Location, Construction and Maintenance of Roads

GOODELL

The Location, Construction and Maintenance of Roads

BY

JOHN M. GOODELL

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PREFACE

In the summer of 1916, several State highway engineers reported to the American Highway Association that there was need of a concise explanation of the best current practice in locating, constructing and maintaining country roads, not combined with information about city pavements. It was found by these engineers that the information in many excellent engineering treatises proved confusing to rural road officials because they did not have sufficient technical knowledge to draw a line between what was applicable to country highways and what was restricted to urban conditions. Inquiry showed that such an outline of road-building would be welcomed by the road officials of other States, and the preparation of this book was accordingly begun.

Highway engineers in all parts of the country generously contributed material and advice. Special attention was paid to ascertaining reasons for unusual methods, in order to avoid the publication of anything useful only in restricted localities and possibly leading to trouble if tried generally. The purpose was to furnish information of a national value rather than an expression of the views of a few individuals, who inevitably have personal preferences and prejudices. As each section was finished it was submitted for criticism to engineers or chemists with special knowledge of the subjects discussed, and most of the chapters formed by combining these revised sections were sent out to other engineers for further criticism. Some of the chapters were revised a number of times before they were finally approved. As a consequence, although my name appears as the author on the title page, the book is rather the product of the coöperation of over fifty of the leading American highway engineers and the patient and intelligent handling of the details of the work by Miss Isabelle Stockett, at the time chief clerk of the American Highway Association.

This book appeared originally as Part II of the 1917 Good Roads Year Book. Its wide circulation, the many references to it in technical journals, and its use as a textbook by engineering colleges, indicating that the volume had won a distinct position in technical literature, led the Directors of the American Highway Association to assign the copyright to the D. Van Nostrand Company, when the Association was dissolved a few days ago. By this action the results of the coöperative labors of so many specialists will remain available to the public.

Added to the text as it appeared in the Good Roads Year Book is a chapter on the reasons for improving roads. This is part of a "good roads manual" for public officials, not technically educated, which had considerable circulation in manuscript form among road commissioners applying to the American Highway Association for such information. It is printed here as a concise justification of the expenditure of public funds for road improvements, a subject which highway engineers must frequently discuss at public meetings.

John M. Goodell.

Upper Montclair, N. J., March, 1918.

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LOCATION, GRADES, WIDTHS AND CROSS-SECTIONS OF RURAL ROADS

The improvement of any road or system of roads must begin with a study of its location and grades, for unimproved roads are often bad in both respects. The purpose of relocation is to enable the road to carry the anticipated traffic with the least effort and loss of time. It is impracticable to relocate all roads and improve their grades at the present time, and highway officials must be satisfied with gradually eliminating or at least reducing the defective conditions. In order to carry on this work efficiently, however, the entire system of roads under a board or commission must be studied as a whole, so that the whole body of taxpayers may be benefited as uniformly as practicable by the work done annually. The work should be planned in a broad way several years in advance, if possible, for it is only in this way that the needs of all parts of the district can be met without favor or prejudice. This is particularly important where the needs are great, the road funds meager, and property has been developed along locations where roads should never have been laid out. The situation in such cases has been summed up as follows by W. S. Keller, State highway engineer of Alabama:

> The genuine bad roads cannot be maintained for the reason that they have never been constructed. The great amount of work necessary to keep them in passable condition disheartens the man who is by law compelled to work them. Until these roads are relocated, avoiding heavy grades and marshy bottoms, sharp angles and useless twists, and are graded so they will have good drainage, we may expect them to be bad.

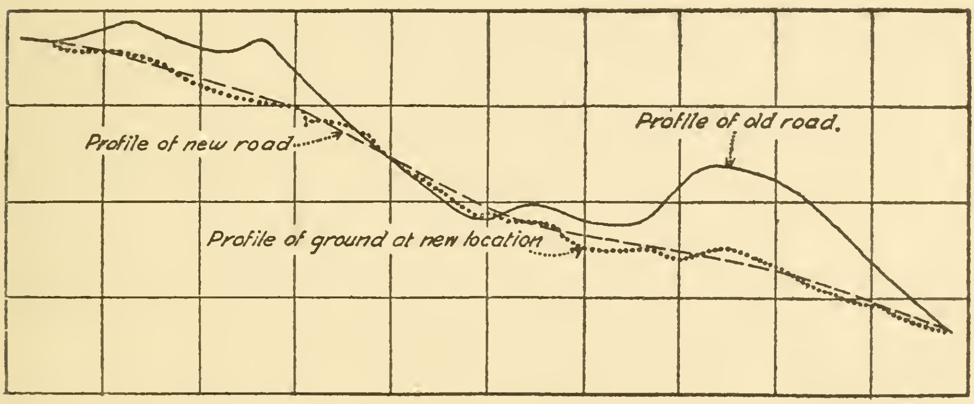
Location.—It is evident that the road should be as nearly straight between the points it connects as the configuration of the country traversed will permit. It is desirable, however, to restrict grades to 6 per cent and to avoid expensive cuts, fills and bridges. To locate the road properly and meet all local conditions in the best manner requires competent engineering services; if they are not obtained there is a strong probability that after the country develops new locations must be made to meet the increased transportation needs and the expenditures for new rights-of-way will be far greater than to-day. But if, for the present, engineering services are out of the question, the road authorities can at least relocate roads that are plainly unnecessarily low and marshy and unnecessarily steep and high. This is particularly the case where roads have been laid out on the section lines of the government land surveys. However desirable the rectangular parceling of unoccupied land may have been in attracting settlers, it has proved a heavy handicap on transportation by introducing many right-angle turns and causing needless length in the roads of these regions. The following comment on this condition was made by W. S. Gearhart, State engineer of Kansas:

> A 60-foot road on two sides of a section of land occupies 14.55 acres, while a road 60 feet wide in a diagonal direction through the section occupies 10.28 acres. Thus there is a saving in the diagonal road of 4.27 acres and 0.587 mile of distance. The saving in the cost of right of way, assuming that the land along the section line is as valuable as on the diagonal line, is $85.40 if the land is worth only $20 per acre. This amount in most cases would be sufficient to grade the 1.413 miles of diagonal line in first-class condition. If a man lives 4 miles north and 4 miles east of his market-place he is 5.657 miles on the diagonal line from it; that is, on the section-line road he must travel 4.686 miles farther in making the round trip than on the diagonal line.

The same official has reported that a county commission built a mile of road on a section line, which crossed the same stream three times. By adopting a somewhat different location and making the road 1½ miles long, the stream would be crossed but once and the road become of greater service to the community. "More than $3,000 worth of steel bridges were bought, it will cost not less than about $2,500 for the abutments to set these three structures on, and an expenditure of $2,500 will be necessary to make the road passable, or a total of about $8,000 to accommodate four men whose property is reported as probably not worth as much as the cost of the road." Instances of this nature prove the desirability of having roads located by engineers without interference from political or personal influences. The assertion that such services are unnecessary in connection with such relatively inexpensive highways as dirt roads is best answered by pointing to the action of the Utah State road commission in substituting an entirely new location about 15 miles long for an old route in Beaver County. This was done by the engineers because the new line had better alignment, grades and road materials.

The influence of soil conditions and the presence or absence of road materials may not be given due consideration in locations made by persons who are not engineers. The following comments on this point were made by A. N. Johnson in a report on the highways of Maryland:

Should it happen that two locations are possible with about equal advantages and disadvantages, except that one was over a different soil from the other, that location should be taken which traverses the soil best calculated to insure a good road-bed. For example, if it were possible to avoid going through a clay section when a more open soil could be had close at hand, much would be saved both in the cost of construction and in the subsequent maintenance by going over the more open soil. It is hardly necessary to state that crossing soft, boggy soil should be avoided whenever the expense of going around such a place would be no more than for crossing it. If possible it is always well to locate a road in the vicinity of good road-material, either a suitable stone or gravel, for the proximity of such material lessens for all time the cost of maintenance of the road, and when this point is considered such a location would be warranted even at an increased first cost.



PROFILE OF ROAD IN BALTIMORE COUNTY, MD.

Showing How Relocation Saved a Large Sum in the Improvement of the Road.

Value of Engineering Services.—Few persons realize that the expense of engineering services in relocating old roads is generally more than offset by the saving in the cost of construction of a properly located road over one improperly located. The engineer knows how to fit the road to the ground in hilly country so that the material from the cuts may be used in making nearby embankments and costly rock excavation will be reduced to the lowest practicable amount. On the Maryland State highways, the expense of moving 100 to 150 cubic yards of earth is from $50 to $75, which is equal to the cost of making a mile of careful surveys that may be reasonably expected to save more than 150 cubic yards of such earthwork. The accompanying illustration shows the saving in excavation expenses on a road in Baltimore County, Md. The hilly character of the old road made necessary heavy reductions in grade to give a highway properly accommodating the traffic. The heavy cutting to give suitable grades along the old location is shown by the diagram, while the light excavation and filling required on the new location is also indicated. Such savings of cost can only be made by competent engineers. The amount of detail which the engineers' survey must furnish depends on the character of the road to be built and the nature of the country. Less detail is necessary for an earth road in a flat country than a brick road in a hilly district, for example, but enough should be obtained to make sure that the final location is along the line on which the cost of transportation plus the interest on the first cost plus the cost of maintenance of the road will be the minimum for the available funds for first cost. The last point is important, for the best location is often governed by the amount of money which can be spent on construction.

In carrying out extensive work by contract, experience shows that low bids from responsible contractors are best secured when full information is obtained for their use in preparing estimates. For instance, in carrying out road improvements in Vermilion County, Illinois, under a $1,500,000 bond issue, about 1800 drawings of plans, profiles and cross-sections were prepared in the first two months of the work. These were plotted on Plate A 4 by 20 profile paper cut into 32-inch lengths. The longitudinal scale of the plans was 80 feet to 1 inch and the tranverse scale 40 feet to 1 inch. The horizontal scale of the profiles was 80 feet to 1 inch and the vertical scale 4 feet to 1 inch. The plans show all section corners, bench marks, fence lines, shade trees, farm entrances, property owners' names, drains and culverts to be built, and any other data necessary for a complete knowledge of the working conditions. The cross-sections are plotted on a scale of 4 feet to 1 inch. An 11 by 8½-inch map was made of the location of 14 sources of sand and gravel, the plants furnishing paving brick and the railways running from them to the district where the roads were to be built, and 24 by 20-inch maps were made showing the roads, railways and sidings available for contractors' use. The existing road grades were shown on small maps, and other small maps showed the location and size of proposed bridges and culverts.

Grades.—The effect of grades on hauling is usually stated in the following manner: If a horse can pull 1,000 pounds on a level road, he can pull 810 pounds with the same effort on a 2 per cent grade, 720 pounds on 2½ per cent grades, 640 pounds on 3⅓ per cent grades, 540 pounds on 4 per cent grades, 400 pounds on 5 per cent grades and only 250 pounds on 10 per cent grades. These figures are only approximate but they show the importance of reducing grades as much as possible where traffic is heavy. Where traffic is not heavy, the cost of reducing grades below 3 or 4 per cent, if it must be done by expensive construction or considerable lengthening of the road, is generally considered an unwarranted expense.

A thoroughly consolidated roadbed is a valuable public asset and in planning grade improvements it is sometimes undesirable to cut 6 to 12 inches into such a road for a long distance in order to secure a theoretically perfect profile.

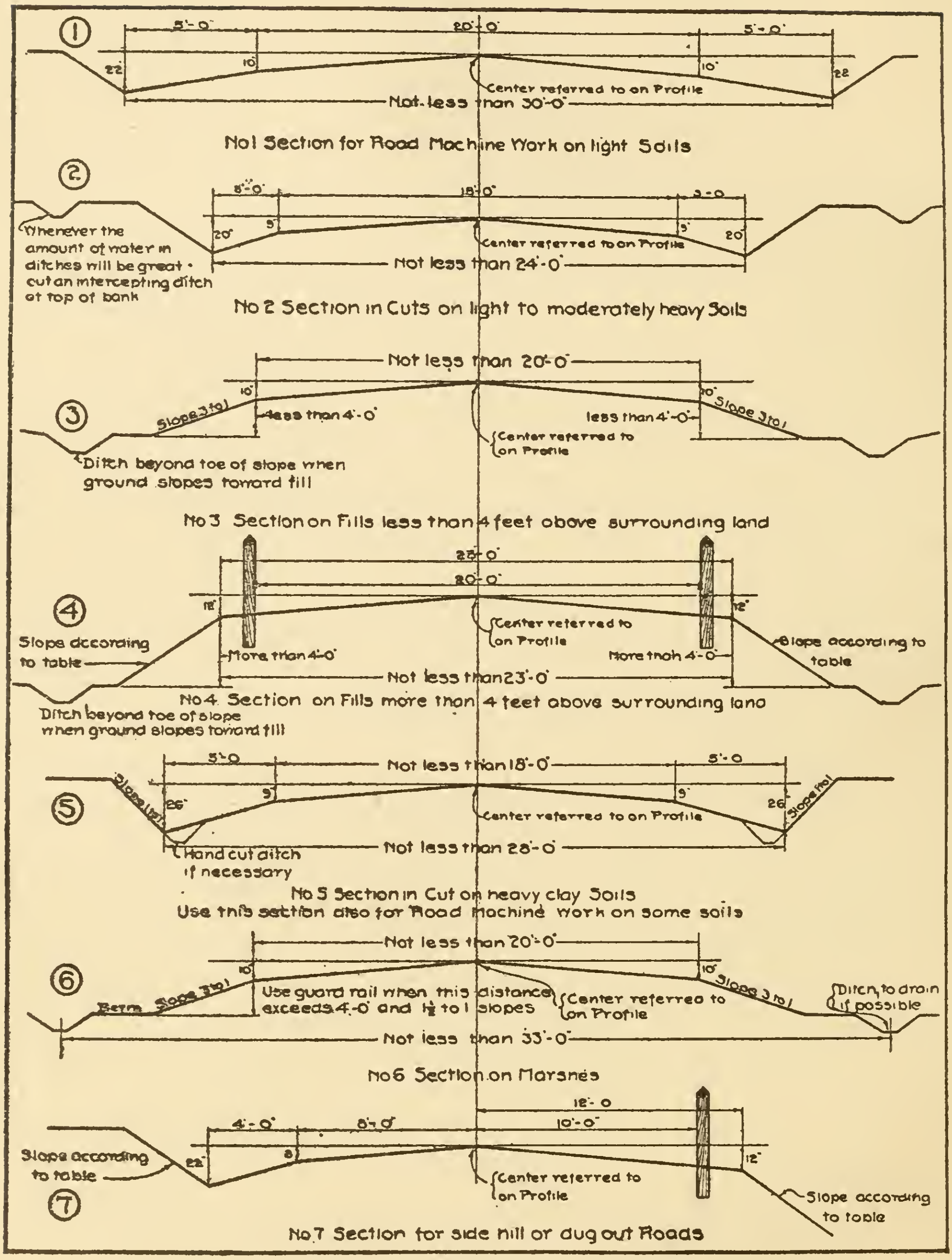
Where a road will probably have considerable automobile traffic the grades up a hill should be flattened somewhat at the top if necessary, so the driver can see an approaching car when it is 300 feet from him. When the change in grade at the summit is not more than $6\frac{2}{3}$ per cent, no flattening is necessary. If the change is 10 per cent a vertical curve about 200 feet long should be employed; for a 13 per cent change, a curve 292 feet long and for a 16 per cent change, a curve 360 feet long.

Widths.—Highway commissions in many parts of the country are reporting that their roads are often too narrow to accommodate the traffic coming on them as soon as they are improved. State Highway Commissioner Everett of New Hampshire reports that the standard width of 21 feet from ditch to ditch is not wide enough on many of the roads under his jurisdiction, and the experience of the Wayne County road commission, in Michigan, shows that the minimum width of hard-surface roadway in the district around Detroit should be 16 feet and 18 feet, and should be adopted wherever practicable. These comments relate to double-width roads. A width of 8 feet, previously used for single-width roadways, is now generally considered too narrow and 9 and 10 feet are advocated.

Many of the State highway departments have established standard cross sections for earth roads. The present standards in Wisconsin are shown in the diagrams on the next page. They are also the standards for macadam and gravel roads having a hard surface 9 feet in width. Where the slopes are not indicated they are made in accordance with the accompanying table. Guard rails are used when the vertical distance from the edge of the shoulder to the top of the ditch is more than 4 feet.

Slopes Required by Wisconsin Commission in Road Work in Different Kinds of Soil

SOIL	ALL CUTS	FILLS LESS THAN FOUR FEET	FILLS OVER FOUR FEET
Sand and sandy gravel	2 to 1	3 to 1	2 to 1
Loam	$1\frac{1}{2}$ to 1	3 to 1	$1\frac{1}{2}$ to 1
Clay and clay gravels	1 to 1	3 to 1	$1\frac{1}{2}$ to 1
Hard pan	$\frac{1}{2}$ to 1	3 to 1	1 to 1
Solid rock	As it stands	3 to 1	As it stands



Standard Earth Road Sections, Wisconsin

The Wisconsin sections are wide enough to carry a 16-foot roadway. It is now generally held that the distance from ditch to ditch should be 24 feet, even for a single-width road, if local conditions permit. In some States, where the legal right-of-way is only 30 feet, it is impracticable to secure 24 feet between ditches and have proper fences and banks along the road where it is in cuts. It is necessary to obtain extra wide rights-of-way in such cases or to make the road narrow.

It has been claimed that if a hard surface is placed on a roadbed, the width of this pavement need not be so great as when the traffic is carried by a less durable surface, and consequently a smaller width between ditches and less earthwork are required. This argument ignores the fact that a narrow roadway concentrates the travel and may cause the improved surface to carry a volume of traffic for which it is unsuited. For this reason 9 and 10 feet for a single-width surfaced roadway and 16 or 18 feet for a double-width roadway are generally favored. In recent years a new factor has become important in determining the proper width of hard surfacing. Heavy motor trucks and omnibuses are now in regular service on many roads. If they turn off a hard surface on to a soft shoulder they may become mired or unmanageable and crash through fences or guard rails before the brakes stop them. The driver is usually on the left hand of such a truck where he cannot easily see the edge of the hard paving, and consequently he keeps his truck well toward the center of the road in order to avoid trouble on the shoulders, although the driver of a lighter vehicle would keep farther over to the side.

Where the road is used by carts or trucks that make a loaded trip in one direction only, as well as in other sections where funds are not available at present for a double-width paved roadway, an 8 to 10-foot pavement has been laid on half the road, with one side along the center line, as though a similar pavement were to be laid at once on the other side of the road.

Rights-of-way.—The width of the road is restricted in the older parts of the country by narrow rights-of-way, which are troublesome limitations on road improvements. Cuts and fills of more than a few feet widen the strip occupied by the road, ditches and side slopes. Telephone poles and trees along the road require space, and provision for both is desirable. As a result of long experience in Massachusetts and California, reinforced by observation in many other States, Austin B. Fletcher, state highway engineer of California, recommmends securing a minimum of 50 feet for right-of-way, and 60 feet wherever practicable.

Acquiring rights-of-way is an annoying feature of the work of highway commissions, and in any extensive undertaking experience shows that the best results are obtained if the business is handled by one man, with whatever assistance is needed. Diplomatic methods are best but legal warfare is sometimes necessary, and whatever means must be used should be employed promptly in order to have the right-of-way available for construction as soon as it is time to begin work. In some States, it is unnecessary for the authorities to pay for private property taken for public use in advance of actually taking possession. If the property owner is dissatisfied with the original offer of payment or the award made to him by the public authorities, he may pursue his remedy in the appropriate court, even though his land has already been occupied by the public. In other States no rights-of-way can be taken before they have been acquired, after a vast amount of red tape, by donation, purchase or condemnation. The western States are particularly oppressed by such roundabout methods of entering upon private property to carry on improvements for the benefit of the entire community.

It has been Mr. Fletcher's experience that the expense of obtaining abstracts of title to ascertain the ownership of land is unnecessary. The method he has employed in securing rights-of-way for hundreds of miles of California highways is the following: When the field parties are making the original surveys, the chiefs of party usually inquire from the occupants of the land surveyed who the owners or those interested in the property may be. This gives a clue to the ownership. Thereafter one of the staff visits the proper county officers and ascertains from the assessment rolls or the records who purport to be the owners. Deeds or agreements are then prepared, containing the proper descriptions, and it is very rare, indeed, that any objection has been made to the accuracy of the instrument submitted. By thus performing its own title searches, even though thay may not have always been the most exact from a title lawyer's standpoint, the authorities have saved thousands of dollars and have never had an injunction or ejectment proceeding instituted against them by objecting land owners.

Curves.—Sharp curves and right-angle intersections are danger places where vehicles move rapidly. The width of the roads should be increased on sharp curves, except where it is already wide, and the right-of-way at right angle intersections should be widened and cleared so as to give drivers on the crossing roads a good view of approaching vehicles. This is not always practicable, unfortunately, but road commissions should keep in mind that these places are dangerous, that it is their duty to reduce the dangerous conditions on the roads under their charge and that it is less expensive to improve these places now than it will be later.

On curves on a road with a uniform cross-section there is a tendency for the drivers of motor vehicles to stay on the inside of the curves because the centrifugal effect of passing on the outside is unpleasant. In order to make motor travel equally agreeable on any part of the cross-section of curving roads, it is now the practice to superelevate the outside of the road, as is done on railways. Experiments with different angles of superelevation on California roads have led the highway department of that State to adopt a slope of $\frac{3}{4}$-inch rise to each foot of width of the roadway on all curves having radii of 300 feet or less. The transition from the standard crowned cross-sections to the uniform transverse slope stated is made in a distance of about 80 feet. In passing from the straight to the curved road, the outside of the road is gradually made horizontal and then gradually tipped up until there is the same slope throughout the section from the inside to the outside edge. In this transition the inside edge remains at the same elevation it would have if the ordinary crowned cross-section were maintained; the change is made by adding to the height of the other parts of the standard section, so the improvement is generally called "banking the curves."

Grade Crossings.—The elimination of grade crossings is a problem that frequently complicates the location or relocation of highways. The usual method of carrying the road under or over the railroad tracks is so costly that its general use on rural roads is impracticable. Some of the narrow underpasses with sharply curving approaches that have been built on roads used by numerous automobiles at high speed are almost as dangerous as the grade crossings they replace. Attention is therefore being given more and more to comprehensive relocation as a means of reducing the number of grade crossings and making those remaining less dangerous than before. For example, there was a Wisconsin road 23.9 miles long with 16 grade crossings and 15 such crossings on branch roads feeding it, in addition to 3 underpasses and 2 overhead bridges. A careful study by the State highway commission showed that by reasonable relocation the total number of crossings could be reduced to 16 at grade, 4 underpasses and 2 overhead bridges, and the 16 grade crossings would be on the branch roads, none remaining on the main road. The total cost of right-of-way and construction for such an improvement was estimated at $35,000, much less than the cost of elimination in the usual manner.

The New York State highway department has had a long experience in treating grade-crossing problems and as a result has adopted the following general rules for location at such crossings:

1. The alignment should be laid out so that approaches are on a tangent which is at least 400 feet long, 200 feet on each side of the crossing. The angle that the highway makes with the railroad should not be less than 60 degrees. The grade of the approaches should not be greater than 6 per cent, and there should be a portion level or nearly so for a distance of not less than 100 feet on each side of the crossing.

2. On the highway within 200 feet of the railroad, on each side, traffic should have a clear view of approaching trains for a distance of 1,000 feet. (See Rule 5.)

3. The width of the planked crossing shall not be less than 24 feet, measured at right angles to the center line of the highway. The ends of the pavement should be protected by an edging of stone or concrete placed at a sufficient distance from the ends of the ties to allow for replacing them.

4. A standard danger sign should be placed at each side of the crossing along the highway in a prominent location at least 400 feet from the crossing.

5. When the view of the railroad either way, as required in 2, is less than 1,000 feet, or when there is a great deal of traffic on either the highway or railroad, or when vision may be blocked by cars or trains as in the case of a railroad with two or more tracks, a flagman should be employed to warn highway traffic.

The New York State highway department's rules for the elimination of grade crossings are as follows:

1. Subways shall have a clear head-room of not less than 13 feet and a clear width between abutments of not less than 26 feet. The approaches when in a cut shall have a minimum width of 28 feet between bottoms of slope. When a highway passes over a railroad the clear height over said railroad shall be not less than 21 feet and the approaches when on embankment shall be not less than 28 feet wide across the shoulders.

2. The alignment and grade of approaches shall be such that traffic at any point within the limits of the elimination will be able to see that approaching it for a distance of 300 feet. The maximum allowable grade shall be 6 per cent.

3. Bridges carrying railroads over highways shall be of a solid-floor, ballasted type. Drainage of such floors shall be such that water will not drop upon the roadway. Bridges carrying highways over railroads shall have solid concrete floors with a minimum width of roadway of 18 feet.

4. When an elimination is made on a highway already improved, the pavement shall be of the same type as the existing pavement. If the highway is not improved the pavement shall be the same as that contemplated.

5. Subways shall be drained in a thoroughly satisfactory manner.

6. The limits of an elimination shall be taken as the points of intersection of the approach grades of the elimination with the grade of the existing highway.

REGULATIONS OF THE CALIFORNIA HIGHWAY COMMISSION REGARDING SURVEYS AND PLANS[1]

Part 1. Surveys

(a) *Note Books.*—Survey note books will be furnished to the chief of party by the Division engineer. No survey note book other than the standard book so furnished shall be used, and the use of loose sheets is prohibited. The notes placed therein shall be the "original" notes of the survey and shall not be copied from sheets or from other books.

The standard book shall be used for alignment, topography and levels, and for all other information which the survey parties are required to secure; all notes shall begin at the bottom of the page and read upward.

On beginning a survey the chief of party shall see that a proper entry of the Division, county and route, is made upon the label pasted to the inside of the front cover of the note book.

Attached to the back cover of each book are several pages showing the "standards" required in all surveys. All survey notes shall conform in so far as possible to such "standards" to the end that all surveys and the manner of taking the notes thereof shall be uniform throughout the work.

At the beginning of each day's work the following data shall be entered in the book: Date; weather conditions; names of members of party and duties of each.

When no notes are taken on a working day or portion of a day, the date shall be entered and the reason for the loss of time shall be stated clearly and concisely.

All survey and other notes shall be suitably indexed on the first ruled page of the note book.

Every day at the close of the work the notes shall be copied neatly upon specially printed sheets furnished by the division engineer and numbered consecutively, and after careful checking such sheets shall be forthwith forwarded to the division engineer.

No note book shall contain notes relating to more than one route or to more than one county.

[1] From Austin B. Fletcher, State Highway Engineer of California.

(b) *Alignment Notes.*—The base line of the survey shall be referred to the true meridian, which shall be determined by observation on polaris. The chief of party before beginning a survey shall procure all tables and other data needed for such determination and observations shall be made from time to time to ensure the accuracy of the work. The line shall also be checked by magnetic bearings taken at each transit point. All angles in the base line shall be azimuth angles read from the back sight and repeated with the telescope reversed.

Complete traverses shall be run in all surveys and computed in the field. If the error of closure exceeds 1:5000 the division engineer shall be notified and the party shall not move camp until he has authorized such moving. The closures shall be completed and computed in such lengths as the division engineer shall prescribe.

The base line shall be as nearly as may be in the center of the proposed road. When it is apparent that a tangent base line will not follow the approximate center of the proposed road, a curve of suitable radius shall be run. Curves shall be measured by computing the length of the arc and not by chords.

If the survey follows an existing road, wire nails not less than 5½ inches in length shall be driven flush with the traveled way at all angle points in the base line, at the beginning and ending of all curves and on long tangents at intervals not exceeding 1000 feet.

When the base line does not follow a traveled way or when the roadway is so soft that nails will not hold their position, wooden stakes driven flush with the ground shall be used and the transit point indicated thereon by a small nail.

All transit points shall be properly referenced as provided under the caption "Stakes."

Stations shall be established every 100 feet on the base line and indicated by short wire nails driven through bits of red cloth into the ground to serve as temporary markers during the survey. The stations and half stations shall be also permanently marked by stakes set on both sides of the proposed road sufficiently far removed from the base line to prevent their being disturbed during the building of the road.

(c) *Stakes.*—All stakes which are to be used for establishing grades shall be made from 2 x 3 inch scantling, from 24 to 30 inches in length, laid flat and sawed diagonally into two wedges, with the sharp ends approximately ¼ inch thick. The lumber from which the stakes are made shall be sound, reasonably free from knots, and planed on all sides. These stakes shall be driven into the ground to about one-half of their length with the 2-inch face parallel to the base line. On the right side of the road the station number shall be marked plainly on the side of the stake facing Station O, and on the opposite side of this stake shall be marked to the nearest tenth, the offset from the base line. The face toward the road must be reserved for marking during construction. On the left hand side of the road, the offset from the base line shall be marked on the side of the stake facing Station O and the station number on the opposite side.

All stakes used to mark monuments and for transit points shall be wedge shaped, not less than 1 foot in length nor less than $\frac{7}{8}$ x 2-inch at the top. Such stakes shall be driven flush with the ground unless they are so located as not to endanger the traveling public. Short nails driven into the tops of these stakes shall indicate the monument and transit points.

All monument and transit points shall be referenced by three ties to natural objects or, if such do not exist, to stakes, as shown by the "standards" at the back of the note book.

(d) *Topography.*—All objects, such as houses, barns, fences, gates, field entrances, trees, telephone and telegraph poles, power lines, railroad and railway tracks, within a distance of 150 feet on either side of the base line shall be located by offsets from the base line and recorded in considerable detail, and the limits of the "traveled way" on all existing roads shall be indicated. Separate sketches, with levels and dimensions of all essential features, shall be made in the note book of all bridges, large culverts and other appurtenances of the road, and plainly referenced in the topography notes.

The azimuth from the back sight to the boundary lines of all incorporated cities and of all counties shall be ascertained and recorded. The azimuth of the boundary lines of all entering and intersecting highways, of township lines, and of division lines between property holdings shall be ascertained and recorded with reasonable accuracy, and when feasible the names of the owners of property abutting on the proposed road shall be recorded.

When it is desirable to locate topographic features from a sub-tangent, the station will be measured from the nearest end of the curve.

(e) *Levels*—Whenever there is a known government bench within 3 miles of the survey, the datum plane of such bench shall be adopted for the work. If no such bench is available, a datum plane shall be assumed at such an elevation as will be low for all parts of the survey.

Benches shall be established during the progress of the work at each end of the survey, at city and county lines, and at other convenient points not more than 1000 feet apart, and at shorter intervals on grades.

Where no permanent objects or structures exist, a long, substantial stake shall be driven firmly into the ground and properly referenced.

On bench marks, at turning points, and on construction stakes, elevations shall be determined to hundredths of a foot.

Cross section levels shall be taken to tenths of a foot at each 100-foot station and at half stations, at entering and intersecting roads, for not less than 200 feet from the base line, at driveways and field entrances and wherever the surface of the ground changes abruptly. The elevation of the center of the traveled way of an existing road shall be taken and properly noted when it does not coincide with the base line. The cross sections shall include the whole width between fences, and where the grade is likely to be changed substantially the cross sections shall cover a width sufficient to include all ground likely to be affected.

Sections shall be taken at all culverts and water crossings, and elevations shall be taken a sufficient distance up and down all streams to afford data for designing new structures.

(f) *General Data.*—The survey notes shall contain data concerning:

1. The location of outcropping boulders and bedrock, suitable for road metal or concrete.
2. The location of all quarries near the proposed road.
3. The location and approximate quantity of field stone available in the vicinity of the road.
4. The location of all gravel pits.
5. The location of points where good river sand can be obtained.
6. The available points where water for sprinklers and steam rollers can be obtained.
7. The location of all railroad spur tracks or sidings within reasonable haul of the proposed highway and the name of the railroad.
8. The most advantageous locations for rock crushing plants along the road.
9. The current wages paid to teamsters and laborers in the locations through which the road will pass. Amount paid for hire of mules or horses (without driver) per day. Amount paid for man and two-horse team per day.
10. The locations where special underdrains should be installed due to the existence of unstable sub-soil conditions. Inquiry should be made of residents and local officers regarding spots that break up badly in wet weather.
11. The approximate area of the watershed at each stream crossing if it can be readily obtained. All high-water marks should be noted and inquiry as to whether or not water overflows the road.
12. All general information that may prove of value in the construction of the highway.

Part II. Plans

(a) *Drafting.*—All drafting so far as possible shall be done in the division offices. At the Sacramento headquarters, the drafting shall be limited to work of a general nature, such as the design of standards, general maps and to such revision work of the plans made in the division offices as may be necessary. No drafting shall be done in the survey party camps except such as is immediately needed in the mountainous country to facilitate the choice of lines and grades.

The plans, profiles and cross-sections shall be plotted in the division offices from the copies of the survey notes sent in daily by the survey parties as required under the rules for surveys.

(b) *Working Plans.*—The plan and profile of every road survey shall be plotted on detail paper 30 inches in width and of such length as may be found convenient, the plan to be plotted above the profile, and such drawings shall be known as the "Working Plans."

Plans and profiles shall be plotted from left to right, the plan on the scale of 1 inch to 100 feet and the profile to the same horizontal scale and to the vertical scale of 1 inch to 20 feet.

The base line of the survey shall be plotted by coordinates obtained from the traverse sheets which have been made and calculated in the survey camps and said base line shall be inked in red before the topography is plotted. All angles and curve points shall be marked by small circles, and the even stations by a line $\frac{1}{8}$ inch in length drawn at right angles across the base line.

The even stations and the plus distance of all angle and curve points shall be numbered below the base line. The calculated bearings of the base line, together with the tangent and curve lengths and the radii of the curves, shall be indicated above the line. The right-of-way lines shall be shown in red. They shall be properly referenced to the base line and land corners. Where they are not parallel to the base line their bearings and lengths shall be indicated. The topography and lettering other than that relating to the base line shall be done neatly and so as to permit of tracing easily but such details shall not be inked.

All drafting details shall conform to the conventions shown on the specimen sheet furnished to each drafting office.

The north point shall be indicated at intervals of not more than fifty stations.

The datum line of the profile shall be drawn $\frac{3}{4}$ inch from the bottom of the sheet and inked in black. Perpendiculars shall be erected at each even station and inked in black. The even stations and plus distances shall be numbered below the datum line and the elevations of the present surface of the ground shall be shown above the datum line and to the left of the perpendiculars. The elevations of the proposed finished road surface shall be shown in red and to the right of the perpendiculars.

The present ground surface shall be drawn in black, and the proposed finished surface of the road and proposed rates per cent of grade in red. Points of change in the rate of the finished grade and the beginning and end of vertical curves shall be indicated by small circles.

No title need be placed on the working plans; they shall be identified by the file number, and such plans shall bear the signatures of the employees concerned in their preparation and the date.

(c) *Cross Sections.*—The cross sections shall be plotted to the scale of 1 inch to 5 feet vertical and horizontal on specially ruled sheets, 20 by 30 inches in size, furnished by the highway engineer. They shall be plotted from the bottom of the sheet upward and so as not to interfere with one another more than is necessary. The station numbers shall be placed directly below the datum line and across the base line. The present ground surface, the elevation at the base line and the station number shall be inked in black. The proposed finished surface, together with the elevation at the center of the proposed roadway, shall be shown in red.

(d) *Layout Plans.*—The layout plans shall be on tracing cloth 20 by 30 inches in size and the first sheet shall carry the title, small index or key maps, conventions, and the necessary certificates and signatures, and such sheet will be prepared in Sacramento. The subsequent sheets shall be traced from the working plan, shall be authenticated by the signatures of the division engineer and the highway engineer, shall state the whole number of sheets in the set and the number of the individual sheet, the file number, and on each sheet shall be shown the true North Point. These plans shall conform as closely as is practicable in workmanship and appearance to the specimen sheet hereinbefore referred to.

(e) *The Grade Line.*—The grade shall be established tentatively on the profile under the direction of the division engineer and transferred to the cross-sections and the proposed finished surface of the roadway and slopes shall be drawn on the sections with the aid of templets to be furnished by the highway engineer. If it appears to be desirable to shift the center of the roadway from the base line, the new alignment shall be located on the working plan by a dotted redline. The limits of earth work shall be shown on the plan by a dotted red line where they extend beyond the fences or known right-of-way lines.

After the grade line has been so tentatively established and the estimates have been completed, the working plan, cross-sections and estimates, together with sketches of special structures, shall be submitted to the highway engineer for his scrutiny.

(f) *Accessions.*—Every plan made in a division office and which is to remain there after it has been signed by the division engineer, shall be entered in the "Accession Book" and described as required by the captions therein. All other plans and maps received at such offices, and which are to remain there, shall be likewise entered in said book.

(g) *Filing of Plans and Note Books.*—All plans shall be filed flat in drawers in the division offices but during their preparation the working plans may be rolled and folded afterward.

When completed, the layout plans shall be filed at Sacramento headquarters and on the completion of a contract the cross-sections shall be likewise filed at Sacramento, blue prints thereof being furnished to the division offices.

All note books shall be filed at Sacramento when the contract relating to the surveys therein is completed.

All documents, whether plans, books or papers, which relate to road contracts shall be stamped with the file mark adopted.

DRAINAGE, CULVERTS AND BRIDGES[1]

In most parts of the country water is one of the most destructive influences on roads. When it collects on the surface it tends to injure the roadway unless the latter is paved with some hard, impervious material. The mudholes on earth, gravel and broken stone roads become soft, so that traffic increases their area and depth rapidly. The impervious crust is finally broken through, allowing water to reach the roadbed, which gives way under heavy loads and the condition of the roadway becomes very bad. If water collects in the ditches, it percolates sideways into the roadbed, softening it and eventually causing subsidence which produces marked irregularities in the surface, so that mudholes form there. If the subgrade on which the roadbed is carried is soggy, a road can not be maintained on it. Charles J. Bennett, State highway commissioner of Connecticut, has reported an instance of this in a city where a 7-inch broken stone roadway was placed on a poorly drained clay subgrade. The roadway broke up when frost came out of the ground and became so impassable that stringers were laid on it and covered with crossplank to furnish a driveway. This heaving action of frost will eventually destroy any roadbed in which water is allowed to collect. The water expands every time it freezes. The expansion opens up the earth, so that gradually more water enters it and finally there is so much in the pores and cracks that its expansion throws up the roadway.

Troubles with water are particularly noticeable on grades. The water is not shed so quickly from the roadway on steep slopes as it is on fairly level roads, but runs toward the side ditches at an acute angle with them. If there is any check to the flow at the side of the roadway, such as irregularities of the surface or vegetation offer, some scouring will eventually take place, and it is for this reason that the good condition of the shoulders of steep roads is important. The scouring of ditches on steep grades is a common occurrence after heavy rains, and experienced maintenance men regard it as an injury that must be repaired immediately. If the road is on a fill and also on a grade, the handling of water requires special care if heavy gullying of the slopes is to be avoided. A gully may be cut a quarter of the way across a new

[1] Revised by W. F. Childs, Jr., Resident Engineer, Maryland State Roads Commission.

road in such a location by a single heavy rain. An unusual case of the effect of water on slopes has been mentioned by Mr. Bennett. A road which led up a steep hill was originally only wide enough for one vehicle and was the drainage channel for the surface water of the hillside. The surfacing was washed away by every heavy rain. A new road was built by filling in stone to a depth of 4 feet, with an open box culvert at the bottom to carry whatever water might penetrate beneath the road from the sides. This stone fill extended the entire width of the road, from shoulder to shoulder, and very deep, wide ditches were provided at each side. There has been no trouble with this road since it was reconstructed in this way, showing what good drainage can do even in an exceptionally bad place.

In any drainage work it is necessary to allow for the different water-holding capacities of different materials. Experiments by the United States Office of Public Roads and Rural Engineering show that with the same condition of dryness, clay will take up more water than sand, but will not part with so much. The rate of drainage from saturated sand is almost twice as fast as from saturated clay during the first twenty-four hours after the materials are allowed to drain. Silt is the slowest material to drain and the loams come between sand and clay. While silt and clay absorb more water than sand, they allow water to percolate very slowly indeed in comparison with sand, and it is for this reason that they form water-tight barriers when confined so their grains can not flow away. When in a loose condition silt permits the smallest amount of percolation, and calling the rate with this material 1 the rate with loose clay is nearly 3, loose sandy loam nearly 28 and loose sand nearly 54. With compacted materials, however, such as exist in a well-built roadbed, the lowest rate of percolation is with clay; calling it 1, the rate with compact silt is 2, compact sandy loam 15, and compact sand 93. The experimental investigations make clear the reason for particularly careful drainage of clay and silt subgrades.

General Methods of Drainage

Road drainage is chiefly a matter of, first, climate; second, topography; and third, soil. It may be treated separately under two heads, surface draining and sub-surface or under-drainage.

In the case of surface drainage, the surface water may be shed in four ways, first, by cross-slope or crown in construction; second, by longitudinal grade after the crown is determined; third, by discharge into natural water-courses; and fourth, by discharge into artificial outlets.

The crown should be determined by, first, character or type of road; second, the locality; and third, by grade. The crown for a natural earth road or a shell road should be made from 1 to 2 inches higher in construction than that which is ultimately desired. This opinion is based on the fact that these types of roads are more susceptible to consolidation and displacement under traffic than most other roads.

In thickly populated districts a high crown is dangerous to traffic and the cross-slope of roads constructed through towns or other thickly populated districts should be reduced to that which is just sufficient to shed water to the gutter line. In such districts high crowns cause a sliding motion of vehicles and bring an extra strain upon lower portion of the wheels which is objectionable and causes public criticism, which, if not considered, brings about a certain amount of prejudice against modern road construction. Finally, in considering crowning of roads the question of grades must not be overlooked. Ordinarily the practice is to increase the crown as the grades become steeper. For all grades up to and including 5 per cent, the crowns mentioned in the next paragraph are considered sufficient. When the grade is in excess of 5 per cent the crown should be so increased that the water will be shed to the side of road rather than run down its surface or, at least, make a curve in its course of final discharge.

The minimum and maximum crowns which it is desirable to use may be determined by multiplying half the width in feet of the hard-surfaced roadway by $\frac{1}{2}$ to 1 inch for gravel roads, $\frac{1}{2}$ to $\frac{3}{4}$ inch for macadam, $\frac{1}{4}$ to $\frac{1}{2}$ inch for roads with a bituminous surface, and $\frac{1}{8}$ to $\frac{3}{8}$ inch for brick and concrete. Formerly curved cross-sections were used with impervious pavements, which were quite flat at the center and increased in curvature toward the sides, with the result that there was a wholly needless slope at the latter. This has been changed of late, and there is a tendency to use uniform slopes from the sides toward the center, where an angle is avoided by introducing a very flat curve. The unpaved shoulders are often given a slope of 1 inch per foot of width.

There are two general methods of draining the roadbed, by side ditches and by underdrains, which will be explained in more detail later. In flat country, the roadbed is best kept dry by raising it above the neighboring land, just as railway roadbeds are raised. If this is not done, it is very difficult to keep roads in good condition.

In undeveloped swamp country, George W. Cooley, State engineer of Minnesota, has found the most permanent roadbeds can be built by constructing the embankment of material dredged from a drainage ditch on the upper side of the road and a smaller ditch on the lower side. When the swamps have soundings of 2 to 5 feet, he considers that the elevation of the bottom of the dredged ditch may be disregarded except that it should not be above the suitable theoretical grade line. This is because the surrounding land is swampy at all times and the subgrade can not be drained by any means short of draining the whole swamp.

In ordinary flat prairie country, the elevations recommended by H. E. Bilger, road engineer of the Illinois highway department, vary with the kind of soil used in the roadbed, as follows: with dense clay or gumbo, where the obtainable grade of the side ditch is less than 0.4 per cent, not more than 800 feet of earth road in one stretch should have its crown less than 12 inches above the adjacent fields, unless the road is along a ridge or on a side hill so that culverts will deliver the water from the uphill ditch to natural outlets on the downhill side. In partly impervious soils, such as loams, the same elevation should be maintained, when the side ditches have a slope of less than 0.2 per cent. With sand, gravel or very loose soil, the crown should be 6 inches above the adjacent fields.

It is troublesome enough to care for the surface and underground water on the right-of-way, without having the work aggravated by water from adjacent property. On hillsides, therefore, the water flowing down the slopes toward the road is often intercepted by ditches along the crest of the cuts, as shown in Cross-Section 2 on page 6, and carried away to suitable outlets. Such ditches are sometimes called "berm ditches." In sections where irrigation is practiced, considerable trouble is sometimes experienced as a result of the overflowing of the road, and to prevent this the following law has been enacted in Colorado:

> No person or persons or any corporation shall cause waste water, or the water from any ditch, road drain or flume, or other place, to flow in or upon any road or highway so as to damage the same, and any such person, or persons or corporation so offending or violating any of the provisions of this section for which there is no specific penalty provided shall pay a fine of not less than $10 nor more than $300 for each offense, and a like fine of $10 for each day that such obstruction shall be suffered to remain in said highway, and shall also be liable to any person, or persons or corporations in a civil action for any damages resulting therefrom; and it shall be the duty of the road overseer in the district in which such violation shall occur to prosecute any person, persons or corporation or corporations violating the provisions of this act.

The water accumulating in the ditches should be discharged as quickly as possible into neighboring outlets. After light rainfalls, this may not seem important, but when a heavy rain occurs in the early spring while the roadway is impervious the need of numerous outlets is evident. This is particularly true on slopes, where a large quantity of water in the ditches is liable to scour them badly. As it is not always practicable to find natural drainage channels on each side of the road, culverts must be built to carry the water under the roadway from one ditch to the other, as well as to provide adequate channels for the brooks crossing the rights-of-way.

Although properly designed and well-built culverts protect a road-bed from injury, it is sometimes desirable to avoid the use of large structures of this class if it can be done by relocating the road. This is particularly the case where the beds of the streams are in alluvial soil which is readily eroded by swiftly moving flood waters. In such cases there is uncertainty whether unpaved channels to and from the culvert will not become so eroded that the structure will settle. Culverts of large size in such localities are comparatively expensive, and if there are many of them it is always well to ascertain if the number can not be reduced by changing the position of the road. In a few cases winding brooks have had straight channels dug to accomplish the same purpose. This is particularly the case in districts where the roads follow straight section lines without regard to topography.

The most elaborate investigation of surface and underground roadbed drainage that has been made in this country was undertaken by a committee of the American Railway Engineering Association, which reached the following conclusions:

Side ditches should be provided in cuts, whether the subgrade be in rock or earth. The minimum side ditch should be 1 foot wide on the bottom and 1 foot deep below subgrade. The minimum grade for side ditches should be 0.30 per cent If the rate of grade of the track in any cut is less than 0.30 per cent, the cut may be widened to permit side ditches to be constructed on 0.30 per cent grades, or drain pipes may be laid to proper grades below the ditches to any available outlet.

Efficient subdrainage of wet cuts and of saturated soil upon which embankments rest may be attained by the use of pipe drains. They should be laid immediately below the center of the side ditch in cuts and about 10 feet from the toe of the slopes of embankments and on grades of not less than 0.20 per cent. Care should be taken to locate the pipe at such depths that no displacement will be made in its alignment by the subsidence of the roadway under traffic. To this end the trench in which the tile is to be laid should be dug down into a motionless stratum underlying the saturated material which it is desired to drain. The trench above the pipe should be completely filled with cinders or other porous material which filters the water and aids its passage to the pipe and prevents the intrusion of the saturated material under pressure of traffic.

A water pocket beneath the track may be drained by small cross drains laid in cinder-filled trenches, or by trenches filled with cinders, gravel or similar material.

The committee recommended that no pipe be used with an inside diameter of less than 6 inches, except for cross drains. It will rarely be necessary to use larger sizes than 12 inches. The trench should not be wider than is needed for digging it economically and laying the pipe.

Surface intercepting ditches should be constructed on the uphill side of all cuts where they may be opened without causing slides. Open ditches should be dug along, and about 10 feet from, the toes of embankments resting on soil liable to become unstable if saturated, to divert water flowing toward the embankment. Where an open ditch may endanger such an embankment, a drain pipe may be laid along the toe of its slope. In constructing ditches on slopes above cuts, they should not be larger than necessary in order that they may not become the notch or score from which a slide will start. They should be 10 to 25 feet from the crest of the cut, and the material excavated from them should be deposited on the side nearer the roadbed.

Side Ditches

The cross-section of side ditches should be such that they can be formed and maintained by road machines, if practicable, for the use of such equipment in places for which it is suitable gives the desired results at lowest cost. The sections shown on page 226 illustrate the capabilities of road machines. In the final shaping of the road, care must be taken not to dig the ditches too deep at any place, leaving a depression to hold water. The purpose of a ditch is to carry water away without retaining any of it. If any depressions exist they must be remedied in some effective manner.

Very good results can be had by making side ditch 2 feet wide on the bottom with a 4:1 slope on the road side and a slope on the back side equal to the angle of repose of the particular material encountered in the excavation. The 4:1 slope on the road side is not dangerous to traffic, the slopes can be grassed with a good texture of grass and the slope is not so steep as to become gullied by water shed into the ditch from the surface of the road where the crown is excessive or the grade steep. The slopes can also be made and maintained with a road machine.

The grade of the flow-line of the ditch should be 0.5 per cent if possible, rather more than the recommendation for railway ditches previously quoted, but in flat country it is sometimes impracticable to secure such a grade. Under such conditions the grade lines for the ditches should be given by a surveyor, and the excavation made to conform exactly to the lines. When finished, these flat ditches must be maintained on the true grades, or water will fail to run off quickly. Flat ditches are often made wide and shallow, so as to expose as much water to evaporaton as possible, and on well-maintained level roads care is taken that these shallow ditches are not unduly shaded by trees and shrubs, so that evaporation will be checked.

Where there are two convenient outlets with a side ditch running from one to the other, the grade may be improved and a deep, unsightly ditch avoided by selecting a good intermediate summit and drawing water both ways to the outlet. This summit may be regulated by the grades desired or by holding them from 6 to 12 inches below the sub-grade at the summit and running straight flow-line grades each way to the outlets.

Deep, narrow ditches with steep sides have two defects frequently observed where roads are not maintained properly. One defect is the danger they offer to vehicles which may be crowded into them for any reason. The records of the Iowa State highway commission for September, October and November, 1916, show that in that State alone 353 automobiles turned turtle, resulting in 5 deaths and 451 injuries. Just how many of these accidents were due to ditching the cars is not stated, but this is generally regarded as the usual cause of overturning. Where the ditches are deep or the road is on an embankment with steep slopes, substantial guard rails should be provided. During September, October and November, 1916, the Iowa records show that 167 cars went over embankments, killing 7 persons and injuring 234. Such a list points more clearly than general arguments to the great importance of guard rails that will act as real guards.

The second defect is the relatively high velocity which water may acquire in a deep, narrow ditch. If the latter is protected against erosion high velocity may cause no trouble, but such protection is not common and when the water rushes through an earth ditch the latter will become eroded and both the roadbed and the bank may be severely injured.

The maintenance of ditches cut in earth on slopes is hardly possible unless water-brakes are constructed in them. These are usually heavy timbers placed across the ditch and projecting several inches above it. They check the flow of the water at intervals down the hill, and thus prevent a velocity which will be destructive. The ditches where they are used must be cleaned out after every rain or the bottoms will become filled to the top of the timbers and later storms will gully the road and the banks at their ends. In some cases, the water-brakes are heavy concrete beams. Where the water attains an erosive velocity in ditches paving protects them better than the waterbrakes.

Wherever practicable ditches in earth on grades exceeding

5 per cent should be paved. This adds somewhat to the first cost, even when field stone suitable for the purpose can be obtained in the vicinity, but the first cost is offset by the reduced expense for maintenance.

The outlets from the ditches should receive careful attention, because they are frequently a source of needless expense for maintenance. There should be a paved channel of sufficient size leading from the ditch to the waterway into which the water is discharged. If field stone for such a pavement can not be obtained, it will be advisable to employ concrete.

The protection of the embankments by grass or other vegetation is a remedy for scouring used on many railways and some highways. Witch grass is a good species for the purpose, but must not be used near cultivated land. Bermuda grass and red top have been recommended for some localities and other varieties are probably better suited for different local conditions. On the Southern Railway the banks have been held by planting the volunteer or Japanese honeysuckle in parallel horizontal rows about 10 feet up the slopes. Where the slopes stand satisfactorily except during heavy rains, and the material is such that vegetation will not grow on them, they are sometimes held in place by covering them with coarse cinders and gravel. This prevents the water from coursing down them unchecked and thus checks erosion.

At every driveway from a road into adjoining property, there is likely to be an obstruction of the ditch crossed by this drive. If the ditch is shallow with gently sloping sides, the best drive from a drainage viewpoint is a paved strip from the roadway across the ditch into the property. Unfortunately this is not often practicable and rarely adopted when it is. The usual driveway is formed by filling dirt over a flimsy plank drain or a line of 4-inch tile on an insecure foundation, and this affords wholly inadequate drainage. A culvert with an ample waterway should be provided, with a substantial facing or headwall at each end. Sometimes culverts under driveways can be omitted in the case of shallow side ditches, by locating a summit at the entrance and running the grade down in both directions from it to well-defined outlets.

At such drives attention should be paid to the amount of water they may discharge into the side ditches. Sometimes on a hillside a driveway will discharge a large volume of water at such a high velocity that, unless properly led away, part of it will flow across the road to the other side, which does the shoulders and roadway no good and may cause serious injury.

Underdrainage

The usual method of repairing a wet place adopted by an untrained roadbuilder is to dump stone over it. After the stone has been forced into the mud by the traffic, more stone is dumped there, with the result that a mudhole is formed at each end of the stone fill. The water is in the earth and must find an outlet somewhere. Instead of trying to seal it up, the proper remedy is to carry it off by some kind of underdrainage. The problem of caring for underground water is, first, a matter of soils; second, a matter of topography; and third, one of temperature. There are many soils of a gravelly, sandy, or similar character, which ordinarily are self-draining to a degree and do not require particular attention. The difficulty is with those highways built on clayey or loamy soils which are more or less retentive and do not drain readily.

When the entire roadbed is somewhat damp or soggy it was formerly the general practice to lay a foundation of large stones wedged together by small stones and thoroughly rammed. This is called a Telford foundation and is 6 inches or more thick. It is still used extensively for the purpose but there are substitutes for it which have come into use. In some cases from 6 to 12 inches of coarse gravel or small field stone are placed on the subgrade and rolled. Still another type of drainage foundation, developed first in Massachusetts, is formed by excavating the subgrade to a V-shape cross-section, 6 to 8 inches deep at the sides and 12 to 18 inches deep at the center, and filling this with field stones, the largest at the bottom. With any of these types, there should be an outlet every 50 feet or so from the lowest part of the foundation, formed by cutting a trench through the shoulders to the side ditches and backfilling it with coarse gravel or stone. Even when the road is not on wet land, many engineers build cross drains filled with stones at 50-foot intervals in the top of the subgrade of gravel and macadam roads. They are 5 or 6 inches deep at the center and are at right angles to the ditches except on hills, where they incline slightly downhill from the center.

In many parts of the country stone or gravel is unavailable for such drainage work and drain tile has been employed. It has proved successful and economical, even when stone could be obtained, provided it was laid properly. Many engineers recommend using drains whenever water remains in the ground for a considerable period of time within 3 feet of the surface. The reason for this is that the maintenance of a well-drained road is easier work than if the subgrade is soggy. If a heavy rainfall soaks the top of a road which is already soft below the surface, heavy loads are liable to rut it seriously, because it will take much longer to dry out than a well underdrained road. In the early spring, when the water in the ground freezes and thaws alternately, good underdrainage is particularly useful in preventing the upheaval of parts of the road.

The influence of a well-laid line of drain tile upon the position of the upper surface of the ground-water, called the "water table" by many engineers, is greater than many persons realize. Prof. Ira O. Baker has reported the following experimental proof of the extent of this influence. Lines of drain tile were laid 50 feet apart and 2½ feet deep in a field notoriously soggy and heavy on account of the presence of hardpan which held the water "like a jug." Where the field was without drainage the water rose to within 6 inches of the surface. Where it was drained, the water level midway between the drains was 18 inches below the surface, showing that even in such very heavy soil, the top surface of the ground-water 25 feet from the drain was only 1 foot above the tile. It is this wide influence of good drains which makes the effect of a single line of deep-laid tile along one side of a road greater than that of shallow lines along both sides. The general rule of agricultural drainage experts is to place drains 100 feet apart and at a depth of 3½ to 4 feet.

The drain is best laid in a trench below the ditch at the side of the road from which the greatest amount of ground-water is expected. Although a large number of drains laid perfectly horizontal for long distances have given satisfactory service, it is desirable to give them a uniform slope of at least 2 inches per 100 feet if possible. This is a somewhat lower minimum grade than some engineering books recommend, but is warranted by experience. The tile should not be smaller than 4-inch, and if the ground contains a large amount of water and the outlets of the drains are far apart, larger sizes may be desirable, particularly in level country.

Tile should not be laid except from grade lines given by the engineer, and they must be laid accurately to line and grade. The trench to receive them should be no larger than is necessary to lay them properly at the least expense, but in opening a trench it is sometimes less expensive to make it wider than required for the tile, because of the extra cost of digging in a very narrow trench. In any case the bottom should be cut very carefully so as to have it exactly on the right grade. If there is any probability that the bottom will settle and throw the tile out of alignment, a 4 by 1-inch plank is sometimes laid to support the tile. The ends of the tile are laid touching. Some engineers recommend covering the top half of the joint with tar paper or burlap, but this is probably unnecessary if the trench is back-filled with clean gravel or broken stone from 1 to 4 inches in size, which is the best material to use. In any case the filling should be porous and placed carefully so as not to move the tile. When the gravel or stone filling is within 12 inches of the surface, some engineers cover it with about 3 inches of hay or straw before the earth filling is placed to form the bottom of the side ditch.

The outlets of the drains should be constructed with special care, because they are particularly liable to injury. They are preferably made of stronger pipe than agricultural tile, firmly supported and protected at the end by a substantial wall or facing. A drain with its end stopped is of little value.

Pipe drains are the most serviceable type, but there are various substitutes. One of these is a covered trough of rough stone, another is a similar plank trough, and another is merely a mass of gravel and stones, with the largest pieces at the bottom. The drawback of all of these is that they tend to break down or become clogged with fine material, which can not enter a properly laid tile drain.

Where the side ditches are on very flat grades, they are sometimes drained into the underdrains at intervals of about 0.1 mile by blind catch-basins. These are merely masses of coarse gravel, stone or brickbats reaching from the bottom of the ditch to the tile, and covered at the top by a low pile of similar material which acts as a screen. By this means the side ditches need not be cut so deep as to be dangerous. Where the side ditches carry large quantities of water which must be drained off in this manner, large drain tiles are needed and open brick or concrete inlets like those used on sewerage systems may be used.

Where an embankment is built on a wet side hill, the latter must first be underdrained thoroughly to prevent slipping of the embankment. When an embankment in such a locality begins to slip, the trouble may sometimes be remedied by digging large, deep intercepting ditches on the high side, leading to the nearest culverts. These ditches are usually filled with stone. Any pockets in the ground near the uphill toe of the embankment, in which water may collect and soften the neighboring earth or clay, should be filled.

Size of Culvert Openings and Bridge Waterways

The waterway to be provided for large culverts and bridge openings depends upon many conditions, which have been stated as follows by Prof. A. N. Talbot:

1. The variation of the rainfall in different localities.

2. The meagreness of rainfall data, since records are generally given as so much per day and rarely per hour, while the duration of the severe storms is not recorded.

3. The melting of snow with a heavy rain.

4. The permeability of the surface of the ground, depending upon the kind of soil, condition of vegetation and cultivation, etc.

5. The degree of saturation of the ground and the amount of evaporation.

6. The character and inclination of the surface to the point where the water accumulates in the watercourse proper.

7. The inclination or slope of the watercourse to the point considered.

8. The shape of the area drained and the position of the feeders.

The importance of this item will be seen in comparing a spoon-shaped area where the main watercourse is fed by branches from both sides so arranged that water from the whole area reaches the culvert at the same time, with a long, narrow basin in which, before the water from the upper part reaches the opening, the rainfall from the lower portion has been carried away and the severe part of the storm is past.

While there are three formulas giving the size of waterways for drainage areas of different sizes, it is generally agreed by engineers that it is best to find out by examination and inquiry if possible the flood heights of any stream that is crossed. The condition of neighboring culverts and bridge openings during floods should be investigated, and the nature of the channel of the stream and the character of its drainage basin ascertained. Such records are not only helpful in determining the size of the structure under consideration but are of value in showing the degree of reliance that can be placed on a waterway formula.

A formula widely used in the Central States was proposed in 1887 by Prof. A. N. Talbot. The area in square feet of the net waterway is found by multiplying the three-fourths power of the acres drained by a coefficient. This coefficient was taken by Professor Talbot as 0.33 for rolling farming land subject to floods when snow melts and the valley drained is three or four times as long as it is wide, 0.16 to 0.2 in districts not affected by snow and with the valleys several times longer than wide, and from 0.67 to 1.0 for steep, rocky ground. The waterways given by this formula are stated in the table on the next page.

Square Feet of Waterway Required by Talbot's Formula for Passing the Runoff from Areas Stated of Different Classes of Land

ACRES DRAINED	LEVEL LAND	ROLLING LAND	HILLY LAND	MOUNTAINOUS	ACRES DRAINED	LEVEL LAND	ROLLING LAND	HILLY LAND	MOUNTAINOUS
10	1.1	2.3	3.4	4.5	180	9.8	19.7	29.5	39.3
20	1.9	3.8	5.7	7.6	200	10.6	21.2	31.8	42.5
30	2.6	5.1	7.7	10.2	240	12.2	24.4	36.6	48.8
40	3.2	6.4	9.5	12.7	280	13.7	27.4	46.1	54.8
50	3.8	7.5	11.3	15.0	320	15.1	30.3	45.4	60.5
60	4.3	8.6	12.9	17.2	360	16.5	33.1	49.6	66.1
70	4.8	9.7	14.5	19.4	400	17.9	35.8	53.7	71.6
80	5.4	10.7	16.1	21.4	440	19.2	38.4	57.6	76.9
90	5.8	11.7	17.5	23.4	480	20.6	41.2	61.8	82.3
100	6.3	12.6	19.0	25.3	520	21.8	43.6	65.3	87.1
120	7.3	14.5	21.8	29.0	560	23.0	46.0	69.1	92.1
140	8.1	16.3	24.4	32.6	600	24.2	48.5	72.7	97.0
160	9.0	18.0	27.1	36.1	640	25.4	50.9	76.3	101.8

About 1880 the Santa Fe system began to measure accurately the area of the waterways of streams during floods in Missouri, Kansas, Indian Territory and Texas. The work was done as carefully as possible and in 1897 the results were summarized and a table of waterway areas issued by James Dun, chief engineer of the system, for the use of his engineers. The collecting of such information was continued after that date, and in 1906 an enlarged table was printed for public use, which is extensively employed by railway and highway engineers in the section of the

Square Feet of Waterway Given by Dun's Table for Passing the Runoff from Areas Stated; Applicable to Missouri and Kansas

Area, square mile	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
Waterway, square feet	2.0	4.0	6.0	7.5	9.0	10.5	12.0	13.5	15
Area, square mile	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Waterway, square feet	16	25	32	38	44	51	56	62	66
Area, square mile	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
Waterway, square feet	70	74	78	81	85	88	91	94	97
Area, square mile	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
Waterway, square feet	100	110	120	130	140	150	160	170	180
Area, square mile	1.9	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4
Waterway, square feet	190	200	220	240	260	280	300	321	340
Area, square mile	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.5
Waterway, square feet	357	373	388	403	417	430	443	455	483
Area, square mile	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
Waterway, square feet	509	533	556	579	601	622	641	660	679

country mentioned. A portion of the table is reproduced here. Mr. Dun stated that it did not give waterways large enough for the floods that occurred at very long intervals and were of unprecedented severity, for which he did not consider it advisable for provision to be made. He recommended waterways 60 to 80 per cent as large as those tabulated for culverts and bridge openings in Illinois, about 5 per cent larger waterways for Texas when the areas drained exceeded 1 square mile, and from $1\frac{1}{2}$ to $6\frac{1}{2}$ per cent smaller waterways in New Mexico for areas exceeding 1 square mile.

About thirty years ago, C. C. Wentworth, of the engineering staff of the Norfolk & Western Railway, made a careful study of the area of the culverts which had proved of sufficient size on that road, and found that for drainage basins of one acre and upward, the square feet of culvert cross-section should be equal to the two-thirds power of the number of acres drained. This formula has been used for many years on that railway and found entirely satisfactory. The accompanying table gives the areas computed by it for a number of drainage districts. These relations hold good quite generally over the area between the Blue Ridge and the Ohio River, and have been found to agree with flood discharges in Maine, Connecticut, and New York. It has been suggested that with rainfalls of less intensity or flatter slopes than those of the section which furnishes the data on which the formula is based, the areas of necessary waterways may be taken at some percentage of those given by the formula.

Square Feet of Waterway Required to Discharge the Runoff from Areas of 1 to 99 Acres, Computed by the Wentworth Formula

	0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
0	......	1.0	1.6	2.1	2.5	2.9	3.3	3.7	4.0	4.3
10	4.6	4.9	5.2	5.5	5.8	6.1	6.3	6.6	6.9	7.1
20	7.4	7.6	7.9	8.1	8.3	8.5	8.8	9.0	9.2	9.4
30	9.7	9.9	10.1	10.3	10.5	10.7	10.9	11.1	11.3	11.5
40	11.7	11.9	12.1	12.3	12.5	12.7	12.8	13.0	13.2	13.4
50	13.6	13.8	13.9	14.1	14.3	14.5	14.6	14.8	15.0	15.1
60	15.3	15.5	15.7	15.8	16.0	16.2	16.3	16.5	16.7	16.8
70	17.0	17.2	17.3	17.4	17.6	17.8	18.0	18.1	18.3	18.4
80	18.6	18.7	18.9	19.0	19.2	19.3	19.4	19.6	19.8	19.9
90	20.1	20.2	20.4	20.5	20.7	20.8	21.0	21.1	21.3	21.4

Culverts

As the amount of water to be carried across the roadway by a culvert is usually small, the majority of such structures are made of some kind of pipe. The defects which such culverts develop at times are generally due to lack of attention to features essential for good construction. The pipe must be laid on a perfectly firm support. If the trench for it is cut too low and must be leveled by replacing some of the material, the latter should be consolidated thoroughly before the pipe is laid, and as it takes considerable time to do this properly, it pays to be careful to excavate in the first place to the exact grade.[1] After the pipe has been laid and the joints filled if it is made of bell-and-spigot lengths, the backfilling should be done with the same care used in good sewerage work. The earth should be rammed thoroughly around the sides of the pipe, taking care not to disturb it in doing this, and not more than 6 inches of earth should be spread without ramming. The 2 feet of fill immediately over the pipe should be similarly placed in 6-inch layers and rammed, and while the material above this need not be placed so carefully it should be thoroughly consolidated.

The inlet and outlet of the pipe should be at the bottom of the ditches it connects or at the level of the bed of the brook that it carries across the road. Each end should have a wall or facing resting on an absolutely firm foundation far enough below the surface to remain unaffected by frost and heavy enough to hold back the bank resting against it. Concrete makes the best facing, but substantial masonry and heavy planks have given good service when properly used. By locating and protecting the ends of the pipe in this way two important advantages are gained, first, the thorough drainage of the side ditches and, second, the prevention of undercutting of the ends of the pipe. If the bottom of the ditch or bed of the brook is soft, it should be paved for some feet above and below the culvert to prevent serious erosion during severe storms. At irregular intervals several years apart the ditches and brooks are exceptionally flooded and the water is liable to rise above the top of the pipe. If the culvert has been constructed as just recommended no danger need be feared, for the road will act as a dam for a few hours until these excessive quantities of water are discharged. A poorly built culvert is likely to be washed out, however, and carry part of the road with it. Standard plans for culvert headwalls can be obtained from most State highway departments and from the United States Office of Public Roads and Rural Engineering at Washington.

Where a pipe culvert is carried across a side-hill road, discharging on the outer slope, some form of channel is often necessary for carrying the water down the side of the embankment

[1] If the sub-grade is soggy it is well to lay the pipe on a concrete floor running from the foundation of one headwall to that of the other. Bell joints should be laid up-hill.

without causing erosion. Gutters of rough stone paving, concrete channels and metal troughs have all been used for this purpose.

When a culvert is formed of two pipes laid side by side, which is desirable where the grades are very flat, or the bed of the brook is wide and the depth of water shallow even after heavy rains, particular care must be exercised in consolidating the filling between the pipes.

In a few places, where timber is abundant and cheap, culverts of heavy plank are used, but at the best, they are only temporary structures, and it is unwise to put temporary works which are costly to replace in a roadway graded to permanent lines. The same is true of box culverts of dry masonry, with unpaved bottoms. Masonry culverts laid carefully in cement mortar are rarely so cheap as permanent pipe or concrete culverts. Plans and instructions for building concrete culverts can be obtained on application from most State highway departments and from the United States Office of Public Roads and Rural Engineering.

Any type of concrete culvert should be built carefully or frost will cause trouble with it. The sand and gravel or broken stone must be clean and graded so as to give a dense mixture, and the mixing of the mortar must be thorough. The forms must be strong and tight and located so that the structure will be true to grade. The headwalls in particular should be carried down to a secure foundation, and piling or a substantial timber platform should be used to carry the concrete in case there is any doubt whatever of the supporting power of the underlying material.

The general tendency of rapidly flowing streams is to lower their beds. This results in time in leaving the culvert floor rather high for the natural bed of the stream and the water finds its way underneath. A substantial cross wall at the outlet end of the culvert, carried well below possible wash, is effective in stopping this class of under-cutting, A frozen earth floor will sometimes act like a plank floor in causing such undercutting, and hence good cross-walls are advisable in all culverts, whether floored or not. If the channels leading to or from a culvert are in soft material liable to erosion, they should be paved or protected by brush and heavy stones.

Bridges

Structures with a clear span exceeding 6 feet are generally classed as bridges and should be permanent improvements on any road brought to final grade and alignment. There has been such great waste of money in past years on the bridges on rural roads that the highway departments of most states have prepared standard plans and specifications which cover most needs of local road officials, and similar standards have been prepared by the United States Office of Public Roads and Rural Engineering. Structures of this character should only be built under competent engineering supervision, both as to substructures and superstructures. There is an unfortunate tendency on the part of highway commissions to endeavor to save money by omitting desirable precautions such as piling, which insure the safety of the bridges under conditions which an engineer recognizes as dangerous. For example, an unusually heavy rainfall in northeastern Iowa in June, 1916, washed out 163 bridges. Some were old structures that needed replacing at an early date, but others were expensive new structures of good design and construction except for the fatal omission of the piling under the foundations which was recommended by the engineers but left out to reduce the cost. Not a bridge built according to the standards of the State highway commission was damaged.

There are many bridges which have been in service for a long period of time without suffering any injury, although their substructures are in streams with an easily eroded bottom and banks. For example, the Walhouding aqueduct on the Ohio canal system, built about 1830, has four piers and two abutments in a stream with a fairly swift current, rising suddenly to a great height. Both its banks and bed near the aqueduct are rapidly eroded unless protected. The piers and abutments rest on double platforms of hewn timbers, laid crosswise and carried by piles driven close together near all four sides of each base. Brush and heavy stone were placed on the river bed around each foundation and a row of strong piles was driven across the river bed just below the aqueduct to prevent the removal of the brush and stones by the current. Such a record of endurance made by structures built before the beginning of the present era of scientific engineering shows how needless are most of the washouts of expensive bridges that occur every year.

As bridges on improved roads should be permanent structures, they should be designed to carry a heavy roller followed by a trailer loaded with coal. A bridge capable of supporting a 15-ton roller will carry any of the heaviest field guns now used in Europe.

Money is saved by having the plans and specifications for bridges of reinforced concrete or steel prepared by an experienced engineer, so that all bidders on its construction will base their estimates on the same structure and that structure will be adapted to the locality and service. If each bidder must prepare his own plans, the expense of doing so is added to the cost of the fabrication of the steel and the erection of the structure. This makes a general increase in the cost of bridges in a district where the practice is followed, for many unsatisfactory plans must be prepared for one that is satisfactory. Furthermore the commission awarding the contract must not only pick out the lowest bidder but also decide which is the best plan, which may not be that offered at the lowest price.

In level country where a stream overflows its banks during heavy floods and bridges above the flood level require long expensive approaches, what are known as overflow bridges are coming into quite extensive use. They are structures designed to be submerged by the floods and to offer as little obstruction as possible to the water passing over them. If the floods are likely to carry large quantities of brush, the bridges are kept particularly low so the brush will pass freely over them when they are submerged. The roads leading to a number of such bridges have concrete pavements extending to the limits of the submerged areas, for earth, gravel and broken stone roads are liable to serious injury from water flowing across them. As the injury to overflowed embankments generally starts at the top of the downstream slope, the latter is often protected against scouring by covering it with heavy stone. Stone with rounded edges is less suitable for this purpose than stone of an angular shape, because the former is rolled about more easily.

Fords

Where money is limited, the cost of building even a submerged bridge is heavy, and the stream to be crossed is shallow, a ford is sometimes constructed as a serviceable temporary expedient. In Washington County, Utah, for example, there is a stream with a sandy bottom which is dry at some seasons and dangerous during floods on account of the treacherous nature of the wet sand. A ford has been constructed which consists of two rubble walls 4 feet deep and 2 feet wide, with a 2-foot rubble fill between them. The entire width of this rubble fill from one wall to the other is 20 feet, and the stones of which it is made were laid in a dense mixture of sand and clay, which is not easily washed out of the voids between the stones. The upstream wall was laid dry but had 16 inches of clay puddled against the entire depth of its outer face. The downstream wall was laid in lime mortar.

Near Shelbyville, Tennessee, fords have been made passable at all times by constructing a number of parallel culverts close together to carry the usual flow of the stream and building a concrete roadway over these culverts to give a safe footing for horses and a secure roadway for automobiles during high-water when the roadway is submerged.

EARTH AND SAND-CLAY ROADS[1]

As a very large proportion of our country roads must be earth roads for many years and the basis for any type of surfaced highway is a properly located, drained and graded earth road, the relative importance of this type is very great. If earth roads were properly constructed and maintained, and their culverts and bridges were permanent structures, a large part of the road taxes now wasted would produce useful returns. It is proper for both highway commissions and engineers to devote a large part of their time and money to the improvement of the main roads which are of service to the largest number of taxpayers, but there is a deplorable lack of efficiency in the care of the local dirt roads in many parts of the country. In some States, of which New York, Illinois and Iowa are examples, these roads are under some supervision, directly or indirectly, by the State highway department, but generally the local authorities do as they please. For instance, in 1916 there were 71,000 miles of roads in Wisconsin in sole charge of local officials, who spent about $4,500,000 on them. The work was subdivided among nearly 13,000 road districts, each with a road supervisor, and there were 3750 members of town boards with general control over road work. Of these 16,750 officials, about one-fifth drop out of office annually. During the ten years ending December 31, 1916, nearly 50,000 men were in charge of local road work and over $40,000,000 spent by them, with few perceptible lasting improvements. A system giving such results is manifestly wrong, and should be replaced by one with a smaller number of road officials having greater authority and responsibilities and serving longer terms. It will seem from the following notes that the construction and maintenance of earth roads calls for executive ability and skill that cannot be obtained unless fair permanence in office is assured.

The construction of earth roads falls into two general classes, that where there are cuts and fills and that where the road is formed by building a low embankment on the surface. Except where the length of road is great enough to use elevating graders with economy, these two classes are generally built by different methods.

[1] Revised by W. S. Keller, State Highway Engineer of Alabama.

Cuts and Fills

In grubbing roots and breaking hard ground to a shallow depth, a rooter plow is often used, which is a heavy type of subsoil plow made for the purpose. The road plow is a heavy form of turning plow used in hard ground where the cuts are shallow. Either type is drawn by four to eight horses or a tractor. Plows are also specially made for pushing soil already loosened from ditches toward the center of the road.

When the cut is more than a few feet in depth and the material loosened with difficulty, it is often blasted. The fastest and most economical method of doing this is to sink holes across the cut on a line back from the face a distance about one-fourth greater than the depth of the cut and about the same distance apart. When the cut is 6 feet or more deep, the line of holes is kept about 6 feet from the face and the holes are sunk about 6 feet apart. They are loaded with a low-strength explosive and care must be taken not to loosen the ground below the finished grade line. The use of explosives in road grading in other material than rock has been extending rapidly on account of its low cost and the rapid progress that can be made under suitable conditions, for the blasts leave the clay or hardpan in a broken up condition making it easy to handle. On side-hill cuts in heavy ground, where the slope is steep and there is some question about the security of an embankment to carry the outer part of the road, a safe roadway can often be blasted out of the hill at a cost comparing favorably with a road partly supported by a retaining wall. Even on easier slopes, where a long side-hill cut in heavy ground must be made and the excavated material can be employed as an embankment to carry the outer part of the roadway, the excavation is often made by blasting. Blasting is also an effective method of breaking up stumps and boulders.

Where the material is easily handled and can be dumped within 100 feet of the cut, slip scrapers are generally regarded as the least expensive equipment. The Fresno scraper is regarded as better than the slip scraper for hauls exceeding 100 feet. If the haul exceeds 100 feet and is under 1000 feet, wheel scrapers are ranked highly. The large sizes are most desirable for economy on hauls over 600 feet. The material is usually plowed so the wheelers can be loaded easily, and it is necessary to have about one of them for every 100 feet of haul in order to work most economically. Bottom-dump wagons can be made to give very low hauling costs if enough are provided so that while one is being loaded at the cut, the driver and team which brought it in can be used in hauling a loaded wagon.

In recent years traction steam shovels have been growing steadily in favor for road grading. They make shallow cuts as easily as deep cuts, and have taken out earth and rock at very low figures when the equipment for removing the excavated material was properly selected and used so as to keep the shovel working most of the time. The economy of steam shovel operation depends upon the proportion of the working day that it is actually digging, and this depends upon having wagons or cars ready to receive the excavated material. The wagons or cars may often be run along the top of the bank of a shallow cut and kept moving in a continuous line, saving the delay of turning and backing up to the shovel, which is necessary when they move over the graded cut. The utility of a shovel on road-work is increased if it can be employed in a gravel pit or quarry when not grading.

The bottom of the cut should be carried down approximately parallel to the finished cross-section, and care should be taken not to disturb the material below the grade line. In very heavy ground, the final trimming is sometimes done by hand, but generally a road machine can be used to advantage.

Where a fill is made, the surface must be cleared. Stumps should be grubbed out[1] and all large material liable to decay should be removed, for if left in place the fill will settle as it rots or have loose places likely to retain moisture. If the fill is on a steep side-hill, the latter should be cut into a series of level benches or steps and the drainage should receive careful attention. If the hill has a gentle slope, it is usually sufficient to plow parallel furrows, which will furnish a sufficiently uneven surface to hold the fill. The object in any case is to unite the material in the bottom of the embankment with that of the hillside.

If the road will be maintained as an earth road for several years, so it will have ample time to become consolidated under traffic before any surfacing is applied, there is usually little reason for limiting the thickness of the layers in which the embankment is built. But if a surfacing is to be given the road at an early date, the layers should not exceed 2 feet for high fills and 1 foot for low fills. The teams and scrapers moving over the fill compact it to some extent. Formerly little attention was paid to smoothing the surface of the layers, but of late this has been considered important in some states and drags are kept at work on a bank a large part of the time. George W. Cooley, State engineer of Minnesota, has explained this leveling work as follows:

[1] It is not customary in the South to require green stumps and roots to be grubbed where the fill over their tops is as much as 18 inches. Any matter in process of decay must be removed but a green stump sealed in a fill so that air will not reach it lasts forever.

In Minnesota the plan has been adopted in the construction of earth roads to require the continual use of a drag or planer on grade building. This latter plan has been found very efficient and renders future work on the surface less expensive, besides tending to produce a more compact road bed. The tool found most satisfactory in this work is that known as the "Minnesota road plane," which consists of the two blades of an ordinary road drag, fixed between a pair of runners about 14 feet long, the blades set at an angle of about 60 degrees to the runner and made rigid or adjustable as may be deemed best. The planer is hauled on a line parallel with the axis of the road and its operation is similar to that of the ordinary drag, with the additional advantage of making a smoother surface. The old style drag without runners has a tendency, especially on new work, to increase the waves or undulations frequently occurring on road construction, while the planer eliminates these faults and as a general maintenance tool has proved the most satisfactory.

All embankments settle or "shrink" for some time after they have been built. If the material is broken into small pieces and trampled by teams, the shrinkage will be less than if it is dumped in large masses. There is little shrinkage in a well-built earth dam to impound water, but road embankments need not be built so carefully, and it is probably desirable to allow for at least 10 per cent shrinkage of embankments over 3 feet high and at least 15 per cent for those under 3 feet. If loamy material is used in the embankments the shrinkage will probably be greater than this.

Grader Work

A large part of the earth roads now built or reconstructed are made with road machines. These are built in many sizes for both horse and tractor hauling, and serve a variety of purposes in an economical manner. They are not adapted for making cuts and fills, although frequently employed in shaping a road after the grading has been done. The method of using the machine on construction is explained in the following instructions prepared by W. S. Gearhart, State engineer of Kansas:

In building new roads with a road grader the dead weeds and grass should first be burned off before any grading work is done, and the width of the road to be graded should be staked so the ditches can be properly lined up. Then plow a light furrow with the point of the grader blade, carrying the rear end of the blade well elevated.[1] On the second round drive the wheels in line with the point along the hollow made the first round, plowing a full furrow with the advance end of the blade, dropping the rear end somewhat lower than before. The third time move toward the middle of the road the earth previously plowed, then return to the ditch and plow it out deeper, moving the earth toward the middle whenever as much has been plowed as the machine will move at once. Repeat this process until the ditches are the proper depth, and then cut off the outer slopes of the ditches by placing one wheel of the grader in the bottom of the ditch and the other one on the bank. This can be done easily

[1] A plow is necessary in breaking up the ground except in light soils.

if the bank is not more than 30 inches above the bottom of the ditch. Then trim the earth to the true cross-section. Thoroughly harrow the loose material with an ordinary straight-tooth harrow if there are no clods, going over it until the bumps have been leveled off, the low places filled up and the material well compacted. If there are sods or tough lumps of earth in the road a disk harrow should be used to pulverize this material, and the disk harrow should be followed by a drag or a straight-tooth harrow to level and smooth the road. No newly graded road can be finished in good shape without using either the harrow or the drag, or both.

In the later rounds of a road machine, in the final shaping of the road, part of the loose material in the center of the road is pushed back to the shoulders. The settlement on fills will result in losing about 2 feet in the width of the roadway, and the fills should be made wider than the standard sections to allow for this loss. In doing this final work, the blade of the grader is set at an angle of about 45 degrees with the direction of travel, its ends adjusted to the slope of the road, and lowered as a whole on successive rounds.

If the work is on a scale large enough to warrant the use of two graders hauled by a tractor or roller, a trained grading crew is often able to build a good roadbed at very low cost. Mechanical traction has resulted in the development of methods of construction impracticable when teams of four to eight horses were employed, and as a general proposition mechanical traction is most economical when the sections to be graded are a quarter of a mile or more long, and there is enough work in the vicinity to keep a tractor busy most of the time.[1] Time lost in standing idle or moving long distances from one grading job to another reduces the economical advantage of a tractor on work not well organized. In many cases the hauling is done by a road roller. Tractors and rollers are particularly good investments where labor and teams are hired at high rates and not always obtainable. Mechanical traction is so much more powerful and rapid than horse traction, that its total saving on road work can only be figured by including the saving in labor charges due to speedy construction.

Where road grading is carried on by day labor by district officials, preparation is sometimes made for it in late fall or early spring by plowing up the ground along the lines of the ditches and slopes. This disintegrates the sod and prevents the roots of grass and weeds from forming clods which must be broken up by disk harrows or thrown out of the road with forks. While it is allowable to build an embankment on good sod after it has been burned over, neither sod nor any other organic material

[1] Traction grading with heavy road machines is better adapted for some conditions than others, and the advice of an experienced engineer should be obtained before purchasing expensive equipment

should be allowed in the embankment unless reduced to small, disconnected bits. If clods are left in a fill, particularly in the top, it is very difficult to maintain by dragging a hard, uniform surface free from depressions and waves.

Grading by machines is often followed up immediately by hand trimming and the removal of loose stone. Easing upon work by leaving steep, untrimmed slopes and uneven ditches results in heavier maintenance expense.

In organizing grader work, it is desirable to keep on hand repair parts of the machines, such as blades and whiffletrees, as well as plow points and other parts of the equipment likely to wear out. The small tools should be selected with care, for observation by efficiency specialists has shown that the shape of a shovel, for example, has considerable effect on the amount of shoveling a man can accomplish in a day. Hard earth cannot be dug economically by the shovel best adapted for loose earth, and neither is best for gravel and broken stone.

On extensive work the elevating grader has proved an economical and rapid machine when a mile or more of road can be traversed without turning the outfit. Such a grader is often hauled by a traction engine, which rolls the material it passes over and thus assists materially in making a compact road. The method of using the grader depends upon the nature of the work to be done. In cuts, the grader often discharges the excavated material into wagons driven beside it until full. These wagons haul the material to the nearest fills. In light cuts, the material is deposited on the roadway and moved to the nearest low places in the road by slip or wheel scrapers. The cut is usually started at the shoulder and the grader moves toward the roadside on successive rounds, so that the excavated material is deposited nearer and nearer to the center of the road by the elevating and discharging device. The road should be dragged during construction, and as soon as the rough grading is finished it should be shaped at once. In this connection attention is called to the following comment by the Iowa highway commission:

> The impassable condition to which some contractors and county road crews reduce their roads while cuts, fills and other improvements are being carried out, is absolutely inexcusable. The worst conditions usually arise at leveling or smoothing up while dumping is in progress. The dirt of the fill so dumped packs in humps so that sometimes it is impracticable to eradicate the unevenness for years. A little care in spreading the dirt evenly at the time of dumping results in the fill packing in thin, even layers instead of humps. Such a road is travelable during construction, and when the fill is completed the job is done. A Marshall County road crew solved the problem by keeping a light road drag at hand. From time to time a team was unhooked from a scraper and hitched to this. A few minutes work put the freshly dumped material into thin layers instead of humps.

The utility of a road roller on earth roads is generally underestimated. After the earth has been given as much crown as the road can have and still enable the traffic to use its entire surface readily, any further improvement of the surface drainage must be attained by decreasing the porosity of the earth. This can be done by oiling the road as described later in the section on Surface Applications, and by reducing the pores of the earth by rolling. The latter is particularly useful in compacting places of a yielding character. Many counties have purchased rollers, placed them in charge of competent men, and rent the outfits to the townships as the latter need them. In some cases, a roller is bought by a number of townships, acting as a whole. The work of a roller outfit is likely to be unnecessarily expensive if it is not carefully planned so as to avoid long journeys to do small jobs.

Dragging

Earth roads under light traffic can be kept in good condition during a large part of the year by dragging and proper care of the ditches. It is an axiom in road maintenance that defects in the surface of a road should be remedied as soon as they appear, because traffic will develop them quickly. The earth road is particularly subject to injury because it does not have hard stone locked in place to resist the destructive effect of horses' shoes, narrow tires and pneumatic tires. On the other hand it is more easily repaired than any other road, because as soon as its surface is wet by rain the ruts and holes can be filled by hauling a drag over the surface. This scrapes material from the high points into the depressions and rubs down the whole surface. The following explanation of the nature of the improvement has been given by A. R. Hirst, State highway engineer of Wisconsin:

> If a sample of moist earth is taken from the traveled portion of a road over a gumbo, clay or black prairie soil, it will be found practically impervious to water, as may be proved by forming a roughly shaped dish of damp earth and filling it with water. It will be noticed that the dish is practically water-tight. Earth in this condition is what the clay workers call puddled. It has been worked and reworked by the carriage wheels and animals' hoofs until nearly all the traveled portion of a sticky muddy road is covered with a layer of this impervious, puddled earth. As usually found on most of the roads, this puddled earth is full of holes and ruts, which are filled with water that cannot escape through the impervious soil. As long as the water remains the soil cannot dry out and the road is kept in a most uncomfortable if not impassable condition. It is also a matter of observation that this puddled earth when compressed and dried becomes extremely hard. On these two facts, the imperviousness of puddled earth and its hardness when dried, rests the theory of road dragging.

When the road drag is properly used it spreads out the layer of impervious soil over the surface of the road, filling up the ruts and hollows until a smooth surface is secured. As a small amount of material is always to be pushed to the center, a slightly rounded effect will be given to the road, which may be increased or decreased as desired by subsequent dragging. By forcing the mud into the hollows and ruts it is evident that the water must go out, which it does by running off to the side of the road. The drying out of the road is thus much facilitated and the road is made immediately firmer because the water is squeezed out. The effect of traffic over the road tends to press down and thoroughly compact each thin layer of puddled earth which the drag spreads over the surface every time it is used. After the first few draggings it will be noticed that the road is becoming constantly smoother and harder so that the effect of a rain is scarcely noticeable, the water running off the surface which is so smooth and hard as to absorb but little of it.

The drag is an old implement. It was described in a book by William Gillespie published in 1851 and widely used by students of engineering and public officials, yet the drag did not come into favor until about 1900. Even today it is not used on more than a small percentage of the roads where it should be employed regularly. It has a number of forms, the essential feature being two parallel blades held vertically or nearly so about 2½ feet apart by a frame of some sort. The bottom of each blade scrapes over the surface of the road. The rear blade projects 12 to 16 inches to one side of the front blade so that when the drag is pulled at an angle of 30 degrees, the ends of the blades will be on a line parallel with the center of the road. The drag is hauled by a chain, to which the team can be hitched at points that will make the drag lie diagonally on the road as it is pulled along. The manner of its use has been described substantially as follows by the United States Office of Public Roads.

Under ordinary circumstances the position of the hitching link on the draw chain should be such that the runners will make an angle of from 60 degrees to 75 degrees with the center line of the road, or in other words, a skew angle of from 15 degrees to 30 degrees. It is apparent that by shifting the position of the hitching link the angle of skew may be increased or diminished as the conditions require. When dragging immediately over ruts or down the center of the road after the sides have been dragged, it is usually preferable to have the hitching link at the center of the chain and to run the drag without skew. When the principal purpose of the dragging is to increase the crown of the road, the drag should be sufficiently skewed to discharge all material as rapidly as it is collected on the runners. On the other hand, if depressions occur in the road surface, the skew may perhaps be advantageously reduced to a minimum, thus enabling the operator to deposit the material which collects in front of the runners at such points as he desires by lifting or otherwise manipulating the drag. It is impracticable to prescribe even an approximate rule for fixing the length of hitch, because it is materially affected by the height of the team and the arrangement of the harness, as well as by the condition of the road surface. Experience will soon teach the operator, however, when to shorten the hitch in order to lessen the amount of cutting done by the front runner and when to lengthen it in order to produce the opposite effect. Care should be taken that a ridge, often called a "potato ridge," is not left in the center of the road.

When the road surface is sufficiently hard or the amount of material which it is desired to have the drag move is sufficient to warrant the operator standing upon the drag while it is in operation, he can greatly facilitate its work by shifting his weight at proper times. For example, if it is desired to have the drag discharge more rapidly, the operator should move toward the discharge end of the runners. This will cause the ditch end of the runners to swing forward and thus increase the skew angle of the drag. The operator may, of course, produce the opposite effect by moving his weight in the opposite direction. In the same way, he can partially control the amount of cutting which the drag does by shifting his weight backward or forward, as the case may be.

The rule frequently cited, that all earth roads should be dragged immediately after every rain, is in many cases entirely impracticable and is also very misleading because of the conditions which it fails to contemplate. It is true that there are many road surfaces composed of earth or earthy material which do not become very muddy under traffic, even during long rainy seasons, and since such surfaces usually tend to harden very rapidly as soon as the weather clears up, it may be desirable to drag roads of this kind immediately after a rain. Such roads, however, would not ordinarily need to be dragged after every rain, because of the strong tendency that they naturally possess of holding their shape. On the other hand, many varieties of clay and soil tend to become very muddy under only light traffic after very moderate rains, and it is evident that roads constructed of such materials could not always be successfully dragged immediately after a rain. Sometimes, in fact, it may be necessary to wait until several consecutive clear days have elapsed after a long rainy spell before the road is sufficiently dried out to keep ruts from forming almost as rapidly as they can be filled by dragging. In many cases of this kind, however, it is possible greatly to improve the power of the road to resist the destructive action of traffic during rainy seasons by repeatedly dragging it at the proper time.

Maintenance by dragging is most successful when well organized. The results obtained by good management in Hopkins County, Kentucky, are frequently cited as indications of this, and for this reason the following account of the work there is quoted from a report by the Kentucky department of highways.

In 1912 a county engineer was appointed. The county roads were measured under his supervision and 2-mile sections designated, and in January, 1913, drags were started on about 100 miles of the county roads. This original contract was only for dragging the roads, which work was to be done four times between January 1 and April 1, at a cost of $10 to $12 per mile. As the sections dragged were not continuous, the citizens at once appreciated the difference between the maintained road and that which was not maintained. Consequently the next contract, which called for dragging and also for cleaning the ditches for six months, until November, 1913, resulted in contracts for 150 miles of road and at a reduced cost. In November, 1913, a contract substantially like that now in use was adopted and the time of the contract was for one year, or until November, 1914. Over 200 miles were maintained this year at an average cost of $28 per year per mile. For the year from November, 1914, to November, 1915, the benefit of the maintained roads was so well understood by the citizens that 560 miles were under contract at an average cost of $24.35 per mile per year.

In November, 1915, a two-year contract was entered into, which the county may revoke for non-performance of the obligation at the end of the first year. About 520 miles are now under contract, at prices ranging from $12 to $40 per mile per year, the average being $22.10. It is expected this mileage will soon be increased. Originally a contractor was allowed to have charge of 8 miles, but now he is not allowed to contract for more than 4 miles of road. Under the 1915 contracts the contractor must trim the branches which overhang and interfere with travel on the roadway; keep the roadway between ditches free from shrubbery and weeds; keep the ditches clean, free from obstructions, and at all times capable of carrying the water. "He shall by June 1 each year grade the roads with dump scraper, grader, drag and ditcher, or in any way he may see fit, so that the center of the roadway shall be crowned so that the water will flow from the center of the road to the side ditches, and at no place will the water stand on the road or run down the road. The road shall be dragged from ditch to ditch at each dragging, when the road is wet, but not sticky."

A record of the number of draggings is kept by the county engineer on cards which, before mailing by the contractor, are countersigned by the rural route carrier or a reliable citizen. The contractor also hauls material and constructs all culverts and bridges of 10-foot span or under, and keeps the approaches to and the floors and abutments of all bridges and culverts on his road in good traveling condition. An analysis of these contracts shows that where the contract has been faithfully executed there is a decrease each year in the cost per mile, mainly because the farmer contractor has learned from experience that continuous maintenance makes a lower cost of time and labor each succeeding year.

In the semi-arid regions, the soil is often of a very light nature, so lacking in adhesive qualities that strong winds or flowing water erode it and travel abrades it rapidly into fine dust. It is in its best condition to carry travel when it is moist, but if it becomes saturated with water it is almost impassable. Chuck holes a foot deep are formed in dry weather in an earth road through such soil, and as they become filled with light dust they are a serious impediment to easy travel. Clay or gravel containing clay improves the roads when worked into them. The ditches should be wide and shallow, rather than deep, and the crown should be rather low for an earth road, in order to retain moisture in the roadbed. For the same reason, all grading and ditching are best done just before or during the rainy season, in order to have plenty of water to pack the soil. On account of the pulverulent nature of the material, the ends of all culverts must be planned carefully and riprap or some other material placed to prevent erosion about the inlets and outlets. The main problem with earth roads in such soils is to keep the roadbed damp and to incorporate with it adhesive or fibrous material which will act as a binder.

Sand-Clay Roads

The grains of which sand is composed are usually hard and tough and able to resist abrasion if held securely in place. In an asphalt pavement they are held by the asphalt and a wearing surface of great resistance to abrasion results. In a sand-clay road they are bound together by clay in a less firm manner but one giving excellent results on well-drained roads carrying light traffic. The aim of the builder of such a road is to employ just enough of the stickiest clay at his command to fill the pores of the sand and to mix these materials together so thoroughly that there are neither lumps of clay nor pockets of loose sand left in the surfacing. This gives the maximum amount of hard sand to carry the traffic and the minimum amount of clay to bind it. More sand makes a less durable road and more clay makes one which becomes soft more rapidly when wet.

There is a great difference in the value of different clays for such work. Some of them become dough-like when mixed with a certain amount of water and can be molded into objects which retain their shape after drying. If these molded objects are immersed in water they will retain their form for a long time. These varieties are called "plastic clays" and the most plastic are called "ball clays." There are other varieties which fall to pieces more or less quickly when wet, as quicklime does, and they are therefore called "slaking clays." They are more easily mixed with sand than the plastic clays but they have much less binding power and a road built with them is less durable when dry and more easily rutted when wet. The amount of clay to be used can be determined by a simple field test described as follows by Andrew P. Anderson:

From typical samples of each of the available clays, test mixtures, varying by one-half part, are made with the sand so that each clay is represented by a set of mixtures ranging by successive steps from one part sand and three parts clay to four parts sand and one part clay. These are worked up with water into a putty-like mass and from each mix two equal quantities are taken and rolled between the palms of the hands into reasonably true spheres, labeled and placed in the sun to dry. When thoroughly baked, a set of spheres representing any one clay is placed in a flat pan or dish and enough water poured gently into the pan to cover them, care being taken not to pour the water directly on the samples. Some samples will begin to disintegrate immediately. Those breaking down most slowly contain most nearly the proper proportion of sand and clay for the particular materials. The relative binding power of the various clays may then be determined by comparing the hardness and resistance to abrasion of the various dry samples having the correct proportion of sand and clay, as determined by the water tests.

In February, 1917, representatives of 21 state highway departments and of the U. S. Office of Public Roads recommended the following mixtures for hard, medium and soft classes of sand-clay roads.

Hard class: Clay, 9 to 15 per cent; silt, 5 to 15 per cent; total sand 65 to 80 per cent; sand retained on a 60-mesh sieve, 45 to 60 per cent.

Medium class: Clay, 15 to 25 per cent; silt, 10 to 20 per cent; total sand, 60 to 70 per cent; sand retained on a 60-mesh sieve, 30 to 45 per cent.

Soft class: Clay, 10 to 25 per cent; silt, 10 to 20 per cent; total sand, 55 to 80 per cent; sand retained on a 60-mesh sieve, 15 to 30 per cent.

By clay is meant material separated by subsidence through water and possessing plastic or adhesive properties; it is generally below 0.01 mm. in diameter. By silt is meant the fine material other than clay which passes a 200-mesh sieve and is generally from 0.07 to 0.01 mm. in diameter. By sand is meant the hard material which passes a 10-mesh sieve and is retained on a 200-mesh sieve, and is generally from 1.85 to 0.07 mm. in diameter.

The larger part of the following explanation of the construction of sand-clay roads was prepared by W. S. Keller, State engineer of Alabama, where many miles of sand-clay roads have been built and are giving good satisfaction:

Every farmer who lives in a section of country where both sand and clay are prevalent, is more than likely traveling over a section of natural sand-clay road but is ignorant of the fact. He can call to mind some particular spot on the road he travels, though it may not be more than 100 feet in length, that is always good and rarely requires the attention of the road hands. Good drainage will be noticed at this place and if he takes the trouble to investigate, he will find that a good mixture of sand and clay forms the wearing surface. If this 100 feet of road is always good then the entire road can be made like it provided man will take advantage of the lesson taught by nature and grade the road so that the drainage will be good and surface the balance of the road with the same material. If it is not possible to find this ready mixed surfacing material convenient to the road it may be possible to find the two ingredients in close proximity. In case the road after grading shows an excess of sand, clay should be added, or in case clay predominates, sand should be added to produce good results. There are four general ways in which sand-clay roads may be built:

1. Ready mixed sand and clay placed on clay, sand or ordinary foundation.
2. Sand and clay placed on soil foundation and mixed.

3. Clay hauled on a sand foundation and mixed with the sand.
4. Sand hauled on a clay foundation and mixed with the clay.

Taking up the various methods in order:

1. A natural mixture of sand and clay can often be found where the two materials are found separate. The most important point is to know the natural mixture when seen. The very best guide to this is to find a natural piece of good road. A sample from the best of this good section will, by comparison, indicate what is required, close to the road to be surfaced. This natural mixture of sand and clay can be noticed where red clay and sand crop out, usually well up in the hills, having in ditches and cuts the appearance of red sandstone. A good stratum of well mixed sand and clay will stand perpendicular in cuts and ditches, resisting erosion almost as well as sandstone. A test of the best natural sand-clay mixtures will show the sand forms about 70 per cent of the whole. The test is very simple. Take an ordinary medicine glass, measure 2 ounces of the mixture into the glass and wash out the clay. Dry the remaining sand and measure again on the medicine glass. The loss will be the amount of clay originally contained in the mass.

Before placing any sand-clay on the road, the road should be graded to the desired width. The surface of the graded road should be flat or slightly convex. The sand-clay should be put on from 8 to 12 inches in thickness, depending on the character of the subgrade or foundation. With a hard clay for foundation, 8 inches of sand clay will suffice. If the subgrade is sand it is well to put on as much as 12 inches of the surfacing material. After a few hundred feet of surfacing material has been placed, a grading machine should be run over it to smooth and crown the road surface before the top becomes hard and resists the cutting of the blade. It is a good plan to turn the blade of the machine so as to trim the edges of the surface part, discharging the excess sand and clay onto the earth shoulders. After one round trip with the blade turned out, the remaining dress work with the machine should be with the blade turned in, with the exception of one trip down the center of road with the blade at right angles to the axis of the road for the purpose of distributing any excess of material left in the center.

After the machine work, it is well to follow with a drag, which smooths any rough places left by the machine and leaves the road with a smooth, even surface. A sand-clay road, unlike other roads, cannot be finished in a short space of time. It can be left in an apparently finished condition with a hard smooth surface, but it will be found on close examination that the hard surface is in reality only a crust, below which there are several inches of loose material. After the first hard rain the crust softens, the road becomes bad and the work appears to be a failure. This, however, is just what is needed to make it eventually good. After the surface has dried until the mass is in a plastic state, it should be dragged until the surface is once more smooth, with proper crown, and should be kept this way by dragging at least once a day until the sun has baked it hard and firm. The mistake of keeping traffic off during this process of resetting should not be made. The continuous tamping of the wheels of wagons and hoofs of horses is just what is needed to compact the sand-clay into a homogeneous mass. The ordinary roller is not very effective in this work, but corrugated rollers have given excellent results. One type which is widely used has 18 cast-iron wheels weighing 300 pounds each, which compress the bottom of the mixture first. As the material becomes more and more compact the wheels ride higher and higher and finally the surface is so hard that the roller does not sink into it at all. A drag is an indispensable machine in the construction of any kind of sand-clay road.

2. Sand and clay placed on a soil foundation and mixed. This is necessary where the old road has neither a sand nor clay foundation and it is impossible to find the two ingredients ready mixed, but possible to get both in separate state near at hand. The clay should first be placed on the road to a depth of 4 inches and the required width. It is not wise to place more than a few hundred lineal feet of clay before the sand is hauled, as the clay rapidly hardens and makes the mixing process difficult. After, say, 400 feet of clay has been placed, the clay should be broken by means of a plow and harrow, if it has become hard, and sand to a depth of 6 inches placed on it. This should be plowed and harrowed in thoroughly. This is best done immediately following a rain, as the two can be more satisfactorily mixed. The traffic aids the mixing and should be encouraged on the road. After the mass appears to be well mixed, the road should be properly shaped, as previously explained. The road should be given watchful attention and should sand or mud holes appear, a second plowing and mixing should be given it.

3. Clay hauled on a sand foundation and mixed with the sand. The mixing process is similar to that described under second head. It is only necessary to add that as the foundation is sand, a little more clay will be necessary than where the foundation is of clay or soil.

4. Sand hauled on a clay foundation and mixed with clay. The clay foundation should be plowed to a depth of 4 inches and harrowed with a disk or tooth harrow until the lumps are thoroughly broken or pulverized. Sand should then be added to a depth of 6 inches and mixed as before described.

Sand and clay can be mixed best when wet, but as most road construction is done in the summer months, it is necessary to do most of the mixing dry and keep the road in shape after the first two or three rains, while the passing wagons and vehicles give the road a final wet mixing. A sand-clay road is the cheapest road to maintain, for the reason that it can be repaired with its own material. With a drag or grading machine ruts can be filled with material scraped from the edges, whereas on gravel or macadam roads, this is not possible. The repairing of these roads can be done almost exclusively with the drag, only enough hand work being required to keep the gutters open and the growth of weeds cut on the shoulders. Holes are repaired by adding more sand-clay, and when many of them appear fresh sand-clay should be spread over the surface of the road. If the road gets into really bad condition, the roadbed should be plowed up, reshaped and fresh sand-clay added. This is unnecessary where the road is maintained properly and the travel is not too heavy for the type of construction.

GRAVEL ROADS[1]

At the close of 1914, 45 per cent. of the surfaced roads in the United States were gravel roads, as shown in detail in a table in Part III of this volume. The presence of good gravel in many parts of the country and the low cost of constructing and maintaining gravel roads will make them a leading type for many years to come.

Some gravels are much better for road construction than others. In Michigan, where three-fifths of the surfaced roads are built of gravel, the value of this material for the purpose is held to vary with the percentage of pebbles in it, the road-building value of the rock of which the pebbles are composed, and the cementing properties of the fine material mixed with the pebbles. In this State at least 60 per cent by weight of the gravel for state reward roads must be pebbles larger than ⅛-inch. No pebbles larger than 2½ inches are used in the bottom of the road and none larger than 1½ inches in the top. The binder required for holding the pebbles together is clay, uniformly mixed with the pebbles, free from lumps, and amounting to not over 10 per cent of the total weight of the gravel.

There is a large mileage of gravel roads in New Jersey, and as a result of experience with them, the State highway department rejects gravel with over 5 per cent retained on a 1½-inch circular opening and over 35 per cent retained on a ½-inch circular opening. Three grades are recognized. Grade A is a pebble gravel with a clay binder with not less than 25 nor more than 35 per cent retained on a ¼-inch circular opening, not less than 40 nor more than 60 per cent retained on a 10-mesh sieve, not less than 8 nor more than 20 per cent passing a 200-mesh sieve, and the balance a fairly well graded sand. Grade B is a sandy gravel depending upon oxide of iron for its cementing properties, with 20 to 40 per cent retained on a 10-mesh sieve and 10 to 25 per cent passing a 200-mesh sieve. Of this material passing a 200-mesh sieve, at least 40 per cent must be soluble in a 1:3 dilution of hydrochloric acid. Grade C is gravel which does not fall under either of the previously mentioned grades but is approved by the engineer for the bottom part of gravel roads.

[1] Revised by Frederic E. Everett, State Highway Commissioner of New Hampshire.

In Illinois, the State highway department requires the gravel to be rather uniformly graded in size from fine material to pebbles that will just pass a 3½-inch ring, and not over 15 per cent of the mass (exclusive of clay) passing a ⅛-inch ring. It must not contain over 5 per cent of loam but it must have 15 to 25 per cent of clay by dry measure. If a local gravel does not form a good bond, the contractor must supply a bonding gravel for the top ¾-inch of the road. All of this material must pass a 1-inch screen and contain 40 per cent of pebbles retained on a ¼-inch screen and from 20 to 30 per cent of clay and loam, not more than 5 per cent being loam.

The variations in these specifications show the range of properties of the materials found useful by experience. Few attempts have been made to prepare a general specification for road gravel on this account. The following requirements were adopted by the American Society of Municipal Improvements in 1916 and recommended by the Committee on Materials for Road Construction of the American Society of Civil Engineers:

Two mixtures of gravel, sand and clay shall be used, hereinafter designated in these specifications as No. 1 product (for top course) and No. 2 product (for middle and bottom courses.)

No. 1 product shall consist of a mixture of gravel, sand and clay, with the proportions of the various sizes as follows: All to pass a 1½-inch screen and to have at least 60 and not more than 75 per cent retained on a ¼-inch screen; at least 25 and not more than 75 per cent of the total coarse aggregate (material over ¼-inch in size) to be retained on a ¾-inch screen; at least 65 and not more than 85 per cent of the total fine aggregate (material under ¼ inch in size) to be retained on a 200-mesh sieve.

No. 2 product shall consist of a mixture of gravel, sand and clay, with the proportions of the various sizes as follows: All to pass a 2½-inch screen and to have at least 60 and not more than 75 per cent retained on a ¼-inch screen; at least 25 and not more than 75 per cent of the total coarse aggregate to be retained on a 1-inch screen; at least 65 and not more than 85 per cent of the total fine aggregate to be retained on a 200-mesh sieve.

It is evident that the most useful information concerning the value of any gravel for road work is obtained by examining a road built of it. If there is a good gravel road and the source of this gravel is not known, a sample of the gravel can be analyzed mechanically by a portable sand tester, and the gravel deposits in the vicinity tested by the same instrument until one is found showing about the same properties. An exact agreement should not be expected. Tests of the gravel in a satisfactory road in the State of Washington and of the material in the pit from which it was obtained gave the following variations:

Mechanical Analyses of Identical Gravel Sampled at Pit and in the Road

PASSING	PIT	ROAD	PASSING	PIT	ROAD	PASSING	PIT	ROAD
	per cent	*per cent*		*per cent*	*per cent*		*per cent*	*per cent*
200 sieve	4.1	6.4	30 sieve	10.2	6.5	2 sieve	3.5	8.3
100 sieve	8.0	8.1	20 sieve	14.7	12.1	¾ inch	1.2	5.7
80 sieve	6.6	4.7	10 sieve	14.5	12.7	1 inch	......	1.9
50 sieve	16.3	7.4	8 sieve	2.6	3.4	1¼ inch	......	6.4
40 sieve	13.1	6.9	4 sieve	5.2	9.5	1½ inch	......	.....

Where coarse gravel is composed of rock pebbles giving a cementitious powder some engineers consider it unwise to use enough clay binder to fill the voids. If roads of coarse gravel bound with a large amount of clay are used by many automobiles the pebbles become dislodged and the road does not become hard, it is claimed. Consequently these engineers prefer to use a smaller amount of clay and to allow the traffic to wear down the road and produce the necessary binder by attrition and internal disintegration of the mass of gravel. This process makes it necessary to maintain the road carefully for some time after its completion, but is stated to give a better road eventually with some classes of gravel.

In New England, where gravel roads have been built extensively, it is generally considered safe to use on roads for light traffic the gravel from any pit where the face stands vertical and has to be loosened before it can be shoveled. Other gravels usually have to be supplied with a binder. It is always desirable to make a careful search for all deposits of gravel and an examination of the quality of each before deciding upon the deposit to use. In Dubuque County, Iowa, for instance several months were spent in such an investigation because the local limestone was too soft for road use. Finally a satisfactory pit was found 1½ miles from the road to be improved, and by transporting it on a light narrow-gauge railway to the road and then distributing it by branches of this railway and by motor trucks and dump wagons, its cost on the road was kept down to a satisfactory figure.

Preparing the Gravel

The management of the gravel pit should receive enough study and attention to make sure that the material is delivered to the wagons or cars at the lowest cost. The organization for the purpose will depend upon the location of the pit, the quality of the gravel and the quantity of material to be taken out. Where there is only a small percentage of the gravel which is over size, and the remainder runs a uniformly good mixture, the large stones can be removed by a flat gravel screen, or, on small works, can be forked out during loading. It is not always necessary to go to the expense of screening. With a good foreman in the pit it may be possible to get a proper mixture of the material from a pit where the gravel lies in strata of different sized pebbles, provided there is also a good foreman on the road, so that the strippings, if any, will be placed on the shoulders and the overlarge material will be used for foundations in low places.

Where there is a considerable proportion of overlarge stone in the gravel it is customary to set up a crushing and screening plant at the pit. For example, Kane County, Illinois, has an outfit consisting of a jaw crusher, screen, elevator and storage bin holding 15 cubic yards. The gravel is first screened, because by taking out the material of suitable size for road work only the large stone is fed to the crusher and its capacity is thereby much increased. The presence of the small stone in the crusher tends to clog it and retard the breaking of the large stone. The screened and crushed material is discharged by gravity from the bins into the 5-yard motor trucks which are used for delivering it. The pit material is delivered to the screen by a belt conveyor, 18 inches wide and 40 feet long. One end of the belt is under a platform having a hopper over the belt. The gravel is brought by slip scrapers to the platform and dumped through the hopper onto the conveyor.

In some plants of this character the gravel is run over a bar screen or "grizzly" which holds back all oversize stone and delivers it to the crusher. This keeps the large stone entirely out of the screen. In Wisconsin work the screen has ½-inch perforations for the first half of its length and 1¾-inch perforations for the second half, giving three sizes of gravel. The jaws of the crusher are set to give about equal parts of the two coarser sizes separated by the screen.

As the pebbles composing gravel are rounded and do not lock together as well as broken stone, it is customary to use somewhat smaller sizes of gravel than of crushed stone. Gravel obtained from beaches and rivers is usually more rounded than that from pits and consequently may not be so good for roads, unless suitable binding gravel can be used for a wearing surface or limestone screenings or other good binding material can be used with it.

Pit-run Gravel Roads

Many miles of gravel roads have been built by dumping the gravel on the roadbed, spreading it roughly and allowing traffic to consolidate it. The consolidation is a tedious process, but good roads often result in the end, particularly if the road is kept well dragged so that ruts and holes are prevented. Better results are obtained, however, if the gravel is rolled after it is spread. The loads of large stone should be dumped at the low or soft places on the roadbed. In deep, mealy sand, the subgrade is sometimes covered with marsh hay, wet sand or fine

Cubic Yards of Loose Gravel Required to make One Mile of Road of Different Widths and Thicknesses. Based on Table of Commissioner of Public Roads of New Jersey.

WIDTH	THICKNESS OF ROAD AFTER CONSOLIDATION, INCHES						
	6	7	8	9	10	11	12
feet							
6	880	1,027	1,173	1,320	1,467	1,613	1,760
7	1,027	1,198	1,369	1,540	1,711	1,882	2,054
8	1,173	1,369	1,564	1,760	1,956	2,151	2,346
9	1,320	1,540	1,760	1,980	2,200	2,420	2,640
10	1,467	1,711	1,956	2,200	2,444	2,689	2,934
11	1,613	1,882	2,151	2,420	2,689	2,958	3,226
12	1,760	2,053	2,346	2,640	2,933	3,227	3,520
13	1,807	2,224	2,542	2,860	3,178	3,496	3,614
14	2,054	2,396	2,738	3,080	2,422	3,764	4,108
15	2,200	2,567	2,933	3,300	3,667	4,033	4,400
16	2,346	2,738	3,128	3,520	3,912	4,302	4,692
17	2,493	2,909	3,324	3,740	4,156	4,571	4,986
18	2,640	3,080	3,520	3,960	4,400	4,840	5,280
19	2,787	3,250	3,716	4,180	4,644	5,109	5,574
20	2,933	3,422	3,912	4,400	4,888	5,378	5,866

Cubic Yards of Crushed Stone or Gravel Required to Give Different Depths when Lying Loose on One Mile of Roadways of Different Widths. Based on Table of Wisconsin Highway Commission.

WIDTH OF SURFACE	DEPTH OF LOOSE MATERIAL, INCHES							
	1	1¼	1½	2	3	4	5	6
feet	*cu. yds.*	*cu. yds.*	*cu. yds.*	*cu. yds.*	*cu. yds.*	*cu. yds.*	*cu yds.*	*cu. yds.*
8	130	160	195	260	391	521	652	782
9	147	180	220	294	440	587	734	880
10	163	200	244	326	489	652	816	977
12	196	240	293	392	587	783	980	1,171
14	218	280	342	436	684	913	1,141	1,369
15	244	300	366	488	733	979	1,222	1,466
16	261	325	391	522	782	1,043	1,304	1,565
18	294	367	440	588	880	1,174	1,468	1,760
20	326	400	488	652	978	1,304	1,632	1,954
22	359	440	537	718	1,076	1,434	1,796	2,148
24	392	480	584	784	1,174	1,564	1,960	2,342

Weight in Pounds Per Cubic Yard of Sand and Gravel. From "Mineral Resources of the United States, 1915."

STATE	SAND	GRAVEL	STATE	SAND	GRAVEL	STATE	SAND	GRAVEL
Alabama......	2505	2790	Massachusetts	2710	2810	Oregon.......	2620	2880
California.....	2645	2895	Michigan.....	2895	2985	Pennsylvania	2500	2680
Florida........	2605	2680	Minnesota....	2865	2880	Texas........	2695	2910
Illinois........	2820	3005	Missouri......	2680	2840	Washington..	2930	3065
Indiana........	2700	2945	New Jersey...	2600	2730	W. Virginia..	2570	2780
Iowa...........	2720	2850	New York....	2590	2760	Wisconsin....	2800	2970
Kentucky.....	2580	2830	Ohio..........	2700	2830	Average......	2665	2820

NOTE: The average weights were obtained from 670 producers of sand and 560 producers of gravel in all parts of the country; the range was from 2200 to 4000 pounds for sand and from 2200 to 4200 pounds for gravel. The weights given for each state are the averages of the reports from ten or more producers in that State.

brush to hold the gravel. The stone should be well raked and no stone larger than 2 inches should be allowed in the top of the road.

It is best to lay the gravel in two courses, each 5 or 6 inches thick when loose. The spreading of the first course begins at the place on the road where the gravel reaches it and in this way the material is consolidated by the teaming over it. When this is very hard work enough clay is sometimes added to pack the gravel. Some engineers require this course to be harrowed. It is desirable to shape this course with a grading machine and roll it, but if the equipment is not available it can be improved by using a drag or a road plane, as described on page 266.

After a considerable stretch of the bottom course has been finished, the second course can be started, beginning at the end farthest from the gravel pit, so as to have the teaming do as much consolidation work on the bottom course as possible. Some engineers require the entire bottom course to be finished before the second is started. It is best to harrow the second course because pit-run gravel usually needs good mixing and the harrow will bring the large stones to the surface, so they can be thrown aside. If the gravel needs a binder the harrowing will help to distribute it evenly. If too much clay is added the road is likely to rut in wet weather and be dusty in dry weather. After the harrowing, the surface is shaped with a grader, if one is available, or with a drag or plane. It should then be rolled, and with some gravel the rolling gives the best results if the road is first wet.

Gravel is a surfacing material, it will not make a defective roadbed good, although it may temporarily improve it. Consequently it is best to allow a new roadbed to be used as an earth road for a year, so it will have a chance to settle. If it is kept well dragged during this seasoning period, it will become hard enough to sustain the gravel. If it is known that gravel will be placed after a year's use, the earth road should be dragged to a very flat crown, in order to prevent too much crown in the gravel road. When gravel must be placed on a fresh roadbed, it is sometimes advisable to lay a 6-inch course and allow that to become consolidated by traffic before the second course is laid. If there are any defects in the roadbed they will become apparent during the early use of the road and can be repaired before the completion of the surfacing. If only the bottom course is laid the first season it should be well dragged, for inequalities in the bottom course are usually reproduced in the upper course, no matter how carefully the latter is laid and shaped.

There are two methods of placing gravel. That usually employed on pit-run gravel roads is called the feather-edge method. The roadbed to receive the gravel is graded to a very small crown and the gravel is spread on it to a nearly uniform thickness until within about 12 inches of the edge, when the bed is sloped off to a mere row of pebbles at the edge. In the second method of construction, a shallow trench, sometimes called a "gravel bed" or a "box," is excavated in the top of the roadbed, and the gravel deposited in it. If it rains this trench is likely to become muddy and to prevent this drainage channels should be cut through the shoulders to the side ditches. Bank gravel will become consolidated and shed water more quickly than stream gravel and it is better suited for the trench method in consequence. The feather-edge method is less expensive and more easily carried on if traffic must be permitted on the road during construction.

The following explanation of the construction of a two-course feather-edge gravel road was written by H. E. Bilger, road engineer of the Illinois Highway Department:

When the bonding material in the gravel is not entirely satisfactory with respect to both quality and quantity, it is usually advisable that two-course construction be adopted. Whether or not the work is to be done by contract, it is important that there be used some positive and accurate method of determining the volume of gravel delivered upon the roadbed. There are several methods by which this can be accomplished, but experience seems to indicate that by the use of temporary side-board forms the desired results can be assured and this method is not uneconomical.

Upon the satisfactory completion of the roadbed there should be set thereon, true to line and grade, temporary side forms having a width equal to the depth of the loose gravel, which should be shown on the plans. These boards should be held in place by stakes at such intervals as will prevent lateral deflection greater than about 3 inches from the true alignment. Whether the gravel is hauled by wagons, motor trucks, industrial railways, or other vehicles, it may be dumped directly upon the subgrade. After there has been placed upon the subgrade a sufficient quantity of gravel for the lower half of the road, it should be distributed to a uniform depth by the use of a blade grader, drag scraper, or otherwise. While this course is being spread, all the larger stone should be raked or otherwise placed directly in contact with the subgrade. Upon this course of gravel there should be placed such an amount of bonding clay as may be necessary in order that the gravel will comply with the specifications.

After the gravel has been spread it should be thoroughly harrowed several times over until the cores formed by dumping it have been entirely loosened up to a density equal to that in the other portions of the gravel. The importance of this thorough harrowing can scarcely be overestimated, for in order to secure the results it is essential that the voids in the gravel be reduced to a minimum, which means that a maximum density of material must be obtained, and this density is closely approached by harrowing until the pebbles of the several sizes become so placed as to occupy the spaces between those of a large size. The cost of this harrowing as compared with the results obtained is practically negligible, and if necessary it would actually be more advisable to do away with the rolling and retain the harrowing than to do away with the harrowing and retain the rolling. The harrow should be of the stiff tooth type, and should have metal teeth at least 1-inch in diameter, extending about 6 inches below the frame. The spacing of the teeth should be such as will admit of the free passage of the stones between them, and yet so displace them as to produce the density desired. The design of the harrow should provide a weight of from 8 to 12 pounds upon each tooth.

After the second course of gravel has been placed, it should be spread until its upper surface comes flush with the top of the side forms and its cross section conforms to that desired. The forms should then be removed and the gravel allowed to take its natural position. Upon this second course there should be distributed the necessary quantity of bonding clay. It should then be thoroughly harrowed several times, as before, until the cores formed by dumping the gravel have been entirely loosened up and the clay has been uniformly distributed throughout. The harrowing should continue until a uniform density of material is obtained throughout the upper course.

Having done this, the earth shoulders should be shaped by the necessary cutting and filling until the cross section conforms approximately to the finished work. Material other than the natural earth should not be used in forming these shoulders, and all vegetable matter should be strictly prohibited from entering into the work. Upon having shaped the shoulders, the graded roadway over the entire width should be rolled several times over until it is thoroughly compacted, forming a firm, smooth surface, free from waves and according to the requirement of the plans. The rolling should begin at the extreme outer edges of the shoulders and should work toward the center, at each rolling of the gravel allowing an overlap of one-half of the width of one of the rear wheels, and each wheel should cover the entire gravel surface.

Should the condition of the gravel or its bonding material be such as not to compact readily under the action of the roller, sprinkling or other means should be employed to compact the gravel as the engineer may direct. The speed of the roller should not exceed about 100 feet per minute. It is quite probable that after rolling there will appear either on the shoulders or the gravel certain depressions and other irregularities. To correct these defects suitable material should be added or removed and they should then be rerolled. The finished surface should conform to the cross section shown on the plan and should present a smooth and even appearance. Should the gravel, with its natural or artificial mixture of bonding clay, for the upper 4 inches of the road, be of such character that it will not insure a satisfactory wearing surface with a dense body and uniform texture, a 1-inch coating of bonding gravel should be applied uniformly over the entire surface of the gravel road. This bonding gravel should then be raked and rolled into the road surface until all the interstices are filled and the surface is smooth, of a uniform texture and free from waves.

Screened Gravel Roads

In some States, preference is given to gravel roads built like macadam roads, the gravel being screened so that the courses will be composed of material of different sizes. This is the case in Wisconsin, for instance. In that State, except on sandy roadbeds, construction is started at the end of the road farthest from the gravel supply, when screened gravel is used, because the roller can be run continuously without interfering with the teams bringing the gravel. The first course consists of material from $1\frac{3}{4}$ to about 3 inches in size spread to a loose depth of 6 inches. The voids are filled with gravel under $\frac{1}{2}$-inch in size and the road is then rolled. This course is laid for a distance of about 400 feet, and the second course is then started. This consists of about 5 inches of $\frac{1}{2}$ to $1\frac{3}{4}$-inch stone with the voids filled like those of the bottom course. The surface is shaped with a grader and rolled and flushed like a macadam road.

In many instances better results are obtained, according to J. T. Donaghey, chief inspector of the Wisconsin highway commission, by crushing the gravel fine enough for practically all the material to pass a $1\frac{3}{4}$-inch ring. The screen is partly jacketed so that just enough of the material passing the $\frac{1}{2}$-inch openings is carried into the $\frac{1}{2}$ to $1\frac{3}{4}$-inch size to fill the voids in the latter. This mixture is used in both the bottom and top courses and results in a type of road which Mr. Donaghey considers more easily built, more satisfactory and more cheaply maintained than any other gravel type. Where clay is added to assist in binding or there is naturally an excessive amount of clay in the gravel, it is advisable to place a covering of sharp sand or gravel on the finished surface to protect it until the excess clay has worked to the surface and washed off.

In the work in Kane county, Illinois, to which reference has already been made, George N. Lamb, county superintendent of highways, places the lower course in a trench or box and rolls it and the shoulders until there is no difference of elevation where they meet. The second course is then placed with the edges feathering out a foot or two over the shoulders.

The following instructions for preparing the subgrade were issued in 1914 by the Wisconsin highway commission:

Starting at the desired point, set two stakes opposite the reference stake, the distance between them being the width of the new road. To do this, refer to the grade sheet, which gives the distance from the side stake (placed when the survey was made) to the center of the new road. Subtract from this distance one-half the desired width of road and put in a stake with inside edge at this distance from the reference stake. Opposite this stake place another with its inside edge distant the width of the road from the inside edge of the first one. All stakes for subgrade should be made of ½-inch round iron about 24 inches long, and about twenty-five should be kept on each surfacing job. Stake out 700 or 800 feet at a time. Be sure that the stakes are in line, except at bends or on curves. Usually curves will have to be staked out by eye to get good results.

With a road plow cut as close to the inside edge of stakes as possible withour disturbing them, turning the furrow toward the center of subgrade. Plow about 5 inches deep. One furrow on each side is generally sufficient. Plow should be equipped with shoe or wheel and coulter. If a rooter is used, three furrows on each side will usually be necessary. Make first cut about 5 inches deep as close to stakes as possible, the next 6 inches nearer the center of the road. Drop the shoe down so rooter will run about 3 inches deep for the third cut, working 6 inches nearer center of subgrade than previous furrow.

A light grader that can be handled with two horses is best for shaping. Use with the blade so set as to move the plowed ground from the center of trench or subgrade on to the bank outside of stake line. This work cannot be accomplished neatly with the grader alone, as some of the earth will roll back into the trench under the best of conditions. Make the trench deep enough. The depth at the sides should be at least the total loose depth of the two courses of material and more than this on sandy soils. It is much easier to throw out excess material with the road grader after the surface is laid than it is to bring extra material up from the ditches or to haul it in by wagons during the finishing when the trench has not been made deep enough to hold the stone. Nothing is more essential than a good solid shoulder, and the time to get it is before material is placed in the trench. In clay soils after making the trench, plow drains through the shoulders every 50 feet on both sides and every 25 feet at low points between hills and immediately clean them out so they will drain the subgrade in case of rain.

The following procedure is not advised, as it is usually the most expensive way of getting shoulders. If the road has once been covered with crushed stone or gravel, and it is not desired to tear up the old surface, shoulders can be brought up to the stakes by bringing in dirt with the road machine from the side banks or from the ditches (if the latter material is fit to use), or can be hauled in with wagons. If the old road has a crown of one inch to the foot, it will take approximately 1,100 cubic yards of compacted material per mile to build up 6-inch shoulders and retain the minimum width of 20 feet on top. The cost of hauling and placing this material is usually very much greater than the value of the stone or gravel saved. As a matter of fact, no material is wasted if the subgrade or trench is cut in the old surface, the stone or gravel thrown out making an excellent shoulder. Failure is inevitable if an attempt is made to build a gravel or stone road with a heavy roller without first getting proper shoulders to support the material while it is being rolled.

Straighten up stakes and drive them firmly. Tie a chalk or binder twine line to stakes on each side so line will draw on inside faces of stakes, drawing it tight. It is usually best to put in additional stakes at 50-foot points so this line will not sag. These lines are to guide the laborer in trimming the shoulders so the edges will be straight and the grade uniform. On a 9-foot road, if these lines are set 7 inches above center of subgrade, they will be 1 foot higher than the bottom of trench at the shoulder. On a 15-foot road set lines 6 inches above center of subgrade. They will then be one foot higher than the bottom of trench at the shoulder. The blade of an ordinary square point dirt shovel is 1 foot long and can be used by the laborer to tell when trench is deep enough at sides by setting blade of shovel up to line. When trench is finished, it should run with a uniform slope from center to edge. Clean out drainage trenches through shoulders, so that they really drain out from the trench. This will keep the trench from filling up in case it rains. It is well to widen the trench and road on the inside of curves, and to elevate the outer edge of curves.

After the subgrade has been properly shaped to the same crown (or, better, a slightly greater crown) than the finished road is to have, it should be rolled until hard, especially if recently filled. Any hollows that develop during the rolling should be filled. Roll enough, but stop before the top layer of earth starts to slip. Wet spots in the subgrade should be shoveled out, filled with good earth or cinders and rolled. Don't leave sink holes with the expectation of filling them with crushed stone. They must be dug out and refilled with good material if a firm surface is to ever be gotten at that point.

In spreading gravel or broken stone many engineers place on the subgrade wood or concrete blocks of the desired loose depth of the course. In Wisconsin, however, the material is spread by requiring a load to cover a certain length and width of surface. The foreman is given a table of the length of 9-foot road which loads of different sizes will cover and the spreader is required to

Length of Road in Linear Feet Which a Load of Stone of Given Size will Cover to the Given Loose Depths. Based on Table of Wisconsin Highway Commission.

WIDTH OF ROAD	LOOSE DEPTH	SIZE OF LOAD IN CUBIC YARDS								
		1	1¼	1½	1¾	2	2¼	2½	2¾	3
feet	*inches*	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*
8	3	13.5	16.9	20.2	23.6	27.0	30.4	33.7	37.1	40.5
	4	10.1	12.6	15.2	17.7	20.2	22.6	25.3	27.8	30.3
	5	8.1	10.1	12.1	14.1	16.2	18.2	20.2	22.3	24.3
	6	6.75	8.4	10.1	11.8	13.5	15.2	16.9	18.5	20.3
9	3	12	15	18	21	24	27	30	33	36
	4	9	11.25	13.5	15.75	18	20.25	22.5	24.75	27
	5	7.2	9	10.8	12.6	14.4	16.2	18	19.8	21.6.
	6	6	7.5	9	10.5	12	13.5	15	16.5	18
10	3	10.8	13.5	16.2	18.9	21.6	24.3	27	29.7	32.4
	4	8.1	10.1	12.2	14.2	16.2	18.2	20.2	22.3	24.2
	5	6.5	8.1	9.7	11.3	13.0	14.6	16.2	17.8	19.4
	6	5.4	6.7	8.1	9.4	10.8	12.1	13.5	14.8	16.2
12	3	9	11.2	13.5	15.8	18.0	20.2	22.5	24.7	27.0
	4	6.7	8.4	10.1	11.8	13.5	15.1	16.9	18.5	20.2
	5	5.4	6.7	8.1	9.4	10.6	12.1	13.5	14.8	16.2
	6	4.5	5.6	6.7	7.8	9	10.1	11.2	12.3	13.5

make the loads cover just this length. When this method is followed it is convenient to have the loads hauled of the same size. The man placed in charge of the spreading should be selected carefully, because a large amount of money can be wasted by placing too much material on the road. The depth of the loose material should be checked as often as possible on this account.

When the gravel is bought by weight it is the Wisconsin rule to take the weight of a cubic yard of pit gravel at 3000 pounds and of crushed gravel at 2650 pounds. If the material is wet it will weigh more than when it is in a normal condition and allowance should be made for this.

Special Binders

Gravel roads are now being built for quite heavy traffic with binders giving greater toughness to the road than clay or rock powder will afford. Examination of many roads after several years of use has shown that there is less large stone and more small stone in them than when they were built. This change is considered due to the internal disintegration of the stone by the loads coming upon it, part of the reduction taking place when the road is heavily rolled during construction and part later under heavy travel. The special binders are used to hold the stone so firmly together that after the rolling of the road there will be no further internal disintegration. The method of using bituminous binders for this purpose is explained in the chapter on bituminous roads, and the method of using glutrin in the chapter on broken stone roads.

Maintenance

The maintenance of gravel roads must begin immediately after the road is thrown open to travel. A small hole in a gravel road, unless immediately repaired, soon becomes a large hole. A few large holes mean a ruined road and a large expense for resurfacing. Furthermore a gravel road, no matter how well rolled, cannot be considered finished until traffic has gone over it and tested every part. For this reason, some engineers allow traffic on the road before the roller has left it, so that any weak places may be revealed and repaired at once while the equipment is still at hand. The rounded pebbles of pit gravel do not interlock like pieces of crushed stone but are usually held together by a clay binder which is not so strong as the cementitious powder from some classes of rock. Until travel has broken down the pebbles and furnished rock powder which will act with the clay and form a rigid mass, a gravel road is not so firm as a crushed stone road and needs more maintenance.

The gravel roads of New Hampshire are used throughout the summer by a heavy automobile traffic, particularly on Saturdays and Sundays. They are nevertheless kept in good condition by the patrol system of maintenance at very low cost, considering the destructive use to which they are subject. Each patrolman has a section for which he is responsible, and a number of sections are united in a division under the general supervision of a maintenance foreman, who is in immediate charge of all maintenance work and reports to the division engineer. Each patrolman must supply a horse and dump cart, shovel, pick, hoe, rake, stone-hook, axe, iron bar, iron chain and tamp. Special tools are furnished by the State highway department. The methods of maintainance are indicated in the following quotations from the instructions issued to the patrolmen:

One dragging in the spring is worth two in the summer. It is better to drag a mile of road several times and get it in good condition, than to drag 2 or 3 miles and not finish any part of it. Don't drag a soft section when it is so wet that the first vehicle to pass will rut it all up. First fill the holes and ruts with new material and then drag as the surface dries out. Every patrolman should have material dumped in small piles along the side of his section so that on a rainy day he can at once fill all holes and ruts in which water is collecting.

When the weather is unsuitable for dragging, as during a dry spell, all patrolmen should cart on all the new material possible in order to fill all ruts and holes and resurface worn-sections. Carting is very essential during dry periods and should never be neglected. Whenever a patrolman is in doubt as to what to do next the general rule is to cart new material, for all roads are wearing out under travel and it is necessary that the surface be continually renewed to take the place of the old material that is thrown out as mud or blown away as dust.

Save all the sods, leaves, rubbish, stones and refuse that you clean off your road and dump this waste material in places where the bank is steep so that by flattening the side slope there will be no need of a guard-rail, or dump the material back of a present guard-rail so that later this guard-rail can be removed.

Oiling gravel roads generally requires careful preparation of the surface because the large amount of clay binder has a tendency to interfere with the formation of a satisfactory oiled surface. Consequently the surface should be thoroughly cleaned and a comparatively light oil used. The first applications are likely to be disappointing, but if holes and ruts are filled promptly, two or three applications on carefully cleaned surfaces during the first year will eventually give a good wearing surface, provided the roadbed and gravel have been thoroughly consolidated and the traffic is not too heavy for this type of road. It is the general opinion at present that surface applications should not be made until a gravel road has had at least one year's service. The methods of doing the work are given in a later chapter.

WATER-BOUND MACADAM ROADS

Water-bound macadam roads are adapted to highways carrying moderate traffic, for experience shows that even when a large part of the traffic is motor-driven this type of construction can be maintained successfully by surface applications, as described in a later chapter. Where a gravel road is not quite able to carry the traffic, a macadam top course on a gravel base has been adopted as a standard type by the highway departments of a number of States. The following statements give the views regarding water-bound macadam held by three State highway departments having a large mileage of it under their charge:

New York: The department is still building a large mileage of water-bound macadam. Because of the presence of local material and other favorable conditions this is, in cost, the cheapest durable road which can be built; and it is the belief of the department that on all roads of ordinary or light traffic this type is still a satisfactory one for general use. Of course this type must have surface treatment with oil, and this is planned for in all cases. (Edwin Duffey, State commissioner of highways, 1916.)

Michigan: During the early existence of the department, macadam roads constituted as much as 50 per cent of the mileage constructed. As the use of the automobile became more widespread, the percentage of macadam roads built each year decreased, owing to the excessive cost of maintaining this type under the automobile traffic. Within the past two years, however, waterbound macadam roads have been again growing in favor, because it has been found possible with a bituminous surface treatment to maintain them in a condition comparable in the point of service to the higher types of roads. The first treatment, which is made after the road has been seasoned by opening it to traffic for three or four months, is essentially a part of the initial cost of construction. (Frank F. Rogers, State highway commissioner, 1916.)

Wisconsin: It is not at all an economical type of surfacing unless intensely maintained with surface treatments and a patrol system, but when so maintained gives economical service even on heavily traveled roads. (Wisconsin highway commission, 1916.)

Stone

The roadbuilding properties of different rocks are explained in the next chapter. The following notes on the selection of stone were prepared by Prevost Hubbard and Frank H. Jackson, Jr.[1] The ideal rock for the construction of a water-bound macadam

[1] "The Results of Physical Tests of Road-building Rock," Bulletin 370, United States Department of Agriculture.

road resists the wear of traffic to which it is subjected to just that extent which will supply a sufficient amount of cementitious rock dust to bind or hold the larger fragments in place. It is generally admitted that the ordinary macadam road is not well suited to any considerable amount of automobile traffic, because such traffic rapidly removes the binder without producing fresh material to take its place.

Cementing value is a necessary quality for rocks used in macadam road construction. As determined by test, cementing values below 25 are called low; from 26 to 75, average, and above 75, high. In general, the cementing value should run above 25. For rocks which show a low French coefficient of wear, however, a relatively high cementing value is more necessary than for those which have a high French coefficient. Interpretation of results of the cementing value test is subject to a number of influencing considerations. For instance, it has been found that certain feldspathic varieties of sandstone give excellent results in this test, while experience has shown that they do not bind well when used in the wearing course of macadam roads. In the case also of certain varieties of the trap group, low results are frequently shown by laboratory tests for rocks which bind quite satisfactorily upon the road, provided traffic is sufficiently heavy to supply the requisite amount of fine material. Certain granites, gneisses, and schists which are not suitable for use as binding material give good results in this test. In such cases it is usually found that the highly altered nature of the material reduces its toughness and resistance to wear to such an extent as to condemn it for use.

Experience has shown that in general the following table of limiting values for the French coefficient of wear, toughness, and hardness may be used in determining the suitability of a rock for the construction of the wearing course of a macadam road:

Limiting Values of Physical Tests of Rock Suitable for Water-bound Macadam

TRAVEL	FRENCH COEFFICIENT	PERCENTAGE OF WEAR	TOUGHNESS	HARDNESS
Light	5 to 8	5 to 8	5 to 9	10 to 17
Moderate	9 to 15	2.7 to 5	10 to 18	14 or over
Heavy	16 or over	Under 2.7	19 or over	17 or over

With relation to the limitations for hardness it may be noted that when any given value for toughness falls within certain limits which define the suitability of the material for macadam road construction under given traffic conditions, the corresponding value for hardness will fall within similar limits for hardness. In this connection it will be seen in the table that a maximum limit for hardness is only given in the case of light traffic. It has been found that the great majority of samples having a French coefficient of wear of from 5 to 8 and a hardness of over 17 are granites, quartzites, and hard sandstones, which are unsuited for use in the wearing course of water-bound macadam roads due to their lack of binding power.

The weight of a cubic yard of crushed stone varies considerably, depending upon the rock, the size to which it is broken and the amount of shaking the sample receives before its volume is measured. The range in weight of a cubic foot of solid rock is 162 to 221 pounds for trap, 165 to 200 pounds for schist, 156 to 175 pounds for felsite, 156 to 193 pounds for quartzite, 125 to 193 pounds for limestone, and 125 to 187 pounds for granite. The total range from the lightest limestone to the heaviest trap is over 75 per cent and the crushed rock will show the same variations. Consequently, when broken stone is bought by weight it should be actually weighed before estimating the quantity required for good work.

Crushed stone is the most important branch of the stone industry. The production of this material for road building in the different states is given in a table on page 198 of this book. The requirements for railroad ballast and concrete as well as for road work are so large that commercial broken stone is available in many parts of the country at a lower price than the cost of quarrying and crushing local material. It is sometimes economical, even at a greater initial cost, to import stone from a distance if thereby a more durable road may be had than is possible with the use of local stone.

Much of the stone is crushed locally, usually in portable plants. These comprise a crusher with an engine and boiler, revolving screens, portable bins and an elevator to lift the stone after it is crushed into the screen and sometimes into the bins. The capacity of a crusher should be adjusted to the road roller capacity. If the crusher furnishes more stone than the roller can consolidate, it is too large to work economically. If the crusher can not supply enough stone to keep the roller at work, the latter will operate uneconomically. Furthermore the arrangements for supplying stone from the crusher to the road must be such that the expensive equipment at each end of the line will be kept operating all the time. There is some difference of opinion as to the proper capacity of a crusher, for in some sections of the country it is held that from 60 to 80 cubic yards of broken stone is as much as a single roller will consolidate properly, while in other sections it is held that a roller which does not consolidate 75 tons per day is not doing good service.

Where the stone supply is limited to ledges at infrequent intervals but little choice in the location of the crushing outfit is possible. If field stone or ledges are available alongside the road at frequent intervals a crusher can serve about two miles of road most economically. Local conditions, however, affect the proper arrangement of the plant so greatly that no precise rules can be drawn up. It occasionally happens that the availability of water for the boiler is of more importance than any other factor in determining the location of the outfit.

If possible, the crusher should be set low enough so that a platform can be built at the level of the opening into which the stone is dumped. The carts are driven onto this platform and the material is handled most economically in this manner. The men who set up the plant should have had experience in this work. Much depends on the proper alignment of the several parts and the delays in operation will be avoided if the work is done properly in the first instance.

The screens in such portable plants have three sections about 4 feet long and 30 inches in diameter. The first section has perforations which are $\frac{1}{2}$-inch in diameter. The perforations of the second section are generally $1\frac{1}{4}$ inches in diameter where comparatively hard stone is used and $1\frac{1}{2}$ inches in diameter where softer stone is employed. With the very soft stone used in some of the Central States, the perforations are sometimes $2\frac{1}{2}$ inches, and the third section of the screen is omitted. The perforations in the third section are from 2 to $2\frac{1}{2}$ inches in diameter as a rule, depending upon the maximum size of the stone which is allowed in the road, but this maximum size varies widely in different States. In New York stone up to $3\frac{1}{2}$ inches in size is used in the bottom course and in Ohio pieces of sandstone as large as 6 inches in their longest dimensions are permitted in the bottom course of some roads. Stone passing a 4-inch circular opening is also permitted under some conditions. In Wisconsin the bottom course is usually made of stone 2 to $3\frac{1}{2}$ inches in size; in this case the perforations in the screen are $\frac{1}{2}$, 2 and $3\frac{1}{2}$ inches.

The stones too large to pass through the openings in the third section of the screen drop out and are run through the crusher again. There is sometimes a conveyor to carry these tailings from the end of the screen to the crusher. The jaws of the crusher should be set to give as few tailings as possible and the length of the screen sections should be adjusted to accomplish the same purpose. The operation of the screens should be observed from time to time in order to make sure that material which should pass the openings in each section does not flow along the screen so rapidly that there is a failure to separate it out by the right section of the screen. If the screen revolves too rapidly fine material will be carried into the coarser grades. Stone purchased from commercial crusher plants is often observed to run small, the best separation occurring in the product which is obtained during a time of minimum demand. This is because more time is then given to the stone in its passage through the screens. It is impracticable to obtain a complete gradation of the sizes of stone and for this reason highway engineers often permit variations from the nominal maximum and minimum dimensions of any size. For instance the $\frac{3}{4}$-inch stone specified in New Jersey may contain up to 5 per cent of material larger than $1\frac{1}{4}$ inch and up to 8 per cent smaller than $\frac{5}{8}$ inch, although the nominal range of size is from $\frac{5}{8}$ to $1\frac{1}{4}$ inch.

There is no uniformity in the designation of the sizes of crushed stone; what is termed as No. 1 stone in Ohio is entirely different from No. 1 stone in New York.

Drainage

The investment in a macadam road is so great that every precaution should be taken to have the roadbed thoroughly drained. The methods of doing this were explained in the chapter on drainage. If they are not employed wherever necessary the road will inevitably become rutted and marked by holes during prolonged wet weather, and the maintenance of such places will entail an annual expenditure far greater in the end than the cost of proper drainage work.

Formerly Telford foundations were used in all wet, soggy ground under well-built broken stone roads but experience has shown that with good underdrainage equally satisfactory foundations can be built of coarse gravel. This is dumped on the bottom of the road after the soft material has been excavated to a considerable depth. The mass of gravel should be drained into the side ditches by constructing blind drains through the shoulders at intervals of not over 50 feet.

Where suitable field stone is available for a Telford foundation it is still sometimes used. The New York requirements for stone for this purpose are a thickness of not less than $1\frac{1}{2}$ inches, a depth equal to the depth required for the foundation, from 6 to 8 inches, and a length not more than one and a half times the depth. The New Jersey specifications require stone 5 to 10 inches long, 2 to 4 inches wide and at least 6 inches deep. Some engineers advise placing this stone on a bed of gravel, while others believe that if gravel is available it is best to make the entire base of it and not employ Telford, since the latter is quite expensive. The stone must be set on their broader base, lengthwise across the road, and wedged by driving small stone into the interstices. The projecting points should be broken off with a stone hammer, the depressions in the top filled with stone chips, and the foundation rolled.

The V-shaped drain described on page 27 is a substitute for a Telford foundation which has received much favor in some states.

Sub-Grade

It is necessary to place the stone for a macadam road in a box or trench in order to roll it successfully. The method of excavating the sub-grade was described on page 60. The bottom must be slightly crowned. This is for two reasons; first to shed any water which may sink through the macadam, and second, to keep the amount of stone required for the road to the minimum actually necessary. The sub-grade must be rolled until hard in order, first, that the stone placed on it can not be driven into it and thus serve no useful purpose, and second, to turn toward the sides of the road, into the blind drains leading to the ditches, any water which may penetrate the courses of stone.

The depth of the box or trench is fixed by the desired depth of the macadam roadway. This is rarely less than 6 inches at the center and is sometimes considerably more, although there is a question whether a greater thickness than 8 inches after rolling serves any useful purpose. The harder and tougher the stone, the less need be the thickness of the road, provided the sub-grade is firm. Usually the sides of the macadam roadway are 1 to 2 inches thinner than the center.

On very sandy soils, to keep the sand from working up through the stone, a covering of clay, hay, straw, or fine brush is spread over the subgrade.

Placing the Broken Stone

It is customary to begin placing the broken stone as soon as a few hundred feet of the subgrade has been prepared to receive it, because it is undesirable to expose the rolled earth surface to the danger of drenching by rains for a longer period than is necessary.

The first course is rarely if ever spread to a greater depth than 6 inches when loose, because a roller cannot compact a deeper course of stone in a satisfactory manner. The thickness is seldom less than 4 inches. The largest size of the screened stone is used. In some states it is forbidden to dump the stone directly on the subgrade, on the ground that this leaves a mass of consolidated small stone in the center of the heap which remains almost intact when the pile is leveled. Accordingly the stone must be deposited on dumping boards about 6 feet long and 3 feet wide, from which it is shoveled to the subgrade. This is no longer a generally adopted requirement, however, but it is not unusual to require a load to be deposited in several dumps so that the least amount of shoveling and raking will be required.

Costs Per Mile Corresponding to Different Costs Per Square Yard. Based on Table Published by Commissioner of Public Roads of New Jersey

Width, feet	8	10	12	14	16	18	20
Square yards, per mile	4,693½	5,866⅔	7,040	8,213⅓	9,386⅔	10,560	11,733⅓
Cost per sq. yd.							
$0.25	$1,173.33	$1,466.67	$1,760.00	$2,053.33	$2,346.67	$2,640.00	$2,933.33
0.30	1,408.00	1,760.00	2,112.00	2,464.00	2,816.00	3,168.00	3,520.00
0.35	1,642.67	2,053.33	2,464.00	2,874.67	3,285.33	3,696.00	4,106.67
0.40	1,877.33	2,346.67	2,816.00	3,285.33	3,754.67	4,224.00	4,693.33
0.45	2,112.00	2,640.00	3,168.00	3,696.00	4,224.00	4,752.00	5,280.00
0.50	2,346.67	2,933.33	3,520.00	4,106.67	4,693.33	5,280.00	5,866.67
0.55	2,581.33	3,226.67	3,872.00	4,517.33	5,162.67	5,808.00	6,453.33
0.60	2,816.00	3,520.00	4,224.00	4,928.00	5,632.00	6,336.00	7,040.00
0.65	3,050.67	3,813.33	4,576.00	5,338.64	6,101.33	6,864.00	7,626.67
0.70	3,285.33	4,106.67	4,928.00	5,749.33	6,570.67	7,392.00	8,213.33
0.75	3,520.00	4,400.00	5,280.00	6,160.00	7,040.00	7,920.00	8,800.00
0.80	3,754.67	4,693.33	5,632.00	6,570.67	7,509.33	8,448.00	9,386.67
0.85	3,989.33	4,986.69	5,984.00	6,981.33	7,978.67	8,976.00	9,973.33
0.90	4,224.00	5,280.00	6,336.00	7,392.00	8,448.00	9,504.00	10,560.00
0.95	4,458.67	5,573.33	6,688.00	7,802.67	8,917.33	10,032.00	11,146.67
1.00	4,693.33	5,866.67	7,040.00	8,213.33	9,386.67	10,560.00	11,733.33
1.05	4,928.00	6,160.00	7,392.00	8,624.00	9,856.00	11,088.00	12,320.00
1.10	5,162.67	6,453.33	7,744.00	9,034.67	10,325.33	11,616.00	12,906.67
1.15	5,397.33	6,746.67	8,096.00	9,445.33	10,794.67	12,144.00	13,493.33
1.20	5,632.00	7,040.00	8,448.00	9,856.00	11,264.00	12,672.00	14,080.00

NOTE: When the cost per square yard is greater than $1.20, the corresponding cost per mile can be found by adding to the tabulated cost for a rate of $1.00 per square yard, the tabulated cost for a rate equal to the difference between the given rate and $1.00. The costs per square mile for widths greater than 20 feet are found by adding together the costs for two of the tabulated widths which will give the desired width.

The easiest method of distributing the stone is by using an automatic spreader wagon which deposits it in a layer of approximately the right thickness. The methods of determining the thickness are explained on page 61.

When a hundred feet or so of the first course has been spread, the rolling should begin. A roller weighing about 600 pounds per inch of width of roll is usually recommended for rolling hard rock, but one of three-fourths this weight will probably do better work with soft limestone. The roller starts at the edges of the stone and care should be taken that the shoulders are not crushed during the trips near the sides of the trench. The roller should not be run much faster than 100 feet per minute. After both sides are moderately firm, the roller should move gradually toward the center until the whole lower course is thoroughly compacted. The rolling should be stopped as soon as the pieces of stone begin to break. Sometimes it is found that a wavy motion continues and the stone will not compact. This may be due to a wet subgrade, which will probably give no trouble if allowed to dry for a day or two, or it may be due to the use of a very hard stone, when the application of a little sand or fine gravel may remedy the difficulty. With some soft, coarse, gravel stones a crawling motion may be noticed, which can be prevented by a light sprinkling of coarse sand, stone screenings and sometimes by water. The rolling is continued until the stone has no movement when the men walk over it. If depressions develop during the rolling they must be filled with stone of the same size as that used in the course and rolled until firm.

Some engineers advise harrowing the loose stone with a spike-tooth harrow in order to mix the stone thoroughly and to save a part of the rolling. This would be of advantage if full loads of stone were dumped directly on the subgrade, for it would break up the cores of small stone in the center of the piles. Other engineers recommend using a blade grader to shape the loose stone just before rolling.

It is not customary to apply a binder of gravel or screenings to the bottom course in some states and it is required in others. It is apparently a detail depending considerably upon the hardness of the stone used. If the stone is relatively soft and the bottom course is constructed of a large size of stone, a binder may prevent the internal disintegration of the stone under loads to some extent, but with the somewhat smaller, hard trap rock used in Massachusetts, for instance, screenings are unnecessary.

After about a hundred feet of the bottom course has been rolled, the second course is spread. This consists of the size from $\frac{1}{2}$ to $1\frac{1}{4}$ or $1\frac{1}{2}$ inches, and the loose depth is 3 to 5 inches. Large loads should not be dumped directly on the bottom course. The top course is usually given its final shaping with rakes. This course is rolled commencing on each outer edge with the rear wheel half on the stone and half on the shoulders; the roller is gradually worked toward the center. If depressions are developed during this work, they must be filled, and the rolling should continue until the surface is hard and uniform in contour.

The surface is then covered with the binder. The material used for this purpose varies with the character of the stone in the top course. Generally screenings are employed, but in states where the top course is composed of rather large sizes of stone the screenings have small stone mixed with them. In Maryland limestone screenings are not permitted with trap rock without the consent of the engineer. A. R. Hirst, State highway engineer of Wisconsin, advises using a clayey pea gravel or disintegrated granite with crushed quartzite or granite, and if these are unavailable he prefers a bituminous binder.

Screenings are rarely if ever permitted to be dumped on the road. They should be placed in piles along the road at such intervals that they can be distributed readily and enough material will always be available. In Massachusetts it is not customary to place the screenings to a greater depth than 1 inch. In Michigan the depth is about ¾ inch and in Wisconsin about ½ inch on State roads.

Although the screenings are sometimes rolled dry, after being spread, the usual practice is to sprinkle the road with water before rolling. The road must be sprinkled until the screenings are thoroughly wet and do not stick to the wheels of the roller. Where hard, small stone is used in the top course more water is generally employed than where the stone is larger, and an attempt is made to flush the screenings into the interstices between the stones. If the screenings are picked up by the roller at any time, more water must be applied. The sprinkling and rolling are continued until water is carried along in front of the roller wheels at every point of the road.

Rolling must be done carefully for the appearance of the road will depend upon this work.

After the road has dried sufficiently, the shoulders should be smoothed off with a road machine, if one is available. The shoulders should be trimmed so the water can flow from the center of the road to the ditches along every foot of the way. All surplus material should be removed, and the shoulders should be rolled as far out as it is safe to run the roller.

Glutrin Binder

For a number of years, glutrin has been used extensively as a binding material for both gravel and broken stone roads. It is an adhesive binding liquid whose base is the lignin derived from the sulphite pulp wood process. It is sold in a concentrated state and should be diluted with water before use.

It should be understood that when the road material to be treated is other than stone, it should contain at least 10 per cent of clay. When this is lacking in the original road material, it should be evenly added as the road material is put in place. When used on gravel or sand-clay roads, glutrin should be diluted with water in the proportion of one part glutrin to not less than three parts water. This mixture should be applied by means of any distributor which will spread it uniformly. The application should be continuous, so that the road is kept moist, but not so rapidly as to permit the forming of pools or the flowing off to the sides. Penetration must be secured, and consequently the distributor should make at least four trips over the road in applying the amount of glutrin called for in the specifications. This is usually about ½ gallon of glutrin to the square yard.

When used in the construction of broken stone or slag roads, the glutrin should be applied during the process of puddling the top course. The puddle should be begun as usual with plain water, but as soon as the screenings are thoroughly saturated, glutrin should be placed in the sprinkler in the proportion of one part glutrin to five parts water, and the puddling completed with this mixture. The specifications usually call for ½ gallon of glutrin to the square yard to be used in this process. A still stronger bond can be secured if, after the road has been puddled in this manner, it is allowed to dry out and a surface application is then made over the center 80 per cent of the width of the road, of 0.2 gallon of glutrin, diluted in the proportion of one part glutrin to three parts water. As soon as the road is dry, it can be opened to traffic.

There have been many miles of glutrin-bound roads constructed in Connecticut and New York, which have been given a bituminous top course, or even an oil treatment, the purpose being to bind the mass of stones thoroughly together with glutrin to prevent the internal disintegration of the gravel or stone by traffic and to protect the glutrin from surface water.

Glutrin should not be used with a pure siliceous material like quartz, unless at least 10 per cent of clay is added. With broken stone, the fine material produced in rolling, furnishes a substitute for the clay required with gravel.

Maintenance

Where there is very little automobile traffic the old-fashioned methods of maintenance are still applicable. If the road was built late in the fall, particularly if trap rock was used, it is possible that loose stone will appear on the surface in the spring. They should be removed and need cause no apprehension. Holes and ruts should be filled with small stone and screenings, preferably during a rain so the traffic will begin to bind the patch as soon as the weather clears. When the top course has been worn down so that the large stone of the bottom course show in places, the road should be repaired. If the top course is to be less than 3 inches thick the stone can be spread on the road and treated like the top course of a new road. If the course is to be made of 3 inches or more of loose stone, it is generally best to loosen up the road by means of spikes placed in the wheels of the roller or by the use of a scarifier.

This method of maintenance is practically obsolete on account of motor traffic. The shearing action of the wheels of an automobile on a water-bound road speedily loosens the stones of the top course and it is necessary to protect the surface by a tenacious mat of bituminous material and stone. Experience shows that this should not be applied until the road has seasoned for a few months. If the road is finished late in the fall, so that no opportunity will be afforded for it to season before winter closes down construction work, the surface can be bound with calcium chloride to hold it until spring, when the bituminous mat can be applied.

The ordinary method of maintaining the road is to clean it thoroughly and then apply a road oil uniformly over the surface. Some of these oils are so thin that they soak into the surface while others must be covered with sharp sand or screenings free from dust. The methods of doing the work are explained in the chapter on surface applications.

ROAD BUILDING ROCKS

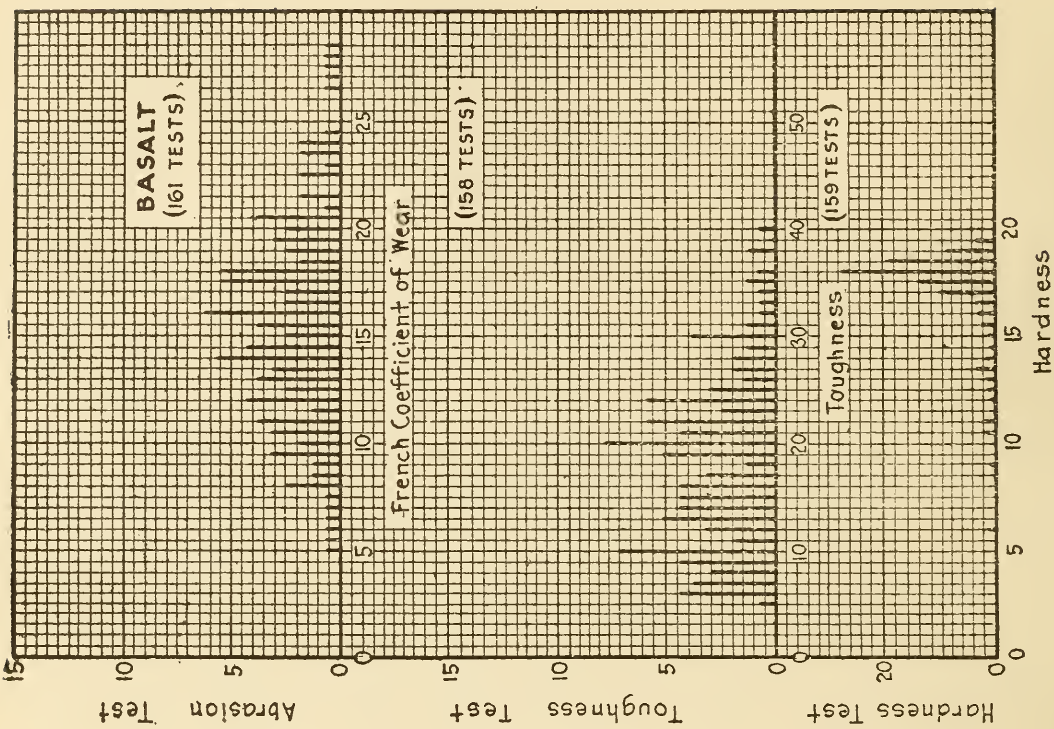
Mineral Composition.[1]—Reports of geologists and mineralogists on road-building rocks classify them according to their origin as igneous, sedimentary and metamorphic.

Igneous rocks are those which have solidified from a very hot liquid condition and their physical condition, technically termed "structure," depends largely on the rate of cooling of the fused material. The "intrusive" or "plutonic" type of igneous rocks cooled slowly at great depths below the earth's surface, and the minerals composing it are usually in large and well developed particles. This type includes granite, syenite, diorite, gabbro, and peridotite. The "extrusive" or "volcanic" types of igneous rocks cooled more rapidly upon the earth's surface and are finer grained. They frequently show a so-called "porphyritic" structure on account of the presence of larger crystals in a fine-grained, dense mass forming the main mass of the rock. This type includes rhyolite, trachyte, andesite, basalt and diabase.

Sedimentary rocks are made up of fragments of minerals or shells that were moved about, mainly by water, and finally deposited on the beds of lakes or seas in more or less parallel layers. There they became cemented together by the pressure upon them and changes in the composition of a part of their constituents. This last change is of the same general nature as that occurring far more quickly in the case of plaster or mortar. This class includes calcareous types of rock like limestone and dolomite, and siliceous types like shale, sandstone, and chert (flint). Both types are usually distinctly bedded or stratified.

Metamorphic rocks were produced from the two classes just mentioned by pressure and heat. The long-continued shearing and compressive forces sometimes produced a "foliated" or "schistose" character, with a parallel arrangement of the minerals composing them, or a "massive" or "nonfoliated" character. Gneiss, schist and amphibolite are foliated metamorphic rocks, and slate, quartzite, eclogite and marble are nonfoliated metamorphic rocks.

[1] Abridged from Bulletin 348, U. S. Department of Agriculture, "Relation of Mineral Composition and Rock Structure to the Physical Properties of Rock Materials," by E. C. E. Lord, petrographer, Office of Public Roads and Rural Engineering.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Toughness
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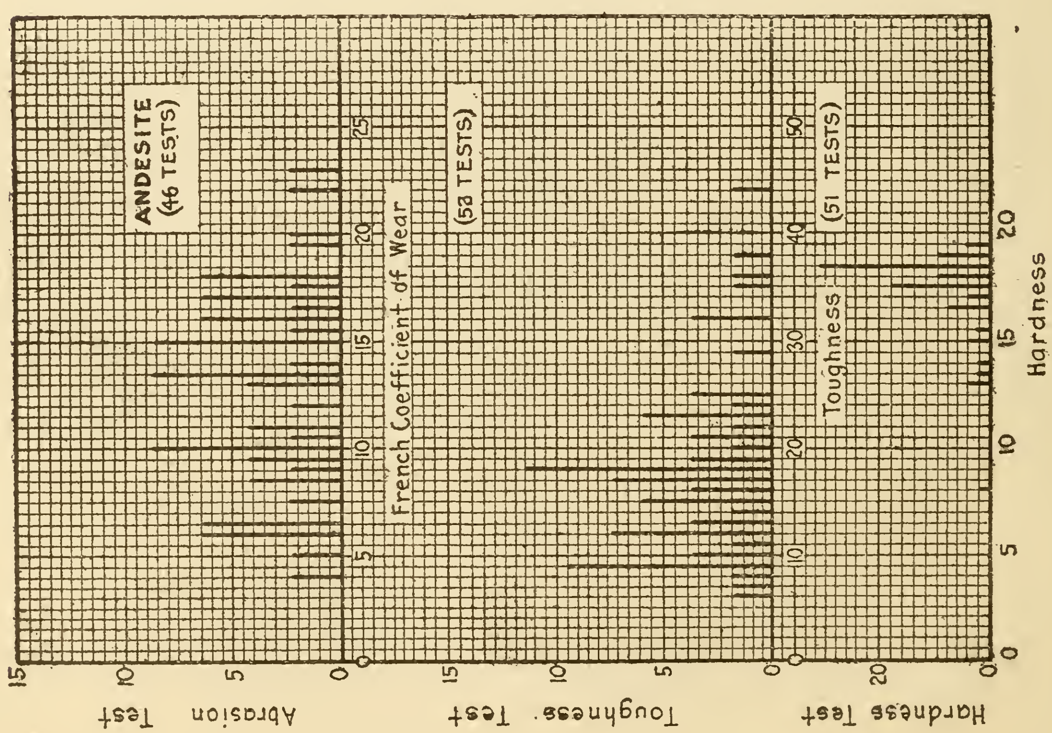
Hardness
Abrasion Test
Toughness Test
Hardness Test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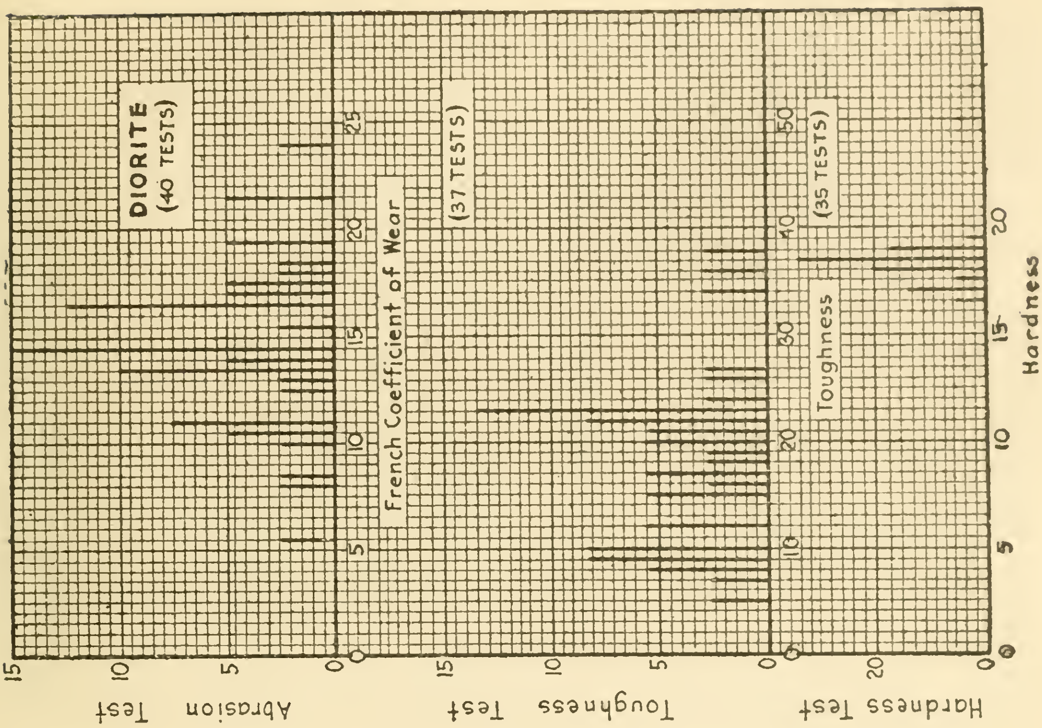
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Toughness Test
Hardness Test


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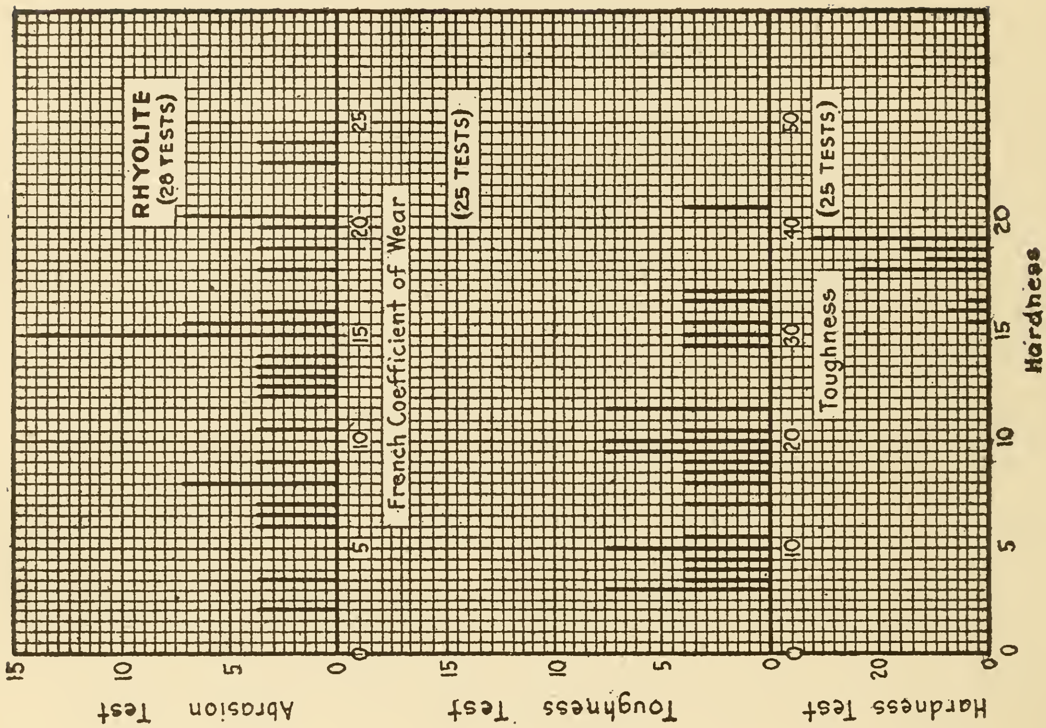
(169 TESTS)
Hardness
Abrasion Test
Toughness Test
Hardness Test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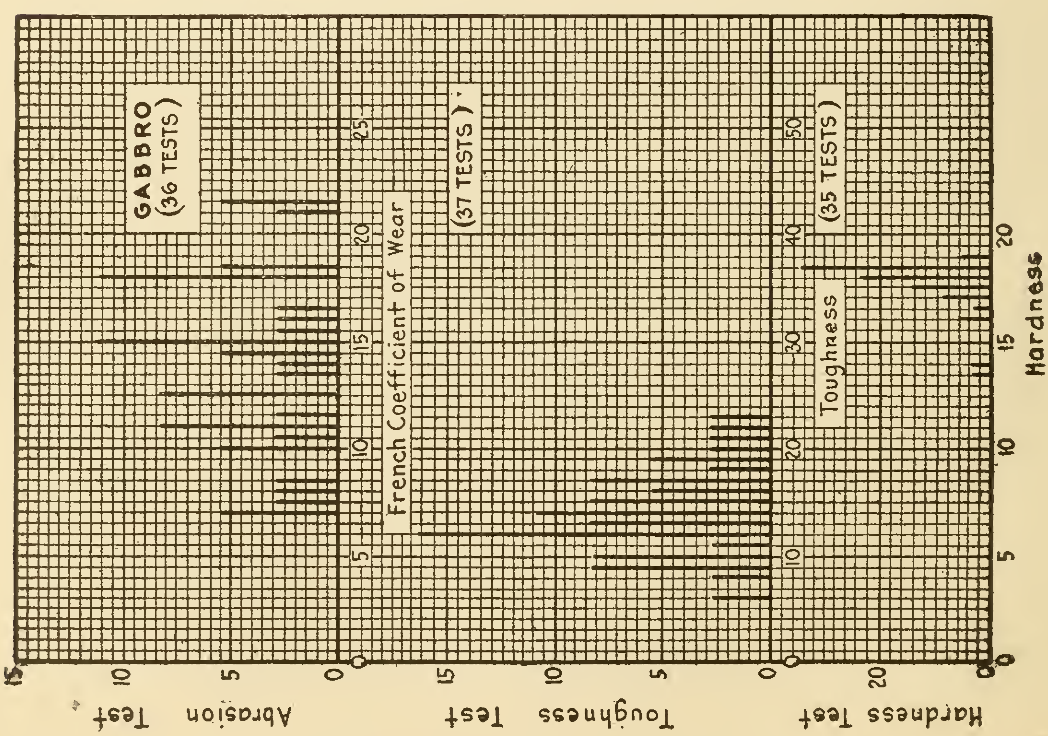
Hardness
Abrasion Test
Toughness Test
Hardness Test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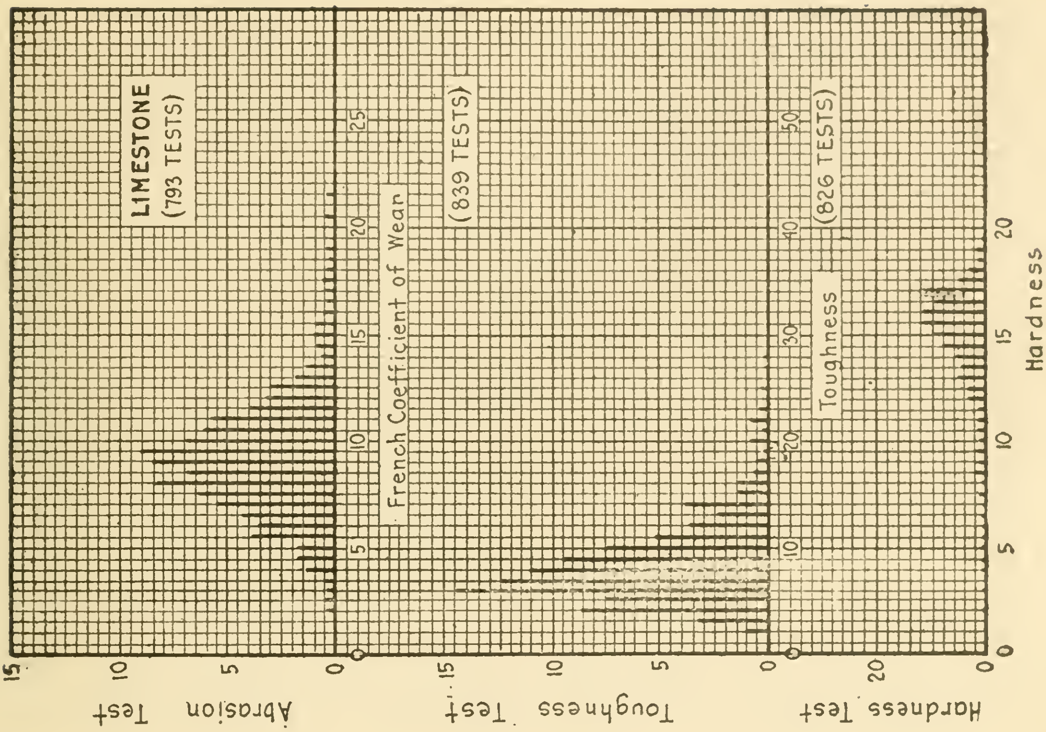
Hardness
Abrasion Test
Toughness Test
Hardness Test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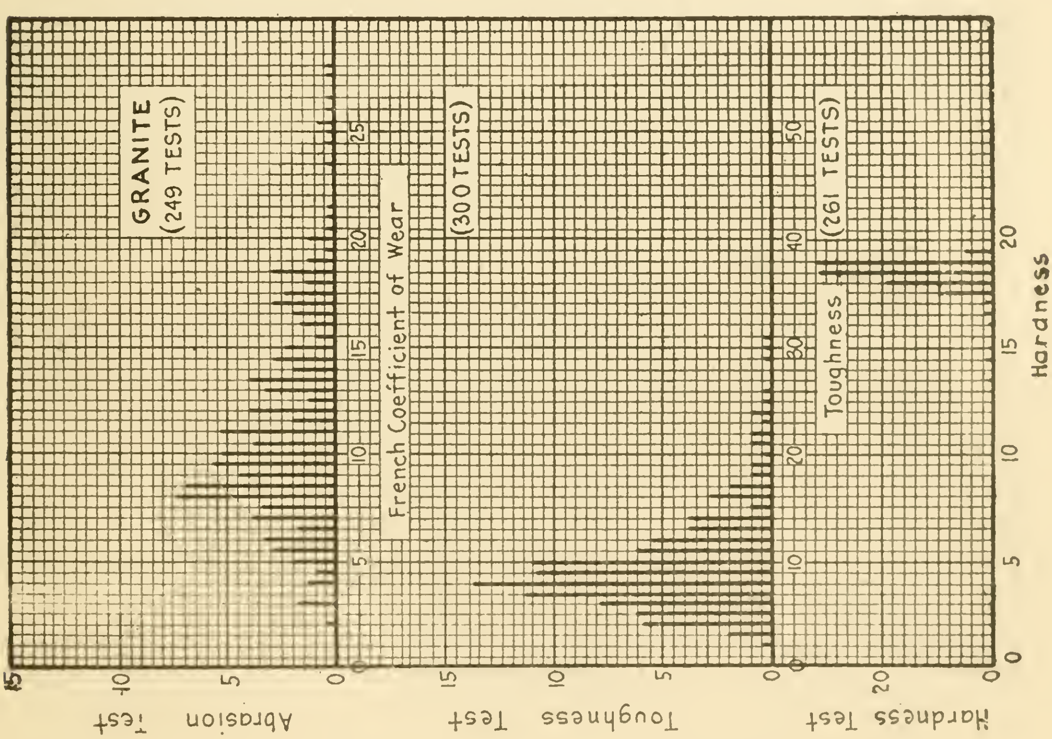
Hardness Test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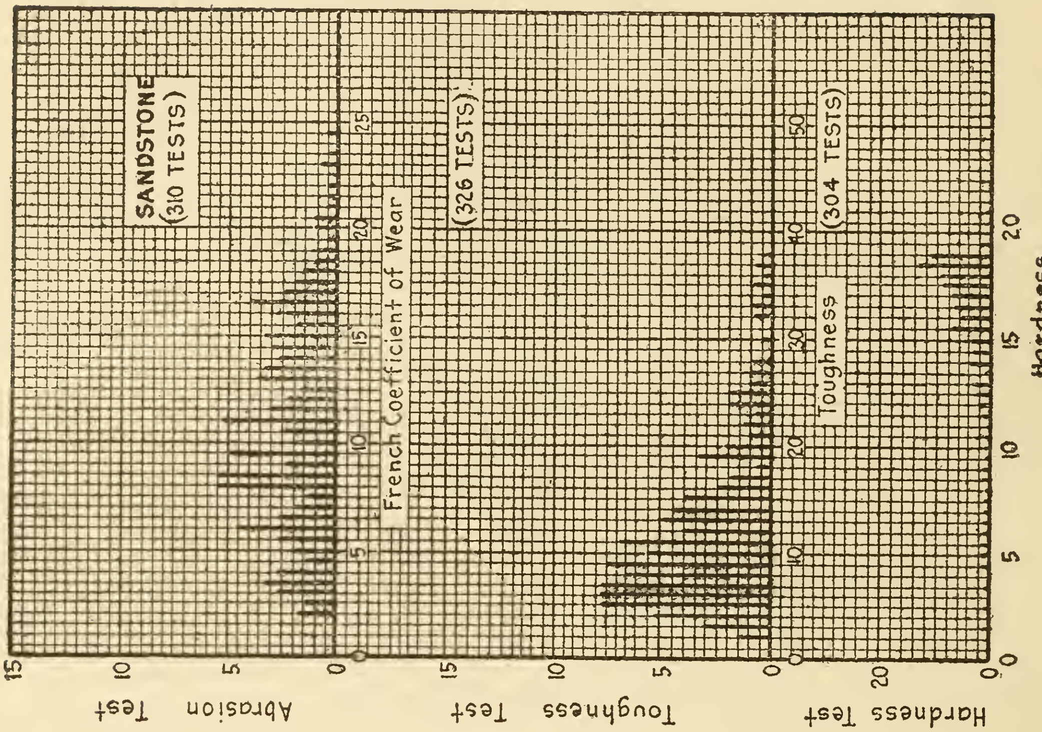
Hardness
Abrasion Test
Toughness Test
Hardness Test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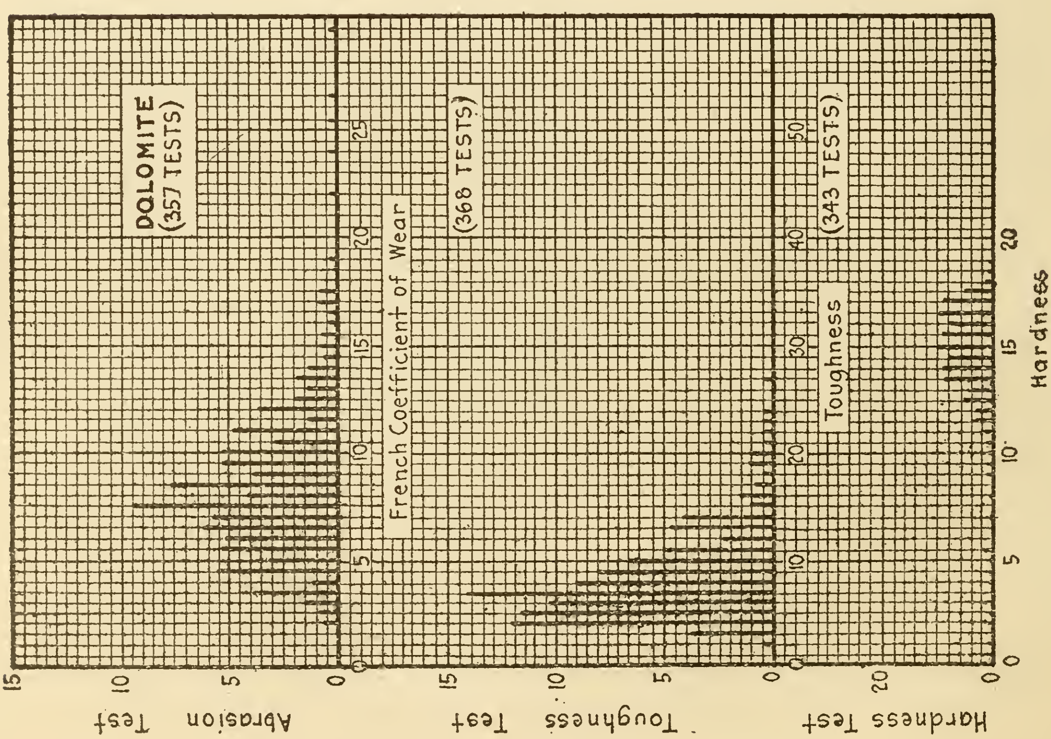
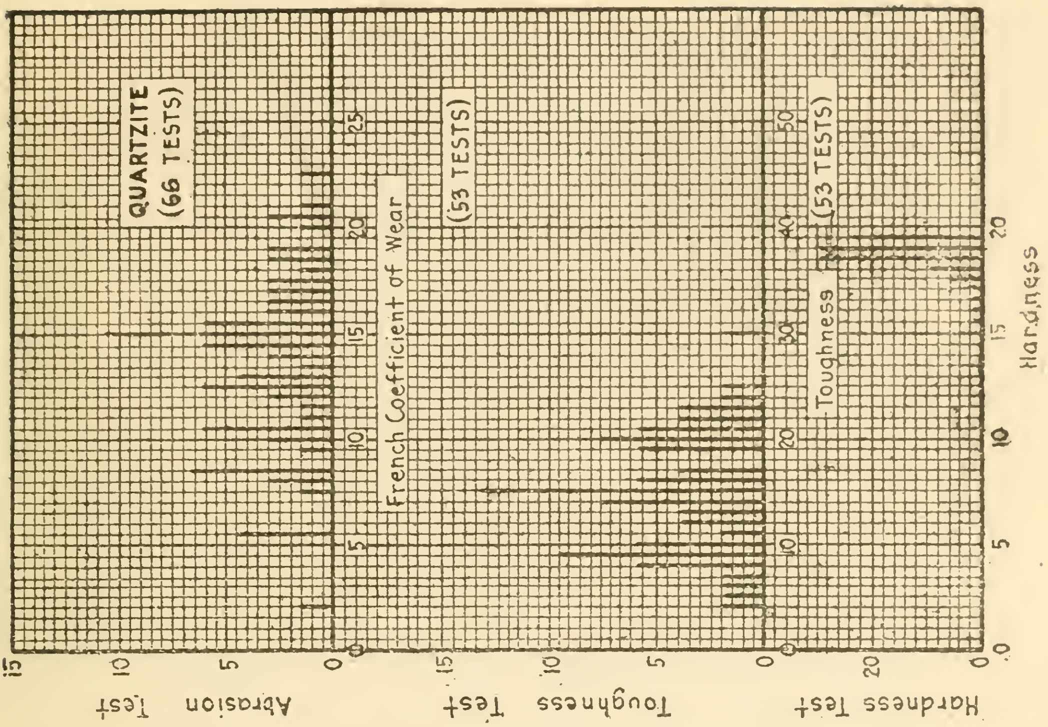
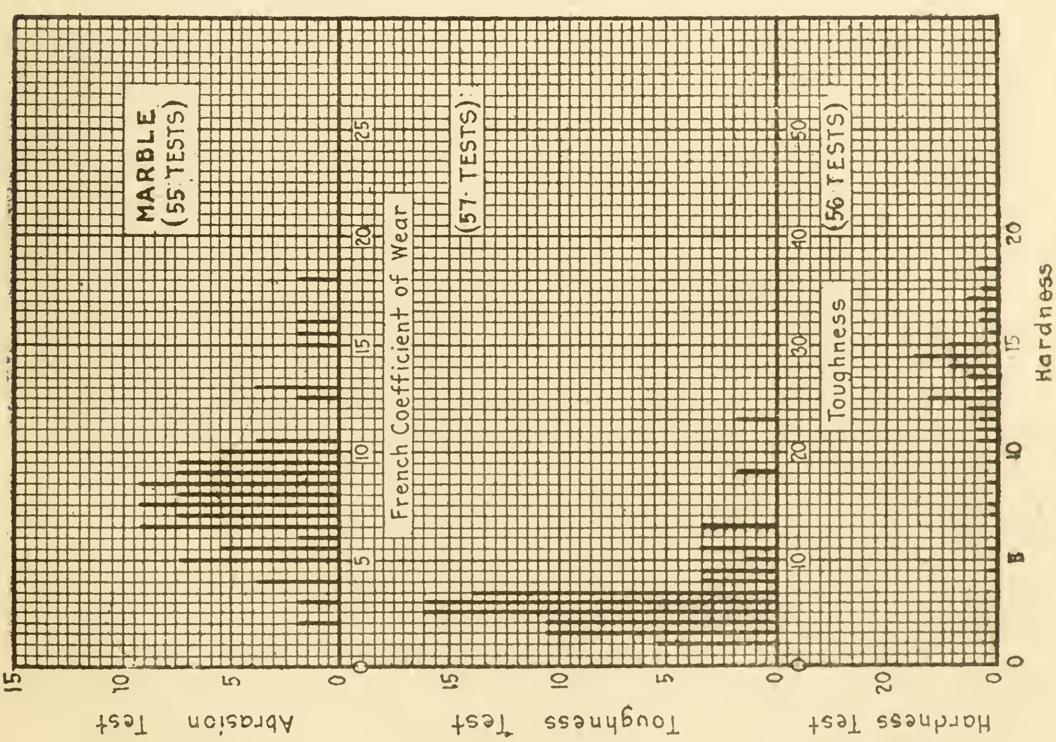
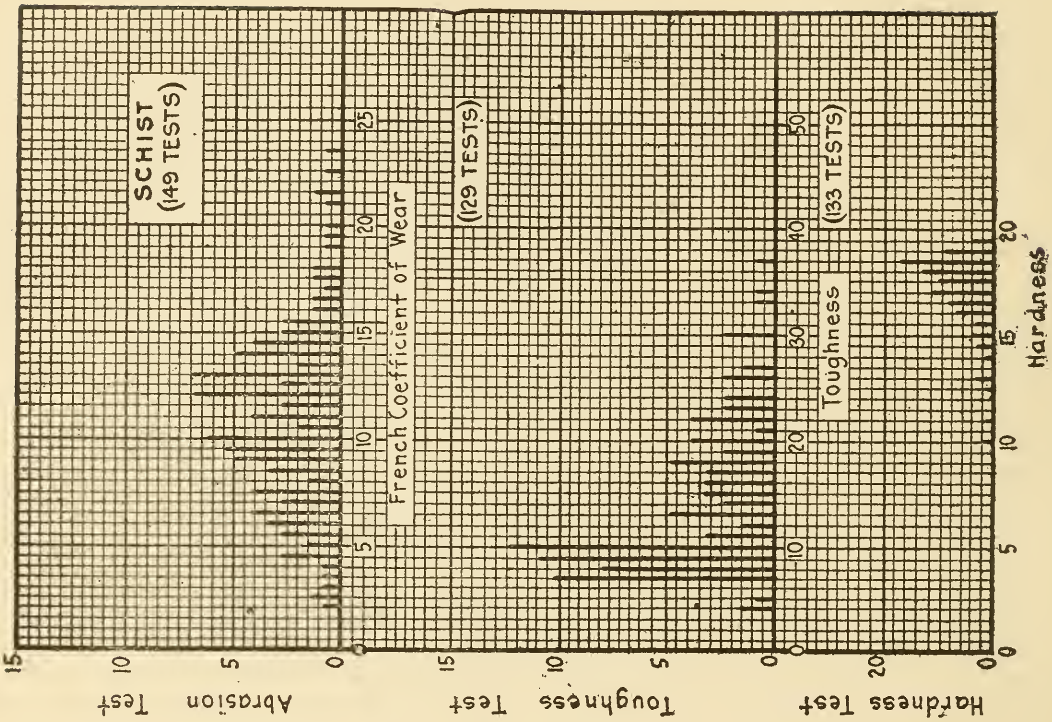
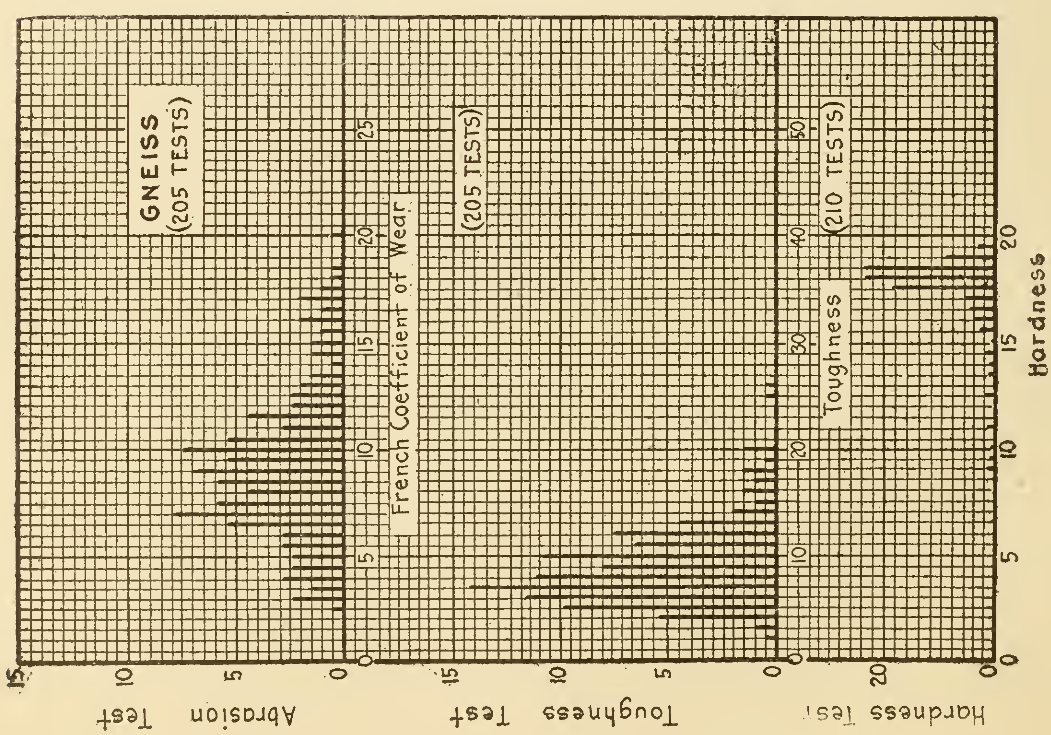
Hardness
Abrasion Test
Toughness Test
Hardness Test


DOLOMITE
(357 TESTS)
French Coefficient of Wear
(368 TESTS)
Toughness
(343 TESTS)
Hardness
Abrasion Test
Toughness Test
Hardness Test


QUARTZITE
(66 TESTS)
French Coefficient of Wear
(53 TESTS)
Toughness
(53 TESTS)
Hardness
Abrasion Test
Toughness Test
Hardness Test


MARBLE
(55 TESTS)
French Coefficient of Wear
(57 TESTS)
Toughness
(56 TESTS)
Hardness
Abrasion Test
Toughness Test
Hardness Test


SCHIST
(149 TESTS)
French Coefficient of Wear
(129 TESTS)
Toughness
(133 TESTS)
Hardness
Abrasion Test
Toughness Test
Hardness Test


GNEISS
(205 TESTS)
French Coefficient of Wear
(205 TESTS)
Toughness
(210 TESTS)
Hardness
Abrasion Test
Toughness Test
Hardness Test

The original mineral components of igneous rocks and the essential part of metamorphic schists are quartz, plagioclase, orthoclase, augite, hornblende, muscovite, biotite, rock glass, magnetite and garnet. These are called primary minerals. Rock glass, included among them, is a mineral of variable composition found in certain volcanic rocks which cooled very rapidly. It is extremely brittle and when present in appreciable quantities has a tendency to lower the wearing properties of the rock. Orthoclase and plagioclase are usually called "feldspar" by engineers and biotite and muscovite are called "mica."

Quartz is the most widely distributed mineral known. It has a specific gravity of 2.66 and a hardness of 7 in Mohs' scale.[1] When present in large quantities, especially when finely consolidated, as in fine-grained, igneous and massive metamorphic rocks, the resulting material is extremely hard and offers great resistance to wear.

Orthoclase and plagioclase are among the principal ingredients of igneous and metamorphic rocks and some sandstones. Their specific gravity is 2.54 to 2.76 and their hardness 6 to 6.5. Many coarse-grained feldspathic rocks break down readily under impact on account of the cleavage of these minerals. In fine-grained rocks the effect of this cleavage is less marked, and some of them are extremely hard and tough.

Augite and hornblende are the chief iron-bearing or dark silicate constituents of basic igneous rocks, commonly called "trap rocks," and the crystalline schists derived from them. Their specific gravity is 2.93 to 3.71 and their hardness 5 to 6.5. Their crystalline shape is such that they interlock very compactly with other minerals, which is one of the reasons for the marked durability of trap rocks.

Biotite and muscovite occur chiefly in granite, gneiss and micaceous schist. Their specific gravity is 2.7 to 3.2 and their hardness is 2 to 3. The flaky character of mica is well known and is largely responsible for the foliated character of many metamorphic rocks and their resulting inferior wearing properties in roads.

Magnetite has a specific gravity of 5.18 and a hardness of 5.5. Garnet has a specific gravity of 3.15 and a hardness of 7.5. They occur in only two road-building rocks, peridotite and eclogite, and in some cases materially increase the wearing properties of the rock.

Secondary minerals are produced by the alteration of rocks, mainly by the chemical action of water and carbonic acid on primary rock constituents. The chief secondary minerals are

[1] Mohs' scale of the relative hardness of minerals is as follows: 1, Talc; 2, gypsum; 3, calcite; 4, fluorite; 5, apatite; 6, orthoclase; 7, quartz; 8, topaz; 9, corundum; 10, diamond.

calcite, dolomite, kaolin, chlorite, epidote, limonite, serpentine, talc, zeolite and opal.

Calcite has a specific gravity of 2.6 and a hardness of 3. Dolomite has a specific gravity of 2.9 and a hardness of 3.5. These two minerals are the chief constituents of limestones and dolomites, and cannot be distinguished microscopically. They cleave freely and hence many calcareous rocks break down readily when used in roads.

Kaolin is derived to a large extent through the decomposition of orthoclase. It sometimes occurs in small crystal flakes resembling white mica (muscovite), and sometimes as minute grains of very indefinite composition. In the latter form, called "amorphous," kaolin has a great effect on the binding property of rock powders, for it becomes glue-like when wet, and when dry it binds together firmly the other mineral particles with which it is associated.

Chlorite and epidote are derived from augite, hornblende, biotite and plagioclase and are most abundant in trap rocks and dark crystalline schists. Chlorite is a soft green mineral which occurs either in mica-like flakes or as very fine scales and fibers of indefinite composition. In the latter form it has cementing properties like those of amorphous kaolin. Epidote (specific gravity, 3.25–3.5; hardness, 6–7) occurs as yellowish green crystals which, when present in appreciable quantities, apparently increase the wearing properties of rocks.

The results of a study of several hundred road-building rocks indicate that the effects of their mineral composition on their value for highway purposes are probably as follows:

Igneous and nonfoliated metamorphic rocks, owing to a preponderance of hard silicate minerals combined with greater uniformity in structure, are more durable than other road-making materials, finer-grained varieties offering greater resistance to abrasion than coarse-grained types.

The resistance to wear of igneous and metamorphic rocks, containing an abundance of quartz, hornblende, augite, epidote, and garnet, is greater than that of similar rocks rich in mica, chlorite, serpentine, and calcite.

Foliated metamorphic rocks, owing to the parallel arrangement of their mineral constituents, are, as a rule, deficient in toughness and therefore not well adapted to road construction.

Sedimentary rocks are usually deficient in wearing properties, except in the case of highly indurated sandstones, containing a moderate amount of siliceous clay, cement, and limestones or dolomites rich in quartz and having very little clay.

Rocks for road making break down under impact into fragments, the shape and physical character of which are conditioned by mineral composition and structure.

The effect of weathering is generally to lower the resistance to wear of road materials, owing to the development of soft, in part glue-like (colloidal) products of alteration. Where the secondary minerals are harder and more crystalline the wearing properties of the rocks are proportionately increased.

The cementing value of road materials is conditioned chiefly by the glue-like (colloidal) products of rock decay and increases in a general way proportionately with these products, reaching a maximum in rocks free from quartz.

The slaking property of rock powders is dependent in the case of siliceous igneous and metamorphic rocks chiefly on the physical character of the primary mineral components, whereas in basic igneous rocks and sandstones it is caused to a large degree by glue-like (colloidal) products of rock decomposition.

Physical Properties.[1]—The success or failure of a rock for road building depends largely upon the extent to which it will resist the destructive influences of traffic. The three most important physical properties are hardness, toughness, and binding power Hardness is the resistance which the rock offers to the displacement of its surface particles by abrasion; toughness is the resistance which it offers to fracture under impact; and binding power is the ability which the dust from the rock possesses, or develops by contact with water, of binding the large rock fragments together. In order to approximate as closely as possible in the laboratory the destructive effects produced by traffic, climatic agencies and faulty construction, certain physical tests have been developed.

Hardness is determined by subjecting a cylindrical rock core 25 millimeters in diameter, drilled from the specimen to be examined, to the abrasive action of quartz sand fed upon a revolving steel disk. The end of the specimen is worn away in inverse ratio to its hardness, and the amount of loss is expressed in the form of a coefficient as follows:

Coefficient of hardness $= 20 - w/3$, where w equals the loss in weight after 1,000 revolutions of the disk.

Toughness is determined by subjecting a cylindrical test specimen 25 by 25 millimeters in size to the impact produced by the fall of a 2-kilogram hammer upon a steel plunger whose lower end is spherical and rests upon the test piece. The energy of the blow delivered is increased by increasing the height of fall of the hammer 1 centimeter after each blow. The height of blow in centimeters at failure of the specimen is called the toughness.

[1] Abstracted from Bulletin 370, U. S. Department of Agriculture, "Results of Physical Tests of Road Building Rock," by Prévost Hubbard, chemical engineer, and Frank H. Jackson, Jr., assistant chemical engineer, Office of Public Roads.

A test devised by the French and sometimes called the Deval test, for measuring the combined action of abrasion and impact, is as follows: Five kilograms of freshly broken rock between 2 and 2½ inches in size is tested in a special form of cylinder so mounted on a frame that the axis of rotation of the cylinder is inclined at an angle of 30° with the axis of the cylinder itself. The fragments of rock forming the charge are thus thrown from end to end twice during each revolution, causing them to strike and rub against each other and the sides of the cylinder. After 10,000 revolutions the resulting material is screened through a $\frac{1}{16}$-inch sieve and the weight of the material passing is used to calculate the percentage of wear. The French coefficient of wear is calculated from the per cent of wear as follows:

$$\text{French coefficient of wear} = 40 \div \text{percentage of wear}$$

To determine the binding power, or cementing value, as it is usually called, 500 grams of the material to be tested is crushed to pea size and ground with water in a ball mill until it has the consistency of a stiff dough. It is then molded into cylindrical briquettes 25 by 25 millimeters in size, which, after thorough drying, are tested to destruction in a special form of impact machine. A 1-kilogram hammer falls through a constant height of 1 centimeter upon an intervening plunger, which in turn rests upon the test piece. A graphic record of the number of blows required to destroy the specimen is obtained. The number of blows producing failure is called the cementing value of the material.

The specific gravity, weight per cubic foot, and the water absorption in pounds per cubic foot are obtained on samples of rock which are tested to determine their road-building qualities. The weight per cubic foot is calculated from the specific gravity of the material obtained on a 10-gram sample by the usual displacement method. The gain in weight of this fragment after four days' continuous immersion in water is used to calculate the water absorption in pounds per cubic foot of the solid rock.

Results of Tests.—Because of the fact that the various rock families, when subjected to the tests outlined, give results which are more or less distinctive of a group or type, these results can best be discussed in many cases collectively. There are 14 families of rock which are more or less commonly used in macadam-road construction. The variations which have been found to exist in the three principal tests for each of these are shown in graphic form in the diagrams on pages 76–82. The values of the tests are arranged as abscissæ, with the zero points to the left and the values numerically increasing toward the right.

The ordinates or vertical lines represent the percentages of the total number of samples having values corresponding to the abscissæ on which they are plotted. The figures in parentheses in the upper right-hand corner of each block represent the total number of determinations from which these percentages were calculated.

Andesite, Basalt, Diabase, Diorite, Gabbro, and Rhyolite comprise the well-known group of road-building rocks commonly known as "trap." The average toughness of all the traps, with the exception of gabbro, which runs somewhat lower, is about 18. This is a considerably higher average than that shown by any of the other types or groups. The same relationship holds true in the abrasion test, the average French coefficient of wear running from about 13 to 15. Comparatively slight variations in hardness are noted for any family or for the group as a whole, the average hardness for which is about 18. The binding power of the traps varies through wide limits, depending largely on the degree of weathering they have undergone. The specific gravity of this group averages about 2.9, giving an average weight per cubic foot of 180 pounds. Individual samples are seldom less than 2.7 nor more than 3.2 specific gravity. Water absorption may vary from a few hundredths of 1 per cent to over 7 per cent.

Granite is characterized by low toughness and high hardness. The average value for the former is about 8, while that for the latter runs as 18.5. The abrasion test develops an average French coefficient of wear of about 11. Cementing values run low, the only exceptions being very highly weathered material which usually shows low toughness and resistance to wear. The specific gravity averages 2.7. The weight per cubic foot averages 168 pounds. Water absorption has been found to run from about 0.04 to 3 per cent.

The limestones and dolomites, or magnesium limestones, are undoubtedly the most widely used road-building rock. The average French coefficient of wear is about 8, toughness 7, and hardness 15. The cementing values are usually good, about 75 per cent of all samples tested running over 25. The specific gravity of the limestones and dolomites averages close to 2.7. In general, the weight per cubic foot will average about 168 pounds for the limestones and 170 pounds for the dolomite. Absorption may vary from a few hundredths of 1 per cent to over 13 per cent.

The sandstones are characterized by wide variations in the results of all tests. The average French coefficient of wear is about 12, average toughness about 10, and average hardness about 16. The cementing value of sandstones varies widely, depending upon their composition. Their specific gravity averages 2.62. The weight per cubic foot averages 164 pounds. Absorption runs from a few hundredths of 1 per cent to about 2 per cent.

The average toughness of marble is about 5 and the average hardness is less than 14. Marbles usually show good cementing value tests, with about the same range as the limestones and dolomites. The specific gravity ordinarily falls between 2.7 and 2.9 and the weight per cubic foot averages 173 pounds, which is somewhat higher than the average for either limestone or dolomite. The maximum absorption is under 2.5 per cent.

Quartzites show an average toughness of 15. The quartzites invariably show a low cementing value. Their specific gravity usually lies between 2.6 and 2.8 and their average weight per cubic foot is about 167 pounds. Their water absorption runs from a few hundredths of 1 per cent to nearly 3 per cent.

Gneiss and schist show similar physical properties. The average French coefficient of wear for the gneiss samples is about 9. Their average hardness, toughness, specific gravity, weight per cubic foot, and absorption are approximately the same as for granite.

The schists show an average French coefficient of wear of about 12. Their average hardness is about 17.5 and their toughness averages 11. The toughness test for both gneiss and schist is made perpendicular to the plane of foliation. If taken horizontal to the plane of foliation much lower results would be obtained, as failure would then occur along these natural lines of cleavage. The specific gravity of schists usually lies between 2.65 and 2.90 and the average weight per cubic foot is about 181 pounds. Water absorption is seldom over 2 per cent for this family.

With the exception of the highly altered varieties, both gneisses and schists show a rather low cementing value.

Chert is a very hard material, but frequently shows a low resistance to wear, owing to its tendency to fracture along lines which have developed as shrinkage cracks in the rock structure. For this reason it is extremely difficult to test for toughness. The cementing value of pure chert is usually low, but some highly weathered deposits develop in service good cementing value, especially if a high-binding clay is associated with it. The French coefficient of wear has usually been found to average 5, toughness 16, and the hardness coefficient between 19 and 20. Specific gravity usually lies between 2.4 and 2.65 and the average weight per cubic foot is about 160 pounds. Water absorption may run from a few tenths of 1 per cent to over 8 per cent.

Shales and slates are highly laminated rocks that tend to break into flat plates not suitable for road-building purposes. They are seldom used in road construction, except perhaps as a filling for sub-foundations. They vary greatly in nearly all of their physical properties.

Many varieties of slag resemble in certain outward respects the common road-building rocks. However, in general, they are more porous and glassy, and vary so greatly in physical properties that with reference to their physical characteristics from the standpoint of road construction they cannot well be considered as a single class with definite limits or general average numerical values.

CONCRETE ROADS

Although concrete pavements were laid at Bellefontaine, Ohio, in 1893 and 1894, the type did not attract general attention until fifteen years later. During 1913, over 10,000,000 square yards were laid, eight times as much as in 1911. This rapid development was accompanied by marked differences in methods of construction, which aroused some apprehension that poor results from inferior methods would retard the logical adoption of the type in places for which it was suited. Accordingly road and street engineers and contractors from all parts of the country met in February, 1914, for a three-day discussion of concrete road building. The report of this conference exercised a standardizing influence on methods of construction, as had the somewhat earlier adoption by the American Concrete Institute of standard specifications for concrete roads and pavements. Some of the methods of construction presented features which required detailed investigation, and committees were appointed for such work. In February, 1916, a second national conference was held, at which the reports of these committees were received and discussed. This chapter summarizes the information presented at that conference.

Foundation and Subgrade

The following opinions regarding foundations and subgrade were adopted by the 1916 conference:

When roadways are constructed over fills, extreme care should be observed to insure the use of proper materials in layers of such thickness that they may be thoroughly compacted so that when the fill is completed there will be a minimum of settlement. In general, fills shall be made in thin layers, the depth depending on the character of material to be used in making the fill. The fill should be allowed to stand for as long a time as possible, giving it an opportunity to settle thoroughly before the pavement is placed thereon. Deep fills should be allowed to settle through one winter wherever such procedure is possible. Puddling will be found advantageous in compacting deep fills. Wetting and rolling shall be performed when making a fill in order to secure thorough compactness. Fills should never be made with frozen materials nor with lumps greater than 6 inches in their greatest dimension.

The fundamental requirement of the subgrade is that it should be of uniform density so that it will not settle unevenly and cause cracks in the surface of the pavement. No part of the work is more worthy of intelligent care and painstaking labor than the preparation of the subgrade. The slight additional cost necessary to insure good results is abundantly justifiable. When the pavement is constructed on virgin soil, care should be taken to remove all soft spots so as to insure a uniform density; and if constructed on an old roadbed, even greater care must be taken to secure uniform density, as the subgrade is likely to be more compact in the center than at the sides. An old roadbed should be scarified, reshaped and rolled. The subgrade adjacent to curbs should be hand-tamped.

The importance of a uniformly firm support for the concrete slab was not fully appreciated by all roadbuilders. There was an opinion among some that the concrete would act as a beam and distribute the loads coming on it over such a wide area that inequalities in the sustaining power of the earth would prove unimportant. The number of cracks in concrete pavements attributable to unwarranted confidence in this beam action is beyond proof, but today the opinion is generally held that the money spent in securing a firm foundation is a wise outlay to insure low maintenance charges. This is particularly the case where an old road is used for a foundation. It is unlikely that a concrete pavement will be laid on it until the old road needs repairs. If the surface is then merely leveled by a thin course of stone or gravel, it is possible that there will be weak places, particularly along the sides of the road.

Drainage

The 1916 conference adopted the following statement of the principles which should govern the drainage of the roadbed supporting a concrete slab:

> The drainage of the roadbed is of vital importance. If the subgrade is not well drained there is danger of unequal settlement and of frost action, which will cause cracks. The method of drainage to be used will depend on local conditions. For streets, as well as roads, tile drains may be used which should be laid on each side of the roadway, or on one side only, with cross-drains leading thereto at a suitable depth, depending on the width of the pavement. Drainage trenches, if placed under the subgrade, should be completed before final rolling.

There is an objection to the use of cross-drains under thin concrete roads which is not serious in most cases but may be under some conditions. It is practically impossible to compact the material over a blind drain as thoroughly as that of the main portion of the subgrade, and each blind drain is likely to be a weak place in the foundation. An alternative for them which some engineers have advised is the construction of a blind drain just outside each edge of the concrete slab and extending 8 or 10 inches below the subgrade. These drains are connected every 50 feet with the side ditches by blind drains. All drains under the roadway should have a covering of sand or fine gravel on top to prevent the mortar in the wet concrete from passing into the broken stone or gravel of the drain.

Cross-section of Roads

The following statements were adopted by the 1916 conference regarding the section of the concrete pavement:

> The thickness of a concrete road or pavement is controlled by many factors, each of which should be given consideration. In view of the increasing use of the heavy motor truck and bus, it seems unwise to build pavements with a thickness of less than six inches at any point. In general, pavements should be thicker at the center than at the sides. Alleys with an inverted crown, and narrow one-slope roads, should have a uniform thickness. Wherever the thickness can be increased without excessive cost, to secure a flat subgrade, or one nearly flat, such increase is advisable.
>
> The desirable width for single-track roads is 10 feet. The desirable width of double-track roads is 18 feet. The total width of the roadway should not be less than 20 feet for single-track roads and not less than 26 feet for double-track roads.
>
> The crown of roads and pavements should be not less than one one-hundredth nor more than one-fiftieth of the total width. Except in unusual cases, one one-hundredth will be sufficient for country roads and one-fiftieth will be considered satisfactory for alley pavenents. For city streets an average crown of one-seventy-fifth will generally be found sufficient and should not be reduced, except on grades.

Single-track concrete roads are occasionally built on the right-hand side of the roadway going in the direction of the heavy traffic. This gives the loaded wagons the better surface. The templet used in determining the section of the road is the same as for a double-track road but only one-half the road is concreted. In Huron and Medina Counties, single-track roads have been built as one-slope roads instead of half the section of double-track roads, and this construction is preferred by some engineers.

In Wayne County, Michigan, it has been decided to make concrete roads 18 feet wide wherever possible, and never less than 16 feet. Near Detroit the width will be 20 feet. While this increase in width from 10, 12, 15, and 16 feet will add materially to the first cost, it is expected to prove economical in the long run, because the expense of maintaining heavy broken stone or gravel shoulders will be avoided. This maintenance is a large sum on comparatively narrow roads with heavy traffic.

There is a decided difference of opinion regarding shoulders for concrete roads. Some engineers hold that the natural soil should be used, and where satisfactory shoulders cannot be made of it the width of the concrete should be increased. Other engineers recommend gravel or broken stone shoulders after experience with them. The difference of opinion is probably due to differences in the quality of the earth which must be used for earth shoulders and to differences in the character of the traffic, upon which the opinions are based. There is no question, however, that if traffic makes frequent use of shoulders of clay or clayey loam, they are speedily ruined, and if heavy traffic makes frequent use of macadam shoulders, the junction between the concrete and broken stone becomes a long rut. In either case the proper maintenance of the shoulders will be expensive. If two macadam or gravel shoulders wider than 4 feet are considered necessary, it is advisable in every case to consider the alternative of an increased width of concrete. The construction of gravel and macadam shoulders should be postponed, if practicable, until a month after the concrete road has been finished, and they should be left slightly higher than the concrete to facilitate turning out on them.

In cuts, where the grades are over 5 per cent, it is usually necessary to pave the ditches and to use gravel or macadam shoulders. The maintenance of these ditches and shoulders is expensive, and it is possible that money will be saved in the end, even on single-track roads, by increasing the width of the concrete and adding a concrete ditch and curb at each side. The ordinary construction will call for a 10-foot concrete road, 8 feet of shoulders and 8 feet of ditches, a total of 26 feet width of cut at the bottom of the excavation. For this can be substituted a concrete roadway 16 feet wide with two integral curbs bringing the total width to 17 feet 8 inches. The curb acts as an abutment for the toe of the slope.

On fills over 5 or 6 feet high, where turning out on a soft shoulder may cause a serious accident, it is desirable to widen a single-track pavement to 16 feet unless the top of the fill is so wide that an overturned car will not roll down the slope. In any such case, the safety of the public requires a more careful study of the dangers on embankments than was given to the subject before automobiles became numerous. Attention is called to the record of deaths and injuries on page 25.

Materials

Cement is bought for most road work under the standard specifications of the American Society for Testing Materials, which were revised in 1916. They are printed in the next chapter.

The following statements regarding fine and coarse aggregate were adopted by the 1916 conference:

The selection of proper aggregates for concrete road construction is of utmost importance. Clean, hard, well-graded materials are absolutely essential to success. For this reason samples of the materials proposed for use should be submitted to the engineer for approval before orders are placed. These samples should be carefully inspected; and if possible laboratory tests made to determine their suitability. If laboratory tests on shipments cannot be made, field tests can be used to furnish a general indication of quality.

The different aggregates should be kept clean and separate.

Aggregates to be used in the wearing course of two-course pavements should never be placed on the subgrade but on planks or some other means provided to keep them free from dirt. When aggregates are placed directly on the subgrade care should be used by the shovelers to avoid getting clay or earth shoveled from the subgrade into the mix. Aggregates should not only be clean when they are delivered on the job, but clean when placed in the mixer.

Investigations to determine the usefulness of the rattler test to show the value of different concrete mixtures for road work indicate that it may prove of value. For the present, however, the older practice of relying on tests of the stone is being followed wherever any testing is done. Generally the best clean, hard and tough crushed rock or gravel is used, provided it will give a concrete harder than the mortar used with it. It is desirable to use stone having a French coefficient of wear of at least 8.

Experience indicates that cracks occur more often in gravel concrete than in stone concrete. Probably this is largely due to the very fine material on the surface of most gravel pebbles, which must be washed off carefully to make the material fit for road work.

Fine aggregate, or "sand," is generally required to pass a $\frac{1}{4}$-inch screen. Not more than 25 per cent must pass a 50-mesh sieve and not more than 5 per cent a 100-mesh sieve. It must contain no vegetable or other deleterious matter and not over 3 per cent by weight of clay or loam. The sand should be tested frequently in the field by shaking a sample with water in a graduated glass and allowing it to settle for an hour. If there is more than about 5 per cent of very fine material showing on the top of the sand, samples should be sent to the laboratory. Natural sand or screenings from hard, tough, durable rock may be used. Natural sand sometimes contains vegetable acids which reduce its value for good concrete. Their presence is determined by making similar briquettes of the natural sand and of standard Ottawa sand, and no natural sand should be used in road work which does not give a strength at least equal to that obtained with Ottawa sand. The best sand is that in which the coarse particles predominate. Improvements can sometimes be made by mixing two natural sands or a fine sand and screenings.

The standard specifications for coarse aggregate, or "stone" call for material passing a 2-inch round opening, with not more than 5 per cent passing a screen having four meshes per inch and without any intermediate sizes removed.

The water used in making the concrete must be free from oil, acid, alkali or vegetable matter.

Proportions

The 1916 conference adopted the following statements of the principles governing the proportions of the materials:

The method of measuring materials for the concrete, including water, should be one which will insure accurate proportions of each of the ingredients at all times. It is recommended that a sack of Portland cement, containing 94 pounds net, be considered the equivalent to 1 cubic foot.

The proportions should not exceed 5 parts of fine and coarse aggregate measured separately to 1 part of Portland cement, and the fine aggregate should not exceed 40 per cent of the mixture of fine and coarse aggregates.

The standard specifications for one-course country roads call for one sack of cement to not more than 2 cubic feet of fine aggregate and not more than 3 cubic feet of coarse aggregate, with the volume of fine aggregate never less than half that of the coarse aggregate. A cubic yard of the mixed concrete must contain at least 1.7 barrels of cement. The amount of water used must be enough to produce concrete holding its shape when struck with a template. Concrete which has partly hardened must never be used.

The standard specifications for two-course pavements call for a base mixed in the proportions of 1 sack of cement to not more than 2½ cubic feet of fine aggregate and not more than 4 cubic feet of coarse aggregate, with at least half as much fine as coarse aggregate. Two grades of top aggregate are specified for the top course; No. 1 must pass a ½-inch screen and have not over 10 per cent passing a ¼-inch screen, and No. 2 must pass a 1-inch screen and have not over 5 per cent passing a ¼-inch screen. Two mixtures are specified for the top course. Mixture 1 consists of one sack of cement to not more than 1 cubic foot of fine aggregate and not more than 1½-cubic feet of No. 1 top aggregate. Mixture 2 consists of one sack of cement to not more than 1½ cubic feet of fine aggregate and not more than 2½ cubic feet of No. 2 top aggregate. The volume of fine aggregate must equal half the volume of top aggregate in either mixture.

The quantities of cement, sand and gravel required to build a mile of road of different widths and thicknesses are given in the accompanying tables, supplied by the Portland Cement Association. They are based on the assumption that a barrel of cement is equivalent to 4 cubic feet and the voids in the stone are 45 per cent. Variations from the tabulated quantities may amount to 10 per cent either way.

The proportions of cement, sand and stone should be such that the concrete will have the properties desired for a road. Where good stone is expensive but softer stone is cheaper, a two-course pavement utilizing the poor stone in the base and the hard stone in the top may prove more economical than a thinner one-

Quantities of Cement, Sand and Stone Required for One Mile of Single-Course Concrete Road of Different Widths and Thicknesses

(*Furnished by the Portland Cement Association*)

WIDTH	THICKNESS		AREA CROSS SECTION	SUPERFICIAL AREA	VOLUME CONCRETE	MIX; 1: 2: 4			MIX; 1: 2: 3			MIX; 1: 1½: 3		
	Side	Center				Cement	Sand	Stone	Cement	Sand	Stone	Cement	Sand	Stone
ft.	*ins.*	*ins.*	*sq. yds.*	*sq. yds.*	*cu. yds.*	*bbls.*	*cu. yds.*	*cu. yds.*	*bbls.*	*cu. yds.*	*cu. yds.*	*bbls.*	*cu. yds.*	*cu. yds.*
10	5	6¼	0.540	5,867	951	1436	428	856	1654	494	732	1818	405	809
10	6	7¼	0.633	5,867	1113	1680	496	991	1938	578	856	2124	473	946
12	5	6½	0.667	7,040	1173	1771	521	1043	2040	610	903	2240	498	997
12	6	7½	0.778	7,040	1369	2067	608	1218	2382	710	1054	2614	582	1164
14	5	6¾	0.799	8,213	1407	2125	625	1250	2448	732	1084	2685	597	1195
14	5	7	0.821	8,213	1445	2182	650	1298	2514	751	1113	2760	607	1228
14	6	7¾	0.929	8,213	1635	2469	728	1455	2845	850	1259	3121	695	1390
14	6	8	0.951	8,213	1673	2526	753	1504	2911	870	1288	3195	703	1422
16	5	7	0.938	9,387	1651	2493	735	1469	2873	859	1271	3153	702	1403
16	6	8	1.086	9,387	1912	2887	851	1702	3327	994	1472	3652	813	1625
18	5	7¼	1.083	10,560	1907	2880	849	1697	3318	992	1468	3642	810	1621
18	6	8¼	1.250	10,560	2200	3322	979	1958	3828	1144	1694	4202	935	1870
20	5	7½	1.235	11,733	2173	3281	967	1934	3781	1130	1673	4150	924	1847
20	6	8½	1.420	11,733	2499	3773	1112	2224	4348	1300	1924	4773	1062	2124
22	5	5	1.019	12,907	1794	2709	798	1597	3122	933	1381	3426	762	1525
22	6	6	1.222	12,907	2151	3248	957	1914	3743	1119	1656	4108	914	1828
24	5	5	1.111	14,080	1955	2952	870	1740	3402	1017	1505	3734	831	1662
24	6	6	1.333	14,080	2346	3543	1044	2088	4082	1220	1806	4482	997	1994
30	5	5	1.389	17,600	2444	3690	1087	2175	4253	1271	1882	4670	1038	2077
30	6	6	1.667	17,600	2934	4430	1305	2611	5105	1526	2259	5603	1247	2494

course pavement of the harder stone. In any case the amount of mortar used should be about 10 per cent in excess of the voids in the stone. There is so much variation in the grading of sand and stone that a 1 : 2 : 4 mixture in one place may be equal to a 1 : 2 : 3 mixture in another. As the work progresses, the quality of the concrete must be watched carefully, and the proportions shifted so that the greatest density will be obtained. Attention to this feature of the work is considered very important by experienced concrete road builders.

Quantities of Cement, Sand and Stone in One Mile of Two-Course Concrete Road of Different Widths and Thicknesses

(Furnished by the Portland Cement Association)

WIDTH	BASE Thickness		VOLUME CONCRETE	BASE MIX; 1: 2½: 4			BASE MIX; 1: 2: 4			TOP Thickness		VOLUME CONCRETE	TOP MIX; 1½: 2½			TOP MIX; 1: 1: 1½		
	Side	Center		Cement	Sand	Stone	Cement	Sand	Stone	Side	Center		Cement	Sand	Stone	Cement	Sand	Stone
ft.	*ins.*	*ins.*	*cu. yds.*	*bbls.*	*cu. yds.*	*cu. yds.*	*bbls.*	*cu. yds.*	*cu. yds.*	*ins.*	*ins.*	*cu. yds.*	*bbls.*	*cu. yds.*	*cu. yds.*	*bbls.*	*cu. yds.*	*cu. yds.*
30	5	5	2445	3399	1247	2005	3692	1100	2176	2	2	977	2043	454	756	2902	429	644
10	4	5¼	787	1094	401	645	1188	354	700	2	2	326	682	152	253	968	143	215
10	5	6¼	951	1322	485	780	1436	428	846	2	2	326	682	152	253	968	143	215
12	4	5½	977	1358	498	801	1475	440	870	2	2	391	819	182	303	1161	172	258
12	5	6½	1173	1630	598	962	1771	528	1044	2	2	391	819	182	303	1161	172	258
14	4	5¾	1177	1636	600	965	1777	530	1048	2	2	456	955	212	354	1355	200	303
14	5	6¾	1407	1956	718	1154	2125	633	1254	2	2	456	955	212	354	1355	200	303
14	4	6	1216	1690	620	997	1836	547	1082	2	2	456	955	212	354	1355	200	303
14	5	7	1445	2009	737	1185	2182	650	1286	2	2	456	955	212	354	1355	200	303
16	4	6	1392	1935	710	1141	2102	626	1239	2	2	523	1091	243	404	1546	228	346
16	5	7	1651	2295	842	1354	2493	743	1469	2	2	523	1091	243	404	1546	228	346
18	4	6¼	1612	2241	822	1322	2434	725	1435	2	2	586	1226	272	454	1739	257	390
18	5	7¼	1906	2649	972	1563	2878	858	1696	2	2	586	1226	272	454	1739	257	390
20	4	6½	1846	2566	941	1514	2787	831	1643	2	2	651	1362	302	504	1935	286	429
20	5	7½	2174	3022	1109	1783	3283	978	1935	2	2	651	1362	302	504	1935	286	429
20	4	4	1304	1813	665	1069	1969	587	1161	2	2	651	1362	302	504	1935	286	429
20	5	5	1630	2266	831	1337	2461	734	1451	2	2	651	1362	302	504	1935	286	429
22	4	4	1434	1993	731	1176	2165	645	1276	2	2	716	1498	333	555	2128	315	472
22	5	5	1793	2492	914	1470	2707	807	1596	2	2	716	1498	333	555	2128	315	472
24	4	4	1563	2173	797	1282	2360	703	1391	2	2	781	1634	363	605	2322	343	515
24	5	5	1955	2717	997	1603	2952	880	1740	2	2	781	1634	363	605	2322	343	515
30	4	4	1955	2717	997	1603	2952	880	1740	2	2	977	2043	454	756	2902	429	644

Mixing

The principles that should govern mixing were stated as follows by the 1916 conference:

The ingredients should be mixed in a batch mixer. The mixing should be continued for at least one minute after all the materials are in the mixer and before any of the concrete is discharged. The speed of the mixer should not exceed 16 revolutions per minute; however, the time and not the number of revolutions should be the gage of proper mixing.

The practice is to mix concrete entirely too wet. The consistency should be such as not to require tamping, but not so wet as to cause the separation of the mortar from the aggregate in handling and placing. The strength and wearing qualities of the concrete are vitally lessened by an excess of water in mixing.

The reason for fixing one minute as the minimum time for mixing is that tests have shown that water is not worked through the mass as it should be in less than a minute. A smaller quantity of water can be used with long-time mixing than with short-time mixing and the same degree of fluidity obtained. On account of the desirability of keeping the amount of water as close as possible to 1 gallon per cubic yard of concrete, at least one minute mixing time is desirable. If a large quantity of water is used and the mixing time is less than a minute, the product may appear uniform to the eye when it actually is not well mixed.

The reason for restricting the speed of the mixer to 16 revolutions per minute is that at a higher speed some of the material sticks to the drum and there is considerable splashing as the concrete is discharged. At least 10 revolutions are necessary to mix the aggregate.

Placing

The principles governing placing were stated as follows by the 1916 conference:

> If the subgrade has been disturbed by teaming or other causes, it should be brought to its former surface, and thoroughly moistened with water. The concrete should be deposited rapidly to the required depth and width. The section should be completed to a transverse joint, with the use of intermediate forms or bulkheads, or a transverse joint may be placed at the point of stopping the work. In case the mixer breaks down the concrete should be mixed by hand to complete the section. Where reinforcement is used it should be embedded in the concrete before the concrete has begun to harden; the concrete above the reinforcement should be placed within 20 minutes after the placing of the concrete below.
>
> In two-course pavements the top should be placed within twenty minutes after the placing of the bottom.

The standard specifications allow forty-five minutes as the maximum time between the laying of the bottom course and the placing of the top course.

Practically all concrete roads are built with special paving mixers which discharge the concrete on the road where it is to be used by means of chutes or buckets hauled along a boom that can be swung from one side of the road to the other. The pitch of the chute should be steep enough to deliver concrete of a proper consistency readily. In the attempt to cover considerable area, contractors sometimes set the chute at a flat angle and use too much water, in order to make the concrete flow readily. Tests have shown that the least angle of the chute should be 20 degrees. If the chute is new or rusted, concrete with a proper amount of water will flow rather slowly down a 20 degree slope until the metal surface has been smoothed by the wet mass. For this reason the chute may need a steeper slope at the outset than later.

Forms

The 1916 conference adopted the following statement of the principles that should govern the use of forms to retain the concrete at the sides of the roadway:

Metal forms of sufficient strength to withstand the necessary hard usage are preferred. When wooden forms are used they should be of at least 2-inch stock and capped with a 2-inch angle iron, so constructed that adjacent sections can be lapped. Forms should have a width not less than the thickness of the pavement at the sides. Particular care should be exercised to see that the top edges of forms are clean so as to avoid unevenness in the finished pavement. If forms are warped or stakes not properly placed, a poor alignment of the edge of the concrete slab will result.

They must be set firmly and the topes must be true to grade, because they support the templets, bridges and other appliances used in finishing the surface. The steel angles on wood forms are necessary to enable the finishing work to proceed in a satisfactory manner. By having the angles project 3 or 4 inches beyond the end of the wood at one end and set back the same distance at the other, the alignment of the forms will be facilitated. Painting wood forms will prevent warping and add to their life. Where a power-driven striking and finishing machine is used, specially heavy forms securely held in place are needed.

Joints

While transverse joints are omitted on some work, they are generally required because of the prevailing opinion that they reduce the cracking of the concrete. They are constructed by placing across the road a strip of prepared filler made for the purpose. This filler is usually held in place by a steel templet until the concrete is deposited against it. The templet is then removed and the concrete settles against the filler. The joints are of two types, with and without metal protection plates. The following statements regarding them were adopted at the 1916 conference:

Transverse joints should be placed across the pavement perpendicular to the center line about 50 feet apart. There seems to be a tendency to lengthen the distance between joints. Joints should extend entirely through the pavement, as well as through the curb if integral curbs are used. Joints should be constructed perpendicularly to the surface of the pavement to avoid the possibility of one slab rising above the other.

The tendency of present practice is toward the omission of metal protection plates for joints. It is possible that the value of metal protection plates is dependent somewhat on the character of the aggregate used, and it is considered that they are more essential in street pavements than in country highways.

The standard specifications call for $\frac{1}{4}$-inch transverse joints at intervals of not more than 36 feet. The filler must project at least $\frac{1}{8}$-inch above the concrete during construction, and after the completion of the pavement it is trimmed off $\frac{1}{4}$-inch above the surface. The traffic flattens out the projecting material and hardens the top of the joints. Experience shows that it is very desirable to have the joints form a plane surface perpendicular to the surface of the road.

Measurements of the expansion and contraction of concrete roadway slabs have been made by R. J. Wig, C. S. Laubly and W. A. McIntyre, from which they drew the following conclusions: Contraction and expansion are caused by both temperature changes and changes in moisture conditions, and under climatic conditions similar to those at Washington, D. C., the effects from these two factors in concrete road surfaces are approximately of the same magnitude. In concrete roads, expansion and contraction are sufficient to cause frequent transverse cracks unless joints are provided. The actual movement in any particular case depends upon the character of the concrete and of the subgrade. A sloppy concrete shows greater movement than a concrete mixed only moderately wet.

Organization of the Work

In order for the work to proceed economically, it is necessary for the mixer to be kept running most of the time. This can only be accomplished if repair parts are kept on hand and materials are supplied as needed. If the materials are delivered by rail it often pays to keep men at the sand and stone plants to see that the railroads furnish cars as needed and the shipments are made on time. If the contractor operates his quarry he must see that precautions are taken to reduce delays due to breakdowns or other causes to a minimum. The delivery of materials along the road calls for careful planning of both plant and organization. In any case, provision should be made against delays due to insufficient materials by storing supplies of cement, sand and stone on the work. The cement can be stored in a shed at the railroad siding or in tents with raised wood floors along the road. The sand can also be stored along the road. The stone is best stored at the railroad siding, because it is costly to rehandle and by doing the work at one place mechanical appliances can be used which will reduce the expense materially. The organization should be arranged to avoid all unnecessary handling of materials, not only because this involves a labor charge but also because transportation equipment is doing no useful work while being loaded or unloaded. Tractors with trailers, motor trucks and industrial railways are generally used for hauling, and by having competent repairmen to keep them in order and running them with two shifts so as to use them about eighteen hours a day, very low unit costs are often obtained in comparison with the expense of hauling by horses or mules.

The water supply must be planned to wet the subgrade, supply the mixer and keep the concrete wet for a number of days after it is laid. While it has been delivered along the road in tanks, it is usually pumped through a pipe, generally 2 inches in diameter. As the water which must be used sometimes contains sand which will score the cylinders or plungers of a high pressure pump so as to put it out of service, it is often lifted by a centrifugal pump in such cases into a storage tank where the sand has an opportunity to settle before the water is drawn by the high-pressure pump. If the tank has two chambers separated by a partition running nearly up to the water level, the separation of the sand will be improved, for the stream water can be delivered into one chamber where most of the sedimentation will occur and be drawn from the other. There should be a relief valve in the pipe line near the pressure pump so as to prevent breaking the pipe if all the gates on it are closed. If no valve is used the pump should be belt driven, so that in case the pressure rises the belt will slip. The friction head in a 2-inch pipe when discharging 50 gallons per minute is about 85 feet per 1000 feet of its length, and when discharging 60 gallons per minute the friction head is about 115 feet. Consequently the pump must have power to overcome a considerable pressure due to friction as well as that due to the highest elevation to which the water must be raised.

The size of the paving gang will depend upon the size of the mixer, which should depend in turn upon the rate at which materials can be delivered to it. There are two[1] sizes of mixers, one in which two sacks of cement are used in each batch of concrete and the other taking a three-sack batch. The smaller machine requires about two men handling cement, two shovelers and two wheelers for sand, three shovelers and three wheelers for stone, a helper at the mixer and a man to bundle the cement sacks. The larger machine requires about two men to handle cement, three shovelers and three helpers for sand, four shovelers and four wheelers for stone, a helper at the mixer and a man to bundle sacks. In addition the crew requires a foreman, a mixer operator, a fireman, two men setting forms, a pump tender, three or four men spreading and floating the concrete, two finishers, and one or two attending to the curing of the concrete. To keep

[1] During 1916, four-sack mixers were used on several roads, so it is probable that there will be three sizes of mixers in regular use soon.

such a gang working efficiently in the comparatively small area occupied by a concreting job it is necessary to have the materials deposited so they can be handled expeditiously and without confusion.

Finishing

The principles which should govern the finishing of concrete were stated as follows by the conference:

> The surface of the concrete should be struck off by means of a templet moved with a combined longitudinal and transverse motion. The excess material accumulated in front of the templet should be uniformly distributed over the surface of the pavement except near the transverse joint, where the excess material should be removed.
>
> The concrete adjoining the transverse joint should be dense and any depressions in the surface should be filled with concrete of the same composition as the body of the work. After being brought to the established grade with a templet, the concrete should be finished, from a suitable bridge, with a wood float to true surface. A metal float should not be used.[1]
>
> Brooming of the surface is not necessary and grooves are objectionable even on grades.

For country roads the templet or strikeboard is often made of two 2 by 10-inch planks 1 foot longer than the road is wide. The lower edge is cut to the desired crown of the road and shod with a strip of $\frac{1}{4}$ by 4-inch steel fastened with countersunk screws. It has a handle on each side at each end, so it can be moved along easily with a kind of sawing motion. This motion fills all depressions with concrete and has no tendency to drag out the large stone. A slight excess o :concrete is always kept ahead of the strikeboard, and a workman often walks in front of the board to spread the concrete and take care of any excess that may accumulate in front of it. It is usually necessary to run the strikeboard over the surface three times; with very angular stone it may be necessary to go over it four times.

Finishing is now regarded as very important. At Sioux City, Iowa, where the concrete streets are unusually free from cracks, the success with this type of roads is attributed to the special care spent in the finishing. A wood float is preferred to a steel trowel for finishing because it is believed to make a more dense surface which is not slippery. The bridge from which the men work is a 2 x 12-inch plank, trussed to prevent deflection and supported by the side forms. No finishing should be done while there is free water on the surface. For finishing at unprotected joints a float split lengthwise, so as to fit over the joint filler, is used.

[1] Owing to the rapid development of belt finishing it is probable that finishing by wood floats will not be considered essential by many engineers after this year.

Power finishing machines are now used to some extent as a substitute for hand finishing. They operate by rapidly increasing and decreasing the weight on the area of concrete on which they rest. These vibrations of load joggle the concrete, increasing its density and leaving a satisfactory finish when the concrete has a suitable consistency and the work is conducted carefully.

During 1915 and 1916, an increasing use has been made of belt finishing. The work is done with canvas belts from 12 to 24 inches wide. In Wayne County, Michigan, where the method has been used for the longest time, a 12-inch belt about 1 foot longer than the width of the road, is preferred. It has a handle at each end and is pulled gently back and forth across the surface after the latter has been shaped by the strikeboard. After the surface is finished in this way, it is gone over a second time with another belt, and sometimes a third time with a third belt. The belts are washed at the close of each day.

When belts are used for finishing it is desirable to shape the concrete with a strikeboard having a face about 8 inches wide and long handles like those of a plow at each end. With such a strikeboard the men can tamp as well as shape the concrete, and thus leave the surface in better condition for the belt than is the case with a thin strikeboard.

Curing

The protection and curing of the concrete must be carried on carefully because the best concrete may be seriously damaged by too rapid drying out of the surface in hot or windy weather, by exposure to low temperature or by being opened to traffic too soon. The principles which should govern the work were stated as follows by the 1916 conference:

> Even the best concrete may be seriously damaged by too rapid drying out, early exposure to low temperature, or by being opened to traffic at too early a period. Hot sun and drying winds are most liable to dry out the concrete too rapidly, thus causing shrinkage cracks or causing a surface which will not wear well under traffic. The use of a canvas covering will be found effective in overcoming this condition.
>
> Sprinkling should also be employed as soon as the concrete is hard enough to prevent the surface being pitted. An earth covering or protection by ponding should be employed after the first day. Under most favorable conditions such protection should be given the pavement for at least two weeks. Water should be added during this period to keep the concrete wet.
>
> In cool weather it is often advisable to omit the earth covering, thus allowing the concrete to harden more rapidly. Sprinkling should not be omitted during the day in case the surface shows a tendency to dry out. When there is danger of frost, sprinkling should be omitted and a covering of canvas or straw and canvas used.

Placing concrete in roads and pavements in temperatures at or near freezing is not advisable, and if in special cases, such work is unavoidable, the water and aggregate should be heated and precautions taken to protect the concrete from freezing for at least ten days.

Chemicals to lower the freezing temperature of the mixture should not be used. Concrete should not be deposited on a frozen subgrade.

The canvas provided for protection during hot and windy weather, should be sufficient to cover at least half the surface laid during a day. Strips 2 yards wide are used and they are about a yard longer than the width of the pavement so that each end can be weighted. They are supported on frames so as not to touch the concrete, and are kept in place until the concrete has hardened.

The curing of concrete by ponding is not only more economical in many cases than the use of wet earth but it has a greater advantage in permitting the inspector to determine at a glance if the curing is proceeding properly. It is difficult to make certain that an earth covering is kept properly wet, but there can be no question whether water is standing on the concrete. Banks of earth are constructed along each edge of the pavement and transverse banks at each expansion joint and more frequently where the grades make them necessary. The water is kept at least 2 inches deep over the center of the road.

If there is danger of a heavy storm which will pit the surface of fresh concrete it must be protected by canvas. Contractors are advised to request the nearest forecasting station of the United States Weather Bureau to send its daily bulletin of the probable weather conditions during the next thirty-six hours.

The standard specifications require both water and aggregates to be heated if the temperature drops to 35 degrees or is likely to do so within twenty-four hours, and the concrete laid under these conditions must be specially protected from freezing for at least ten days. A canvas cover will be sufficient to protect the concrete against frost during the first night and after that about 3 inches of straw or marsh hay held down securely will probably serve. If a sharp lowering of the temperature is anticipated the straw should be covered with canvas. It is cheaper to take all necessary precautions than to tear out and replace damaged concrete. Even a light freezing of the top will make the surface scale.

Maintenance

The following explanation of methods of maintenance was prepared by A. H. Hinkle, L. C. Herrick, John W. Mueller and Maurice Hoeffken for the 1916 conference:

Joints and cracks can be successfully treated by thoroughly cleaning them and filling when dry, and preferably during warm weather, with hot tar, then covering with dry sand or screenings. The tar should be permitted to lap over the spalled edges of the crack, but not to exceed 1 inch. The most desirable covering is clean, coarse sand or cleans creenings of stone, slag or gravel, that will pass a $\frac{1}{2}$-inch circular opening, and be retained on a $\frac{3}{16}$-inch mesh screen. The tar should be poured when hot enough to run readily into the crevices of the pavement (about 200° to 250° F.). It is believed that no large excess of the tar should be used as the frequent use of such an excess might eventually build up an elevation on the surface which would be objectionable to traffic. The covering of screenings or sand should be put on immediately after pouring the tar so that while in the liquid state it will unite with the screenings or sand in sufficient degree to prevent the tar from sticking to wheels of vehicles or melting during hot periods and running from the cracks.

The use of a mastic consisting of a mixture of hot tar and sand, in place of pure tar, for filling the cracks and joints, gives promise of excellent results; but perhaps it is too soon to give definite specifications for this mixture. The filling of the larger and more open cracks or joints with the mastic, and the use of the pure tar for filling the minor openings in the pavement and such as are made necessary by settlement after the joints have been originally filled with the mastic, may be found to be most satisfactory.

A pouring can with a round or vertical spout is very satisfactory for pouring tar in filling cracks and joints. Inasmuch as it is desired that the tar shall lap over the edges of the crack or joint, the use of a conical pouring can would be of doubtful economy.

Small holes and shallow depressions can be successfully treated as follows: Clean surface thoroughly. Where the surface is disintegrated it should first be thoroughly swept with a steel broom in order to remove all loose spalls or foreign matter; afterward, the dust must be removed by sweeping with a rattan or house broom. The hot tar is then applied to the dry concrete and rubbed well with a squeegee or stiff broom to secure a good bond to the surface of the concrete. The tar is then covered with coarse sand or screenings ($\frac{1}{2}$ to $\frac{3}{16}$ inch) of stone, slag or gravel. The amount of tar used will vary from $\frac{1}{2}$ to 1 gallon per square yard, depending upon the depth of the depression to be filled. When more than $\frac{1}{2}$ gallon per square yard is used, it should be applied in two coats and the excess screenings swept off before the second coat is applied. The more tar that is applied to the surface, the more desirable it is to have the coarser material for a covering. In filling small holes the application of the tar in two layers would, of course be unnecessary.

To repair larger holes and deeper depressions than those discussed above: Thoroughly clean and paint the surface with tar. Fill the hole or depression with broken stone, preferably of such size that they will not exceed in diameter one-half the depth of the depression to be filled nor exceed in size stone suitable for an ordinary tar macadam. The stone should be levelled off and compacted as well as may be by tamping or rolling so as to conform to the true surface of the road. The voids are then filled with the hot tar and screenings applied to the surface, which is again compacted and treated as in building a tar macadam.

The use of a cold mix consisting of clean, hard stone chips coated with a coal tar cutback, for filling such holes and depressions, as described under the above paragraph, has been followed to some extent with very promising results. The stone chips are first thoroughly coated with the cold tar preparation by turning with shovels after the tar has been sprayed upon them, as in mixing ordinary cement concrete. The mixture is then permitted to stand a few days until the lighter oils vaporize from the tar, which leaves the stone coated with the heavy tar. The coated chips are then well tamped into the hole or depression to be filled, the shallower depressions being first painted with the pure tar. Coarse sand or fine screenings are then spread over the surface. If the voids appear quite open after the coated chips have been thoroughly tamped, a light application of the tar is made to seal up the voids before the surface screenings are applied.

Where the pavement is disintegrated badly or broken clear through so as to require rebuilding, it should be cut away with vertical edges. After the subgrade is levelled and compacted and the edges and subgrade thoroughly dampened (but the foundation not made muddy), the part cut away is replaced with new concrete conforming in quality as nearly as possible to the concrete of the surrounding pavement. It is well to coat the edges of the old concrete with cement grout. Care should be taken that the surface of the new concrete conforms to the surface of the adjacent concrete. The new concrete should be kept well dampened for about seven days, and protected from traffic (ten days in warm weather and much longer in cold weather) until thoroughly hardened. If the replacement is over an excavation the concrete should be properly reinforced.

STANDARD SPECIFICATIONS FOR PORTLAND CEMENT[1]

1. Portland cement is the product obtained by finely pulverizing clinker produced by calcining to incipient fusion, an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

2. *Chemical Properties.*—The following limits shall not be exceeded:

Loss on ignition, per cent	4.00
Insoluble residue, per cent	0.85
Sulfuric anhydride (SO_3), per cent	2.00
Magnesia (MgO), per cent	5.00

3. *Physical Tests.*—The specific gravity of cement shall be not less than 3.10 (3.07 for white Portland cement). Should the test of cement as received fall below this requirement a second test may be made upon an ignited sample. The specific gravity test will not be made unless specifically ordered.

4. The residue on a standard No. 200 sieve shall not exceed 22 per cent by weight.

5. A pat of neat cement shall remain firm and hard, and show no signs of distortion, cracking, checking, or disintegration in the steam test for soundness.

6. The cement shall not develop initial set in less than forty-five minutes when the Vicat needle is used or sixty minutes when the Gillmore needle is used. Final set shall be attained within ten hours.

7. The average tensile strength in pounds per square inch of not less than three standard mortar briquettes composed of one part cement and three parts standard sand, by weight, shall be equal to or higher than the following:

[1] Adopted by the American Society for Testing Materials in 1904 and revised in 1908, 1909 and 1916. These specifications are the result of several years' work of a special committee representing a United States Government Departmental Committee, the Board of Direction of the American Society of Civil Engineers and Committee C-1 on Cement of the American Society for Testing Materials, in cooperation with Committee C-1. The specifications as here printed are but the first part of the Society's "Standard Specifications and Tests for Portland Cement," as officially published.

AGE AT TEST	STORAGE OF BRIQUETTES	TENSILE STRENGTH
days		*lb. per sq.in.*
7	1 day in moist air, 6 days in water..................	200
28	1 day in moist air, 27 days in water.................	300

8. The average tensile strength of standard mortar at twenty-eight days shall be higher than the strength at seven days.

9. *Packages, Marking and Storage.*—The cement shall be delivered in suitable bags or barrels with the brand and name of the manufacturer plainly marked thereon, unless shipped in bulk. A bag shall contain 94 pounds net. A barrel shall contain 376 pounds net.

10. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building which will protect the cement from dampness.

11. *Inspection.*—Every facility shall be provided the purchaser for careful sampling and inspection at either the mill or at the site of the work, as may be specified by the purchaser. At least ten days from the time of sampling shall be allowed for the completion of the 7-day test, and at least 31 days shall be allowed for the completion of the 28-day test. The cement shall be tested in accordance with the methods hereinafter prescribed. The 28-day test shall be waived only when specifically ordered.

12. *Rejection.*—The cement may be rejected if it fails to meet any of the requirements of these specifications.

13. Cement shall not be rejected on account of failure to meet the fineness requirement if upon retest after drying at 100°C. for one hour it meets this requirement.

14. Cement failing to meet the test for soundness in steam may be accepted if it passes a retest using a new sample at any time within 28 days thereafter.

15. Packages varying more than 5 per cent from the specified weight may be rejected; and if the average weight of packages in any shipment, as shown by weighing 50 packages taken at random, is less than that specified, the entire shipment may be rejected.

PETROLEUM AND RESIDUUMS[1]

A large part of the materials used as dust preventives and binders to hold together the mineral constituents of roads are obtained from petroleum. Petroleum is a term which covers mineral oils of a great variety of characteristics, all alike in being composed of a great variety of complex chemical compounds called hydrocarbons, of which there is a very large number. The investigation of the properties of these hydrocarbons and their derivatives requires a knowledge of organic chemistry which few roadbuilders possess, and because some of them have attempted to tread the veritable mazes of this extremely complicated domain of chemistry, no little confusion has arisen. The main facts regarding petroleum and the other hydrocarbons used in roadbuilding are definitely known, but the details of any group of these compounds are best left for the chemical specialist, who is making steady progress in his researches concerning them.

Paraffin and Asphaltic Oils

The roadbuilder's interest in petroleum is largely in its base, a term used to designate a part of oil left after distilling off the more volatile portions. The base is sometimes made up of compounds of the paraffin group or series, as chemists term such allied compounds. Marsh gas is a member of the paraffin series, and its least complex representative. A few other members are gases but most of them are liquids or solids, and their number is legion. The base of other petroleums is made up of compounds called polycyclic polymethylenes by the chemist, and as these compounds occur in native asphalts such a base is called asphaltic. The base of other petroleums is made up of both paraffin and asphaltic compounds and such petroleums are called semi-asphaltic.

The gaseous hydrocarbons are of no interest to the roadbuilder. The liquid and solid hydrocarbons are what determine the value of petroleum for his purposes. The liquid and solid paraffins are greasy materials without binding properties, while the asphaltic materials are sticky. Consequently the roadbuilding value of petroleum depends upon the asphaltic compounds in its base.

[1] Revised by Prévost Hubbard, chief of road materials tests and research, United States Office of Public Roads.

Paraffin oils have been used successfully as dust preventives when sprinkled in small quantities on a clean road, but if used in large quantities they form a greasy, dirty surface and seem to lubricate the pieces of stone in the road, which becomes rutted rapidly.

Petroleum is obtained from many districts, which are called fields in the industry. The leading fields which supply or have supplied materials for roadbuilding in the United States are discribed substantially as follows by John D. Northrop in *Mineral Resources of the United States, 1915:*

1. The Appalachian field embraces all oil pools east of central Ohio and north of central Alabama, including those of New York, Pennsylvania, West Virginia, southeastern Ohio, Kentucky, Tennessee, and northern Alabama. The oils of the Appalachian field are in the main of paraffin base, free from asphalt and practically free from sulphur, and they yield by ordinary refining methods high percentages of gasoline and illuminating oils—the products in greatest demand.

2. The Lima-Indiana field embraces all areas of oil production in the northwestern part of Ohio and in Indiana. The petroleum of the Lima-Indiana field contains some asphalt, though consisting chiefly of paraffin hydrocarbons with sulphur compounds.

3. The Illinois field lies in the southeastern, south-central and western parts of the State, comprising about 16 counties. Illinois oils contain varying proportions of both asphalt and paraffin and differ considerably as to specific gravity and distillation products. Sulphur is generally present.

For commercial purposes it is customary to group under the title "Mid-Continent field" the areas of oil production in Kansas, Oklahoma, northern and central Texas, and northern Louisiana. Mid-continent oils vary in composition within wide limits, ranging from asphaltic oils poor in gasoline and illuminants, to oils in which the asphalt content is negligible and the paraffin content relatively high and which yield correspondingly high percentages of the lighter products on distillation. Sulphur is present in varying quantities in the lower grade oils.

5. The term "Gulf field" includes that portion of the gulf coastal plain of Texas and Louisiana in which petroleum is found in domes, associated with rock salt and gypsum. Oils from the Gulf field are characterized by relatively high percentages of asphalt and low percentages of the lighter gravity distillation products. Considerable sulphur is present, much of which, however, is in the form of sulphureted hydrogen and is easily removed by steam before refining or utilizing the oil as fuel.

6. The California field is mainly located in Kern, Fresno, Orange, Santa Barbara and Los Angeles Counties. The Cali-

fornia oils are generally characterized by much asphalt and little or no paraffin and by small proportions of sulphur. The chief products are fuel oils, lamp oils, lubricants, and oil asphalt.

Oils from Wyoming and Colorado are in the main of paraffin base, suitable for refining by ordinary methods. Heavy asphaltic oils are also obtained in certain of the Wyoming fields.

7. Mexican field. This extends along the Gulf of Mexico from the vicinity of Tampico to the vicinity of Tuxpan, and produces asphaltic and semi-asphaltic petroleum.

8. Trinidad field. A large amount of asphaltic petroleum is produced on the island of Trinidad.

Clifford Richardson gives the following explanation of the relation between this petroleum and Trinidad asphalt:

Rising from the sands in which it occurs and coming in contact with the colloidal clay forming a portion of the mud existing below the crater or depression which holds the asphalt, it is emulsified with it and converted into the material which we recognize as Trinidad lake asphalt.

Refining Petroleum

Crude asphaltic petroleum has been used as a dust preventive and as a binder, but generally the petroleum is refined to obtain a number of valuable materials occurring in it. The crude oil is first allowed to settle in tanks in which the mineral matter

Petroleum Marketed in the United States in 1915 by Fields
(John D. Northrop, in *Mineral Resources of the United States*, 1915)

FIELD.	QUANTITY (BARRELS OF 42 GALLONS)	VALUE	AVERAGE PRICE PER BARREL
Appalachian	22,860,048	$35,468,973	$1.552
Lima-Indiana	4,269,591	4,114, 228	0.964
Illinois	19,041,695	18,655,850	0.980
Mid-continent	123,295,867	72,437,701	0.588
Gulf	20,577,103	9,802,901	0.476
California	86,591,535	36,558,439	0.422
Colorado and Wyoming	4,454,000	2,400,503	0.539
Other fields	14,265*	24,295*	1.703
	281,104,104	$179,462,890	$0.638

* Includes Alaska, Michigan, and Missouri.

NOTE: The Barber Asphalt Company reports that the importation of crude petroleum from Trinidad has been as follows: 1914, 140,438 barrels; 1915, 330,022 barrels; 1916, 372,000 barrels. The imports of crude petroleum from Mexico are reported by John D. Northrop as follows: 1914, 16,245,975; 1915, 17,478,472 barrels.

A preliminary estimate by J. D. Northrop of the 1916 production in the United States is 292,300,000 barrels.

Degrees Baumé, Specific Gravities, Weights in Pounds per Gallon and Volume in Gallons per Pound of Petroleum at 60°F.

(From "United States Standard Tables for Petroleum Oils," United States Bureau of Standards)

DEGREES BAUMÉ	SPECIFIC GRAVITY	POUNDS PER GALLON	GALLONS PER POUND	DEGREES BAUMÉ	SPECIFIC GRAVITY	POUNDS PER GALLON	GALLONS PER POUND
10.0	1.0000	8.328	0.1201	19.6	0.9358	7.793	0.1283
10.2	0.9986	8.317	0.1202	19.8	0.9346	7.783	0.1285
10.4	0.9972	8.305	0.1204	20.0	0.9333	7.772	0.1287
10.6	0.9957	8.293	0.1206	20.2	0.9321	7.762	0.1288
10.8	0.9943	8.281	0.1208	20.4	0.9309	7.752	0.1290
11.0	0.9929	8.269	0.1209	20.6	0.9296	7.742	0.1292
11.2	0.9915	8.258	0.1211	20.8	0.9284	7.731	0.1293
11.4	0.9901	8.246	0.1213	21.0	0.9272	7.721	0.1295
11.6	0.9887	8.234	0.1214	21.2	0.9259	7.711	0.1297
11.8	0.9873	8.223	0.1216	21.4	0.9247	7.701	0.1299
12.0	0.9859	8.211	0.1218	21.6	0.9235	7.690	0.1300
12.2	0.9845	8.199	0.1220	21.8	0.9223	7.680	0.1302
12.4	0.9831	8.188	0.1221	22.0	0.9211	7.670	0.1304
12.6	0.9818	8.176	0.1223	22.2	0.9198	7.660	0.1305
12.8	0.9804	8.165	0.1225	22.4	0.9186	7.650	0.1307
13.0	0.9790	8.153	0.1227	22.6	0.9174	7.640	0.1309
13.2	0.9777	8.142	0.1228	22.8	0.9162	7.630	0.1311
13.4	0.9763	8.131	0.1230	23.0	0.9150	7.620	0.1313
13.6	0.9749	8.119	0.1232	23.2	0.9138	7.610	0.1314
13.8	0.9736	8.108	0.1233	23.4	0.9126	7.600	0.1316
14.0	0.9722	8.096	0.1235	23.6	0.9115	7.590	0.1318
14.2	0.9709	8.086	0.1237	23.8	0.9103	7.580	0.1319
14.4	0.9695	8.074	0.1239	24.0	0.9091	7.570	0.1321
14.6	0.9682	8.063	0.1240	24.2	0.9079	7.561	0.1323
14.8	0.9669	8.052	0.1242	24.4	0.9067	7.551	0.1324
15.0	0.9655	8.041	0.1244	24.6	0.9056	7.541	0.1326
15.2	0.9642	8.030	0.1245	24.8	0.9044	7.531	0.1328
15.4	0.9629	8.019	0.1247	25.0	0.9032	7.522	0.1330
15.6	0.9615	8.007	0.1249	25.2	0.9021	7.512	0.1331
15.8	0.9602	7.997	0.1250	25.4	0.9009	7.502	0.1333
16.0	0.9589	7.986	0.1252	25.6	0.8997	7.493	0.1335
16.2	0.9576	7.975	0.1254	25.8	0.8986	7.483	0.1336
16.4	0.9563	7.964	0.1256	26.0	0.8974	7.473	0.1338
16.6	0.9550	7.953	0.1257	26.2	0.8963	7.464	0.1340
16.8	0.9537	7.942	0.1259	26.4	0.8951	7.454	0.1342
17.0	0.9524	7.931	0.1261	26.6	0.8940	7.445	0.1343
17.2	0.9511	7.921	0.1262	26.8	0.8929	7.435	0.1345
17.4	0.9498	7.910	0.1264	27.0	0.8917	7.425	0.1347
17.6	0.9485	7.899	0.1266	27.2	0.8906	7.416	0.1348
17.8	0.9472	7.888	0.1268	27.4	0.8895	7.407	0.1350
18.0	0.9459	7.877	0.1270	27.6	0.8883	7.397	0.1352
18.2	0.9447	7.867	0.1271	27.8	0.8872	7.388	0.1354
18.4	0.9434	7.856	0.1273	28.0	0.8861	7.378	0.1355
18.6	0.9421	7.846	0.1275	28.2	0.8850	7.369	0.1357
18.8	0.9409	7.835	0.1276	28.4	0.8838	7.360	0.1359
19.0	0.9396	7.825	0.1278	28.6	0.8827	7.351	0.1360
19.2	0.9383	7.814	0.1280	28.8	0.8816	7.341	0.1362
19.4	0.9371	7.804	0.1281	29.0	0.8805	7.332	0.1364

NOTE: Tables for oils of greater specific gravity than 1.000 and of the comparative volumes of oils at 60° and other temperatures are given on pages 129 and 131.

and water are separated from the oil. The latter is drawn off into cylindrical stills set horizontally in brickwork like boilers. There is a furnace below the still, and the latter contains steam coils and sometimes steam jets at the bottom of the stills. The heating by means of the furnace and the steam coils and jets should be conducted very carefully, if the final products are to be used for road work, and careless heating has resulted in very undesirable materials being sold for highway purposes. The vapors from the stills are removed to condensers and liquefied.

The distillate that is obtained until the temperature reaches about 300°F. and the specific gravity of the product is about 0.73 is refined to furnish gasoline and naphtha. While the temperature is increased from 300° to 575°F., the specific gravity of the distillate increases to about 0.82, and the oil produced during this stage is treated to supply kerosene. If it is desirable to produce as much kerosene as possible the furnace is heated and the sides of the still kept as cool as possible, so that some of the heavy vapor driven off in the bottom of the still will condense in the top and fall back into the much hotter material at the bottom, "cracking" these heavy vapors into lighter compounds. One result of such cracking is often the liberation of free carbon, which settles into the material in the bottom of the still. Asphaltic oils can be cracked at a lower temperature than paraffin oils.

If road oils for surface treatment are desired, the distilling process is stopped after the light distillates are driven off. The thick oil left in the still is called the residuum, and some people look upon it as a by-product and the name "residuum" as having a somewhat derogatory signification. As a matter of fact the residuum obtained in distilling some petroleums is by far the most important product obtained from them. Some Californian and Mexican oils contain such a large amount of asphaltic compounds and so little light oils that by stopping the refining process when the residuum has the consistency desired for some classes of paving materials, it is unnecessary to add any other bitumen to fit it for use.

In the patented Trumbull process, the oil is heated and then allowed to flow down the inner surface of a large vertical heated cylinder. The vapors are drawn from the top of the cylinder and the asphaltic residuum is collected at the bottom. The temperatures used and the rate at which the crude oil is fed to the top of the cylinder fix the consistency of the residuum.

One of the earliest attempts to improve the process of refining petroleum so as to yield the maximum quantity of products useful for paving was made by Dubbs. By adding sulphur to the residuum while it was at a high temperature he produced materials which have been widely used as fluxes. About the same time Byerly found that by blowing air through the heated residuum asphaltic products were obtained, the oxygen performing the same function as the sulphur used in the Dubbs process. Some of these blown-oil products have been used as fluxes and others have been used for a great variety of purposes. Some asphaltic oils furnish a residuum which does not require blowing to obtain road material but this treatment is generally employed with semi-asphaltic oils when such a product is desired. Apparently the hydrocarbons of the paraffin series are little affected by the blowing process, which affects compounds of other series.

Meaning of Analyses.—The characteristics of the residuums from various oils are given in the accompanying table. The following notes explain the significance of the information in the table, and are abridged from Prévost Hubbard's *Dust Preventives and Road Binders.*

Specific Gravity.—The mark "25°/25°C." indicates that the determination was made at 25°C. (77°F.) and the result expressed in comparison with water at the same temperature. The test is mainly useful in identifying the material, but also gives a rough indication of the amount of heavy hydrocarbons which give body to the material. Material having a specific gravity exceeding 0.93 or 0.94 should be heated before use.

Flash Point.—This test is of value as differentiating between the heavy crude oils and cut-back[1] products, and the fluid residuums. It also shows the point to which a refined oil has been distilled and whether it is advisable to heat the material before application.

Loss at 160°C.—The loss in weight is an indication of the relative losses by volatilization of different road oils in actual service. It is an empirical test, like the rattler test for paving bricks. The residue should be sticky. If it is desirable for the material to maintain its consistency after application, it should show a low loss. If the material is applied by a method which requires more or less fluidity, a high loss is permissible, in order that the material may rapidly attain the desired consistency in the road, although a high loss is not necessary in the case of dust preventives. The loss is now usually determined at 163°C.

Loss at 205°C.—The purpose of this test is to show the effect of a high temperature as compared with 160° or 163°. It is not often made.

Bitumen Soluble in CS_2.—The solubility of the bitumen itself is independent of its character and consistency, so the amount and character of insoluble material is of most interest.

[1] A cut-back product is one made by fluxing a dense asphalt with a light oil.

Properties of the Residuums from Different Petroleums
(Mainly from *Dust Preventives and Road Binders*, by Prévost Hubbard)

	PENNSYLVANIA OIL RESIDUUM	OHIO OIL RESIDUUM	ILLINOIS OIL RESIDUUM†	KANSAS OIL RESIDUUM	GULF OIL RESIDUUM	CALIFORNIA OIL RESIDUUM	SEMIASPHALTIC BLOWN OIL	MEXICAN OIL RESIDUUM
Specific gravity, 25°/25°C.	0.9202	0.9318	0.941	0.9328	0.9735	1.006	0.974	1.000
Flash point, degrees C.	186.0	224.0	187.0	196.0	214.0	191.0	260.0	196.0
Loss at 160°C., 7 hours, per cent	5.3	0.3	1.46‡	2.6¶	0.8	3.2	0.18‡	4.0
Character of residue	Soft	Soft	Soft	Soft	Soft	Soft	....	Fluid
Loss at 205°C., 7 hours, per cent	14.2	7.4*	....	5.7*	6.2*	17.3*	0.68	....
Character of residue	Soft	Soft	....	Soft	Soft	Soft	Dense	....
Bitumen soluble in CS_2, air temperature, per cent	99.8	99.4	99.8	....	99.6	99.7	99.92	100.00
Organic matter insoluble, per cent	0.2	0.6	....	....	0.4	0.3	....	0.0
Inorganic matter, per cent	....	....	....	....	....	....	....	0.0
Bitumen insoluble in 88°B. naphtha, air temperature, per cent	4.3	3.8	5.9§	3.6	4.8	7.7	22.05§	15.00
Soluble bitumen removed by H_2SO_4, per cent	21.9	17.0	....	14.4	20.9	54.9	25.16	....
Saturated hydrocarbons in total bitumen, per cent	74.8	83.0	....	....	79.4	41.9	74.84	....
Solid paraffin, per cent	11.0	11.4	....	7.8	1.7	0.0	5.1	0.0
Fixed carbon, per cent	3.0	3.7	4.0	4.1	3.5	6.0	....	9.0

* Loss at 200°C. † Viscous, slightly sticky. ‡ Loss at 163°, 5 hours.
§ 86°B. naphtha. ¶ 100°, 7 hours. ‖ Sticky and somewhat harder than original material.

Inorganic Matter.—This indicates in some cases the nature of the dense bitumen.

Insoluble Organic Matter.—This affords an indication of whether oil has been distilled destructively.

Bitumen Insoluble in 88°B. Naphtha.—The hydrocarbons insoluble in paraffin naphtha are termed "asphaltenes" and those which are soluble "malthenes." The former tend to give body and consistency and the latter contribute adhesive properties to a road material. Blown oils contain very high amounts of insoluble hydrocarbons, sometimes as much as 25 to 30 per cent. The character of the bitumen dissolved in naphtha, after the solvent has evaporated, is instructive, for a sticky residue indicates better road building qualities in the original material than that which is greasy.

Soluble Bitumen Removed by H_2SO_4 and Saturated Hydrocarbons in Total Bitumen.—These tests are mainly of value as indicating the source of the material under examination. Clifford Richardson gives the following explanation of the significance of the tests in *The Modern Asphalt Pavement:*

> Hydrocarbons in general are divided into those which are saturated and those which are unsaturated, the former being stable and the latter reactive and very susceptible to change, combining with or being converted into other hydrocarbons by the action of sulphuric acid and other reagents. The saturated can be separated from the unsaturated hydrocarbons by strong sulphuric acid, and this will be found to be a very important means of differentiating the oils and the solid bitumens among themselves, by determining the relative proportions of these two classes of hydrocarbons which they contain.

Solid Paraffin.—This test confirms the information obtained from an inspection of the residue after the test of the loss at 160°C. The heavy liquid hydrocarbons of the paraffin series are probably more detrimental in road oils than are the solid paraffins.

Fixed Carbon.—Fixed carbon is the coke resulting from the ignition of the bitumen in the absence of oxygen.

Fluxes

Fluxes are petroleum products which are mixed with harder bituminous materials to soften them to any desired consistency. Petroleum with a paraffin base furnished the first flux used in the asphalt paving industry.

Asphaltic or semi-asphaltic flux is the residuum left on distilling petroleum having an asphaltic or semi-asphaltic base to a point where the residuum is a dense liquid when cool but any further distillation will produce a solid residuum when cold. It is characterized by a relatively low amount of saturated hydrocarbons. While it resembles natural maltha in some respects, it differs in remaining soft after heating to 400°F., most malthas becoming hard pitches after such treatment.

ASPHALT AND NATIVE SOLID BITUMENS[1]

The following definition of "asphalt" has been adopted by the American Society for Testing Materials:

Solid or semi-solid native bitumens, solid or semi-solid[2] bitumens obtained by refining petroleum, or solid or semi-solid bitumens which are combinations of the bitumens mentioned with petroleums or derivatives thereof, which melt upon the application of heat and which consist of a mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.

This definition is dependent upon the same society's definition of "bitumens," which is:

Mixtures of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids, or solids, and which are soluble in carbon disulphide.

These definitions were prepared after numerous conferences of road engineers and producers of materials, and while adopted by the society are not accepted by all specialists.

The following definitions are given by Clifford Richardson in *The Modern Asphalt Pavement:*

Native bitumens consist of a mixture of native hydrocarbons and their derivatives, which may be gaseous, liquid, a viscous liquid or solid, but, if solid, melting more or less readily on the application of heat, and soluble in turpentine, chloroform, bisulphide of carbon, similar solvents, and in the malthas or heavy asphaltic oils. Natural gas, petroleum, maltha, asphalt, grahamite, gilsonite, ozocerite, etc., are bitumens. Coal, lignite, wurtzelite, albertite, so-called indurated asphalts, are not bitumens, because they are not soluble to any extent in the usual solvents for bitumen, nor do they melt at comparatively low temperatures nor dissolve in heavy asphaltic oils. These substances, however, on destructive distillation

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[1] Revised by Prévost Hubbard, chief of road materials tests and research, United States Office of Public Roads.

[2] Solid bituminous materials are those having a penetration at 25°C. (77°F.) under a load of 100 grams applied for five seconds, of not more than 10. The significance of "penetration" is explained on page 121.

Semi-solid bituminous materials are those having a penetration at 25°C. (77° F.) under a load of 100 grams applied for five seconds, of more than 10 and a penetration under a load of 50 grams applied for 1 second of not more than 350.

Liquid bituminous materials are those having a penetration at 25°C. (77° F).) under a load of 50 grams applied for one second or more than 350.

give rise to products which are similar to natural bitumens, and they have been on this account defined by T. Sterry Hunt as "pyro-bitumens," which differentiates them very plainly from the true bitumens."

Asphalt is a term used industrially to cover all the solid native bitumens used in the paving industry and specifically to include only such as melt on the application of heat, at about the temperature of boiling water, are equally soluble in carbon bisulphide and carbon tetrachloride and to a large extent in 88° naphtha, those hydrocarbons soluble in naphtha consisting to a very considerable degree of saturated hydrocarbons, yielding about 15 per cent of fixed carbon and containing a high percentage of sulphur. Under this definition it can be seen that grahamite is not an asphalt, since it is not largely soluble in naphtha and yields a very high percentage of fixed carbon on ignition. It is also less soluble in carbon tetrachloride than in carbon bisulphide. Gilsonite is not an asphalt, since the saturated hydrocarbons contained in the naphtha solution are very small in amount and quite different in character from those found in asphalt.

Roadbuilders use the term "natural asphalts" to designate the native solid or semi-solid asphalts, and "oil asphalts" to designate the corresponding materials prepared from petroleum or maltha. Some producers of oil asphalts object to the term on the ground that the material obtained by distilling away the lighter parts of asphaltic petroleum is as "natural" as that obtained by refining native asphalts. By "rock asphalt" is meant sandstone and limestone impregnated with asphalt or maltha. "Asphaltic sands" are mixtures of asphalt or maltha and sand, the latter in loose grains which fall apart when the bitumen is extracted; many of them are called rock asphalts because in their natural condition the maltha cements them into a rock-like mass.

The sources of the asphalts used in the United States are given in the accompanying table. The quantities of materials there stated were not all used for road and street purposes, as there are many other uses to which some of them are put.

Trinidad Asphalt.—Trinidad asphalt comes from the island of that name. The main source is on La Brea Point, about 28 miles from Port of Spain, the chief town. Here there is a circular pitch lake of nearly 115 acres extent, between which and the sea are other pitch deposits more or less mixed with sand. The former furnishes the "lake asphalt" and the latter the "land asphalt" of the paving industry.

The material in the lake is described by Clifford Richardson as an emulsion of water, gas, bitumen, fine sand and clay. It is in constant motion owing to the evolution of gas, and for this reason, whenever a hole is dug in the surface, whether deep or shallow, it rapidly fills up and the surface resumes its original level after a short time. Although soft it can be readily flaked out with picks in large conchoidal masses weighing 50 to 75 pounds. It is honey-combed with gas cavities and resembles a Swiss cheese in structure. It is of uniform composition, as follows: Water and gas volatilized at 100°C., 29 per cent; bitumen soluble in cold carbon disulphide, 39 per cent; bitumen absorbed

American Production and Importation of Asphaltic Materials, 1915
(Compiled from report by John D. Northrop in *Mineral Resources of the United States*, 1915. Output stated in tons of 2000 pounds, except in case of imports, which are in tons of 2240 pounds)

	1915		1914	
	Tons	Value	Tons	Value
American bituminous rock....	44,329	$157,083	51,071	$162,622
Wurtzelite (elaterite), gilsonite	20,559	275,252	19,148	405,966
Grahamite....................	10,863	94,155	9,669	73,535
Total American natural bituminous material.............	75,751	526,490	79,888	642,123
American road oils and fluxes.	417,859	2,392,576	171,447	....
American oil asphalts and pitches......................	246,644	2,323,007	189,408	....
Total American road oils, asphalts, etc..................	664,503	4,715,583	360,855†	3,016,969
Mexican road oils and fluxes*	174,854	1,325,201	111,058	....
Mexican oil asphalts and pitches*....................	213,464	2,405,235	202,729	....
Total Mexican road oils, asphalts, etc*.................	388,318	3,730,436	313,787	4,131,153
Imports of asphalt				
Trinidad†..................	92,107	498,900	61,708	334,635
Bermudez..................	28,659	144,595	58,755	295,765
Cuba......................	391	9,243	458	11,407
Barbados..................	64	6,426	71	6,592
Mexico....................	56	755	140	2,048
Switzerland...............	200	1,637	620	3,706
Italy.....................	492	3,438	247	1,477
France....................	....	....	100	1,317
England...................	774	9,801	628	6,269
Germany...................	658	4,854	1,354	10,856

* Refined in the United States from imported Mexican petroleum.
† There are discrepancies in the figures in the report.

by mineral matter, 0.3 per cent; mineral matter, 27.2 per cent; water of hydration in clay and silicates, 4.3 per cent.

Trinidad land asphalt reached the places where it is found either by overflowing from the lake or by intrusion into the soil from the same subterranean source that supplies the lake asphalt.

Its character is much affected by the effect of the weathering to which it has been subjected. Clifford Richardson states that refined land asphalt of good quality differs from the lake supply by its higher specific gravity due to the larger amount of mineral matter it contains, by a higher softening or melting point, and a somewhat lower percentage of bitumen and, in consequence of these facts, a much greater hardness at all temperatures. Land asphalt requires much more paraffin flux than lake asphalt, and asphaltic oil fluxes offer certain advantages over paraffin fluxes for use with land asphalt.

Composition of Refined Trinidad and Bermudez Asphalts
(Clifford Richardson)

	TRINIDAD	BERMUDEZ
Specific gravity at 77°F. (25°C.)	1.40	1.08
Streak	Blue black	Black
Lustre	Dull	Bright
Structure	Homogeneous	Uniform
Fracture	Semi-conchoidal	Semi-conchoidal
Hardness	2	Soft
Melts	235°F. (113°C.)	183°F. (84°C.)
Penetration at 77°F. (25°C.)	4	20
Loss at 325°F. (163°C.), 7 hours	1.1%	3%
Character of residue	Smooth	Smooth
Loss at 400°F. (205°C.) 7 hours	4.0%	8.2%
Character of residue	Blistered	Wrinkled
Bitumen soluble in CS_2	56.5%	94.4%
Bitumen retained by mineral matter	0.3%	....
Mineral matter	38.5%	3.6%
Water of hydration	4.2%	....
Vegetable matter	....	2.0%
Bitumen soluble in 88° naphtha	35.6%	62.2%
Percentage of total bitumen which above is	63.1%	65.4%
Soluble bitumen removed by H_2SO_4	61.3%	62.4%
Saturated hydrocarbons in total bitumen	24.4%	24.4%
Pure bitumen soluble in $C\,Cl_4$	100.0%	99.5%
Fixed carbon	10.8%	13.4%

Bermudez Asphalt.—Bermudez asphalt comes from a pitch lake in Venezuela about 30 miles from the coast in an air line. The lake is about 1½ miles long, 1 mile wide, of irregular shape and covers about 900 acres. It is covered with a crust from a few inches to 2 feet thick, having some grass and shrubs, with a few palms, and the pitch is visible on the surface in but few places. It is very wet, so that excavations fill with water and it is difficult to excavate the pitch, which has an average depth of 4 feet. The deposit is probably formed by the exudation of a large quantity of soft maltha. The asphalt from the lake varies greatly in the amount of water it contains, which fluctuates between 11 and 46 per cent. This water is not emulsified with the bitumen but is adventitious surface water. The material for industrial use is selected, and when refined has the composition given in the accompanying table, which also gives the composition of refined Trinidad asphalt.

Meaning of Analyses.—The significance of most of the terms used in this table are explained in the section on Petroleum. The new terms are the following:

Streak is the color of a rubbed or scratched surface.

Hardness is stated in terms of Mohr's scale, in which 1 is the hardness of talc, 2 that of rock salt, 3 that of calcite, 4 that of fluorite, etc. When a bitumen is softer than I on this scale its hardness is stated by its behavior in a penetration test, explained below.

Melting point is determined by an arbitrary test, because bituminous materials are made up of a mixture of hydrocarbons and their derivatives and can not have a true melting point, such as a definite compound possesses.

Penetration is determined by the distance that a need'e of specified size loaded with a specified weight will penetrate into a sample of the material in a specified time. Usually a No. 2 needle loaded so that the total weight is 100 grams and a time period of 5 seconds is employed, but a 50-gram weight and a 1-second time period are used with liquid bitumens. Prévost Hubbard makes the following statement regarding this test:

> The penetration test is a convenient one to employ for identification and control, and is often indicative of the value of an oil or asphalt product for construction work. While the test for bituminous road materials is made in the same manner as in asphalt paving work, the standards for road purposes are somewhat different. No oil product should be employed in macadam construction with a penetration higher than 25 mm. when tested at 25°C. with a No. 2 needle for five seconds under a weight of 100 grams, unless it possesses the property of hardening considerably when subjected to the volatilization test. On the other hand, it is rarely necessary to require a penetration as high as that for asphaltic cement used in the topping of an asphalt pavement, for the reason that the upper course of a macadam road has much greater inherent stability than the sand course of the asphalt pavement. A penetration of from 10 to 15 mm. is usually considered sufficient for road work. If a material having a much lower penetration is selected, its susceptibility to temperature changes will have to be considered.

Organic matter insoluble is a term of uncertain significance which has been explained by Clifford Richardson as follows:

> On adding together the percentages of bitumen soluble in carbon disulphide and of inorganic matter obtained on ignition, the sum will seldom amount to 100.0. The difference has been considered for many years as

organic matter not bitumen (insoluble). This may be true in exceptional cases, but recent investigations have shown that it is not at all so in many bitumens. For example, in Trinidad asphalt it has been found to consist of the water of combination of the clay which the material contains and some inorganic salts which are volatilized on ignition. The amount of organic matter is extremely small. In other cases, it may consist to a considerable extent of grass and twigs, as in the seepages which have run out over sod. On the whole, therefore, it seems desirable not to describe it by any definite name, but merely as an undetermined difference.

Pure bitumen soluble in CCl_4 (carbon tetrachloride) is not usually determined unless a road oil has been badly cracked or a solid bitumen like grahamite has been added, so that the percentage of hydrocarbons insoluble in 88° naphtha is high. The bitumens insoluble in carbon tetrachloride but soluble in carbon bisulphide are called "carbenes."

Other Asphalts.—Maracaibo asphalt is found on the Limon River about 50 miles west of Maracaibo, Venezuela. According to Clifford Richardson it is an exudation from maltha springs. When carefully refined it contains from 92 to 97 per cent of bitumen soft enough to be indented by the finger nail. It contains a very small percentage of malthenes and has a higher softening point than either Trinidad or Bermudez asphalt.

Cuban asphalts are found in small quantities in many places on the island and what little use of them is made in the United States is mainly for varnishes. A deposit 18 miles from Havana has furnished material used in street pavements.

Asphaltic materials are found in many places in Mexico, and some of them have been developed more or less. What is usually known among roadbuilders as Mexican asphalt is prepared from the malthas and petroleums obtained mainly from the Tampico and Tuxpan district.

Natural asphalt has been obtained in California at several places, but the most noted deposits are no longer worked.

Refining natural asphalt consists merely in driving off the water it contains by heating the material to about 325°F. in large tanks containing coils of pipes through which steam is passed. In the bottom of the tanks are steam jets which agitate the asphalt. The vegetable impurities, if any, are skimmed from the top. The refined asphalt is drawn off while it is liquid into barrels for shipment. When it is to be used, it is melted with a residuum flux.

Solid Bitumens not Asphalts.—Gilsonite is a hard, brittle bitumen with a reddish brown streak and a conchoidal fracture, obtained mainly from Utah and Colorado. It is sold in two grades, gilsonite selects and gilsonite seconds, the former being the more pure. Gilsonite from different mines varies considerably, and some of it is of little value for use in paving mixtures.

Grahamite is a hard, brittle bitumen with a black streak, otherwise resembling gilsonite in appearance. Its softening point is very high and not yet definitely determined. It is obtained mainly from Oklahoma.

Properties of Gilsonite and Grahamite
(Clifford Richardson, *The Modern Asphalt Pavement*)

	Gilsonite		Grahamite
Specific gravity, 78°/78°F....	1.044	1.049	1.171
Streak........................	Brown	Brown	Black
Lustre........................	Lustrous	Lustrous	Dull
Fracture.....................	Sub-conchoidal	Sub-conchoidal	Hackly
Hardness.....................	2	2	Brittle
Softens.......................	260°F.	300°F.	Intumesces
Flows.........................	275°F.	325°F.	Intumesces
Loss, 325°F., 7 hours.........	0.9%	2.3%	0.1%
Loss, 400°F., 7 hours.........	1.2%	4.0%	0.5%
Bitumen soluble in CS_2......	99.0%	99.9%	94.1%
Insoluble organic matter....	0.0%	0.0%	0.2%
Mineral matter...............	0.0%	0.1%	5.7%
Bitumen soluble 88° naphtha	47.2%	15.9%	0.4%
Soluble bitumen removed by H_2SO_4.................. ..	87.7%	71.8%	25.0%
Total bitumen as saturated hydrocarbons..............	5.9%	4.5%	0.32%
Bitumen soluble in 62° naphtha........................	67.4%	30.3%	0.7%
Bitumen insoluble in CCl_4 ..	0.0%	0.4%	68.7%
Fixed carbon................	13.0%	13.4%	53.3%

Manjak resembles grahamite and is obtained from Barbadoes and South America. Its lack of uniformity and its high price have prevented any large use of it for American pavements, although it is used successfully in preparing other materials.

Fluxing Solid Bitumens.—Paving materials are made from solid bitumens by fluxing them with petroleum residuums by two methods. In the first method the residuum is heated to above the temperature at which the solid bitumen melts and the latter is then added. Grahamite does not melt but intumesces and the residuum to flux it must be raised to an exceptionally high temperature. The mixture is agitated until the bitumen is all melted and the combined material is of uniform quality.

In the second method, the residuum is heated to about 350°F. and air is then blown through it for six to forty hours, depending upon the quality of the old and the properties desired in the finished product. As soon as it reaches the proper consistency the blowing is stopped and enough solid bitumen mixed with it to give a paving material having the required properties.

ASPHALTIC MATERIALS FOR ROADS[1]

The selection of bituminous materials for road purposes should be based upon the local climatic conditions, the volume and character of the traffic, the character of the stone to be used, and the type of road to be constructed or maintained. Such conditions manifestly call for expert advice. The requirements of several state highway departments are given here merely as indicating the way in which specialists have met the needs of their respective localities.[2]

Some of the requirements for road oils can be met by a few crude asphaltic petroleums. Prévost Hubbard gives the accompanying analysis of a crude California petroleum of this character. This oil contained a small amount of water, and care in heating it would be necessary to prevent foaming. Hubbard says that "this oil is capable of increasing greatly in consistency after application and would serve as an excellent binding medium."

[1] Revised by Prévost Hubbard, chief of road materials tests and research, United States Office of Public Roads.

[2] Among the engineers to whom this chapter was submitted was F. H. Joyner, Road Commissioner of Los Angeles County, California, who prepared the following comment, which illustrates forcibly the necessity of the services of a specialist in extensive road improvements:

"From a study of the notes you submitted made by my assistants and myself, and from reports of the chemist and chief road oiler, we reached the decision that our study and conclusions on what we call road oils are of value only here in California, where we use only the native oils. While there is much in the notes that would not be applicable to our California oils or asphalts, I do not believe it would be necessary or proper to propose any changes in the notes."

The following statement by W. Arthur Brown, chemist of the Los Angeles county road department, explains the views mentioned by Mr. Joyner:

"The desirable constituent of a first-class road is asphalt. The asphalt carpet coat demands an oil that contains the highest grade of asphalt. It also demands that this asphalt be thin enough to spread well. It should enter all the interstices of the road surface. When the lighter constituents of the oil have served their purpose, namely, that of carrier and distributor, they are no longer needed, in fact, they are not needed except, possibly, in very small amount. They should then be of such a nature that they will volatilize readily. We do not wish a possible volatile constituent that is solid or nearly so in cold weather but thin and acting as a fluxing agent in hot weather.

The specification of the Los Angeles county highway department is a departure from, and simpler than, the older ones requiring fixed carbon, asphaltene, viscosity, float test, loss on heating during a certain number of hours at a specified temperature, ductility test, etc. This specification requires that the oil be reduced on the Brown evaporator in a specified time. This test determines the percentage of asphalt and insures the

Crude California Petroleum Adapted for Road Work

(From Prévost Hubbard's *Dust Preventives and Road Binders*)

Character	Black, viscous, sticky.
Specific gravity 25°/25°C	0.984
Flash point, degrees C	160.0
Loss at 100°C., 7 hours, per cent	5.25
Character of residue	More viscous than crude
Loss at 163°C., 7 hours, per cent	16.4
Character of residue	Sticky, very viscous
Loss at 205°C., 7 hours, per cent	30.0
Character of residue	Solid, not brittle
Soluble in CS_2, per cent	99.77
Organic matter insoluble, per cent	0.12
Inorganic matter, per cent	0.11
Bitumen insoluble in 86° naphtha, per cent	9.8
Fixed carbon, per cent	2.05

Viscosity, mentioned in this table, is explained by Prévost Hubbard as follows:

If it is desired to apply a road binder at a given temperature, as for instance when it is to be heated by means of steam, a determination of its viscosity at that temperature is often of value. The test also serves as a means of identification. When a viscous material is to be cut with one of lower viscosity in order to bring it to a proper consistency for application, the actual viscosity of the mixture should be ascertained and not calculated from that of the two constituents for the reason that this property is not additive.

In reporting the results of the test, the temperature of the material, the quantity used in testing, and the time in seconds taken by the material in flowing through a short tube of standard dimensions in what is called an Engler viscosimeter, are recorded. The longer the period of time taken by the material in flowing through the tube, the greater its viscosity.

The float test is employed in determining the relative consistency of very viscous materials. The results are reported in seconds of time that a float containing the material under test will remain floating in water at a stated temperature. It is considered a very useful test in controlling the preparation of road

volatile oil being of such a nature that it will leave the oil when once it is applied on the road. The percentage of asphalt is also much nearer the actual in the oil than by the methods of heating in an oven at a lower temperature. These specifications also require a stickiness test. This stickiness test, made on the Brown adhesivemeter, when interpreted in accordance with the entire specifications, especially with the time to reduce to asphalt, determine whether the oil has sufficient binding properties to hold the particles from displacement from each other and from the base. The stickiness and loss are standardized against road oils found on the market throughout California. The results of the tests have been carefully compared with actual service results, which are in accord with laboratory results in every case so far known."

oils from given materials, for by continuing the heating until the residue gives a predetermined result in the float test, a uniform product will be obtained.

The ductility test shows the distance in centimeters that a briquette of the material will stretch before breaking, when pulled at the rate of 5 centimeters per minute. The briquette is 1 cm. square at the smallest section and has a cross-section of 2 square cm. at the clips, which are 3 cm. apart.

State Requirements for Asphaltic Materials for Penetration Roads

	ILLINOIS		OHIO	NEW YORK	PENNSYL-VANIA
	Grade A	Grade B	Grade A-1	Grade A	
Specific gravity, 25°/25°C.	1.000+	0.97–1.00	0.97+	0.97+	......
Flash point, degrees C., min.	163	200	180	190	......
Ductility at 25°C., centimeters, min.	50	15	30	40	45
Penetration, 100 gr., 5 sec., 25°C., mm., min.	5–12*	5–8	9–16‡	14–19	9–15
Loss at 163°C., 5 hrs., per cent, max.	6	2	5	5	5
Character of residue	Smooth	Smooth†	§	§	......
Bitumen soluble in CS_2, per cent, min.	....	99.5	......	......	99.0
Pure bitumen products	99.5	....	99.5	99.5	......
Bermudez products	95.0	....	95.0	96.0	......
Cuban products	80.0	....	81.0	81.0	......
Trinidad products	65.0	....	66.0	66.0	......
Solubility in 86° naphtha, per cent	72–85	72–80	72–85	70–88Δ	98.5
Solubility in CCl_4, per cent	....	99.4+	98.9+	......	......
Fixed carbon, per cent	8–16	7–14	8–16	......	......

* 8–12 for material with 90 per cent total bitumen, 7–10 for material with 80 per cent to 90 per cent bitumen and 5–8 for Trinidad material having less than 80 per cent bitumen.

† Penetration of residue at least 60 per cent of that of the original material.

‡ 9–12 for pure bitumen products, 12–16 for fluxed native asphalts.

§ Penetration of residue at least half that of original material.

Δ In 76° naphtha.

NOTE—Illinois specifies a brittleness test as follows: "A cylindrical prism of the bituminous binder 1 cm. in diameter, after being maintained at a temperature of 5°C. (41°F.) for 20 minutes, shall bend 180 degrees at any point without checking or breaking." New York specifies a toughness test as follows: "It (the bituminous material) shall show a toughness at 32°F. not less than 15 cm. Toughness is determined by breaking a cylinder of the material 1¾ inches in diameter by 1¾ inches in height in a Page impact machine. The first drop of the hammer is from a height of 5 cm. and each succeeding blow is increased by 5 cm." New York also specifies a maximum of 4.7 per cent of paraffin.

State Requirements for Asphaltic Materials for Bituminous Concrete Roads

	ILLINOIS		MARYLAND	NEW YORK		OHIO		PENNSYLVANIA
	Grade A	Grade B		Grade A-1	Grade A-2	Grade A-2	Grade A-3	
Specific gravity, 25°/25°C.	1.00+	0.97–1.00	....	0.97+	0.97+	0.97+	0.97+	....
Flash point, °C., min.	163	200	300	190	190	180	180	....
Ductility at 20°C., cm., min.	50	15	20‡	25	25	30	25	50‡
Penetration, 100 gr., 5 sec., 25°C., mm., min.	5–12*	5–8	6–8.5	8–12	6–8	7–12‖	6–8	5–6.5
Loss at 163°C., 5 hrs., per cent, max.	6	2	5	4	4	5	5	3
Character of residue	Smooth	Smooth†	§	§	§	§	§	§
Bitumen soluble in CS_2, per cent, min.	....	99.5	....	....	....	....	....	....
Pure bitumen products	99.5	....	....	99.5	99.5	99.5	99.5	....
Bermudez products	95.0	....	....	96.0	96.0	95.0	95.0	....
Cuban products	80.0	....	....	81.0	81.0	81.0	81.0	....
Trinidad products	65.0	....	....	66.0	66.0	66.0	66.0	....
Solubility in 86° naphtha, per cent, min.	72–85	72–80	....	68–88¶	68–88¶	72–85	70–85	....
Solubility in $C\ Cl_4$, per cent, min.	....	....	....	....	....	98.9+	98.9+	....
Fixed carbon, per cent	8–16	7–14	....	8–17	8–17	8–17	8–17	....

* 8–12 for material with over 90 per cent of bitumen, 7–10 for material with 80 per cent to 90 per cent of bitumen, and 5–8 for Trinidad products with less than 80 per cent of bitumen.

† Penetration of residue at least 60 per cent of that of original sample.

‡ At 50 penetration and 25°C., an increase of 2 cm. required for each increase of 0.5 in penetration above 5.

§ Penetration of residue must be at least half that of original material.

¶ In 76° naphtha.

‖ 7–9 for pure bitumen products and 9–12 for fluxed native asphalts.

NOTE.—Illinois specifies a brittleness test as follows: "A cylindrical prism of the bituminous binder 1 cm. in diameter, after being maintained at a temperature of 5°C. (41°F.) for 20 minutes shall bend 180° at any point without checking or breaking." New York specifies the following toughness test: "It shall show a toughness at 32°F. not less than 10 cm. for grade A-1 and not less than 5 cm. for Grade A-2. Toughness is determined by breaking a cylinder of the material 1¾ inches in diameter by 1¾ inches in height in a Page impact machine." New York also specifies a maximum of 4.7 per cent of paraffin scale.

State Requirements for Asphaltic Materials for Surfacing

	NEW YORK		OHIO		
	Grade H. O.	Grade C. O.	Grade H. O.	Grade M. O.	Grade C. O
Specific gravity, 25°/25°C.	0.96	0.93	0.96	0.93	0.91
Flash Point, degrees C.	163	52	......	......	....
Ductility at 20°C., cm.	*	‡	......	......	....
Loss at 163°C., 5 hours, per cent.	10	30	5	25	30
Character of residue	....	....	......	......	Sticky
Bitumen soluble in CS_2, per cent.	99.5	99.5	99.5	99.5	99.5
Solubility in 86° naphtha, per cent.	75.90†	80–95†	80–94	85–97	90–98
Fixed carbon, per cent.	6–14	10	6	3.5	3
Paraffin scale, per cent.	4.7	4.0	......	......	....

* The residue after evaporation to 10 mm. penetration at a temperature not exceeding 500°F., must amount to 85 to 95 per cent of the original volume and have a ductility of at least 25 cm.

† In 76° naphtha.

‡ The residue after evaporation to 10 mm. penetration at a temperature not exceeding 500°F. must amount to 50 to 65 per cent of the original volume and have a ductility of at least 25 cm.

Note—New York specifies the following toughness test: Grade H. O. shall show a toughness at 32°F. not less than 20 cm. determined by the Page impact test. Ohio requires a viscosity of 10 to 60 at 100°C. for 50 cc. for Grade H. O., 40 to 80 at 50°C. for 50 cc. for Grade M. O., and 5 to 12 at 50°C. for 50 cc. for Grade C. O.

Shipping Road Oil.—Small quantities of road oil are shipped in tight wooden 50-gallon barrels, such as are used for shipping molasses, or in steel barrels. These barrels make the oil cost 2 to 3 cents a gallon more than the price for the oil itself. Uninjured empty barrels can generally be resold to the shipper. Heavy oil is troublesome to remove from barrels, and they are usually dumped into the open heating kettles and broken up. When the oil is warm the broken pieces of wood are raked out and used for fuel. If there is no heating kettle on the job, the barrels of heavy oil must be kept close to a fire or in a very warm room before the oil can be poured from them into the distributor.

Larger quantities of oil are shipped in tank cars, holding 8000 or 12,000 gallons. Where a large amount of oil is to be used annually near any railway, it will be desirable for the officials to supply a tank into which the oil can be run as soon as the car arrives. The season for roadwork is limited and during it there is a brisk demand for tank cars. The oil company which loses the service of a car for a week or ten days, while it stands on a siding waiting to be emptied, is obliged to add an equivalent item to its overhead expense, and the road district which provides for prompt discharge of tank cars is in a position to demand,

and will probably get, quotations shaded somewhat to recognize its sense of business fairness.

If oil must be used hot, a $\frac{3}{4}$ or 1-inch steam connection must be made with the heating coils of the tank car. For this reason, the car is often spotted on a siding near an electric station or mill, but the steam can also be furnished by a road roller, traction engine or other convenient source. It will take from twelve to twenty-four hours to heat a tankful of heavy oil to 150° to 170°F., which is high enough to allow it to be pumped. The temperature can be increased after that in the distributor. The amount of steam supplied to the heating coils of the car is regulated by a valve on the exhaust pipe of the coil, which is adjusted to prevent a waste of steam. As some road oils have a low flash point, great care must be taken to prevent any oil coming in contact with a flame. The temperature of the oil should be tested from time to time with a thermometer, to see that it is not overheated. If there is any water in the oil it will give a great deal of trouble if heated quickly, and if foaming is detected the rate of heating should be checked at once.

Specific Gravities, Degrees Baumé, Weights in Pounds per Gallon and Volume in Gallons per Pound of Oils at 60°F. Having Specific Gravities Exceeding 1.00

SPECIFIC GRAVITY	DEGREES BAUMÉ	POUNDS PER GALLON	GALLONS PER POUND	SPECIFIC GRAVITY	DEGREES BAUMÉ	POUNDS PER GALLON	GALLONS PER POUND
1.00	0.00	8.328	0.1201	1.15	18.91	9.577	0.1021
1.01	1.44	8.411	0.1189	1.16	20.00	9.660	0.1009
1.02	2.84	8.495	0.1177	1.17	21.07	9.744	0.0997
1.03	4.22	8.578	0.1165	1.18	22.12	9.827	0.0985
1.04	5.58	8.661	0.1153	1.19	23.15	9.910	0.0973
1.05	6.91	8.744	0.1141	1.20	24.17	9.994	0.0961
1.06	8.21	8.828	0.1129	1.21	25.16	10.077	0.0949
1.07	9.49	8.911	0.1117	1.22	26.15	10.160	0.0937
1.08	10.74	8.994	0.1105	1.23	27.11	10.243	0.0925
1.09	11.97	9.078	0.1093	1.24	28.06	10.327	0.0913
1.10	13.18	9.161	0.1081	1.25	29.00	10.410	0.0908
1.11	14.37	9.244	0.1069	1.26	29.92	10.494	0.0889
1.12	15.54	9.327	0.1057	1.27	30.83	10.577	0.0877
1.13	16.68	9.411	0.1045	1.28	31.72	10.660	0.0865
1.14	17.81	9.494	0.1033	1.29	32.60	10.743	0.0853

NOTE: For a similar table of oils of specific gravities less than 1.00 see page 112.

Pumping Road Oil.—In order to remove the oil from the tank car to the distributors, some form of pump is generally necessary, for it is not often that the car can be placed on a siding or trestle high enough to allow it to be emptied by gravity.

If a lift pump set in the top of the car is used, it should be a 3 or 4-inch size. With it one man can fill a 600-gallon distributor in twenty minutes.

In many cases a hose or pipe is connected to the bottom of the car and run to an oil pump, operated by a steam or gasoline engine, which forces the oil into the distributor. A 1½ or 2-inch power-driven rotary pump will deliver 600 gallons in ten to fifteen minutes. These pumps work with either hot or cold oil. A water tank pump can be used with cold oil but hot oil will ruin the valves speedily. A 2-inch suction tank pump will fill a 600-gallon tank in thirty to forty minutes.

The hose used in the connections between the pump and the bottom of the tank car should be as short as possible because the oil often destroys it rapidly. It is desirable to have a cut-off valve in the connection pipe. When everything is coupled ready for use, the discharge valve in the bottom of the car is raised by means of a vertical stem running up to the dome of the car, and the flow of oil is controlled by the cut-off valve, for the manipulation of the tank valve is quite troublesome.

Heating Road Oil.—As the fixed and operating charges at an oil storage plant are about the same irrespective of the amount of oil delivered into distributors, it is desirable to load as many carts daily as practicable, in order to reduce the unit cost of such work. In California, where large amounts of oil are used in surfacing concrete roads, oil stations have been designed with particular attention to effecting such economics. It is considered desirable to have the oil at a temperature of 300° F. when it is applied, so it is heated to 325° for delivery within 10 miles and 350° for longer deliveries.

The oil is discharged from the cars into storage tanks or pits holding 10,000 to 25,000 gallons. These contain steam coils to warm the oil sufficiently to enable it to be pumped into a circulating tank holding 2000 to 3000 gallons, where it is heated further by steam coils. The oil is then pumped through a heater and back into the circulating tank until its temperature is about 200°, after which the temperature of the heater is raised and the oil pumped through it into the distributor. The whole operation takes one and one-half hours.

The heater resembles a return tubular boiler. The furnace has a fire brick arch and walls and is heated by oil burners. The heated gases pass over the furnace arch in a chamber formed of ordinary brick masonry, and finally escape through a steel stack. The oil is pumped through a multiple grid of 3-inch pipes. The design is made on the assumption that with furnace temperatures of 1800° to 2000°, 1 square foot of heating surface will transmit 3 British thermal units per hour per degree of change in temperature.

Volume of Oil at 60°F. Equivalent to Unit Volume at Stated Temperatures in Fahrenheit Degrees

0°F	0	10	20	30	40	50	60	70	80	90
......	......	......	......	......	......	......	1.000	0.996	0.992	0.988
100	0.984	0.980	0.977	0.973	0.969	0.965	0.962	0.958	0.954	0.951
200	0.947	0.943	0.940	0.936	0.933	0.929	0.926	0.922	0.919	0.916
300	0.912	0.909	0.906	0.903	0.899	0.896	0.893	0.890	0.886	0.883
400	0.881	0.877	0.875	0.871	0.868	0.865	0.862	0.859	0.856	0.853

NOTE: This table is based on the assumption that the volume of oil increases 0.4 per cent for every increase of 10°F. above 60°. This rule is exactly applicable only to some oils. In Los Angeles County, Cal., the rate of increase in volume is taken at 0.3 per cent in the specifications of the county road department.

Purchasing Oil.—Oil increases in volume from 0.3 to 0.4 per cent for each 10°F. rise in its temperature. The oil is bought on the basis of its volume at 60°F. and if measured at any other temperature its volume must be computed, or, in the case of an oil having an increase in volume of 0.4 per cent per 10°F., the accompanying table will give the volume at 60° with a minimum amount of figuring. To use it, multiply the tabular number for the temperature at which the measurement was made by the measured quantity of oil. For example 1,100 gallons of oil at 375°F. multiplied by 0.888 gives 978 gallons as the volume at 60°F. If the rate of increase per 10°F. was 0.3 per cent, the volume at 60°F. would be 995 gallons.

TAR AND TAR PRODUCTS[1]

The tar used in roadbuilding is obtained by refining the crude tar produced in the destructive distillation of coal, in making enriched water gas and in certain classes of coke ovens. It is a complex mixture of many hydrocarbons and is not a simple chemical substance.

In a city gashouse, gas is produced by heating coal in retorts usually about 8 feet long, 15 inches high and 18 inches wide. The tar is driven off with the gas and is collected for the most part in "hydraulic mains" which act as water seals for the gas. The gas is further cooled in a condenser, where more tar is deposited, and the remaining tar is removed in a tar extractor and scrubbers. The tar obtained at each stage in the process is different from that obtained at the other stages, but all of it is usually run into large wells, where the accompanying ammoniacal water rises and is drawn off. The character of the tar varies greatly. It is much affected by the temperature at which the coking is conducted, as well as by the character of the coal used. High temperatures result in an increase in the amount of free carbon in the tar, and this increase in free carbon is accompanied by an increase in specific gravity. The presence of ammoniacal water with oils distilling below 110°C. is stated by Prevost Hubbard to be the distinguishing features of all crude coal tars.

Another class of tar is obtained from by-product coke ovens. The retorts in this case are much larger but are operated in much the same way as the retorts of illuminating gas plants, except that the main endeavor is to produce the maximum amount of coke instead of gas. For this reason the temperatures are lower than those usually employed in coal-gas works and the tar is likely to have a comparatively low amount of free carbon and a comparatively high amount of oils. There are several types of by-product coke ovens, and some produce tars better suited for road work than other types.

Water gas is made by passing steam over hot coal, in which process no tar is produced. This gas is a mixture of hydrogen and carbon monoxide, and burns with a flame of no value for

[1] Revised by Prevost Hubbard, chief of road materials tests and research, U. S. Office of Public Roads.

illumination. It must therefore be mixed with hydrocarbons, which are usually obtained by cracking a grade of petroleum distillate called gas oil. In the purification of this enriched or "carburetted" gas, tar is obtained which is called water-gas tar. It is lighter than coal tar and the water it contains is practically free from ammonia, which is an identifying characteristic of this material. It has a comparatively high amount of heavy oil and a low amount of pitch.

In some gas works both coal gas and water gas are made and the tar from both processes are collected together, resulting in mixtures which may vary greatly in composition.

The crude tar is stored in tanks at the refineries, each class by itself. As much water is removed by settling as is possible, since this is the cheapest method of getting rid of it. After settling, the tar is pumped into a still. Sometimes the tars from several sources are mixed so that a product with certain characteristics can be obtained which are unattainable by refining tar from one source. The stills are set in brick like horizontal boiler shells and are heated very carefully at first to prevent the water in the tar from causing foaming. The vapors from the still are liquified in condensers. Water and light oils are first driven off, then intermediate oils and finally heavy oils. The road materials are obtained from the residuum. The distillation must be stopped early if a light road tar is desired, while the process is carried much further if a binder is desired. In the final stages, the contents of the still are agitated by jets of air to prevent coking.

The composition of several crude tars and of the heavy pitches made by refining them is given in the accompanying table. The figures must not be considered more than representative of general characteristics, for individual tars in the same class vary greatly.

Tar products for road purposes are called "straight-run" when they are the residuums left after refining crude tars to the degree which will furnish a material of suitable composition, and "cutback" when they are made by fluxing a hard pitch with a lighter distillate.

The effect of free carbon in tar upon its utility for road purposes has been a subject of protracted controversy. Philip P. Sharples makes this comment:

Experience has seemed to settle that a moderate amount of free carbon is beneficial in a road tar, thus bearing out the practical experience gained in the use of coal tar materials in other directions. At the same time, an excess of free carbon is not desirable, since it tends to make the material difficult to work and also reduces to a considerable degree the amount of true bitumen available. On the other hand, a certain percentage of free carbon seems to enhance the binding power of the refined tar. The upper

Characteristics of Crude Tars and Their Residual Pitches

(From Philip P. Sharples)

	Horizontal gas, 16th Street, New York		Horizontal gas, Astoria, N. Y.		Inclined gas, Astoria, N. Y.		Coke oven,[2] Lebanon, Pa.		Vertical gas, Providence, R. I.		Water gas, Ravenswood	
	Tar	Pitch	Tar	Pitch	Tar	Pitch	Tar	Pitch	Tar	Pitch	Tar	Pitch
Specific gravity, 15.5°C.	1.293	1.357	1.267	1.306	1.238	1.284	1.187	1.281	1.153	1.225	1.074	1.190
Free carbon, per cent	37.5	46.1	28.9	33.5	24.3	30.4	10.8	19.3	4.0	10.4	0.3	1.1
Viscosity, Engler, 100°C.	30.0	......	21.8	......	14.9	......	3.0	......	2.1	......	1.6	......
Melting point, degrees F	......	127	......	131	......	130	......	133	......	145	......	139
Oil[1] per cent	......	......	13.2	......	14.3	......	21.8	......	28.8	......	45.1	......
Fixed carbon, per cent	......	51.5	......	42.0	......	37.9	......	28.8	......	19.1	......	23.8
Tar acids in oil, per cent	......	......	14.0	......	21.0	......	4.0	.....	29.0	......	0.0	......
Ash, per cent	......	0.4	......	0.21	......	0.10	......	0.48	......	0.23	......	0.06

[1] Amount of oil produced when the tars are distilled to a soft pitch.

[2] Semet-Solvay ovens. Concerning this type Prevost Hubbard makes the following comment: "The low percentage of free carbon is characteristic of the Semet-Solvay coke oven tars, which usually carry from 3 to 10 per cent of this constituent. The Otto-Hoffman ovens produce higher carbon tars as they are fired at a higher temperature."

NOTE.—"It will be noted that there is a great difference in specific gravity, the specific viscosity, and the percentage of free carbon, and that these vary in somewhat the same way. While this accord in the variations is marked in the type of samples taken, it is not inversely true, and we may have samples in which the variations would not fall in the same place in the different columns, although there are no very marked diversities. The amount of oils produced when the tars are distilled to a soft pitch varies inversely. This is also subject to individual variations, although the general quantities yielded vary as indicated. In the tar acids produced, however, it will be noted that the different tars show no gradual variation. The one marked feature of this line is the absence of tar acids in the water-gas tar oil; but even here samples may be found which have small percentages of acid. It is also possible to obtain coke-oven tars which contain a large percentage of tar acid."—*Philip P. Sharples.*

limit may perhaps be set at 25 per cent for a binder and perhaps 22 per cent for a tar used for hot surface application. The lower limits on these classes of materials should certainly not be less than 12 per cent for binder materials and 10 per cent for hot surfacing materials. With cold surfacing materials the free carbon is necessarily much lower, as its presence in large quantities reduces the penetration. With cold surfacing materials 4 per cent may be placed as a desirable minimum.

Prevost Hubbard makes the following comments on free carbon in his Dust Preventives and Road Binders:

In tars of the same consistency, those of low carbon contents have a greater inherent binding strength than those of high-carbon contents. In tars whose bitumen contents are of the same consistency those of high carbon contents have a greater inherent binding strength than those of low carbon contents, but the binding capacity of the former is lower. In sand-tar mixtures containing a relatively large amount of high carbon tar, the carbon may act as a filler and add to the mechanical strength of the mineral aggregate, but better results in this respect can be obtained by the use of a smaller quantity of low carbon tar of the same melting point, together with a mineral filler. The waterproofing value of high-carbon tars is in general less than that of low-carbon tars. Free carbon retards the absorption of tars by porous surfaces. When tar is exposed in comparatively thin films free carbon has little or no effect in retarding volatilization.

Applying these facts to the use of tar in road treatment the following conclusions are logically deduced: (1) In the treatment of old road surfaces a low carbon tar is to be greatly preferred to a high carbon tar. (2) In ordinary bituminous road construction, both from the standpoint of efficiency and economy, a low-carbon tar is to be preferred to a high-carbon tar whose bitumen content is of the same consistency.

The distillation test of tars furnishes information regarding their utility for road work. Formerly the test was made on material which might or might not contain water, but the tendency of specialists at present is to remove any water from the samples by preliminary distillation at a low temperature, for no water is permitted in tar for hot application under most specifications now. The distillation is carried on in an Engler flask and is conducted in a series of stages. The terminal temperatures of the stages have usually been 110°C., 170°C., 270°C. and 300°C., but recently it has been proposed to make another stage with a terminal temperature of 235°C. The test is one which must be conducted with careful observance of the procedure specified for the method followed or the results will not be comparable. The distillate obtained during each stage is called a "fraction."

The 1916 requirements of several State highway departments for different grades of tar are given in the table on pages 136 and 137.

Specifications of Several State Highway Departments for Tar Products for Different Classes of Road Work

	NEW JERSEY				NEW YORK					
	Coal tar		Water gas tar		High carbon			Low carbon		
	N	M	UA	U2	Binder	H.O.	C.O.	Binder	H.O.	C.O.
Specific gravity	1.12–1.18	1.22–1.30	1.09–1.12	1.14–1.17	1.2+	1.19+	1.14–1.18	1.16+	1.14+	1.10–1.13
at degrees C	15.5	15.5	25	25	25	25	25	25	25	25
Float test, seconds	......	120–150	......	16–20	......	18–28	......	......	15–25	......
at degrees C	......	50	......	100	......	......	......	......	100	......
Viscosity	150–300[1]	......	60–100	......	......	......	125[3]	......	......	125[3]
Free carbon, per cent	4–12	15–25	3	3	12–25	10–22	4–12	5	4	2
Distillation, per cent	......	......	......	......	......	......	......	......	......	......
to 170°C., maximum	7	0.1	3	1	0	0	5	0	1	5
170°–235°C., maximum	......	......	20	5	3	10	18	5	12	20
235°–270°C., maximum	35	15	37	15	12	16	25	15	20	28
270°–300°C., maximum	......	......	50	30	16	20	32	20	25	25
Specific gravity of distillate at 15.5°C	1.01	1.03	......	......	1.03[2]	1.03[2]	1.01[2]	......	......	......
Melting point of residue, degrees C	75	75	60	65	75	75	70	75	75	70
Melting point, ball and ring, degrees C	......	......	......	......	27	......	......	27–34	......	......

	Pennsylvania				Ohio					Illinois
	High carbon		Low carbon		High carbon		Low carbon			
	Binder	C, oil	Binder	C, oil	Binder	H.O.	C.O.[7]	Binder	H.O.	Binder
Specific gravity	1.2	1.14–1.18	1.15–1.175	1.10–1.13	1.2–1.27	1.18–1.25	1.0–1.18	1.16–1.20	1.14	1.26
at degrees C	15.5	15.5	25	25	25	....	25	....	25	25
Float test, seconds	......	....	20–24	....	120–180	120–180	....	150–210	120–180	120–180
at degrees C	......	....	100	....	50	32	....	50	32	50
Viscosity	......	200–300[1]	....	180–280[6]	....	....	6–15[9]	....	....	....
Free carbon, per cent	12–25	4–12	3	3	10–22	10–20	4–12	10	8	22
Distillation, per cent	......	....	....	....	....	....	....	....	....	....
to 170°C., maximum	0	7	0.5	2	0	1	5	0	1	5[9]
170°–235°C., maximum	......		3	18	10	16		10	20	
235°–270°C., maximum	......	35	12	33			28			....
270°–300°C., maximum	......		25	43	20	24		20	25	15[10]
Specific gravity of distillate at 15.5°C	......	1.01	....	....	1.03[2]	1.03[2]	....	1.00[2]	1.00[2]	....
Melting point of residue, degrees C	74[4]	65	....	....	75	75	70	75	75	....
Melting point, ball and ring degrees C	37–43[5]	....	65	60	....	....	....	....	....	....

[1] At 40°C. first 100 cc.
[2] At 25°C.
[3] At 60°C.
[4] Residue after carrying distillation to 315°C.
[5] Determined by ½-inch cube method.
[6] First 50 cc. at 40°C.
[7] This tar may contain not over 1 per cent of water.
[8] First 50 cc. at 50°C.; specific viscosity.
[9] The distillate to 110°C. must not exceed 2 per cent.
[10] To 315°C.

Note.—New Jersey limits the naphthalene in the distillate of water gas tars to 2 per cent, and specifies a loss on evaporation of 28 and 12 per cent of grades UA and U2 respectively. Illinois requires a cylinder of tar 1 cm. in diameter, after remaining at 0°C. for twenty minutes, to bend into a semicircle of 3 cm. diameter, without checking or breaking.

BITUMINOUS ROADS[1]

Bituminous materials are used on gravel and broken stone roads in three ways: (1) thoroughly mixed with the stone or gravel before the latter is placed on the roads; (2) driven into the interstices between the stone after the latter has been placed on the road; (3) applied to the surface of a finished gravel or broken stone road. The first method produces what is now commonly called bituminous concrete and the second method bituminous macadam. These will be described in this section and surface applications will be described in the next section.

Rock for Bituminous Roads.[2]—In bituminous road work observations indicate that in some cases it is advantageous to use a rock of relatively high absorption rather than one with low absorptive qualities, owing to a better adhesion of the bituminous material by a partial surface impregnation of the rock.

While the binding or cementing value of a rock is a most important consideration from the standpoint of ordinary macadam construction, the same is not true of broken-stone roads which are carpeted or constructed with an adhesive bituminous material. The French coefficient of wear is also of relatively less importance, owing to the fact that the fine mineral particles produced by the abrasion of traffic combine, or should combine, with the bituminous material to form a mastic which is held in place and protects the underlying rock from abrasion so long as it is kept intact by proper maintenance. The toughness of the rock is of more importance, as the shock of impact is to a considerable extent transmitted through the seal coat and may cause the underlying fragments to shatter. It would, therefore, seem that the minimum toughness of a rock for use in the construction of a bituminous broken-stone road or a broken-stone road with a

[1] It is the purpose of this chapter to indicate the methods followed in several sections of the country where bituminous roads have been built extensively rather than to recommend any methods as the best for all conditions. Revised by P. St. J. Wilson, chief engineer, United States Office of Public Roads and Rural Engineering; F. H. Joyner, road commissioner of Los Angeles County, Cal.; and W. R. Farrington, division engineer, Massachusetts Highway Commission.

[2] From Bulletin 370, United States Department of Agriculture, "Physical Tests of Road-Building Rock," by Prevost Hubbard, chemical engineer, and Frank H. Jackson, Jr., assistant testing engineer, Office of Public Roads.

bituminous-mat surface should, for light traffic, be no less than for ordinary macadam subjected to the same class of traffic. For moderate and heavy traffic, however, the same minimum toughness should prove sufficient, owing to the cushioning effect of the bituminous matrix. No maximum limit of toughness need be considered for any traffic.

In the case of bituminous concrete roads, where the broken stone and bituminous material are mixed prior to laying and consolidation, it generally appears advisable to set a minimum toughness of 6 to 7 for light-traffic roads, instead of 5, in order to insure that the fragments of rock which have been coated with bitumen shall not be fractured under the roller during consolidation; and 12 or 13 for moderate and heavy traffic, instead of 10 and 19, as in the case of water-bound macadam roads.

Bearing in mind the fact that availability, cost, and various local conditions generally control the selection of proper limits, the accompanying table may be used as a general guide for minimum limits of the French coefficient of wear and toughness in connection with bituminous broken-stone roads.

Bituminous Materials.—Climatic conditions, the volume and character of traffic to be carried by a road, the kind of stone to be used, and the methods of construction vary greatly in different places and have an important influence on the determination of the bituminous materials to be used. For this reason it is not practicable to have a general specification of universal applicability. The requirements for bituminous binders of a number of states are given in the tables on pages 126, 127 and 136.

In most cases the binders are furnished by the contractors under specifications of greater or less detail. In Massachusetts the State highway commission usually purchases its material and furnishes it to the contractors, although contractors are occasionally required to supply it.

Bituminous Macadam.—Roads of this type are frequently said to be built by the "penetration" method because the bituminous material is made to penetrate the interstices of the road from the surface. The grading, drainage and rolling of the subgrade are carried out as in the case of waterbound macadam roads. On the subgrade is laid a base or bottom course, then a top course to which the bituminous material is applied, and finally a thin "seal" coat of bituminous material covered with screenings or gravel to protect the main mass of the road from the weather and other deteriorating influences.

The depth of the bottom course varies with the character of the subgrade, the traffic, the quality of the stone, the character of the top course and the preferences of the highway authorities. Probably 6 inches at the center and 4 inches at the sides are

Limits of Physical Tests of Rock for Bituminous Roads

(Recommended by Prévost Hubbard and Frank H. Jackson, Jr.)

	LIGHT TO MODERATE TRAVEL			MODERATE TO HEAVY TRAVEL		
	French coefficient	Percentage of wear	Toughness	French coefficient	Percentage of wear	Toughness
	At least	*Not over*	*At least*	*At least*	*Not over*	*At least*
Broken stone with bituminous carpet	5	8	5	7	5.7	10
Bituminous macadam with seal coat	5	8	5	7	5.7	10
Bituminous concrete	7	5.7	7	10	4	13

Gallons of Bituminous Material per Mile of Road for Different Rates of Application

GALLONS PER SQUARE YARD	WIDTH OF ROAD IN FEET						
	9	10	12	15	18	20	22
0.20	1,056	1,174	1,408	1,760	2,112	2,347	2,582
0.25	1,320	1,467	1,760	2,200	2,640	2,933	3,227
0.33	1,742	1,936	2,323	2,904	3,484	3,872	4,259
0.40	2,112	2,347	2,816	3,520	4,224	4,694	5,163
0.50	2,640	2,934	3,520	4,400	5,280	5,867	6,454
0.60	3,168	3,520	4,224	5,280	6,336	7,040	7,744
0.67	3,538	3,931	4,716	5,896	7,075	7,862	8,648
0.70	3,696	4,107	4,928	6,160	7,392	8,214	9,035
0.75	3,960	4,400	5,280	6,600	7,920	8,801	9,680
0.80	4,224	4,694	5,632	7,040	8,448	9,387	10,326
0.90	4,752	5,280	6,336	7,920	9,494	10,561	11,616
1.00	5,280	5,867	7,040	8,800	10,560	11,734	12,907
1.25	6,600	7,334	8,800	11,000	13,200	14,668	16,134
1.50	7,920	8,801	10,560	13,200	15,840	17,601	19,361
1.75	9,240	10,267	12,320	15,400	18,480	20,535	22,587
2.00	10,560	11,734	14,080	17,600	21,120	23,468	25,814

average depths.[1] In Massachusetts, where the foundation is prepared very carefully, sometimes consisting of 12 inches or more of gravel or telford, an 18-foot roadway usually has a bottom course 2 inches thick at the sides and 3 inches thick at the center, after rolling, except on stone foundations, where the standard thickness is 2 inches at all points of the cross-section. These thicknesses are increased in some cases.

The Massachusetts specifications call for smaller stone than those of most states, and give the engineer the final decision

[1] On roads where the traffic promises to be heavy, it is often considered best to have the same depth the entire width of the road.

regarding the proportions of the $\frac{1}{2}$ to $1\frac{1}{4}$-inch size and the $1\frac{1}{4}$ to $2\frac{1}{2}$-inch size which shall be mixed together for this course, the intention being, where stone is crushed locally, to vary these proportions in order to use the output of the crusher. In New York and Pennsylvania the maximum size of the stone for this course is $3\frac{1}{2}$ inches. The Pennsylvania specifications require the stone to have a French coefficient of wear of not less than 10, and permit the use of gravel and of broken slag which weighs 70 pounds or more per cubic foot, measured loose. In Ohio, if sandstone is used in the bottom course, pieces as large as 6 inches are permitted; the maximum size with other rocks is 4 inches. In Illinois and California the maximum size is 3 inches. These variations are due mainly to differences in the average quality of stone available in the different states.

After the stone has been spread, it is sometimes harrowed. The Illinois specifications call for the use of a tooth harrow weighing 10 to 12 pounds per tooth. The course is then consolidated with a roller, one weighing 10 tons or more being generally required. It is next covered with screenings, small gravel and sometimes coarse sand, which are broomed and rolled dry until the interstices are filled, but not over-filled. Some engineers consider the course finished at this stage, while others require it to be sprinkled with water and rolled so as to consolidate it still further.

On the work under a number of State highway departments, the stone for both the top and bottom courses must be shoveled from the carts into place, or be dumped on platforms and shoveled from there into place, or be spread over the road by distributing wagons built for the purpose. In other states the stone for the bottom course may be dumped on the subgrade and shoveled from these piles into its final place. Stone for the top course is never permitted to be dumped in piles on the bottom course. The screenings or other fine material used on the road are generally required to be delivered along the road before construction begins.

Other types of bottom courses than those made of graded aggregates are occasionally used. Many macadam roads in good condition have had a bituminous macadam top course put on them. Macadam roads when in poor condition are often scarified, new material added where needed, and then rolled, thus furnishing a suitable bottom course at minimum expense. If these old roadways are thus used, their drainage should be carefully examined and all defects remedied before the top course is laid. In the New York state highways, a base of run-of-bank gravel not larger than $3\frac{1}{2}$ inches is sometimes used. In this case the material passing a $\frac{1}{4}$-inch screen must not be more than 5 per cent in excess of the voids in the remainder of the material after this fine stuff has been removed.

In Massachusetts the top course is usually 2 inches thick, and as stone from $1\frac{1}{4}$ to $2\frac{1}{2}$ is required the largest pieces become imbedded slightly in the bottom course by the rolling. More than 15 per cent of the $\frac{3}{4}$ to $1\frac{1}{4}$-inch stone, which is permitted in the bottom course, is not desired in the top course because experience has convinced the Massachusetts engineers that its presence makes a less durable road. More bituminous binder is required with coarse than small stone, but the entire quantity can be applied at one time, while if small stone is used it has been found desirable to construct this course in two layers in order to be certain that the smaller voids existing with such stone are filled.

The top course in most States is usually from 2 to 3 inches thick.

The top course of the New York State highways is made of $1\frac{1}{4}$ to $2\frac{1}{2}$ inches stone, in Pennsylvania 1 to 3-inch, in Ohio $1\frac{1}{2}$ to $2\frac{1}{2}$-inch stone for a course less than 3 inches thick and $2\frac{1}{2}$ to 4-inch stone for a course 3 inches or more thick, unless the stone has a loss on abrasion of less than 6 per cent, when the size is reduced to 2 to $3\frac{1}{2}$ inches; in Illinois 1 to $2\frac{1}{4}$ inches. The Ohio and Illinois specifications require it to be harrowed.

In rolling this course, it is usually considered desirable to roll adjacent strips of the shoulders as well, so as to unite the shoulder and roadway as completely as practicable. It is also generally considered desirable to roll the stone until it is "locked" in place so the binder distributor can pass without leaving any impression, but not to the maximum density. The reason for this is that the bituminous material is believed to be more uniformly distributed if the course of stone is capable of further compression after the binder has been applied. Some stone hard enough to carry travel should not be rolled heavily, for if heavily rolled the voids will be so reduced that the binder will not penetrate into them properly.

No bituminous material should be applied except when the stone on the surface is clean and free from dust. The application is now made in many cases with a pressure distributor, which is required by some State highway departments; it is also applied by gravity distributors and, on small work, by hand pouring cans.

Distributing wagons often have some kind of fire-box for keeping the binder hot. Gravity distributors discharge their contents through nozzles or other spraying devices at their rear about 12 inches above the road. The shape and location of the nozzles are so selected that the binder will be distributed uniformly over a strip of the road somewhat wider than the distance between the wheels. The binder flows from the nozzles by gravity, and as the contents of the tank are drawn off the pressure on the nozzles decreases and the rate of flow per minute is reduced. In order to maintain a uniform flow, a control valve in the outlet pipe is provided. The rate of application of the material is regulated by this valve and the speed of the distributor.

Pressure distributors are used where it is desired to have better control over the rate of application of the binder than is practicable with gravity distributors, and also to obtain the best distribution and penetration. In some types, compressed air or steam is admitted to the top of the tank so that the pressure on the surface of the binder, whether the tank is full or almost empty, is sufficient to drive the material through the nozzles with considerable force. In other types, the binder is driven out of the nozzles by a small pump. The nozzles of the pressure distributors are generally about 6 inches from the surface of the road. In some cases the binder is forced through a hose ending in a nozzle which the operator moves along just above the surface of the road.

Bituminous material is also distributed from tank wagons without any suitable piping and nozzles of their own. This is done by attaching to their rear end a light two-wheel sulky having the necessary distributing apparatus, which is connected by piping with the outlet of the tank wagon. Attachments are also made for this purpose which can be bolted to an ordinary tank wagon.

Pouring cans resemble garden watering cans in appearance. The top is usually partly covered to prevent the binder from slopping out, and there is generally a removable screen which intercepts anything likely to clog the nozzle. The nozzle is a slot 6 to 10 inches long, which is usually adjustable. A skillful man can apply bituminous material in this way very uniformly, but the expense on large work is greater than with distributors.

The binder can be heated in portable kettles, usually mounted on wheels, in distributing wagons, oil heating pits, or in tank cars, the method to be followed depending upon the amount of material to be heated.

The amount of binder used is from $1\frac{1}{4}$ to $1\frac{3}{4}$ gallons per square yard, depending upon the depth and size of the stone. If an asphalt binder is used it must be applied at a temperature of about 300°F. and if tar at about 200° to 225°F. After it is spread it is covered with small stone, usually from about $\frac{1}{4}$ to $\frac{3}{4}$ inches in size; in New York State work stone of $\frac{5}{8}$ to $1\frac{1}{4}$ inches is specified. In Massachusetts good results have been obtained in some cases with sand. After this dressing has been spread it is often gone over with brooms to make certain that all voids in the surface are filled, and the material unformly distributed, and the brooming should be finished with the brooms working parallel with the line of the road.

After the top course has become firm under the roller, the surface is swept clean and the seal coat is applied. This is usually spread at the rate of $\frac{1}{3}$ to $\frac{3}{4}$ gallon per square yard, and is covered with $\frac{1}{4}$ to $\frac{3}{4}$-inch stone chips or pea gravel. The road is then broomed, using a lock street broom for the purpose, and then given a thorough rolling as to consolidate it as much as possible and the broom can be attached to the roller during this final rolling. A liberal use of both the hand broom and the lock street broom, or the broom fastened to the roller, during the screening and finishing of the road will do much to insure that the dressing is evenly taken up by the oil and a smooth riding surface obtained that will not start the pounding of automobiles and the consequent rippling of the surface.

In the State highway work of Illinois, there are there courses and a seal coat in bituminous macadam construction. The second course is 1 to $2\frac{1}{4}$-inches stone, harrowed, rolled, and treated with 1 gallon of binder per square yard. This is covered with $\frac{1}{4}$ to $\frac{1}{2}$-inch screenings, which are broomed into the voids and the excess swept off. A second application of binder is then made at the rate of $\frac{1}{2}$ gallon per square yard and covered with torpedo gravel ranging in size from $\frac{3}{8}$-inch down to fine sand. This is broomed until the voids are filled, when the surplus is removed. Another application of binder is made at the rate of $\frac{1}{2}$ gallon per square yard and covered with torpedo gravel at the rate of about 1 cubic yard per 200 square yards of road. The wheels of the roller may be wet to prevent them from picking up the binder; some engineers object to such wetting and require the wheels to be oiled.

Where the grade is steep, the Massachusetts highway commission has recently tried the practice of leaving the surface rather rough, so as to afford a foothold for horses and resistance to skidding for automobiles.

Bituminous Concrete.—When the stone and binder are mixed together thoroughly before they are placed on the road, it is practicable to use both small and large stone and thus reduce the volume of the voids to be filled with bituminous binder. This material is placed on any of the bottom courses used with bituminous macadam and also on concrete. It is essential for the bottom course to be dry and clean when the mixture is spread over it.

The size of the stone required by different State highway departments varies somewhat, and some departments have a number of standard proportions. In Massachusetts crusher-run trap from $\frac{1}{4}$ to $1\frac{1}{2}$ inches is specified for some roads, and also crushed gravel, which will be mentioned later. In New York, $\frac{5}{8}$ to $1\frac{1}{4}$-inch stone is used for a course 2 inches or less in thickness, and for thicker courses stone up to $2\frac{1}{4}$ inches in size is allowed. In both New York and Maryland materials are permitted which will give a finished pavement with less than 10 per cent passing a 2-mesh screen, 8 to 22 per cent passing a 4-mesh, 25 to 55 per cent passing a 10-mesh, 18 to 30 per cent passing a 40-mesh, 5 to 11 per cent passing a 200-mesh, and 7 to 11 per cent of bitumen. In Maryland a mixture is also used containing two parts of $\frac{1}{4}$ to $1\frac{1}{4}$-inch stone and one part of sand with 25 per cent passing a 20-mesh screen and 5 per cent passing 80-mesh. To this mixture is added 5 per cent of powdered limestone or cement and 7 to 9 per cent of bitumen. In Illinois the proportions are left to the engineer, but the purpose is to obtain the equivalent of a thorough mixture of 1 cubic yard of grit sand passing a $\frac{3}{8}$-inch ring with 40 to 80 per cent passing a 10-mesh sieve, and 3 cubic yards of $\frac{3}{4}$ to $1\frac{1}{2}$ inch stone with 30 to 80 per cent retained on a 1-inch ring. Instead of the stone 3 cubic yards of $\frac{3}{8}$ to 1-inch gravel with 20 to 70 per cent retained on a $\frac{5}{8}$-inch screen may be used.

The amount of bituminous binder on the Massachusetts work is about 20 to 24 gallons per cubic yard of stone. In New York, for the work with broken stone without fine material, 18 gallons are used per cubic yard of stone and the purpose is to have the finished course contain from 5 to $7\frac{1}{2}$ per cent by weight of bitumen. On the Illinois work, from 27 to 30 gallons of binder containing 95 per cent or more of bitumen is used per cubic yard of stone or gravel, and if the binder contains less than 95 per cent of bitumen the quantity must be increased proportionately.

Although stone and tar binder have occasionally been mixed cold, as in Rhode Island, it is customary to mix the stone and bituminous material hot. There is a marked difference of opinion regarding the temperature to which the stone should be heated, Massachusetts requiring this to be 180°F. or more and Illinois 300° to 375°. A high temperature will injure some binders and not others, and it is therefore important to have the aggregate uniformly heated to the proper temperature for the binder used, the weather conditions, and the length of haul from the mixing plant to the road. The binder is heated in kettles or tanks. The temperature for asphalt is 275° to 375° and for tar 200° to 275°, the limits varying somewhat with the grades used. Special care must be taken to prevent overheating. Sometimes hot stone and cold binder are mixed. The mixing on small work can be done by hand, but is more quickly and thoroughly performed on large work in mixers made for the purpose.

The best equipment for any contract will depend upon local conditions, among which the transportation of the mixed material is an important factor. The mixture must be delivered on the site at temperatures of 150° to 280°, according to the binder used. The maximum permissible drop between the temperatures of the material at the mixer and when it reaches the road, freedom from segregation in the mixture, and the practicable speed of delivery, fix the maximum length of haul. If the maximum length of haul permits the use of a central plant for the whole work, it is often practicable to locate it at the crusher plant and save some labor charges. Portable plants for use along the road have been greatly improved in recent years and are used extensively.

The wagons for transporting the mixture should be tight, and under some weather and hauling conditions their contents should be covered with canvas to keep them from becoming chilled. The bodies of motor trucks are sometimes jacketed or insulated for the same purpose.

The mixture should be shoveled from the wagons, or dumped on wood or metal platforms from which it can be shoveled. The shovels are often heated, as are the rakes used in spreading the mixture. It is considered desirable by some engineers to prohibit delivering hot mixture on the road within one hour of sunset.

When the edges of the pavement are not protected by a stone or concrete curb, the New Jersey highway department requires the contractor to place temporary curbs of 6 or 8-inch planks of the same thickness as the finished top course.

When it is necessary to lay half of the width of a road so as to allow traffic on the other half, the base of the first half is allowed to project about 2 feet beyond the center line of the roadway. The top course in such cases ends only a few inches beyond the center line, for this will insure all of it resting on a firm base. After the second half of the base has been constructed, the inside edge of the top course already laid is cut back vertically or nearly so along a straight or properly curved line so as to obtain a perfect joint with the second half of this course.

After the material has been spread, it should be rolled immediately. Sometimes an initial compression is given with a 3- to 6-ton tandem roller and the final compression with a 10-ton macadam roller, but the usual practice is to use a 7- to 10-ton roller giving 200 to 300 pounds per linear inch of roll. The wheels may be oiled to prevent the binder from sticking to them. This rolling is continued until the roller leaves no marks in passing. Any places which can not be reached by the roller are rammed with a hot iron tamp.

The road is often given a seal coat at the rate of $\frac{1}{3}$ to $\frac{3}{4}$ gallon of binder per square yard, which is at once covered with pea stone or grit. The binder is often the same material used in the bituminous concrete but sometimes it is a more fluid grade.

Some engineers require it to be applied with a squeegee distributor. The seal coat is rolled until it is thoroughly incorporated with the top course.

Mixed Gravel-Asphalt Roads.—The Massachusetts highway commission has built a number of roads with mixed gravel-asphalt surfaces on gravel and broken stone bases. The surfacing with a gravel base is 2½ inches thick after rolling. The following notes from its 1915 report describe the construction:

> A road, 18 feet in width with 3-foot shoulders, was built everywhere, the curves being banked and widened to 21 feet. A gravel foundation was put in wherever the bottom was bad, and about 4 inches of local crushed stone was spread and well rolled.
>
> On this was spread, as evenly as possible, about 3 inches of a bituminous mixture made of gravel that had been run through the crusher and sand or stone dust, mixed with a heavy asphaltic product. The gravel and sand and the asphalt were thoroughly heated and were mixed in a hot mixer, and then carted onto the road and spread. The surface was rolled down to about 2 inches in thickness when the mixture was sufficiently cool not to crawl under the roller.
>
> Great care is necessary to insure a uniform product, uniformly heated, mixed and spread, and that sufficient asphalt is used and no more than sufficient to bind the mixture properly. The quantity of asphalt has to vary somewhat, according to the amount of voids in the mineral aggregate. The variation is usually from 18 to 22 gallons of the hot asphalt to the cubic yard of gravel. When the mixture is right it has about the consistency of brown sugar and compacts under the roller, though when it is first spread and rolled it sometimes has a few hair cracks which the traffic soon irons out. The asphaltic product used in this work has a penetration of from 80 to 120 with a Dow penetrometer.

Sand and Oil Roads.—In 1905 the Massachusetts highway commission surfaced a road at Eastham by distributing hot asphaltic oil over the sand which is practically the only material in the vicinity, applying 1½ gallons to the square yard in two applications. The results were so encouraging that more sand-oil roads have been built and the experience thus gained has shown what are the requirements for success. They are now built by both the penetration or layer method and by the mixing method. They are considered suitable when the traffic is mostly light teams and automobiles and will not stand up if used daily by many heavily loaded teams. The average daily traffic in 1915 on one successful layer road was 20 heavy teams, 17 light teams and 253 automobiles. On a mixed road it was 6 heavy teams, 23 light teams and 505 automobiles; on another mixed road 21 heavy teams, 38 light teams and 197 automobiles.

It is desirable for success to use a hard, strong, sharp and well-graded sand, such as is abundant on Cape Cod, where this type of construction has been developed. Many sands are too fine, too uniform in size, too rounded or not strong enough. Fair results have been obtained with some fine sands, however.

An oil asphalt of good quality that will bind and not lubricate must be used. For the layer type, the preference in Massachusetts is for an oil with a viscosity of 150 to 200 seconds at 200°C., using a Lawrence viscosimeter or about 1038 to 1384 with 100 cc. at 100°C. in an Engler viscosimeter. From 1½ to 2 gallons per square yard are used, in two applications, with a covering of sand after application. In the mixed type, oil asphalts having a penetration of 60 to 135 by the Dow penetrometer have been tried, but that now used ordinarily has a penetration of 90 to 125. From 16 to 22 gallons per cubic yard of sand have been used; the present average is 18 gallons. The Massachusetts commission advises testing each carload of oil before using it.

In the layer type of construction, the commission spreads clay or loam over the sand subgrade to reduce the rutting of the surface by wheels and pitting by horses' hoofs when the oil cart passes over it. The oil is then spread evenly while hot with a distributing cart and immediately covered with sand. This process is then repeated.

In the mixed type of construction the sand and oil are mixed hot to form a mastic which is spread over the sandy subgrade and rolled. The subgrade is carefully shaped and hardened as in the case of the penetration type. The mastic sheet is about 4 inches thick at the center and 3 inches at the edges. The best results have been obtained by keeping the road constantly shaped with a road scraper during rolling, and a seal coat of ½ gallon of a lighter oil such as is used in layer work improves the surface and decreases maintenance charges. In the early work the sand was heated on sheets of iron, but this overheated parts of it and underheated other parts, so that now the heating is done in rotary heaters.

If the traffic in the future proves too heavy for these roads, the commission believes they can be greatly improved and strengthened at a moderate cost by using harder asphalt, greater care in grading the sand, and the addition of cement and stone dust. In this way a sheet asphalt pavement 2 inches thick can be laid on the old sand-asphalt road as a base.

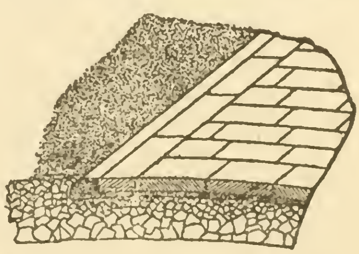
Asphalt Blocks on Country Roads

As designed and manufactured for use on country roads, the asphalt blocks are 5 inches wide, 12 inches long, and 2 inches deep, weigh about eleven pounds each, and have a specific gravity of about 2.40.

The asphalt block was developed and perfected on the theory that crushed trap rock, on account of its preëminent hardness and inherent grittiness, made the best known material for a roadway surface, the one thing needed being a cement, or binding material, to keep all of the particles permanently in place. This was accomplished by the use of an asphaltic cement to bind together the properly graded particles of crushed trap, the hot mixture being consolidated by tremendous pressure into blocks so dense and free from voids as to be practically non-absorbent. In the asphalt block, therefore, we have an asphaltic concrete, or macadam, mixed, in exact proportions, at a central plant, under conditions insuring absolute uniformity, and receiving the compression necessary to produce a dense and non-absorbent material.

Not only has a special block been produced, but a special method of construction has been worked out, designed to utilize what is left of the worn and rutted macadam road as a foundation for the blocks. This is accomplished by scarifying the surface, if necessary, filling up the deep ruts, rolling with a heavy steam roller, and laying upon the surface of the old macadam, a bed of cement mortar about 1 inch in thickness, to serve the double purpose of forming a firm unyielding bed for the blocks, and binding them securely to the macadam foundation underneath. By this method the material used in the original construction of the road is not thrown away, but used as foundation for a permanent wearing surface. Where the old macadam is too thin, or too badly worn to be safely used as a foundation, it will be necessary to lay a concrete base, but usually there is broken stone enough in the old macadam to supply what is needed for laying concrete.

A pavement may be laid of any desired width, contour, grade, or crown. It is perfectly feasible to pave one-half of the roadway, or only a narrow strip in the center, and extend the paved area at a later date as traffic necessities require, or as appropriations become available. It is not necessary to set curbstones or heading stones to border or define the paved area, since a row of stretcher blocks held firmly in place by a shoulder of mortar, as shown in the sketch, answers the purpose perfectly and leaves the entire roadway surface smooth and uniform.



A good example of this construction is on the Albany Post Road, through the villages of Hastings-on-Hudson, Dobbs Ferry, Irvington, North Tarrytown, Town of Mount Pleasant, Briarcliff and Ossining, N. Y., on the Boston Post Road in Pelham Manor and Rye, N. Y., on 9 miles of roadway from Daytona to Deland, Volusia County, Florida, and on Nassau Street, Princetown, N. J., a section of the Lincoln Highway.

BITUMINOUS SURFACE APPLICATIONS[1]

Surface applications vary widely in character, according to their purpose. In most cases such an application is essentially a maintenance measure, but in the case of the bituminous mats or wearing courses used in California, or the mats now laid on new water-bound macadam, the first cost of such work is essentially a part of the first cost of the improvement. The practice in making such surface applications of any general type varies widely in different parts of the country, more widely than the practice in any other branch of road work. Whether greater uniformity will prove desirable or the work can be done successfully by a wide variety of methods can not be definitely determined until the records of such work and of the traffic on roads are kept with more detail and uniformity than at present. The widespread interest in the subject was one of the leading characteristics of highway affairs in 1916, and was an evidence of the conditions mentioned.

Oiling Earth Roads

Surface applications on earth roads were made in California many years ago, and a method of incorporating oil and earth by a special form of roller was employed for some time. More recently well built earth roads in Iowa and Illinois have received surface applications as a maintenance measure. The experience in these states shows that while some success follows applications on roads that are not in good condition, it is very desirable to have the surface properly shaped and hard before the oil is applied. The oil binds the grains of earth together and reduces the dust, but it does not give the resistance to attrition which a hard surface affords. The treatment is therefore one which must be regarded as adapted only for roads with light traffic and light vehicles. If sand instead of earth is present, the methods of construction first used in Massachusetts and described on page 147 should be considered.

If the road has ruts and holes in the surface and is poorly drained, water will collect in puddles, soften the oiled crust at

[1] Revised by George H. Biles, second deputy State highway commissioner of Pennsylvania, and B. H. Piepmeier, maintenance engineer of the Illinois State highway department.

these places, and seep into the roadbed. The material under the crust will give way under heavy loads and the money spent in oiling will be largely lost, because the oiled material will become mixed with the unoiled material below and dust will be produced about as freely as on an unoiled road. Furthermore, the oiling of a mudhole often aggravates troubles due to such a defect.

The surface to receive the application must be dry, or the oil will not penetrate the pores, and it must be free from dust, for the oil forms flakes or scales with the dust and these are a worse nuisance than plain dust, being very irritating to the eyes.

Both cold and hot applications have been used successfully in Iowa, but the State Highway Commission prefers to heat the oil as it apparently gives enough better penetration to justify the additional expense. It is desirable to secure the advice of a specialist in selecting the oil. A light oil must be used and as it may have a low flash point, care should be taken to keep it at a temperature below its flash point and to prevent any of it coming into contact with a flame. The first application is made at a rate of about $\frac{1}{2}$ gallon per square yard, and later applications at the rate of $\frac{1}{4}$ to $\frac{1}{3}$ gallon. The brief experience in such work indicates that two light applications annually for two years and afterward a single application annually will be sufficient on a road adapted for such treatment and not subject to traffic requiring a more durable surface. During 1916 the Illinois State highway department issued the following advice on the work.

The best results may be secured during the first application, by applying either a cold oil or at least a very thin product that will penetrate the surface of the road several inches and at the same time contain as many binding elements as possible so as to seal all pores in the earth, making it waterproof and at the same time adding some binding qualities that may assist the bond of the soil itself. A suitable product, as is commonly expressed, may vary from 30 to 60 per cent in asphalt. After the surface of the road has been thoroughly saturated, a hot oil or a slightly heavier product may be used.

If the heavier oils are used for the first application they will not readily penetrate the surface of the road and will consequently form a mat on top. The forming of the mat before the surface of the road is more or less waterproof may be a serious fault as moisture will accumulate beneath the mat and the road will be much slower in drying out than it would had the oil not been applied. The mat surface with a soft subsoil will rut more readily, besides breaking and scaling off in large pieces, making the road surface rough and undesirable.

The Illinois authorities recommend covering the oiled surface with clean, hard sand, at the rate of a cubic yard to 100 to 150 square yards.

Broken Stone Road Surfacing

It has been found that a surface application on a new water-bound macadam road may prove unsatisfactory, although if the road is exposed to traffic for three months the desired results are obtained if the treatment is properly carried out. This is probably due to the large amount of fine, lightly-bound dust on the roadway, which is removed by the early traffic, or to the greater stability of the road as a result of its consolidation by traffic. In New York, macadam roads finished so late in the fall that they can not have three months wear before winter, are given a surface application of calcium chloride as a temporary protection against raveling during the months that must elapse before bituminous surfacing can be placed.

In making thin surface applications to an old road that is thick enough to carry the prospective traffic and has a surface in fair condition, the ruts and holes must first be patched. This is best done several days in advance of the surfacing. Each hole or rut is swept clean,[1] painted with bituminous material and filled with $\frac{3}{4}$ to $1\frac{1}{2}$ inch stone and binder. The stone and binder are often mixed at a central point and carted along the road by the patching gang, for use where required. Just before the surfacing is done, the road is swept thoroughly, often with some type of revolving broom. Sometimes wire brooms are used first and then fiber brooms. The oil is applied hot or cold according to quality at the rate of about $\frac{1}{6}$ to $\frac{5}{8}$ gallon per square yard, as the engineer considers best, and then covered with clean screenings, granulated slag or gravel at the rate of about 60 pounds per square yard. It is advisable to secure the advice of a specialist in selecting the oil. The oil is applied by hand on small work, but usually with a distributor. If the screenings are distributed by hand they should be previously deposited in piles at convenient intervals along the roadside. They are also distributed by spreader carts. The length of time the road should be closed to traffic depends upon the weather, character of the oil, and the amount of screenings used, varying from 1 to 48 hours.

If the road oil rises through the screenings, or "bleeds," in hot weather, more screenings should be spread over those places. If the road is used mainly by automobiles, a thin covering of screenings is sometimes spread first and later a covering of sand or other fine material, to act as a filler and prevent the tires from dislodging the screenings.

The following rules for the amount of bituminous material to be used in surfacing broken stone roads were prepared by George H. Biles, second deputy highway commissioner of Pennsylvania:

[1] It is desirable to cut the edges of a hole so as to secure vertical faces to which the new material will adhere properly; a patch with a feather edge is liable to be unsatisfactory.

If the surface of the road is made up of pieces of ballast size stone (3-inch) from which traffic has removed all the fine material, leaving large surface voids between the stone, enough of the bituminous material must be applied so that it will flush up level to the top of the large pieces of stone and firmly bind the chips and gravel which lie in the crevices between the stone.

If, on the other hand, the surface of the road is equally clean, but traffic has not removed the fine particles between these stones to the same extent, and the crevices between them are consequently smaller, then a somewhat smaller amount of bituminous material should be used, since an excess will again flow off the road.

In treating a road which has recently been resurfaced, it will be found often that even after all the screenings and fine material have been swept from the top of the road leaving the large stones bare, there will still be a certain amount of dust and fine material between the stones which has not yet been compacted thoroughly by traffic and which will absorb the bituminous material like a blotter, leaving only a brown stain in these spaces. In such cases, the amount of application must be increased until this fine material is well saturated and there is enough of the bituminous material near the surface of the road to bind thoroughly the covering of chips or gravel.

The first application of a bituminous surfacing to a waterbound macadam road may be disappointing. The hoofs of horses are liable to dislodge the mat and the surface will have a spotted appearance. After several applications, however, the macadam surface will become protected everywhere.

On the New York State highways which are thick enough to carry the traffic but are too rough to be treated satisfactorily with cold oil and screenings, surfacing with two applications of hot oil is sometimes done. After the old road is patched and cleaned, it is covered with 0.4 to 0.6 gallon of oil to the square yard, over which just enough 1-inch stone is spread to cover the surface. This is rolled lightly and then covered with 0.3 to 0.4 gallon of oil per yard. This is covered with $\frac{1}{2}$ inch stone in the thinnest possible layer, which is rolled as soon as the oil is cool enough to permit it.

On the Illinois highways, when a double application is made, about $\frac{1}{4}$ gallon per square yard is used on each application, and the preferred covering is torpedo sand, $\frac{1}{8}$ to $\frac{3}{8}$ inch in size, but clean, stone chips are also employed. The total amount of covering material with such a treatment is one cubic yard for each 125 square yards of road. When a single application is made $\frac{1}{3}$ to $\frac{1}{2}$ gallon of oil per square yard and a cubic yard of torpedo sand for every 150 square yards of road are employed.

Bituminous sandstone obtained in Kentucky has been used in parts of that state for re-surfacing old macadam. The latter is scarified, smoothed with a road machine, and enough new stone added to give the desired thickness and contour. This is rolled thoroughly and then covered with pulverized bituminous sandstone to a depth of about $1\frac{3}{4}$ inches, loose, when spread. It is desirable to allow the sun to shine on the loose material for a few hours, until it appears slightly oily, and then roll it, slowly at first and later more rapidly.

Concrete Road Surfacing

While surface applications to concrete roads have been employed in a number of states, there is no agreement as to their desirability. They have been used to the greatest extent in California, where both thin wearing surfaces and an asphaltic mixture are used. The following information concerning both types was supplied by Austin D. Fletcher, State highway engineer of California.

The thin bituminous wearing surface is about half an inch in thickness when completed. After it has been under traffic for a few months it is found to contain a fairly uniform mixture of mineral aggregate and bituminous binder consisting of about 8 to 11 per cent of bitumen and the balance mineral aggregate of a fairly uniform grading running from dust to rock of $\frac{1}{2}$-inch maximum diameter. It shows no tendency to flow or creep and the surface remains true and free from rolling. The concrete base, however, must be finished with a true, smooth surface to make a good riding highway as this type of surfacing is not thick enough to smooth up to any considerable extent a concrete pavement whose surface is uneven.

The procedure in laying this thin wearing surface is as follows: First the surface of concrete is cleaned of dirt, dust films and any thin coat of laitance. This is best accomplished by opening the bare concrete to traffic for a month or two. The iron shod traffic and the rapidly moving rubber tires are of greatest help in breaking any weak layers of dirt or laitance and exposing the surface of the concrete proper. This "traffic cleaning" is followed by brushing with revolving street brooms and hand brooms. In some cases flushing the surface with water is a help in washing off any thin coat of clay. It is of greatest importance that the asphaltic oil bind to the solid concrete and not to any overlying weak film of dirt. The care taken in getting a clean concrete is without doubt in a large measure responsible for the success of this surfacing because of the strength of the bond between the concrete and the bituminous wearing coat. The few failures where the wearing surface has been stripped from the concrete have been nearly always easy to trace to a pavement improperly cleaned prior to the application of the road oil.

After the concrete has been cleaned the asphaltic oil is applied by a pressure distributor at the rate of $\frac{1}{4}$ gallon per square yard. This oil surface is immediately covered by a layer of either crushed rock screenings or fine gravel of $\frac{1}{8}$ to $\frac{1}{2}$ inch. This material may contain some fines and dust but should be fairly clean.

The screenings are applied by shoveling from piles placed at frequent intervals alongside the road. The shovelers can be taught to so throw the screenings that they will cover the road surface with a fairly uniform thickness. The road can now with advantage be given a light rolling but this is not necessary. Any excess screenings should be swept into piles alongside of the road to be used on the second application of road oil. This is applied on the second application at the same rate and is covered with screenings as before.

The road is now thrown open to traffic and during the first two weeks may require further screenings to take up excess oil. The traffic is of great assistance in forcing the screenings into the oil and compacting and making a homogeneous carpet on the concrete.

The oil is applied to the road at a temperature of from 250° to 300°. It contains approximately 90 per cent of 80° penetration asphalt. In California the road oil companies classify this product as a "90–80" road oil.

In building the thin bituminous wearing surface for concrete pavements two physical properties of the road oil are of greatest importance. First the oil must be of such a viscosity that when applied to the road it will readily combine with the screenings that are thrown upon its surface. A very viscous oil will form a hard surface and the screenings will lie there without being absorbed and to a large extent be thrown off the road by the passing traffic. Only a small amount will settle or be forced into the oil and the surface will not build up into a satisfactory protecting wearing coat.

The second physical property of great importance is that the road oil must be cementing or adhesive so that it will bind tightly to the concrete surface and bind together all of the fragments of stone screenings. It should be an active cement and if it is not sticky then the wearing surface will not be firm enough to resist the push and pull of the passing traffic.

The State highway routes leading from the great centers of population have required a higher type of surfacing to meet successfully the demands of heavy traffic.

After proper curing of the concrete its surface is cleaned of all dirt and dust films and given a paint binder coat composed of asphaltic cement and engine distillate of lightest gravity. The asphalt used has a penetration between 80° and 90°, the mix being one part asphalt and one to two parts distillate, the exact proportion of distillate being determined by trial. The satisfactory mixture is one that paints the concrete with a thin, uniform, glossy black film which becomes hard two hours after application.

The surfacing used has the following composition expressed in percentages:

Bitumen soluble in carbon disulphide, 7½–10

Aggregate:

PASSING	REFUSING	
200 sieve	....	8–13 per cent.
80 "	200 sieve	14–25 "
40 "	80 "	17–29 "
10 "	40 "	5–11 "
4 "	10 "	15–25 "
2 "	4 "	3–10 "
2 "	....	100 "

The asphaltic cement used has a penetration of from 70 to 90 degrees, District of Columbia standard, and passes the usual requirements for solubility, volatility and ductility. The heating of asphalt, aggregates and dust and mixing and laying follow the usual practice.

Prior to the laying of the surfacing, the testing laboratory makes grading tests of such sand, limestone dust and rock screenings as will be available for the work and selects such of these that give the desired mix. In this selection the following points are considered important:

Let a be taken as the percentage of asphaltic cement that will be used in the finished material. Then the dust passing the 200-mesh sieve should at least equal $a-1$. The fine sand passing the 80 mesh and retained on the 200 should be approximately $2a$. If the available sand is high on the finer sieves a may be taken as high as 9.5 per cent. If the sand is coarse, a may be as low as 8 per cent for the trial mix. The coarse aggregate passing the No. 2 sieve and retained on No. 10 should be from 28 to 35 per cent of the other mix. If these points are satisfied by the available material the weights of coarse aggregate, fine aggregate, dust and asphaltic cement can be given to the road crew for a trial batch. Under field working conditions a trial batch will show if the mix is "wet" or "dry" and by a slight change in the percentage of asphaltic cement a mixture can be made that will rake and roll properly. In this way the mineral aggregate is not changed but kept under known satisfactory grading. As the work proceeds, grading tests should be run at frequent intervals on the different mineral aggregates to insure a uniform grading in the finished pavement. Analysis of samples of the different batches should also be made to check the uniformity of the mix.

The surface after thorough rolling should have a specific gravity in excess of 2.20 if the sands and crushed rock screenings are of average specific gravities. A sample of the finished pavement taken each day and tested for specific gravity will indicate if there has been insufficient compression, either due to method of rolling or to the surface being too cold when rolled.

BRICK ROADS[1]

Brick pavements have been used on the streets of American cities for many years and the United States Bureau of the Census reports that in 1909 they formed nearly 24 per cent of the entire mileage of paved streets in 158 cities. Some of the early brick pavements gave satisfactory service for many years, but others did not. The unsatisfactory early experience was due in part to the use of unsuitable materials, in part to the improper reconstruction of pavements cut to permit laying pipes, and in part to the defective methods of construction employed, just as was the experience with other types of block pavements. It is not possible to build lasting block pavements unless the blocks are prevented from settling, which results in holes in the surface, or from tilting over on their bottom side, called "turtling," which results in a rounding of the upper edges of the blocks, called "cobbling." These defects led to better methods of construction, so that when bricks came into use on country highways success was assured if municipal experience was taken as a guide. There are always ccmmunities as well as persons unwilling to profit by the experience of others, however, and consequently some brick roads have been built of poor materials and by poor methods with the inevitable unsatisfactory results. Such unfortunate experience was unnecessary then and is unnecessary today; it was largely due to ignorance of the requirements for good work, carelessness, lack of proper supervision, and a desire to cheapen the cost of such roads below the amount needed for proper construction.

Paving Bricks

Paving bricks are made from a great variety of shales and fire clays and consequently bricks of equal worth vary considerably in appearance. Shale contains iron which makes shale bricks red when burned under normal oxidizing conditions and brown

[1] Revised by William W. Marr, chief state highway engineer of Illinois; A. H. Hinkle, deputy highway commissioner of Ohio; P. M. Tebbs, engineer of construction of the Pennsylvania State Highway Department; Will P. Blair, secretary of the National Association of Paving Brick Manufacturers; and W. C. Perkins, chief engineer, R. T. Stull, ceramic engineer, and F. A. Churchill, of the Dunn Wire-Cut Lug Brick Company.

or nearly black when burned under reducing conditions. Fire clays have less iron than shales, the iron being present in a combined state, and bricks made from them are buff-colored, unless reducing conditions during burning darken them. The shales and fire clays are often unsuited for making paving bricks as they occur, and then material from one stratum in a pit must be mixed with that from another stratum or that from one pit with that from another, and sometimes with sand or surface clay.

The raw materials are crushed and ground dry in large revolving pans under heavy rolls, called "mullers." This material is screened to remove pieces of too large size, and is then conveyed to a pug mill, in which the materials are mixed somewhat as concrete is mixed in a continuous concrete mixer. Here enough water is added to convert the material into a thick mud, which is beaten by the revolving blades into a condition of uniform consistency and composition. This mud is fed continuously into a brick machine, where it is forced by an auger through a die, whence it emerges as a fairly hard bar of rectangular section, which is cut mechanically into bricks. This bar of hard clay may be approximately 4 by 4½ inches in section, in which case it is cut about every 9 inches, forming "end-cut" bricks, or it may be approximately 9 by 4½ inches in section and cut every 4 inches, forming "side-cut" bricks. These bricks are sometimes submitted to a reshaping process before drying, in which case they are called "re-pressed" bricks, and sometimes they are dried as they are finished by the brick machine, in which case they are called "wire-cut" bricks. For drying, the bricks are placed on cars which are run very slowly through a long, tunnel-like heater, into which hot dry air is admitted continuously. After remaining on the cars in the tunnel about twenty-four hours their weight is reduced from 15 to 20 per cent. The bricks are then ready for burning, one of the most important steps in the manufacturing process. The bricks are stacked in kilns in such a way that the heated air circulates freely around them, and great care must be taken in the regulation of the temperature throughout the entire burning process, from the time the kiln is first warmed until it is cool enough to permit the withdrawal of the bricks.

In laying paving bricks a space is left between successive rows for the material which forms the joints, and as it is very desirable for these joints to be of a uniform width, one side of a paving brick has either two or four lugs, which are small projections from the surface of the bricks.[1] These projections serve to keep

[1] There are some bricks which do not have lugs but have raised letters or four projections, one near each corner, on one face. Raised letters are not permitted on bricks for Ohio State roads.

the adjacent faces the proper distance apart when the bricks are forced into contact during the paving operations. These projections extend $\frac{1}{8}$ to $\frac{1}{4}$ inch from the side or face. In one class of side-cut bricks the cutting is done by wires which are moved across the bar of clay so as to produce the lugs needed on one side of the brick. These are called "wire-cut lug" bricks. In another type of side-cut bricks, $2\frac{1}{2}$, 3 and 4 inches deep, the ribs are moulded on one of the sides as it comes through the die. A wire-cut side is placed on top in laying such bricks, which are called "vertical fiber" bricks in some parts of the country. Other types of projections are made by devices attached to the brick machine. In the case of repressed bricks, the projections from one or both sides are made in the press.

There is no universal standard size for bricks but the tendency seems to be toward $3\frac{1}{2}$ inches width, 4 inches depth and $8\frac{1}{2}$ inches length, with a permissible variation of $\frac{1}{8}$ inch either way in the width and depth and $\frac{1}{2}$ inch either way in length. The depth is occasionally reduced as much as an inch for roads having light traffic, when the monolithic and cement-sand cushion types of construction, explained later, are used.

"Hillside" bricks are made for use on grades of 5 per cent or more. They have one or more grooves cut the full length of the bricks, along their edges, in the case of bricks to be laid in the usual manner, or two grooves cut transversely in the case of bricks to be laid parallel with the curb. These grooves are about $\frac{3}{8}$ inch deep and are intended to prevent slipping of horses or automobiles. Bricks with beveled edges are used for grades, notably on the carriage ramps of the Pennsylvania Terminal in New York, where the travel is very heavy, and quite generally on grades exceeding 5 per cent. throughout Ohio.

Tests of Bricks

The color of the interior of bricks from the same plant gives an indication of their quality, for generally the color is darker in the bricks burned with the higher temperatures. The color of the exterior of the bricks is a less reliable indication of quality, and even interior color is of little or no value in judging the bricks from different plants. The other features of bricks which can be determined by visual inspection are explained in the following description of the bricks which may be rejected under the standard specifications of the American Society for Testing Materials:

All bricks which are broken in two or chipped in such a manner that neither wearing surface remains substantially intact, or that the lower or bearing surface is reduced in area by more than one-fifth.[1]

All bricks which are cracked in such a degree as to produce defects such as are defined in (the previous paragraph) either from shocks received in shipment and handling, or from defective conditions of manufacture, especially in drying, burning or cooling, unless such cracks are plainly superficial and not such as to perceptibly weaken the resistance of the brick to its condition of use.

All bricks which are so off-size, or so misshapen, bent, twisted or kiln-marked, that they will not form a proper surface as defined by the paving specifications, or align with other bricks without making joints other than those permitted in the paving specifications.

All bricks which are obviously soft[2] and too poorly vitrified to endure street wear.

Formerly a number of different laboratory tests of the properties of paving bricks were required by specifications, but today reliance is placed mainly on the rattler test to determine their quality. Its name is derived from the use of a foundry rattler, employed in cleaning iron castings, in making the first tests of this kind on bricks. The rattler used today is constructed specially for the purpose. It is an iron and steel barrel of the cross-section of a 14-sided polygon, about 20 inches long and 28 inches in diameter, inside dimensions, with a shaft projecting from each end. This barrel is mounted in a frame with the shafts horizontal and can be revolved by power.

Ten dry bricks are weighed and placed within the rattler, together with an abrasive charge consisting of 10 cast-iron spheres weighing from 7 to $7\frac{1}{2}$ pounds each and a sufficient number of cast-iron spheres from $1\frac{3}{4}$ to $1\frac{7}{8}$ inches in diameter and weighing from 0.75 to 0.95 pound each, to make a total charge of 300 pounds. The rattler is then revolved 1800 times at the rate of $29\frac{1}{2}$ revolutions per minute. In this way the bricks are subjected to innumerable blows which are considered to imitate the conditions of service more nearly than any other test yet de-

[1] Mr. Tebbs makes this comment: "The area of a standard brick is about 30 square inches and I consider about one-fifth or 6 square inches a very large allowance. I think that a reduction of not more than one-tenth of the area should be permitted." This comment is not approved by Mr. Blair on the grounds that experience has shown no ill effects from the rule of the Society, and to limit the reduction of area to 10 per cent. would increase materially the cost of the bricks.

[2] Mr. Tebbs advises adding the words, "not uniformly vitrified, badly laminated." The phrasing of the standard specifications was debated at great length before adoption, and uniform vitrification was not adopted as a requirement because no brick is uniformly vitrified, strictly speaking. The words "badly laminated" are sometimes used, but objection has been raised to them as not conveying to the inspector the meaning of the engineer, which is to reject bricks having laminations that are separate one from the other, sometimes called "open" laminations.

vised. When the test is finished, the bricks are taken out, all pieces of them weighing less than 1 pound are discarded, and the remainder are weighed. The loss in weight during the test, expressed as a percentage of the original weight, is the form in which the results are stated.

The percentage of permissible loss in the rattler test is fixed at different amounts in order to meet the conditions imposed by differences in travel and the experience of different localities with bricks of various grades. The American Society for Testing Materials gives the following scales of maximum permissible losses for different classes of travel:

CHARACTER OF TRAVEL	MAXIMUM PERMISSIBLE LOSS	
	Average	Single brick
Heavy	22	24
Medium	24	26
Light	26	28

The New York and Pennsylvania State highway departments' specifications call for the medium-travel grade and Ohio and Illinois for the heavy-travel grade. In Illinois the wire-cut lug bricks are given 1 per cent higher permissible loss than the repressed bricks, which must conform to the tabulated requirements. In that State there is a minimum permissible loss specified, 17 per cent for wire-cut and 16 per cent for repressed bricks. The average permissible maximum loss may reach 25 per cent for wire-cut lug bricks if no individual brick loses more than 28 or less than 20 per cent, and may reach 27 per cent if the range of loss of every individual brick is between 29 and 23 per cent. With repressed bricks, the average loss may reach 24 per cent, with a range of 27 to 19 per cent for every individual brick, and 26 per cent with a range of 28 to 22 per cent. These requirements put a premium on uniformity in the bricks, which many engineers regard as of importance in preventing unequal wear of the surface of a brick road. They hold that where soft and hard bricks are laid together indiscriminately, some of the bricks are worn away more rapidly than where a pavement is laid with bricks of a more uniform quality.

In New York and Ohio 30 bricks form a lot for sampling. These represent the hard, medium and light-burned bricks delivered on the job, and each grade is tested separately. During testing there is a large percentage of failures in the abrasion test, partially caused by the selection of light and hard-burned brick. The laboratory results obtained on such bricks serve as a guide in throwing out or culling part of the bricks on the job.

Some years ago the crushing strength and specific gravity of paving bricks were considered properties which should be specified, but experience has shown that it is unnecessary to do so. The specific gravity of fire-clay bricks averages between 2.1 and 2.25 and that of shale bricks between 2.2 and 2.4. The crushing strength of good paving bricks ranges from 10,000 to 20,000 pounds per square inch, when the test load is applied over the entire top surface of the specimens, and may be higher if only a part of the surface is loaded. This is from five to ten times the probable maximum load on a pavement.

The capacity of a brick to absorb water was formerly considered an important indication of its porosity, and low porosity was held to be essential for strength and good sanitary properties, which were then considered as particular advantages of brick pavements. With the improvements that have been made in the rattler test and the increased knowledge of the slight influence of a wide range in porosity upon the sanitary value of such pavements, the absorption test has lost much of its former favor among roadbuilders. It affords useful information in comparing bricks made under identical conditions and for other research work, and it is still required by a few State highway departments. In Ohio, the bricks taken from a rattler after testing in that apparatus must not absorb more than $3\frac{1}{2}$ per cent of their weight of water during immersion for forty-eight hours. In Pennsylvania, the absorption of thoroughly dried bricks immersed in water for twenty-four hours must not exceed $3\frac{1}{2}$ per cent.

Another test, formerly used extensively, probably because the apparatus for making it was available in many schools and easily obtained, is the transverse or cross-breaking test. It is now little used outside of New York and New Jersey. In the former State the test required by the highway department is to place the sample brick on edge on two parallel supports 6 inches apart and load it at the center until it breaks. If the distance in inches between the supports is represented by L, the load in pounds which produces rupture by W, and the width and depth in inches of the brick by b and d respectively, the modulus of rupture will be $3WL/2bd^2$, which must not be less than 2000 pounds in bricks for New York state work.

Curbs

Curbs are required along the sides and ends of brick pavements laid on a sand cushion or laid on natural soil and having sand-filled joints, in order to hold the bricks at those places and also, with some types of base, to hold the material of the base in place. Planks have been used, but their short life compared with that of the pavement makes them undesirable, for nobody can foretell whether they will be renewed as they wear out. In some places stone slabs can be obtained for the purpose at prices which enable them to be used economically. Vitrified curbs are sometimes used, but require more careful bedding than stone curbs, because their shorter length and lighter weight render them more subject to displacement. Concrete is most generally used for curbs. In country highway work the top of the curb is usually flush with the surface of the pavement. If a concrete base is used, the curb is usually an integral part of it, and is generally from 6 to 8 inches wide on top. If a concrete base is not used, the depth of the curb must be governed mainly by the character of the subgrade, the frost hazard and the character of the shoulders. In any case it is desirable to have the top 2 inches of the concrete curb not leaner than a 1:2:3 mixture, finished with a wooden float, and the outer surface should be spaded. This spading is done by placing a spade in the form against the outer plank and rocking it back and forth so as to force the coarse aggregate of the fresh concrete away from the face.

Where the bricks are bedded on mortar or green concrete, most engineers believe that curbs are not needed.[1] If they are omitted special care must be given to providing firm shoulders along the marginal bricks.

The Base

A brick pavement requires an absolutely firm unyielding support. An old macadam road thoroughly underdrained and secure against settlement or upheaval ,is considered a satisfactory support by some engineers. But it is rarely possible to find such a road, for usually the drainage is defective, the cross-section has too much crown, or the grades are wrong. It is then necessary to disturb the hard crust of the road and this is very likely to reduce materially its value as a foundation. In some parts of Florida, where frost is not to be feared, if the sand which prevails is held in place by curbs or planks and thoroughly rolled while damp, it makes a hard, unyielding support not subject to disturbance if good drainage is assured. On the other hand, the black soil of the prairie States, which absorbs water freely and

[1] Mr. Marr states: "Experience in Illinois demonstrates beyond question that curbs are not needed under such conditions. We have had several instances where the edges of the bricks were exposed at intersections to a grinding action of wheels striking them at acute angles, and there seems to be absolutely no danger of the bricks being loosened at the edges under any conditions obtaining in ordinary service."

parts with it slowly, is an unstable material and a strong concrete foundation must be provided for brick roads built over it, so that any differences in the supporting capacity of the subgrade, from one season to another or between adjoining places in the road, are equalized by the concrete slab and do not cause waves in the brick surface.

The methods of constructing the road bed and preparing the subgrade are explained in the chapter on earth roads. It is necessary to have a uniformly firm subgrade, and if there are heavy cuts and fills the grading must be done carefully. It is desirable to allow the subgrade to go through one winter before putting down the pavement, although this is rarely practicable under the usual working conditions. The drainage is particularly important, on account of the difficulty of improving it, if defective, after the pavement is laid.

If the subgrade is firm and well drained, a 6 to 8-inch base of good gravel, broken stone, vitrified clay[1] or slag, thoroughly consolidated by rolling, may prove sufficient for moderate traffic. Such a base should be built in two courses with all the care given to the best macadam construction. In some cases, second quality paving bricks have been used for a base. The subgrade is covered with enough sand to give a depth of 2 inches after rolling with a hand roller. The No. 2 bricks are laid flat on this cushion, parallel with the curb, and the joints are filled with fine sand.

The best base for general use is concrete. A few years ago there was a general opinion that it should be 6 inches thick, but 4-inch bases on well-built subgrades are giving satisfaction where frost action is not serious, and a thickness of only 3 inches or less is under consideration by some engineers. If a secure subgrade is provided, the best thickness is in part determined by the cost of the concrete. A $1:3\frac{1}{2}:6$ mixture with ordinary materials, laid to form a 5-inch base, may be less expensive than a $1:2\frac{1}{2}:5$ mixture of better materials laid to form a 4-inch base. If gravel is used as the aggregate, it is generally economical to screen it and then recombine it, if good concrete is desired. If good concrete is not desired, it will be better to leave out the cement entirely and use the money thus saved in putting down a good base of the

[1] Mr. Hinkle advises eliminating gravel and vitrified clay as materials for a base for this reason: "While fair foundations may be made from these materials, it so frequently happens that poor foundations result from the use of these materials that I think it well to omit referring to them here and hence not encourage their use any more than necessary." Mr. Blair believes that the long experience with gravel foundations in places like South Bend, Ind., warrants their use.

macadam type.[1] The thinner the base, the better the concrete should be. A 4-inch base of poorly graded, dirty aggregate and a pinch of cement is an invitation to early failure. One common defect is insufficient mixing. This should be done in a batch mixer which should be run between 15 and 20 revolutions per minute, and after all the materials are in the mixer, the process should be continued until the mixer has made at least 15 revolutions. The surface of the concrete should be struck off by means of a transverse templet, drawn along the side forms, and be kept well wet for at least three[2] days. No traffic should be permitted on the base for at least seven days after it is laid. On the Illinois state highways, if there are deviations exceeding ¼ inch from the desired shape of the surface, they must be repaired if a sand-cement cushion, described later, is to be employed.

The Cushion or Bedding of the Bricks

One of the causes which contributed to limit the serviceability of some early brick pavements was the imperfect way in which the bricks were supported on the base. The latter was covered with loose sand of inferior quality for its purpose, smoothed off roughly without being consolidated, and the bricks laid on it and driven to a bearing with a paver's tamper. The joints were then filled with sand and the roadway thrown open to travel. The surface was not smooth at the outset, traffic on it soon forced some bricks down more than others, and water percolating in cold weather through the joints into the sand cushion alternately froze and thawed, throwing the bricks into irregular positions. Under such conditions the edges of the bricks became chipped, and finally many of the bricks became broken and dislodged, leaving holes in the roadway. The lesson of this experience was so clear that for a number of years the importance of bedding the brick securely has been generally recognized. Today there are three methods of doing this, termed the sand cushion, sand-cement or dry mortar bed and monolithic or green concrete bed types. The purpose of each is to support the bricks securely at the proper elevation to give the pavement a smooth surface.

Sand-Cushion Type.—A sand cushion is primarily intended to smooth out the inequalities in the top of the base, which were formerly greater than good practice now permits, to provide for the slight variations in the depth of the bricks. Experience

[1] Mr. Tebbs advises the use of concrete exclusively as a base for brick pavements. Mr. Blair holds that experience at Cleveland, Terre Haute and other places shows that under proper conditions a base of other material will prove satisfactory.

[2] Mr. Hinkle advocates at least five days.

shows that the sand must be free from large stones, which prevent satisfactory consolidation of the cushion, and some engineers hold that it must also be free from loam, clay and materials of a greasy nature when wet.[1] Granulated slag is sometimes used instead of natural sand and is believed by some engineers to be superior to ordinary sand. Dry sand must be used, according to some engineers, on the ground that wet sand shrinks in drying and cannot be relied upon to support the bricks at the desired elevation. Other engineers believe that somewhat damp sand is more easily handled and gives as good results. The thickness of this bed in the case of city streets has usually been 2 inches of late, but where a concrete base is used for a country highway and is finished so that no part deviates more than ¼ inch from the true surface, a thickness of 1½ inches is enough. On narrow roads where the concrete base is easily finished to the exact cross-section of the road, 1 inch is probably enough.[2]

The dry sand is cast over the base to a slightly greater depth than the proposed thickness of the cushion. The extra depth is usually about ½ inch where a 2-inch cushion is desired. A plank templet, which is often provided with a steel edge, is then drawn over it to smooth it down to the prescribed cross-section. If the roadway is less than about 25 feet wide, this templet is supported at the ends by the curbs. If the roadway is wider than 25 feet, the templet is long enough to reach from one curb to a longitudinal plank support at the center of the road. The sand is consolidated and brought down to grade by rolling it by hand, using a roller weighing 300 to 400 pounds. After rolling the surface is tested with the templet, the high spots reduced and the low places filled, and the rolling repeated. This process is repeated until a uniform surface at the desired elevation is obtained. The extra elevation of the templet in the first stage of the work is

[1] Mr. Tebbs makes the following comments: "Pennsylvania specifications allow 15 per cent of loam and I advocate the use of a sand containing loam, because it helps to bind it, thereby avoiding the shifting about which often occurs with clean dry sand. It has been proved that dry sand occupies less space than wet sand. Dry sand cannot always be obtained without considerable expense, and I therefore think it advisable to use reasonably dry sand without requiring that it be dried, and as thin a cushion as it is practicable to use. The cushion should be 1 inch or less. This decrease in the depth of the cushion minimizes the shrinkage due to the drying of sand which was moist when placed."

[2] Mr. Marr states: "It has been well demonstrated that the thinner the sand cushion between the rigid base and the brick wearing surface, the better, and its only function is to assure a smooth surface on the pavement. The use of the plain sand cushion is growing less every year and seems to have its greatest advantage in street paving where numerous subsequent openings may be expected and it is necessary to use a soft filler."

obtained by laying strips of wood of the requisite thickness on top of the curbs or other supports of the templet.

If a road carries only light vehicles, a well consolidated sand cushion is a satisfactory support for the bricks. Heavy vehicles, whether drawn by horses or self-propelled, are believed to jar the road although definite tests with a seismograph or a similar instrument are needed to determine the correctness of this opinion. It is certain, however, that if the roadway contains a railway track the whole structure will be jarred by the cars traveling along it. The sand cushion is not considered by many engineers to be a satisfactory support for bricks likely to be jarred, on account of the possibility that the repeated minute vibrations in it may cause parts of it to shift their position. This apprehension has led to the use of the sand-cement bed.

Sand-cement Cushion Type.—The cushion consists of a dry mixture of one part of cement with three to five parts of mortar sand. These materials must be thoroughly mixed dry. If the cushion is to be 1 inch thick, as in Pennsylvania state work, the mixture contains less cement than if it is to be ¾ inch thick as in the Illinois State work. The loose material is given about ¼ inch greater depth than the desired thickness of the finished bed. The mortar is spread and shaped like a sand cushion. In Illinois, where the sand-cement bed has been used extensively, the shaping of the bed for the brick is considered of prime importance and the State highway department requires the contractor to employ skilled men for this part of the work.

There is a difference of opinion as to the best method of moistening the sand-cement bed to convert it into mortar. Some engineers hold that the bricks should be laid on the dry bed and rolled, and then the pavement should be sprinkled sufficiently to allow water to pass down the joints into the bed. This wetting down should be done as soon as the bricks have been rolled. The Pennsylvania highway department requires the mortar bed to be sprinkled lightly just before the bricks are laid. In any case, the mortar bed should not be laid so far in advance that any of it will remain exposed over night, and if any of it becomes wet and the cement sets it must be replaced by dry material.

Monolithic Type.[1]—The monolithic or green concrete bed is not actually a cushion, for the bricks are laid on the fresh concrete base as soon as it has been finished. In this type of work steel side forms for the base are generally specified and curbs are

[1] A monolithic brick pavement was laid about 1904 in Terre Haute, Ind., on the recommendation of Street Commissioner Varrelman of St. Louis. It was on a railroad teaming yard and a private street to the warehouse of Hullmann & Company. This is probably one of the earliest uses of the type in this country.

omitted. The steel forms are considered necessary as supports for the heavy steel templet which is used.

The concrete is placed in successive batches for the entire width of the pavement in a continuous operation. This concrete as placed has a slightly greater depth than the finished thickness of the base, and the workmen are guided in placing it by a light wood templet which rests on the side forms when in use. When it has been brought to a smooth surface of the desired shape, it is finished with a steel templet. This consists of a 6-inch steel I-beam in front and a 6-inch steel channel at the rear, held 2 feet apart by a metal frame at each end. Each frame has two rollers 3 feet or more apart. These rollers rest on the side forms and permit the templet to be moved ahead easily and without jerks. Both beams are bent to the desired crown of the pavement. The lower flange of the I-beam is $\frac{1}{8}$ to $\frac{3}{16}$ inch lower than that of the channel. The space between the two beams is kept filled with dry 1:3 mortar, thoroughly mixed. As the templet is moved along, the I-beam shapes the fresh concrete accurately, and the channel leaves a thin, compacted bed of mortar on its surface, so that the bricks have a support which is true to grade in every respect. Experience shows that particular care must be taken in this type of construction to use concrete which will not flow but will quake. If it flows it will not support the bricks and if it does not quake it will be deficient in strength. The bricklaying should follow closely behind the templet before the concrete takes its initial set, and the workmen are required to move with special care over the bricks just laid. Some engineers require boards to be laid for the workmen to walk and stand on.

Delivering and Laying Bricks

In case the bricks are not tested at the plant, each carload must be sampled as it is delivered and the lot should not be allowed on the road until the samples have been tested and approved. If this is not done, imperfect bricks are likely to find their way into the road, and the work of roadside inspection is made needlessly expensive and prolonged.[1]

[1] Mr. Hinkle calls attention to the following paragraphs in the specifications of the Ohio State highway department: "If all the bricks in a shipment or in several shipments of the same make and kind of bricks appear to be uniform in quality two samples of 12 each may suffice. If in a shipment there appears to be different classes of bricks, such as bricks that appear to be more or less burned than others, a representative lot of 12 bricks is to be secured for each class of bricks, exclusive of the culls. The approximate number of each class sampled should be given on the notification card accompanying the samples. Unless otherwise ordered by the Engineer, at least one lot of samples should be taken for every

Bricks are liable to considerable injury if handled roughly, and to prevent such injury to them after their acceptance by test many engineers specify the manner in which they shall be handled. The requirements of the Illinois highway department are as follows:

Before the fine grading is finished, the bricks shall be hauled and neatly piled without the edging line in sufficient quantities to complete the brick surface. Clamps and conveyors may be used in connection with the work but the bricks shall not be dumped from industrial cars or vehicles, nor shall they be thrown to piles or to industrial cars or to vehicles. The bricks shall not be piled in any place where they will be likely to be besplattered or covered with mud or otherwise injured. In delivering the bricks from the piles for placement in the pavement, no wheeling in barrows will be allowed on the brick surface, but they shall be carried on pallets. They shall be placed upon the pallets so that when delivered to the dropper they will lie in such order that each brick in the regular operation of placing it upon the foundation as prepared, will bring the lugs in the same direction with the best side uppermost.

The bricks are laid with the best side up and the projections for spacing all in the same direction; in highway work they are laid in rows or courses at right angles to the curb. Alternate rows commence with a half brick at the curb and the joints in a row must be at least 3 inches from those in the row last laid. When the row reaches the curb towards which it is laid it must be completed with a bat at least 3 inches long. The fractured end of a broken brick must be toward the center of the road. Brick layers generally carry three or four rows across the roadway simultaneously, as this enables them to save considerable walking. The bricks are laid from the bricks already in place, and no walking is permitted on the cushion or dry mortar bed. In order to keep the cross joints of uniform width, after about six or eight rows have been laid, a 4 x 4-inch timber 3 feet long is moved along the face of the last row and tapped lightly with a sledge.

After the bricks are laid the surface is swept clean and inspected. The soft bricks are replaced by good ones; they are detected by

100,000 bricks, care being taken to secure bricks from different parts of the cars or piles so that the samples submitted will be representative of the bricks to be used. If at any time a shipment of bricks is received in which the quality of the bricks does not appear equal to that of the samples previously submitted, additional samples should be immediately sent to the testing laboratory. A sufficient number of samples in every case should be taken to insure the use of bricks of proper quality, but it should be borne in mind that the charges for transportation are high and only a sufficient number of samples should be submitted for test, which will permit of proper control of the quality of bricks used."

Thousands of Bricks Required to Pave a Mile of Road of Different Widths with Different Numbers of Bricks per Square Yard

BRICK PER SQUARE YARD	WIDTH OF STREET						
	8	10	12	15	18	20	22
33	174.2	193.6	232.3	290.4	348.5	387.2	425.9
34	179.5	199.5	239.4	299.2	359.0	398.9	438.8
35	184.8	205.3	246.4	308.0	369.6	410.7	451.7
36	190.0	211.2	253.4	316.8	380.1	422.4	464.7
37	195.3	217.1	260.5	325.6	390.7	434.2	476.9
38	200.6	222.9	267.5	334.4	401.3	445.9	490.5
39	205.9	228.8	274.6	343.2	411.7	457.6	503.4
40	211.2	234.7	281.6	352.0	422.4	469.4	516.3
41	216.5	240.5	288.6	360.8	432.9	481.1	529.2
42	221.8	246.4	295.7	369.6	443.5	492.8	542.1
43	227.1	252.3	302.7	378.4	454.1	504.6	555.0
44	232.3	258.1	309.8	387.2	464.6	516.3	567.9
45	237.6	264.0	316.8	396.0	475.2	528.0	580.8
46	242.9	269.9	323.8	404.8	485.8	539.8	593.7

dampening the surface of the road for they absorb moisture more quickly than the others. Bricks which are badly broken, spawled or misshaped are turned over or replaced by good ones, but slight chipping of the corners is not considered serious.[1] The surface is then rolled, for which purpose a tandem self-propelled roller weighing 2½ to 4 tons is employed where a sand cushion is used and a hand roller about 2½ feet long and 2½ feet in diameter, weighing about 600 pounds, is preferred for monolithic pavements. The rolling should begin at one side of the road and proceed back and forth on lines slightly inclined toward the center of the roadway. When the center is reached the roller should be used on the other side of the road in the same way. Parts of the pavement which cannot be reached by the roller are rammed with a paver's tamper weighing about 50 pounds, the blows being struck on a 2-inch plank 10 to 12 inches wide and at least 6 feet long.

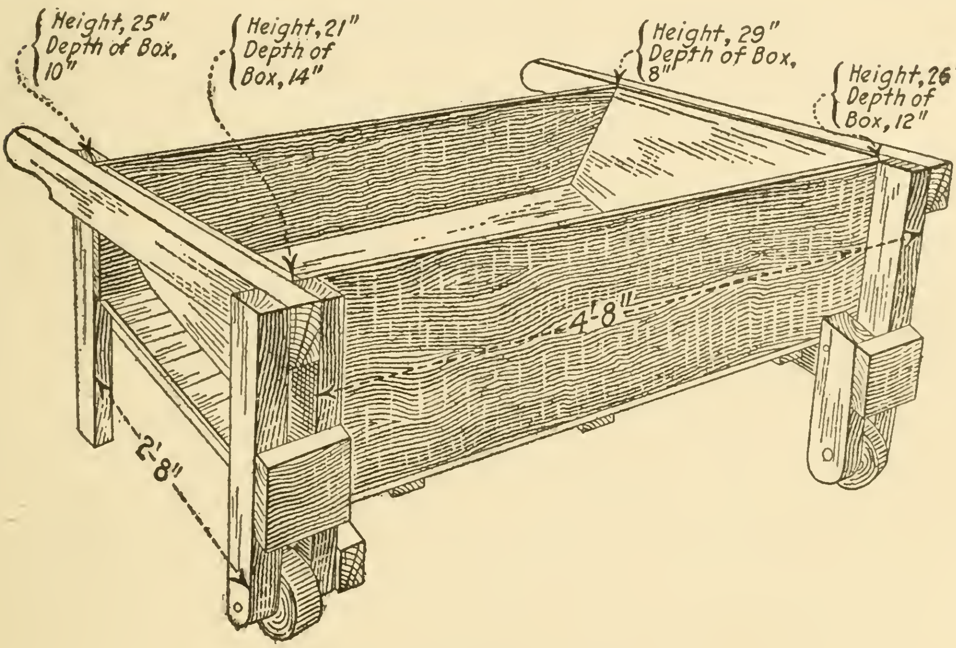
After the rolling, the pavement is again inspected and any bricks which have been broken or seriously injured are replaced. The joints are examined, and if the sand-cushion has been forced up into them more than ½ inch in the sand-cushion type, the bricks are lifted out, the cushion reshaped, and the bricks relaid. This inspection of the joints is only necessary where a sand cushion is used.

[1] Mr. Hinkle considers that it is very desirable for all defective bricks to be culled out before the bricks are laid in the pavement. This will not only save the expense of replacing the defective bricks with good ones, but will avoid disturbing the cushion. This is more important with the monolithic than with other types of pavement.

Filling Joints

Joints between the bricks are filled with sand, cement grout or bituminous material. Sand is objectionable because it gives very little support to the bricks, allows their edges to become chipped, and permits water to percolate down into the cushion. It is no longer employed except for roads for light travel, where the saving in first cost is considered more important than the probability that maintenance expenses will become high at an early date.

Grout Fillers.—The grout filler is strongly advocated by many engineers on the ground that it holds the bricks firmly and does



Box for Mixing Grout

not wear away more rapidly than the vitrified clay. This claim rests upon the assumption that good grouting is done, for poor joints of this type are chipped out by horses' shoes and thus allow the edges of the bricks to become broken. If the grouting is properly done this will not happen.[1] It is extremely im-

[1] Mr. Marr states: "The cement-grouted pavement seems to be the most satisfactory for country highways, and this has led us in our studies in Illinois to attach great importance to the perfection of the grout filler. We have been working along the line that, theoretically, the earth itself is the foundation for the pavement and is in itself wholly adequate, if it is thoroughly settled and properly drained. In other words, we hold that ordinary dry earth sustains any load which we place upon it while it is

portant, however, with cement filler that a rigid foundation be secured.

Grout for filling joints should be made of equal parts of cement and clean, sharp, sand mixed thoroughly while dry. As a general rule, all of it should pass a No. 10 sieve but not more than 30 per cent should pass a screen having 50 meshes to the inch. After the sand and cement are thoroughly mixed dry, water is added to bring the mass to a condition somewhat thinner than thin cream, so it will flow into the joints without any separation of its ingredients. The mixing is kept up continuously, either in a small batch mixer or the box shown in the accompanying illustration. The tendency on extensive work is to use a batch mixer equipped so it can be used for applying the grout. If the box is used, about 2 cubic feet of the dry mixture is made into mortar in each batch. The best grout is obtained when the water is added slowly.

The surface of the pavement to be grouted is cleaned, well wet, and then covered with enough grout to about fill the joints. The grout is taken from the mixing box in scoops and after it is poured from them it is swept into the joints, usually with coarse rattan brooms. After a 50-foot section of road has had the joints filled in this manner, and before the grout first poured begins to set, a somewhat thicker grout is made and applied on the same surface. It is brushed into the joints with squeegees having rubber edges where they rest on the pavement. This process of applying the relatively thick grout and brushing it into the joints with squeegees is continued until the joints are completely filled. It is very desirable to apply the grout, so far as possible, to the exact parts of the pavement where it is to fill the joints. If any great excess of grout is applied at one place in the pavement and swept to another place, the cement and sand are liable to become separated and defective grout will result. If the bricks have rounded edges, the squeegees should be pressed

in this condition, and that the real problem is to keep it in this condition by covering and waterproofing it with some material which will withstand the abrasive action of traffic. This, in turn, leads us to believe that if we use a thin base, such, for instance, as 2 inches of sand and cement mixed, or even 1 inch, or even, theoretically, ¼ inch, the properly grouted bricks will then withstand successfully the action of any such traffic as we have at the present time.

"The mortar bed has for its prime function the insurance of a perfect grout joint, by preventing earth or other foreign matter from working up into the bottom of the joints during construction. It has a secondary value in enabling us to obtain a smoother wearing surface by facilitating the proper grading of the bed on which the bricks lie by the use of mechanical methods such as templets. We have built a 6-mile stretch of brick road 9 feet wide, on a 1-inch mortar bed base, which I believe will demonstrate the correctness of the theory we are now holding."

firmly against them on the last brushing so that no thin edges of grout will remain on the surface, for they break away very soon and are liable to pull a part of the joint filler with them.

To prevent the grout from flowing through the joints beyond the limits of the section where the filling is being done, strips of $\frac{1}{16}$ inch steel 6 inches wide and 3 feet long are inserted in the last transverse joint, to act as a dam until after the initial set of the cement.

After the surface has been inspected, it is the practice in Illinois to cover it with sand, which is kept wet for ten days, and no travel is permitted on the road for three weeks after the grout has been poured. In Ohio and Pennsylvania, the sand is kept damp for at least five and four days respectively, and travel is kept off for at least ten days. In New York travel is kept off for ten days, and the covering must be kept moist for that period. The National Association of Paving Brick Manufacturers advises keeping the covering wet for four days and travel off the road for fifteen days.

Bituminous Fillers.—Bituminous fillers vary greatly in quality, and the experience with some of the materials tried has not been satisfactory. The filler should not become soft during hot weather nor brittle during cold weather, it should adhere to the bricks, and it should not be injured by water. A 1:1 bituminous-sand mastic filler has recently been used considerably. Obviously climatic conditions should govern the selection of the material in some degree, for a filler suitable for the brick pavements of Florida might prove unsatisfactory during a New England winter.

The Ohio State requirements for asphalt fillers are as follows:

Specific gravity, 0.98 to 1.04.

Solubility in chemically pure carbon disulphide, at least 99½ per cent.

Matter soluble in 86°B. paraffin naphtha, 25 to 40 per cent.

Limits for penetration

TEMPERATURE	NEEDLE	WEIGHT	TIME	PENETRATION
°C.		grams		
25	No. 2	100	5 sec.	2.5 to 5 mm.
4	No. 2	200	1 min.	2 mm. or more
46	No. 2	50	5 sec.	10 mm. or less

Melting point by cube method, 80°C. to 120°C.

It shall be free from water and not foam when heated to 350°F.

The Ohio State requirements for coal tar pitch fillers are as follows:

Specific gravity at 25°C., 1.23 to 1.3.

Free carbon on extraction with carbon disulphide, 20 to 40 per cent.

Inorganic matter on ignition, 0.5 per cent.

Melting point by cube method, 57°C. to 63°C.

It shall be free from water and not foam when heated to 300°F.

These bituminous fillers are used hot and the bricks should therefore be dry when the joints are poured. If a sand-cement bed is used, the water for it must be applied through the joints, if it is added in that way, long enough before the joints are filled to permit them to become dried out.

The filler is melted in a kettle, from which it is usually drawn into funnel-shaped pourers terminating in a nozzle having an opening about $\frac{1}{4}$ inch in diameter, with a valve by which the flow through it can be regulated. This is held over the joint, with the nozzle projecting into it, and carried along slowly. The joints are somewhat overfilled by the pourer, on the theory that the early travel on the pavement will force some of the surplus material into the joint and make it more dense. After the joint is poured, some engineers have it dusted over with sand, and it is customary to keep traffic off the pavement until the filler has cooled.

A mixture of tar and sand, called a "mastic filler," has been used to some extent. The hot tar and heated sand are mixed in equal volumes. A softer grade of tar is used in the mixture than that called for by the Ohio specification for a tar filler. This mastic filler is flushed into the joints by pouring it onto the pavement and spreading it with a squeegee.

It is particularly desirable to roll the bricks and fill the joints to within at least 50 feet of the bricklaying work. If rain falls and the cushion becomes saturated, it is impossible to roll the bricks to a firm condition, for the wet sand allows them to rock and the cushion is forced up into the joints. By lifting out a brick here and there, the height of the sand in the joint can be seen and the character of the rolling judged from it.

Expansion Joints

In the early days of brick street pavements, the bricks at the crown of a street occasionally rose in summer as a result of the expansion of the pavement by heat. To remedy this, joints filled with some compressible material were laid along one or both curbs, and some engineers used similar transverse expansion joints at intervals of 50 to 75 feet. The longitudinal joints have proved useful, but there is some question as to the value of the transverse joints in street pavements. The objection to transverse joints is that they are worn away rather rapidly and this causes the travel to chip off the edges of the bricks separated by them. Whenever this chipping occurs to any extent, the pavement soon develops a rut or hole. Cracks in a country road, if properly filled when they first open and kept filled afterward, do not injure it appreciably, and it is generally considered that transverse joints in a brick wearing surface, to prevent transverse cracks, are more likely to cause than prevent trouble.

Expansion joints are of two types, poured and prepared. The former are made by placing a board filler of the thickness of the joint against the curb and laying the bricks against it. The Maryland rule for the thickness of the joints is as follows: On streets 30 feet or more wide, $1\frac{1}{4}$ inches next each curb; on 20 to 30-foot streets, 1 inch next each curb; on 12 to 20-foot streets, $\frac{3}{4}$ inch next each curb; on streets under 12 feet, $\frac{3}{4}$ inch next one curb. In Pennsylvania a $\frac{1}{2}$-inch joint at each curb is specified. On the Illinois brick roads with a sand-cement base a $\frac{3}{8}$-inch joint along one curb is used. The plank filler usually consists of two thin 6-inch boards of a wedge-shape cross-section, dressed on both sides. One of them is laid against the curb with the thin edge on the base, and the other is placed against it with the thick edge downward. The combined thickness of the two is equal to the thickness of the joint. Handles are attached to their upper edges, so they can be lifted out when the grout filler which has been poured has set. The filler for poured expansion joints should meet the requirements for the filler for other joints of this type. With the monolithic and sand-cement cushion types of pavement, the joints should be filled as far as the bricks are laid, each day.

Prepared fillers are now extensively used. They are strips of bituminous material or some kind of felt or fabric impregnated with bituminous material. They are placed against the curb and the bricks laid against them, thus doing away with the board fillers required with poured joints and making it unnecessary to provide heating kettles on pavements with grouted joints.

Experience on the Pennsylvania State highways has shown that a prepared filler extending the full depth of the brick sometimes permitted water to penetrate from the road surface into the cushion, where it froze and heaved the bricks. It is therefore considered advisable on that work to have the prepared filler stop from $\frac{3}{4}$ to 1 inch below the surface of the road and to fill the top of the joint with hot bituminous material.

Where a cement-sand bed is used, a $\frac{3}{8}$ inch prepared expansion joint extending through the entire pavement is recommended by some engineers; it is placed in two strips, the first or bottom strip being placed in the concrete base, and the second strip immediately above it when the bed and bricks are laid.

Small Cubical Bricks

Shortly after small stone blocks were introduced in Europe for constructing pavements having the trade name of "Durax," the county superintendent of Monroe County, N. Y., J. Y. McClintock, employed cubes measuring 2 to $2\frac{1}{2}$ inches on a side for resurfacing old macadam roads to resist motor traffic. In 1916 he stated that vitrified clay cubes had given better results than those of other materials. Those laid in 1916 were $2\frac{1}{4}$ inches in each dimension, weighed about 1 pound each, and were laid 225 to the square yard. The only specification for the cubes is that they must not absorb more than 3 per cent. of their weight when immersed in water. They have been laid on a gravel base, broken slag, broken stone and concrete, and the joints are filled with any local fine material. It is considered advisable to make the base several feet wider than the roadway, so that the gravel or broken stone shoulders adjacent to the cubes shall be supported rigidly and the tendency for the border cubes to become displaced will be minimized.

Aspha-Bric

During 1915 and 1916 attention was directed to the possibilities of asphalt impregnated brick. The idea of impregnating brick with bituminous material is not new. In 1893 brick boiled in coal tar were laid in Portland, Ore., and remained in service 17 years. About 1907 nose brick boiled in asphalt were laid along the tracks of the Los Angeles Electric Railway Corporation and 2500 similar brick were laid along tracks in San Francisco about 1912. Brick boiled in bituminous material have also been laid in Nashville and Chattanooga.

The method of treating brick which came into prominence in 1915 is designed to fill completely the pores in the brick. As the porosity of different grades and makes varies considerably, the quantity of impregnating material required will range from about 6 to 15 per cent of the volume of the brick. As a result of the treatment it is claimed that the brick become impervious to moisture, the bituminous jointing material adheres more firmly to the treated than to the untreated brick, and the wearing properties, as indicated by the standard rattler test, are greatly improved. This last advantage is indicated in the accompanying tabulation of tests of untreated and treated "second" brick conducted by Robert W. Hunt & Company. Each test was made with five untreated and five treated brick, 225 pounds of small shot and 75 pounds of large shot, the rattler making 1800 revolutions at the rate of 30 revolutions per minute. The increase in wear due to

Results of tests of untreated and asphalt impregnated brick. Each sample consisted of five untreated and five treated brick

SAMPLE	1	2	3	4	5	6	7	8	9
Weight in pounds:									
Before treatment....	50.66	48.81	46.50	53.35	45.25	48.65	49.75	47.95	50.03
After treatment.....	56.75	54.01	48.97	55.77	47.49	51.33	54.60	49.94	54.53
Asphalt used........	6.09	5.20	2.47	2.42	2.24	2.68	4.85	1.99	4.50
Loss in weight, pounds:									
Untreated...........	27.02	17.39	28.81	17.19	13.93	11.88	19.57	13.63	11.78
Treated.............	8.38	8.96	6.22	10.07	6.51	6.83	7.36	6.46	6.25
Loss in weight, per cent:									
Untreated...........	53.34	35.63	61.96	32.22	30.79	24.42	39.34	28.43	23.55
Treated.............	14.77	16.59	12.70	18.06	13.71	13.31	13.48	12.94	11.46
Broken brick:									
Untreated...........	1	0	3	0	0	0	0	0	0
Treated.............	0	0	3	1	0	0	0	0	0

impregnation will, it is stated, enable manufacturers to stop their burning at a lower temperature than is now customary, thus materially reducing the number of poor brick in a kiln, and to obtain the necessary strength by impregnating the brick. It is also claimed that grades of brick unsuitable for pavements may be made into satisfactory pavers by impregnation. For example, impregnating clay building brick with 11.3 per cent of asphalt gave a product showing 9.3 per cent loss in the standard rattler test, although untreated brick showed 100 per cent loss after 500 revolutions. Shale building brick which showed 42.4 per cent loss in the rattler test before they were treated, lost only 17 per cent after treatment. Sand-lime brick which showed 100 per cent loss after 400 revolutions lost only 23 per cent after being impregnated with 10 per cent of asphalt. Impregnating clay and shale building brick with 8½ per cent of asphalt reduced the loss in the rattler test from 40.9 to 14.2 per cent. The impregnation of the brick also reduces their absorption of water to practically nothing.

The asphalt-impregnating process begins when the brick are removed from the kilns or dryers. They are loaded on small cars which are run into a cylinder. There they are heated to about 300°F., which expands them, and a vacuum is produced in the cylinder to remove all moisture from the brick and leave their pores open. The cylinder is then filled with a special grade of asphalt at a temperature of 350°F. and the cylinder put under heavy pressure until the gauges show that impregnation is complete. The asphalt is drained off and pressure again applied until the brick have cooled. During cooling they contract somewhat, causing the asphalt to become sealed in the pores.

A BRICK PAVEMENT ON A ONE-INCH CONCRETE BASE[1]

A brick pavement was laid in 1917 in Stockland township, Iroquois County, Illinois, on a one-inch concrete base. This pavement is 9 feet wide, and the contract is for about 6½ miles, of which about 3 miles has been constructed. The contract price for this work is approximately $8700 a mile, of which about $300 is for bridges and culverts and about $450 for grading. The price for the slab alone is $1.50 per square yard.

This pavement is being laid on an old gravel road for a foundation and, in order to secure the full benefit of this old material, the gradient of the new pavement varies but slightly from that of the present road. By not disturbing the old gravel, it has been possible to secure a very firm subgrade and we have no doubt but the pavement will prove very satisfactory. The concrete base is composed of 1 part cement to 2½ parts fine aggregate and 4 parts coarse aggregate. The fine aggregate consists of sand all of which passes a ¼-inch mesh. The coarse aggregate consists of material which would be retained on a ¼-inch mesh and passes a ½-inch mesh. As a matter of fact, there is very little of this material which will not pass a ⅜ inch mesh and it is the same type of gravel that is commonly used for roofing purposes.

I have no doubt but this pavement would be practically as good as if the brick had been laid directly on the old gravel road, but in a construction of this kind, it is necessary to have some sort of a concrete base in order to secure a perfectly smooth and uniform surface on which to lay the bricks.

The subgrade was thoroughly rolled and all soft places, of which there were very few, were removed and the subgrade brought up to a true plane by the addition of fresh material which was thoroughly compacted. Before concrete was placed, the subgrade was well wet; after the concrete was placed, it was struck off by means of a template and the bricks were laid directly on the green concrete.

Two brick setters were used on this job and by having a brick hammer on each side of the road, the setters not only started but finished the courses, as on a pavement of this width no bats, except

[1] By Rodney L. Bell, Division Engineer, Illinois State Highway Department.

one half-sized brick, are required in starting and finishing the courses. Bricks were carried on to the pavement in such a way that the good side of the bricks was always placed up and the lugs all in one direction. By requiring the brick carriers to use some care, a large amount of the culling which ordinarily takes place on a brick road was eliminated. Just as soon as the bricks were culled, the pavement was swept and the rolling started.

One man did nothing but keep the roller moving the entire time. It was a small hand roller about 30 inches in length and 24 inches in diameter and when filled with water weighed about 700 pounds. This weight was sufficient to secure a good surface over the entire length of the pavement. The first rolling was begun at the outer edge and the pavement was rolled parallel to the center line of the pavement. After the entire surface had been covered in this way, the pavement was cross-rolled in opposite directions, the roller making an angle of about 45 degrees with the center line of the pavement.

In order to allow plenty of time to secure a thorough job of rolling, the grouting machine was kept about 100 feet behind the brick layer. The grout mixture consisted of one part cement and 1 part of sand mixed in a machine designed for this purpose. It was the intention to practically fill the joints at the first application so that after the grout had had a chance to settle, it would leave from $\frac{1}{2}$ to $\frac{3}{4}$ inch to be filled with subsequent applications.

The second application of the grout was mixed slightly thicker than the first, and was wheeled back over the pavement from the mixing machine rather than bother with moving the machine back over the pavement a second time. This application was worked into the joints by use of a squeegee and on the final going over, the squeegees were pulled at an angle of about 45 degrees with the joints in order to secure a better surface and to keep the grout from being dragged out from between the brick.

After the grout had set sufficiently, the pavement was covered with 1 inch of loose dirt, which was kept wet for one week. The pavement was opened to traffic after it had been down three weeks.

This work is being paid for by a bond issue which has been voted by Stockland township, Iroquois County, and is under the general supervision of Benj. Jordan, county superintendent of highways of Iroquois County.

HIGHWAY BONDS[1]

The mathematical theory of interest as applied to bond calculations is explained in a section of Bulletin 136 of the United States Department of Agriculture which has tables of much value to those making a detailed examination of the subject. For the usual purposes of highway officials, however, the much simpler tables which are printed herewith are not only sufficient in scope but also more easily used.

The bonds used almost universally until a few years ago were of the sinking-fund type. Parties issuing them have to provide annually during the term of the bonds the stipulated interest and, theoretically, set aside a sum at interest which will amount at the end of the term to the principal of the bonds. This annual sum set aside at interest is called the sinking fund, and the amount which must be raised for such a fund depends upon the interest it bears. This interest is usually quite low in comparison with the interest paid on the bonds.

Unfortunately the financial methods of public officials do not always remain above criticism and it often happens that the annual payment into the sinking fund is forgotten or neglected.[2] Sometimes the money accumulated in the sinking fund is diverted from its purpose. Such departures from sound finance result in a lack of money to pay off the bonds when they become due, as agreed, and it then becomes necessary to issue a new series of bonds to carry this indebtedness. This is a serious matter when the improvements for which the bonds were issued have become of no further use, as in the possible case of a worn-out road surface, or obsolescent, as in the possible case of an overloaded bridge, when the taxpayers who contribute for the second bond issue are obliged to pay for something for which they receive little or no benefit. This is not equitable, and so some states fix the term of bonds which may be issued to pay for certain classes of im-

[1] Revised by B. K. Coghlan, associate professor of highway engineering, Agricultural and Mechanical College of Texas.

[2] Baker, Watts & Co., bankers, of Baltimore, make the following comment: "We view it as a very serious matter to neglect the sinking fund, regardless of the character of the improvement for which the bonds are issued. We think that public officials cannot be too forcibly impressed with the absolute necessity of managing public funds strictly in accordance with the laws and ordinances authorizing bond issues, and any neglect or diversion of public sinking funds should be summarily dealt with."

provements. In New Jersey, for example, the term of bonds for gravel roads is limited to five years, waterbound or bituminous macadam ten years, bituminous concrete fifteen years, 6-inch concrete twenty years, block pavements twenty years, sheet asphalt on a concrete base twenty years, and stone, concrete and iron bridges thirty years. The useful life of the improvement is what must be considered, and this is determined in some cases by obsolescence rather than depreciation, notably in the case of bridges. The attractiveness of bonds for road work would be enhanced in many cases if an equivalent of the following statute, in force in Mississippi, were generally adopted:

> The public highway or highways so surveyed and adopted by such commissioners shall be constructed and maintained out of the proceeds of such bonds; proceeds of such bonds to be used alone in their construction; and the board of supervisors shall levy an annual tax, on the recommendation of such commissioners, on all the taxable property in such district or districts of not exceeding 1 mill on the dollar, which shall be used to supplement the general fund of the county in maintaining said road or roads and the culverts, bridges and levees thereon.

The importance of maintenance of roads is so great that statutes authorizing bond issues for construction should require, as part of the stipulations under which the bonds are issued, an adequate financial provision for the upkeep of the roads during the term of the bonds. This insures a full statement of the financial obligations of the bond issue upon the taxpayers before they vote on the issue.

The investment of the sinking fund affords an indication of the financial ability of a community. In some sections of the country, the investment is intrusted to special boards of sinking fund commissioners, and appointment to such a board is regarded as a high honor, so that the positions are filled by men of the highest business standing. In such cases the community not only feels confident of its financial stability but its bond issues are sought so eagerly that it is not necessary to pay high rates of interest. In a few places, sinking funds have been neglected and the financial standing of the community suffers in consequence.

A second type of bond is known as the annuity bond. An annuity is a fixed sum paid at regular intervals of time for either a definite term or for the life of the beneficiary of the annuity. An annuity bond draws interest at an agreed rate, but at the close of each retirement period stated in the bond, the payment to the bondholders includes both the interest that has accrued during the period since the last payment and enough of the principal to make the full payment a definite, uniform amount at the close of each retirement period. The annual payment at the end of the first retirement period is mainly for interest and that at the end of the last period is mainly for retiring the last of the outstanding principal. The advantage of the plan is that it retires some principal annually and thus saves the taxpayer the expense of paying interest on the whole of a bond issue during its term. This makes annuity bonds less expensive than sinking fund bonds to the county issuing them.

The annuity bond issue possesses the advantage of requiring the same amount to be raised each year, during its term. The annual payments must be adjusted, however, so that the amount of principal retired will be some multiple of $100, $500 or $1000, or whatever sum is the face value of one bond. Consequently the actual payment on annuity issues at the end of a retirement period is not the uniform theoretical amount given in bond tables but an amount varying slightly from it, sometimes more and sometimes less.[1]

The serial bond issue is a type which has found favor with both borrowers and lenders. The farmer finds it desirable because it retires each year a part of the principal, and is thus more economical than a sinking fund bond issue. The purchasers of the bonds like them because there is a strong public sentiment in favor of serial bonds, which gives them standing as a good type of investment security. It is the least expensive method of borrowing money by issuing bonds, as an examination of the accompanying tables will show.

One defect of serial bonds for certain classes of public improvements is that the heaviest payments for interest and the retirement of principal must be made in the early years of the term of the bonds, before the work for which they pay has yielded any returns. Consequently what are known as deferred serial bonds are now used to meet such conditions as often arise in road districts. With such a type of bond, no principal is retired until a certain period, usually five years, has elapsed. During this period interest is paid but nothing more. Thereafter the principal is retired by uniform amounts and the interest charges are met just as in the case of straight serial bonds having a term shorter by five years, or whatever is the deferred period. In this way a road district need not pay anything but interest until

[1] The following comment on this type of bond has been received from John S. Harris, of the banking house of Sidney Spitzer and Company, Toledo: "We would not suggest your recommending the installment (annuity) bonds, as they are very hard to figure and hard to dispose of. It is necessary to figure each year when you collect your coupons the amount of principal and the amount of interest. A serial bond answers the same purpose and is much more attractive to the investing public. Road bonds should not be issued in any other way than as serial bonds, as every one knows that issuing long-time road bonds is wrong."

the improvements have begun to yield a return and it need not pay so much for the use of money as when it issues sinking fund bonds.

The question which taxpayers generally put to public officials regarding a bond issue is what increase such an issue will make in the annual taxes. A series of examples will show how the accompanying tables can be used to answer such questions.

What is the tax rate for a $300,000 issue of 5 per cent, 40-year bonds, retired by a sinking fund drawing 3 per cent, when the tax valuation of the road district is $9,300,000?

The table of the annual cost of sinking fund bonds shows that the annual cost of a $1 bond of this class is 6.326 cents. The annual cost of a $300,000 issue will be $18,978. The additional tax per $100 valuation in the district will be $18,978 ÷ 93,000 = 20.407 cents. Any taxpayer can find out what his additional tax will be by multiplying 20.407 cents by the number of hundreds of dollars worth of property for which he is assessed. If his property is assessed at $2000, for example, his additional tax for roads will be $4.08.

How much money would be saved by issuing annuity rather than sinking fund bonds in this case?

The annual cost of a 1-dollar 4-per cent, 40-year annuity bond is shown by the table to be 5.828 cents, so the annual cost of a $300,000 issue will be $17,484. The additional tax per $100 valuation will be 18.8 cents, or 1.607 cents less than under the sinking fund system. The man whose property is assessed at $2000 would save 32 cents, and the district as a whole would save $1494.51, which would go a long ways toward paying for the engineering expenses of the road improvement.

What is the least expensive type of a $300,000 issue of 5 per cent, 40-year bonds to the above district?

The four accompanying tables show that the straight serial bond is the least expensive type, for the average annual cost of a 1-dollar bond of this type is 5.062 cents. This is equivalent to $15,186 for a $300,000 issue. The additional tax per $100 valuation will be 16.329 cents, 4.978 cents less than under the sinking fund type, which will save 81 cents to the man having property assessed at $2000. The saving to the district will be $3792 as compared with a sinking fund issue and $2298 as compared with an annuity issue.

The drawback of a straight serial bond can be seen from the figures of the payment needed at the end of the first and the fortieth years, 7.5 and 2.625 cents respectively on a 1-dollar bond. Road improvements do not yield any benefits until completed, and by deferring payment on the principal for five years, the additional cost to the community will average only $939 a year. The maximum annual amount will be somewhat higher than in a straight 40-year serial issue, because the principal must be retired in 35 years instead of 40 years, but this disadvantage may not outweigh the desirability of deferring the repayment of the principal.

The management of a bond issue requires attention to all the requirements of the laws governing such matters and a knowledge of the conditions which affect the value of bonds. Every step which the law requires to be taken in connection with such bonds must not only be taken properly but recorded fully and clearly. As soon as the voters authorize the issue, a statement of the fact should be drawn up, showing also the area, population and assessed valuation of the district, the value of its agricultural and industrial products, its material resources and the extent of their development, the banking and transportation facilities serving it, the existing indebtedness of the district, the condition and number of the schools, and all other information which will indicate the resources and character of the community that has decided to borrow the money. This information should be sent to banking houses and insurance companies making a specialty of purchasing public bonds and, if the issue is a large one, it should be advertised in financial journals. There should be ample time between the publication of these notices and the sale of the bonds for purchasers to make a full investigation of them.

[1] Private sales of bonds for public works should be discouraged all sales of bonds should be publicly advertised, and bidders should be invited to submit sealed bids on or before a certain date. The bonds should be sold to the highest responsible bidder who complies with all of the terms and conditions of the sale. The city or county should reserve the right to reject any or all of the bids, as a protection against any effort to pool bids and purchase the bonds at a price considerably less than their value.

Some cities and counties engage competent attorneys, familiar with the preparation of the legal papers pertaining to bond issues, to examine the records prior to the sale and to prepare all necessary forms. The city or county assumes the expense for all such work and furnishes the successful bidder with the approving opinion of the counsel thus engaged and with the executed bonds. Some cities and counties go even further by providing uniform proposal blanks for the bonds and refusing to accept bids not made on such blank. The advantage of these provisions is that the seller knows he is offering a legally and validly issued bond, the buyer has the same assurance, and the value of the issue is certainly enhanced thereby. The seller is undoubtedly reimbursed for the expense incurred in such preparatory work by the price he receives for the bonds.

[1] This and the next paragraph were prepared by Baker, Watts & Company.

Annual cost of a 1-dollar sinking-fund bond for different terms, interest rates and rates of interest on sinking fund

INTEREST ON SINKING FUND	TERM	RATE OF INTEREST ON BONDS, PER CENT							
		4	4.25	4.5	4.75	5	5.25	5.5	6
per cent	*years*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*
2	5	23.216	23.466	23.716	23.966	24.216	24.466	24.716	25.216
	10	13.133	13.383	13.633	13.883	14.133	14.383	14.633	15.133
	15	9.783	10.033	10.283	10.533	10.783	11.033	11.283	11.783
	20	8.116	8.366	8.616	8.866	9.116	9.366	9.616	10.116
	25	7.122	7.372	7.622	7.872	8.122	8.372	8.622	9.122
	30	6.465	6.715	6.965	7.215	7.465	7.715	7.965	8.465
	35	6.000	6.250	6.500	6.750	7.000	7.250	7.500	8.000
	40	5.656	5.906	6.156	6.406	6.656	6.906	7.156	7.656
	45	5.391	5.641	5.891	6.141	6.391	6.641	6.891	7.391
	50	5.182	5.432	5.682	5.932	6.182	6.432	6.682	7.182
2.5	5	23.023	23.273	23.523	23.773	24.023	24.273	24.523	25.023
	10	12.926	13.176	13.426	13.676	13.926	14.176	14.426	14.926
	15	9.577	9.827	10.077	10.327	10.577	10.827	11.077	11.577
	20	7.915	8.165	8.415	8.665	8.915	9.165	9.415	9.915
	25	6.928	7.178	7.428	7.678	7.928	8.178	8.428	8.928
	30	6.278	6.528	6.778	7.028	7.278	7.528	7.778	8.278
	35	5.821	6.071	6.321	6.571	6.821	7.071	7.321	7.821
	40	5.484	5.734	5.984	6.234	6.484	6.734	6.984	7.484
	45	5.227	5.477	5.727	5.977	6.227	6.477	6.727	7.227
	50	5.026	5.276	5.526	5.776	6.026	6.276	6.526	7.026
3	5	28.835	23.085	23.335	23.585	23.835	24.085	24.335	24.835
	10	12.723	12.973	13.223	13.473	13.723	13.973	14.223	14.723
	15	9.377	9.627	9.877	10.127	10.377	10.627	10.877	11.377
	20	7.722	7.972	8.222	8.472	8.722	8.972	9.222	9.722
	25	6.743	6.993	7.243	7.493	7.743	7.993	8.243	8.743
	30	6.102	6.352	6.602	6.852	7.102	7.352	7.602	8.102
	35	5.654	5.904	6.154	6.404	6.654	6.904	7.154	7.654
	40	5.326	5.576	5.826	6.076	6.326	6.576	6.826	7.326
	45	5.079	5.329	5.579	5.829	6.079	6.329	6.579	7.079
	50	4.887	5.137	5.387	5.637	5.887	6.137	6.387	6.887
3.5	5	22.648	22.898	23.148	23.398	23.648	23.898	24.148	24.648
	10	12.524	12.774	13.024	13.274	13.524	13.774	14.024	14.524
	15	9.183	9.433	9.683	9.933	10.183	10.433	10.683	11.183
	20	7.536	7.786	8.036	8.286	8.536	8.786	9.036	9.536
	25	6.567	6.817	7.067	7.317	7.567	7.817	8.067	8.567
	30	5.937	6.187	6.437	6.687	6.937	7.187	7.437	7.937
	35	5.500	5.750	6.000	6.250	6.500	6.750	7.000	7.500
	40	5.183	5.433	5.683	5.933	6.183	6.433	6.683	7.183
	45	4.945	5.195	5.445	5.695	5.945	6.195	6.445	6.945
	50	4.763	5.013	5.263	5.513	5.763	6.013	6.263	6.763
4	5	22.463	22.713	22.963	23.213	23.463	23.713	23.963	24.463
	10	12.329	12.579	12.829	13.079	13.329	13.579	13.829	14.329
	15	8.994	9.244	9.494	9.744	9.994	10.244	10.494	10.994
	20	7.358	7.608	7.858	8.108	8.358	8.608	8.858	9.358
	25	6.401	6.651	6.901	7.151	7.401	7.651	7.901	8.401
	30	5.783	6.033	6.283	6.533	6.783	7.033	7.283	7.783
	35	5.358	5.608	5.858	6.108	6.358	6.608	6.858	7.358
	40	5.052	5.302	5.552	5.802	6.052	6.302	6.552	7.052
	45	4.826	5.076	5.326	5.576	5.826	6.076	6.326	6.826
	50	4.655	4.905	5.155	5.405	5.655	5.905	6.155	6.655

Annual cost of a 1-dollar sinking-fund bond for different terms, interest rates and rates of interest on sinking fund—Continued

INTEREST ON SINKING FUND	TERM	RATE OF INTEREST ON BONDS, PER CENT							
		4	4.25	4.5	4.75	5	5.25	5.5	6
per cent	*years*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*
4.5	5	22.279	22.529	22.779	23.029	23.279	23.529	23.779	24.279
	10	12.138	12.388	12.638	12.888	13.138	13.388	13.638	14.138
	15	8.811	9.061	9.311	9.561	9.811	10.061	10.311	10.811
	20	7.188	7.438	7.688	7.938	8.188	8.438	8.688	9.188
	25	6.244	6.494	6.744	6.994	7.244	7.494	7.744	8.244
	30	5.639	5.889	6.139	6.389	6.639	6.889	7.139	7.639
	35	5.227	5.477	5.727	5.977	6.227	6.477	6.727	7.227
	40	4.934	5.184	5.434	5.684	5.934	6.184	6.434	6.934
	45	4.720	4.970	5.220	5.470	5.720	5.970	6.220	6.720
	50	4.560	4.810	5.060	5.310	5.560	5.810	6.060	6.560

Annual cost of a 1-dollar annuity bond for different terms and rates of interest

TERM	RATE OF INTEREST ON BONDS, PER CENT							
	4	4.25	4.5	4.75	5	5.25	5.5	6
years	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*
5	22.462	22.621	22.779	22.938	23.097	23.257	23.418	23.740
10	12.329	12.483	12.638	12.794	12.950	13.108	13.267	13.587
15	8.994	9.152	9.311	9.472	9.634	9.798	9.963	10.296
20	7.358	7.522	7.688	7.855	8.024	8.195	8.368	8.718
25	6.401	6.571	6.744	6.919	7.095	7.274	7.455	7.823
30	5.783	5.960	6.139	6.321	6.505	6.692	6.880	7.265
35	5.358	5.541	5.727	5.916	6.107	6.301	6.497	6.897
40	5.052	5.242	5.434	5.630	5.828	6.029	6.232	6.646
45	4.826	5.022	5.220	5.422	5.626	5.833	6.043	6.470
50	4.655	4.856	5.060	5.267	5.478	5.691	5.906	6.344

Variations in annual cost of a 1-dollar serial bond for different terms and rates of interest, the principal being retired by the same amount at the end of each year

TERM	PAYMENT	RATE OF INTEREST, PER CENT							
		4	4.25	4.5	4.75	5	5.25	5.5	6
years	*date*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*
5	First year.....	24.000	24.250	24.500	24.725	25.000	25.250	25.500	26.000
	Last year.....	20.800	20.850	20.900	20.950	21.000	21.050	21.100	21.200
	Average.......	22.400	22.550	22.700	22.850	23.000	23.150	23.300	23.600
10	First year.....	14.000	14.250	14.500	14.750	15.000	15.250	15.500	16.000
	Last year.....	10.400	10.425	10.450	10.475	10.500	10.525	10.550	10.600
	Average.......	12.200	12.337	12.475	12.613	12.750	12.888	13.025	13.300
15	First year.....	10.667	10.917	11.167	11.417	11.667	11.917	12.167	12.667
	Last year.....	6.933	6.950	6.967	6.984	7.000	7.017	7.034	7.067
	Average.......	8.800	8.933	9.067	9 200	9.333	9.467	9.600	9.867
20	First year.....	.9.000	9.250	9.500	9.750	10.000	10.250	10.500	11.000
	Last year.....	5.200	5.213	5.225	5.238	5.250	5.263	5.275	5.287
	Average.......	7.100	7.231	7.362	7.494	7.625	7.756	7.887	8.144
25	First year.....	8.000	8.250	8.500	8.750	9.000	9.250	9.500	10.000
	Last year.....	4.160	4.170	4.180	4.190	4.200	4.210	4.220	4.240
	Average.......	6.080	6.210	6.340	6.470	6.600	6.730	6.810	7.120
30	First year.....	7.333	7.583	7.833	8.083	8.333	8.583	8.833	9.333
	Last year.....	3.467	3.475	3.483	3.491	3.500	3.509	3.517	3.535
	Average.......	5.400	5.530	5.658	5.787	5.916	6.046	6.175	6.434
35	First year.....	6.857	7.107	7.357	7.607	7.857	8.107	8.357	8.857
	Last year.....	2.971	2.978	2.985	2.993	3.000	3.007	3.014	3.028
	Average.......	4.914	5.047	5.171	5.300	5.428	5.557	5.685	5.942
40	First year.....	6.500	6.750	7.000	7.250	7.500	7.750	8.000	8.500
	Last year.....	2.600	2.606	2.613	2.619	2.625	2.632	2.640	2.654
	Average.......	4.550	4.678	4.806	4.934	5.062	5.191	5.320	5.577
45	First year.....	6.222	6.472	6.722	6.972	7.222	7.472	7.722	8.222
	Last year.....	6.311	3.316	2.322	2.328	2.333	2.339	2.344	2.355
	Average.......	4.267	4.394	4.522	4.650	4.777	4.905	5.033	5.288
50	First year.....	6.000	6.250	6.500	6.750	8.000	7.250	7.500	8.000
	Last year.....	2.080	2.085	2.090	2.095	2.100	2.105	2.110	2.120
	Average.......	4.040	4.167	4.295	4.427	4.550	4.677	4.805	5.060

Variations in annual cost of a 1-dollar deferred serial bond for different terms and rates of interest, the principal being retired by the same amount at the end of each year beginning with the end of the sixth year

TERM	PAYMENT	RATE OF INTEREST, PER CENT							
		4	4.25	4.5	4.75	5	5.25	5.5	6
years	*date*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*	*cents*
10	1–5 years......	4.000	4.250	4.500	4.750	5.000	5.250	5.500	6.000
	Sixth year....	24.000	24.250	24.500	24.725	25.000	25.250	25.500	26.000
	Last year.....	20.800	20.850	20.900	20.950	21.000	21.050	21.100	21.200
	Average.......	13.200	13.400	13.600	13.800	14.000	14.275	14.400	14.800
15	1–5 years......	4.000	4.250	4.500	4.750	5.000	5.250	5.500	6.000
	Sixth year....	14.000	14.250	14.500	14.750	15.000	15.250	15.500	16.000
	Last year.....	10.400	10.425	10.450	10.475	10.500	10.525	10.550	10.600
	Average.......	9.467	9.641	9.817	9.992	10.166	10.342	10.516	10.867
20	1–5 years......	4.000	4.250	4.500	4.750	5.000	5.250	5.500	6.000
	Sixth year....	10.667	10.917	11.167	11.417	11.667	11.917	12.167	12.667
	Last year.....	6.933	6.950	6.967	6.984	7.000	7.017	7.034	7.067
	Average.......	7.600	7.762	7.925	8.088	8.250	8.413	8.575	8.900
25	1–5 years......	4.000	4.250	4.500	4.750	5.000	5.250	5.500	6.000
	Sixth year....	9.000	9.250	9.500	9.750	10.000	10.250	10.500	11.000
	Last year.....	5.200	5.213	5.225	5.238	5.250	5.263	5.275	5.287
	Average.......	.6.480	6.635	6.790	6.945	7.100	7.255	7.410	7.715
30	1–5 years......	4.000	4.250	4.500	4.750	5.000	5.250	5.500	6.000
	Sixth year....	8.000	8.250	8.500	8.750	9.000	9.250	9.500	10.000
	Last year.....	4.160	4.170	4.180	4.190	4.200	4.210	4.220	4.240
	Average.......	5.733	5.883	6.033	6.183	6.333	6.483	6.592	5.933
35	1–5 years......	4.000	4.250	4.500	4.750	5.000	5.250	5.500	6.000
	Sixth year....	7.333	7.583	7.833	8.083	8.333	8.583	8.833	9.333
	Last year.....	3.467	3.475	3.483	3.491	3.500	3.509	3.517	3.535
	Average.......	5.200	5.347	5.492	5.639	5.785	5.932	6.079	6.372
40	1–5 years......	4.000	4.250	4.500	4.750	5.000	5.250	5.500	6.000
	Sixth year....	6.857	7.107	7.357	7.607	7.857	8.107	8.357	8.857
	Last year.....	2.971	2.978	2.985	2.993	3.000	3.007	3.014	3.028
	Average.......	4.800	4.947	5.087	5.231	5.375	5.519	5.662	5.199
45	1–5 years......	4.000	4.250	4.500	4.750	5.000	5.250	5.500	6.000
	Sixth year....	6.500	6.750	7.000	7.250	7.500	7.750	8.000	8.500
	Last year.....	2.600	2.606	2.613	2.619	2.625	2.632	2.640	2.654
	Average.......	4.489	4.630	4.772	4.914	5.055	5.198	5.340	5.624
50	1–5 years......	4.000	4.250	4.500	4.750	5.000	5.250	5.500	6.000
	Sixth year....	6.222	6.472	6.722	6.972	7.222	7.472	7.722	8.222
	Last year.....	2.311	2.316	2.322	2.328	2.333	2.339	2.344	2.355
	Average.......	4.240	4.380	4.720	4.385	4.799	4.415	4.530	4.759

RESISTANCE OF ROADS TO TRACTION

The resistance to traction of a small number of pavements of different types, in different conditions was investigated in 1915 by the electrical engineering department of the Massachusetts Institute of Technology. A half-ton electric delivery wagon was used, and each test was made by driving the wagon over the test pavement in one direction and then in the other, so that the effect of the wind, if any, would be neutralized by averaging the results of the runs in both directions. The tests are described in a paper presented to the American Institute of Electrical Engineers in June, 1916, by Profs. A. E. Kennelly and O. R. Schurig. The results were summarized in the accompanying illustration.

Curve 1 is nearly flat, and the authors state that if the effect of air resistance was eliminated from the total resistance to traction, the resistance of a good level asphalt pavement would be about 17 pounds per ton at all speeds. Such a pavement in poor condition had a resistance of about 23 pounds per ton when the wagon ran at 12 miles per hour and 25 pounds at 15 miles. There were no tests of wood block pavements in poor condition; curve 2 gives the results for a good pavement.

Curve 3 is for a good brick pavement; the effect of slight wear of bricks was to increase the tractive resistance to 25 pounds per ton at 12 miles and about 30 pounds at 15 miles.

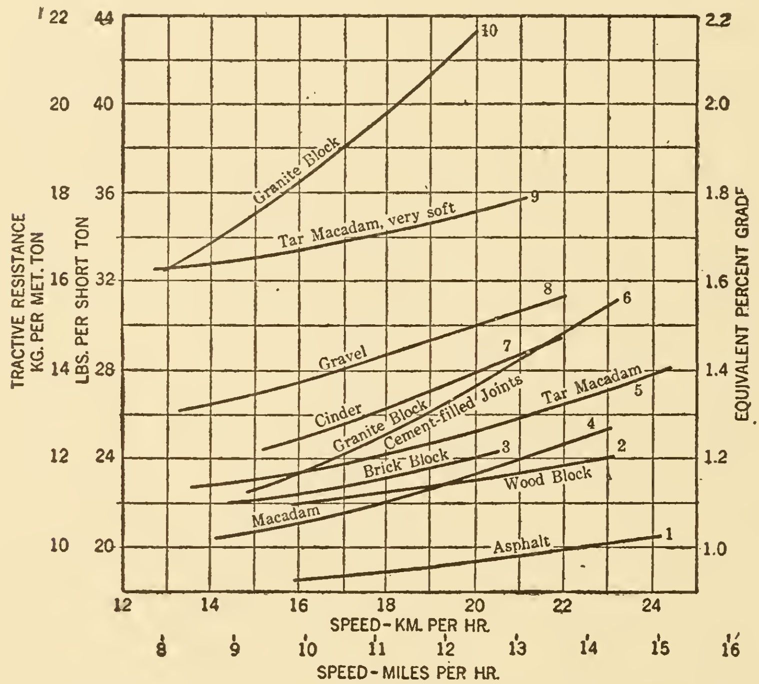
Curve 4 is for a dry, hard water-bound macadam road in fair condition. A similar road in a dusty condition showed an increase of 3 pounds in the resistance to traction at all speeds. A poor, damp road in poor condition offered a resistance of 33 pounds at 10 miles and 39 pounds at 13 miles. Oiling a good water-bound macadam road increased its resistance to traction about 5 pounds, this increase gradually growing larger as the speed increased.

Curve 5 is for bituminous macadam in good condition. The curve for another road in good condition began with a resistance of a little under 26 pounds per ton at 9 miles an hour and increased to 32 pounds at 14 miles. An old road of this type in poorly patched condition offered a resistance of about 29 pounds at 8 miles and 37 pounds at 13 miles. A good road which was recently treated and still soft had a resistance of 33 pounds at 8 miles and nearly 36 pounds at 13 miles, as shown in Curve 9. A very poor, soft road with many holes had a resistance of 41 pounds at 7 miles and 54 pounds at 12 miles, showing what a rapid increase to resistance follows an attempt to go at even moderate speed over such a road.

The authors make the following comments of the tests:

There are three principal elements which determine the tractive-resistance curve for different speeds and a given vehicle, within the range of conditions covered by the tests.

The first element is a constant resistance, the magnitude of which depends on the lack of resilience of the road surface and the tires, that is to say, on the energy losses due to displacement of tire material and road-surface material. This constant ele-



Curves Showing Resistance to Traction at Different Speeds

ment would be encountered upon a smooth, level road of the particular type considered, in the absence of impact, air and wind resistance.

The second element is an increasing resistance with increasing speed due to impact losses. This resistance results from lack of smoothness of the road surface and varies approximately as the second power of the velocity at impact.

The third element is an increasing resistance with increased speed. It is due to the air pressure against the front of the vehicle and varies approximately as the second power of the speed.

The first element is called the displacement resistance, the second the impact resistance and the third the air resistance. The displacement resistance is very marked in Curve 10, for a granite-block pavement with sand joints. The displacement resistance varies, not only with the type and surface quality of the road, but also with the type, dimensions and quality of the tires on the wheels. The same tires were used in the experiments by Kennelly and Schurig. The air resistance of a given vehicle at any given speed is the same for all classes of pavement. The impact resistance of a road depends not only on the type and character of the road surface and the sizes of its irregularities, but also on the type, dimensions and quality of the tires on the wheels, the weight of the truck and the quality of its springs.

Increasing the gross weight of the vehicle by 12 per cent, through load, was found to have no effect on tractive resistance within the observed speed limits for smooth roads in good condition; but on rough roads, a distinct increase in tractive resistance with this extra weight was observed.

RURAL PUBLIC ROADS OF UNITED STATES AT CLOSE OF 1915

Circular 63, United States Department of Agriculture. Prepared by the Division of Road Economics, Office of Public Roads and Rural Engineering.

STATE	TOTAL RURAL ROADS	TOTAL SURFACED ROADS	PERCENTAGE OF ROADS SURFACED	CASH EXPENDITURES FOR ROADS IN 1915	TOTAL STATE FUNDS FOR ROADS TO JANUARY 1, 1916
	miles	*miles*			
Alabama	55,446	5,915	10.7	$4,283,207	$586,405
Arizona	12,075	350	2.9	1,076,178	1,039,388
Arkansas	50,743	1,200	2.3	2,803,000	165,000
California	61,038	13,000	21.3	20,753,281	16,571,091
Colorado	39,691	1,750	4.4	2,193,000	1,024,751
Connecticut	14,061	3,200	22.7	3,484,944	17,019,120
Delaware	3,674	300	8.0	397,500	224,695
Florida	17,995	3,500	19.4	5,501,135	1,135
Georgia	84,770	13,000	15.3	3,700,000	....
Idaho	23,109	950	4.1	1,974,636	572,812
Illinois	94,141	11,000	11.7	9,263,995	1,686,627
Indiana	63,370	27,000	42.6	13,000,000	....
Iowa	106,847	1,000	1.0	13,606,299	255,935
Kansas	111,536	1,250	1.1	5,510,000	30,000
Kentucky	57,916	13,000	22.1	3,122,430	616,715
Louisiana	24,562	2,250	9.1	3,569,709	606,327
Maine	25,528	3,000	11.7	3,293,902	5,865,209
Maryland	16,458	2,950	17.9	5,630,000	17,583,142
Massachusetts	18,681	8,800	46.6	6,557,279	18,999,992
Michigan	74,089	8,600	11.6	10,174,738	3,182,701
Minnesota	93,500	5,500	5.9	8,292,000	4,288,174
Mississippi	45,778	2,500	5.5	2,900,000	....
Missouri	96,124	8,000	8.3	8,369,189	1,791,172
Montana	39,204	775	2.0	3,676,318	34,346
Nebraska	80,338	500	0.6	3,520,000	377,850
Nevada	15,000	75	0.5	250,000	20,000
New Hampshire	14,020	1,800	12.8	2,363,414	3,259,789
New Jersey	14,817	4,600	31.0	7,163,584	8,355,576
New Mexico	11,873	450	3.8	584,919	662,955
New York	80,112	17,500	21.8	24,255,648	96,622,498
North Carolina	50,758	6,500	12.8	5,510,000	38,500
North Dakota	68,000	1,100	1.6	2,500,700	....
Ohio	86,453	30,920	35.8	12,975,688	8,566,275
Oklahoma	107,916	300	0.3	3,410,000	30,323
Oregon	36,819	7,780	21.1	6,182,000	418,975
Pennsylvania	91,556	9,883	10.8	12,541,257	30,801,211
Rhode Island	2,121	1,246	58.8	594,119	3,907,784
South Carolina	42,220	3,500	8.3	1,000,000	....
South Dakota	96,306	850	0.9	1,450,000	....
Tennessee	46,050	8,625	18.7	3,503,500	3,500
Texas	128,960	12,000	9.3	9,500,000	....
Utah	15,000	1,053	7.0	1,213,100	809,732
Vermont	15,082	3,478	23.1	1,475,145	3,671,564
Virginia	53,388	4,760	8.9	4,018,399	2,713,550
Washington	42,428	5,460	12.8	6,670,702	8,552,789
West Virginia	32,024	1,200	3.7	2,759,212	[1]130,978
Wisconsin	75,702	14,050	18.5	9,960,980	4,219,001
Wyoming	14,381	500	3.5	441,291	43,237
Total	2,451,660	276,920	11.3	$266,976,399	$265,350,824

[1] Of this $118,000 was returned to the counties in 1911 by act of legislature.

REVENUES USED IN 1914 IN EACH STATE FOR PUBLIC ROAD AND BRIDGE PURPOSES AND TOTAL OUTSTANDING BONDS FOR ROADS AND BRIDGES AT CLOSE OF 1914

From Bulletin 390, U. S. Department of Agriculture, Prepared by the Office of Public Roads and its State Collaborators

STATE	PUBLIC ROAD AND BRIDGE REVENUES					TOTAL STATE AND LOCAL BONDS
	Total	Per mile of road	Per square mile	Per capita	Per $100 assessed valuation	
Alabama	$3,949,019.00	$71.22	$77.01	$1.840	$0.6900	$5,418,000.00
Arizona	982,721.22	81.38	8.63	4.810	0.7000	295,000.00
Arkansas	1,522,696.20	30.00	28.99	0.960	0.3600	1,467,066.00
California	19,171,984.66	314.09	123.17	8.060	0.6600	32,277,000.00
Colorado	1,937,546.23	48.70	18.69	2.420	0.4600	90,500.00
Connecticut	3,640 962.75	258.90	755.50	3.260	0.3500	7 000 000.00
Delaware	511 628.00	139.25	260.37	2.520	0.5450	1 280 000.00
Florida	2,280,255.09	126.71	41.56	3.020	1.0700	5 959 199.00
Georgia	3,688,172.25	45.72	62.80	1.410	0.4370	127 500.00
Idaho	1,371,468.58	56.22	16.45	4.210	0.8200	1,339,000.09
Illinois	8,734,712.77	91.32	155.85	1.540	0.3700	798,761.55
Indiana	14,233,985.93	194.06	394.89	5.270	0.7500	42,095,357.34
Iowa	10,187,507.32	97.88	183.27	4.580	1.1300	1,960,780.00
Kansas	5,544,048.00	49.92	67.79	3.280	0.2000	....
Kentucky	2,474,621.00	42.52	61.58	1.080	0.2390	705,000.00
Louisiana	1,777,572.12	72.37	39.10	1.073	0.3220	1,588,835.00
Maine	2,642,006.79	112.25	88.37	3.550	0.6330	785,000.00
Maryland	6,000,652.03	364.60	603.62	4.630	0.4850	12,863,700.00
Massachusetts	6,091,875.30	326.08	758.00	1.810	0.1270	10,305,522.82
Michigan	9,261,998.00	124.84	161.13	3.290	0.4000	10,389,029.43
Minnesota	6,458,940.07	69.06	79.88	3.110	0.4400	1,411,889.00
Mississippi	3,960,377.00	86.51	85.42	2.200	0.9620	8,327,172.00
Missouri	5,513,048.71	57.40	80.22	1.670	0.3000	522,500.00
Montana	2,888,400.61	73.67	19.75	7.680	0.8300	2,224,050.72
Nebraska	1,796,277.69	22.37	23.38	1.510	0.3900	....
Nevada	245,013.65	20.11	2.23	2.900	0.2400	38,000.00
New Hampshire	1,590,464.11	113.44	176.11	3.690	0.3620	675,000.00
New Jersey	7,208,287.08	486.49	959.00	2.830	0.2890	14,011,337.00
New Mexico	556,398.82	46.86	4.54	1.690	0.7700	157,000.00
New York	23,231,964.02	292.60	467.00	2.540	0.2080	76,822,088.00
North Carolina	5,215,490.78	102.75	107.00	2.360	0.6970	8,955,300.00
North Dakota	2,402,383.52	34.92	34.23	4.160	0.6800	....
Ohio	14,334,245.98	165.99	351.84	3.000	0.2200	31,175,968.53
Oklahoma	2,112,680.80	19.57	30.45	1.274	0.1769	1,440,000.00
Oregon	5,310,466.76	144.23	55.54	7.890	0.5900	1,615,000.00
Pennsylvania	10,424,580.00	113.86	232.00	1.360	0.2050	127,547,659.00
Rhode Island	446,496.05	205.76	418.50	0.820	0.0720	1,800,000.00
South Carolina	1,024,480.37	24.26	33.59	0.670	0.3510	460,000.00
South Dakota	1,217,809.42	12.64	15.84	2.080	0.3400	....
Tennessee	2,370,560.16	51.48	56.86	1.080	0.3780	6,898,277.00
Texas	9,920,079.11	76.92	37.80	2.540	0.3910	14,615,017.00
Utah	803,070.63	91.15	9.77	2.150	0.4000	541,500.00
Vermont	1,023,941.01	71.86	112.22	2.870	0.4620	....
Virginia	3,224,528.82	60.39	80.08	1.560	0.3720	5,650,994.93
Washington	7,944,717.38	187.25	118.87	6.950	0.7900	1,555,000.00
West Virginia	2,483,747.00	77.55	103.39	2.030	0.2120	1,303,000.00
Wisconsin	9,880,240.50	130.50	178.81	4.230	0.4000	281,078.00
Wyoming	669,661.16	44.06	6.86	4.590	0.3700	....
Total or ave...	$240,263,784.46	$98.22	$80.79	$2.620	$0.3500	$344,763,082.32

EXTENT OF SURFACED ROADS IN THE UNITED STATES AT THE CLOSE OF 1914

From Bulletin 390, U. S. Department of Agriculture, Prepared by the Office of Public Roads and its State Collaborators

STATE	MACADAM	BITUMINOUS MACADAM	GRAVEL	SAND CLAY	BRICK	CONCRETE	MISCELLANEOUS	TOTAL SURFACED
	miles	*miles*	*miles*	*miles*	*miles*	*miles*	*miles*	*miles*
Alabama	431.00	31.00	2,589.50	1,916.00	....	1.00	20.00	4,988.50
Arizona	11.23	13.50	125.70	45.00	....	....	58.00	253.43
Arkansas	362.50	4.00	535.00	175.00	....	21.00	....	1,097.50
California	837.40	877.90	3,563.59	582.25	....	929.19	3,489.40	10,279.73
Colorado	3.00	....	574.25	450.12	....	2.25	164.25	1,193.87
Connecticut	923.42	128.28	1,057.93	840.27	1.33	24.22	....	2,975.45
Delaware	161.50	35.50	21.00	....	....	....	25.50	243.50
Florida	829.16	42.80	42.50	1,163.00	256.24	12.00	484.77	2,830.47
Georgia	234.00	87.00	1,073.00	10,778.00	1.72	.40	168.00	12,342.12
Idaho	42.50	12.00	168.00	449.00	....	4.50	3.00	679.00
Illinois	1,675.11	121.53	7,052.30	2,467.95	82.92	148.80	57.70	11,606.31
Indiana	10,291.29	168.35	20,264.59	150.25	34.75	53.17	....	30,962.40
Iowa	171.30	....	413.00	23.00	....	5.77	1.50	614.57
Kansas	194.30	....	151.85	758.50	4.10	1.35	38.75	1,148.85
Kentucky	10,628.00	59.03	1,713.50	....	.25	2.50	....	12,403.28
Louisiana	....	....	430.00	1,448.00	....	....	189 62	2,067 62
Maine	55.36	43.93	1,139.36	2.26	.05	10.51	1,510.89	2,762.36
Maryland	488.70	1,042.31	243.95	69.00	....	189.34	455.96	2,489.26
Massachusetts	834.30	1,337.33	6,289.57	....	....	....	44.69	8,505.89
Michigan	1,021.19	94.50	5,230.25	1,375.27	....	107.30	....	7,828.51
Minnesota	120.25	19.00	2,825.25	985.33	.50	17.50	....	3,967.83
Mississippi	86.00	29.50	1,281.10	604.25	....	14.00	118.50	2,133.35
Missouri	1,531.05	59.00	3,671.50	1,442.25	1.00	2.77	5.00	6,712.57
Montana	78.00	....	514.25	14.00	....	....	3.00	609.25
Nebraska	39.21	1.30	21.00	1,131.10	2.40	7.53	2.00	1,204.54
Nevada	2.00	....	193.00	67.00	....	....	....	262.00
New Hampshire	61.87	154.26	1,013.70	270.90	....	7.07	151.83	1,659.63
New Jersey	1,809.24	417.63	2,858.52	561.40	....	....	250.67	5,897.46
New Mexico	....	5.00	184.00	72.50	....	....	....	261.50
New York	5,717.97	3,168.63	5,802.97	....	148.53	244.19	553.61	15,635.90
North Carolina	1,111.00	9.00	529.00	4,313.50	....	1.25	40.00	6,003.75
North Dakota	....	....	955.00	....	....	....	....	955.00
Ohio	12,903.87	1,066.29	15,385.93	211.00	640.41	315.67	46.00	30,569.17
Oklahoma	6.70	3.00	6.90	105.00	....	....	....	121.60
Oregon	1,000.72	137.25	3,060.15	300.00	....	28.41	199.87	4,726.40
Pennsylvania	*1,881.80	*198.33	*235.19	....	*269.33	....	7,398.23	982.88
Rhode Island	352.92	107.40	230.10	....	....	....	3.00	693.42
South Carolina	27.50	3.50	85.00	3,101.00	....	....	53.50	3,270.50
South Dakota	....	10.00	212.00	129.00	....	....	12.00	363.00
Tennessee	4,550.50	148.00	2,788.00	613.00	.50	2.00	....	8,102.00
Texas	511.00	181.00	5,258.98	3,490.48	....	11.25	1,074.08	10,526.79
Utah	49.00	15.50	685.75	401.00	....	2.50	....	1,253.75
Vermont	1.94	....	1,165.42	....	....	....	274.67	1,442.03
Virginia	1,177.89	255.77	822.09	1,511.65	....	....	142.17	3,909.57
Washington	502.82	165.52	3,924.48	83.50	26.35	79.42	140.00	4,922.09
West Virginia	771.92	62.95	20.50	....	121.10	18.50	70.00	1,064.97
Wisconsin	1,408.00	183.00	9,597.00	2,054.00	2.40	83.07	72.00	13,399.47
Wyoming	....	....	52.50	....	....	....	416.00	468.50
Total	64,898.43	10,499.79	116,058.12	44,154.73	1,593.88	2,348.43	17,738.16	257,291.54
Per cent	25.22	4.08	45.11	17.16	0.62	0.91	6.90	100.00

* State roads only.

MOTOR-CAR REGISTRATIONS AND GROSS MOTOR-VEHICLE REVENUES, 1913-1915

Circular 59, United States Department of Agriculture. Prepared by the Division of Road Economics, Office of Public Roads and Rural Engineering

	MOTOR-CAR REGISTRATIONS[1]			TOTAL GROSS REVENUES		
	1913	1914	1915	1913	1914	1915
Alabama	[2]5,300	8,672	11,634	$83,000	$113,202	$180,744
Arizona	3,613	5,040	7,753	27,545	34,077	45,579
Arkansas	3,583	5,642	8,021	17,411	56,420	80,551
California	[2]100,000	123,504	163,797	75,000	1,338,785	2,027,432
Colorado	13,000	17,756	28,894	60,833	80,047	120,801
Connecticut	23,200	27,786	41,121	316,667	406,623	536,970
Delaware	2,440	3,050	5,052	24,735	35,672	55,596
District of Columbia	4,000	4,833	8,009	13,228	20,147	29,396
Florida	[4]3,000	[4]3,368	[2]10,850	[4]6,000	[4]6,736	[2]60,000
Georgia	[2]20,000	20,915	25,000	12,000	104,575	125,000
Idaho	2,113	3,346	7,071	35,160	58,580	121,259
Illinois	94,656	131,140	180,832	507,629	699,725	924,906
Indiana	45,000	66,500	96,915	150,345	432,309	587,318
Iowa	70,299	106,087	145,109	787,411	1,040,136	1,533,054
Kansas	34,550	49,374	72,520	186,066	268,471	387,588
Kentucky	7,210	11,766	19,500	52,000	85,883	117,117
Louisiana	[2]10,000	[2]12,000	11,380	[2]10,000	[2]12,000	75,600
Maine	11,022	15,700	21,545	138,509	192,542	268,412
Maryland	14,217	20,213	31,047	150,000	268,231	386,565
Massachusetts	62,660	77,246	102,633	764,154	923,961	1,235,724
Michigan	54,366	76,389	114,845	190,329	([3])	373,833
Minnesota	46,000	67,862	93,269	40,000	132,398	[2]160,540
Mississippi	[2]3,850	5,694	9,669	....	51,146	76,700
Missouri	38,140	54,468	76,462	173,510	235,873	323,289
Montana	5,916	10,200	14,540	12,000	27,000	33,120
Nebraska	13,411	16,385	59,000	26,000	34,325	[2]183,000
Nevada	1,091	1,487	2,009	3,323	4,331	7,875
New Hampshire	8,237	9,571	13,449	152,834	185,288	257,776
New Jersey	51,360	62,961	81,848	661,446	814,536	1,062,923
New Mexico	1,898	3,090	5,100	15,084	19,663	29,625
New York	134,495	168,223	255,242	1,275,727	1,529,852	1,991,181
North Carolina	10,000	14,677	21,000	60,000	89,580	123,000
North Dakota	15,187	17,347	24,908	41,961	55,964	79,245
Ohio	86,156	122,504	181,332	457,538	685,457	984,622
Oklahoma	[2]3,000	13,500	25,032	3,000	13,500	154,892
Oregon	13,975	16,447	23,585	56,873	77,592	108,881
Pennsylvania	80,178	112,854	160,137	841,062	1,185,039	1,665,276
Rhode Island	10,295	12,331	16,362	129,851	157,020	206,440
South Carolina[2]	10,000	14,000	15,000	10,000	14,000	15,000
South Dakota	14,457	20,929	28,724	89,170	125,000	[2]180,000

	MOTOR-CAR REGISTRATIONS[1]			TOTAL GROSS REVENUES		
	1913	1914	1915	1913	1914	1915
Tennessee.......	[3]10,000	[5]19,769	[6]7,618	[2]9,000	39,538	[3]34,000
Texas[2]..........	32,000	40,000	[7]40,000	16,000	20,000	20,000
Utah............	4,000	2,253	9,177	3,000	4,852	[2]60,000
Vermont........	5,913	8,475	11,499	111,460	154,267	218,480
Virginia.........	9,022	13,984	21,357	83,611	120,814	176,875
Washington.....	24,178	30,253	38,823	48,356	60,506	238,717
West Virginia...	5,144	6,159	13,279	40,000	60,648	128,952
Wisconsin......	34,346	53,161	79,741	190,770	293,580	431,977
Wyoming.......	1,584	2,428	3,976	7,920	12,140	19,880
Total.........	1,258,062	1,711,339	2,445,664	8,192,253	12,381,951	18,245,711

[1] Does not include motor cycles nor dealers' and manufacturers' licenses.
[2] Estimated.
[3] Registration law declared unconstitutional.
[4] State registrations only.
[5] Total cars registered under perennial system.
[6] Registrations 1915 only.
[7] American Highway Association received report that there were 138,866 automobiles licensed on April 1, 1916.

PRODUCTION OF VITRIFIED PAVING BRICK IN THE UNITED STATES

(*From "Mineral Resources of the United States, 1915"*)

YEAR	QUANTITY	VALUE	AVERAGE PRICE PER THOUSAND
	thousands		
1895	381,591	$3,130,472	$8.20
1896	320,407	2,794,585	8.72
1897	435,851	3,582,037	8.22
1898	474,419	4,016,822	8.47
1899	580,751	4,750,424	8.18
1900	546,679	4,764,124	8.71
1901	605,077	5,484,134	9.06
1902	617,192	5,744,530	9.31
1903	654,499	6,453,849	9.86
1904	735,489	7,557,425	10.28
1905	665,879	6,703,710	10.07
1906	751,974	7,857,768	10.45
1907	876,245	9,654,282	11.02
1908	978,122	10,657,475	10.90
1909	1,023,654	11,269,586	11.01
1910	968,000	11,004,666	11.37
1911	948,758	11,115,742	11.72
1912	911,869	10,921,575	11.98
1913	958,680	12,138,221	12.66
1914	931,324	12,500,866	13.42
1915	953,335	12,230,899	12.83

OUTPUT OF VITRIFIED BRICK IN 1914 AND 1915 BY STATES

(*From "Mineral Resources of the United States, 1915"*)

	1914			1915		
	Quantity	Value	Average price per thousand	Quantity	Value	Average price per thousand
	thousands			*thousands*		
Alabama	18,679	$248,525	$13.31	29,018	$374,387	$12.90
Arkansas	*	*	12.14	*	*	12.00
California	1,800	39,705	22.06	3,182	66,784	20.99
Colorado	*	*	11.52	*	*	11.59
Connecticut and Rhode Island	*	*	16.03	*	*	12.66
Florida	*	*	12.00			
Georgia	16,470	234,855	14.26	17,193	166,086	9.66
Illinois	157,176	2,086,344	13.27	142,689	1,796,350	12.59
Indiana	42,937	576,892	13.44	35,237	466,873	13.25
Iowa	14,997	211,905	14.13	20,573	300,785	14.62
Kansas	50,707	594,229	11.72	47,511	608,599	12.81
Kentucky	*	*	12.74	*	*	10.85
Michigan	7,733	120,562	15.59	4,420	62,238	14.08
Minnesota	*	*	16.12	*	*	14.18
Missouri	26,217	424,170	16.18	*	*	14.62
Montana	*	*	22.50	*	*	22.01
Nebraska	*	*	11.14	561	8,323	14.84
New Jersey	*	*	15.00			
New Mexico	*	*	10.40	*	*	12.00
New York	31,240	515,672	16.51	24,154	384,458	15.92
Ohio	293,381	3,682,230	12.55	333,288	4,017,758	12.05
Oklahoma	9,912	127,792	12.89	16,537	198,387	12.00
Pennsylvania	151,200	2,052,676	13.58	124,354	1,638,518	13.18
Tennessee	*	*	15.26	*	*	14.47
Texas	1,684	23,599	14.01	*	*	15.45
Virginia	*	*	10.00			
Washington	*	*	18.99	14,861	265,691	17.88
West Virginia	67,750	899,215	13.27	69,474	841,067	12.11
Other States†	39,441	662,495	16.80	59,844	853,107	14.26
Total	931,324	$12,500,866	$13.42	953,335‡	$12,230,899‡	$12.83

* Included in "Other States."

† Includes all products made by less than three producers in one State.

‡ In the total quantity and total value of vitrified brick are included, respectively, 824,359,000 vitrified brick sold for paving, valued at $11,114,427, and 128,976,000 vitrified brick sold for other uses, valued at $1,116,472.

BROKEN STONE FOR ROAD BUILDING PRODUCED IN THE UNITED STATES IN 1914 AND 1915

(*From "Stone in 1915," G. F. Loughlin, "Mineral Resources of the United States"*)

STATE OR TERRITORY	1914		1915	
	Quantity	Value	Quantity	Value
	Short tons		*Short tons*	
Alabama	74,914	$75,528	49,972	$42,116
Arizona	2,600	4,000	....	....
Arkansas	199,417	140,442	113,606	75,044
California	1,707,230	982,321	1,567,505	902,462
Colorado	6,052	10,100	5,842	7,178
Connecticut	360,443	216,064	728,014	330,174
Delaware	53,430	33,501	21,742	21,707
Florida	159,524	84,911	102,517	56,381
Georgia	57,553	37,088	90,244	54,696
Hawaii	41,832	37,049	34,413	36,366
Idaho	....	....	....	....
Illinois	1,838,599	893,889	1,625,250	747,718
Indiana	2,089,103	1,065,360	1,792,261	910,462
Iowa	19,308	17,438	32,437	28,397
Kansas	27,248	20,135	20,046	15,591
Kentucky	545,878	323,075	609,995	379,234
Louisiana	....	....	830	664
Maine	5,950	4,650	1,747	1,409
Maryland	404,523	349,833	334,153	274,644
Massachusetts	649,144	594,666	738,015	599,555
Michigan	530,823	267,702	510,524	224,734
Minnesota	46,944	36,172	59,733	57,286
Missouri	466,143	363,302	553,049	383,022
Montana	4,590	1,271	23,875	5,186
Nebraska	32,137	27,300	....	....
New Hampshire	20,936	13,745	14,845	12,416
New Jersey	827,705	674,202	1,059,749	822,214
New Mexico	....	....	547	407
New York	2,267,264	1,408,490	2,900,165	1,623,570
North Carolina	65,700	65,128	69,238	73,404
Ohio	3,453,360	1,748,075	3,088,599	1,567,676
Oklahoma	15,802	7,441	46,430	29,764
Oregon	218,379	157,267	290,648	202,580
Pennsylvania	1,640,049	1,110,039	1,844,626	1,218,446
Rhode Island	61,373	72,255	91,872	110,167
South Carolina	28,425	27,684	27,111	26,566
South Dakota	14,120	11,300	11,292	8,487
Tennessee	345,765	264,288	441,298	369,296
Texas	196,051	119,218	269,151	164,865
Utah	16,000	19,200	6,500	3,750
Vermont	17,978	13,563	14,929	13,269
Virginia	1,931,852	1,185,271	2,193,898	1,538,149
Washington	162,777	87,259	213,039	111,461
West Virginia	197,245	113,525	196,068	129,106
Wisconsin	1,000,667	635,618	914,295	555,927
Wyoming	....	....	....	....
	21,786,833	13,329,365	22,710,070	13,735,546

GRAVEL AND PAVING SAND PRODUCED IN THE UNITED STATES IN 1914 AND 1915

R. W. Stone in "Mineral Resources of the United States, 1915"

STATE	PAVING SAND				GRAVEL			
	1914		1915		1914		1915	
	Quantity (short tons)	Value	Quantity (short tons)	Value	Quantity (short tons)	Value	Quantity (short tons)	Value
Alabama	5,849	$4,538	*	*	527,891	$138,693	547,656	$116,672
Arizona	...	...	...	...	...	...	*	*
Arkansas	*	*	...	...	673,924	278,876	831,668	314,003
California	106,578	26,714	173,985	$42,841	3,258,718	595,449	2,974,090	709,602
Colorado	...	...	*	*	7,610	3,310	*	*
Connecticut	*	*	...	...	...	...	*	*
Florida	29,000	7,000	*	*	98,435	10,637	16,518	4,495
Georgia	5,610	1,400	*	*	12,244	7,875	22,848	15,071
Hawaii	...	...	...	...	...	...	*	*
Idaho	...	...	...	...	*	*	*	*
Illinois	121,812	39,851	291,436	73,645	4,955,219	793,422	4,424,527	885,548
Indiana	158,443	55,290	240,053	66,894	4,184,093	602,533	2,482,922	591,592
Iowa	201,900	64,340	293,948	97,008	1,087,967	205,820	1,554,199	313,327
Kansas	137,582	37,206	244,103	70,311	160,283	19,512	*	*
Kentucky	21,653	14,272	*	*	815,796	208,770	448,897	162,524
Louisiana	*	*	*	...	738,510	190,717	*	*
Maine	...	...	...	...	*	*	*	*
Maryland	327,750	76,212	163,304	71,517	760,204	268,338	854,180	284,410
Massachusetts	78,380	33,161	47,239	25,444	177,642	50,795	270,906	169,772
Michigan	320,322	74,866	131,466	14,021	2,140,359	530,338	2,457,094	671,970
Minnesota	36,458	15,666	*	*	637,900	236,704	935,252	175,084
Mississippi	...	...	*	*	1,500,291	354,855	991,119	153,627
Missouri	30,327	6,485	*	*	1,321,839	257,827	1,656,745	226,716
Montana	*	*	*	*	13,310	11,970	7,422	5,500
Nebraska	5,259	610	*	*	88,026	16,435	118,970	27,389
Nevada	...	...	...	...	*	*	17,491	1,775
New Hampshire	...	...	...	...	670,000	112,500	583,200	77,760
New Jersey	110,260	39,902	160,256	53,599	2,204,880	672,433	2,112,557	447,388
New Mexico	...	...	*	*	*	*	*	*
New York	82,725	34,148	51,363	21,240	2,149,310	891,762	2,828,887	989,801
North Carolina	...	...	...	...	311,059	42,438	77,241	23,652
North Dakota	...	...	...	...	10,875	5,725	*	*
Ohio	407,025	134,370	501,359	194,026	2,417,805	654,833	2,816,132	922,379
Oklahoma	...	...	...	...	505,737	225,559	*	*
Oregon	3,368	2,607	15,218	14,174	611,821	137,221	368,797	118,960
Pennsylvania	625,171	235,326	291,599	106,828	1,766,651	387,845	1,814,902	433,223
Rhode Island	...	...	...	...	*	*	*	*
South Carolina	...	...	...	...	29,927	4,995	*	*
South Dakota	*	*	*	*	196,909	25,603	239,649	36,826
Tennessee	6,489	2,484	13,815	3,552	445,504	183,296	540,653	203,867
Texas	46,460	14,315	11,904	2,950	1,183,646	433,399	1,494.421	393,121
Utah	44,445	11,300	*	*	184,763	45,162	251,216	29,772
Vermont	...	...	...	...	822	390	*	*
Virginia	*	*	*	*	294,398	87,379	519,850	126,801
Washington	363,745	86,796	83,827	27,628	457,137	162,183	478,707	129,016
West Virginia	44,617	17,819	69,598	27,230	455,804	125,618	114,273	43.016
Wisconsin	222,298	71,560	206,094	67,340	1,294,893	343,230	1,567,840	349,941
Wyoming	...	...	...	...	718,441	48,245	*	*
Concealed totals	36,645	13,761	391,150	97,138	142,215	26,205	1,551,719	443,791
	3,580,171	1,121,999	3,381,717	1,077,346	39,212,858	9,398,897	37,972,548	9.598,391

* Included in "Concealed totals."

THE REASONS FOR IMPROVING ROADS

Good roads are desirable for three distinct reasons, which may be called social, business and pleasure reasons.

Social Benefits from Good Roads.—The social reasons for road improvements appeal to persons living in the country. The women who dwell in the country districts know better than any others what bad roads mean to themselves and their sisters on other farms, and how utterly drab and hopeless is life in the country with inadequate means of communication between themselves and almost their next-door neighbors. The country parson can tell what a handicap bad roads are in his work. Preaching two sermons on Sunday is but a part of his labors. He must visit his parishioners if he is to be the guide, counselor and friend he aspires to be. He knows by hard experience the difficulty of riding or walking over muddy roads and through oceans of slush to those longing for his comforting presence in time of sickness and death, and how hard it is to convey to those who are ill the things necessary for their recovery. The country doctor can likewise bear witness to the restraint and even suffering caused by bad roads. Taking men as they are in the large, the wonder is that there are any who would choose his profession, the most devoted and consecrated of all that serve humanity. He comes when he is called and where. His charity is unmeasurable, his rewards are insignificant. Time with him and with the patient waiting his aid is often the deciding factor between life and death; he knows full well the death rate due to isolation by poor highways.

We cannot state in percentages the increase in the satisfaction of people with country life which follows the certainty a doctor can be obtained when he is needed. It is not yet possible to state in numerals how much better a man is for attending church regularly or how much better a farmer's wife is for driving over a good road whenever she wishes to call on her neighbors. But there is one thing to which everybody will agree; the schools of our rural territory are one of the great defenses of our national prosperity, and the education of our children is one of our best safeguards for the wise government of our republic. And so everyone will admit the importance of these figures: In eight typical rural counties studied by the U. S. Office of Public Roads during a period of five years, the average school attendance increased from 66 out of every 100 pupils enrolled before the roads were improved, to 76 out of every 100 after the improvements.

Ten per cent more children were helped, therefore, to become better citizens by an increase in taxation for roads amounting to only 9 per cent of the total tax for all purposes.

Business Benefits from Good Roads.—The business advantages of road improvements to the owner of a farm can be stated even more definitely, for they can be measured in dollars and cents. In the investigation by the U. S. Office of Public Roads, just mentioned, the observations were carried out in New York, Virginia, Alabama, Florida and Mississippi, in districts which represent typical dairying, farming, mining and lumbering conditions, before and after the construction of roads. The amount of road improvements done in each of them, which produced the improved conditions which will be stated, were as follows:

COUNTY	MILES OF ROADS	
	Total	Improved
Franklin, N. Y.	1,370	369
Spotsylvania, Va.	400	83
Dinwiddie, Va.	524	101
Lee, Va.	450	105
Wise, Va.	300	146
Dallas, Ala.	1,000	218
Manatee, Fla.	575	64
Lauderdale, Miss.	800	147

The investigations by the government's experts were not hasty observations from a buggy or automobile; they were painstaking searches through real-estate transfers, public records, railway reports, school reports and like sources of information, studied on the spot until their accuracy was fully established. They were made from year to year, moreover, to make sure that the local conditions were fully understood and the annual effect of a road improvement was ascertained beyond question.

Real estate transfers showed that the percentage of increase in the value of rural property along these improved roads in about five years was as follows: Franklin, 9 to 114; Spotsylvania, 63 to 80; Dinwiddie, 68 to 194; Lee, 70 to 80; Wise, 25 to 100; Dallas, 50 to 100; Manatee, 50 to 100; Lauderdale, 25 to 50. The transfers on which these figures are based are mostly for property within a mile of the improved roads.

In each county the extent of the districts sending vehicles to the improved road was carefully determined in much the same way that the drainage area of a stream is ascertained. The products of these districts and the proportion of them hauled over the roads were then ascertained. The railway shipments from and into the districts were investigated. In case of doubt the actual travel on the roads was ascertained by counts of the vehicles and their loads. The average length of the haul on the roads was found out. From all these statistics, given in detail in the report, it is shown that the cost of hauling one ton one mile on the roads of these counties was decreased from an average of 33.5 cents before highway improvements were made to 15.7 cents afterward. This saving of 17.8 cents per ton per mile amounts to $627,409 in all. To accomplish it the additional taxes amounted to only 6.3 cents per ton per mile, leaving a net saving of 11.6 cents per ton per mile.

Roads as Sources of Enjoyment.—It is unfair to object to including the pleasure obtained by riding comfortably through the country as one of the returns we receive from our road taxes. It is just as proper to include that kind of pleasure as a justifiable object of expenditure as the investments for liquors, tobacco, the theatre and confectionery. E. W. James, one of the road experts of the United States government, recently made the following statement on the subject:

> The people of the United States spent in 1915 $2,500,000,000 for spirituous and malt liquors $800,000,000 for tobacco, $450 000,000 for the "movies," $300,000,000 for candy, $200,000,000 for soda water and $50,000,000 for chewing gum. The total for these pleasures is $4,300,000,000. So I think it conservative to say that the average man is willing to pay something for pleasure. There can be no question about the pleasure derived from riding on good roads, and that a part of the money invested in such roads can be logically justified on the score of this pleasure. After all, the total annual expenditures on roads in the United States is only equal to our purchase of candy and merely one-eighth of the money spent on liquor.

The Townsman's Interest in City Roads.—When the average townsman dresses in the morning, a large part of the clothes he puts on are made of cotton, which has to be teamed over a good many miles from the plantations to the shipping points. If he has fruit, cereal, eggs and toast for breakfast, let us say, about everything he eats has been hauled over several miles of roads, either to be shipped to him or to the mills where it is prepared for shipment. A large part of the furniture in his home and at his office has been made from hardwood hauled over the roads. These and other things which anybody can list for himself must all vary in price to the townsman with the cost of hauling them from the farms and forests to the mills or railroad stations. Just what this fact means has been stated by J. E. Pennybacker, the highway economist of the United States Office of Public Roads, as follows:

The public roads throughout the country, which constitute the primary means of transportation for all agricultural products, for many millions of tons of forest, mine and manufactured products, and which for a large percentage of farmers are the only avenues of transportation leading from the point of production to the point of consumption or rail shipment, have been improved to only a slight extent. By reason of this fact, the prevailing cost of hauling over these roads is about 23 cents per ton per mile. More than 350,000,000 tons are hauled over these roads each year, and the average haul is about 8 miles, from which it can readily be seen that our annual bill for hauling over the public roads is nearly $650,000,000. The cost per ton-mile for hauling on hard surfaced roads should not exceed 13 cents. It is therefore evident that if our roads were adequately improved a large annual saving in the cost of hauling would result.

The difference between 23 and 13 cents is 10 cents, which is the ton-mile tax of poor roads which the city people pay, for most of the hauling is toward markets or shipping points and the cost of this hauling is part of the total expense of products of the land to the consumer. The total is about $280,000,000, which the 45,000,000 people living in the cities and towns of the United States pay annually on account of poor roads. This averages over $6 a year per person.

Poor roads put a much more serious drain on the townsman's pocket-book, however. His food is costing him more every year, and he therefore has a very close, personal interest in having the agricultural lands farmed in such a way that they yield their largest returns at the lowest working cost. This means more than producing milk and vegetables at a low cost; it also includes raising at low expense the wheat and corn from which his flour and meal are made, producing fowls and hogs economically, and reducing the cost of growing cotton. How many intelligent young men, able to earn a good living in a city, will live in the country if they have to travel through miles of mud or dust, at decided physical discomfort, in order to market their products, meet their friends or buy their supplies? How many young women will be willing to live in the country where bad roads isolate them, with only the sparrows for companions, with the doctor almost inaccessible, the schools difficult for the children to reach, and church-going a real labor? Yet if the townsman is to have the things he eats grown for him efficiently and economically he must take his part in making country life agreeable and profitable to these intelligent young people. It means a saving of dollars and cents to him.

Our American Roads.—The length of the rural roads in the United States at the close of 1915 is given in the table on page 192. This table shows that only 11.3 per cent of the total mileage at that time had been surfaced, and that only 2 per cent had been built by the state highway departments or with more or less financial or engineering assistance from the states.

It has been estimated that about 80 per cent of the total travel on these roads is done on about 15 per cent of their total length. The percentages vary in different states. The Iowa Highway Commission found that from 10 to 15 per cent of the roads of each county are main traveled routes, which it is proper to construct and maintain, under the Iowa highway laws, at the expense of the county as a unit. The remaining roads are of less general use and are constructed and maintained by the townships through which they pass.

This division of our highways into main routes and local roads is of fundamental importance in road administration. Public money must be used so as to yield the greatest good to the greatest number of people. But it is human nature for a man living a mile or more from a main road to complain that he is unfairly treated if he must travel over a dirt road part of the way to town while a neighbor has a good, hard-surfaced road running by his place. As a matter of fact, although the hard road does not reach his farm it does help him materially, as Prof. B. K. Coghlan, of the Texas Agricultural and Mechanical College has shown by a recent investigation. He reports:

> Where a farmer lives at a considerable distance from the improved road he will still derive some benefit. In one county, where the gravel roads extend only about 8 miles from town, the farmers living several miles beyond haul wood during the dry spells and pile it at the end of the gravel road; then when bad weather comes and it is impossible to work in the fields they haul this wood to town. In another case two teams are used until the improved road is reached, when one team is unhitched and left with a friend, and the man proceeds to town with the other. In a third instance, where it formerly took two days to haul a load to market, since a good road has been built for about one-half of the distance, two wagons, with two teams each, haul one day until the good road is reached when all the load is put on one wagon, which proceeds to town with one team, the other three teams returning home.

Our main roads which carry four-fifths of the traffic present problems which are often quite different from those of the local roads. Highways must be built to carry the traffic over them at the lowest possible cost for both construction and maintenance. Where the traffic is light, as on local roads and some main roads, comparatively inexpensive types of construction can be maintained at small expense and are therefore better than more expensive types because more miles of them can be provided for the same total cost than is the case with expensive types of construction. As a rule, however, we are trying to get too much work from inexpensive roads and at the same time we are neglecting to maintain them in a condition for giving the most service. For many years to come, a large part of our roads will be earth, top-soil, sand-clay and gravel. That is no reason, however, for their being mud holes in wet weather or sources of blinding dust in dry weather. Well graded, drained and maintained roads of these types are pleasant to ride over and inexpensive to maintain, unless they are called upon to carry more travel than they are capable of supporting. Then they fail just as a beam fails when it is overloaded. The beam is all right for a given loading, but all wrong for a greater one. A road may be all right for a certain travel but all wrong for a greater travel; the failure to recognize this is responsible for a large part of the waste of road taxes today.

Different Classes of Road Improvements.—The improvement of roads comprises a number of classes of work. People who speak of road improvements in Missouri probably refer to grading and draining, while road improvements in Massachusetts usually signify the construction of a hard surface on a road already graded and drained. Such use of the word "improvements" indicates how varied are the really pressing highway needs of different parts of the country and the importance of studying the local resources and transportation requirements of a district before planning the improvement of its roads.

The first thing to be considered in planning good roads is the amount of money which it is wise for a community to spend for them. Most estimates of this nature are based on the existing annual tax receipts available for the purpose. This is not the best basis for a sound judgment. A family of three persons can make an income of $1800 go farther than a family of six persons can. It is the same with roads. To find out roughly how much money can be devoted to road work it is best to divide the assessed valuation of the district by the miles of roads in it. This gives the valuation, or taxable wealth, of the district per mile of road. For instance, Lake County, Mich., has a valuation of only $5420 per mile, showing that not even the entire wealth of the county is sufficient to improve all its roads. Wayne County, Mich., on the other hand, has a valuation of $514,931 per mile, indicating its financial ability to carry out any kind of road improvements in reason. In a rich agricultural district like Calhoun County, Mich., the valuation is $52,294 per mile, indicating that it is financially able to construct whatever kind of main roads may be best suited for the travel on them. We look with pity on the young saleswoman who spends all her money on clothes she does not need, and yet we complain when a county with a very low valuation per road-mile is not intersected with roads as smooth as the top of a billiard table. This shows that we have our foolish ideas, like the flighty saleswoman.

There is a measure of the need for roads, just as there is a measure of the financial resources for roadbuilding. This measure is the travel the road is carrying now and the probable increase in the travel during the next five to ten years. The improvement of a country road results in the slow development of property along it, so that there is a slow annual increase in what is called the residential travel. If the road is on a through route between important cities some distance apart, there may or may not be a material increase in the foreign travel, by which is meant the travel between these cities. This can only be determined by a study of local conditions. The residential travel can be actually counted, however, and this ought to be done. The state highway department or the United States Office of Public Roads and Rural Engineering at Washington will furnish instructions for the work, which can be done by school children under the direction of their teachers. This is a kind of child labor which no reformer will weep over and the efficiency expert will approve.

The travel over a road wears it out in different ways, according to the number and character of the vehicles, the relative proportion of horse-drawn vehicles and automobiles, the climatic conditions and the construction of the road. For the same travel, a road adopted for a moist section with cold winters is needlessly expensive for a dry section with little frost. Some types of roads wear out quickly but are easily maintained, other types withstand travel well but when they need repairs the work is expensive. All these things must be considered in determining the annual cost of a road, which is done in the following way.

The first element of this cost is the first cost of construction per mile of road, including all engineering expenses. Knowing the travel over the road, an expert can estimate the number of years such a road will serve its purpose, if properly maintained, before reconstruction is necessary. This cost divided by the number of years of service gives the annual first cost. To this must be added the annual interest on the first cost per mile. If the construction costs are met by the proceeds of a bond issue, the interest and sinking fund charges on the bonds take the place of the annual first cost and interest just mentioned. The annual cost per mile of maintaining the road in serviceable condition is the last item to be estimated. The sum of all these items is the total annual cost per mile of the road, and this figure is the most important one to the taxpayers. But another unit for measuring cost, which is sometimes very useful, is the cost of the road per vehicle mile. This is obtained by dividing the total annual cost per mile by the number of vehicles using the road annually. The type of construction which gives the lowest cost per vehicle mile is generally the best to employ.

While the preceding notes explain the steps to be taken in planning a good road, they cannot supply the good judgment necessary to take the steps wisely. We admire the skill of a slack-rope gymnast but we are not foolish enough to emulate him. The skill and knowledge needed to select the right type of construction for a road are greater than those required by the slack-rope performer, and yet our minds are so warped by constant use of roads that we are strongly inclined to think we are able to do the work of road engineers. We will be losing money in our road planning until we stop this foolishness.

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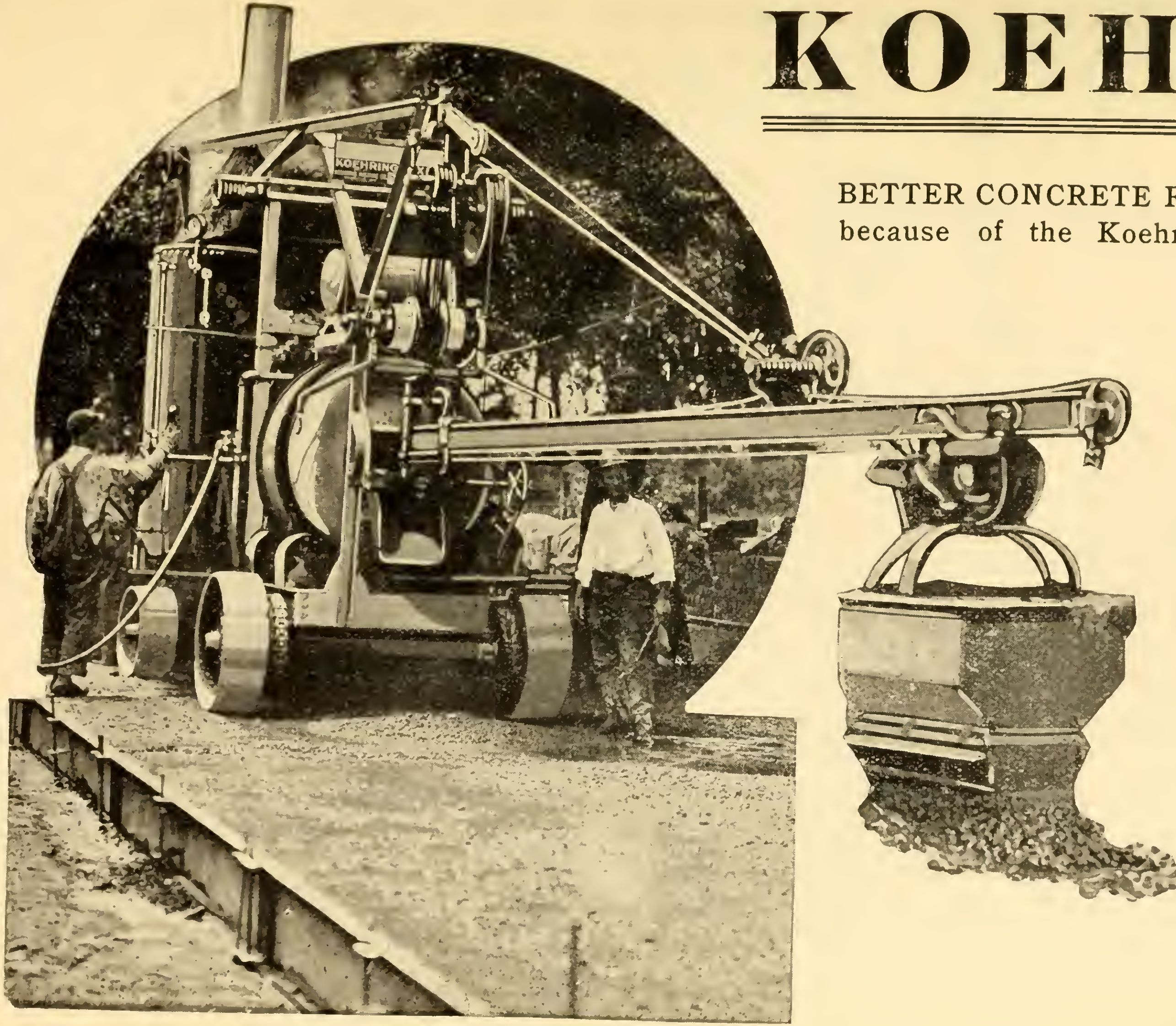
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