wide, 23 ft. 8.5 ins. long and 17 ft. deep. The bin is supported on 18 columns 24 by 24 ins. and 26 ft. high. The whole structure, with the exception of roof, is of reinforced concrete.

A reinforced concrete slab roof on steel trusses was designed for the bin, but a timber and slate Mansard roof was built in its place.

The following data show the cost of structure:

Supervision and labor	$2,655.40
Material (sand, cement, stone, steel and lumber)	2,568.91
Freight and express	195.54
Electric light	7.25
Hauling, telegrams, telephone, mileage, gasoline, oil	185.18
Total cost	$5,612.28

This total cost was distributed as follows:

Supervision (hours)	874
Carpenters (hours)	3,386
Steel gang (bending and placing) (hours)	1,159
Helpers (hours)	110
Laborers (hours)	4,374
Broken stone (cu. yds.)	250
Sand (cu. yds.)	118
Concrete (cu. yds.)	415
Reinforcing steel (lbs.)	45,135
Inch lumber (ft. B. M.)	16,700
Timber, ranging from 2 by 4 to 4 by 6 (ft. B. M.)	16,000
Molding, ¼ round, etc. (lin. ft.)	3,000

Cost of Concreting Swimming Pool at Riverview Park, Chicago.—Engineering and Contracting, Nov. 3, 1915, gives the following:

The pool has over-all dimensions of 148.25 ft. long by 35 ft. wide with walls varying from 5 to 12 ft. in height. (A large cut showing detailed dimensions and type of reinforcement is given in Engineering and Contracting.) The capacity of the tank is about 450,000 gals.

The form work was all done in one week. One 8 hr. shift was worked per day. The concrete was all placed in 2½ days. No water-proofing compound was incorporated in the concrete but as soon as the forms were removed the inside surfaces were given three coats of Ironite. These coats were applied in 2 days' time. One leak developed after the pool was filled. It was located at the junction of the sidewall and the floor. The leakage, which amounted to ¼ in. in level per day, was not large enough to warrant emptying the pool for making repairs. After two or three weeks' service the leak silted up and the flow from this point ceased. The pool is filled with the comparatively clear water drawn from the Chicago mains.

All the concrete was mixed in a ¾-cu. yd. batch mixer set about 40 ft. outside the building. A runway was built up leading from the mixer to the forms. Concrete was conveyed from mixer to forms in Ransome concreting buggies holding 6 cu. ft. each. Two extra men were required to help in pushing the buggies up the incline. The concrete in the floor was all chuted to place—

the buggies discharging into the chute. An 8-ft. wide platform was constructed all around the wall forms and the buggies, running on this platform, were dumped directly into the wall forms.

The forms were made up of panels 2 ft. wide by 15 ft. long. The contractor's labor cost for placing the concrete was $1.20 a cubic yard. The form labor cost 15 cts. a square foot. Carpenters were paid 70 cts. an hour and laborers 40 cts.

The pool contains 220 cu. yds. of concrete. The contract price, exclusive of excavation, was $3,700, or $16.80 per cu. yd.

Cost of Excavating and Concreting a Swimming Pool.—The following is given by A. Crane, Sup't. for the contractor, in Engineering and Contracting, Nov. 2, 1910.

A swimming pool recently built in the annex to the Sinai Temple, Chicago, was excavated under rather difficult conditions, owing to the water encountered and the nature of the soil, which was clean sand. The excavation for the basement of the building was carried 8 ft. below the street level and that for the pool was carried 14 ft. deeper, 11½ ft. of which was below the level of the ground water. The area containing the pool was enclosed by 3-in. tongued and grooved sheeting, the lines of sheeting being 71 × 32 ft. This area was 11 ft. greater each way than the inside dimensions of the pool and allowed for the walls which were 1 ft., 6 ins. wide at the top and 3 ft., 6 ins. wide at the bottom. The sheeting was driven by hand with a wooden maul, two men being kept at this work while the excavation was being carried on.

In order to keep the site unwatered a point system was used. A 3-in. main was laid around the upper edge of the excavation and 1¼-in. points about 16 ft. long were placed every 3 ft. along the inside of the sheeting and connected by hose to the 3-in. main. The 1¼-in. points consist of galvanized iron pipes having solid cone-shaped points at the lower ends. From the lower ends up for 36 ins. they were perforated with ⅛-in. holes and screened with fine wire mesh. As the excavation proceeded the points were lowered and kept just low enough to unwater the site as low as the excavation proceeded. It was necessary to have one man looking after the points, giving them a twist once in a while to keep the particles of sand from clogging the wire mesh. Two Nye pumps, size No. 6, were used, one being set at each end of the work. These pumps were attached to the main so that each pump handled the water from half of the area. Toward the end of the work, however, the water was held back by the concrete floor and only one pump was necessary. A gage on each of the pumps showed them to be creating over 30 ins. of vacuum at every stroke.

The work was all done by hand. The material was shoveled to a scaffold and on to the bank behind the sheeting and then shoveled back to make space for more. The material in the center of the pit had to be thrown toward the edge before being shoveled onto the scaffold thus making four handlings for that part. When the excavation had reached about 3 ft. depth, 12 × 12-in. braces were set in to hold the sheeting.

They were placed about 8 ft. apart, on centers, and butted against 8 × 18-in walling timbers.

In concreting, a Smith ½-cu. yd. mixer, operated by steam, was used, and plank runways led from the mixer out over the work. Sterling buggies of about 7 cu. ft. capacity were used for transporting the concrete. A floor 12-ins. thick was put in and walls battered on the outside, from 3 ft., 6 ins. at the bottom to 1 ft., 6 ins. at the top. The walls varied in height from 4 ft.

to 9 ft.,6 ins. The forms used consisted of 1 × 6-in. sheathing and 2 × 6-in. studding placed 16 ins. on centers.

The number of laborers used on the work varied considerably as this job was only a part of the work on a large building and men were put on and taken away as necessity required. The largest number used on the excavation at any one time, however, was 25 men. Common labor at 37½ cts. per hour was used for excavating and concreting and carpenters at 62½ cts. an hour built the forms. The costs of all labor was accurately distributed and resulted as follows:

96 points at \$1.00 each	\$ 96.00
2,500 sq. ft. sheet piling at \$0.07	175.00
800 cu. yds. excavation at \$0.20	160.00
70 cu. yds. floor slab at \$0.65	45.50
150 cu. yds. walls at \$0.75	112.50
3,000 sq. ft. forms at \$0.04½	135.00
Total labor cost	\$724.00

The pumps were worked continuously in 3 shifts of 8 hours each. The cost of the labor and pumping amounted to about \$800.

One foreman at \$8 per day was also charged to the work.

A coat of Hydrolithic waterproofing cement was put on the interior surfaces, after which a veneer wall of white enameled brick was laid.

Cost of Out-Door Swimming Pool.—Engineering and Contracting, Dec. 10, 1919, gives the following:

The Clifton Park swimming pool in Baltimore, Md., is one of the largest artificial pools in the United States. It was constructed in 1915 under the plans of the engineer of the City Plant Department, which has charge of the operation of the pool.

Site of Pool.—The area selected for the pool construction was triangular in shape, bounded on two sides by city streets intersecting at right angles, with a high railroad embankment, along the other side, containing about 9 acres. The construction of the highways was upon filled ground similar to the railway embankment, but of much less elevation, so that the area without drainage would have formed a natural pond or pool.

General Features of Pool.—The pool is elliptical in shape, with a maximum diameter of 595 ft. and a minimum diameter of 340 ft.

The deep water section of the pool is also elliptical in shape, with a minimum diameter of 170 ft. and a maximum diameter of 356 ft. This deep water ellipse is at one side of the pool area, and from the line of this ellipse the depth increases at a 10 per cent grade. From the shallow edge of the pool to the deep water ellipse, the grade one-half of the way is 1 per cent and for the balance of the way 1½ per cent.

The maximum depth is 9 ft. and the minimum 3 in. The pool has a capacity of 4,500,000 gals., with a water area, when filled, of 3⁷⁄₁₀ acres.

The water supply is obtained through the city reservoir and filtration plant from the Gunpowder River. The water is supplied through one 8-in. inlet pipe and through one needle shower with 1½-in. supply pipe. There is one outlet or drain pipe 14 ins. in diameter. By regulation of inlet and drain valves there is a constant circulation of water, and the pool is emptied and cleaned annually.. The city filtration is depended on for the purity of the water and chemicals are not used. Bacteriological tests of the water have never been made.

Preliminary Work.—A 48-in. combination storm water sewer line from a residential section north of Clifton Park had been carried to and under the railroad embankment into the triangular area where the line was partly exposed. There was also a considerable wash from the railroad embankment, and by way of preparation for the pool construction considerable grading and filling was necessary. The cost of this work was as follows:

4,230 labor hours at 25 cts	$1,057
356 team hire hours at 62½ cts	222
330 ft. 6-in. terra cotta pipe with fittings	69
11,727 cu. yds. of earth at 10 cts	1,172
Total	$2,522

Plans and specifications were prepared by the Park Engineer and contract awarded by the Municipal Board of Awards at an expense of—

	$ 40.00 for design
	62.45 for printing
	25.65 for advertising
Total	$128.10

Contract Work.—The contract work was commenced about the middle of April, 1915, and completed in 94 working days. The time allowance in the contract was 120 working days, with a bonus of $10 per day for completion in less time, so that the bonus earned was $260.

The items of work, done under contract, cost as follows:

Excavation, 4,651 cu. yds. at 35 cts	$ 1,627
Filling and replacing, 5,888 cu yds. at 25 cts	1,472
Trench excavation and backfill, 1,014 lin. ft. at 45 cts	456
10-in. vitrified pipe, 1,014 lin. ft. at 33 cts	334
Lumber placed under drains, 410 B. M. ft. at 3 cts	12
Concrete drain inlets, 7 at $35 each	245
Underdrains in place, 483 lin. ft. at 75 cts	362
Concrete pit and drainage outlet	20
Changes to sewer line (including manhole)	210
Manhole for drainage valve	90
Excavation and backfill, water supply, 510 lin. ft. at 56 cts	285
8-in. cast iron water pipe with connections, 510 lin. ft. at $1.50	765
8-in. supply valve	25
Excavation and backfill for pool drain, 100 lin. ft. at 75 cts	75
14-in iron drain pipe with connections, 100 lin. ft. at $2.40	240
14-in. drainage valve in place	55
Lighting conduit (1½-in.) in place, 2,402 lin. ft. at 24 cts	576
Lighting conduit (2-in.) in place, 300 lin. ft. at 27 cts	81
Light post foundations, 7 at $24 each	158
Light post foundations, 11 at $8.50 each	93
Concrete life buoy bases, 23 at $5.40 each	124
Excavation and backfill for concrete wall alongside of pool at deepest point, 539 cu. yds. at 50 cts	269
Concrete in wall, furnished and placed, 332 cu. yds. at $8	2,656
Steel reinforcement rods for wall and pool bottom, 68,249 lbs. at 2.6 cts. per lb. in place	1,774
Wire mesh reinforcement, 15,670 sq. yds. at 8 cts	1,253
Concrete for pool bottom in place, 1,838 cu. yds. at $5.86	10,770
Concrete walk around pool, 15,473 sq. ft. at 9.6 cts	1,485
Overflow drains and boxes, 6 boxes, 200 lin. ft. of pipe	310
Springboards in place, 2 at $10	20
Concrete structure for sliding boards, with two concrete slides	1,425
Miscellaneous extra work	280
	$27,564

Electric Lighting and Water Supply Pipe.—Electric lighting was installed by park electrician on force account, at a cost for material and labor, as follows:

18 cast iron posts in place, $27	$ 486
3,942 lin. ft. of cable in place at 10 cts. per ft.	394
18 lamps at $4.14 each	74
18 globes in place at $4 each	72
18 transformers at $0.2777	95
18 switches at $4.50 each	81
	$1,202

The cost of water supply, connection made by the Municipal Water Department, was as follows:

Labor	$109.73
Material	159.20
Total	$268.93

The total cost of the pool, including lighting equipment, but not including showers, diving rafts, dressing rooms or other equipment, was $31,946.

Operation of Pool.—All bathers are required to pass under showers before entering the pool, and the use of soap is strictly forbidden. The average daily attendance during 100 days of operation in 1918 was 900 persons, and the average during the first 50 days of operation in 1919, 1,400 persons. The maximum daily use of the pool in 1918 was 4,254 persons on August 6th, and in 1919, 4,674 persons on July 5th. The pool is opened during the first week in June, and is continuously operated for a period of approximately 100 days.

During the winter months the pool is available for skating when ice freezes a sufficient thickness, which is very seldom.

There is a concrete pool building constructed at a cost of $45,000, in which there are four showers and 949 steel lockers of the best grade, with toilet facilities, and with ample accommodations for handling bathing suits, etc. The building contains a steam laundering and drying plant, with the most up-to-date equipment. There are two frame wing additions to the concrete building, in which there are dressing compartments and racks, in which boxes are used for checking clothing as a substitute for steel lockers. These two wings cost $10,000, and will accommodate at one time 2,400 persons or a maximum of 24,000 persons on any one day. The operating organization is under the Superintendent of Clifton Park, and the employees are classified and paid as follows:

	Per week
1 Manager	$20.00
1 Engineer (laundry machine)	20.00
1 Head life guard	18.00
8 Life guards	16.00
8 Lockermen	16.00
1 Head woman attendant	14.00
1 Ticket cashier	12.00
7 Women helpers	10.00

The annual cost of operating the pool is something in excess of $12,000 per year. The exact cost is not known, owing to the fact that the pool has not been in operation under park management long enough to show the depreciation cost of towels and bathing suits. The receipts from the Clifton pool in 1918 (the first year of park operation) were $4,576.96, and the total patrons, not counting free entries from charitable institutions, 83,865 persons.

Costs of Concrete Work on Three Small Tanks at Lincoln Park, Chicago.— Engineering and Contracting, March 22, 1911, gives the following.

The work considered is the construction of concrete pits or tanks, two of which are used for the animals in the zoo and the other being a wading pool for children, with a small wall enclosing a sand court adjacent to one end of the pool.

The work at the sea lion pit consisted in the construction of a new concrete floor and small walls. The total amount of concrete in the work was 40 cu. yds. The cost follows:

Labor	Total	Per cu. yd.
Engineering	$ 12.49	$ 0.312
Foreman, 5 days at $3.25	16.25	0.406
Teams, 6 days at $4.00	24.00	0.600
Common labor, 61¾ days at $2	122.50	3.062
Carpenters, 12 days at $4.80	57.60	1.440
Total labor	$232.84	$ 5.820
Material:		
Lumber	$ 15.00	$ 0.375
Cement, 57 bbls. at $1.35	76.95	1.924
Sand, 22 yds. at $1.65	36.30	0.907
Gravel, 46 yds. at $1.50	69.00	1.725
Expanded metal, 868 sq. ft. at $0.02⅛	18.45	0.461
Total material	$215.70	$ 5.392
Grand totals	$448.54	$11.212

The concrete work done in the coon pit amounted to 30 cu. yds. and the den was faced with granite. The cost of the work follows:

Labor	Total	Per cu. yd.
Engineering, 5 days at $2.50 Engineering, 11 days at $3.70	$ 53.20	$ 1.773
Foreman, 5 days at $3.25	16.25	0.542
Teams, 3 days at $4.00	12.00	0.400
Common labor, 97½ days at $2	195.00	6.500
Carpenters, 24 days at $4.80	115.20	3.840
Mason, 1 day at $4.50	4.50	0.150
Blacksmith, ½ day at $5.00	2.50	0.083
Total labor	$398.65	$13.288
Material:		
Cement, 32 bbls. at $1.25 Cement, hydrolithic 4 bbls. at $6.00	$ 64.00	$ 2.133
Gravel, 24 cu. yds. at $1.50	36.00	1.200
Torpedo sand, 12 cu. yds. at $1.65	19.80	0.660
Granite, 2 cu. yds. at $6.00	12.00	0.400
Steel	15.20	0.507
Acid, brushes, etc	5.25	0.175
Tools	11.02	0.367
Total material	$163.27	$ 5.442
Grand total	$561.92	$18.73

The wading pool consisted of a concrete elliptical basin of 62 ft. and 49 ft. diameters, with an area of 2,386 sq. ft. The floor was built 6 ins. thick and contained 43.2 cu. yds. The floor was sloped to a depth of 2 ft. in the center.

The concrete in this work was mixed with a Cube mixer. The costs of the work were as follows:

Labor	Total	Per cu. yd.
Engineering	$ 14.20	$0.329
Foreman	3.25	0.075
Common labor, 39⅝ days at $2	79.25	1.834
Total labor	$ 96.70	$2.238
Materials:		
Cement, 52 bbls. at $1.35	$ 70.20	$1.625
Gravel, 27 cu. yds. at $1.65	44.55	1.032
Sand, 18 cu. yds. at $1.65	29.70	0.688
Lumber	4.50	0.104
Expanded metal and pipe	45.00	1.042
Tools	5.80	0.134
Total material	$199.75	$4.625
Grand total	$296.55	$6.863
Total cost per sq. ft. of area		$0.12424

Some time later in the season the above wading pool was improved by the building of a small irregular shaped wall enclosing a sand court at one end of the pool. The wall was built rectangular in cross section (6″ × 15″) and 57 ft. in length. Its cost was as follows:

Labor:	Total	Per lin. ft.
Foreman, 1 day at $3.00	$ 3.00	$0.054
Common labor, 8 days at $2.00	16.00	0.281
Finisher, 2⅛ days at $2.25	4.80	0.084
Carpenters, 2½ days at $4.80	12.00	0.210
Total labor	$35.80	$0.629
Material:		
Lumber, 250 ft. B. M. at $25	$ 6.25	$0.110
Cement, 6¼ bbls. at $1.35	8.44	0.149
Sand, 3 yds. at $1.65	4.95	0.087
Gravel, 5 yds. at $1.60	8.00	0.140
Tools	1.21	0.021
Total material	$28.85	$0.507
Grand total		$1.336

Costs of Encasing Steel Structures in Concrete to Prevent Corrosion.—Two methods of encasing steel structures in concrete, namely encasement by pouring and encasement by cement gun, are discussed in one of the appendixes of the report of the Committee on Steel Structures of the American Railway Engineering Association, of which report, Engineering and Contracting April 15, 1914 gives the following abstract:

1. If the floor is protected by concrete encasement poured in place, the cost will be approximately 25 cts. per square foot for an envelope 3 ins. thick.

2. Encasement 3 ins. thick placed by cement gun will cost approximately 23 cts. per square foot.

Specific data on concrete encasement work are given by W. F. Jordan, manager Grand Central Terminal Improvements, New York Central & Hudson River R. R. and by G. E. Tebbetts, Bridge Engineer, Kansas City Terminal Ry., as follows:

Grand Central Terminal.—The cement gun is being used at the Grand Central Terminal for fireproofing and protecting a part of the steel structure. The yard is in two stories, the upper tracks being supported on a steel structure with concrete jack-arches. It was necessary to get the upper tracks in service at an early date, so the fireproofing of the exposed parts of the steel below the jack-arches was not done at the time the floor was built.

The lower parts of the beams, the girders and columns are now being fireproofed with the cement gun, using a minimum thickness of 2 ins.; the average thickness is from 2½ to 3 ins., as in the angles and around the stiffeners there is generally more than the minimum thickness.

The fireproofing is reinforced with a wire mesh, 1½ × 1½ ins. of No. 12 wires; this is attached to ¼-in. rods, which are bent around the steel and fastened to it.

The mixture has generally been 1 to 3, but in cool weather, and where the steel is subject to vibrations from the trains running on it, a 1 to 2 mixture is found to be more economical, as it is not as likely to drop off. It is necessary with this machine to use fine sand, as sand with pebbles in it clogs the hose; all of the sand, therefore, has to be carefully screened.

We find that a cubic foot of 1 to 3 mixture, when weighed in a box of 1 cu. ft. capacity after being moderately shaken down, weighs 3 lbs.; if this mixture is wet and applied with a trowel, after setting it will weigh 127 lbs. to the cubic foot, when shot through a cement gun onto a steel structure and set up, it weighs 144 lbs. per cubic foot. From this one gets an idea of the density of the fireproofing made with this apparatus

In applying the mixture of sand and cement with the cement gun from 20 to 25 per cent of it is lost. Some bounces off as it strikes the structure, some is shot by the steel in working around the angles and to get a smooth surface the mason scrapes off the irregularities, and to get a good surface it is floated.

The labor required to operate one machine is as follows: 1 foreman, 1 operator of the machine, 1 nozzleman, 2 masons for floating, 4 laborers screening, mixing and charging the machines. Carpenters are used when necessary to erect scaffolds.

One of these machines uses compressed air to the amount of 100 ft. of free air per minute at a pressure from 35 to 40 lbs. The hose through which the mixture is conveyed wears out quite rapidly and renewals amount to about $1 per day. We have averaged covering about 500 sq. ft. per day of the thickness mentioned above. This method would appear to give an excellent protection for the steel. The material is very dense and the method of application such that every inch of the structure is uniformly protected. The great thickness used in this work is due to the municipal laws requiring at least 2 ins. of fire protection.

Kansas City Terminals.—On the new structures, which the Kansas City Terminal Railway Co. is building, the encasement is applied in the majority of cases by use of the cement gun. This machine consists essentially of a hopper into which the cementitous materials, made up of 1 part Portland cement to 3 parts dry screened sand, are placed; a hose connected to the bottom of the hopper, through which the mixture is forced by air pressure; a nozzle at the end of the hose, to which another hose supplying water is attached for hydrating the materials. At the end of the hose is a cylindrical nozzle having an annular ring at its base, to which the hose delivering the water is attached. This water is delivered inside the nozzle in the form of a fine spray, through which the materials from the gun pass. The nozzle is made of brass, and to prevent wear on the nozzle proper a rubber lining is used. This lining can be replaced whenever necessary.

Before adopting the cement gun, the claims of the company selling it were investigated and test panels were encased. The conclusion reached was that if the cost was not too great, it would solve the problem of encasement. Comparative estimates made are shown below:

Encasement by Pouring in Forms.—Encasement to be 3 in. in thickness; mixture to be 1:2:4 concrete; reinforcement, wire mesh and bars.

Stone, 1 cu. yd. at $1.25	$1.25
Unloading 1 cu. yd. at 20 cts	.20
Loss in handling at 5 per cent	.07
Sand, ½ cu. yd. at 60 cts	.30
Unloading ½ cu. yd. at 6cts	.03
Loss in handling at 5 per cent	.02
Cement, 1¾ bbls. at $1.25	2.19
Unloading 1¾ bbls. at 5 cts	.09
Loss in sacks at 5 per cent	.03
Total	$4.18
1 cu. yd. equal to 108 sq. ft. 3 in. thick.	
Cost of material per sq. ft	$0.039
Forms 1.63 ft. B. M. at $0.050	.081
Mixing and placing at $5.40 per cu. yd	.050
Insurance on payroll at 5 per cent	.003
	$0.173
Overhead and profit at 8 per cent + 15 per cent = 23 per cent	.040
Cost per sq. ft. of encasement = $0.216.	
Encasement per sq. ft	$0.216
Mesh No. 3 at $0.06	.018
Bars, No. 5, at $0.03	.015
Total cost per sq. ft	$0.249

Say, 25 cents per square foot.

Encasement by Use of Cement Gun.—Encasement to be 3 ins. in thickness; mixture 1:3 mortar; reinforcement, wire mesh and bars Average number of square feet covered in a day of 10 hours, 275 sq. ft. Loss due to gun work, 20 per cent. Loss due to handling sand, 30 per cent. Quantity of sand used in placing 275 sq. ft. 3 ins. thick, 4 cu. yds.

Sand, 4 cu. yds. at $0.60		$ 2.40
Unloading and screening 4 yds. at $0.25		1.00
Cement, 5½ bbls. at $1.25		6.88
Unloading 5½ bbls. at $0.15		.83
Loss in sacks at 5 per cent		.11
Water, per day		.15
Gasoline for compressor, 12 gals. at $0.15½		1.86
Oil waste and handling per day		.60
		$13.83
1 foreman, 10 hrs. at 37.5 cts		$ 3.75
1 finisher, 10 hrs. at 35 cts		3.50
1 nozzleman, 10 hrs. at 32.5 cts		3.25
1 gunman, 10 hrs. at 30 cts		3.00
2 laborers, 10 hours at 22.5 cts		4.50
1 boy, 10 hrs. at 12½ cts		1.25
		$19.25
Repairs, etc., per day	$2.00	
Scaffolding for 275 sq. ft. at $0.15	4.13	
		6.13
Interest on gun, $3,000 at 5 per cent	$0.41	
Insurance on payroll at 5 per cent	.97	
		1.38
Total		$40.59
Overhead and profit 8 per cent and 25 per cent = 33 per cent		13.53
Cost of encasement		$54.12
Cost per sq. ft		$ 0.1968
Mesh No. 3 per sq. ft. at $0.06		.018
Bars, No. 5, per sq. ft. at $0.03		.015
		$0.2298

Say, 23 cents per square foot.

A comparison of the above shows a saving of 2 cts. per square foot in favor of the gun work over the poured encasement, and it might be stated that since this estimate was made we have received bids on actual work that check very closely with the above.

The steel work to be encased was designed with open holes 11–16 ins. in diameter in webs, stiffeners and flanges, so that in placing and attaching the reinforcement there would be ample provision for rigid attachment to the structure. In attaching reinforcement to girder webs and other large surfaces, the bars were placed on small V-shaped iron saddles and wired through the webs to each other. On flanges the rods were run through steel eyebolts attached to the lower flange, the mesh being attached to the bars by wiring. At the junction of the concrete encasement with the floor, which is also of concrete, a splice was provided by use of mesh placed in the floor previously cast, this splice being four inches in width. Fig. 1 shows typical method of attaching reinforcement to girders.

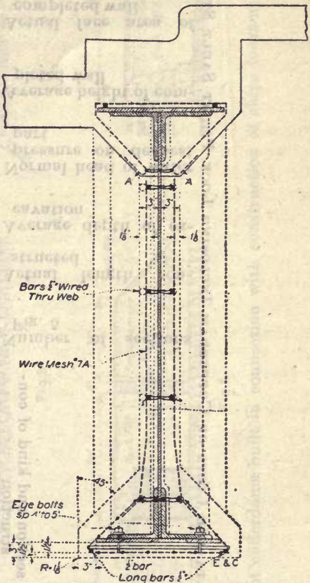


FIG. 1.—Typical concrete encasement of deck plate girder, Kansas City Terminal Ry.

The steel girders were shipped from the shops with a shop coat of linseed oil, which was removed by the use of a caustic soda wash before encasement was started. All rust spots were removed with a wire brush.

Our experience has shown that the 1:3 mixture placed in the gun gives a resulting mortar of approximately 1:2½, this change being due to loss of sand. The sand must be nearly dry, the dryer the better, a mixture of coarse and fine grains giving better results with considerably less loss, than either the coarse or fine alone.

The sand must be screened as particles over ⅛ in. in diameter clog the gun and cause serious delays.

The compressor should be a machine of very ample capacity and an intermediate air storage tank is an advantage.

It was found that it was very difficult to encase the lower flange of a girder, especially so the lower face, and in our work we cast this portion in quite a few cases.

It was also a difficult proposition to get a good, clean job around stiffeners and sidewalk bracket members. On the brackets V-shaped forms were made and used as a backing for the gun work. As to finish, the appearance is fairly good, though far from the smooth, even lines of cast work and a great deal depends upon the finisher as to the final appearance.

Cost of Cofferdams at St. Mary's Falls Canal.—The construction of the third and fourth ship locks at Sault Ste. Marie, Mich., by the U. S. Govern-

TABLE I.—SUMMARY OF GENERAL DATA AND COSTS OF COFFERDAM INCLOSING LOCK PIT AT SAULT STE. MARIE, MICH.

Date of construction	Name of section and kind of construction	Number of sections Fig. 5	Actual length constructed	Average depth of excavation	Normal head of water pressure on deepest part	Average height of completed wall	Actual face area of completed wall	Costs (from engineer's data) Unit cost: Per lin. ft. of wall	Per sq. ft. of wall
			Feet	Feet	Feet	Feet	Sq. ft.		
Nov., 1908, to May, 1910	Southeast cofferdam—two sections:								
	1. Clay wall and oak sheet piles	1	144	10.2	17	20.9	3,015	$34.02	$1.62
	2. Steel sheet piling	2	265	....	22	25.0	6,625	24.02	.96
June, 1908 to, May, 1909	East crib dam	3	402	22.0	21	21.5	8,653	51.40	2.39
June, 1908, to Feb., 1909	North crib dam—timber	4	432	13.5	23	20.9	9,041	38.65	1.85
Nov. to Dec., 1908	Junction dam—clay wall	..	30	....	18	16.6	449	41.70	2.78
Dec., 1907, to Jan., 1909	North cofferdam—clay wall	5	1,313	8.6	14	11.8	15,460	10.96	.93
June, 1908, to Oct., 1909	Northwest cofferdam—clay wall	6	539	6.7	13	14.4	7,709	19.79	1.38
March, 1908 to Jan., 1909	West cofferdam—clay wall	7	258	8.0	10	12.8	3,298	12.43	.97
March, 1908, to April, 1908	Southwest cofferdam—clay wall	8	179	30.0	29	30.3	5,228	19.31	.66
Nov., 1909 to May, 1910	Supplementary work:								
	Lally and southwest dam:								
	Fir sheet piling and tie rods	9	351	....	..	26.5	9,298	12.24	.....
	Stockramming leak	..	100	....	..	....	......	......	.....
Grand total		..	.....	....	..	....	68,776	......	$1.25

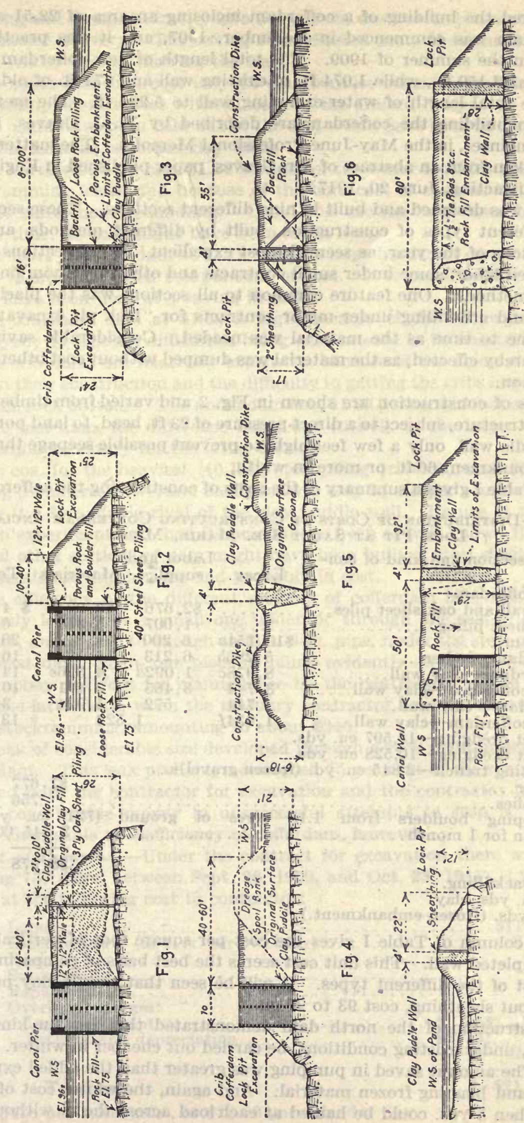


Fig. 2.—Sections of different types of cofferdams built in connection with construction of ships locks at Sault Ste. Marie.

ment required the building of a cofferdam inclosing an area of 22.51 acres. The cofferdam was commenced in December, 1907, and it was practically completed in the summer of 1909. The total length of new cofferdam construction was 3,150 ft., while 1,074 ft. of existing wall and 671 ft. of old dam brought the total length of water-excluding wall to 5,281 ft. The methods employed in building the cofferdam are described by W. J. Graves, U. S. Assistant Engineer, in the May-June Professional Memoirs. The matter that follows is taken from an abstract of Mr. Graves' paper published in Engineering and Contracting, June 20, 1917.

The dam was designed and built in nine different sections. These sections were of different types of construction, built by different methods, and at various seasons of the year, as seemed most expedient. Some sections were built by hired labor, some under small contracts and others by a combination of the two methods. One feature common to all sections was the placing of backfilling and crib-filling under minor contracts for "lock pit excavation," let from time to time as the material was needed. Considerable saving in cost was thereby effected, as the material was dumped without cost other than for excavation.

The types of construction are shown in Fig. 2 and varied from timber crib rock-filled structure, subject to a direct pressure of 23 ft. head, to land portions of clay puddle wall, only a few feet high, to prevent possible seepage through existing embankment 60 ft. or more in width.

Costs.—Table I gives a summary of the costs of constructing the cofferdams.

TABLE II.—DISTRIBUTION OF COSTS OF CONSTRUCTING COFFERDAM INCLOSING LOCK PIT AT SAULT STE. MARIE, MICH.

Name of section and kind of construction	Excav.	Labor and supplies	Materials	Total
Southeast cofferdam:				
1. Clay wall and oak sheet piles		$2,676	$2,224	$ 4,900
2. Steel sheet piling		1,007	5,358	6,365
East crib dam	$10,154*a*	6,200	4,311	20,665
North crib dam, timber	5,286*b*	6,213	5,198	16,697
North cofferdam—clay wall	8,978*c*	1,092*d*	4,326*e*	14,396
Northwest cofferdam—clay wall	3,744	3,465	3,471	10,680
West cofferdam—clay wall	711	572	1,924	3,207
Southwest cofferdam—clay wall	1,934*f*	1,522		13,456

a Contract dredging—15,597 cu. yds.
b Contract dredging—10,528 cu. yds.
c Excavating trench—2,845 cu. yd. (frozen gravel)s.

Labor	$7,677
Supplies	756
Stripping boulders from 1.15 acres of ground (721 cu. yds.), 9 men for 1 month	$ 545.00
	$8,978

d Labor backfilling.
e 7,790 cu. yds. clay.
f 603 cu. yds. (frozen embankment.)

The last column of Table I gives the cost per square foot of vertical face area of completed wall. This unit cost seems the best basis of comparing the relative cost of the different types. It will be seen that simple clay puddle walls, without sheathing, cost 93 to 97 cts.

The construction of the north dam demonstrated that certain kinds of work could, under existing conditions, be carried out cheaper in winter. For example: The amount saved in pumping was greater than the added expense of drilling and blasting frozen material. And again, the winter cost of clay delivery, when 5 yds. could be hauled at each load across the ice without rehandling and dumped directly into the trench, was but 40 per cent of the cost for summer delivery. The saving thus effected more than made up for the added winter cost of thawing the clay.

The southwest dam cost only 66 cts., because considerable work was done by bankrupt contractors without cost to the United States. If the United States could have been held liable, the cost would have been 96 cts. per square foot, the same as for other clay walls.

The northwest dam cost $1.38 because of the water troubles and burden of stockramming leaks, and because of the high cost of summer delivered clay and its subsequent rehandling. Could this section have been built in the winter time, its cost might have been much less.

The short junction dam at $2.78 carries a large burden of overhead expense, and it is unfair to draw comparisons of cost. It is possible that steel piling could have been used at a saving in cost.

The southeast dam at $1.62 is high, because of the elaborate sheathing employed; no especial difficulties being encountered in its construction.

The crib dams are relatively expensive, because of the amount of material used in their construction and the difficulty in getting the cribs in good contact with the rock bottom. The north dam cost $1.85 per square foot against $2.39 for the east dam, the difference being due entirely to the larger quantity of excavation necessary for the latter section.

The cost for the heaviest (40 lbs.) steel piling driven through 25 ft. of hard driving (boulders, gravel and hardpan) was only 96 cts. per square foot. This makes it a formidable rival of the clay puddle wall. Its use at this locality was an experiment and, had its possibilities been as well known then as now, several other sections of dam might have been built of steel sheet piling at a considerable saving in time and probably in cost.

The efficiency of the different sections of cofferdam has been first class. The only leaks were a small one under or through the east crib dam, and another, amounting to enough to fill a 3-in. pipe, under the steel piling of the southeast dam, where one piece of piling evidently struck a boulder. The only money paid out for maintenance by the contractors was in connection with the latter leak, when the masonry contractor bore the expense of a few days stockramming, amounting to about $346.

A leak of considerable size developed through a rock seam under the southwest dam. This leak probably occasioned 75 per cent of the required pumping and both the contractor for excavation and the contractor for masonry spent considerable money in unsuccessful attempts to stop it. This leak is not chargeable to inefficiency of cofferdam, however.

Cost of Pumping.—Under the contract for excavation there was pumped (during 757 days, between Sept. 26, 1909, and Oct. 23, 1911), 1,242,628,000 gals., at the following cost to contractor:

Labor		$11,428
Electric power (at 1 ct. per kw. hour)		6,975
Fuel		403
Supplies		398
Repairs		147
Overhead charges:		
Installing plant	$ 314	
Interest and depreciation	$2,151	
		2,465
Total cost		$21,816

or $0.0176 per 1,000 gals., or $28.90 per calendar day.

Under the contract for lock masonry, the pumping during 858 days (Oct. 23, 1911, to March 1, 1914), amounted to 1,094,760,000 gals., and cost the contractor as follows:

Labor		$12,208
Electric, power (at 1 ct. per kw. hour)		8,221
Supplies, fuel and repairs		2,052
Overhead charges:		
Interest and depreciation	$1,012	
Dismantling (assumed)	300	
		1,312
Total cost		$23,793

or $0.0217 per 1,000 gals., or $27.85 per calendar day.

The battery of pumps originally installed was as follows:

One 10-in. centrifugal with 100-h.p. motor
One 8-in. centrifugal with 85-h.p. motor
One 6-in. centrifugal with 50-h.p. motor
One 5-in. centrifugal with 20-h.p. motor and
One 4-in. centrifugal with 15-h.p. motor

The maximum battery required at any one time consisted of the four latter pumps, the 10-in. being a reserve unit for emergency.

The volume of pumping varied from a minimum daily average of about 850, 000 gals. in winter, while the adjoining canal was unwatered, to a maximum daily average of about 3,000,000 gals. during the summer. The maximum for any one day was about 4,000,000 gals.

Cost of Steel Cofferdam of the Pocket Type.—A steel cofferdam of the pocket type was used in the construction of Lock No. 2, Cape Fear River, N. C., for the U. S. Government. Double rows of Lackawanna sheet piling connected at intervals by transverse rows, were driven around the lock site.

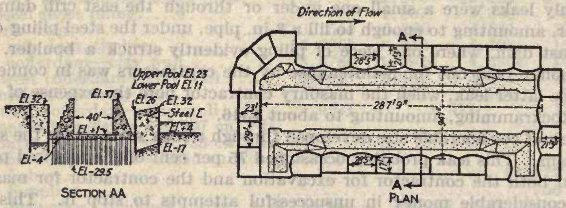


Fig. 3.—Plan and section of cofferdam and lock.

The pockets thus formed were of such dimensions that when filled with earth they could resist the unbalanced pressure on the cofferdam without support. As the steel on the land side was driven well back into the river bank where the ground was level with the tops of the pockets, no filling was necessary on this side. The river pockets were filled with material dredged in the cofferdam enclosure. The following description of the methods employed in the construction of the cofferdam is taken from an abstract in Engineering and Contracting, Jan. 17, 1917, of an article by Norman M. Chivers, Assistant Engineer, in the Sept.-Oct. Professional Memoirs.

The general arrangement of the cofferdam is shown in Fig. 3. The pockets were of two types. Those at the upper end had parallel inside and outside walls tied together by walings and steel cables and rods. The other pockets were without ties, the inside wall being curved to reduce distortions in the steel piling caused by the filling. Driving requirements and limited space for plant dictated the two single wall panels in the upper and lower wings. These panels were held by cables to wooden pile anchorages. Arched web piling, on account of its greater transverse strength, was used in walls held by walings and on the outside of the river pockets; straight web was used in the interior curved walls, the cross walls, and on the outside of the land pockets. The total length of the coffering was 878 ft. It required 1,871.9 tons of piling.

The cofferdam was designed to provide a protection against floods equivalent to that which experience showed to be satisfactory with the cofferdam at Lock No. 1, 33 miles farther down the river. The elevation of the top of the steel was accordingly fixed at 23.4 ft. above the mean low water obtaining at the site before the lower pool level was established by the construction of the dam at Lock No. 1. This elevation corresponded to an average height above the bottom of the river of 28 ft. The lock floor was laid before pumping out so that the coffered enclosure, after pumping out, had a depth of 31 ft.

To make the cofferdam of the height indicated and at the same time secure the necessary penetration in the sand and clay bottom of the river, piles 49 ft. long were required for the outside wall. The piles on the land side of the inside wall were of the same length, but on the river side piles 43 ft. long were used, making the inside wall 6 ft. lower than the outside. By thus sloping the tops of the pockets, the amount of filling required was reduced and dredging operations facilitated. All of the piles in the inner wall were spliced just above the elevation of the lock floor, the lower portions remaining as a part of the permanent construction.

The driving of the steel in the land cofferwall was done by two traveling pile drivers capable of movement parallel and at right angles to the center line of the lock.

The flat on which the tracks were laid was excavated out of the bank and all of the piling driven between the two outer tracks. To form the curve on the inside of the pockets a cylindrical cage moving in the ordinary driver leads and holding one of the hammers at any desired horizontal angle was provided. A similar cage, without any revolving feature, enabled the other hammer to overreach piling already partially driven for making the closure of the pockets. Piles were delivered to the drivers from the stockpiles by hand cars running on a track immediately in front of the machines. Steam for the hammers was supplied from a central boiler plant.

The two hammers used were Warrington steam hammers with striking weights of 3,000 and 1,800 lbs., respectively. Each driver was equipped with two 2-in. jets, supplied by a pump installed on a scow nearby. Both pumps had a rated capacity of 250 gals. per minute at 75 lb. pressure; one with 80 lbs. and the other with 125 lbs. steam pressure. The jets were freely used in both land and river driving.

The penetration of the piles in the land wall varied from 39 to 48 ft. in clay, clay and sand, and marl. Considerable difficulty was experienced in driving to grade, and in several instances of absolute refusal the tops of the piles had to be cut off by the oxy-acetylene flame to permit the travelers to proceed. The smaller hammer drove an average of 9 piles per 16-hour day, and the other an average of 25.6 piles per 16-hour day.

When the land driving was completed, sufficient dredging was done at the upper and lower ends to enable the pile drivers mounted on scows to continue the coffer walls out into the river.

The floating rig being more flexible than that used on the land, and the penetration less, varying from 18 to 21 ft., driving was faster. The smaller hammer drove an average of 17 piles per 16-hour day, and the large hammer 20.5 per 16-hour day.

The curved panels of the river wall were driven to a templet floating on the convex side of the arcs and held in place by adjustable bracing to wooden guide piles located inside the cofferdam enclosure opposite and in line with the cross walls. The bracing was so arranged that the templet could rise and fall with varying stages of the river. Alignment of the templet was secured by means of points established by triangulation on brackets nailed to the wooden piles.

The closure of all pockets was made by a large hammer. This was work which required a great deal of time and care. It was found to be very difficult to keep the piling always vertical, as a leaning tendency often developed in the direction of the driving. This lean gave trouble in closing. In four instances specially fabricated wedge-shape piles had to be used. All of the pockets were closed on the outside wall. Driving proceeded alternately on the rear and cross walls of a pocket until only the four piles nearest a corner remained. These last four piles were then entered, but not driven to grade until all were in place. Driving in succession each pile a few feet at a time completed the closure.

Diagonal steel channel walings were provided for all the cross walls, the holes for the fastening bolts in the piling being burned through with oxy-acetylene flame. The function of these walings was to prevent sliding of one interlock on another, due to the over-turning force on the backs of the pockets. In this they were only partly successful, as will be noted later.

A gap was left at the lower end of the cofferdam for the passage of the dredge which excavated the enclosure and the pile drivers which drove the foundation piles. The dredging was done principally by the Engineer Department Dredge Ajax, with a 5-yd. clam-shell bucket. Approximately half of the material removed, sand and clay, was used to fill the pockets at an average cost of 26½ cts. per yard. The plans required a level bottom everywhere. Considerable material immediately next to the steel could not be handled by a large clam-shell bucket, and had first to be loosened by jetting, and then taken out with a ½-yd. orange-peel bucket. Some blasting also was required in a small shelf of marl encountered in the lower wing. These operations, together with the fact that the over-depth allowance made for shoaling during pile driving proved insufficient, necessitating further dredging by siphon in those areas where piles had been driven, and by the Ajax in other places, greatly increased the cost of excavation. The total average unit cost of material removed was 46½ cts. per yard.

As dredging proceeded in front of the land wall, a serious movement of four of the pockets at the upstream end was noted, showing a tendency to turn over in the direction of the lockpit. The earth back of these pockets had not been disturbed in any way and was not surcharged. No similar movement occurred at the lower end of the wall, although here about 2,500 wooden piles were stacked immediately back of the steel. An examination of the walings on the cross walls of the leaning pockets showed that all of the fastening bolts had sheared off. As it was not found practicable to put in enough bolts to withstand the stress, it was decided to relieve partially the pressure on the back of the wall by excavation and drainage, and to tie the cross walls affected to tree anchorages by means of heavy wire cables. This proved to be a satisfactory solution of the difficulty. The maximum movement of the top of the steel amounted to 7 ft. 6 in., and no further movement was detected when the cofferdam was pumped out.

After all the foundation piles had been driven, the gap left at the lower end of the cofferdam was closed and the bottom sealed with a 5-ft. layer of concrete deposited through a tremie. This concrete was allowed a month to set before the first pump-out.

The pumping plant, located at the upper end of the cofferdam, consisted of a 12-in. Morris direct connected centrifugal designed to discharge 4,200 gals. per minute against a 30-ft. head, and a 10-in. Buffalo centrifugal, of the submerged type, designed to discharge 3,000 gals. per minute against a 32-ft. head. The 12-in. pump was mounted on pontoons inside the cofferdam, and had a discharge pipe made up of short sections to provide for increased lift as the water level fell. The 10-in. pump was rigidly attached to the wall of the cofferdam, and belt-connected to the driving engine on top of one of the pockets.

The first pump-out was purposely extended over two days in order that the coffer walls might be watched. The 12-in. pump alone was used until the pontoons grounded on the lock floor, after which the 10-in. pump completed the unwatering.

A movement of the top of the river wall toward the lock pit of 1½ ins. was the only movement of the cofferdam detected during pumping operations. After the first pump-out the maximum head on the cofferdam was 26 ft. Leakage at ordinary stages of the river amounted to about 200 gals. per minute.

As the Cape Fear River is subject to rapid rises, which at times completely submerged the cofferdam, provision was made for flooding by means of a 24-in. pipe through one of the pockets at the lower end, 12 ft. below the top. Control was secured by an ordinary gate valve operated from a platform outside the cofferdam.

Costs for Driving Summarized.—The unit costs of the different operations in constructing the cofferdam are summarized in the accompanying table. They include payroll, supplies and a charge for repairs to the plant employed.

COST OF DRIVING STEEL SHEETING

	Per pile	Per ton	Per lin. ft.
Driving land piling	$5.18	$5.77	.....
Driving river piling	2.28	2.53	.....
Driving piling, average	3.36	3.75	.....
Splicing piles	.47	.....	.....
Handling piles	.30	.....	.....
Placing wales	.....	.....	$0.79
Driving wood anchor piles	4.57	.....	.....

In addition, it cost $29.45 each to install the tie cables. As 17.7 per cent of the total tonnage of steel in the cofferdam became a part of the permanent structure, the cost of driving chargeable to the cofferdam given above should be reduced by this amount.

Annual Cost of Creosoted Wood Structures.—(Engineering Record, Feb. 7, 1914).

TABLE III.—ANNUAL COST OF STRUCTURES, BASED ON LENGTH OF LIFE

First cost	Length of life in years: 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	25	30
10	2.31	1.97	1.73	1.55	1.41	1.29	1.20	1.13	1.06	0.99	0.96	0.92	0.89	0.85	0.83	0.80	0.71	0.65
20	4.62	3.94	3.46	3.09	2.81	2.59	2.41	2.26	2.13	1.97	1.92	0.84	1.77	1.71	1.65	1.60	1.42	1.30
30	6.93	5.91	5.18	4.64	4.22	3.88	3.61	3.38	3.19	2.96	2.88	2.77	2.66	2.57	2.48	2.41	2.13	1.95
40	9.24	7.88	6.91	6.19	5.63	5.18	4.81	4.51	4.26	3.95	3.84	3.69	3.55	3.42	3.31	3.21	2.84	2.60
50	11.55	9.85	8.64	7.74	7.04	6.47	6.02	5.64	5.32	4.94	4.81	4.61	4.44	4.28	4.14	4.01	8.55	3.25
60	13.85	11.82	10.37	9.28	8.44	7.76	7.22	6.77	6.38	5.92	5.77	5.53	5.32	5.13	4.96	4.81	4.25	3.90

The annual cost of structures having a life of from five to thirty years and a first cost of from 10 to 60 units (dollars or cents) is given in Table III, from the report of the committee on preservation of timber presented at the 1914 convention of the American Railway Bridge and Building Association. Utilizing this table, which is applicable to structures of various types, the committee analyzes the saving in the use of treated piles for trestles on the Southern Pacific.

The Southern Pacific, according to the report, has about 105,000 creosoted Douglas-fir piles in trestles. They were treated by the boiling process, and range in age from one to twenty-three years, with probably more than two-thirds of them over twelve years old. Of this number not more than 500 have ever been replaced on account of decay, and many of those twenty years old are as good as when driven. The committee does not doubt that they will be good for at least thirty years, and estimates the life of the same timber untreated as eight years.

Assuming these piles to average 40 ft. in length, each pile, at 10 cts. per foot, would cost $4. The driving would cost $6, making the total of $10 per pile. If such a pile would last eight years, its cost, as shown in the table, would be $1.55 per year. Similarly, a 40-ft. creosoted pile, at 30 cts. per foot, costs $12, which, added to the $6 for driving, makes a total of $18. If the pile will last thirty years, the annual cost will be $1.17. The difference is 38 cts. per pile, or nearly $40,000 per year for the entire 105,000 piles.

Costs of Treating Seasoned and Unseasoned Ties.—F. J. Angier gives the following data in Engineering Record, Jan. 20, 1912.

An unseasoned tie is generally taken to mean one freshly cut, or one where the sapwood is so completely filled with moisture that it would be impossible to treat the tie thoroughly until this moisture had been at least partially removed. A seasoned tie is one that has been cut for some time and the moisture allowed to evaporate to a greater or less degree. The time necessary to season a tie so that it can be properly treated varies in different localities, as well as in different seasons and with different kinds of wood. At a fair average it requires six hours to treat a charge of thoroughly seasoned ties and nine hours to treat a charge of unseasoned ties. The treatment referred to is with a mixture or creosote and zinc-chloride, known as the card process. At this rate the cost of treating in a plant having a maximum capacity of 1,800,000 seasoned ties a year is as given in Table IV, and the cost of treating in the same plant, where the maximum capacity is reduced to 1,200,000 unseasoned ties a year, is as given in Table V.

TABLE IV.—COST OF TREATING SEASONED TIES
(Capacity of plant 1,800,000 per year)

Unloading, cars to ground, to season, $0.007 each	$ 12,600.00
Loading from ground to trams, $0.0055 each	9,900.00
Switching trams $0.002 per tie	3,600.00
Loading treated ties out, $0.0065 each	11,700.00
Fixed expenses	23,268.00
Preservatives at 15, cts. per tie	270,000.00
Fuel (assumed one-third less for seasoned over unseasoned)	5,600.00
Insurance on 1,000,000 ties (estimated)	4,000.00
Interest on 1,000,000 ties 6 months 5 per cent on $250,000.00	12,500.00
	$353,168.00
600,000 more seasoned ties treated than unseasoned, worth $0.044 each (See statement Table 3)	26,400.00
	$326,768.00

$0.1815 per tie

TABLE V.—COST OF TREATING UNSEASONED TIES
(Capacity of plant 1,200,000 per year)

Unloading one-fourth cars to ground to enable prompt release of cars, $0.007	$ 2,100.00
Loading 900,000 ties, cars to trams at platform, and 300,000 ties, ground to trams, $0.0055	6,600.00
Switching 300,000 ties, yard to retorts, $0.002	600.00
Loading treated ties out $0.0065 each	7,800.00
Fixed expenses	23,268.00
Preservatives at 15c. per tie	180,000.00
Fuel	8,400.00
Insurance on 300,000 ties (estimated)	1,200.00
Interest on 300,000 ties, or 5 per cent on $75,000.00	3,750.00
	$233,718.00

$0.1948 per tie

TABLE VI.—SAVING IN A TREATED TIE AS COMPARED TO AN UNTREATED TIE

Untreated tie:		
First cost	$0.50	
Cost of putting in track	.15	
Cost of tie in track		$0.65
5 per cent interest on investment for six years		.195
Second renewal, end of six years		.65
5 per cent on first investment for six years, and on second investment for six years		.39
Total cost of tie for 12 years		$1.885
Average cost per tie per year		$0.157
Treated ties:		
First cost	$0.70	
Cost of putting in track	.15	
Cost of tie in track		$0.85
5 per cent on investment for 12 years		.51
Total cost of tie for 12 years		$1.36
Average cost per tie per year		$0.113

Saving per tie per year $0.044

Untreated ties are assumed to last six years and treated ties twelve years.

In each case the total cost of handling is shown from the time the ties are received until they are loaded for shipment. The fixed expenses include the salaries of the superintendent, general foreman, office force, engineers and firemen, or all labor which would not change, whether treating seasoned or unseasoned ties. In the case of seasoned ties, where no steaming is done, it is assumed that insurance is carried on 1,000,000 ties for six months and that $250,000.00 will be continually invested at 5 per cent. In the case of unseasoned ties at least 300,000 will always be in the yard.

The figure $0.044 as the annual saving in a treated tie is derived in Table VI.

In addition to the direct saving at the plant there is a better penetration of the preservatives, and a longer life and lessened possibility of injury by steaming. When steaming there is always a large amount of sewage to dispose of, while in non-steaming there is practically none. The disposition of sewage is a difficult problem at most plants, often leading to damage suits.

The Operating Cost of Open-Tank Creosoting Plant.—In Engineering News-Record, July 26, 1917, C. G. Benham gives the following.

Open-tank treatment of timber is desirable for interurban and the smaller steam railroads that have a number of timber bridges and other timber structures to maintain. Such a plant, as here described, is convenient for treating fence posts, paving blocks and the like on very short notice.

The Virginia Railway and Power Co. has operated an open-tank treating plant at Norfolk, Va., since May 1, 1914, using dead oil of coal tar from its own gas-works as a preservative. Water-gas tar was tried as an experiment for a few months and finally abandoned because of the small saving and its doubtful value.

Yellow pine, mostly of merchantable grade, has been the only species of timber treated in the open tank, and has varied in size from 2 × 4-in. to 14 × 14-in. timber of all lengths. A number of pine poles have also been satisfactorily treated. The penetration obtained has been from 12 to 20 lbs. per cu. ft. of timber. Well-seasoned timber is desirable for open-tank treatment; in the case of green timber it is necessary to keep it in the tanks until it becomes well seasoned from the heated oil.

The method of treatment is, first, to place the timber in the tank and weight it to prevent floating, and then cover it with oil. The steam is turned on for about eight hours, at approximately 100 lb. pressure, the oil being kept at about 200°F. The steam is then cut off and the oil and timber are allowed to cool over night. The next day the timber is removed from the tank and placed on the storage piles by the derrick boom.

The following figures give the actual cost of treating at this plant for one month. One foreman (who also operates the electric derrick) at $3, one fireman at $1.50 and four laborers at $1.50 per day are required, working under the bridge supervisor. A total of 39,098 ft. B. M. was treated. The costs were as follows:

Item	Total	Cost per M. Ft. B. M.
Dead oil of coal tar 7,375 gals. at 6½ cts.	$479.38	$12.23
Coal, 6,800 lbs. at $3 per ton	9.10	.23
Labor, including foreman	83.50	2.14
Maintenance of plant	20.00	.51
Interest on $3,000 investment	15.00	.38
Total expense for one month	$605.98	$15.49*
Average penetration, 19.6 lbs. per cu. ft. of timber.		

* No allowance for depreciation has been included in the charges.

Fig. 4 shows the layout of the treating plant. The smaller tank is used for treating only in emergencies. The dead oil of coal tar is brought from the gas-works in a 2200-gal. tank-car that is fitted with a section of pipe to allow filling the treating tanks directly.

Cost of Creosoting Car Sills and Roofing (Engineering and Contracting, June 25, 1919.)—The average cost of the creosote treatment for car sills at the plant of the Marsh Refrigerator Service Co., Milwaukee, Wis., is estimated to be $4.50 per 5 in. × 8 in. × 35 ft. sill. Of the total $4 is for creosote oil, 10

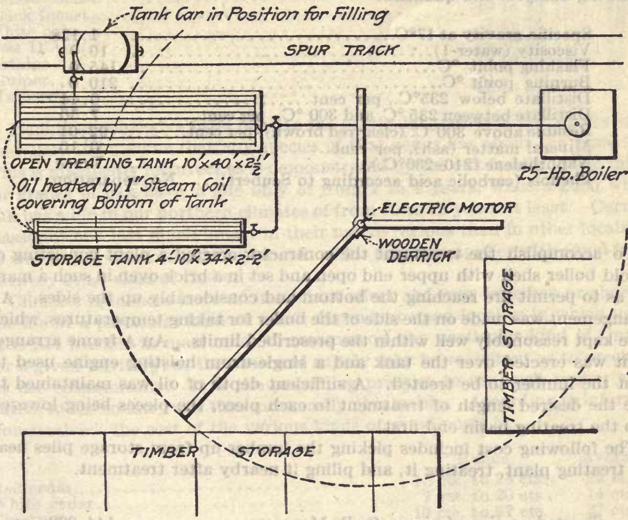


FIG. 4.—General layout of open-tank treating plant.

lb. per cu. ft., for 9.7 cu. ft., or 10.8 gals., and 50 cts. is for labor and overhead. The average cost per M. ft. B. M. is $38.54. In treating the subflooring and roofing two men handle approximately 400 pieces per hour, making the labor cost per piece $.0005. Overhead is estimated at $.0005 and the cost of creosote oil at 8 lbs. per sq. ft. of surface makes a total cost per piece of about $.018 or $10.65 per M. ft., B. M.

Cost of Treating Sheet Piles with Avenarius Carbolineum.—W. D. Jones gives the following, in Engineering and Contracting, July 26, 1916.

In the construction of a timber wharf 50 ft. wide and 1,600 ft. long resting on creosoted piles, at Los Angeles Harbor, a bulkhead was specified as follows:

Lumber.—All lumber for sheet piles must be 4 × 12-in. No. 1 merchantable Oregon pine (Douglas fir), sound, free from large, loose or rotten knots, knot holes, splits, shakes, wain, rot, pitch seams open on both sides of the piece, worm holes or other defects which materially impair the strength of the piece. Each piece shall have a groove 1 in. wide and 1 in. deep cut in each edge. In one of the grooves a spline 1 × 1¾ in. shall be spiked to form a tongue.

Treatment.—All sheeting shall be dipped such that the upper 15 ft. be immersed for at least twenty minutes in Avenarius Carbolineum, which shall be kept at a temperature of 212 to 220°F. during the dipping. The heating to be accomplished by steam coils. (This was not done.) Manufacturers estimate that the amount of Carbolineum necessary for this treatment will be 1½ lbs. per cubic foot of lumber treated. The Carbolineum must be brought to the dipping station in the original containers and must give the following analysis and qualities:

Specific gravity at 17°C.	1.128
Viscosity (water-1)	10.0
Flashing point °C.	145.0
Burning point °C.	210.0
Distillate below 235°C., per cent	0.44
Distillate between 235 °C. and 300 °C., per cent	7.50
Residue above 300°C. (clear red brown), per cent	92.01
Mineral matter (ash), per cent	0.10
Naphthalene (210–230°C.)	Trace
Phenols (carbolic acid according to Seubert)	No separation

To accomplish the treatment the contractor erected a plant consisting of an old boiler shell with upper end open and set in a brick oven in such a manner as to permit fire reaching the bottom and considerably up the sides. An arrangement was made on the side of the boiler for taking temperatures, which were kept reasonably well within the prescribed limits. An A frame arrangement was erected over the tank and a single-drum hoisting engine used to hoist the lumber to be treated. A sufficient depth of oil was maintained to give the desired length of treatment to each piece, the pieces being lowered into the treating basin end first.

The following cost includes picking the lumber up from storage piles near the treating plant, treating it, and piling it nearby after treatment.

Treated portion of pieces ft. B. M.	144,222
Treated portion of pieces sq. ft. surface area	107,984

Cost of treatment—Labor, $1,227.57; equipment service, $66.65; material, $1,136.20.

Cost of treatment per 100 sq. ft. $1.14; equipment service, $0.06; material, $1.05.

Cost of treatment per 1,000 ft. B. M.—Labor, $8.51; equipment service, $0.46; material, $7.88.

A total of 1,196 gals. of carbolineum was used. This amounts to approximately 11,300 lbs., being slightly less than 1 lb. per cubic foot of lumber treated. The cost of this amount of material was, as given above, $1,136.20. Some difficulty was experienced in keeping the shorter lengths of lumber immersed, due to its floating up in the liquid.

Cost and Serviceability of Wood Fence Posts on Railways.—Some discussion of the life and cost of wood fence posts based on the experience of some 44 American railways, are brought out by report of a special committee of the American Railway Engineering Association. Engineering and Contracting, March 19, 1913, summarizes part of this report, as follows:

Wood Posts.—From the data collected the life of wood posts of various kinds actually in use is as follows:

LIFE OF POSTS

	Years	Average years
Red cedar	7 to 25	18
Cedar	10 to 30	—
White cedar	12 to 17	15
Chestnut	10 to 15	12
Locust	7 to 20	—
Yellow locust	15 to 30	20
Black locust	10 to 25	20
White oak	7 to 15	10
Bois D'Arc	12 to 45	25
Catalpa	10 to 25	15
Juniper	15	15
Mulberry	15 to 20	15

Doubtless some give little heed to the particular species of the timber that they use, and assume that any species of that genus has about the same life. This is manifestly incorrect as is demonstrated by the oak family. The inferior grades of oak have a life only of from 2 to 4 years, while a good white oak has a life in our northern climates of from 10 to 12 years at least. Certain classes of oak last much longer in their native regions than in other localities to which they are transported for use. This principle applies with equal force to every other class of timber.

Climatic influences have an important effect and may lengthen or shorten the life of a particular kind of wood, dependent upon locality in which used' It is not feasible in most cases to recommend any particular kind of timber for a given territory, as the source of supply may be so distant as to preclude its use economically. It is the prevailing practice to use such timber as is native to the country and thus most easily obtainable. According to information received, the cost of the various kinds of wood posts is:

	Range	Average
Red cedar	15 cts. to 25 cts.	22 cts.
White cedar	7 cts. to 20 cts.	14 cts.
Chestnut	10 cts. to 27 cts.	27 cts.
Locust	15 cts. to 40 cts.	25 cts.
Yellow locust	20 cts. to 38 cts.	30 cts.
Black locust	15 cts. to 25 cts.	20 cts.
White oak	11 cts. to 40 cts.	20 cts.
Bois D'Arc	13 cts. to 17 cts.	15 cts.
Catalpa	15 cts. to 25 cts.	20 cts.
Juniper	6. cts to 10 cts.	8 cts.
Mulberry	13 cts. to 17 cts.	15 cts.

It will be observed that the relative cost to life of post ranges from ½ ct. to 2 cts. per year of life, the Bois D'Arc and the Juniper being the cheapest posts, but so rare that a more general use is impossible.

It was of interest to know to what extent wooden posts were subject to destruction by fire. Replies received indicated that this varied by from 1 per cent to 5 per cent, with the exception of one road which reported a loss of 30 per cent from this cause. We think it fair to assume that the average loss by fire is around 3 per cent.

Costs of Three Types of Board Fences.—Engineering and Contracting, May 19, 1915, gives the following:

Figs. 5 and 16, show types of board fences built under the supervision of John H. Gardinier of Lake Charles, La. Fairly close cost records were kept excepting for gates, the labor cost for which was included in the placing of boards. In the corral fence there were two 8-ft. gates and in the town fence two 12-ft. and two 8-ft. and one 4-ft. gates.

The holes for the posts were dug with a 6-in. post hole digger, the ground was moist and would have been fairly easy digging if it had not been for the numerous small roots encountered for the first foot under the surface, as these fences were built in the pine woods. The posts for the corral fence were set by contract at 15 cts. apiece, costing the same as for the town fence by day labor. But the three men by contract made $3 a day. The only difference in price of having the posts set by contract and day labor was that the posts set by the day men were a little more carefully set.

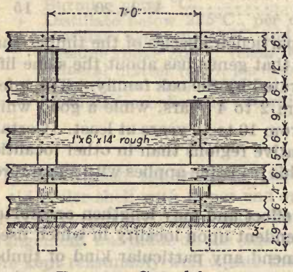


FIG. 5.—Corral fence.

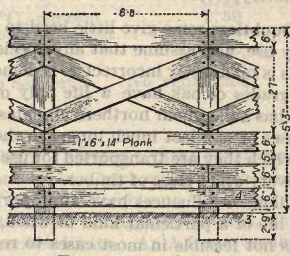


FIG. 6.—Town fence.

ITEMIZED COST OF CORRAL FENCE

360 posts, 4-in. × 6-in. × 8-ft., 5,760 ft. B. M. at $14.75	$ 84.96
Lumber, 1-in. × 6-in. × 14-ft. plank, 6,300 ft. B. M. at $15.50	97.65
160 lbs. nails at $2.20	3.52
Labor setting posts	54.00
Labor placing boards	50.54
Two per cent use of tools on labor	2.09
Distributing material	8.50
Total cost	$301.26
Cost per lineal foot labor	0.04148
Cost per lineal foot, material	.07806
Total cost per lineal foot	0.11954

Posts set by contract at 15 cts. each.
Boards placed by day labor: One man, at $2.50; 2 men at $2.00 each.

ITEMIZED COST OF TOWN FENCE

570 posts, 4-in. × 6-in. × 8-ft., 9 120 ft. B. M. at $14.75	$134.52
Lumber, 1-in. × 6-in. × 14-ft., 11,466 ft. B. M. at $15.50	177.72
248 lbs. nails at $2.20	5.46
Labor setting posts	85.50
Labor placing boards	119.81
Distributing material	31.50
Use of tools	4.11
Total cost	$558.62

Posts set by day labor: One man, at $2.50; 2 men at $1.75 each.
Boards placed by day labor: One man, at $2.50; 2 men, at $2.00 each.

Cost per lin. ft. for labor	$ 0.05371
Cost per lin. ft. for material	.09244
Total cost per lin. ft	$ 0.14615

Cost setting posts 15 cts. each.

ITEMIZED CÔST OF PARK FENCE

173 posts, 4-in. × 4-in. × 5-ft., 1,153 ft. B. M. at $15.25	$ 17.58
Lumber, 1-in. × 4-in., 809 ft. B. M. at $15.00	12.13
Nails 30 lbs	.66
Labor setting posts and placing boards	40.00
Distributing material	2.50
Use of tools on labor	.80
Total cost	$ 73.67
Labor: One man, at $2.50; 2 men, at $1.75 each.	
Labor cost per lin. ft	$ 0.03252
Material cost per lin. ft	.02737
Total cost	$ 0.05989

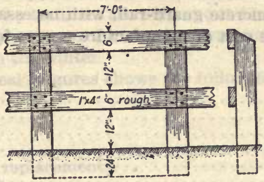


FIG. 7.—Park fence.

Small Pile Driver for Putting Down Fence Posts (Engineering and Contracting Sept. 4, 1918).—Posts for the 17-mile board fence at the American Lake (Washington) cantonment were put down at the rate of about 180 per 8-hour day by means of a small pile driver mounted on a 2-horse truck. The posts were pointed, were 5 ins. to 10 in. ins diameter, and 9 ft. long, of which 3 ft. was below ground. They were spaced 8 ft. apart. The pile driver had a 4-h.p. Fairbanks gasoline engine operating a small drum by means of a friction clutch. The crew consisted of an engineman, a teamster and two men handling posts. The actual driving time per post was 60 to 90 seconds. The hammer weighed 600 lb. and had a 6-ft. drop when beginning driving.

Cost of wooden and concrete guard rails are given in the report of Hubert K. Bishop embodied in the 1910 report of the New York State Highway Commission and abstracted in Engineering and Contracting, Nov. 15, 1911, as follows:

The proper maintenance and repair of guard-rail is a rather serious proposition. A large amount of money was expended during 1910 in rebuilding and repainting guard-rail. In order to serve its purpose and protect the traveling public from danger, the guard-rail should be in sound condition. It is also necessary for the looks of the road that it should present a neat and uniform appearance.

The weakest part of the guard-rail as built under the present standard is the posts which rot off below the ground line, causing the guard-rail to become insecure and to lose its alignment, thus presenting a very bad appearance.

Assuming that a wooden guard-rail will last eight years, the depreciation charge is approximately 3 cts. per foot per year. Adding to this the necessary cost of painting and straightening of 3 cts. per year, we would have an annual cost of 6 cts. per foot per year for wooden guard-rail. On Jan. 1, 1910, there was 1,383,220 ft. of guard-rail in the State. The annual cost of maintenance of this guard-rail at the above figure would be $82,993 per year. It must be borne in mind that this item is constantly increasing with every new road which is being built.

Assuming that the above figure of 6 cts. per foot per year is correct for the annual cost of such guard-rail, $1,25 per foot could be expended in eliminating this guard-rail and the cost to the State eventually would be less. If some form of concrete or pipe rail or even the guard-rail with concrete posts could be substituted for the present standard form of guard-rail, the annual cost of this item could be materially lessened.

During 1910 experimental work was carried on under the direction of Frank W. Bristow, Superintendent of Repairs in Division 5, and John Y. McClintock, county engineer, Monroe County, with a view to devising some form of guard-rail to take the place of the standard wooden type. With this end in view 1,233 lin. ft. of steel-concrete guard-rail, with necessary steel-concrete posts, were constructed. The cost of manufacture was as follows:

		Per lin. ft.
Lumber	$ 32.46	$0.026
Steel	139.64	0.114
Cement	57.62	0.046
Gravel	10.00	0.008
Metal cores	77.00	0.063
Labor	231.83	0.188
Miscellaneous	5.35	0.004
	$553.90	$0.449

The engineer in charge of this work estimated the following as the fair cost when making not less than 128 lin. ft. of rail and 16 posts per day, with metal cores and wooden forms already paid for:

	Per lin. ft. including rail and one post for each 8 ft.
Foreman	$0.03
Steel	.08
Cement	.05
Gravel	.01
Labor	.09
Tools, etc	.01
Total	$0.27

For this guard-rail the bars were made 8 ft. long, except end bars, which were 8½ ft. long. They were 9 ins. wide by 7 ins. high, and were cored out from below to leave concrete 2 ins. thick, and 3 cross diaphragms connecting the sides and top, placed one at center and one 4 ins. back from each end. The steel reinforcement consisted of 4 bars ⅜-in. square placed horizontal at each corner, and a loop of same size at and in each diaphragm. It was expected to sustain without breaking 6 tons pressure concentrated at center, acting either vertically or horizontally. The bars rested on top of the posts without any fastening, while the sides and diaphragms formed sockets inclosing the head of the posts, which prevented their being shoved off either sideways or endways, and the weight of the bar, about 300 lbs., held it firmly on the posts.

The posts were 6½ ft. long by 5 ins. by 7 ins. square, with four ⅜-in. square bars, one in each corner. The posts were set 3½ ft. in the ground, making the finished guard-rail 3 ft. 2 ins. high.

Some data on the cost of setting this guard-rail were:

Six men working 4 hours dug and set 11 posts, without post augur, and fitted and put up 12 rails, which figures 6 cts. per lin. ft.

Six men working 9 hours dug and set 21 posts, without post augur, and set on 20 rails, which figures 7½ cts. per lin. ft.

It was estimated that under ordinary conditions, this guard-rail could be made and erected for 50 cts. per lin. ft.

Cost of Washed Sand and Gravel (Engineering and Contracting, Feb. 21, 1917).—Some interesting figures on the cost of producing sand and gravel were given by B. E. Neal, in a paper presented before the joint meeting of the Indiana and Illinois Sand and Gravel Producers' Associations, Dec. 28, 1916. In submitting the figures Mr. Neal pointed out that the gravel business is a spasmodic one, that in a year there are only about 4 months of good business and that there are heavy expenses for repairs, replacements and for carrying the organization through the winter.

A summary of Mr. Neal's figures shows the following:

	Per ton, Cts.
Plant cost—Operating	12½
Stripping	2
Repairs and replacements	6
Office and selling expense	5
Taxes and insurance	½
Plant depreciation	3
Depletion of gravel deposit	1
Interest on investment 5 per cent	1
Total	31

These figures Mr. Neal believes are about the average cost of producing commercial material under average conditions. By average conditions is meant a bank of gravel 30 to 40 ft. thick covered with about 3 ft. of stripping and running about 40 per cent above the ¼-in. and 60 per cent below. The above conditions are believed to be at least as good as are found in the average pit in Indiana.

The item operating cost includes the cost of loading and washing gravel, the cost of power and labor to transport the gravel from the bank to the plant and the cost of the monthly men while not actually engaged in repairs; also the cost of fuel or electric power, as the case may be. Mr. Neal stated that the experience of his company showed the cost of producing salable material, not considering the material wasted in a production, to be not far from 12½ cts. per ton.

The cost of stripping item varies more or less with local conditions. To move the stripping and get it clear away from the scenes of operation, Mr. Neal believes, would cost on an average 30 cts. per cubic yard of stripping moved. This in the case of the bank mentioned above would make the average stripping cost 2 cts. per ton of gravel. Regarding the item repairs and replacements Mr. Neal calls attention to the fact that producing gravel is heavy and hard work and is the hardest usage that machinery of all kinds can be put to. He believes the average repairs for plants, including repair labor, will average 6 cts. per ton on the year's output.

Plant depreciation is figured on the basis of 15 per cent per year. In giving this figure Mr. Neal states that plants of the cable excavator type must be moved every 3 or 4 years, and that plants of the elevator type with shovels and donkey engines have expensive machinery which does not last for many years. Mr. Neal doubts very much if this amount of depreciation would have covered the cost during the past 6 or 8 years, owing to the changes in gravel specifications which have necessitated rebuilding the plants. As a result of figuring over several plants, their costs and their capacities, Mr. Neal believes that it takes an average plant investment of at least 20 cts. per ton of yearly output. In other words, a plant which will produce 100,000 tons of commercial material could be be erected and made ready for business with a plant investment of less than $20,000. On the basis of 15 per cent depreciation this would mean a cost of 3 cts. per ton for gravel produced.

The item "depletion of gravel deposit" is figured on the basis of there being 65,000 tons of gravel per acre.

Cost of Operating Gravel Washing Plant at Wayne County, Michigan.— Engineering and Contracting, Dec. 3, 1919, gives the following:

A washing plant with a capacity of 200 cu. yds. per day was erected at the gravel pit, leased by the County Road Commissioners to furnish material for two concrete roads. The entrance was graded and an industrial railway laid right up to the chutes from the washing plant bins.

The location of the pit was central to the roads being built, thereby shortening the haul about ½ mile over the distance from the railroad siding if commercial material had been used. The lay-out of the gravel pit was such that it was much cheaper to arrange a yard at the pit than it would have been to unload from railroad cars.

A small stream fed by local springs furnished an abundant supply of water, which was pumped 1,000 ft. through two lines of 3-in. pipe to the washing plant by electric motor. A single line of 4-in. pipe would have been sufficient, but two 3-in. lines were used because this pipe was in stock. The plant was operated by a small electric motor, making it comparatively simple in operation.

The cost of operation, exclusive of interest and depreciation, according to the last annual report of the Commissioners was approximately as follows:

	Total per day
4 teams loading hopper at $8	$32.00
2 scraper holders at $5	10.00
1 foreman at $6.50	6.50
1 operator at $6	6.00
2 car loaders at $5	10.00
Motor rental at $1.50	1.50
Electric current estimated	10.00
Total (200 cu. yds. at 38 cts)	$76.00

On the basis of an average daily output of 200 cu. yds. the cost amounts to 38 cts. per cubic yard, plus 15 cts. for the cost of the material in the pit, making a total of 53 cts. per cubic yard for the material loaded in the industrial cars ready to haul. It will be noted in the above cost that the largest item is the teams loading the hopper which feeds the belt. This item could have been reduced by the installation of a drag line bucket and hoisting engine, but owing to the short run which this plant had it was not considered advisable to invest in so large an equipment.

The plant cost approximately $7,200 erected, and supplied about 10,000 cu. yds. of material, from the pit. It is expected to operate the plant next year for furnishing gravel and sand for maintenance work.

Cost of Excavating, with Drag Line, Aggregates for Concrete Road Work.— Stanley E. Bates in Engineering and Contracting Sept. 22, 1915, gives the following:

The plant is located in Elkhart County, Indiana, and was erected by the contractor for supplying the aggregates for constructing some 3 miles of concrete road.

Fig. 8 shows the general layout of the plant, the essential features of which are a bucket and carriage mounted on a slack line cable running between a mast on one side of the river and an anchor on the other, a hoist to operate the bucket, and a screen, crusher and loading bin. Three-phase, 60-cycle alternating current from a 2,200-volt power line, stepped down by three transformers to 440 volts, is used throughout the plant.

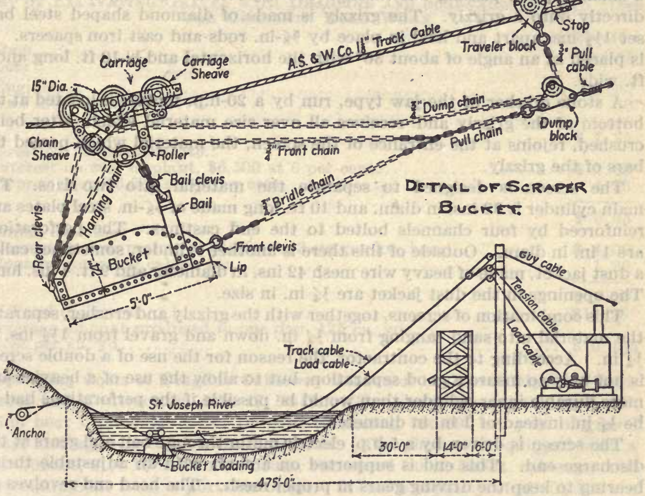


FIG. 8.—Dragline gravel excavating plant at Elkhart, Ind.

From Fig. 8 the operation of the dragline in digging the gravel from the river bed and elevating it to the top of the screening and loading plant, can be followed. The power to operate the cables is supplied by a 50-h.p. two-drum electric hoist, equipped with a friction clutch of the band type which operates the drum at two speeds, high speed being three times as great as low. This two-speed arrangement is particularly adapted to dragline excavation as it furnishes great power at slow speed for digging and then, when the bucket is full, the drum can immediately be thrown into high by means of a single lever clutch, bringing the bucket rapidly to the dumping point.

To the forward drum of the hoist is attached the load cable which passes over a sheave attached to the top of the mast and thence to the bucket. The rear drum operates the tension cable which, through a set of fall blocks also at the mast top, furnishes the means of slackening and tightening the track cable. Both the tension and load cables are ¾-in. diam. Details of the bucket, which has a capacity of 1 cu. yd. and of the carriage and chain mountings, are shown in Fig. 8.

The mast is 65 ft. high, of an A-frame type, the legs 14 ft. apart at the bottom. Each leg is built up of 6 × 10-in. timbers spliced through the middle portion to give added resistance to bending. In addition to this, they are trussed on each side with ⅝-in. wire rope. Three guy lines of 1-in. cable run from top of the mast to anchors about 100 ft. back of the base and 75 ft. apart. Two auxiliary guys of ⅝-in. cable lead to anchors close to the river bank. The track cable running across the river is 1½ ins. in diam. and nearly 500 ft. long.

The bucket drops its contents against a dump board built at an angle of nearly 45° at the top of the structure. The material then slides down into a small hopper, passing out through the 1½ × 2-in. opening in the bottom directly onto a grizzly. The grizzly is made of diamond shaped steel bars set 1½ ins. apart and held in place by ⅝-in. rods and cast iron spacers. It is placed at an angle of about 30° with the horizontal and is 10 ft. long and 3 ft. wide.

A stone crusher of the jaw type, run by a 20-h.p. motor, is located at the bottom of the grizzly and receives all over size material which, after being crushed, rejoins at the entrance of the screen, the material which passed the bars of the grizzly.

The screen is designed to separate the material into two sizes. The main cylinder is 32 ins. in diam. and 10 ft. long made of ⅛-in. steel plates and reinforced by four channels bolted to the end castings. The perforations are 1 in. in diam. Outside of this there is another cylinder, sometimes called a dust jacket, made of heavy wire mesh 42 ins. in diameter and 9 ft. 4 ins. long. The openings in the dust jacket are ¼ in. in size.

This combination of screens, together with the grizzly and crusher, separates the material into sand ranging from ¼ in. down and gravel from 1½ ins. to ¼ in. According to the contractor, the reason for the use of a double screen is not only to insure a good separation, but to allow the use of a heavier and more durable inner cylinder than would be possible if the perforations had to be ¼ in. instead of 1 in. in diameter.

The screen is driven by a 5-h.p. electric motor through belt and gears at the discharge end. This end is supported on a shaft with an adjustable thrust bearing to keep the driving gears in proper mesh. The head end revolves on two wide faced rollers.

To aid in the separation of the sand and gravel, water is pumped into the cylinder through a 2-in. pipe line from the river by a centrifugal pump driven by a 5-h.p. motor. This pipe runs inside and along the axis of the screen and is perforated, thus delivering the water uniformly over the material.

Below the screen are the loading bins, two for sand and one for gravel. Each holds about 15 cu. yds. of material and has two discharge chutes, one on each side. The bottoms of the bins are built in the shape of an inverted V, with a slope of about 30°.

The amount of material excavated and screened per day has averaged about 125 cu. yds., though if necessary this could be increased nearly 100 per cent. Three men are needed to operate the plant, an engineer and two laborers. One of the latter is located at the grizzly and keeps the material moving freely, seeing that it doesn't clog at any point. The other assists in loading the motor trucks.

The gravel from the river runs about two parts of fine material to one of coarse and as the specifications for the road call for concrete of a 1:2:3 mix, there is a large excess of sand. At present this is stored in piles around the plant and sold locally as there is demand for it. It is clean and sharp, an excellent material for concrete work, and brings about $1 per cu. yd. delivered.

Cost of Producing Gravel and Sand.—Owing to rain delaying the progress of the concrete work, the material plant has not been in continuous operation. Cost figures, therefore, are not representative but the tabulation below is based on the work done so far and will give a fairly good idea of what may be expected of a plant of this type, working under unfavorable conditions. In computing interest, etc., it was assumed that the plant was in operation only 150 days out of the year, and was producing each day only 125 cu. yds. of sand and gravel.

Cost of Excavating Gravel with Dragline and Screening to Two Sizes for Concrete Road Work

Item	Per 10-hr. day
Labor:	
Engineer	$ 3.25
Two laborers at $2.00	4.00
	$ 7.25
Interest on Investment, etc.:	
Interest on cost of plant, $6,500 at 6 per cent	$ 2.60
Depreciation $6,500 at 10 per cent	4.33
	$ 6.93
Running expenses:	
Current for four motors at 2½ cts. to 3 cts. per kw. hour	$ 4.00
Repairs, renewing cables, etc	1.20
	$ 5.20
Total daily cost	$19.38
Average amount produced in one day, 125 cu. yds.	
Cost per cu. yd	$ 0.155

Operating Costs of Dragline Cableway Excavator in Gravel Dipping (Engineering and Contracting, Jan. 17, 1917.)—The plant was erected by J. W. Gwinn near Cambridge City, Ind. for furnishing 100,000 cu. yds. of gravel ballast and aggregate for a concrete road. The plant was equipped with a 1-yd. bucket, 8 × 10 in. double drum, two-speed hoist, 500-ft. cableway and other equipment from a portable outfit. It has a capacity of about 300 cu. yd. per 10-hr. day and the total investment in the plant approximates $7,000.

The daily operating costs of the plant are as follows:

Engineer	$ 4.00
Fireman	3.00
Laborers	4.00
Coal	3.00
Oil and miscellaneous	1.50
Total	$15.50

This shows a cost of 5 cts. per yard. But the yearly overhead charges should also be taken into consideration, as follows:

	Per year
Interest on $7,000 at 6 per cent	$ 420
Renewal of cables, blocks and sheaves	400
Depreciation of engine and bucket	450
Total	$1,270

Counting on 200 working days, the daily fixed charges will be $6.30, which, added to the pay roll, gives a total daily expense of $21.80. This means that when the plant is working to capacity, gravel which sells for 25 cts. a yard costs only 7 cts. to produce.

The chief difficulty is that conditions constantly intrude to prevent operating the plant at capacity. Mr. Gwinn suffered from the car shortage and was compelled to cut the daily operating hours more than one-half.

Cost of Crushing Rock at the Pocoima Quarry, Los Angeles, Cal.—W. A. Gillette gives the following in Engineering and Contracting, Oct. 4, 1911.

The quarry is operated under the direction of the Los Angeles County Highway Commission, under the direct supervision of Wm. Davidson. The data and segregations have been reconciled with the ledger and payrolls each month as shown on the books of the Los Angeles Highway Commission, beginning Jan., 1911, and running six months, inclusive.

The plant consists of one No. 4 and one No. 6 Austin gyratory crusher, loading bins 1,700 tons capacity; one Bucyrus steam shovel, Type C, Model 60, 2½-yd. bucket, quarry cars, track, electric locomotive, scale house, bunk and boarding houses, and all the equipment necessary for a complete plant. The cost of the plant is approximately $90,000. For the six-month period—Jan.–June, 1911—the cost of producing crushed rock was as shown in Table VII-

TABLE VII.—COST OF ROCK CRUSHING AT THE POCOIMA QUARRY

	Totals	Per ton	Per cent. of total cost
Supt. and office	$ 2,292.10	$0.0224	3.97
Stripping—labor	8,804.67	.0860	15.26
Drilling and blasting—labor	2,041.46	.0199	3.54
Powder*	789.14	.0077	1.37
Other material	124.83	.0012	.22
Loading and transporting quarry to crusher	27,094.24	.2646	46.95
Material	549.28	.0054	.95
Hauling muck—labor	8,148.60	.0796	14.12
Plant operation—labor	2,000.77	.0195	3.47
Loading and shipping—labor	752.94	.0074	1.30
Maintenance—labor	1,703.89	.0166	2.95
Material	784.93	.0077	1.36
General labor	493.52	.0048	0.86
Power cost	2,134.51	.0208	3.70
Items of improvement	1,130.00	.038	......
Interest on plant investment	2,750.00	....	......
Grand total	$61,594.88	$0.6016	100.02
Credits—boarding house profits	4,217.66	$0.0412	......
	$57,377.22	$0.5604	......

NOTE.—The average number of men employed per day was 92, and per night 58, making a total of 150. The live stock amounted to 31. The total number of shifts was 227, and total tonnage produced was 102,377, making the average per shift 372 tons.

*6,928 lbs. of powder used or .0067 lb. per ton.

The county is buying crushed rock from various other plants at from 53½ cts. to $1.10 per ton f. o. b. at plant, the prevailing price being around 70 cts. per ton.

As far as management is concerned the showing made is very much out of the ordinary, particularly in view of the fact that to a large extent Mexican labor, at $2 per 8-hr. day, has been used.

As will be noted in the table, 15.26 per cent of the total cost is for stripping, and 14.12 per cent of the total cost is for handling muck. This is 29.38 per cent of the total cost, and is equivalent to 16.56 cts. per ton. This is an extra expense which could have readily been saved, had proper judgment been used in selecting the quarry location. There appears to be no logical reason for not having selected a proper site as there are numerous good ledges of suitable rock available.

It will be noted that I have not given the item of depreciation which of course must be taken into account. Part of this, however, is covered in the items maintenance, material and items of plant improvement. We could add 5 cts. a ton for plant depreciation, and still have a good showing. The rock is a disintegrated granite.

The Cost of Unloading Crushed Rock from Railroad Cars by Slip-Scraper.—In Engineering and Contracting, Oct. 22, 1910, H. R. Postle gives the following:

The writer, aided by some experiments and suggestions, has recently constructed and operated a device that is, he believes, the solution of the problem for the ordinary contractor who must have a plant adapted to small jobs, movable from place to place and adapted for all kinds of railroad cars. Unloading crushed rock ordinarily costs from 20 to 25 cts. per ton, but, by means of this apparatus, rock is being unloaded for about one-third to one-half of this amount.

The method is to draw the rock over the end of the car, through a chute hung to the end of the car, and into the wagon by means of an ordinary slip-scraper (largest size), to which is attached a ⅝-in. wire cable connected to a hoisting drum operated by a gasoline engine.

The chute is built of 2-in. lumber and is 6 ft. wide at one end, 5 ft. at the other end, and 5 ft. long, and is supported by two legs, so that it just clears the wagons, allowing them to be driven under or moved ahead. A roller 3 or 4 ins. in diameter is mounted on the outer end, over which runs the cable drawing the scraper and against which the scraper falls when dumping.

The hoist drum and gas engine are mounted on a low truck so as to be easily moved. The engine is a 10 h.p. gas engine, belted to the hoist drum with an 8-in. belt. The hoist drum is 12 ins. in diameter and 10 ins. wide.

The method of procedure is to place the loaded railroad cars in one end of the switch, move each car in turn into the same position for unloading, and, when unloaded, move it to the other end of the switch. An extra length of rope is provided so that a hitch can be made to the cars to move them into position. The cars are thus moved more quickly than the apparatus can be moved from car to car.

Six or seven men are needed to unload from 200 to 250 tons of rock per day. One acts as foreman, two handle the scraper, one is engineer and the others shovel up the surplus rock which the scraper can not reach. The two men handling the scraper drag it to the farthest end of the car, signal the engineer, who throws in the clutch, when immediately the scraper starts toward the chute, gathering a full load of rock and pushing some ahead of itself, is drawn through the chute and dumps its load at the end thereof into the wagon.

The writer in loading 5 yds. (6 ton) dump wagons, found that they could be loaded in an average of 10 minutes by 12 scraper loads. About seven-eighths of a car can be unloaded by the scraper by having the two or three shovelers shovel the rock away from the sides and farther end of the car when the rock is getting low in the car.

From 200 to 250 tons per 8-hr. day can be unloaded for the following costs:

One foreman	$ 3.50
One engine man	3.00
Two scraper men	5.00
Three shovelers	6.00
Gasoline, oil, repairs, etc	2.50
Total	$ 20.00

If only 200 tons are unloaded, the cost is 10 cts. per ton. The cost of the apparatus is:

Gas engine, ten horse-power	$350.00
Hoist drum	125.00
Truck	50.00
Large scraper	10.00
One hundred and twenty-five feet cable	9.00
Pulley block	3.00
Total	$547.00

The irregularity with which cars of rock are received, makes such an apparatus especially valuable to any contractor, inasmuch as when no cars, or less than a day's run, are received, he need not have a gang of shovelers to lay off or provide for.

Cost of Handling Stone from Cars by Slot, Elevator and Bin Method.— During the road construction season (1919) the County of Brant, Ontario, unloaded broken stone from cars and into an elevated bin by the slot, elevator and bin method, at a cost of about 3 cts. per ton. The following information on this method is from an abstract in Engineering and Contracting, April 7, 1920, of a paper presented at the 6th annual conference of Ontario Road Superintendents and Engineers by Alan Mair Jackson.

A slot 4 ft. deep across the track is excavated 16 ins. wide between ties and is lined with ties one on top of the other. A plate some 9 ft. long and 16 ins. wide is set in this slot at a slope on which stone runs freely, i. e., 30 degrees from the horizontal. The plate should be set so that the largest material will pass under the rail at the upper end and the lower end so that it will discharge on the buckets of an elevator. The elevator is set in a pit at one side of the track with the center of the lower tumbler about 5 ft. below base of rail. With this setting, a 30-ft. elevator standing at 60 degrees from horizontal will have sufficient length to fill a 55-ton bin. The motor, consisting in this case of a 9 h.p. oil engine, is set under the elevator in a small portable house and provided with a clutch drive, by 6 in. belt, onto the jack shaft of the elevator. The elevator is of standard construction 14 ins. wide and delivering about 120 buckets per minute.

The flow of stone to the elevator is controlled by an ordinary slide door operated by a lever and is set between angles fastened to two plates lining the sides of the 16 in. slots at the lower end. The pit in which the elevator is set is made large enough for the operator to get down to the lower tumbler and is timbered on the track side and decked over. A trap door is left in the deck so that the lever operating the stone feed may be got at and cover boards are provided for the slot across the tracks so that the whole may be left safe when not in operation. The usual spacing of ties is about 20 in. centers, which leaves approximately 11 in. space between ties.

Two of these outfits were installed by the County of Brant last year and operated during the construction season. The total kerosene purchased at 20½ cts. for unloading 1,854 tons was 33 gals., giving a cost for fuel of about $\frac{4}{10}$

ct. per ton A 50-ton car can be unloaded in 2½ hours, though allowing for oiling round and starting up, Mr. Jackson figures 3 hours about a fair allowance. The operator in each case has been an unskilled man paid 40 ct. per hour. The bin used discharges through four 12 in. × 12 in. openings in the bottom by means of any one of which a 1½ yd. wagon can be filled in 30 seconds. The height from the ground to bottom of bin is 6 ft. 8 in., though this can be increased by lowering the roadway. The cost of unloading 50 tons may be taken as follows:

3 hours' time at 40 cts	$1.20
50 tons at 4/10 ct. for fuel	.20
Oil and waste and grease	.10
Total	$1.50

The outfits cost approximately $1,800, made up as follows:

Engine and clutch	$ 545
Elevator	650
Lumber for bin and pit	215
Ironwork for bin and slot	225
Construction	165
Total	$1,800

Mr. Jackson estimates that the unloaders can be taken down and re-erected for about $200.

A bin of this capacity is not portable in the strict sense of the word but the bins used in Brant county last year were made so that the whole structure could be readily taken apart. No nailed parts would have to be torn out except the lining boards of the end of the bin, each of which requires two 4-in. nails, so that no loss should occur in knocking down the bin.

Cost of Loading Gravel by Mechanical Loaders and by Hand.—Comparative figures on the cost of loading road gravel by various methods were given by P. Philips, District Engineer of the Department of Public Works of British Columbia, in a paper presented at the recent convention of the Provincial District Engineers. The matter following, given in Engineering and Contracting, June 2, 1920, is taken from his paper.

A "Haiss" mechanical loader was introduced to Delta district this past summer and has been in continuous operation up to the present time. This machine has given results which have more than justified its introduction. With a few exceptions the pits in Delta district are not ideally situated for loading gravel, having shallow faces. The machine has reduced the cost of loading gravel by at least 50 per cent, for it will easily load 160 cu. yds. per day at a cost of 12.3 cts. per cubic yard and under more favorable conditions has loaded for 6.6 cts. per cubic yard.

Where the gravel is to be hauled a long distance it is absolutely essential that the loader be kept in constant operation either by having portable bunkers in conjunction with it or by increasing the number of trucks.

The loader is self-propelling, simple to operate, requires only an intelligent skilled laborer to run it. The crew consists of three men, one to operate the machine (this man is paid 50 cts. per hour more than the ordinary laborer), two men stripping the face of pit, loosening the gravel, cleaning away roots and debris. With the above crew the loader can be fed to its full capacity. If the pit has a high face one man can be dispensed with.

A clamshell was used on Nicomen slough for loading rock tailings into scows. The cost of loading 2,000 cu. yds. of material was 6 cts. per cubic yard; 2,000 cu. yds. cost 16 cts. per yard to load on account of an insufficiency of scows.

The capacity of bucket is ⅞ cu. yd. and the daily capacity is 300 cu. yds. The daily cost of operation is:

Engineer, fireman and helper	$15.00
Fuel, oil, upkeep, depreciation	5.50
	$29.50
Cost per cubic yard	6.8 cts.

Where the material is suitable for scraper work this method compares favorably with the mechanical loader. The cost of loading 90 cu. yds. of fine rock with team and scraper was 14 cts. per cubic yard. It must be considered whether the amount of material available will justify the expense of erecting bunkers.

A man will shovel loose gravel at the rate of 15 cu. yds. per day. The cost is 27 cts. per cubic yard.

The following tabulation shows costs for loading truck, assuming the truck makes 8 trips per day with a load of 2 cu. yds., taking into consideration the cost due to delay in loading:

Loading by Hand—16 Cu. Yds.

3 men for 2.8 hours	$ 4.20
2.8 hours delay of auto truck at $30 per day	10.50
Total cost	$14.70

Mechanical Loader—16 Cu. Yds.

16 cu. yds. at 12.3 cts	$ 1.97
⅘ hours delay of truck	3.00
Total cost	$ 4.97

Ration List for Construction Camps (Engineering and Contracting, March 19, 1919).—As the result of an analysis of mess practice in the lumbering industry, made by the engineers of the Spruce Board of the U. S. Army, the following was suggested as a satisfactory ration list for camp messes:

	Pounds per man per day	Pounds per man per 90 meals
Meats, fish	1.25	37.50
Eggs	0.156	4.68
Lard, etc	0.08	2.4
Butter and substitutes	0.15	7.5
Cheese	0.05	1.5
Milk, canned	0.25	7.5
Milk, fresh	1.00	30.00
Beans	0.125	3.75
Potatoes	1.00	30.00
Peas	0.10	3.00
Corn	0.10	3.00
Tomatoes	0.10	3.00
Onions, carrots, parsnips, etc	0.125	3.75
String beans, asparagus, etc	0.062	1.86
Sugar (all purposes, baking, cooking, table, etc.)	0.20	6.00
Syrup and molasses	0.25	7.50
Jams and jellies	0.031	0.93
Flour (all kinds)	0.90	27.00
Oatmeal	0.10	3.00
Cornmeal	0.02	0.60
Cornstarch	0.02	0.60
Rice and barley	0.02	0.60
Dried and canned fruits	0.25	7.50
Fresh fruits, etc	0.25	7.50
Tea	0.01	0.30
Coffee	0.071	2.13
Total	6.670	203.10

Commissary Supplies on a Canadian Survey.—Engineering News, Nov. 5, 1914, publishes the following data from a paper by H. T. Routly in the Annual Report of the Ass'n. of Ontario Land Surveyors.

The average number of men boarded was 18, including the cook.

In a brief comment upon this list Mr. Routly says:

"We have always believed in feeding our men what they liked, within reasonable limits, and it is interesting to note the difference in requisitions of different parties.

CONSUMPTION OF FOOD AND SUPPLIES BY A CANADIAN SURVEY PARTY
(The figures are the amount per man per day)

Supplies	Quantity per day	Supplies	Quantity per day
Apples	.035 lb.	Matches	.006 box
Apricots	.025 lb.	Onions	.005 lb.
Bacon Br.	.215 lb.	Peaches	.025 lb.
Bacon L. C.	.475 lb.	Peas	.049 lb.
Bacon pickled	.022 lb.	Pepper	.007 lb.
Baking powder	.010 lb.	Pickles	.002 gal.
Barley	.005 lb.	Potatoes	.525 lb.
Beans	.120 lb.	Potatoes, desic	.028 can
Butter	.154 lb.	Prunes	.050 lb.
Beef	.813 lb.	Raisins	.077 lb.
Candles	.378 candle	Rice	.037 lb.
Cheese	.062 lb.	Rolled oats	.055 lb.
Coal oil	.003 gal.	Salt	.021 lb.
Cocoanut	.002 lb.	Soap	.041 cake
Coffee	.017 lb.	Spice	....
Corn	.064 can	Sugar, brown	.178 lb.
Corn flakes	.098 lb.	Sugar, gran	.265 lb.
Cornstarch	.004 pkg.	Syrup	.007 gal.
Cream	.200 can	Tea	.036 lb.
Currants	.052 lb.	Tomatoes	.073 can
Flavoring	....	Turnips	.075 lb.
Flour	.825 lb.	Yeast cakes	.007 box
Jam	.015 lb.		
Lard	.092 lb.		
Macaroni	.115 lb.		

The above table is simply an analysis of actual quantities and costs on this particular contract. A change of cooks will often make a great difference in the comparative amounts of various items used.

"In most of our northern work we used desiccated potatoes, but on this contract some of the ordinary tubers were used. These were frozen solid coming in, and it may be of interest to note that the best method of preparing frozen potatoes is not to thaw them with cold water, as is usually done, but to brush them clean, give them a quick rinse with hot water, plunge them at once into a pot of boiling water, and cook them with jackets on."

A Tropical Ration List.—R. C. Hardman, gives the following in Engineering and Contracting, May 3, 1916. In going over some old papers recently the writer found a list of rations used some ten years ago in the Philippine Islands by the Bureau of Engineering, or Bureau of Public Works, as it is now called. The rations were for the use of reconnaissance parties, survey parties and construction camps. It will be noted that all the articles are such as can be well preserved under the extreme climatic conditions encountered in the tropics.

Provision	Quantity		Cost Unit	Cost Total
Pork sausage	6	cans	$0.225	$1.35
Beefsteak and onions	1	can	.325	.325
Corned beef hash	7	cans	.185	1.295
Compressed ham	2	cans	.26	.52
Beef stew	2	cans	.28	.56
Corned beef	2	cans	.275	.55
Mock turtle soup	2	cans	.27	.54
Bacon	4	lbs.	.20	.80
Flour	17	lbs.	.0405	.69
Corn meal	5	lbs.	.095	.475
Rolled oats	5	lbs.	.155	.775
Crackers, soda	4	lbs.	.14	.56
Bread, Boston brown	4	cans	.13	.52
Pork and beans	2	cans	.18	.36
Corn	4	cans	.165	.66
Succotash	4	cans	.18	.72
Potatoes	15	lbs.	.0235	.355
Onions	5	lbs.	.0295	.15
Peaches, evaporated	2	lbs.	.145	.29
Apples, evaporated	2	lbs.	.17	.34
Prunes	2	lbs.	.105	.21
Jam, blackberry	4	cans	.15	.60
Jam, strawberry	2	cans	.15	.30
Coffee	3½	lbs.	.27	.945
Tea, Early Breakfast	⅓	lb.	.40	.135
Sugar, granulated	10	lbs.	.079	.79
Cream, Highland con	8	cans	.11	.88
Lard	5	lbs.	.16	.80
Baking powder	1	lb.	1.07	1.07
Pickles	1	qt.	.425	.425
Vinegar	1	qt.	.065	.065
Mustard, French	⅓	bot.	.205	.07
Salt	⅓	bot.	.18	.06
Pepper	⅓	box	.60	.20
Tomato catsup	2	pts.	.375	.75
Total				$18.60

The above rations were for one American for 30 days, and were ample for the time. In most localities it was possible to supplement this fare with chickens, eggs, fish, shrimps, crabs, frogs, and various native vegetables and fruits.

For Filipino "surveymen" the ration was three condensed milk cans full of rice per day with an occasional can of salmon when fresh fish could not be obtained.

Cost of Reforesting, Wachusett Reservoir, Boston, Mass.—The following matter is taken from an abstract (Engineering and Contracting, March 23, 1910) of a paper by E. R. B. Allardice published in the Jour. Assoc. Eng. Soc., Jan. 1910.

An outline of the general policy adopted in the reforestation of the marginal lands of the Wachusett Reservoir, comprising as they did 1,090 acres of arable, pasture and light sprout land, 280 acres of thick sprouts and young, thin timber land and 1,475 acres of heavy timber or forest land, was as follows: 1st, to establish two forest nurseries, one on each side of the reservoir, for the raising from seed of coniferous trees, mostly native white pines, to form the ultimate or final forest, and of deciduous trees to act as fillers and aid in the final development of the conifers; 2d, to plant all of the first mentioned class of land with a mixture of white pines and hardwoods; 3d, to underplant the second class with white pines, making what are hereafter termed "Improvement Thinnings in Young Pine Stands," as the growth of the pines demanded;

4th, to make "Improvement Thinnings in Original Timber Stands," as opportunity permitted; 5th, to clear and maintain a fire guard 40 ft. wide around the outside limit of the reservation, to serve as a protection against fires having their origin on abutting land; 6th, to maintain some of the present and build necessary additional internal forest roads 15 ft. wide, making accessible all areas and acting as secondary fire lines, dividing the entire reservation into lots containing from 15 to 30 acres; and 7th, to clear and maintain a 50-ft. margin along the forested portion of the flow line of the reservoir, and to plant the inside half of it with white pine and arbor vitæ closely spaced, forming an effectual screen or hedge to keep the greater part of the foliage from adjoining forests from being blown into the reservoir.

Table VIII shows that it costs about $15.40 per 1,000 trees, or $19.20 per acre (1,390 trees per acre), to raise the trees from seed, prepare, plant and

TABLE VIII.—STATISTICS RELATING TO REFORESTING WACHUSETT RESERVOIR LANDS

Work accomplished to Dec. 31, 1908

Total area of nurseries	8.0 acres
Total area planted	1,330 acres
Total number of trees planted: coniferous	948,000
deciduous	902,000
Total length of reservoir margin planted	32.0 miles
Total length of fire guard cleared and maintained	20.8 miles
Total length of forest roads cleared and maintained	30.0 miles
Planted area thinned	488 acres
Original timber stands thinned	209.0 acres

TABLE OF COSTS

(Wage rate, $1.75 per 8-hr. day)

Nurseries:	
Clearing nursery on south shore	$200 per acre
Maintenance of nursery, first-year seedlings	$1.50 per 1, 000 trees
Maintenance of nursery, second and third year seedlings	$1.75 per 1,000 trees per year
Plantings:	
Clearing areas preparatory to planting	$ 4 per acre
Transplanting seedlings from nursery to field	5.25 per 1, 000 trees
Transplanting seedlings from nursery to field	$5.50 per acre (6 × 6 ft. planting)
Improvement thinnings:	
Among planted trees	$6 per acre
In original timber stands	$20 per acre
Fire protection:	
Clearing marginal fire guard 40 ft. wide	$150 per mile
Maintaining marginal fire guard	$27 per mile per year
Clearing and grading forest roads 15 ft. wide	$120 per mile
Maintaining forest roads	$8 per mile per year
Maintaining fire parol	$100 per year

Reforestation—Summary of costs on planted pine stands
(Wage rate, $1.75 per 8-hr. day)

Item	Per 1,000 trees planted	Per acre planted
Preparing nurseries	$0.40	$0.60
Seedlings (1 year)	1.50	2.25
Transplants (2 years)	3.50	4.50
Preparatory clearing	3.00	4.00
Field planting	5.25	5.50
Clearing 40-ft. fire guard	0.75	1.00
Clearing 15-ft. forest roads	1.00	1.35
Maintaining 40-ft. fire guard (per year)	0.14	0.19
Maintaining 15-ft. forest roads (per year)	0.06	0.09
Maintaining fire patrol	0.02	0.03
Improvement clearing	4.25	6.00

protect the lands planted, through the time of the final planting in the field; that it costs about 22 cts. and 31 cts. per year respectively to maintain efficient fire protection; that in sprout and scrub land it costs about $4.25 and $6 respectively for an improvement thinning, which will probably have to be made twice during the first ten years, after which time the trees should care for themselves.

Comparative Costs of Wood and Steel Trestles for Stocking Ore.—Stuart R. Elliott, in a paper before the Lake Superior Mining Institute, gives the following, an abstract of which was published in Engineering and Contracting, Sept. 1, 1915.

From the figures obtained from several mines it has been found that in five years the total cost of repairs and renewals on wooden stocking trestles amounts to the original cost of the trestle. Breakage in legs is exceedingly high, often amounting to as much as 33 per cent per year. If, for any reason, ore is not shipped and the legs are allowed to remain in the pile for several seasons it has been observed that they rot rapidly. Weather conditions have considerable to do with the percentage of broken legs. If ore is dumped on a frozen face of the stock pile, and this new ore freezes rapidly, it will often move in a mass down on the frozen face and break the legs. Large masses of frozen ore also shift in this way during loading with the steam shovel.

The cost for erecting and dismantling was accurately kept at two large mines for a period of years, and was found to amount to $1.20 per foot. Under unusual conditions this cost has run as high as $1.60 per foot. The portion of the trestle between the shaft and the point where the ore is stocked is usually called the permanent trestle, the other part being the stocking trestle. The permanent trestle is put up in a very substantial way and is very expensive, costing as much at $15 per foot. After a period of 10 years this permanent trestle is sure to be in bad repair. A few of the stringers not directly below the tracks will probably last for a short additional time, but for the sake of an estimate it can be assumed that the permanent trestle will have to be entirely rebuilt in 10 years. In making the following comparative statement of the cost of wood and steel trestles, the expenditure each year at 6 per cent compound interest has been used. This yearly expenditure has been capitalized and figured at compound interest for a period of 20 years. It is found that at 6½ years the costs for wooden and steel trestles of the same length are practically identical. As the length of time increases the capitalized amount for repairs, renewals, erecting and dismantling, figured at 6 per cent compound interest, increases very rapidly. At the end of 20 years the saving in favor of the steel stocking trestle is $117,000. It is impossible to estimate the saving due to better tracks and operating conditions, and consequently the minimizing of delays on the surface. With a wooden trestle a certain number of carpenters and extra laborers must be employed. Only a part of their time can be charged against the stocking trestle, but it is necessary to have them so that they can be used when repairs are needed. At the Negaunee mine we have only one carpenter, whose entire time is spent in the shop.

Table IX gives the total and unit costs of the concrete and steel permanent stocking trestle built at the Negaunee Mine. The columns, spaced 114 ft. centers, are 4-ft. in diam. for the upper 28.5 ft. and are belled out to a 6-ft. diam. in the lower 10-ft. There is only one column in each bend.

The plate shells of the columns are ¼-in. thick. They rest on and are bolted to pyramid-shaped reinforced concrete bases, which are 12 ft. wide,

Table IX.—Total and Unit Costs of Piers and Trestle

Piers	Total cost	Cost per yd.
Excavation, 1,800 cu. yds	$ 994.65	$ .553
Concreting, 1,352 cu. yds	5,142.70	3.80
Bolts, washers and forms	2,167.94	2.185
Reinforcing steel	1,423.89	1.053
Total	$9,729.18	$ 7.197
Average cost per pier	540.41	

Trestle (2, 594 lin. ft.)	Total cost	Cost per lin. ft.
Steel erected, 2,594 lin. ft	$35,100.00	$13.53
Columns (18), covering 2,094 lin. ft	9,729.18	4.65
Small piers for curved trestle (20), 500 lin. ft	641.93	1.28
Decking 500 lin. ft	1,870.07	3.74
Ties and fastenings, covering 2,094 lin. ft	1,627.59	0.78
Walk and railings, 500 lin. ft	358.78	0.72
Temporary tracks for unloading 2,594 lin. ft	355.89	0.14
Rails and laying 2,594 lin. ft	1,545.48	0.60
Total	$51,228.92	$19.71

26 ft. long and 6 ft. deep: Each base is reinforced with 52⅞-in. round rods, which radiate in all directions through the base and extend up into the shells for a distance of 20 ft. In the bottom of each pyramid the rods are tied to seven old rails, which extend across the long dimension of the base. At a point about 20 ft. above the base the rods are attached and properly distributed around two horizontal rings in the shells. Above these rings other rods are spliced so that the reinforced bars extend to within a few inches of the top of the columns. The height of the trestle from rail to sollar is 42 ft.

When the excavation for the base of a column was made and the form constructed filled the carpenters were busy constructing the form for the next base. In a short time after one base was completed the forms could be moved to the next excavation. In this way only a small amount of lumber was used. Before the bases were completed the bridge builders were on the ground and were ready to begin placing the steel shells in position. For handling the heavy shells a railroad track was laid along the entire length of the trestle.

The length of span between columns is 114 ft. Extending 19 ft. each way from the center of each column there are two short plate girders, each 38 ft. in length. Between these girders there are two other girders 76 ft. long.

At each column the girders rest on horizontal 8-in. I-beams supported by four braces which are firmly connected to the columns and which extend down at an angle of 45°. The plate girders are made up of angles and two 42 × ¼-in. plates. The distance from center to center of girders, or center to center of tracks, is 20 ft. The entire length of the part of the trestle from which ore can be stocked is 2,094 ft. In addition, there are 500 ft. of curved trestle extending from the shaft and connecting with the trestle. The legs of the curved part are built up of angles and channels, and the stringers are channels and I-beams. On top of the I-beams holes are provided for bolting 5-in. nailing strips. On top of these nailing strips are spiked a 5 × 7-in. sollar to serve as ties. The 40-lb. rails on the plate girders are spiked to 5-in. sawed ties 4 ft. in length. The gage of the track is 30 ins. On the outside of the girders the ties are bolted to 4 × 4-in. timbers placed snugly against the girders. These timbers prevent any shifting of the track at right angles to the length of the trestles. To prevent the ties from creeping they were attached at intervals, by hooked bolts, to the small angles inside of the girders. Since the tracks were completed, about two years ago, not a cent has been spent on them. They are now in as good alignment as when first put in.

Table X gives the comparative costs of wood and steel trestles, taking the life at 6½ and at 20 years.

TABLE X.—COMPARATIVE COSTS OF WOOD AND STEEL STOCKING TRESTLES

	6½ years	20 years
Permanent wood trestle		
Original cost, 500 ft. at $15	$ 7,500.00	$ 7,500.00
Repairs and renewals, 10 per cent per year	4,875.00	15,000.00
Six per cent compound interest	4,692.29	30,798.02
Total	$17,067.29	$ 53,298.02
Temporary wood trestles		
Original cost, 2,094 ft. at $6	$12,564.00	$ 12,564.00
Repairs and renewals, 20 per cent per year	16,333.20	50,256.00
Erecting and dismantling $1.20 per foot per year	16,333.20	50,256.00
Six per cent compound interest	14,063.33	122,822.09
Total	$59,293.73	$235,898.09
Total cost wooden trestles	$76,361.02	$289,196.11
2,594-ft. steel stocking trestle		
Original cost	$51,228.92	$ 51,228.92
Estimated maintenance cost	1,300.00	4,000.00
Six per cent compound interest	23,949.51	116,867.78
Total	$76,478.43	$172,096.70
Net saving of steel trestle	117.41	117,099.41

Cost of Cantilever Type of Reinforced Concrete Retaining Wall.—Engineering and Contracting, March 22, 1911, gives the following costs of a retaining wall some 16 ft. deep and 250 ft. long built under contract for the Saco-Pette Co. at Newton Upper Falls, Mass. The two types of retaining wall shown in Fig. 9 were considered by the engineers Lockwood, Greene & Co. who estimated a saving of some $700 by using the cantilever type with an estimated cost of $3,542.50. This type of wall was therefore built by contract.

The gravel and sand, which were of excellent quality, where hauled from a bank about one-half mile from the site of the work. Because of the large percentage of sand in the gravel, it was necessary to screen all of the latter, which resulted in a rather high cost for this material of $1.70 per cu. yd. The number of yards of concrete placed is based on the actual number of bags of cement used, the figure obtained being slightly greater than that figured for the wall itself, because of excess concrete placed in the footings over and above the actual cross sections. This yardage was allowed as follows: Actual yards of wall, 272.27; bags of cement used, 1,525; yards concrete, based on cement used, 277.27.

The actual costs of labor and material include a sand floated surface which was applied to the wall after the forms had been removed.

Materials:		
1,525 bags cement at $1.70 per bbl.	$	647.13
249.54 yds. of gravel at $1.70 per yd.		424.22
124.77 yds. sand at $0.50 per yd.		62.39
16.5 tons reinforcing steel at $33 per ton.		544.50
12,894 ft. B.M. lumber at $25 per M. ft.		322.35
600 lbs. wire at $4 per 100 lbs.		24.00
Labor:		
Superintendent, 14 days at $5.33	$	74.67
Foreman, 10 days at $4.00		40.00
Steel helper, 4½ days at $2.50		11.25
Steel man, 2 days at $3.00		6.00
Engineer, 11 days at $3.50		38.50
Carpenters, 200 days at $3.82		764.00
Laborers, 171½ days at $2.00		343.00
Masons, 7 days at $4.80		33.60
Total cost		$3,336.61
Cost per yard	3336.61 / 277.27 =	$12.03

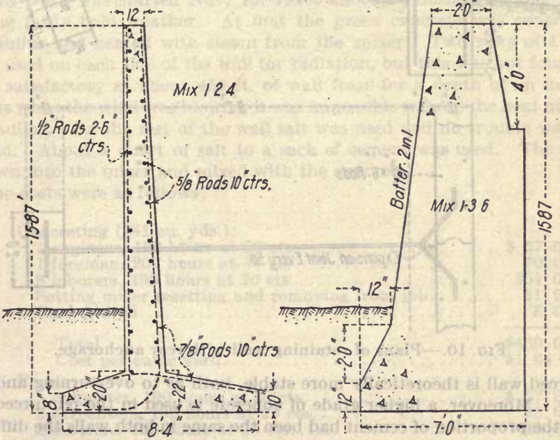


FIG. 9.—Comparative sections of plain and reinforced concrete retaining walls.

Comparative Cost of Plain and Reinforced Concrete Retaining Wall.—J. I. Oberlander, in Engineering and Contracting, May 19, 1915, gives the following data relative to the construction of retaining walls along the banks of the Sandusky River, Tiffin, Ohio.

The city asked for bids on the two types of wall shown in section in Fig. 9, the total length of wall being 2,600 ft. There were 23 bids submitted. The lowest complete bid on the plain concrete design made the cost of this type of wall $5.75 per cubic yard, the total bid being $46,718.75; while the lowest bid received for constructing the reinforced concrete wall was $6.12 per cubic yard, plus 2½ cts. per pound for the steel reinforcement, or a total of $31,476.00. The contract was awarded for reinforced walls. The total bid for constructing the plain concrete wall was thus 48 per cent more than for the reinforced wall.

Considering 17 of the bids received for both types of wall, the average price for plain concrete was $6.117 per cubic yard, while the average prices for the reinforced type were $7.456 per cubic yard for concrete and 2.77 cts. per pound for reinforced steel. The average bid for constructing the plain concrete wall was thus about 32 per cent more than for the reinforced wall, although the

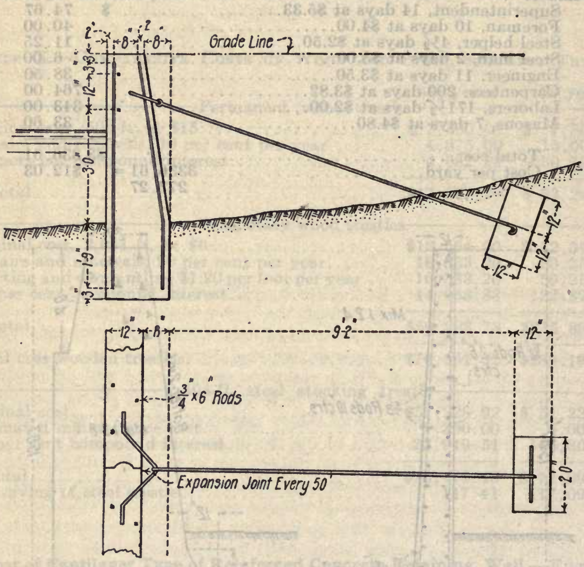


FIG. 10.—Plans of retaining wall with rear anchorage.

reinforced wall is theoretically more stable, both as to overturning and as to sliding. Moreover, a higher grade of concrete is used in the reinforced wall, and if the proportion of cement had been the same in both walls the difference in cost in favor of the reinforced concrete type would have been at least 7 per cent greater.

Cost of Reinforced Concrete Retaining Wall with Rear Anchorage.—R. A. Boothe gives the following costs in Engineering and Contracting, May 20, 1912, for constructing 900 ft. of retaining wall of the type illustrated in Fig. 10.

The wall was built around an island about 10 ft. from the bank. The space between the bank and wall was afterwards filled up with dirt taken out of the beach about 50 ft. from the face of the wall. Normally the water in the lake is about 18 ins. below the top of the wall, but to do this work the lake was drained down until it left a beach in front of the wall about 200 ft. wide.

When the walls were built two openings 10 ft. wide were left in each section so that the dirt could be hauled through. The backfill was a sandy clay and amounted to about 2,000 cu. yds. It was ploughed and hauled in No. 00 slip scrapers. The average haul was 150 ft. and cost 21 cts. per cubic yard including plowing, teams being paid 50 cts. per hour.

The concrete plant consisted of a ⅓ cu. yd. Chicago mixer mounted on skids. The material was hauled about 1 mile from the railroad and dumped in piles near the mixer; from there it was wheeled up runways to the mixer which was fitted with a batch hopper, and from the mixer it was wheeled to the job and placed. As two setups of the plant were made, one in the center of each section the longest haul was about 125 ft.

In placing the concrete the trench was dug for the foundations and the concrete and steel placed, then the forms were placed. These were built in sheets 12 ft. 6 ins. long and 5 ft. high, and were made of ⅞-in. tongue and grooved stuff with 2 × 4-in. uprights on 2-ft. centers. The forms were held together with wiring and two rows of 4 × 4-in. walling on each side. The concrete was poured in 50-ft. sections, and forms enough were built for two sections, so that while one section was being poured the carpenters could be working on the next. As the forms were wrecked on the second day after pouring it was necessary to put the laborers to digging foundation or filling it ahead on every third day until forms could be built.

This work was started Nov. 15, 1910, and was finished on Jan. 3, 1911, during fairly cold weather. At first the green concrete was covered with tarpaulins and heated with steam from the mixer. Two rows of 1-in. pipe were used on each side of the wall for radiation, but this was not found to be very satisfactory as about 450 ft. of wall froze for a depth of an inch. On nights when the wind was blowing it was impossible to keep the heat under the tarpaulins. On the rest of the wall salt was used and no trouble was experienced. About a quart of salt to a sack of cement was used. The salt was thrown into the mixer and mixed with the concrete.

The costs were as follows:

Concreting (281 cu. yds.):	
1 engineer, 190 hours at 30 cts	$ 57.00
1 foreman, 200 hours at 35 cts	70.00
8 laborers, 190 hours at 20 cts	304.00
Setting mixer resetting and removing from job	21.00
Coal and oil	8.00
Total	$460.00
Cost per cubic yard	$1.64 +
Forms:	
1 carpenter, 190 hours at 30 cts	$ 57.00
2 carpenters, 190 hours at 25 cts	95.00
2 laborers, 100 hours at 20 cts	40.00
Total	$192.00
Cost per square foot of forms	$ 0.024
Cost per cubic yard	$ 1.15

Digging the foundation ditch cost 6 cts. per foot.

Cost of Oxy-acetylene Welding.—Engineering and Contracting, May 24, 1911, publishes the following information taken from Bulletin No. 45 of the Engineering Experiment Station of the University of Illinois.

Fig. 11 shows the welding rate and cost in terms of length of weld, section of plate, and volume of filler for blowpipes of various sizes. The cost of operation rises rapidly with the thickness of plate, reaching possibly $4 per hour for labor and gas on ¾ in. plates. The oxy-acetylene blowpipe is best adapted to plates up to ¼ in. thickness. The welding rate is nearly constant at 17.5 sq. ins. of weld section per hour. The cost of welding beveled plates may be estimated also at 25 cts. per cu. in. of filler assuming oxygen at 3 cts. per cu. ft. acetylene at 1 ct. per cu. ft. and labor at 30 cts. per hour. It should also be noticed that, provided this rate holds for any type of grooved joint, if the plates were grooved from both sides, the cost per foot of weld would be only half that for plates grooved from one side only, because the required amount of filler would be reduced one-half.

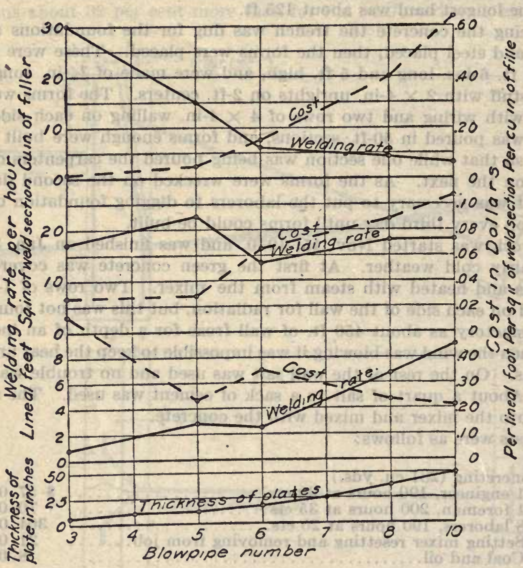


FIG. 11.—Diagram of cost of oxy-acetylene welding.

Diagram for Computing Paint Values.—E. O. Johnson gives the following in Engineering News-Record, April 7, 1921.

In Engineering News-Record of Jan. 6, Prof. A. H. Sabin discussed the question of how much a paint user can afford to pay for paint which will last, say four years and costs $6 per gallon to apply, when he has available at $3.50 per gallon another paint, which also costs $6 to apply, but which lasts five years. The chart reproduced herewith enables such cost calculations to be made more rapidly. It includes the three factors of paint cost, labor cost to apply the paint (both in dollars per gallon), and years of life. Three explanatory diagrams below the main diagram show the method of using it in three different calculations.

In the first example, the case calculated by Prof. Sabin is shown. One paint is worth $3.50 per gallon, costs $6 per gallon to apply, and will last five years; then how much is a gallon of paint worth that lasts only four years, the cost of application being the same? At the intersection of the horizontal for $3.50

paint cost with the vertical through $6 labor cost (upper scale), the diagonal (which represents cost of a gallon of paint applied) is followed down to where it meets the sloping line representing five years of life. From here, following back the horizontal to intersect the line for four years of life, the total-cost diagonal is followed down to intersect the labor-cost vertical, giving the horizontal line $1.60, which is the value per gallon of the second paint.

In the second small diagram the problem is worked out of determining how long a given paint must last in order to be as economical as another paint, for which cost and length of life are known. Following through the lines shown on the diagram, it will be found that a life of 3.47 years should be expected of the cheaper paint.

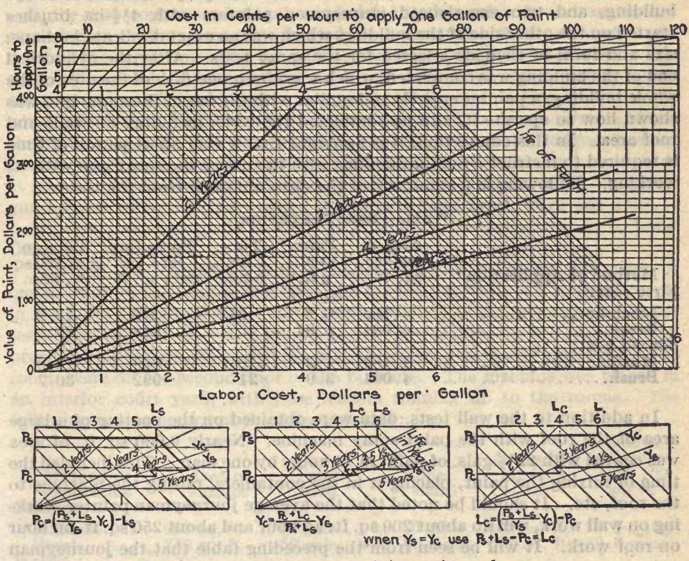


FIG. 12.—Chart for determining paint values.

Sometimes computations of justifiable labor cost to apply paint may have to be made. The third of the small diagrams shows such a calculation. A $3.50 paint is used whose spreading rate requires a man to spend $6 worth of labor time to apply it, and it is customary practice to repaint every five years. If instead a cheaper paint, bought for $1.60 per gallon is used, which, however, requires repainting every three years, it may not pay to spend as much labor in applying it. The calculation, carried out as indicated on the diagram, shows that not over $4.10 labor cost per gallon should be spent.

The formulas by which the calculations may be carried out are noted on the diagrams. Ordinarily, however, the diagrams themselves will be found much more rapid than numerical computation.

Comparative Tests of Applying Paint by Spraying Machines and by Hand.—The following data are taken from Engineering and Contracting, Feb. 25, 1920.

The information which appeared in Paint, Oil and Drug Review was obtained from a private source and is considered as fair and accurate as any individual statement can be. Everything possible was done to make the test thorough and indicative of the results that are to be expected from spray-making machines. The tests were made in government buildings.

The machines used at the United States Naval Hospital, Sept. 17, 1919, consisted of a 4 h.p. motor with a large air tank and a 5-gal. paint tank. The apparatus operated with a 220-volt direct current.

An experienced spray brush operator started the spray on one side of the building, and two experienced journeymen painters with 4½-in. brushes started on the other side of the building, which was an exact duplicate in shape, size and form of the side selected for the spray tests. After the cylindrical end of the building was completed, which was about one-fifth of the area of the whole building, a painter entirely unfamiliar with the use of the spray gun was shown how to operate it, and he completed the tests, including all walls and roof area. In this connection, it is apparent that a very short period of time is required to instruct a man unfamiliar with the use of the spray gun with its working. Following is a summary of the data obtained from the tests.

WALL TESTS (EXTERIOR)

Method of Application	Area of surface, sq. ft.	Paint used, gal.	Time, 1 man, hours	Spreading rate per gal., sq. ft.	Time to coat 100 sq. ft., min.
First coat:					
Machine	4,182	6.5	9½	570	13.5
Brush	4,094	5.97	20	648	29.0
Second coat:					
Machine	4,182	4.3	10½	863	15.0
Brush	4,094	3.9	21	992	30.7

In addition to the wall tests, data were obtained on the coating of a large area of the roof with the paint spray machine. Nearly 9,000 sq. ft. of area was coated with 22½ gals. of paint in 14 hours by one man. This included the time of mixing the paint, placing it in the containers, raising the machine to the roof, etc. It should be noted that the average journeyman painter, working on wall work, will do about 200 sq. ft. an hour and about 250 sq. ft. an hour on roof work. It will be seen from the preceding table that the journeyman painters apparently speeded up their hand brush work, as they were very much interested in the test, and they accordingly made very much higher averages than the figures just given. The results for the roof test follow:

Method of Application	Area of surface, sq. ft.	Paint used, gals.	Time, 1 man, hours	Spreading rate per gal., sq. ft.	Time required to coat 100 sq. ft., min.
Machine	578	1.49	½	386	5.2
Brush	578	1.35	1½	428	15.5

The paint used on the work was a white lead paint, the materials for which were furnished by the Government and mixed by the men. It was tinted with ochre. The first coat weighed 17.6 lbs. per gallon and the second coat, 20 lbs. Both of these paints were easily handled by the spray gun. From observations, it is apparent that the spray gun will successfully handle paint of practically any weight per gallon.

On the first coat all cornices and trim were cut in with the spray gun on the side of the building where the spray gun was used. On the second coat, however, the cornices and trim were cut in with the brush to be sure of a neat job, and the time for this brush work was counted in as spray gun time.

Observation of the character of finish given by the spray versus the hand brush work on the completed first coat showed a slightly more uniform film for hand brush work. On the second coat there was no apparent difference in the appearance. Both coats dried in about the same period of time, whether applied by spray or brush.

In the roof work the paint tank was hoisted to the roof and two hose leaders carried from the spray machine located on the ground. Two operators could work at the same time with the paint tank, which was fitted with two spray guns. The paint used for the roof work was a red oxide of iron paint. Only one coat was applied, which gave very good hiding power. Even in this work, which was done on the roof of the building, subjected to strong currents of air, there was apparently not very much loss of paint, the pebbled roofing showing probably less paint loss by dropping than where hand brush work was used. It was observed, however, that the overalls of the painters using the spray gun became somewhat more soiled than where hand brush work was done.

Another test was made at General Pershing's Headquarters, U. S. Land Office, on Oct. 3, 1919.

This test was conducted with a modern interior lithopone flat paint of cream color for the ceilings and light buff for the side walls of a series of rooms in the Land Office building. Both paints weighed 14 lbs. per gallon. In the tests upon which data was obtained, one room was done by two painters with brushes, and two rooms were done with the spray gun by one operator. The rooms were on the second floor of the building. The machine was placed in an interior court yard, with hose leaders running up to the rooms. The following is a summary of the data obtained:

Method of application	Area of surface	Paint used	Time (1 man)	Spreading rate per gal.	Time required to coat 100 sq. ft.
Ceiling:					
Machine....	660 sq. ft.	1.64 gals.	1 hr. 50 mins.	402 sq. ft.	16.5 mins.
Brush......	250 sq. ft.	.50 gals.	2 hr. 30 mins.	500 sq. ft.	60.0 mins.
Walls:					
Machine....	1,490 sq. ft.	4.75 gals.	3 hr. 30 mins.	408 sq. ft.	10.8 mins.
Brush.......	750 sq. ft.	1.25 gals.	2 hr. 50 mins.	600 sq. ft.	22.6 mins.

It will be noted from the above chart that especially good results were obtained on the ceilings with the spray brush. This method of painting seemed to be very much preferred over the ordinary method of application by hand brush. The ceilings were all arched, four arches meeting in the center of the room. The side walls had four projecting columns, one at each corner, and between the tops of these columns and the arches of the ceiling there was over a foot of school cornice. Each room also had a chimney projection and large recessed combination windows. The surface, therefore, was not of the ordinary type.

The hand brush work was marred by streaks and in places the covering was poor. The spray gun work was much better, as a heavier coat of paint could be applied.

During both the work on the naval hospital and on General Pershing's headquarters, it was found that the journeymen painters did not seem at all hostile to the use of the spray gun. In fact, after they had become accustomed to it some of them became very enthusiastic about its use, stating that they were less fatigued at night than when they used hand brushes, especially on certain types of work. It would appear, therefore, that journeymen painters, after they have had a little experience with the gun would become enthusiastic regarding its use on certain forms of their work.

Cost of Painting Highway Bridges.—Charles D. Snead, in Engineering and Contracting, March 26, 1919, gives the following:

Estimating Amount of Paint Required.—Knowing the weight, or by estimating the weight of a structure, we may approximate the amount of paint required. The old rule, namely, ½ gal. of mixed paint for the first coat and ⅜ gal. for the second and third coats per ton of steel give fair approximations. The weight of light steel bridges may be calculated approximately from the following formula by Kunz:

$W = (0.12\,L + 12)\,(1.6 - 0.03B)\,BL.$

W = weight of steel in pounds.

L = length of span in feet.

B = width of roadway in feet.

Cost of Painting.—The cost of applying the paint will vary due to different prices paid the labor and the same is true with regard to cleaning. This cost may be approximated by assuming a painter to cover 600 sq. ft. of surface per day. Applied to gallons of paint it means that a painter will apply about 1½ gals. of paint in an 8-hour day or if applied to tons of steel, one painter should cover about three tons per day. This approximation will be found to agree fairly closely to the actual cost if much scaffolding is to be done. The cost of cleaning will vary still more. It may be estimated if the steel is in bad condition that it will require one man one day to clean a ½ ton of steel, while if there are places which may be skipped, one may clean a ton within the same period of time. With the data expressed in hours, it can at once be referred to any scale of wages.

Cost of Painting the St. Louis Municipal Bridge.—R. D. Spradling gives the following in Engineering and Contracting, July 15, 1914.

The Municipal Bridge, which spans the Mississippi River at St. Louis, Mo., consists of three main double-deck river spans and a long approach at each end of the structure. Each of the three main spans has a length, center to center of end pins, of 668 ft.

The trusses are spaced 35 ft. c. to c. The lower or railway deck carries two tracks 13 ft c. to c. supported by four stringers connected to the main floor beams which are plate girders 7 ft. 9 ins. deep. The upper or highway deck consists of a 30 ft. roadway between the trusses with side walks 6 ft. wide cantilevered on the outside of each truss. There is a clearance of 22 ft. between the base of rail of the bottom of the main floorbeam of the upper deck and the base of rail of the lower deck.

Paint and Painting.—The specifications required that the shop coat of red lead should be retouched where necessary, and that in doing this all rust and dirt should be removed by scraping thoroughly and brushing with wire brushes. After the retouching was finished a coat of graphite paint was applied, and after about three days another coat was applied. At first, no drier (except that used in mixing the paint) was allowed. Later, however, when on two or three occasions sudden rains had washed off the fresh paint, the contractor was permitted to use a small amount of Japan drier. The specifications required that the red lead should be 94 per cent pure and that 30 lbs. of red lead should be used to each gallon of linseed oil. This made a very thick paint, and it proved to be excellent for retouching rusty places. The first coat was of brown graphite and the second was black, which make it easy to determine whether the structure had been thoroughly covered with two coats. The paint was received at the work ready mixed, and required only a small amount of stirring before its application.

Very little difficulty was experienced in reaching all parts of the structure. In all cases where scaffolds were swung two men worked on a scaffold, and these men were able to move it without assistance. One man was detailed to keep the men supplied with paint, although at times two men were required for this work. The most difficult part of the work consisted of painting about 12,000 sq. ft. of cast-iron grating on the sidewalk. As the apertures in this grating were about 1-in. square, the use of brushes proved unsatisfactory and small swabs were substituted for the brushes. In general the weather conditions were excellent.

Cost of Labor and Materials.—Table XI gives the length of time required, and the labor and material costs for painting each of the three river spans.

By referring to Table XI it will be noted that the cost of labor and of paint materials is not far from the same—$5,989.90 for labor and $5,812.60 for paint materials, a total of $11,802.50 for the 13,775 tons of steel in the three spans. This cost does not include any overhead expense, nor does it include the cost of paint brushes and miscellaneous items. The contractor used 450 paint brushes, at $1.60 each, the total expense for this item being $720. The estimated cost of miscellaneous items was $100.

The great variation in the quantity of materials used and in the cost of painting span No. 1 and spans Nos. 2 and 3 was due to the fact that span No. 1 was erected first and had been subjected to wear incident to the erection of the other two spans. On spans Nos. 2 and 3 the painters were all Greeks, and they proved to be very efficient workmen. They were cautioned to brush the paint out thoroughly, both to obtain a good surface and to insure economy of paint.

The total amount of materials used and the average amount per ton are shown in following tabulation.

Item	Material	Total quantity	Quantity per ton
Retouching	red lead	15,300.0 lbs.	1.11 lbs.
	linseed oil	629.0 gals.	0.0457 gal.
First coat	graphite paint	1,833.5 gals.	0.133 gal.
	linseed oil	50.0 gals.	0.00363 gal.
Second coat	graphite paint	1,497.83 gals.	0.1088 gal.

Cost of Wrecking Buildings of the Panama-Pacific Exposition. *Wrecking by Dynamite.*—Engineering Record, Aug. 12, 1916, gives the following:

In removing the structural frames of the several buildings it was first intended to pull them down section by section and bent by bent, by means of donkey engines and the necessary winches and lines. This plan was abandoned after it had been employed to some extent, and the frames are now being razed by dynamite, as it was found possible to do this with but little more loss of material. In many cases, such as in taking down the domes of the main palaces, the cost of dynamiting is less than 1 per cent of what it would have been if the structures were dismembered and dismantled by hand.

TABLE XI.—TIME REQUIRED AND COSTS OF LABOR AND MATERIALS FOR PAINTING ST. LOUIS MUNICIPAL BRIDGE IN 1914

	Labor					Materials			
Item	Elapsed time, days	Elapsed time, hours	Hours per ton	Total cost at 35 cts. per hour	Cost, cts. per ton	Quantity used	Unit cost	Total cost	Cost, cts. per ton
Span No. 1									
Retouching........	25	1,350	0.294	$ 472.50	10.3	7,000 lbs. red lead.........	$0.055	$ 385.00	13.0
						282 gals. linseed oil........	0.75	211.50	
First coat..........	23	3,551	0.770	1,242.85	26.9	747.5 gals. graphite paint..	1.30	971.75	21.2
Second coat........	23	2,281	0.498	798.35	17.5	557.5 gals. graphite paint..	1.30	724.53	15.8
Span No. 2									
Retouching........	18	893	0.195	$ 312.55	6.7	4,520 lbs. red lead.........	$0.055	$ 248.60	8.5
						188 gals. linseed oil........	0.75	141.00	
First coat..........	24	2,103	0.457	736.05	15.9	557 gals. graphite paint....	1.30	724.74	16.2
						25 gals. linseed oil.........	0.75	18.75	
Second coat........	21	2,296	0.500	803.60	17.5	527 gals. graphite paint....	1.30	685.10	15.0
Span No. 3									
Retouching........	28	761	0.166	$ 266.35	5.8	3,780 lbs. red lead.........	$0.055	$ 207.90	7.1
						159 gals. linseed oil........	0.75	119.25	
First coat..........	18	1,855	0.405	649.25	14.0	529 gals. graphite paint....	1.30	687.70	15.4
						25 gals. linseed oil.........	0.75	18.75	
Second coat........	16	2,024	0.442	708.40	14.6	514.33 gals. graphite paint.	1.30	668.63	14.5
Totals........	..	17,114	.....	$5,989.90	....		......	$5,812.60	....

The usual procedure of bringing down the domes, which stand 162 ft. high and cover an area of 102 ft. square, is to cut the dome and its supporting columns entirely free from other portions of the structure and dynamite the two corners on the side toward which the dome should fall. Previous to the falling, all of the walls, studding and braces are stripped from the skeleton, leaving only the heavy timber columns which carry the weight of the dome proper. The dome itself consists of segmental timbers supported on a circular girder, which in turn rests on four trusses each carried by two columns. At each corner of the dome there are thus two columns, each consisting of four 12 × 12-in. timbers. The method of dynamiting is to bore each timber and insert a stick of dynamite about 6 ft. from the base, connecting all eight sticks by wire for simultaneous firing by battery. Bringing down the domes this way costs, for labor and powder, about $6.50 for each dome. From the dynamited domes about 60 per cent of the timber in the trusses is salvaged and about 70 per cent of the timber in the columns.

The average cost of salvaged lumber, in the yard was $5.50 per thousand; the value of this lumber varied from $5 to $20 per thousand.

The cost of recovering steel f. o. b. cars exposition grounds was $10 per ton; this steel could be sold for about $16.25 per ton.

The proportion of iron and steel to wood salvaged was as follows:

In domes—1 lb. of metal to 1 ft. B. M.

In other than domes—¾ lb. of metal to 1 ft. B. M.

Wrecking with Oxyacetylene Torches.—The following matter is from Engineering Record, Dec. 16 and Dec. 23, 1916.

In wrecking the Palace of Horticulture, the General Welding & Cutting Works, which purchased the structure for $5,000, stripped off the glass and woodwork, and when nothing remained but the steel skeleton used oxyacetylene torches to cut it down.

The dome proper was 150 ft. in diameter and 100 ft. high above the supporting arches, or 175 ft. from floor level to top of dome. When the structure was stripped down to the steel skeleton, four men equipped with life-belts and oxyacetylene torches were put to work, starting at the top of the dome. In ten days they had entirely dismembered the dome proper. The removal of the entire steel frame, which was accomplished by a crew of only eight men, was completed in about three weeks. The steel totaled about 600 tons in weight, of which 350 tons was included in the skeleton of the dome proper.

The plan first proposed for the wrecking involved the cutting off of vertical members so that the circumferential bands would fall in a single piece. The Department of Safety of the California Accident Commission, however, suggested that it would be better to cut out sections of the circumferential bands between uprights, taking one section at a time. They insisted further that the workmen should be provided with the safety belts. It was pointed out that the dismantling of the structure in this way would not only be a safer procedure but would probably involve the loss of less material due to breakage.

This proved to be the case, as the short sections which were allowed to fall were comparatively light, and it is estimated that not more than 2 per cent of the steel was damaged in falling. This was in large measure owing to the fact that the area into which the pieces fell from the dome was a soft earthfill, and the fallen pieces were removed promptly so that sections falling later would not strike them. Of course, the members of the supporting frame which could be handled by tackle after being cut free were taken down that way. As a result of the precautions to safeguard workmen not a single accident was reported on the work, although it was considered an unusually high risk.

Wrecking the Tower of Jewels is said to have cost $25,000 including insurance and overhead. This structure contained 1800 tons of structural steel and about 2,000,000 ft. B. M. of lumber, but its 435 ft. of height considerably complicated the problem of economical dismantling in a way that would not damage the salvable material. The safety of workmen was also considered an important item. During erection of the structure there were three fatal and a number of minor accidents, and it was believed that the work of dismantling would be more dangerous.

Wrecking operations were started April 2, 1916, and the last standing column was taken down Nov. 23. During this time, in which the crew on the job ranged from 12 to 20 men, neither serious nor fatal accidents were reported.

The wreckers began at the top, lowering most of the material from derrick booms. The steel frame was unbolted or cut with acetylene torch where necessary. The columns which supported the arch 125 ft. high in the base of the structure were stripped and their upper parts removed so that the height of the columns which it was finally necessary to "fall" was only 90 ft.

The work was done in such a way that less than 2 per cent of the structural steel shapes were damaged in handling, and thus the major portion of the steel commanded a high price. The resale of the structural-steel members netted $65,000, in addition to which the major portion of the lumber in the structure was disposed of at from $10 to $12 per 1,000 ft. B. M. Most of the steel was sold to a local rolling mill which manufactures structural shapes.

Comparative Cost of Wood and Coal for Construction Plant Fuel.—J. R. Sherman gives the following comparative data in Engineering and Contracting, April 8, 1914.

Kachess Dam, which was built in 1911–12 by the United States Reclamation Service, is located at the lower end of Lake Kachess, near Easton, Wash. During the construction of this dam both coal and wood was used extensively as fuel on practically all of the dirt handling machinery. The work being located in a heavily timbered forest reserve, wood appeared to be without question the cheapest fuel to use, since no charge was made by the Forest Service for the timber so used. Twelve miles from Easton, however the Roslyn coal mines are located, from which a large part of the bituminous coal burned in the northwest is mined.

The wood used was cut by contractors on individual contracts for $1 for 16 in., $1.25 for 36 in. and $1.40 for 42 in. wood per rick, a rick being 4 ft. high by 8 ft. long; the only requirements being that the wood should be cut as near to the work as possible and piled so as to admit of easy access for the wood wagons.

The wood was distributed to the various machines by Government forces, the average amount hauled with a team, wagon, driver and one extra man being 2½ ricks of 16 in. wood, 2 ricks of 36 in. wood and 1½ ricks of 42 in. wood. The length of haul varied from a few hundred feet to approximately one-half mile, the roads for the greater part of the season being in good condition.

Mine run coal was purchased from the Roslyn Fuel Co., Roslyn, Wash., the contract price being $2.75 per ton f. o. b. Roslyn. At Easton the coal was sacked by hand and hauled by team and wagon from Easton to the works, a distance of three miles. The average load for a four-horse team was three tons.

The itemized cost of the coal delivered at the machines is given below:

Item	Per ton
Purchase price	$2.75
Ry. freight, Roslyn to Easton	0.37
Freighting from Easton to camp	0.90
Sacking and storehouse expense	0.38
Distributing at camp	0.52
Total	$4.92

The unit cost of distributing at camp as shown above was obtained by dividing the total cost of distribution by the total tons used. There was a large amount of coal used that did not have to be distributed, the coal being unloaded near the tracks so that the dinkey engines used to haul the dirt trains could coal up from the storage bins.

A comparison of the costs of fuel used on some of the machines during the season of 1912 is given in Table XII.

TABLE XII

Machine	Fuel used	Total cost	Cu. yds. excavated or hauled	Cost per cu. yd.
Steam shovel	Wood, 16-in., 36-in., 42-in.	$1,275.45	58,799	$0.022
Steam shovel	Coal	1,023.36	82,918	0.012
Lidgerwood drag-line excavator	Wood, 36-in.	902.40	38,709	0.023
Lidgerwood drag-line excavator	Coal	324.72	19,596	0.016
Dinkey engine shovel run	Wood, 16-in.	494.77	57,719	0.0086
Dinkey engine shovel run	Coal	423.12	72,221	0.0059
Dinkey engine excavator run	Wood, 16-in.	182.20	11,610	0.0157
Dinkey engine excavator run	Coal	393.60	44,544	0.0088
Steam roller	Wood, 16-in., 36-in.	275.14	31,750	0.0087
Steam roller	Coal	300.12	77,673	0.0039

It should be stated that while the machines were using wood it was necessary to keep an extra man employed for splitting. On the dinkeys and steam roller this wood splitter was not used all the time, as one man was able to split wood enough in 8 hours to run the machines 16 hours. On the steam shovel and drag line excavator a wood splitter was employed for each shift, the wages being $2.20 for 8 hours' work.

The steam shovel used was a 45-ton Bucyrus with a 1½-cu. yd. dipper and was used to excavate the finer material for the embankment, working in a pit approximately 1,300 ft. long and with an average depth of cut of 20 ft.

The drag line excavator was manufactured by the Lidgerwood-Crawford Co., and was used to excavate gravel for the embankment. It was a 65-ton machine with a 70 ft. boom and a 1½ cu. yd. Page bucket.

The dinkey engines were made by the Vulcan Iron Works and were operated on a 24-in. gage track and weighed 9 tons each. The average length of haul for the dinkeys operating on the steam shovel pit was 1,000 ft. and the average train was 15 1½ cu. yd. cars. The length of the haul for the dinkeys on the gravel run was about 3,000 ft. and the average train consisted of 12 1½ cu. yd. cars.

Approximately 12,000 cu. yds. of the steam shovel excavation was hauled by teams, which accounts for the difference in yardage excavated by the steam shovel and that hauled by the dinkeys on the steam shovel run.

The itemized cost of the coal delivered at the machines is given below:

Item	Per ton
Purchase price	$2.75
Ry. freight, Roslyn to Easton	0.70
Freighting from Easton to camp	0.09
Sacking and storehouse expense	0.15
Distributing at camp	0.33
Total	$4.02

The unit cost of distributing at camp as shown above was obtained by dividing the total cost of distribution by the total tons used. There was a large amount of coal used that did not have to be distributed, the coal being unloaded near the tracks so that the dinkey engines used to haul the dirt trains could coal up from the storage bins.

A comparison of the costs of fuel used on some of the machines during the season of 1912 is given in Table XII.

TABLE XII

Machine	Fuel used	Total cost	Cu. yds. exca- vated or hauled	Cost per cu. yd.
Steam shovel	Wood, 16-in., 36-in., 42-in.	$1,275.15	58,700	$0.022
Steam shovel	Coal	1,023.36	82,848	0.012
Lidgerwood drag-line excavator, 65-ton	Wood, 36-in.	902.40	38,700	0.023
Lidgerwood drag-line excavator	Coal	324.72	19,386	0.016
Dinkey engine shovel run	Wood, 16-in.	404.77	67,719	0.0060
Dinkey engine shovel run	Coal	123.12	72,221	0.0059
Dinkey engine excavator run	Wood, 16-in.	182.20	11,610	0.0157
Dinkey engine excavator run	Coal	393.00	44,344	0.0088
Steam roller	Wood, 16-in., 36-in.	375.14	31,130	0.0097
Steam roller	Coal	300.12	77,673	0.0039

It should be stated that while the machines were using wood it was necessary to keep an extra man employed for splitting. On the dinkeys and steam roller the wood splitter was not used all the time, as one man was able to split wood enough in 8 hours to run the machines 16 hours. On the steam shovel and drag line excavator a wood splitter was employed for each shift, the wages being $2.20 for 8 hours' work.

The steam shovel used was a 45-ton Bucyrus with a 1½-cu. yd. dipper and was used to excavate the finer material for the embankment, working in a pit approximately 1,300 ft. long and with an average depth of cut of 20 ft.

The drag line excavator was manufactured by the Lidgerwood-Crawford Co., and was used to excavate gravel for the embankment. It was a 65-ton machine with a 70 ft. boom and a 1½-cu. yd. Page bucket.

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Approximately 12,000 cu. yds. of the steam shovel excavation was hauled by teams, which accounts for the difference in yardage excavated by the steam shovel and that hauled by the dinkeys on the steam shovel run.

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