THE
CONCRETE HOUSE
AND ITS
CONSTRUCTION

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Construction

Residence of W. L. Clements, Bay City, Mich.   *Albert Kahn and Ernest Wilby, Architects*

A notable example of an all-concrete house. While surpassing the average house in beauty of design, it has the further merit of being fireproof and indestructible.

The Concrete House

and

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By Maurice M. Sloan

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Preface

The demand for fire-resisting, durable and sanitary construction has been the dominant note in most that has been said and written on the subject of architecture during the last decade. The American dwelling of the best class is a model of convenience, comfort and beauty, and these attributes may be found even in houses of moderate cost. But with rare exceptions, three fatal defects accompany *modern* construction. Modern houses are not fire-resisting, not durable and, to a lesser degree, not sanitary.

Knowledge of these facts, coupled with that newly awakened, irresistible demand for vastly increased economy and efficiency in the nation's industrial and social development, has led American architects to concentrate every effort toward the solution of the problem. They found that the highest standard of fire-resisting construction was so closely allied with extreme durability and sanitary excellence as to embrace these three important structural reforms under that single head. Iron and steel did not, unless protected, represent fire-resisting construction, and in this investigation many other materials were rejected as non-fireproof in themselves.

In the average house, fire starting in the cellar soon transforms the building into a smoking ruin. Only the eternal vigilance of our fire departments, maintained at a cost of more than $100,000,000 annually, prevents the destruction of thousands of homes each year.

A study of the fire losses of this and European countries shows our annual loss to be $2.51 per capita, while in the cities of the six leading nations of Europe it is only 33 cents.

That fire-proof construction is the exception rather than the rule, is due mainly to a mistaken idea of its cost. Fire-resisting floors and

roofs are not prohibitive in cost, and even though the architect be wedded to concrete, brick or stone in the matter of walls, he is in favor of fire-proof interior construction.

The purpose of this book is to make clear the advantages of concrete in the construction of dwellings.

Experiment and research have reduced the list of available fire-resisting materials to practically two products—concrete and clay. Concrete is not only a superior fire-resisting material, but ranks supreme from the standpoint of economy, owing to the facility with which it may be used for practically every structural detail of a house. Its wide range of adaptability has been demonstrated by such architects as McKim, Mead & White, who used concrete with distinguished success in the new Pennsylvania Terminal Station, in New York city, where it is usually mistaken for costly stone work. Carrere & Hastings chose simple concrete blocks for the costly Steers mansion, near Greenwich, Conn. Mr. Grosvenor Atterbury, in charge of the Sage Foundation work, achieved remarkable results with concrete in seeking to better the living conditions of the laboring classes by his invention of cheap houses of solid and seamless concrete, a type more durable, sanitary and fire-resisting than the majority of our most costly dwellings.

In work of this kind, as well as in great engineering achievements, is to be found indisputable evidence that the restricted use of concrete in the construction of dwellings is not due to any defect or limitation of the material itself, but chiefly because architects have failed to give the subject the serious consideration it deserves. The fact that concrete is a comparatively new material has also had a retarding influence, but now that striking examples of its extreme utility as well as perfect adaptability to artistic expression are to be found in many sections of the country, there is promise that concrete houses will become the rule rather than the exception.

This book does not treat of the subject in a superficial way, but goes into all the details of concrete construction as applied to houses, and it is published with the conviction that it will have a real and practical value to the architect.

Above the costly Travertine stone, imported from Italy, the interior walls are faced with concrete, colored and cast in imitation of this stone. Even experts have been deceived as to the point where the stone ends and the concrete begins. The economy and utility of concrete for architectural purposes is strikingly exemplified in this magnificent building.

Chapter I
The Advantages of Concrete for House Construction

Workingman's Cottage, Sewaren, N. J. Sage Foundation Homes Co. Grosvenor Atterbury, Architect, N. Y.

A fireproof, sanitary, and indestructible house, built throughout of huge, precast concrete slabs, and intended to solve the problem of better living conditions for working classes at minimum cost.

Chapter I
The Advantages of Concrete for House Construction

Fireproof Qualities of Concrete.—It would be difficult to plan and construct a house that would ignite quicker or burn faster than the common type of dwelling. Every architect and builder understands the danger of studded partitions, wooden floor joist and outside sheathing, the close proximity of timber construction to chimneys and flues, the inaccessible recesses of the hollow frames into which chips and shavings have fallen, the knob and tube work of electric wiring. To mention these features of the ordinary house brings realization of the constant peril confronting those obliged to live in them.

The antithesis of all this is found in concrete. Concrete means fireproof walls and floors at very little cost in excess of combustible construction. Floors of concrete are non-combustible. Moreover, they will confine smoke and flames to the room in which a fire may start. They practically eliminate the danger of suffocation from smoke, so often followed by loss of life. Concrete not only affords a sense of security in this respect, but so far as the building itself is concerned makes insurance unnecessary. There is no instance on record where a building constructed of reinforced concrete throughout has been destroyed by fire or conflagration.

In tests of concrete panels conducted by the U. S. Geological Survey, a heat of 1700° Fahr. was maintained for two hours. At the expiration of that time paper labels on the backs of the specimens were not even scorched and the concrete could be touched by the hand without discomfort. Professor Ira H. Woolson, formerly of Columbia University, now Consulting Engineer of the National Board of Fire Underwriters,

used as a test-house a structure with four-inch walls of cinder concrete which, according to the last report, was intact after tests aggregating twenty hours. The temperature ranged from 1700° to 1900° Fahr., which is in excess of estimated conflagration temperatures. Moreover, at the end of each four-hour test, and while the walls were red hot, a stream of water at 60 pounds nozzle pressure was played back and forth over the ceiling for ten minutes—a terrific punishment—but the walls remained intact. All this is far in excess of anything buildings encounter in ordinary fires. In a word, in the true concrete house, lamps might explode, furnaces melt of their own heat, wires become crossed and flues overheated, or any of the hundred and one accidents occur that cause fires, without the slightest danger to the building. Only the contents could be destroyed. Many owners of concrete buildings carry no insurance on the structures.

In every large city of a million or more inhabitants, from five to ten fires start each day. Some days the list is greatly in excess of this number. They are never noted by the public unless of the spectacular kind, involving great loss of life or property, or attended with dramatic features. But were it not for the ever-vigilant fire departments, each one of these incipient fires might easily cause a conflagration. It costs the country one hundred millions a year just to extinguish such fires. Our total loss from fire is $450,000,000 annually. In nearly every instance the damage is caused by the use of combustible material in building construction. Concrete is non-combustible.

Durability.—As to the stability or strength of a concrete house, the following is an example strikingly typical: Preceding the recent earthquake in Jamaica, there was a scarcity of water, and at the concrete residence of Mr. Alfred Mitchell, in Port Antonio, bath-tubs were used as temporary tanks or reservoirs. During the earthquake this house was rocked until the water splashed over the sides of the tubs. Mr. Mitchell, whose American residence is New London, Connecticut, wrote that the house had passed through the ordeal without showing the least crack. Other buildings in the district were utterly demolished. This remark-

Residence of Alfred Mitchell, Port Antonio, Jamaica.

Chapman and Fraser, Boston, Architects

A reinforced concrete house which passed undamaged through the Jamaica earthquake. Though rocked until water splashed from half-filled bath tubs, not a crack appeared in the walls.

Residence of Mrs. Gaston Daus, Ocean City, N. J.

Grant M. Simon, Architect, Phila.

A house built with solid, 6-inch concrete walls, which is unique in that the exterior surface was left just as it appeared when forms were removed.

able strength may be obtained in the small and cheap concrete dwelling as readily as in a large and costly house. In this matter of durability we again encounter in concrete the very opposite of other materials. It improves with age. Its known life runs into thousands of years. Wood shrinks, warps, burns and decays; stone and brick units fall apart and are disrupted through the action of frost and temperature changes. Concrete is improved both in quality and appearance by exposure to the weather. It may be used for foundations, walls, floors, roofs, stairways and chimneys, thus making a solid, seamless house throughout.

Vermin-Proof Qualities.—With concrete it is possible to so build walls and floors as to make them impervious to rats, mice and other vermin, too often the purveyors of disease. In a word, concrete houses may be made as sanitary as they are fire-resisting. Concrete floors and walls tend to prevent either the admission or accumulation of things dangerous to health, many of which find protected habitat in the recesses of the ordinary house.

Non-Conductivity of Concrete.—The low conductivity of concrete, which makes it such an admirable fire-resisting material, also retards the entrance of cold. When properly made it is devoid of cracks and imperfect joinings. Settlement of walls, so common in buildings of brick and stone, is not apt to occur. It is not a paradox to say that the concrete house is cool in summer and warm in winter. It has been found by actual experiment that a saving of 20 per cent. in the cost of fuel has been obtained by substituting concrete for brick, stone or frame. In the concrete house shown in Fig. 14 the temperature is 15 degrees lower than the outside temperature on the hottest days of summer.

Sound-Proof Qualities of Concrete.—Concrete possesses marked sound-proof qualities. When concrete is used throughout a dwelling there results a minimum of sound transmission, insuring the quiet and repose so essential to the ideal home. Allied to this is the exceedingly desirable attribute of rigidity, which in turn means non-vibrating floors. The

virtue of concrete in this respect is so pronounced that in factory construction it has come to be regarded as an economic factor of the highest importance, making for increased efficiency as well as representing a material saving in the wear and tear of machinery.

Low Cost of Upkeep.—As stated, concrete means the elimination of insurance on the building and the same thing applies to the cost of upkeep or repairs. For this reason it is highly important to determine whether the cheapest construction is not, after all, the most expensive. At the expiration of seven or eight years, repairs become an important item in the case of the average house, and this should be carefully estimated when the first cost is considered. If the value of property is to be maintained it must be kept in first-class condition and in the case of ordinary construction this can only be done through constant repairs.

Walls of concrete, especially when solid and untreated as to surface finish, require absolutely no repairs, and when floors and roofs are constructed of the same material the up-keep would be confined merely to the painting of windows and doors. The prevailing notion that the cost of a concrete house is far in excess of other materials is absolutely wrong. The partial imitation of other houses in concrete—that is to say, a house with concrete walls—may exceed slightly the cost of other types, but it has frequently happened, especially where sand and stone were convenient, that the cost was less. But in the true concrete house, that is to say, a house of concrete throughout, its duplicate in stone or brick would be prohibitive in cost. As matters stand to-day, there is no fair basis of comparison, for, as stated, all that has been done up to date, except in very rare cases, has been to build the usual type of house with concrete walls. The trend at present, however, is toward the absolutely fireproof and indestructible house that shall be of concrete from foundation to roof. The same type of house in brick or stone, if practicable at all, would cost three times as much as the concrete house. It is in looking at the concrete house from this point of view that we begin to comprehend its true significance and value.

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Chapter II

Architectural Design and Treatment
of Concrete Houses

A concrete house in which severe and simple outlines are balanced by decorative borders in low relief.

Chapter II

Architectural Design and Treatment of Concrete Houses

The fundamental rule of all good architectural design is that the appearance of the building shall express the structural capabilities of the materials of which it is composed. The great main divisions of architectural history are marked either by the adoption of new materials or by improved methods of using the old ones. But as all transition in architectural styles is slow and gradual, elements of previous architectural design still appear in the newer styles. So it is that the columnar halls of the Egyptian temple take their proportions and construction from the rock temples carved in the mountain side, where gigantic pillars were left to support the roof of the vault, as in modern mine workings.

The Greeks, following the precedent of the Egyptians, built with the stone column and superimposed lintels until the Romans developed the arch, and learned that great spans could be made by supporting an arch ring of stones upon heavy buttresses. It remained, however, for those masters of Gothic architecture, the medievalists, to produce a new architecture by balancing arch thrust with arch thrust, and supporting the whole gigantic and, withal, light and wonderful structure upon isolated piers, the beauty of which has never been surpassed.

The Development of a Particular Style.—The difference thus seen between the two great historical divisions of architecture is based on the structural design. In the first instance the elements of the classic orders are the lintel and the column, while in Gothic architecture the design depends upon the vault, arch and buttress. All other sub-divi-

sions of architectural design are purely adaptations of these, and illustrate either growth or decadence.

In modern times new materials have been introduced. The use of structural steel has developed designs impossible with any other material; but even with this modern material the use of the column and lintel is adhered to. For the application of an entirely new principle in construction one must turn to reinforced concrete. This differs from all other

Fig. 1.—A false or strained surface treatment representing waste of time and money.

materials heretofore used in that it is composite, using the tensile resistance of steel to develop the compressive resistance of a monolithic artificial stone, and, with it all, possessing a quality of fireproofness beyond that of any material previously employed for building purposes.

If particular styles of architecture can be developed from the column, lintel and arch, it is certain that in the use of a new material such as reinforced concrete, a style of architectural design and decoration can be

developed which will express truly the nature and capabilities of the material. Unfortunately, it is difficult to overcome the habits of years and the training of past generations, so that up to the present time the architectural designer has shown, in handling reinforced concrete, the influence exerted by previously used materials.

The effort of the architectural designer to imitate masonry construction in handling reinforced concrete is very evident in the building illustrated in Fig. 1. This shows an effort to deceive the observer into a belief that the structure is built up of blocks cemented together, and, in order to make the deception doubly real, the joints are boldly marked by casting a bevel into the concrete to illustrate the chambered joints of massive masonry construction. Not satisfied with this effort to simulate masonry, the designer sometimes goes to the extent of bush-hammering the center section of the blocks, after the manner of the earliest methods of dressing stone.

In the design of dwelling houses the user of concrete first employed hollow concrete blocks, and the early efforts were exerted in making these blocks look like rock-faced ashlar. Unfortunately, all of the molds had the same pattern, and instead of getting the variations of light and shade which make up the life of rock-faced stonework, the entire building became a monotonous repetition of units, with the same highlights and shades.

The thoughtful designer who is about to use concrete as a structural and decorative material will endeavor to determine how best he can use the peculiar properties of concrete and reinforced concrete to obtain a true expression of the capabilities of the material and at the same time to develop a structure which will be pleasing.

The essential difference in the possibility of reinforced concrete, as compared with the lintel and column supports of the classic orders and the vaulted arch and buttress of the later medieval construction, is that it is practically a masonry material, possessing, besides the great compressive resistance of stone, the tensile strength of the steel which can be embedded in it. It is therefore possible to develop a particular style of architecture in working in this material, though it can be used for the

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Fig. 2.—One-story concrete workingman's cottage, exemplifying simple and direct use of concrete.

Fig. 3.—A carefully studied design, showing frank treatment of concrete walls and surface finish.

development of almost any architectural treatment, a feature which is particularly valuable in house construction.

Architectural Composition of Concrete Houses.—The use of concrete in monolithic construction for dwelling houses has been somewhat limited, although rapid advance is being made, both for houses of moderate cost and pretentious residences of great cost.

Fig. 4.—Buttressed porch construction in monolithic concrete.   Impracticable in other types of masonry.

To illustrate the wide range that concrete has already reached in dwelling house construction reference is made to Figs. 2 and 3, which show an interesting comparison with reference to size and cost.

In Fig. 2 there is shown a one-story concrete cottage erected at Ada, Oklahoma.   The design of this dwelling would probably not please the æsthetic taste of the architectural designer, yet one cannot help

considering how superior in architectural pretensions this small dwelling is in comparison to its prototype built of wood, replete with band-sawed brackets and fussy wooden finials and cornices, so familiar two decades ago in houses of equal value. Fig. 3, on the other hand, shows a concrete house which has been carefully studied by a skilled architect, and it is peculiarly interesting from the fact that the actual texture of the concrete of which the walls are composed shows in the illustration. One of the excellencies of this house is in the design of the façade. There has been a very evident appreciation of the character of the material in that no attempt has been made to form imitation arches over the heads of the openings. The nature of the material is also expressed in the formation of the gables, both at the peak and the eave line, in the buttresses of the chimney, corner walls, and coping and buttresses of the garden wall.

One might dispute the statement that such buttresses as illustrated in Fig. 4, which shows the construction of a porch of a solid concrete residence built in Milwaukee, are expressive of reinforced concrete construction. They, however, are certainly monolithic in their profile, as it would be extremely difficult and impractical to build such buttresses in masonry. This design is also expressive of the material on account of the formation of the arched openings, which would be impractical in ordinary masonry construction. The drain spouts or scuppers from the porch are an ornamental detail indicative of the material when used to the best advantage.

In order to illustrate a few of the structural possibilities of reinforced concrete with reference to house construction, and to show how these possibilities will eventually develop a new style of house architecture, attention is called to Figs. 5 and 6.

In Fig. 5 an interesting example of the use of reinforced concrete is shown in the projecting porch or balcony at the rear of the building, and the detail illustrates the possibilities of the material for features of this character. If the building had been constructed of timber, this projecting porch would have been carried on unsightly posts, or insecure and unenduring wooden brackets, whereas by the use of concrete a perfectly safe

Fig. 5.—A house showing the adaptability of concrete to the construction of projecting masonry.

Fig. 6.—Concrete as adapted to the requirements of English half-timber design.   Note monolithic corbel or shelf supporting window.

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and everlasting construction is accomplished. While the dwelling here described is not intended to be presented as a particularly pleasing design, it illustrates very well the use of concrete in wall construction.

To further show the practicability of reinforced concrete in the construction of details which could not be so well accomplished by other materials, attention is called to Fig. 6, and is particularly directed to the manner in which the bay-window on the side is supported by a monolithic corbel or shelf. It also shows the manner in which reinforced concrete walls can be decorated to meet the requirements of the English half-timber house design. All of the walls of this house are of solid concrete, the surface being finished by bush-hammering.

A consistent and interesting detail is also shown in the porch and open promenade connected with the house, this work being really excellently designed, massive and simple, and altogether pleasingly expressive of the capabilities of the material.

To further show the beginning of the designer's appreciation of the possibilities of solid concrete for house construction, attention is directed to Fig. 7. It shows the long spans possible for such details as porch construction. It must be remembered that such spans are obtained without any danger of settlement due to deflection or the shrinkage of timber. They typify the material, and will become, as the architectural designer attains skill in the handling of the material, more and more prominent in reinforced concrete house construction. Again, the peculiar adaptation of the material in forming the base or ledge support for the bay window is illustrated in this example, and the possibilities of reinforced concrete are also shown in overhanging pent-roofs at the eave line. These are unique since they are constructed of concrete, which is admirably suited to the purpose.

The illustration which is the subject of these remarks is a twelve-roomed house constructed at Winthrop, Mass. This house when partially completed was instrumental in stopping the sweep of a serious conflagration. At the time of the fire the outside walls were up to the second story, and while the wood window-frames were burned away, the concrete was not damaged, and the construction was resumed. The floors of this

dwelling are of concrete construction, and the example may be studied for possibilities in the design of concrete dwellings of similar size.

Solid concrete construction lends itself admirably to designs in which simplicity predominates both in plan and in elevations. Concrete is never more interesting than when in flat wall surfaces it shows to advantage the proportion and placing of the window and door

Fig. 7.—A porch illustrating the practicability of long span construction in concrete.

openings, and when the gray walls are made beautiful and interesting by the high lights and shadows of a bright sunlight.

An example of the consistent use of concrete in house construction is illustrated by Fig. 8, which shows a concrete house of the utmost simplicity; one extremely beautiful in this quality. A study of the perspective shows that the structure is entirely devoid of appliqued ornamentation, and, in fact, the only attempt at a purely architectural orna-

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mentation is found in the molded architrave over the main entrance doorway. The cornice is beautiful because it expresses the material, and no attempt has been made to copy classic details in dentil courses, mutuals and frieze moldings. Certainly, the use of such ornament in a building of this character would have been frivolous and misplaced, and particularly unfortunate because of the probably unsatisfactory results which would have been unavoidable.

Fig. 8.—A beautiful house in which concrete has been consistently treated throughout.

The illustration under discussion shows conclusively that the success of a concrete building architecturally, depends more upon the proportion of the mass, the arrangement of the voids, or window and door openings, and in the true expression of the material used than upon any features which may be denominated as architectural ornamentation. How successful this house is when built of concrete can be better understood by

attempting to consider it when constructed of any other material. For instance, the imagination could not see any beauty in a building of this design if made of wood, in which the walls were of weather-boarding or shingles. If constructed of squared ashlar, it would certainly have the formidable appearance of a fortification, and as a dwelling house would be still more undesirable if made of rubble masonry. It is certain that

Fig. 9.—A small house of simple design expressive of monolithic construction.

no more successful use of concrete could have been made for a house of these proportions and surroundings.

That concrete is as adaptable to the construction of smaller houses, and can be used with success from an architectural standpoint for a house of entirely different design and surroundings from that which was described above, is shown in Fig. 9. This house is fortunate in the design of the porch, and the entire structure has been handled

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with a simplicity which is pleasing, and expressive of monolithic construction.

A very excellent expression, also, of the best that has been done in monolithic construction for housework is shown in Fig. 10, and while this conception has not the simplicity of the two residences previously described, it shows in the long sweep of the span over the porch entrance,

Fig. 10.—A second example of the adaptability of concrete to long span construction. Note porch.

and in the simplicity of the steps and balustrades of the porch, an excellent use of the material. While one feels that there is a restlessness in the spacing and proportions of the window openings, and in the topping out of the porch posts with the somewhat conventional ornamentation, yet, in general, this dwelling has a far better appearance than some of the accepted best work of houses built of wood and stone.

Another example of concrete house construction which has much

to commend it is illustrated in Fig. 11. One cannot help but feel that a mistake has been made so far as the architectural design is concerned in using the evidently wooden beams and porch rails at the roof of the porch, and also that the roof and dormer are hardly consistent in wood with the monolithic and massive lower portion of the house. At the same time the simplicity and general mass and proportion of voids to wall

Fig. 11.—A house of commendable simplicity, but inconsistent in its timber accessories.

surface is most excellent, and would be still more appreciated if the photograph showed the deeper shadows which would occur with bright sunlight.

If there is one style of architecture with which monolithic concrete construction fits better than another, it is the California or Mexican "Mission," as expressed in the low rambling buildings with the deep recessed porches and Spanish tiled roofs so favorably known and extensively used in California.

A costly and interesting example of residence construction of this type is shown in Fig. 12. Everything in the design is indicative of the strength and monolithic possibilities of the material. One will notice upon close examination that the face of the porch wall near the base of the piers sweeps out in a radius, and that the base of the bay window on the side is also strengthened and made interesting by a sweeping and

Fig. 12.—Typical California or "Mission" house. A type admirably adapted to concrete construction.

broadening curve toward the foundation. The formation or outline of the gable walls could only be expressed properly in a material like concrete, which could be molded to the required form. One feels that the color scheme is expressive of harmony, a pleasing combination of flowers, tropical foliage, and red-tiled roof, all emphasized by the deep shadows and bright sunshine of a semi-tropical land.

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While monolithic concrete for house construction is possible of great development in the way of particular and pleasing styles of architecture, it has, in the hands of skilled designers, attained beautiful and picturesque results when used with other materials in following the older types of country house construction. In Fig. 13 is shown how reinforced concrete may be successfully used in the construction of a "Colonial" country

Fig. 13.—Attractive use of concrete as adapted to familiar types of the country house.

house. The entire effect of this residence is one of repose and dignity, and its proportions and details are such as to class it with the suburban architecture of best Colonial type.

The use of concrete in the construction of a modern suburban home in which the effort has been only to follow the most recent style of suburban house architecture without any special emphasis of the character of the material, is shown in the very successful design illustrated

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in Fig. 14. This house was built with monolithic walls, and is extremely pleasing in the accomplished simplicity and interesting details of the front and side of the building shown in the perspective.

Concrete has been considerably used in combination with other materials, and the success of the combination can be seen in Fig. 15. Here the two ends of the structure, which is a twelve-roomed country house, are made interesting by the rubble work indicating the chimney-breast and chimney, and the use of boulders to bring out and enhance the appearance of the plain concrete wall must be commended. The entire design, with the rubble entrance posts supporting the open timber trestle, together with the tile roof and wide-extending eaves, makes a picturesque and, on the whole, pleasing and homelike concrete house composition.

Architectural Details of Monolithic Concrete.—While the best architectural effects have been obtained in those houses which have been constructed entirely of concrete, by a careful study of the proportions of the building and the arrangement and location of the window and door openings, and arches and supports of porch construction, yet it is frequently desired both by the owner and the architect that concrete dwellings should have some ornamentation. It is hardly necessary, nor does it lend to the appearance of the building, to attempt to ornament concrete houses located in the country, or in truly suburban districts. In the construction, however, of villas, and of houses located in the more pretentious parts of provincial towns and cities, there is probably some excuse for the use of ornamentation and embellishment of concrete exteriors.

A study of architectural details for reinforced concrete house construction will certainly show that the finer details of the classic, or a full revival of the classic or Renaissance architecture, are not suitable when applied to the decoration of dwellings of concrete. For instance, such a detail as that shown in Fig. 16 is of a degree of fineness incompatible with its being made of cement or concrete and used in conjunction with monolithic walls for house decoration. On the other hand, a detail like that

Fig. 14.—A handsome house showing successful use of concrete, but without emphasizing its character.

Fig. 15.—Interesting example of the combined use of concrete and rubble work.

Fig. 16.—Concrete should be translated into simple and original forms as opposed to the elaborate detail shown above.

illustrated in Fig. 17 is consistent with the nature of the material, and embellishes by its simplicity the monolithic construction of which it is a part.

If the architectural details or ornamentations are to be cast monolithic with the walls, they should be simple and bold in their outline, and of such a contour that the forms can be made at a minimum expense, and at the same time the perfection of detail insured and left undamaged by the removal of the forms. The purpose of ornamental moldings, band courses and decorative features is to furnish, by the de-
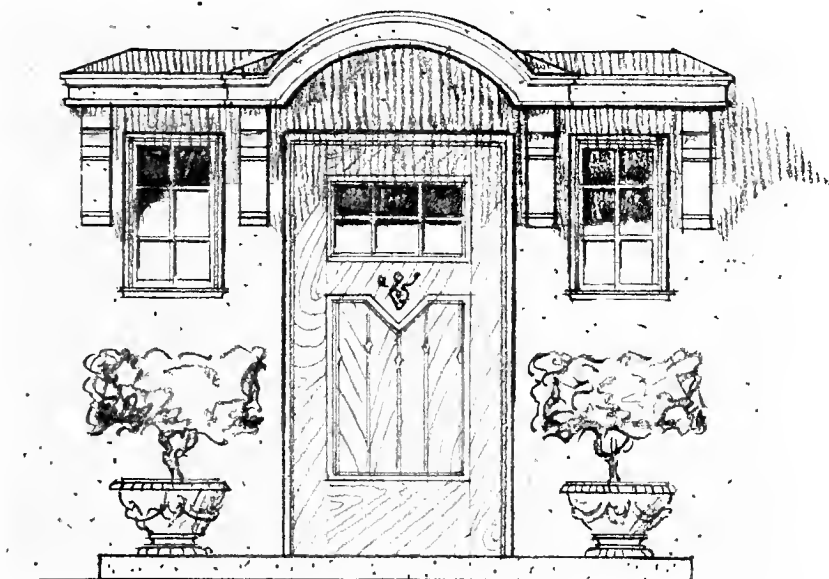
Fig. 17.—Restrained embellishment, consistent with the simplicity of concrete.

marcation of the lights and shades of their several surfaces, a relief and interest to the otherwise bare and box-like form of the building produced by the plain walls. It is not necessary that moldings, especially in concrete houses, should be curved after the fashion of the crown and other moldings in classic architecture. They are equally effective for the purpose if made with simple intersecting planes, as illustrated in Fig. 18 at (a), (b), and (c).

Upon comparing details suitable for cut stone, and those adaptable to concrete construction, it is interesting to note in Fig. 19 how the natures of the two materials are expressed in the profiles and forms of the
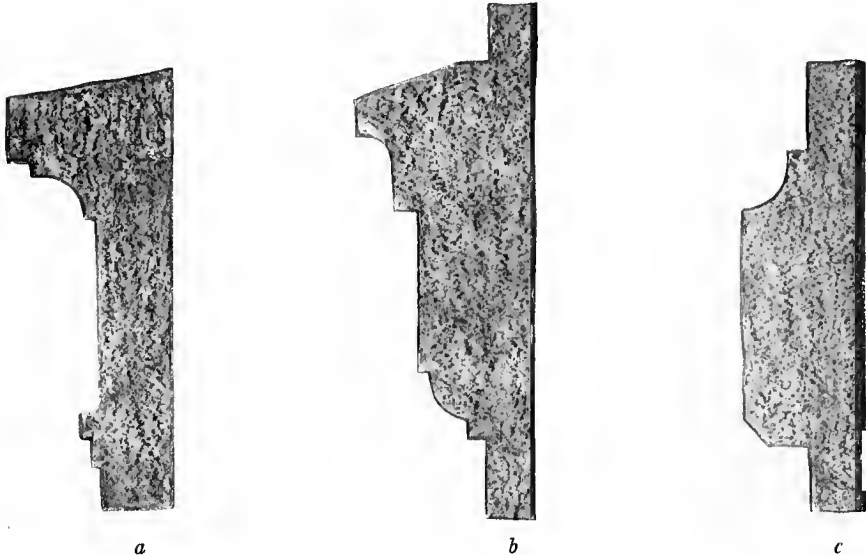

a   b   c

Fig. 18.—Profiles suitable for concrete detail.

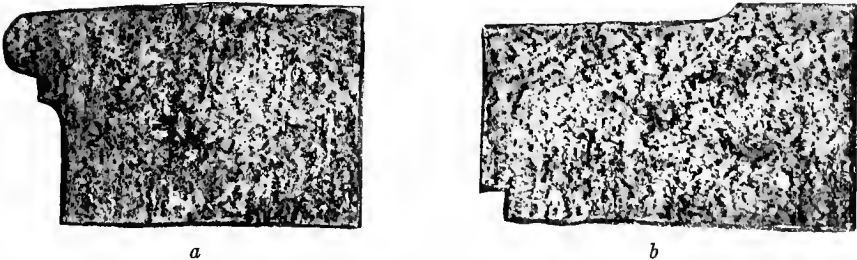window-sills herewith shown.   In the figure at (*a*) is a consistent detail for a cut stone sill, such as would be used in Colonial work when made of

a   b

Fig. 19.—The more simple of the two would be effective in concrete.

marble or limestone.   This expresses the curved lines of the classic, while the detail shown at (*b*), though probably lacking in the beauty

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of the classic curves, expresses boldly and efficiently a monolithic material, and is so formed that it can be successfully used in such construction.

In concrete house design the most interesting part of the façade is the porch and main entrance, and owing to the nature of the material such details as those illustrated in Figs. 20 and 21 are always interesting and good. When the designer confines himself to these simple forms, the
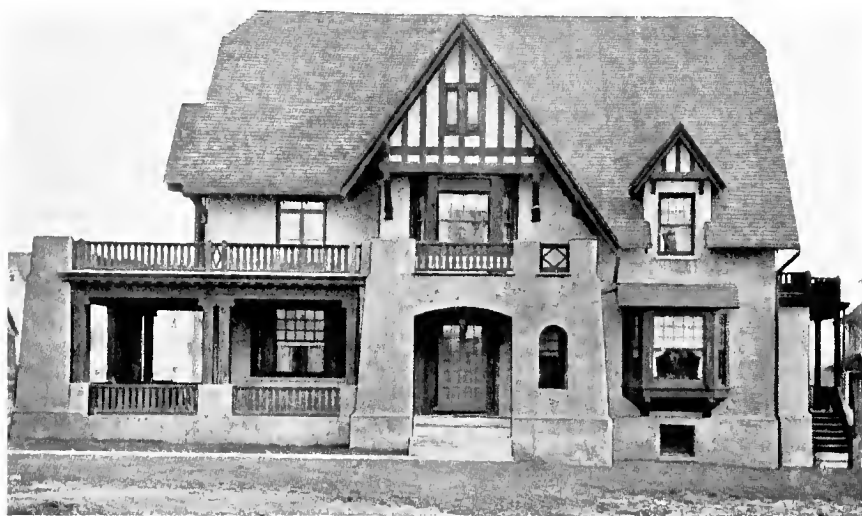

Fig. 20.—Façade of simple design more appropriate than elaborate ornamentation.

general effect of the dwelling amply repays in simplicity for the omission of more elaborate ornamentation.

To say that concrete construction as applied to dwellings should be developed along original and simple lines does not mean that elaborate or highly ornamented work is impracticable. On the contrary, the most complex and intricate patterns can be reproduced by the use of glue molds if the architect finds it necessary to embellish his building with a multitude of detail, including even undercut work. This can be done at far less cost than would be the case if the design were carved in

stone, and, moreover, once the molds are made, a casting may be repeated indefinitely.

Architectural Details of Molded and Cast Concrete.—It is desirable in some instances to incorporate in the design of concrete houses decorative features in the nature of spot ornamentation, cartouches, medallions,
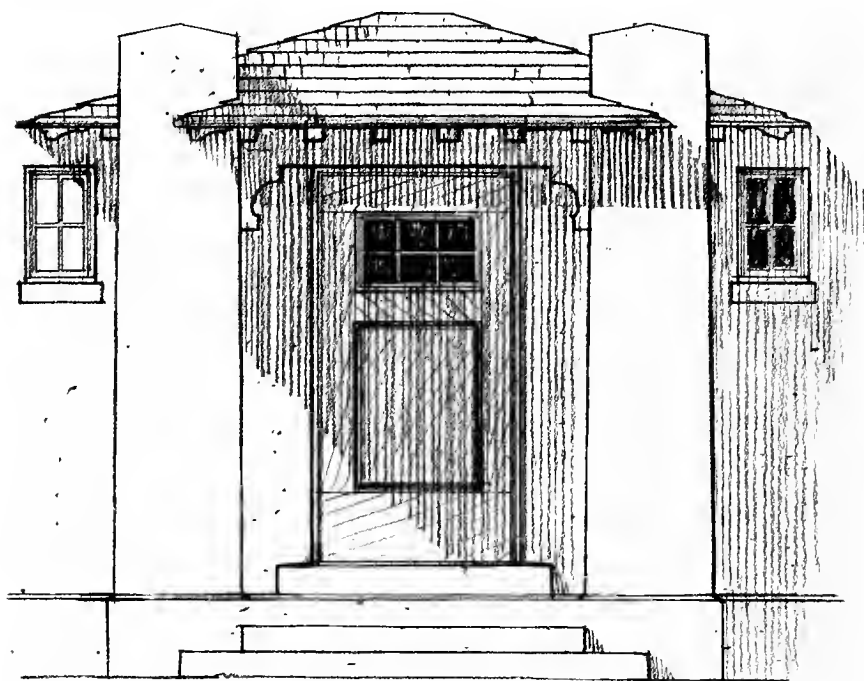

Fig. 21.—A porch and entrance representing direct and simple treatment of concrete.

and entablature decorations over doors and windows. It is seldom practical to cast as a part of monolithic concrete, decorative features in the nature of modeled work, which includes figures, foliage and work in bas-relief.

There are two reasons why decorative features should not be made monolithic with the structure. One is, that if these ornamentations are

repeated it is necessary to have a considerable number of forms and molds, which increases the expense, and another and very excellent reason exists in the fact that it is difficult to produce such work in concrete without liability of having it spoiled in the process of casting or during the construction of the building. It is, therefore, best to make such ornamentations in cement or artificial stone and either set them in recesses left in the walls or else set them when the walls are being cast.

If such a detail as is indicated in Fig. 22 is required as a decorative feature of a concrete dwelling, the color and texture of the material of which the cartouche or ornamentation is made should be carefully studied with reference to that of the wall. The best work that has been done in the way of molded and cast cement or artificial stone ornamentation is that in which the work has, after being cast, been gone over by hand and properly chased and undercut. It is only in this way that character can

Fig. 22.—A decorative detail that compares favorably with costly carved stone work.

be given to the material, and, when this is done, the work compares very favorably with the best work in carved stone.

It is by the use of separately molded panels and decorative features cast of cement that suitable character and an element of decoration can be given to concrete dwellings. The use of such ornamentation lends to the dignity of the structure from the fact that it harmonizes in color, and when properly modeled and executed gives the peculiar interest always in evidence where carved work is used.

Some suggestions of the possibilities in the way of decorative orna-

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ment cast of cement or made of artificial stone may be observed in Figs. 23 and 24, and a skilled designer can use such details, when cast separately from the building, with an assurance that they will be perfect upon the completion of the structure.

Architectural Decoration in Color.—One of the first means of decorating concrete structures was to introduce band courses and spot ornamentation made up of colored tile set or embedded in the concrete, in more or less pleasing color harmony or contrast. For this purpose tiles of different manufacturers were used, but from experience it has been found that tiles of uniform color and texture throughout were more satisfactory than those which had been slip-glazed, or in which the color was only in the form of an enamel. While the latter is approved for interior decoration, such as around fireplaces, it has not weathered as well as it should when used on the

Fig. 23.—A fine example of separately cast concrete detail.

exterior of buildings. It has crazed, and in some cases the entire enameled surface has disappeared from the tile.

Therefore, a good rule to observe in the use of colored tile for decorative schemes in concrete houses is to employ only tile of natural color throughout. Such tile should be selected with reference to its color permanency.

In the use of tile mosaic and similar surface color decoration the best effects are obtained by using such ornamentation sparingly. The design should be carefully studied with reference to color and the ar-

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rangement of the tile, and must be placed with absolute accuracy, as otherwise the entire effect of the ornament would be lost, and it would become, instead of an interesting detail, a blemish. This is best understood by referring to Fig. 25, which shows a carefully studied doorway with mosaic inlay on the two main piers. These are so near the eye that they are subjected to close scrutiny, and if they were not placed exactly central, plumb and level, the appearance of this beautiful detail would be spoiled. This doorway is a very interesting example of what can be done with monolithic concrete properly proportioned and studied.

Instead of using tiles and mosaics for color effect, very elaborate and rich ornamentation of polychrome terra-cotta can be worked out and has been successfully used. There are great decorative possibilities in the proper use of this material, from the fact that any shade and color can be produced upon the most richly molded

Fig. 24.—Pedestal showing the adaptability of concrete to elaborate undercut work.

surface. Where bold ornamentation is required for cartouches, brackets,

and panels in colors, nothing is as admirably adapted to the beautifying of concrete surfaces as terra-cotta, either in glazed or dull colors.

Color effects can also be obtained for the decoration of freize courses and flat medallions or panels, by using for such local or spot ornamentation, colored aggregates, which may be cast in slabs separately and set in place, or, in some instances, could, by the arrangement of the forms, be cast monolithic with the walls. This form of ornamentation will hardly appeal to the architectural designer except for interior decoration, for such features as fireplaces, panels in vestibules, and work of this character.

The Decorative Features of Timber Construction for Concrete Houses. —It must not be considered that reinforced concrete is not generally adaptable to other than the peculiar style of structure to which it seems to lend itself so admirably. There has been and still is a considerable demand for what is known as the "English half-timber" country house, and reinforced concrete walls worked up with wood half-timber construction securely fastened in place, or embedded in the concrete, give a much more permanent and substantial construction than the usual half-timber work consisting of batten boards with metal lathe and cement plaster between them. In the hands of a skilful designer reinforced concrete can be used very successfully with half-timber construction, and an excellent example of it so applied is shown in Fig. 26.

Nor is the use of wood in connection with concrete walls confined to the "half-timber" construction, but may readily be used as illustrated in Fig. 27, which shows the entrance to a residence built of concrete with monolithic walls. Further possibilities of wood and timber construction in connection with the monolithic concrete are shown in the picture of the front porch of the same house. The neatly profiled projecting ends of the porch timber, resting upon the beautifully molded pillars, can but give interest and attraction to this well-designed suburban residence. Even the porch rail, though of wood, is of such simplicity as to harmonize well with the clean outline and dignified plainness of the porch walls and outside construction.

Interior Decoration and Details.—Reinforced concrete interior

Fig. 25.—A carefully studied concrete doorway relieved by mosaic inlay.

Fig. 26.—Successful use of concrete combined with half timber construction.

Fig. 27.—Porch showing combination of timber and monolithic construction.

details must necessarily be plain and simple in their profiles, though if artificial stone or cast cement is used, decorative features for fireplaces can be replete with ornamentation. To illustrate some of the best interior details in concrete, the attention is called to the fireplace shown in Fig. 28. This fireplace is refined in the extreme, and is a relief when compared with the stock mill-constructed affairs so often seen in the modern house.

Even more plain, but quite effective, is the fireplace shown in Fig. 29. This substantial design conveys the sense of security and durability always desirable in a fireplace. The rough lintel is in pleasing contrast with the smoother surface, and the work throughout is simple and direct, showing how effective concrete work can be made.

Somewhat more elaborate, but still interesting, are the fireplaces shown in Figs. 30 and 31. That in the former illustrates how monotony in design may be relieved by the introduction of figures or designs in low or high relief.

Fig. 28.—Concrete fireplace with plain and simple profile.

Where beam and slab construction is used for the floors in houses of larger size, the concrete beams and girders make admirable beamed ceiling effects. Usually it is customary to plaster the concrete with a white coat, but a good decorator could finish the rough concrete so as to give rich effects by means of carefully studied color schemes and stencilled

Fig. 29.—Effective concrete work expressed in dignified design.

Fig. 30.—Example of smooth and rough textures in surface finish.

Fig. 31.—Elaborate but interesting treatment of concrete.

Fig. 32.—Example of beautiful and dignified interior construction.

Fig. 33.—Adaptability of concrete in the construction of stairways.

ornament. To illustrate how beautiful and dignified an interior of this construction can be the attention is called to Fig. 32. It only requires, in constructions of this kind, for the best effect obtainable, to have the beams go central over points of support, and to study the panelling of the beams and girders of the ceiling so as to obtain symmetry and equality of spacing.

There are possibilities in concrete for the most interesting stair constructions. Concrete is adaptable to such a variety of forms, and when properly reinforced, so self-supporting, that the lines of the usual conventional stairs or steps can be departed from radically. Spiral or flying stairways, with graceful, sweeping horses and rails, are entirely practical and possible at a minimum cost in concrete construction.

The possibilities of this material for both the construction of the stair and the rail are shown in Fig. 33, and whether the entire stairway and rail are of monolithic construction, as illustrated in this photograph, or whether other materials are used for embellishment, it is certain that for interest, simplicity, and beauty there are few rivals to that shown in the figure.

Chapter III
Details of Construction

A doorway showing the adaptability of concrete to either plain or ornamental
work.   Note the great contrast between the elaborate undercut floral
decoration and the simple units comprising the structural features.

Chapter III
Details of Construction

Types of Floor Construction.—In building construction there are practically four types of floor construction, when classified as to their structural formation. These are the flat slab, the beam and girder, the hollow tile and concrete joist construction, and what is known as panel construction.

The simplest form is the flat slab of concrete, supported by walls or partitions, and of sufficient thickness and reinforcement to span the intervening space between the walls.
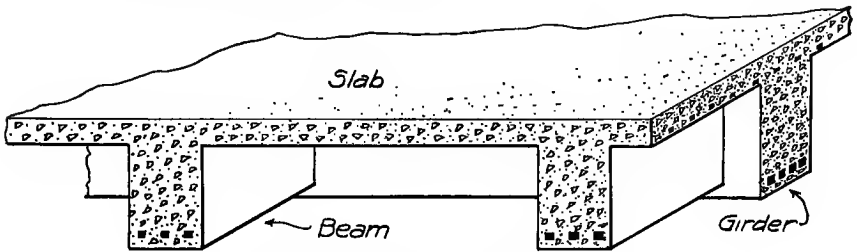
Fig. 34.—Slab and beam construction.

Where the spans are too great for a flat slab, it is then usual to support the concrete slab on concrete beams and girders which are monolithic with the slab, and which have the general appearance indicated in Fig. 34.

In buildings where the floor loads are comparatively light, a type of construction known as the concrete joist construction has been extensively used. A section through such a floor is illustrated in Fig. 35 at (*a*) and (*b*). In each of these sections it will be noticed that both of the main supports of the floor are concrete joists, reinforced with steel rods, and the intervening space between the joists is filled in with hollow

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terra-cotta tile. The illustration at (*a*) shows this type of construction for floors where the load is very light, and where the rectangular joists are strong enough to carry their portion of the load from center to center of the adjacent tile. In Fig. 35 (*b*) is illustrated a construction which is stronger than that shown at (*a*), from the fact that several inches of concrete are placed upon the top of the tile, and being monolithic with the concrete joists, additional compressive area is provided, thus insuring the capability of the floor for carrying greater loads. The purpose of the
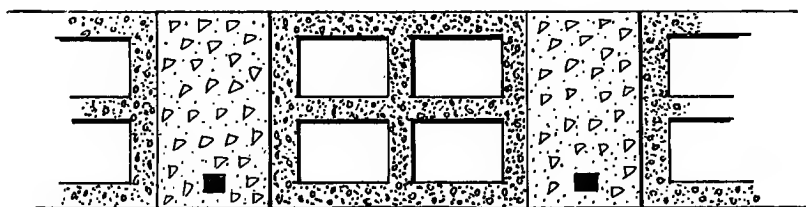
(*a*)
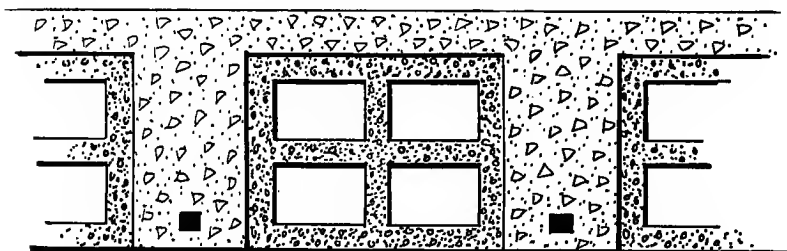
(*b*)

Fig. 35.—Floor sections, showing arrangement of concrete and hollow tile of concrete.

hollow tile in this floor construction is purely to fill in the space between the joists, and to form sides into which the concrete can be poured. The tile also provides a plastering surface to form a flat ceiling.

The advocates of the hollow tile and concrete joist floor constructions claim that the adherence of the concrete to the sides of the hollow tile insures greater strength in the floor construction because the upper one or two inches of the tile adds to the compressive resistance of the concrete,

or, at least, extends the area of compression in the upper part of the system.

There are several varieties of the hollow tile and concrete joist construction, and one of the most recent of these types, known as the "Hinton" system, is illustrated in Fig. 36. Upon examination of this illustration it will be seen that instead of forming the hollow tile blocks with vertical sides, the sides are splayed in such a manner as to make the concrete joists wide at the top and narrow where reinforced with the steel. By the use of such a block the compressive area of the concrete is increased, and less concrete is used, as it is saved where not required, namely, below the neutral axis. A third merit claimed is that the tiles almost meet at the bottom and form a uniform material for plastering. This is of some
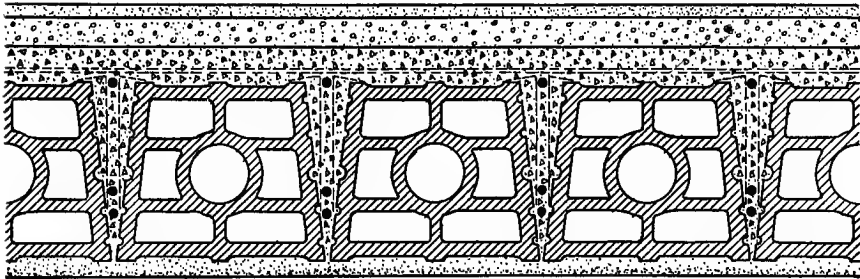
Fig. 36.—Arrangement of concrete and hollow splayed tile.

advantage where the ceiling is to be painted or decorated, as the possibility of different markings or discolorations by the two materials is avoided.

The panel construction differs little from the flat slab construction, except the slab is supported upon beams on all four sides without intermediate beams, and the slab is usually reinforced in two directions. Sometimes the flat slab is simply supported upon posts or columns of concrete which are spread at the top. This relieves the slab for some distance out from the column, thus reducing the stresses. To such systems the name of "mushroom" has been given, though there are three or more similar systems variously known. These systems have not as yet been

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much used in house construction, though they could well be employed in more pretentious work.

Methods and Types of Steel Reinforcement.—In reinforcing concrete, plain round bars have been used successfully, and buildings which have been so reinforced have withstood all stresses and vibrations. There is, however, a general preference for some type of bar or reinforcing rod which gives a greater bond in the concrete; that is, the bar is rolled, or formed with projections, so that when embedded in the concrete it would require a greater force to withdraw it than a plain bar. Bars which have been specially rolled or formed for reinforcing concrete are known as "deformed" bars. There are so many types of these bars that it is impossible to illustrate them all, and consequently only a few of the older and more usual forms are given. These bars are shown in Fig. 37, at (a), (b), (c), and (d).

(a)

(b)

(c)

(d)

Fig. 37.—Types of reinforcement.

The figure at (a) represents a "square twisted" steel bar. This type of bar is extensively used, as there is no patent on it, and the additional cost of the twisting is slight. It is probably more used than all of the rest of the reinforcing bars on the market.

In the figure at (b) there is illustrated what is known as the "corrugated" bar. This is one of the first deformed bars put on the market, and gives a maximum cross section, and a good deformation with a minimum increase in weight.
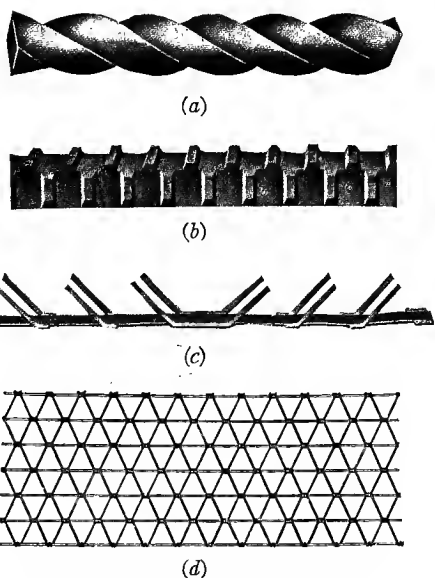
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The bar at (c) is known as the Kahn bar, in which the deformation is practically obtained by shearing the stirrups and bending them directly from the rolled fins on the sides of the bar. This bar is made in many sizes and several different sections.

While there have been many different types of deformed bars placed on the market, those shown may be considered as representative, and are quite commonly used.

In the reinforcement of slabs in house construction expanded metal or woven wire may be conveniently and cheaply employed. The latter is particularly good from the fact that it is woven with large wires in one
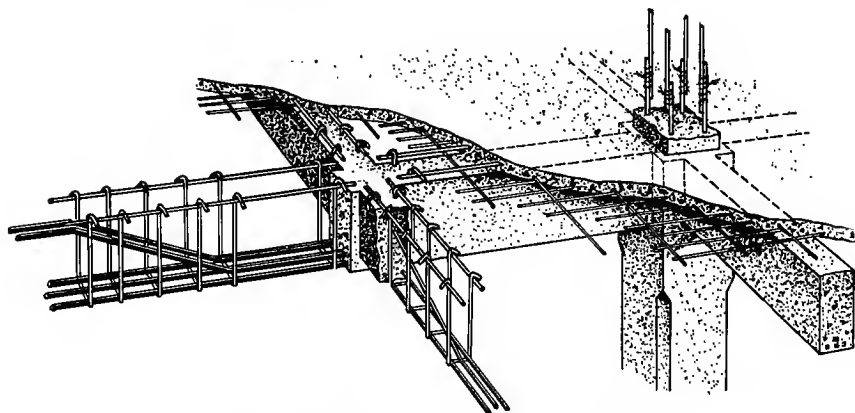
Fig. 38.—Example of fabricated reinforcement.

direction and small wires in the other, making it economical for slabs of rectangular shape reinforced in two directions. This reinforcement is shown at (d) in the figure.

As reinforced concrete construction was developed there were a number of types of steel reinforcement placed on the market in the nature of fabricated material, in which the several reinforcing rods and bars, together with the stirrups, were held together in a frame or unit. In general practice, however, there seems to be a preference among con-tractors to use what is known as the "loose bar" system, illustrated in Fig. 38. Here the several straight bars and trussed bars are cut to length, bent either in the shop or at the building, and are placed in the form

separately. Sometimes they are supported from the bottom of the forms by means of small cast blocks of cement, or else are tied together with sheet iron or bar iron supporters, and are held in place by wiring, or supported on the stirrups which rest upon the top of the centering. The stirrups are sometimes wired to the steel reinforcing bars, and are held at the proper distance apart by a rod, to which they are secured by wire.

While the loose bar system causes additional work in the field, it is a question whether any of the patented systems of fabricated frames can compete in cost, from the fact that there is royalty to pay, additional care in handling, and sometimes additional freight rates, due to a different freight classification.
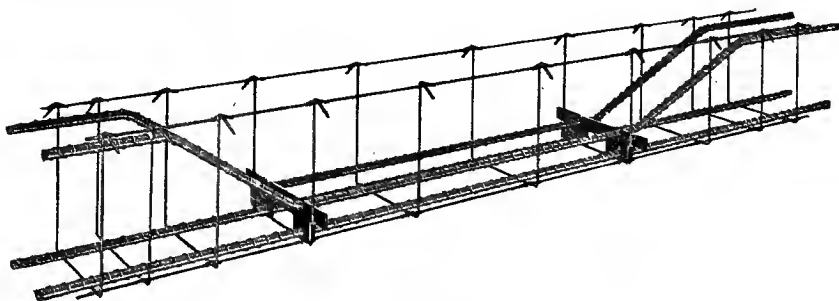

Fig. 39.

One of the best fabricated systems of steel reinforcement is that illustrated in Fig. 39. This system is very practical, and from the fact that it can be shipped in a flat condition and pulled into shape, is very conveniently handled, and can probably be purchased in the shop for less cost than most of the fabricated systems on the market.

Another system of girder frame that can be used particularly in house construction is what is known as the electric welded frame, illustrated in Fig. 40. In this frame the stirrups are welded to the reinforcing bars. By this arrangement the proper amount of the steel reinforcement for any beam or girder is insured, and the number and spacing of the stirrups fixed. It is also in a very convenient form for shipment.

Methods of Finishing Floors.—Reinforced concrete floor slabs may be finished upon the top with any material, and in house construction it is probable that wood floors are the most desirable. Some houses have been built with concrete floors, especially apartment houses. The concrete finish can be placed directly upon the reinforced concrete slab
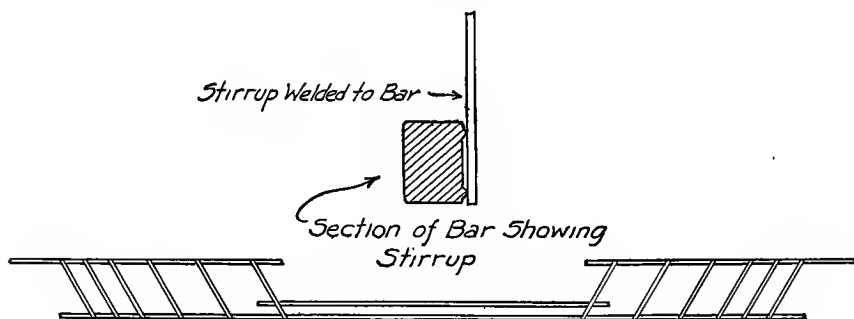

Fig. 40.—Electrically welded frame reinforcement.

at the time it is put in place, or, if this is not practical, the slab can be swept clean, washed with dilute muriatic acid, the acid thoroughly removed by washing with water, and the top coat worked on. This method is successful when care is used in the application and workmanship of the top finish. A section of a floor so constructed is illustrated in Fig. 41. Usually the finish is 1 inch in thickness, and sometimes in house

Fig. 41.—Concrete floor slab with top coat.

Fig. 42.—A wooden floor on concrete slab.

work brass sockets are inserted at or near the corners of rooms so that the rugs may be secured in place.

Another method of applying a concrete finish is to place on top of the concrete slab, some time after it has been poured, two inches of cinder concrete, and finish with the one-inch top coat as described above. It is usual to use a cinder concrete mixture consisting of one part of Portland

cement, two parts of sand or gravel, and six parts of clean boiler cinders. In the top coat use one part Portland cement, one part sand, and one part crushed stone or granite grits.

When a wood floor is desired, and this would ordinarily be used in house construction, it is best to use the construction illustrated in Fig. 42. Here 2″ x 3″ sleepers are laid, 16 inches center to center, upon the concrete. Sometimes nails are driven in the side of the sleeper and the space between is filled with cinder concrete, this being made level with the top of the sleepers. Either a rough floor to receive a fine hardwood floor, or the finished floor, is laid directly upon the sleepers. It would be best in house construction, if the finished floor is to be laid directly upon the sleepers, to paint the back of the flooring, so that any moisture that may remain in the sleepers or in the cinder concrete will not warp and twist the flooring.

Roof Construction.—The roofs of concrete houses should necessarily be entirely fireproof, and consequently the roof covering should be supported upon a construction which will not ignite and burn. A house, however, differs from the manufacturing building or warehouse with regard to the roof construction in that it is not likely to be subject to the shock and weight from falling walls, or the débris from adjacent structures on fire. It can therefore be of lighter construction than is usually required for fireproof commercial buildings of reinforced concrete. It must also be considered that the roof of a house, in its slopes, intersections, and skylines, has much to do with the architectural appearance of the building. The construction is, therefore, considerably influenced by the general formation of the roof, that is to say, whether it is flat or sloped. The degree of slope also influences the roof covering.

In buildings which are designed on classic lines, having square parapets and flat roofs, there is probably no better construction than a reinforced roof slab. This slab is carried upon beams and girders in the same manner as the floor construction, and may be built either with a slope or flat. To drain the flat roof, build up the cinder concrete as indicated in Fig. 43. The advantage of constructing the roof in this manner is that
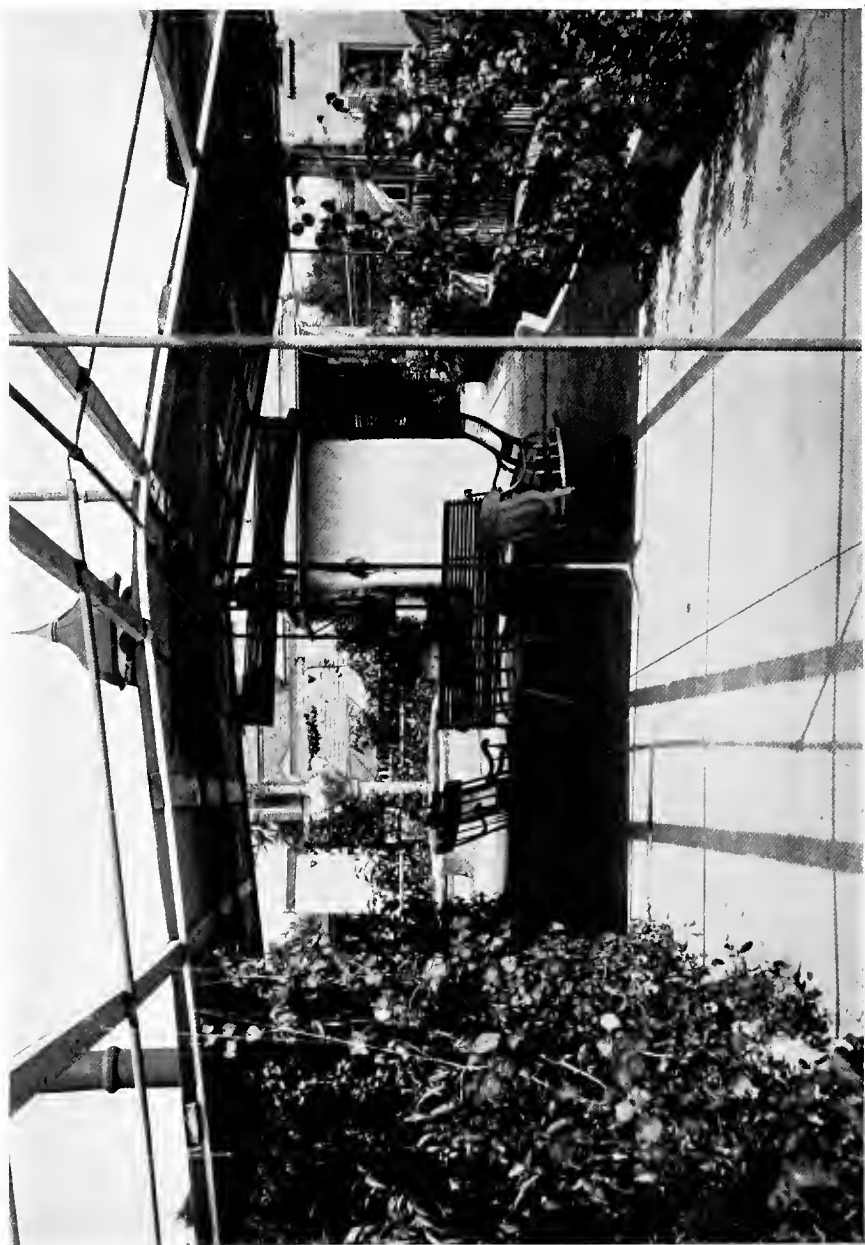
A flat concrete roof transformed into an attractive garden. Concrete is peculiarly adapted to unique construction of this character.

A frank and direct use of concrete designed with reference to economy, utility, and minimum cost for up-keep.

quite frequently the forms used for the floor construction can be used for the roof forms. The additional thickness of the cinder concrete gives insulation against temperature changes.

The proper covering for a flat concrete house roof, which does not appear in the perspective or elevations of the building, is either some form of prepared roofing or else 4-ply slag and gravel roof. Many of these roofs are guaranteed for a period of ten years, and are entirely serviceable and satisfactory.

In placing such a roof it is the usual practice to smooth over the top of the cinder concrete forming the slope of the roof with cement mortar, so as not to have any projecting stones or edges of aggregates, which are likely to cut through felt. Then the first layer of felt is well secured to
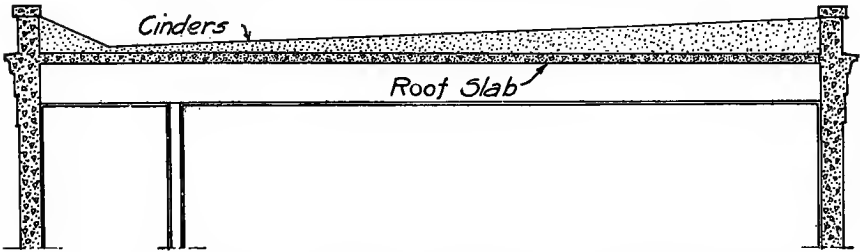

Fig. 43.—Flat slab roof with cinder concrete top coat sloped for drainage.

the concrete with hot pitch. This has always been sufficient to hold the roofing in place. It is good practice to build up gussets around all the parapet walls, and run the felt up and under some form of coping tile, or else in cheaper work, fasten it under a cleat which is secured to nailing strips left in the concrete. These two forms of construction are shown at (a) and (b) in Fig. 44.

The extent of flat roofs in house construction is such that it is entirely safe to make a concrete roof slab and cover it with a top coat of a damp-proof cement mixture, thus doing without any roofing material. Shrinkage or settlement cracks may occur, however, and the integrity of the roof is, of course, destroyed if it does crack.

This danger of concrete cracking is reduced to a minimum where the

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areas of the roof are small, such as would be the case in house construction, and could be entirely obviated by dividing the roof up in sections and putting in expansion joints, as illustrated in Fig. 45. In this construction a V-shaped piece of copper is placed on the forms or centering, and embedded in the concrete slab, the joint being afterward raked out and filled with asphalt or mastic cement. In using asphaltic preparations for filling a joint of this kind the best result is obtained by heating the crevice with a torch before the asphalt is poured in.

Cement Coping

Felt Roofing

Felt Flashing

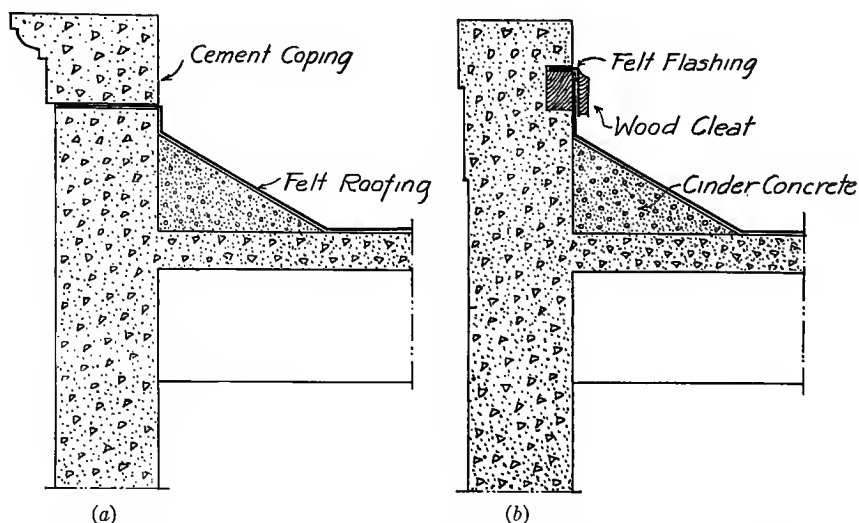*Wood Cleat*

Cinder Concrete

(a)   (b)

Fig. 44.—Two types of concrete roof construction combined with felt covering.

Where the roof of a concrete house is flat, and where the item of cost is not a consideration, one of the best roof coverings is flat or promenade tile, laid in bitumastic cement. Such roofs are very desirable where it is proposed to use the roof as a roof-garden or observatory. A somewhat cheaper way of accomplishing the same result is to cover the concrete roof slab, after it has been smoothed off with cement, with a prepared or felt roof covering, and then placing on this covering a thick concrete finish for a wearing surface—at least 1½ inches thick—marked off in blocks for appearance.

As the roofs of houses are subjected to extremely light loads, they can be economically constructed with rectangular concrete beams, either cast in place or cast on the ground and used as joists, and then covered with some material such as trussed metal lath, or ferro-inclave, the former being illustrated at (a), Fig. 46, and the latter at (b). The advantage of using these is due to the fact that no centering is required. They are arranged to plaster with cement mortar on both sides, and a reinforced slab is thus obtained sufficiently strong for any roof construction. Such construction can sometimes be used at less cost than a monolithic slab.

Fig. 45.—Method of constructing expansion joints and applying filler.

In the use of such materials, wires or other means of fastening should be left in the joist, so that the metal reinforcing sheets can be secured to them. If the building is built with concrete walls, light steel beams can be used for framing the roof, and the slab construction secured to them, though the use of such steel beams is attended by a diminution of the fireproof properties, provided they are not in turn protected by a covering of at least a 1½-inch thickness of concrete.

(a)

(b)
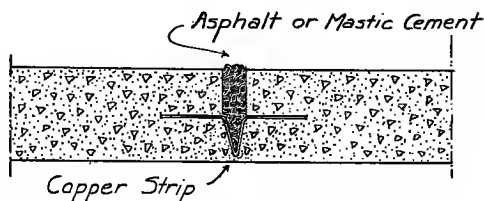
Fig. 46.—Metal lath and ferro-inclave reinforcement in light roof construction.

If it is desired that the roof of a concrete house should be covered with slate, or with flat, corrugated, or special interlocking tile or asbestos shingles, and if the roof is sloping and of concrete construction, it is necessary to provide some means by which the slate or tile may be secured to it. Quite frequently the roof is constructed with cinder concrete, which is sufficiently porous to allow the nailing of furring strips to the top of the roof, so that the slate or tile may be fastened to them. The best practice would be to imbed in the

concrete nailing strips, and cross-furr the roof as indicated in Fig. 47, thus providing a secure nailing for the slate or tile. The spacing of the furring strips is regulated by the character of the roof covering. The strips to which the furring strips are fastened should be nailed to them with solid copper or copper-sheathed nails.

The construction of roofs for concrete buildings, as to gutters and eaves, varies little from buildings constructed of other materials. Concrete, however, has an advantage in that overhanging cornices and stop gutters are readily constructed and molded, and may be flashed in any manner by using furring strips and nailing blocks embedded in the concrete.
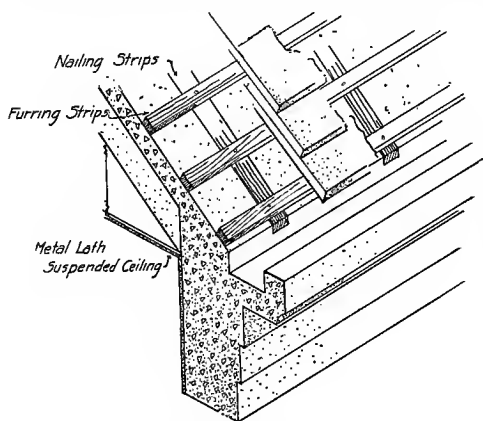

Fig. 47.—Details of roof construction where slate or tile is to be used.

Concrete is a material of such great durability and permanency that in designing the eaves or cornices of buildings an effort should be made to avoid the use of hanging gutters of metal. The best results are obtained by casting stop gutters or recessed gutters directly in the concrete, and making these damp-proof by means of carefully graded aggregates, thus obtaining a dense concrete, or by painting with waterproof cement paints, or by lining them with metal.

Tin is not a good material for the formation of eave boxes and the lining of gutters of concrete, from the fact that placed next to concrete it does not seem to be as durable as when used in conjunction with wood construction. Copper or lead should always be used where the use of metal flashings or gutter linings is unavoidable or desirable.

Some suggestions for the construction of the gutters and eaves of concrete dwellings may be seen in Figs. 48, 49, and 50. In the first mentioned figure there is shown the detail at the eaves of a building constructed with concrete walls and roof slab, and having for the roof cover-

ing one of the many excellent forms of interlocking tile roofs. Here the gutter is cast directly in the concrete of the cornice, and is flashed with copper. It is interesting to note the manner in which the copper flashing is secured in this detail.

Wide projecting eaves are admirably adapted to the design of concrete houses. The detail shown in Fig. 49 is suggestive of the manner in which the gutters for such roofs could be arranged so as to secure per-
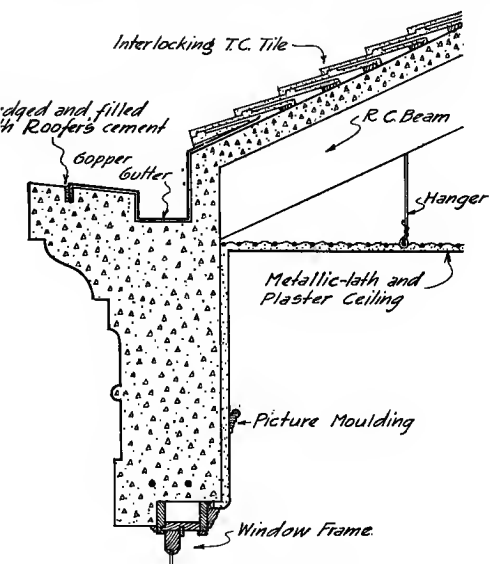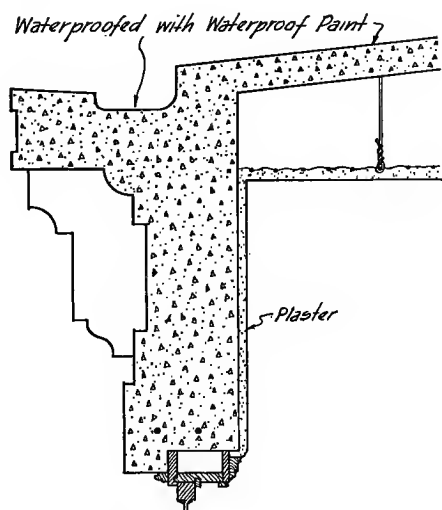

Fig. 48.   Fig. 49.

Figs. 48 and 49.—Suggestions for the construction of gutters and eaves for concrete dwellings.

manency, and thus avoid the trouble so likely to arise with galvanized iron or copper hanging gutters. As the gutter in this detail is well outside of the building wall, no very great care need be used to have it especially water-tight, so that the metal flashing may be omitted, and the gutter may be finished with a cement mortar coating made waterproof by the use of properly graded aggregates; or, since it is not within the range of vision, it could be coated with a waterproof paint.

A gutter inexpensive to construct is shown in Fig. 50, and this gutter

may be formed in a variety of ways. It also acts as a good snow-guard, is efficient, and excellent in appearance.

All of these concrete gutters and cornices are enduring, and have the advantage of requiring no repair expense, an item very frequent with the same features of frame houses and those of masonry or brick having the usual wooden roofs.

Window and Door Frame Construction.—Since concrete is a mono-lithic material, there is no real necessity for arching window or door open-
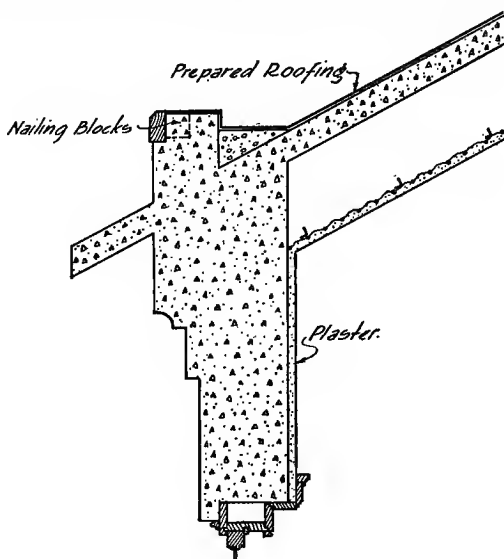

Fig. 50.—Another suggestion for the construction of gutters and eaves for concrete dwellings.

ings, and it is surely very inconsistent to accentuate the hoods of such openings by showing arch rings marked in joinings to simulate voussoirs. In consequence, the window and door openings are made either with a square head, or, if the architectural design requires, are formed on the curves, either segmental or three-centered, though such arches have little structural significance, especially where the concrete is reinforced with steel rods or bars.

In masonry and in brick structures it has been the usual practice to

Entrance of Albert Kahn's residence, Detroit, Mich. Doorway and steps
cast in solid concrete. A striking example of the economy of concrete as
compared with cut stone.

A concrete living room porch in a seashore house. Note concrete flower boxes anchored to the walls and fountain cast with concrete partition. Dampness has never penetrated partition wall.

build up window or door frames as the masonry or brickwork progressed. While this can be done with concrete construction, it is not the best practice. In pouring the wet concrete and in working the formwork around the openings the millwork is not benefited, as any excess of water in the concrete is apt to buckle and warp the millwork. The best practice is to place the door and window frames after the wall, with its openings, has been cast.

In the setting of all door and window frames the primary requisite is to obtain a weatherproof joint between the frame and wall construction, both at the jambs, sill and head. The best practice in window construction where a reveal frame is used is to rebate the wall as indicated in Fig. 51, and in constructing the window frame to make it of such a size that it can readily be placed from the back. The inside face of the frame is extended to scribe to the opening, as indicated at *a*, and by this means the frame can be secured in place to wooden nailing blocks set in the concrete, or else by plugging the wall after the concrete has set.
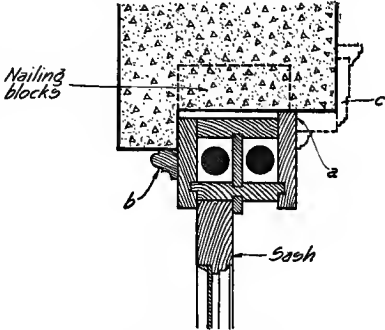

Fig. 51.—Detail of weatherproof joint between frame and wall construction.

A finish is secured on the outside by the reveal molding, as at *b*, and the construction made further weatherproof by the casing, as shown at *c*. The head of such a frame can be designed as shown in Fig. 52, both the reveal molding and the inside trim being around the head of the frame, and a rebate being formed in the concrete at the head, as was done on the jambs.

While concrete sills can be molded monolithic with the walls, it is far better to mold the sills separately and set them in place, constructing the sill of the window frame as shown in detail in Fig. 53. In this figure the molded treatment or artificial stone sill is shown at *a*, the wood sill of the frame at *b*, while the inside trim and apron are indicated at *c*.

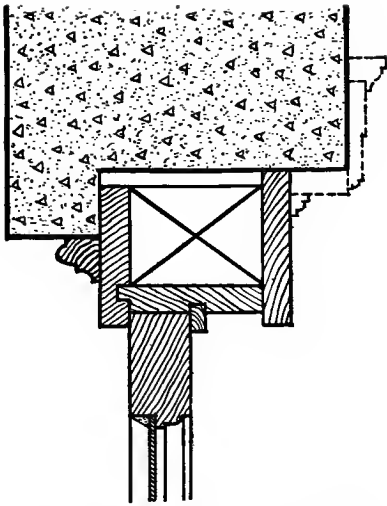In the best work an effort is always made to insure a weatherproof

Fig. 52.—Detail of window construction. Reveal molding and inside trim placed around head of frame.

joint between the wood sill and the cement sill, and the best practice is to insert a weatherstop, as shown at *d*. This weatherstop consists of a $\frac{1}{8}''$ x $1''$ galvanized strip, which breaks the joint between the wood and cement sills by entering grooves formed in each, thus preventing the entrance of moisture.

What was said with reference to the jamb and hood construction for window frames applies equally to door frames, though it is sometimes best to construct door frames without a rebated jamb, and depend upon some other means to make a weatherproof joint between the wood frame and the concrete. Such a detail is illustrated in Fig. 54, and the security of the joint between the wood frame and the concrete is obtained
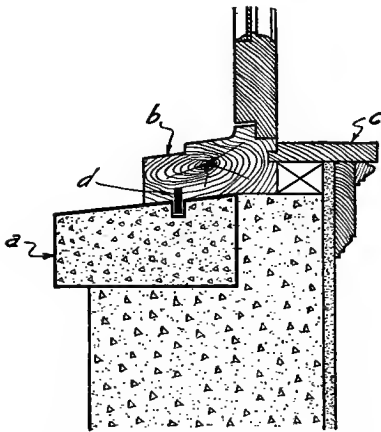

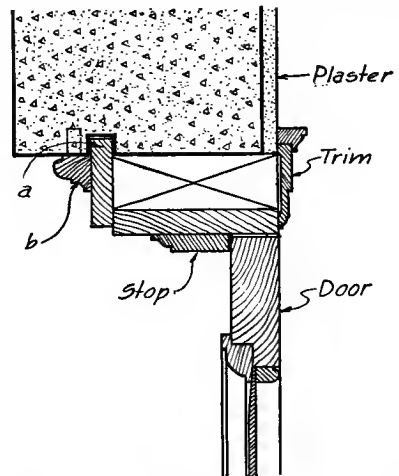Fig. 53.—Separately molded sill set in place.

Fig. 54.—Detail of construction for door frames in concrete houses.

by casting a groove in the concrete, and by extending the outside casing into the groove. This construction is shown in the figure at *a*. The door frame is still further secured and made tight in place by plugging the jamb and nailing under the stop bead, as shown at *b*.

An interesting detail of another type of construction for a door frame is that illustrated in Fig. 55, which shows a plank front frame arranged in a rebate.

It is best in the construction of concrete houses to eliminate cut-stone work as much as possible, and to form the sills monolithic with the wall or cast them separately. It is best not to depend for the threshold upon a projection formed of concrete, as when worn it is difficult to replace. A metal or hardwood threshold is superior. In the best work this threshold would be of cast brass, properly secured to the cement sill. Of course there is no reason why bluestone, granite or specially cast concrete stone sills should not be set on the concrete walls, and be introduced for the sills of door openings where there is apt to be excessive wear.
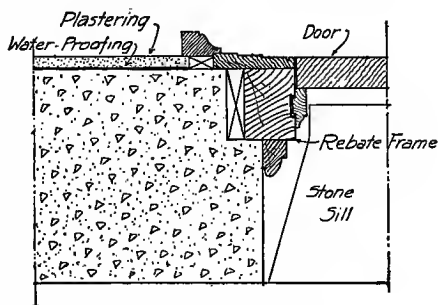

Fig. 55.—Plank frame for door arranged in a rebate.

Concrete Wall Construction.—In house construction, concrete walls, and especially those reinforced with steel rods or bars in two directions, have some advantages over walls built of stone or brick.

In the first place, concrete walls may be made only two-thirds the thickness of brick and masonry walls and still be of equal or greater strength. Since such walls are monolithic, they are less liable to buckle, and the junctions at corners are stronger; besides, the work over the heads of window and door openings is more secure, as there is no tendency for arches to loosen and drop, and joints, as those between the voussoirs, to crack.

Concrete walls are good non-conductors, and make warm winter

and cool summer houses; particularly are they excellent in retaining heat from the fact that there is less likelihood of leakage through cracks such as is the rule rather than the exception in brick and masonry walls. Walls of concrete are, when properly constructed, much more likely to be water and weatherproof, and in this respect are an improvement over brick and stone walls of rubble masonry, as such walls are ordinarily constructed. In this fact there also exists one marked point of superiority of concrete for wall construction as compared with masonry or brick walls, which is that from the very nature of the material a concrete wall must be solid and free from the structural defects that are so evident in walls of masonry where the workmanship is bad or even fair.

Strength of Concrete Walls.—There is no doubt of the great strength of reinforced concrete walls, but careful consideration has been given to this part of reinforced concrete construction in framing the building laws for cities of the first class, and these are interesting, as they indicate the best practice, which may well be adhered to in the construction of country houses.

The New York city regulations governing the use of reinforced concrete contain the following interesting and instructive paragraph:

> "Exterior and interior bearing and enclosure walls of reinforced concrete supporting floor and roof loads shall be securely anchored at all floors, and of such thickness that the compressive stress shall not exceed 250 pounds per square inch, but in no case shall the walls be less than 8 inches in thickness. The thickness of such walls shall not in any instance be less than $\frac{1}{20}$ of the unsupported height."

And further in reference to the reinforcement of concrete walls the law states:

> "Steel reinforcement shall be placed near both faces of the wall, running both horizontally and vertically, and weighing not less than $\frac{1}{2}$ pound per square foot of wall."

Method of Supporting Floors.—The best practice in concrete house construction is to use, in conjunction with the concrete walls, fire-proof

Typical sectional form for concrete wall construction.

Method of securing window frames during wall construction.

[77]

Wall recesses for timber joist.

Pouring concrete into a column form.

floors, ordinarily also of reinforced concrete construction. When such floors are used they become monolithic with the walls, and a very rigid and secure building is obtained by allowing the reinforcing rods of the beams to interlace with those of the walls.

Should wood construction be used for the floors in dwellings where the walls are of concrete, as is sometimes done in the smaller houses, the
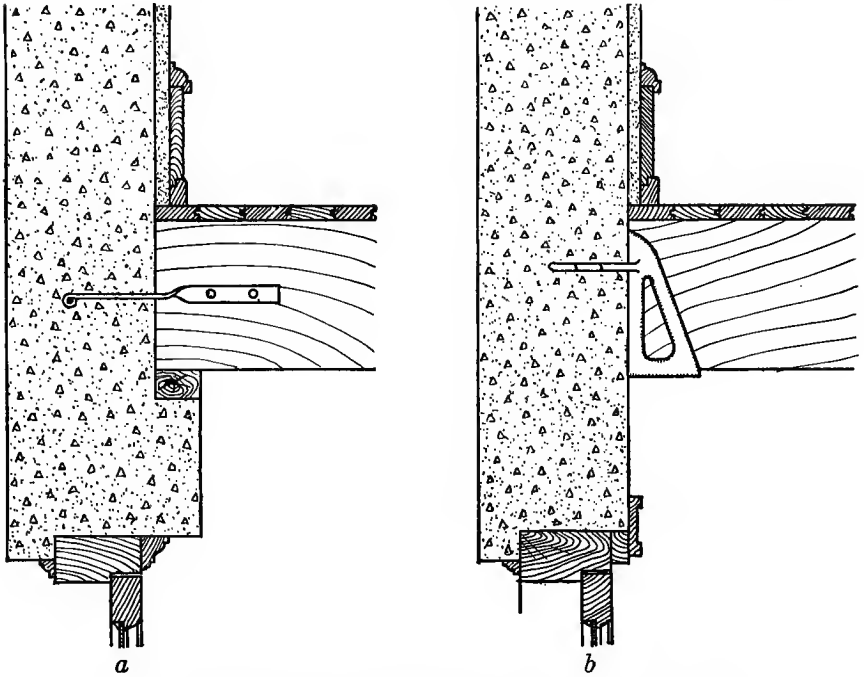

Fig. 56.—Two methods of setting wooden joist in concrete walls.

joist may be set and cast in place, or else be supported in the ways illustrated in Fig. 56 at (a) and (b).

The objection found to the method of supporting the ends of the joists or floor timbers by setting them and casting them in place is that when the ends of the timbers are thus confined the wood is liable to decay. They should always set in a pocket somewhat larger than their dimensions, so that the air may get to the wood and prevent dry rot.

The manner of supporting the joists or floor beams shown in Fig. 56

at (*a*), is good, from the fact that the wall may be run up several stories and the floors rapidly constructed after the centering for the walls has been removed. By arranging the iron ties and embedding their ends in the concrete, every fourth or fifth joist may be used to tie the building together, or if so desired, every joist may be tied in. One advantage exists here in that the ledge makes an excellent bearing for the joist, and is also very convenient for sizing the joists and bringing them to a level.

Joists or floor beams may also be supported in a very secure and effi-
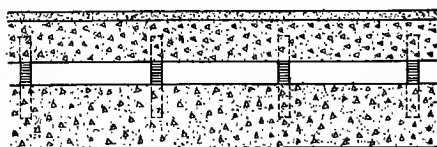
(*a*)
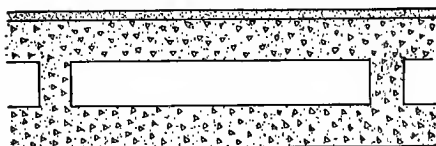
(*b*)

Fig. 57.—Hollow walls fastened together with copper, galvanized iron, or concrete ties.

cient manner by using wall hangers, as shown in the figure at (*b*). These hangers are known as "Duplex Concrete Hangers," and are made for 2″, 3″ and 4″ joists, especially for concrete construction, though any hanger of suitable design could as well be used.

Both of the methods shown in the figure permit all of the ends of the joists or floor timbers to be well ventilated.

Hollow Concrete Walls.—As any dead air space in a wall or floor of any material is most excellent on account of the insulation it provides in case of either heat or cold, as well as sound, and also because a drier interior wall surface is obtained, concrete walls so cast have some advantages over solid concrete walls. The best construction is to make the two walls as distinct as possible and to provide as few connections

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between the two walls as is practical to insure the stability of both. In fact it is far better to unite the two walls with only copper or galvanized iron ties, as shown in Fig. 57 at (*a*), than to tie them together with cross walls of concrete as illustrated at (*b*). Such walls as the latter are costly, and somewhat difficult to construct unless special or patented forms or centerings are used. Generally the air space desired may be obtained by some other means, such as a veneer lining or furring, at a considerably less cost and, withal, greater efficiency.

Veneered, Lined and Furred Walls.—In order to insure against dampness, and more especially to prevent the possibility of condensation on the inside of walls of concrete, a condition which is hardly likely to occur except under extraordinary conditions of exterior cold and great

Fig. 58.—Furring inside concrete walls with hollow brick, plaster block, or tile.

interior humidity, and also to provide greater insulation, it is best where the expense is not a factor in the problem of dwelling house construction to veneer, line or furr the walls on the inside.

A good practice is to veneer or line the inside walls with hollow brick, plaster block, or tile, as shown in Fig. 58. A method equally efficient is to furr the walls on the inside with metal lath and furring strips. In either case the desired air space is obtained without in any way destroying the fireproof properties of the construction. An excellent lining for concrete walls is found in a layer of cork, which may be stuck to the walls with cement, and which readily takes plaster.

Concrete walls 8 inches in thickness, painted on the inside with a damp-proof paint proper for covering concrete, will answer every purpose.

Chapter IV
Operations in the Field

The huge cored slabs for walls, floors, roof and partitions and even stairways
are precast and assembled in manner shown.

Chapter IV
Operations in the Field

With the structure satisfactorily designed, successful construction of a building of any material is dependent upon the careful selection of the component materials and a working knowledge of how to combine them properly. The wide distribution of sand, rock and gravel (known as *the aggregate*) and the extensive use of concrete have increased general knowledge as to what constitutes good materials and the ability to do good work. Such results have been brought about by following definite methods which have now become common practice.

Selection of Materials.—In selecting Portland cement always secure a brand guaranteed to meet the requirements of the standard specifications of the United States Government or those of the American Society for Testing Materials. Portland cement may be had in cloth sacks, paper bags or wooden barrels. More commonly it is shipped in cloth sacks with an allowed rebate for the return of empty bags in good condition. Each bag of cement weighs 94 pounds net and four bags constitute a barrel of 376 pounds. One bag of loose cement is practically equivalent to one cubic foot. On account of its sensitiveness to moisture, Portland cement must be carefully protected from dampness at all times, even when piled at the site of the work.

Sand for concrete should be had hard and clean and should have grains grading in size from $\frac{1}{4}$ inch down. Pit and stream sands are generally of good quality, but drift sand is usually too fine of grain to make good concrete. The presence of dirt can easily be ascertained by pouring a small quantity of sand into a pail of clear water or by rubbing a portion between the palms of the hands. A practical test may be made

by placing a four-inch depth of sand in a fruit-jar, and by adding water until the jar is within one inch of full and by shaking the contents vigorously. If, after the water has again become clear, there is a layer of mud more than one-fourth inch in thickness, the sand should not be used without first washing.

The most suitable stone for crushed rock is one which is clean, hard, breaks with sharp angles and to which mortar easily adheres. Trap, granite and hard limestone are among the best. The use of shale, slate, and very soft limestones and sandstones should be avoided. The crushed rock should be screened only sufficiently to remove the fine dust. The maximum size of stone allowable is often dependent upon the thickness of the object to be molded. It is common practice to fix the extreme limit at $1\frac{1}{4}$ inch in diameter.

Bank-run gravel, just as dug from the pit or taken from the stream bed, seldom runs even and rarely has the proper proportions of sand and pebbles for making the best concrete. An ideal pit gravel is 40 per cent. sand. Since there is generally too much sand in proportion to the pebbles, it is advisable and economical to screen the sand from the pebbles and then to remix them in the correct proportions. As a general rule, pebbles larger than $1\frac{1}{4}$ inch in diameter are discarded; all material smaller than $\frac{1}{4}$ inch is considered sand. Gravel should contain no rotten stone and should be clean.

Depending on the character of the particles, sand, crushed rock and gravel vary in weight from 100 to 110 pounds per cubic foot.

For fire-proofing and for various other purposes requiring low stresses, cinder concrete is frequently used. The cinder should consist of hard, clean, vitreous clinker free from sulphides, unburned coal and ashes. A clean cinder will not discolor the palms of the hands when rubbed between them.

The water used in mixing the concrete should be clean and free from oil, alkali and vegetable matter.

Proportioning and Mixing.—The proper proportion for combining the Portland cement and the aggregate is dependent upon the quantity and

Residence of Oliver Jones, Margate Park, N. J.

Carey & Reed, Contractors, Phila.

This attractive house, though exposed to the deteriorating influence of the seashore, is built with solid six-inch walls, untreated as to exterior texture. (See living room porch, page 72.)

Residence of Alfred Douglas Flinn, Yonkers, N. Y.

Putnam & Cox, Architects, Boston

A substantial concrete house built in 1906. Exterior walls, floors and most of the partitions are of reinforced concrete. Inside plastering placed directly on the concrete. Exterior, pebbledash finish.

character of the materials and the purpose for which the resulting concrete is intended. For reinforced and damp-proof concrete that proportion is desirable which produces the densest concrete possible. Under other conditions only sufficient cement is used to develop the strength required of the concrete. For reinforced and damp-proof concrete, a $1:2:4$ mix is commonly employed. Where compressive strength alone is a requisite, the concrete is frequently proportioned $1:2\frac{1}{2}:5$. For massive foundations, a $1:3:6$ concrete may be used. In such proportions, the first numerical term refers to the parts of Portland cement, the second to the parts of sand and the third to the parts of crushed rock, screened gravel, or other coarse aggregate. The proportions are based on measurements by volume in which a bag of cement is considered one cubic foot. If pit gravel is used, although the saving in cement will usually more than compensate the cost of screening and remixing, similar proportions are adopted in which the second or sand term is dropped. Such proportions then read $1:4$, $1:5$ and $1:6$. Cinder concrete is usually made in the proportion 1 part cement to $2\frac{1}{2}$ parts sand to 5 parts cinders. On large work, and where the determination of the exactly correct proportions is expedient, the voids in the sand and stone are determined by saturation with water or by specific gravity. With the proportion of voids thus carefully ascertained, there is generally used an excess of 5 to 10 per cent. of cement over the voids in the sand and a 5 per cent. excess of sand over the voids in the stone.

In making a batch of concrete the amount of each material required should be actually measured by volume, otherwise concrete entirely homogeneous in texture and appearance can not well be produced. Since a bag of Portland cement (loose) is equivalent to one cubic foot, for convenience all measurements should be based on the cubic foot as the unit. As a means of measuring, a bottomless box, or a device equally exact, should be employed. The sizes of measuring boxes are dependent upon the amount of concrete to be mixed in each batch.

The materials can be thoroughly mixed into concrete either by hand or by machine. The method selected is dependent entirely upon conditions. Where the work is of such a character and size as to war-

rant the investment, much faster progress can be made by using a machine mixer. The machine should be of such a type as to insure uniform mixing of the materials throughout the mass of concrete. There are many such machines on the market and the merits of each, as adapted to the user's particular needs, should be carefully studied.

For work of moderate magnitude, measuring boxes of convenient size are specified in Table 1.

TABLE 1.—SHOWING QUANTITIES OF MATERIALS AND APPROXIMATE RESULTING AMOUNT OF CONCRETE FOR TWO-BAG BATCH, USING SAND AND STONE

Kind of Concrete Mixture	Proportions by Parts			Two-bag Batch						
				Materials				Size of Measuring Boxes. Inside Measurements		Water in Gallons for Medium Wet Mixture
	Cement	*Sand*	*Stone or Gravel*	*Cement*	*Sand*	*Stone or Gravel*	*Concrete**	*Sand*	*Stone or Gravel*	
				Bags	Cubic Feet	Cubic Feet	Cubic Feet			Gallons
1:2:4 concrete....	1	2	4	2	3¾	7½	8½	2' x 2' 11½"	2' x 4' 11½"	10
1:2½:5 concrete..	1	2½	5	2	4¾	9½	10	2' x 2½' 11½"	2' x 5' 11½"	12½
1:3:6 concrete....	1	3	6	2	5¾	11½	12	2' x 3' 11½"	2' x 6' 11½"	13½

There are several slightly different and entirely satisfactory methods of mixing concrete by hand. When sand as a fine aggregate is used with a coarse aggregate (such as crushed rock, screened gravel, cinders, etc.), the sand is carefully measured and the entire quantity required for one batch of concrete is spread out in a thin, oblong shape upon a smooth, tightly jointed mixing board. Upon the sand is scattered evenly the full amount of Portland cement needed. The two materials are then mixed dry by shoveling, with the laborers working opposite

* Amount of concrete resulting is only roughly approximate. In estimating quantities use Table 2, page 92.

each other in pairs. They turn the cement and sand with a dragging stroke which is very effective in mixing the materials. During this operation a helper aids the mixing by using a garden-rake. The turning continues until the cement and sand no longer show in streaks and the mass has a uniform color.

The mixture is again spread out in its original oblong shape and the measured full amount of stone or other coarse aggregate is scattered evenly over it. About one-half to two-thirds of the required amount of water is sprinkled over the stone, after which the mass is turned. The concrete is thrown into a ridge, is cut open to a crater shape, and the remainder of the water is added. Turning is continued, and a little water added to the dry spots until the mass is thoroughly mixed.

For bank-run gravel (or other material in which the fine and coarse aggregate are not separated) the method of mixing is slightly different. One-half of the total aggregate required is spread out in oblong shape, the full amount of Portland cement is scattered over it, and the remainder of the aggregate is added. The materials are turned dry until they are thoroughly mixed, when the mass is cut open and water added in the same manner as described above when sand and crushed rock are used.

The amount of water necessary to a batch of concrete is dependent upon the character and condition of the aggregate and the consistency required of the concrete for the purpose and for the manner in which it is to be used. When possible, and especially for reinforced construction, it is advisable to use that consistency commonly known as *mushy*, in which state the concrete is sufficiently wet that, when being transported from the mixer to the work in buckets or in wheelbarrows, its surface naturally becomes smooth and level. With all things equal, mushy wet concrete is most dependable for completely filling all space in the forms, for securing a perfect bond with the metal reinforcing, and for producing a very dense concrete.

For certain effective surface treatments and for detailed ornamental castings a *dry* concrete is frequently used. The amount of moisture required is a variable quantity. At least sufficient water should be used to give the material the plasticity common to molding sand. For mas-

sive work dry concrete should be wet enough to flush mortar slightly to the surface under heavy tamping. Dry concrete attains a working strength more quickly than wet concrete, and the forms may be removed sooner, but ultimately the wet mix surpasses it in strength.

In casting ornamental concrete, and for other purposes, a mortar is frequently required. Sand is generally chosen as the fine aggregate, though stone screenings of various kinds are often used. The proportions are dependent upon the sizes of the particles in the aggregate. In general 1 part of cement is used to $1\frac{1}{2}$ or 2 parts of fine aggregate. Mortars too rich in cement are liable to check and thus injure the appearance of the surface.

At the greatest, not more than thirty minutes should elapse between the mixing of the concrete and the depositing of it into permanent position. The methods of handling the concrete between the mixer and the forms vary with the size of the work. On large construction, hoists are used in connection with distributing spouts. For smaller structures derricks, wheelbarrows, and buckets are the usual means of conveyance.

Estimating Quantities of Materials Needed.—For estimating the quantities of materials needed for any structure, Tables 2 and 3 will be of considerable service. In making up the estimate, compute the total cubic feet of mortar or concrete required and, for the barrels of cement and cubic yards of sand and stone, multiply this total by the decimal figure under each respective heading. These tables are based on ordinary sand and on average conditions of 45 per cent. voids in broken stone with the dust screened out.

TABLE 2.—ESTIMATING QUANTITIES OF MATERIALS FOR MORTAR

Mixture	Quantities of Materials in One Cubic Foot of Mortar	
	Cement	Sand
	Barrel	Cubic Yard
1:1½	0.1481	0.0311
1:2..	0.1239	0.0344
1:2½	0.1052	0.0370

TABLE 3.—ESTIMATING QUANTITIES OF MATERIALS FOR CONCRETE

Mixture	Quantities of Materials in One Cubic Foot of Concrete		
	Cement	Sand	Stone or Gravel
	Barrel	Cubic Yard	Cubic Yard
1:2:4 concrete	0.058	0.0163	0.0326
1:2½:5 concrete	0.048	0.0170	0.0341
1:3:6 concrete	0.041	0.0174	0.0348

To illustrate the manner of using these tables, assume that 25 cubic feet of 1: 2 mortar and 850 cubic feet of concrete are required for a bungalow. Of this concrete, 90 cubic feet of a 1:2½:5 mix are needed for the footings and foundations and the remaining 760 cubic feet of a 1:2:4 mix for cellar and house walls, etc.

ESTIMATE FOR BUNGALOW

Cement for 1:2 mortar .... 25 × 0.1239   3.10 bbls.
Sand for 1:2 mortar..................... 25 × 0.0344   0.86 cu. yds.

Cement for 1:2½:5 concrete .... 90 × 0.048   4.32 bbls.
Sand for 1:2½:5 concrete............... 90 × 0.0170   1.53 cu. yds.
Stone for 1:2½:5 concrete .... 90 × 0.0341   3.07 cu. yds.

Cement for 1:2:4 concrete .... 760 × 0.058   44.08 bbls.
Sand for 1:2:4 concrete................. 760 × 0.0163   12.39 cu. yds.
Stone for 1:2:4 concrete .... 760 × 0.0326   24.78 cu. yds.

Formwork and Centering.—The formwork and centering for reinforced concrete construction, while it is purely falsework, which is taken down, removed and is no part of the finished structure, enters considerably into the cost of any concrete building.

To illustrate the great percentage to the cost of construction the form work and centering bear to the finished structure, it might be stated that reinforced concrete for house construction in place is worth about $21.00 a cubic yard for the usual wall and floor construction. This cost is, roughly, divided equally between the concrete, the steel, and the form and centering, the cost of each being, approximately, $7.00 for every cubic yard of concrete poured.

This cost shows how important it is that the formwork and centering should be of such a design that it may be economically constructed, and,

at the same time, produce well molded work. It is not sufficient that the formwork shall be smooth, for unless care is taken in its construction and support the finished work will show sagged floor slabs, beams and girders, posts and piers out of plumb, and floor members twisted and warped.

The strength and accuracy with which form construction must be designed and executed cannot be too forcibly brought to mind, especially where cast concrete is a feature of exterior treatment and architectural decoration of a building. Nothing can look worse than brackets, mutuals or pilaster caps which, while otherwise well wrought, are placed out of plumb due to carelessness in placing the forms and in supporting them.

Concrete constructors, realizing the importance of cheap forms, have devised and patented many particular ideas of more or less merit. In form and centering construction, however, like other structural evolutions, there has been a "survival of the fittest," and in nearly all instances the patented forms, due to their costliness and lack of adaptability to particular operations of construction, have not been generally used. Forms of simple design, so arranged as to be readily put together and taken down, have been almost standardized where concrete construction has been carried on extensively.

Built-up Form Construction for Floors.—The several types of form construction may be generally classified according to the manner in which they are built, as "built-up," "unit panel construction," and "constructive formwork."

In the first type, the beams and girders of the floor construction are formed in the concrete by building up wooden troughs having the size and shape of the beams and girders, properly supporting these upon suitable uprights well braced, and covering the spaces between the beams and girders with battened panel sections supported upon joists or ribs resting upon ledger boards nailed to the sides of the beam and girder form.

This type of form construction for concrete floors, where beams, girders and slabs occur, has come into common use, and a working draw-

ing giving the usual sizes of the pieces used in the construction of these forms is given in Fig. 59.

Unit Panel Construction.—In the second type, the unit panel construction, the panel formed by the beams and girders is made up in the form of a box, which, when inverted and properly supported upon the
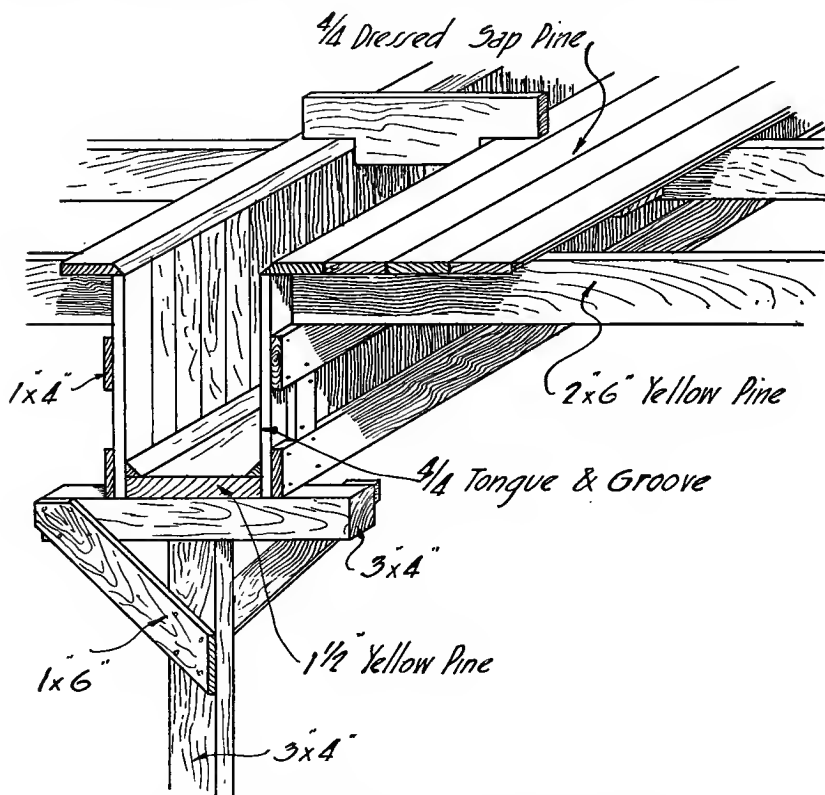

Fig. 59.—Details of forms used in built up-construction.

bottom boards of the beams and girders, makes up the side forms for these structural members, and also provides a centering for the slabs.

These panel forms are sometimes made in sections, so as to be collapsible, as shown in Fig. 60.   The operation of the form is explained by the note in the illustration.

As the unit type of form construction is used especially where there are a great number of unit panels of the same size, they would not be so practical for individual house construction, though they could well be used if a number of houses of the same plan were to be built, as in an operation.

Constructive Forms.—In the third type of form construction an effort is made to minimize the cost of centering by incorporating in the
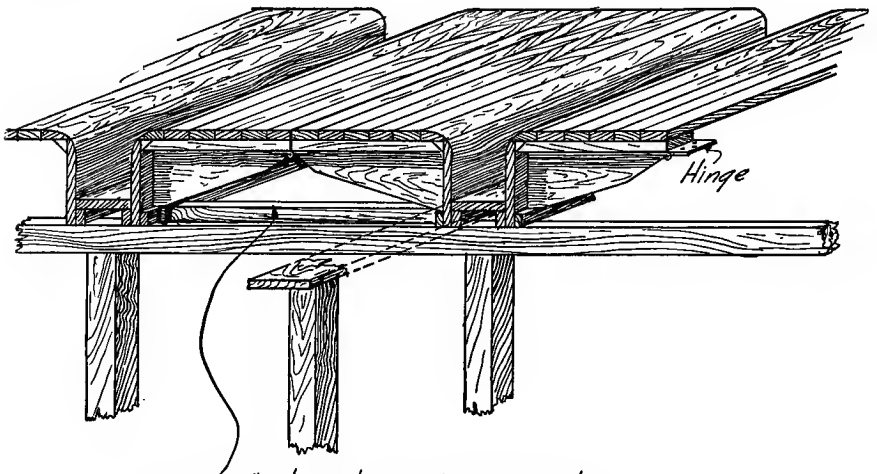
Piece wedged in place, when supports
are knocked down and wedges removed
form may be collapsed

Fig. 6o.—Unit panel forms made in collapsible sections.

actual concrete construction a means by which the sides of the beams and girders, or supporting members, can be formed, the space filled, and a saving in more costly material accomplished.

This type of form construction is emphasized in what is known as "Hollow-Tile" and "Joist Construction," and in such constructions as "Ferro-Dome" and "Corr-Tile." In the Ferro-Dome construction the stamped steel boxes, when properly spaced upon supports, with flat boards for the bottom of the intersecting beams, form a mold for the sides of the beams, as shown in Fig. 61. Sometimes, as in the Corr-tile con-

struction shown in Fig. 62, instead of these metal forms, square blocks of terra-cotta are used, with flanges and channel tile, making a complete form for intersecting beams; thus all that is needed for constructing the work is a flat centering properly supported on studding.
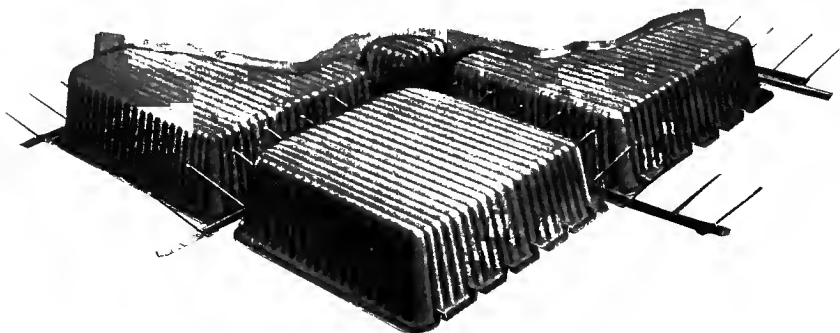

Fig. 61.—Example of Ferro-Dome construction.

Various kinds of patented forms have been devised which are supposed to have the economical advantage of being adjustable to any length of span, and so arranged that by spreading them, different widths of beam could be obtained. It is considered that by the use of such forms their cost was practically made up on the first job for which they were used, and that the cost of the form construction on subsequent work was reduced to the mere expense of hauling the forms to the site and placing them upon the proper centering, with a small percentage of loss due to deterioration. Such form work for floor construction in house work is hardly practical.
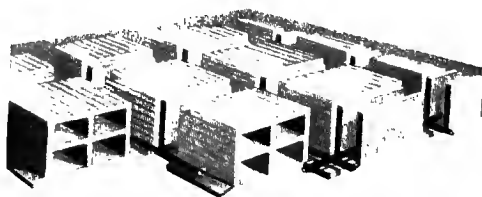

Fig. 62.—Example of Corr-tile construction.

Forms for Wall Construction.—In the construction of concrete walls two kinds of wooden forms are used—namely, those which are constructed

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to cast an entire story height of wall, and those which are arranged to build the wall in sections of two, three, four, or five feet in height.

The former method requires, of course, the most lumber and carpentry labor, but it is the most expeditious, while by the use of the latter, or sectional forms, the cost of the form construction is reduced to a minimum, but the work proceeds much more slowly.

Besides those forms of lumber made up by carpenters on the job, there are several types of patented forms which are usually of the sec-

Fig. 63.—Typical example of form work in one-story wall construction.

tional type, and are so arranged with units of different lengths and corner units, as to allow a wall of any length or plan to be built.

Forms for the Construction of a Story Height of Wall.—The arrangement and construction of the formwork, where a story height of wall is to be placed at one time, is shown in Fig. 63. With this type of formwork for molding concrete walls, the one side of the form, as at *a a*, must

be built first, either upright or on the ground and raised, and then securely braced to hold the side plumb and true. The uprights, as at *b b*, may be 3″ x 4″, or preferably 2″ x 6″ yellow pine, spaced not further apart than 24 inches from center to center. The sheathing nailed to the uprights may be either $\frac{4}{4}$ x 2½″ face tongued and grooved yellow pine flooring, or else 1″ x 12″ sap-pine boards dressed on one side. It is not necessary that the back braces, at *c c*, be of any more strength than enough to hold the form in position and secure it against wind pressure, because both sides of the form must be tied together to resist the pressure of the
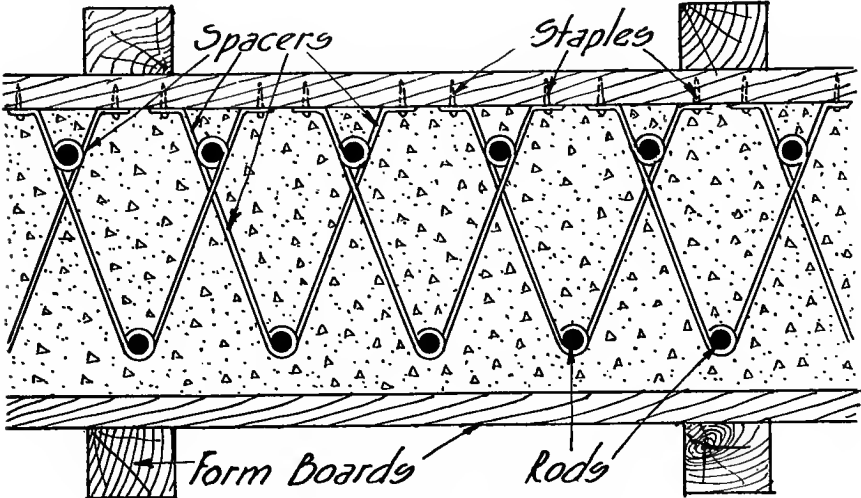

Fig. 64.—Spacers for reinforcement.

wet concrete. It would not be practicable or economical to provide sufficient back braces to resist the bulging or buckling effects due to this cause.

When one side of the form has been constructed in this manner, the other side may be built and placed, being braced in position; before the sheeting boards are put on, the steel reinforcement should be put in position and secured to the side of the form first erected. The best way to fasten and place the steel is to provide looped spacers, as shown in Fig. 64, through which the vertical rods may be passed, and which

are so arranged as to be secured to the back form with staples. These also form a bearing or support to which the horizontal reinforcement can be wired.

Method of Tying and Separating the Sides of Forms.—The braces shown in Fig. 63 are only intended to hold the two sides of the forms vertical and the mass of the wet concrete contained between them in a plumb and secure manner until the concrete has set. It is never considered good practice to attempt to brace both sides of the forms for a wall so strongly and at such frequent intervals as to exclude the necessity
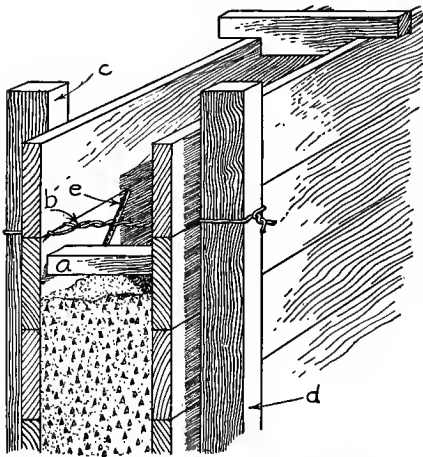

Fig. 65.—A common method of bracing and tying wall forms.

of other ties between the two sides. Usually wire ties or bolts are used to hold in the sides of the forms and prevent them from bulging on account of the hydrostatic pressure of the wet concrete. When the ties or bolts are drawn up it is difficult to regulate the tension so that the forms will not be either bulged or pulled in and otherwise warped and distorted. To avoid this trouble some means is employed to keep the sides of the wall forms at the same distance apart when the bolts or wire ties are drawn up.

The usual methods of tying the sides of the forms together, and arrangements for separating them at proper distances, are shown in Figs. 65, 66, and 67.

In Fig. 65 is shown a method which meets with much favor on account of its cheapness and the convenience with which the materials may be obtained. The separator *a* consists of a small stick of wood smoothed and accurately cut to length, while close to it is placed the wire tie *b*, of No. 18 gauge soft iron. This is formed in U-shape, passed around

the upright c, through holes in the forms, and twisted around the upright d. The proper tension is obtained by twisting the wires with a bar, as at e. Sometimes, owing to the fact that the wire cuts into the wood of the uprights, a small metal plate or another stick of wood is inserted between the wire tie and the upright.

When wooden separators of this kind are used they are generally pushed through the concrete while the work is still "green"; or, at least, before it has set hard. When the forms are removed the ends of the wire
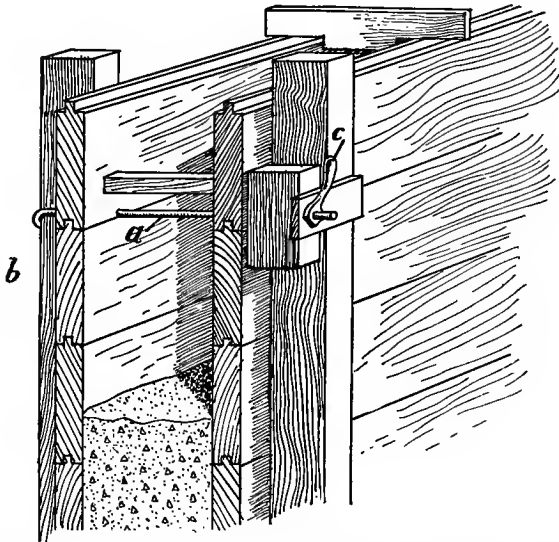

Fig. 66.—The use of the hook bolt as a substitute for wire ties.

ties are cut off and the work is finished by filling the holes left in the concrete when the wooden separators are driven out.

One of the disadvantages of using the wire ties and cutting them off in this manner is due to the fact that some of the ends will be exposed, will rust, and this iron rust running down the surface of the wall will cause unsightly stains.

This difficulty can be obviated by the use of a hooked bolt, illustrated in Fig. 66. The bolt a is formed with a hooked end to fit over the upright as at b; it passes through the two forms and is brought to the

proper tension by the use of a bar, an iron plate washer and a wrench nut, as shown at *c*. In this construction the bolt is withdrawn before the concrete has completely hardened, though the bolts may be loosened by partially removing them, or by turning them while the concrete is setting up. In this way they may be more readily withdrawn when the forms are taken down. Sometimes instead of the wooden separator, an iron pipe separator is slipped over the bolts and left in the concrete wall.
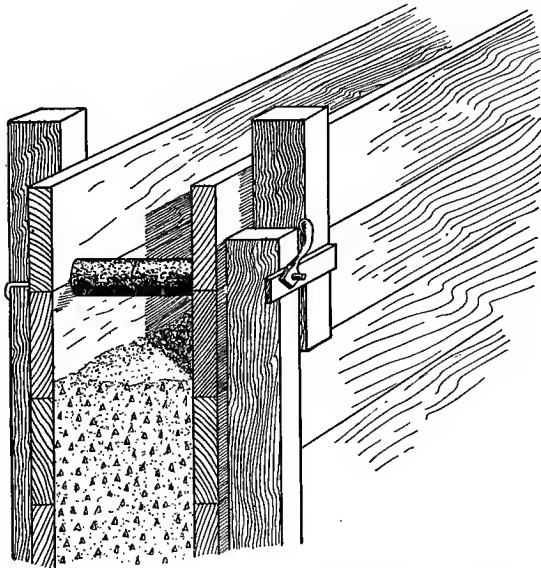

Fig. 67.—A practical type of wall form separator.

These pipe separators are, however, costly, and have the same objection as the wire ties with regard to rusting at the ends.

A good wall form separator is that known as the "McCarty Concrete Separator." This is simply a spool or cylinder of concrete with a hole through the center for the tie-bolt, molded to the length required for the thickness of the wall and left embedded in the concrete. Being cement, it becomes incorporated with the concrete of the wall, and is not subject to the objection found in metal separators. This separator with the tie-bolt is illustrated in Fig. 67.

A clever device which can be used with wire ties, and by which the ends of the wire ties can be covered with the concrete on the surface of the wall after the forms have been removed, is illustrated in Fig. 68. This device is clearly shown in the figure, and its use in conjunction with the wire tie, or with a rod tie with hooked ends, is shown in the illustration. When the form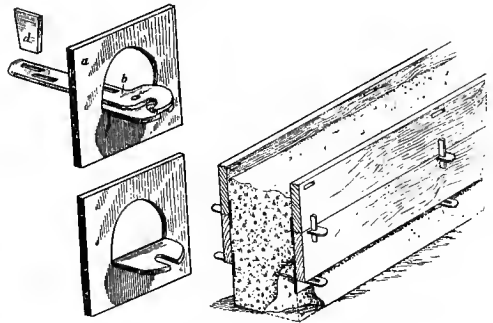s are to be taken down the wed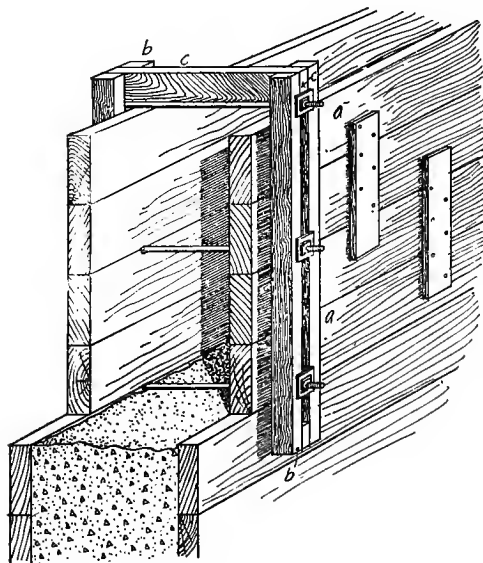ge at d is knocked out and the forms removed; then the device may be released from the wire or hooked tie by knocking over the end of the hooked lever,

Fig. 68.—A clever device used in connection with wire ties

as at b, thus releasing the device from the tie. In this way the ends of the tie do not come closer to the surface than one-half or three-quarters of an inch, and are covered by the concrete. The hole left in the surface of the wall by the removal of the device can be filled by plastering or grouting.

Panel or Sectional Wall Forms.—Where the wall is to be constructed in sections three or four feet high, the formwork becomes comparatively simple. A good arrangement for the construction of concrete walls in sections is to use battened panels, as at $a\,a$ in Fig. 69,

Fig. 69.—Panel or sectional wall forms.

supported and braced by the uprights *b b*, made up of two pieces of 2″ x 6″ timber, held together by separators at the end, as at *c c;* when braces of this kind are used bolts can be placed in any position, and the separator at the top holds the braces together as a yoke. The braces are sufficiently long to grip that portion of the wall already constructed, and in this way the form construction for the portion of the wall to be built is held plumb and secure over the finished wall. The tie-bolts may be
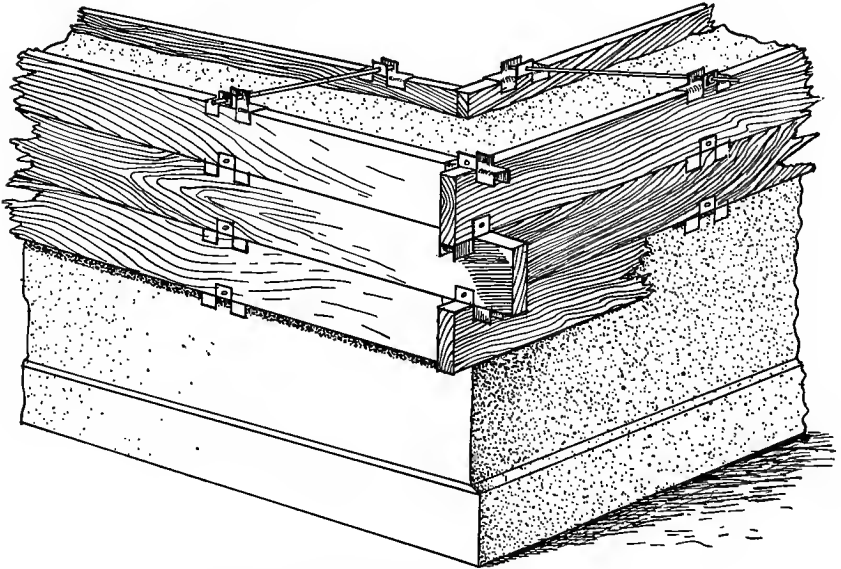

Fig. 70.—"Sullivan Pressed Steel Plank-Holders.

oiled or soaped so that they can be more readily withdrawn from the concrete.

Where there is much wall to construct, or where the contractor can use the braces for a number of operations, they may be made of channel or angle irons placed back to back, held together with separator plates and rivets. These are much more costly, of course, than the wooden braces, and somewhat heavier to handle.

Another method of constructing concrete walls in sections is illustrated in Fig. 70, which shows the use of what is known as the "Sullivan

Pressed Steel Plank-Holders." By means of these the form-boards are interlocked at the corner and together, and they also act as a washer and grip for the tie-bolts; wire ties may be used with them as well as bolts.

Forms for Hollow Wall Construction.—Hollow walls built of concrete have been used for house construction to some extent. The advantage of a hollow concrete wall consists in the dead-air space contained between the inside and the outside wall, which insulates the building, tending to make it cool in summer, and allowing it to retain the heat in winter. Concrete
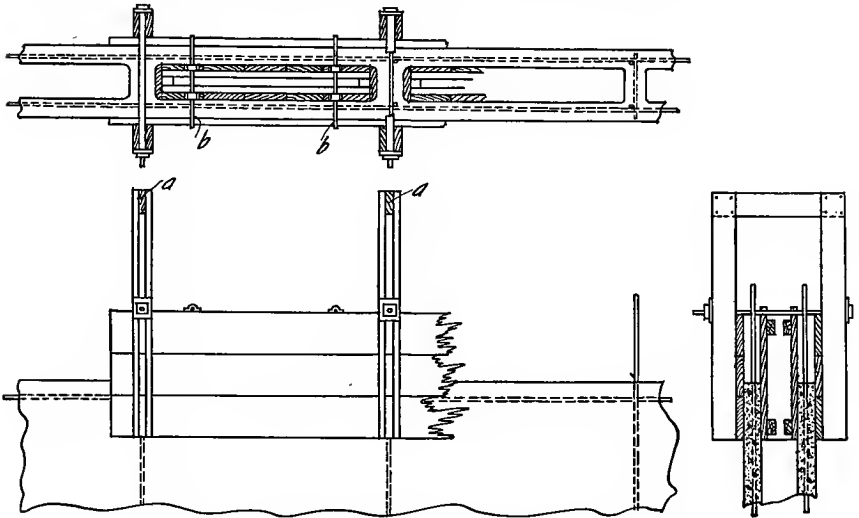

Fig. 71.—Wooden forms for hollow wall construction.

is, however, such an excellent non-conductor, and solid concrete walls are so much superior to brick and stone walls with regard to their ability to prevent radiation, that the additional expense required to build hollow walls of concrete is hardly warranted.

Forms for the casting of hollow concrete walls are necessarily complicated, and are particularly so when attempts are made to construct them with wooden forms. It is only possible to construct hollow walls by means of sectional forms arranged to cast two or three feet of the wall at a time. Fig. 71 illustrates a type of wooden form construction that

can be used where a hollow wall is desired. The outside forms are of the usual battened type, braced by the slotted wooden braces yoked at the top, as shown at *a a*. The bars, at *b b*, which support a wooden core box, rest upon the top of the battened forms for molding the outside of the wall. This core box is so arranged that it can be wedged out to the required width by means of cleats or wedges, and after the concrete has been cast these cleats or wedges are released and the core box is slightly collapsed, thus allowing it to be withdrawn.

Many devices can be gotten up which will permit the collapsing or slight reduction in size of the core box, arranged to operate by the use of wedges or keys driven into place, or released by a blow from a hammer.

Good results at reasonable cost in the construction of hollow concrete walls can only be obtained by spending much care and thought upon the construction of the core box, and where there is much work of this kind to be done it would be better to use specially designed metal forms for the construction of hollow walls. There are several types of patented hollow-wall forms on the market which can be used economically where several buildings are to be built.

Patented Steel Forms.—Steel forms made up in units, with special devices for clamping the several units together, have been developed and used to a considerable extent. It is impossible here to describe at length the several types of patented sectional steel and steel-lined forms. One of the most recent types of steel forms for wall work is illustrated in Figs. 72 and 73. The former shows in detail the unit sections of the forms and the method of clamping them together at the junction of the units, while the latter shows their use in the construction of an all-concrete dwelling. In general, the units are 24″ square, and are made of No. 16 galvanized sheet iron, reinforced around all four sides by 1″ x 1″ x ⅛″ steel angles; the units are arranged with two clamps on the right hand edge, so that when these clamps are turned into position they tie the adjacent edges of the units together. Besides these clamps, dowel-pins are provided on each plate which fit into corresponding holes in the adjoining unit. In the use of these unit forms the window
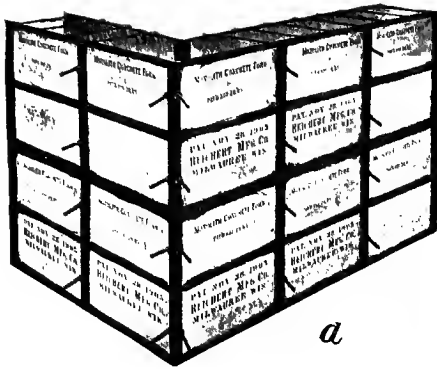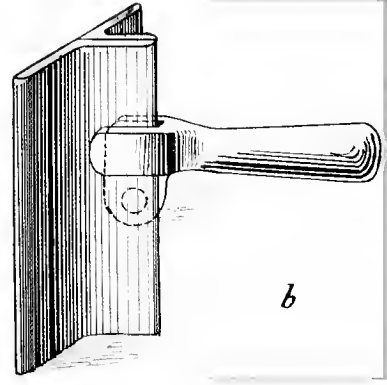
Patent steel forms used in concrete wall construction.

Patented steel forms in use.

and door frames are set in conjunction with the forms, and are cast in place. In order to make the construction as adjustable as possible to any dimensions, other widths of units may be had in increments of two inches, and three-inch plates are used in order to get odd sizes. The units are tied together by wire ties which pass through holes in the angles, and a detail of the clamping device previously described is shown in Fig. 72.

Remarks Regarding Forms and Their Construction.—It is an accepted fact by those who have had much experience in concrete construction that it is not economical to use poor grade lumber for forms. The cost of using old lumber, because of the work required to patch it, extract the nails, and prepare it so as to give results in any way satisfactory, is greater than to purchase new.

All lumber for form work should be either white pine, yellow pine or spruce; hemlock should not be used ordinarily for exposed work. When the lumber is delivered it should be carefully piled, with spaces between the boards, with the top layer pitched to shed water, and where possible, it should be protected from the sun. It is vital that the boards for form construction shall not be badly warped or twisted, and any care that can be given to prevent this amply repays for the trouble.

The joints in form construction should be close—especially where a wet mixture of concrete is used, though the best results are not always obtained by using matched boards. The moisture sometimes causes the wood to swell, and when they are driven up tight there is a tendency to buckle which sometimes results in poor work.

It is of the utmost importance that the bottom of floor forms when in place shall be clean of all shavings, sawdust and chips before the concrete is placed, and the same precaution must be used with reference to wall forms.

In winter time all form work must of course be clear of ice or snow before the concrete is placed. In summer time, or hot weather, form work should be kept well wetted in order that the lumber may not shrink and leave large cracks through which a wet mixture of concrete will run, and by which unsightly fins or markings are left upon the concrete.

Method of raising and adjusting steel forms by the two-tier process. Forms designed and patented by Read & Morrill, Brooklyn, N. Y.
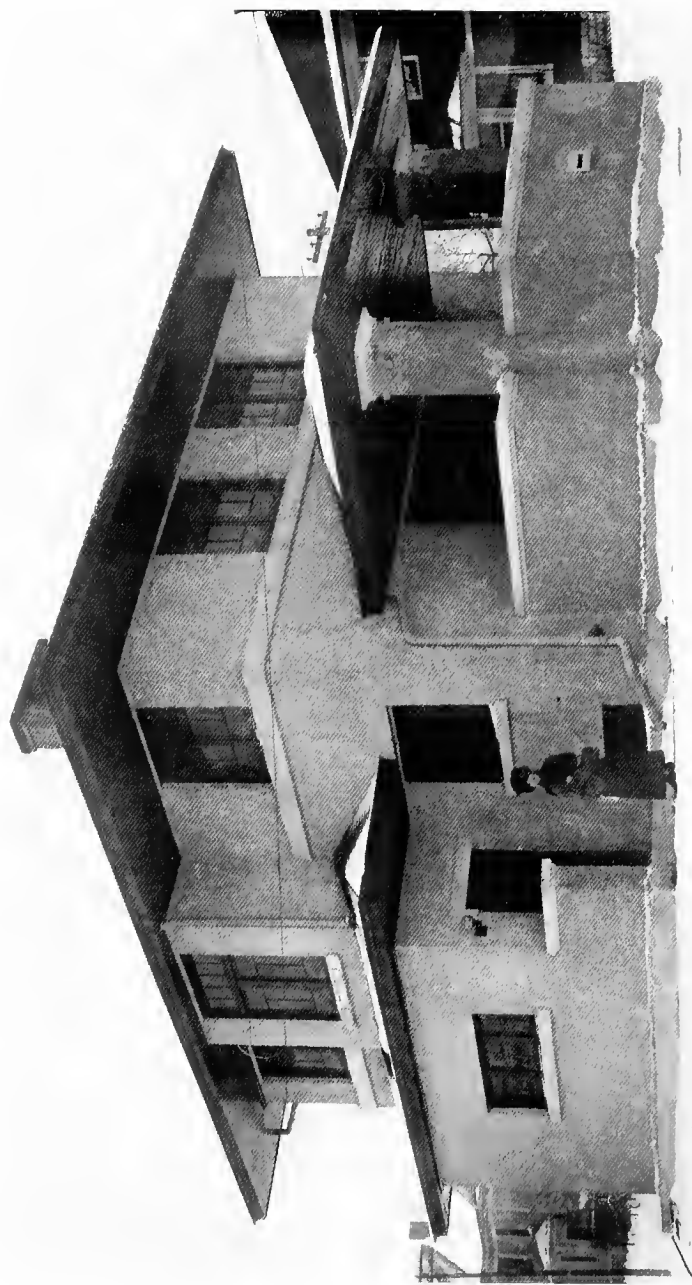
Residence of G. L. Calkins, Ottumwa, Ia.   *Harry E. Throne, Architect*

House constructed with Van Guilder hollow concrete walls.   Mixture and plaster applied directly to walls.

It is not well in house construction to oil the forms. In the first place, it is apt to leave the concrete discolored and stained on the outside. It is also likely to cause trouble where the concrete is plastered on the inside, by the oil coming out in the finished plaster work. There seems to be no real necessity for or advantage to be gained in oiling either wall or floor forms in the construction of dwelling houses.

Selection and Care of Steel Reinforcement.—It is generally conceded that any type of deformed steel bar is superior to plain round rods for the purpose of reinforcing concrete. In the selection of the type of deformed bar the constructor should be governed by the pattern of bar which is most available in the locality of the proposed building site. If there is an operation contemplated, which would require a great amount of steel reinforcement, then prices can be obtained on several types of deformed bars, with the idea of getting the best possible quotation. It will generally be found that the most available deformed reinforcing bar is the square twisted bar, and that this bar fulfills every requirement of a uniform net section, as well as a deformation without an increase in the weight of the bar.

The only advantage of plain round bars is that they are less costly than any type of deformed bar, and can be obtained from the stock of any local dealer in sufficient quantity for the construction of a concrete house of ordinary dimensions.

Where reinforcing steel is sent from the mill, or even from a distant wholesale dealer or broker, it is usually shipped in open freight cars, and generally it is necessary to haul the steel from the siding or freight station. It is best, if possible, to haul it in wagons of sufficient length to prevent it from trailing on the ground.

In any construction work annoyance and loss of time are saved by exercising care in the disposal of the materials, and the manner of taking care of steel reinforcement is not an exception to this rule. The steel, upon delivery, should be sorted out with reference to the position it occupies in the building, and with regard to sizes. In a very large operation of concrete houses the steel should be placed in racks and checked off as

used. If some system is not adopted in taking care of the steel reinforcing bars, it will be found that some of the longer bars will be used in places for which shorter bars were ordered, and that the short bars left over will not meet the requirements of the conditions for which the longer bars were needed.

All steel reinforcing bars before being placed in position should be cleaned of loose scale by using a wire brush. They should, of course, never be painted, and should be free from oil, clay, or dirt. Material of this kind on the steel will destroy its bond in the concrete.

While the ordinary steel reinforcement will stand a great amount of rough handling, yet it is best not to attempt to bend suddenly or otherwise subject the steel to severe shocks, especially where high carbon steel is being used, as sometimes the steel rods will be broken off. Accidents of this kind are more likely to occur in cold weather.

Kinds of Steel Used for Reinforcing.—Two grades of steel are used in the manufacture of reinforcing rods or bars, generally known as "high carbon" and "low carbon" steel. Such terms are probably misleading, as usually so-called "high carbon" steel is made by the Bessemer process, and has an ultimate tensile strength of between 80,000 and 90,-000 pounds, while the steel commonly denominated as "low carbon" is made by the open-hearth process, and has a tensile strength of from 60,000 to 70,000 pounds. There is also what is known as "re-rolled" steel, which is a term applied to reinforcing bars which have been rolled from discarded railroad rails, these being split up and the heads or bulbs of the rails being rolled into reinforcing bars. The re-rolled material is generally about 10 cents per cwt. less costly than the newly manufactured stock.

Square reinforcing bars are frequently designated as "cold-twisted" or "hot-twisted," these terms being applied to square twisted bars which have been deformed by being twisted cold or hot respectively.

Selection of Kind of Steel.—There is considerable diversity of opinion among engineers as to the best kind of steel to use for reinforcing

bars. The high carbon steel gives the greater tensile resistance and also a greater elastic limit, but it is also less ductile and can be bent with less surety than the low carbon steel.

In concrete dwellings the floor loads are never great, and the labor is less likely to be skilled in the fabrication of the steel, so that it would seem best to use steel with low tensile strength, and having the capability of being bent cold at any angle without sign of fracture or the likelihood of developing flaws.

Among the best reinforcements for dwellings are woven-wire fabrics. In such materials the wires possess great tensile strength from the fact of their having been drawn through dies. They are admirably adapted to concrete construction because they can be bought in rolls of any length, and being a fabric, there is no danger of misplacement of the reinforcement. The lighter cross wires supply without any care or attention the necessary shrinkage rod.

Price and Manner in which Steel Reinforcement is Sold.—All steel rods and bars are sold from what is known as a "base price." This base price is for all rods or bars of $\frac{3}{4}$-inch in diameter or over. If the bars are less in size than $\frac{3}{4}$-inch there is what is called a "size differential," which is a fractional part of one cent a pound above the "base price." The present differential for sizes is given in the following table:

$\frac{3}{4}$ -inch Bar.		Base.		
$\frac{11}{16}$	"	"	$ .05 per cwt.	
$\frac{5}{8}$	"	"	.05	" "
$\frac{9}{16}$	"	"	.10	" "
$\frac{1}{2}$	"	"	.10	" "
$\frac{7}{16}$	"	"	.20	" "
$\frac{3}{8}$	"	"	.25	" "
$\frac{5}{16}$	"	"	.35	" "
$\frac{1}{4}$	"	"	.50	" "

This schedule of size differentials is based on plain material. Usually deformed bars cost $2.00 or more a ton extra, while either cold or hot twisting adds about a tenth of a cent a pound, or $2.00 per ton, to the

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cost of plain bars. In buying reinforcing steel it must also be under-
stood that there is what is known as a "shearing differential," and
also a "quantity differential"; the former is a cost of .05 of a cent
a pound on all bars less than 5 feet in length, while the latter is a
charge of .15 of a cent a pound for shipments from the mill of less
than two thousand pounds.

To all of these prices must be added the freight rate from the mill
to the point of delivery, and also the cost of hauling, before the actual
cost per pound delivered at
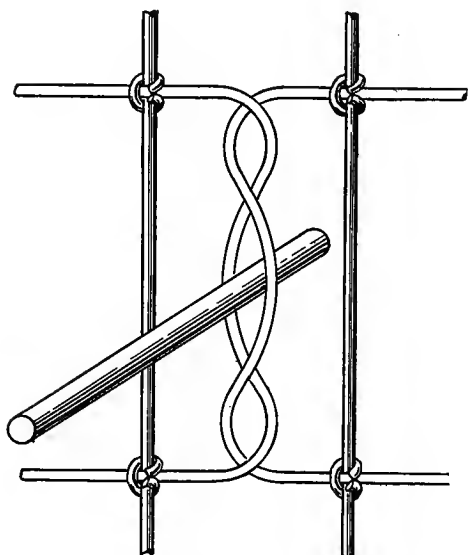the site can be determined.

**Use of Expanded Metal
and Woven Wire Fabrics.—**
Both expanded metal and
woven wire fabrics must be
handled intelligently in the
field.

Expanded metal is fur-
nished in gauges from 4 to 18,
in sheets 6, 8, and 12 feet in
length, and in widths of from
1 to 6 feet. The usual way of
shipping expanded metal is in
flat bundles containing five or
six sheets wired together.

Fig. 74.—Attaching the edges of wire reinforce-
ment.

In using expanded metal
the long diagonal of the mesh
must always be parallel with the span of the slab, as otherwise the full
tensile strength of the material is not obtained. Expanded metal should
be lapped on the ends at least 6 inches, and such laps should occur over
points of support.

In using wire fabrics it is well to interlace them, or join them, at the
longitudinal edges. They may be wired together, or lock-woven wire
fabric may be secured along the edges, as illustrated in Fig. 74. Some-

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times, however, merely a short piece of wire hooked at both ends is used for securing the edges of the fabric.

Methods of Bending, Fabricating, Securing and Placing Reinforcement.—The most economical practice in working and fabricating steel reinforcement is to make careful bills of material, and have the reinforcing rods or bars of the required length sent to the site of the operation, and to do the bending and fabricating of the steel on the operation.

Fig. 75.—Hand shear for cutting reinforcement.

There is always some cutting to do, and it will be found economical to provide on the job a hand-shear, of the design shown in Fig. 75. With this shear rods up to 1 inch square can be cut without much difficulty, especially if the shear is securely mounted and an extension is made to the lever by means of a piece of pipe. Where truss or other rods are to be bent, diagrams should be made and the bars bent according to such diagrams.

There are a number of simple devices that can be arranged to facilitate the bending of rods or bars to the required angle. One of the simplest of these consists of a strongly constructed table, made up of at least 8″ x 8″ pieces securely braced and fastened, and arranged with a cast or wrought iron plate which has secured to it an iron block and a movable block which can be set in such a manner as to clamp the steel, either by means of wedges or by clamping devices, as illustrated in Fig. 76.

Stirrups may be bent by machine and sent directly from the shop, delivered in the required form, or else they may be bent in a heavy machinist's vise, such a vise being very useful when securely mounted, for working steel reinforcement.
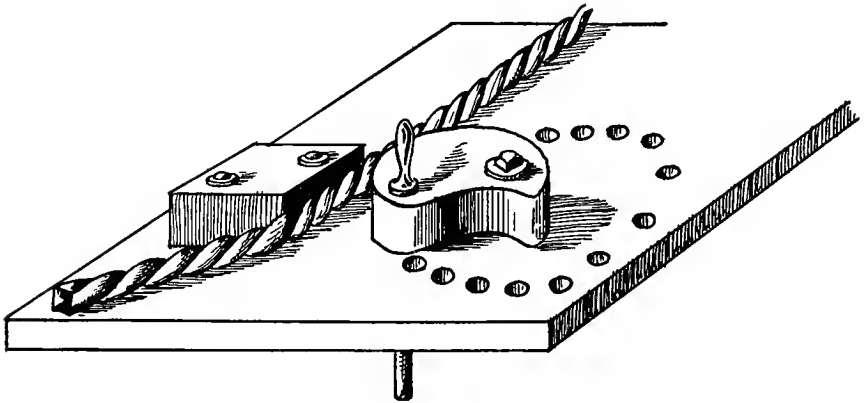

Fig. 76.—Reinforcement bending table.

It is very seldom in house construction that large-sized reinforcing rods would be used, and rods up to 1 inch in diameter can readily be bent cold. Reinforcing rods larger than this are generally heated in a small portable forge, and bent while hot.

For fastening reinforcing rods and bars together, and for securing the stirrups, as well as for fastening cross-bars in wall reinforcement, and slab rods, no better method has been found than that of wiring them together. This, of course, can be done with pliers, but where there is much to do the device illustrated in Fig. 76 has been used successfully, and with a resultant saving in time. This device is known as

the "Curry Tyer," and the illustrations show clearly the method of operating. By the use of this tool the wire is given a uniform number of twists, and the rods or bars are secured much more positively than can be done with an ordinary plier. It is also claimed that much time is saved in cold weather by the use of this device, as with ordinary pliers the work is necessarily slow from the fact that the workmen's hands become numb.

Protection of Work.—During the hardening period, concrete should be protected from sun, wind, and frost. In house construction much of this protection is afforded by the forms.

Intense heat of the sun in midsummer and high, dry winds tend to evaporate water from the surface of green concrete and thus injure its appearance. This is easily prevented by such means as enclosing and shading the concrete with canvas. Freshly placed concrete, even though protected, should be sprinkled with water as soon as this can be done without pitting the surface. It may then be covered with sand, if expedient, and thereafter wet as often as necessary. When possible, the exposed surface of concrete should be safeguarded from sun and wind until the concrete has attained an age of thirty-six hours.

Alternate freezing and thawing of concrete which has not had opportunity to set, seriously injure it. Consequently it has been customary, and is still usual practice, to conclude all concrete work in early winter as soon as there is danger of freezing. Within recent years, methods have been adopted by means of which urgent concrete work is done even in the dead of winter. Such results are secured either by lowering the freezing-point of the concrete or by heating the materials entering into its composition and by protecting the concrete after it has been placed.

Ordinary salt is the cheapest means of lowering the freezing-point of concrete. It is common practice to dissolve in the mixing water a quantity of salt equivalent to one per cent. (by weight) of the water used for each degree of drop in temperature below the freezing-point, 32° Fahr. However, not more than ten per cent. of salt should be used, as a greater quantity may seriously injure the concrete. Consequently this preven-

Fig. 77.—"Curry Tyer." A convenient method for wiring reinforcement together.

Aberthaw Construction Co., Boston

A dwelling showing adaptability of concrete to varied details of construction. It is used here for walls, chimney, columns, balustrade and floors.

Small and attractive concrete house built at Rosylyn Farms, Carnegie, Pa.

tive is not usable for temperatures lower than 22° Fahr. Calcium chloride is also employed for the same purpose. These salts should not be used in concrete when the appearance of the surface is a matter of consideration, as they are likely to show in spots in the form of white efflorescence. Also in reinforced construction there is probability of salt causing the steel to corrode.

For concreting in cold weather more satisfactory results are procured by heating the aggregate and the water and by keeping the concrete warm until the cement has set. An elaborate and expensive plant is not necessary. The aggregate may be heated by heaping it over steam pipes or coils or by piling it over a make-shift furnace consisting of an old boiler, a metal tube, a semi-circular form, or other simple devices. Likewise water for mixing may be heated in barrels or tanks by steam coils or pipes or in tanks by a furnace. Frequently it is drawn directly from a boiler used to generate steam for other purposes.

Often, even when the temperature of the air is above the freezing-point, green concrete is injured by the use of frosty aggregate. Especially in early spring must sand, stone, and gravel be carefully inspected to see that they contain no frost. In such case the materials must be heated as in freezing weather. Sometimes a stream of water from the well or hydrant is sufficiently warm to dispel the frost when played on the aggregate.

After the concrete is placed in the forms, it is sometimes necessary to prevent it from freezing. Often the forms supply adequate protection for all except exposed surfaces, which should be covered with a tarpaulin, boards, or building paper, freely supported a couple of inches above the concrete. Sand and clean straw are also used. In severe weather similar additional protection is given the concrete in the forms and often a jet of steam is introduced under the tarpaulin covering. For green concrete floors and inside work, all window and door openings are tightly closed and the interior heated by salamanders, sheet-iron stoves, or furnaces.

Concrete amply protected in freezing weather for forty-eight hours after it has been placed is out of danger of frost.

Details of ornamentation must be carefully shielded until the entire

structure is completed.   Sharp corners can be protected from chipping and spalling by placing wooden pieces as buffers on each side.   Ornaments cast as independent units must not be set until the latest time permissible. Such ornaments, as well as those cast in place, should be crated and enclosed with canvas to protect them from falling débris and sticky mortar.
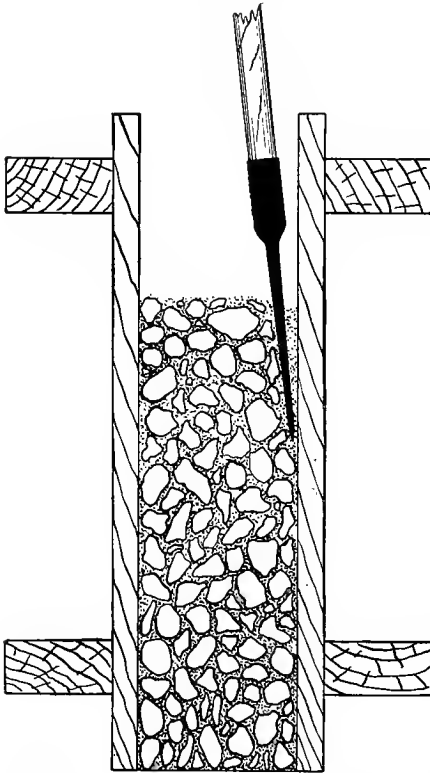
To the exterior faces of tiles paper is glued to prevent the chance adhesion of cement mortar and is later removed by the application of water.   Concrete and tile ornaments can be cleaned with a weak solution of acids, as described under "Surface Treatment" on page 129.

Treatment of Concrete Surfaces.—As in the design of a house, the treatment of a concrete surface is purely a matter of individual taste.   The only thing upon which there is unanimity of opinion is that a surface should not be of the forbidding color and texture sometimes found in sidewalks—a surface perfectly smooth and cold and leaden in hue.   Some architects

Fig. 78.—Tamper for getting mortar face.

have designed attractive houses in which the walls were left just as they appeared when the forms were removed.   Others have adopted this plan as to texture of surface, following with a wash in white or color.   In many cases walls are scrubbed when green, resulting in the removal of the cement film and exposure of aggregates.   The outer coating has sometimes been removed by sand-blasting, and again by bush-

hammering. The nature of concrete is such that it affords great opportunity for the architect to exercise his ingenuity and taste in producing satisfactory results. Various methods of treating surfaces are described below.

Mortar Facings and Untreated Surfaces.—Where utility is the principal point of consideration, a surface sufficiently pleasing for the purpose may be obtained by using a moderately wet mixture (well tamped) and tightly and neatly built forms. With such a concrete, a thin film of mortar usually settles against the sides of the forms. Frequently, due to carelessness and the bridging of the coarser aggregates, small pockets appear when the forms are removed. Such an objectionable feature is easily avoided, either by spading or by the use of facing boards (Figs. 78 and 79).
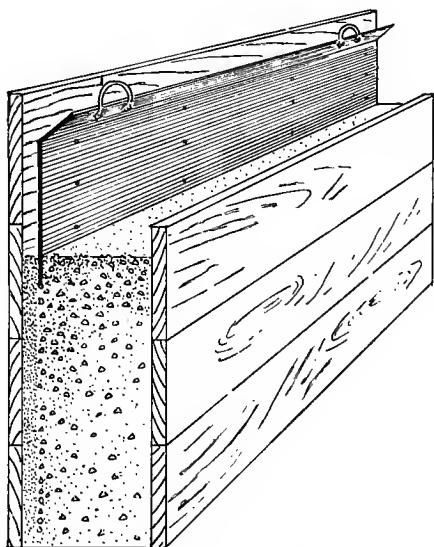
As the name suggests, spading is accomplished by means of a straight garden spade or a special tool of similiar shape, which is forced down and worked to and fro between the concrete and the form

Fig. 79.—Facing board.

in order to force back the coarser aggregate and to permit the flow of wet mortar against the forms. In this manner a surface can be produced which will be as smooth and regular as that of the forms. Since this kind of surface treatment requires close supervision to see that the workmen do not neglect to use the spading tool, there has been developed a more dependable method which secures the same effect by means of a device called a facing board. The facing board consists of a short length, usually 5 feet, of $\frac{3}{16}$-inch sheet-metal plate, 10 to 12 inches wide, with the top 3

inches bent to an outward flare. To the inner face of this plate, near each end and at the middle, are riveted short vertical lengths of one-inch angle irons and simple loop lifting handles. In operation the boards are set ends abutting, with the angle spacers against the inner face of the outside wall form. The ordinary concrete is placed between the inside wall form and the facing board, while the one-inch space between the facing board and the outer form is filled with a mushy wet mortar. The facing board is then carefully worked up, almost out of the concrete, which is again tamped lightly so as to insure a good bond between the ordinary concrete and the facing mortar. This operation is repeated as the work progresses.

By using the original method of a dry mix and tamping, there has come into use a surface finish which in boldness, beauty, and execution of detail has the charming appearance of free-hand sketches. Suitability of design and careful construction of forms are primary requisites of this remarkable treatment. By using a concrete fairly lean in Portland cement and somewhat short in proportion of fine aggregate, and by tamping the concrete thoroughly, there is produced a surface which brings out the sharpness of detail without displaying the minor irregularities and imperfections frequently discernible in the ordinary mortar finish. The surface obtained has all the charm, warmth, and softness of a coarse-grained stone. Its face is rough and deeply pitted, consequently such work is often mistaken for weathered stone. Exposure to the elements for several years has brought forth no evidence of injury from frost and no efflorescent discoloration of surfaces so treated (Fig. 80).

For such untreated surfaces the concrete is usually proportioned 1 part cement to $1\frac{1}{2}$ parts sand to $4\frac{1}{2}$ parts crushed limestone screenings, which must pass a $\frac{1}{2}$-inch mesh and be retained on a $\frac{1}{4}$-inch screen. Such a small amount of water is used that, when the concrete is tamped into place, no mortar flushes to the surface.

Abrased and Tooled Surfaces.—Plain mortar-facing finishes, although productive of a smooth surface, are not always satisfactory for every design. To erase form marks and to produce uniform color, tex-

ture and appearance, such surfaces are frequently abrased or tooled. Three forms of abrasion are in good practice—brushing, scrubbing, and sand-blasting.

Brushing.—Simple character is given an ordinary mortar-faced surface by brushing the green concrete with a stiff fiber or wire brush. Special brushes of slitted sheet metal may be purchased on the market or can be made by clamping together strips of wire cloth or ordinary fly screen.   For a plain brush finish it is advisable that the facing mortar be
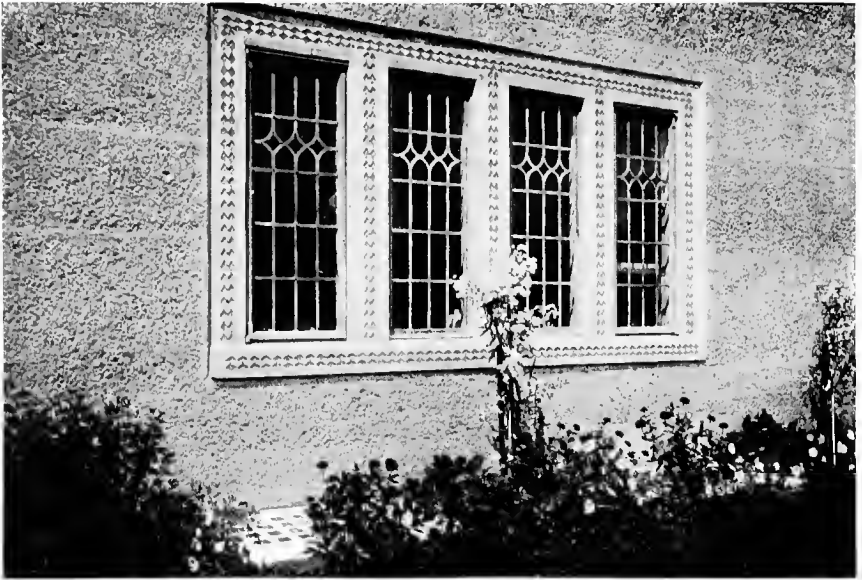

Fig. 80.—Concrete surface that corresponds to coarse-grained building stone.

free of coarse aggregate.   The concrete should be brushed while it is still green, but not so soon as to remove granular particles and to give the surface a pitted appearance.   The length of time between the placing of the concrete and the removal of the forms for this finish is dependant upon weather conditions and the amount of concrete placed.   In summer the forms should usually be taken down on the day following the placing: in cooler weather greater time must be allowed.   The older the concrete,

the more the labor required to produce the desired effect. Often the forms must be planned and built in sections so as to permit early removal and to facilitate this attractive treatment. (See Fig. 81.)

Scrubbing.—Where the forms can not be removed quickly enough to permit of brushing, similar effects are obtained by scrubbing the concrete. Scrubbing is done by means of a concrete brick, soft limestone, or a carborundum stone. As soon as the forms can be removed, the concrete is flushed with water and rubbed vigorously with a number 16 stone. After the roughness and the cement skin have been removed, the lathered surface is washed down, dusted with the 1 : 2 dry mixture of cement and sand, and the scrubbing is completed with a number 30 stone. When the desired effect is obtained, the surplus cement grout is carefully washed from the concrete face. This treatment produces a surface lighter in appearance than that of ordinary troweling, and, by filling the pores with cement grouting, yields a surface at least as entirely waterproof as the original. In case it is desired to treat concrete of considerable age, there may be required the acid treatment described under "Exposed Selected Aggregates," page 129. (See Fig. 82.)

Sand-Blasting.—By means of an air compressor, a small gasoline engine, and a hose with a nozzle, sand can be so forcibly driven against concrete surface as to remove the cement film. Several days previous to such treatment all imperfections of surface should be touched up with mortar or removed by tooling as may be required. Otherwise in attempting to get rid of these irregularities, the surface will be little improved in appearance. If it is desired to preserve sharp lines of architectural detail, these should be protected by covering with heavy paper or wooden strips. Like means should be used in preventing over-treatment and in obtaining homogeneous appearance and invisible boundary lines where two separately applied treatments on adjoining sections merge. For blasting purposes a clean, sharp, hard silica sand or crushed quartz is most effective. The size and shape of the nozzle are dependent upon the power in the compressor, the range, and the size of the blasting aggregate. For materials passing a number 8 and a number 12 screen, a $\frac{1}{4}$ inch and a $\frac{1}{8}$ inch nozzle are respectively used. Likewise correct nozzle
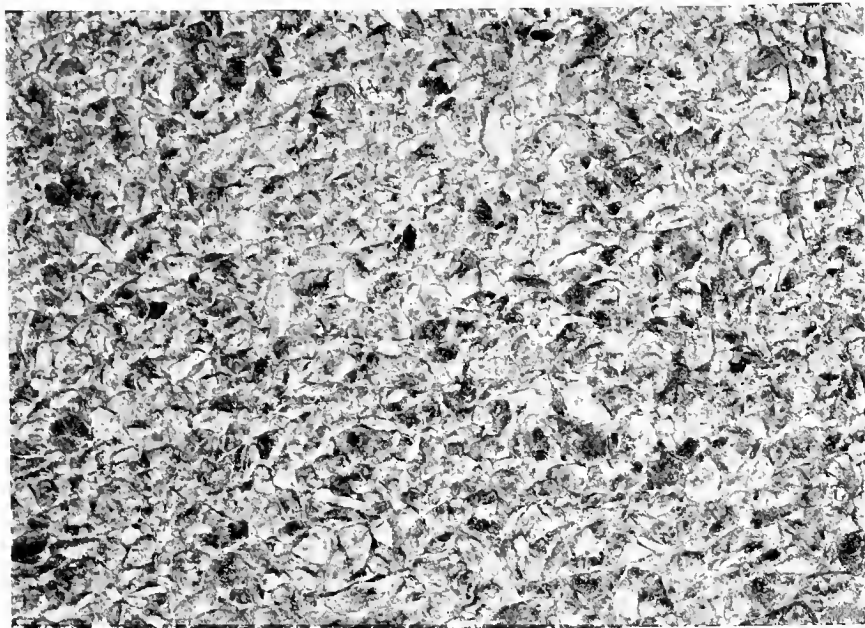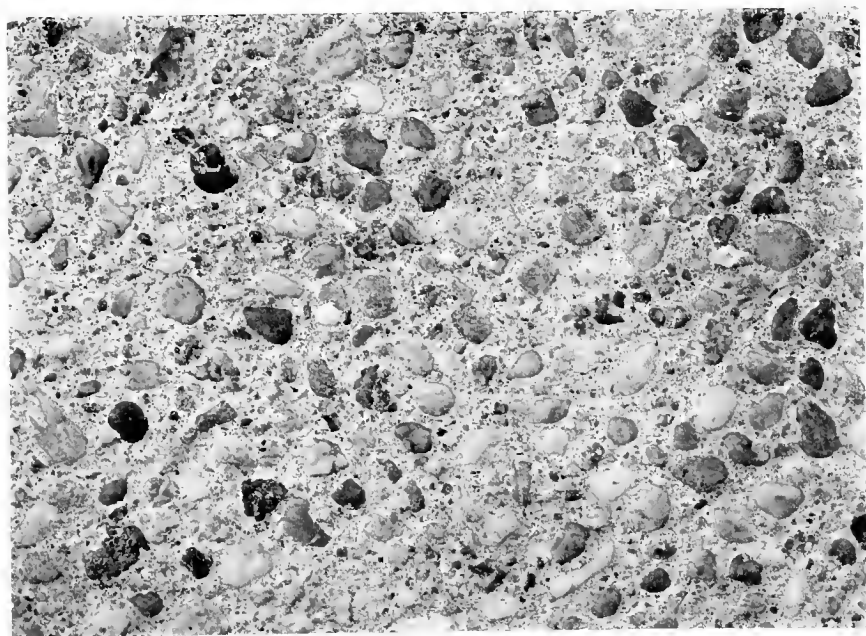
Fig. 81.

Fig. 82.

Fig. 83.—Sand-blasting a concrete surface.

pressure is also a variable quantity. Usually for concrete thirty days old, a working pressure of 60 pounds is adequate. Older concrete may require as much as 80 pounds pressure. The surface resulting from such treatment also has the imprint of age and is very similiar to that produced by scrubbing. For work of considerable size this process is very rapid and inexpensive. (See Fig. 83.)

Tooling.—The lack of character in the ordinary mortar finish may be got rid of by picking the surface with pointed tools. Such treatment chips off the mortar on the outside of the structure, and by roughening the surface changes it from a monotonous plane to a wall of lively and pleasing texture. Ordinary hand-picks and stone-axes have been used to a considerable extent, but the most satisfactory results have been obtained by means of the hand and air-operated bush-hammer.

When the surface is to be bush-hammered, the concrete, during construction, should be faced with materials suitable for rendering the finished results desired. Sand mortars, when bush-hammered, yield a surface of very uniform appearance. Where the surface contains coarse aggregate, a greater variety in appearance is obtained. In order to prevent scaling of mortar and dislodging of coarse aggregate, the concrete should attain considerable age before being treated. Usually such treatment is applied when the structure is one or two months old. In three months the cement generally becomes as hard as the aggregate, and such a surface, while requiring more labor, yields greater individuality.

The size and pointing of tools for hammering are matters of personal opinion. Excellent work has been done with a 9-pound hammer with 32 points on one end and 25 on the other, and also with a hammer of the same weight with 16 and 25 points. The points are merely small pyramids spaced about two-thirds of an inch. On large construction, pneumatic tools facilitate the work and cheapen the cost. Variation in appearance of the surface may be effected by the manner in which the stroke is made. Perpendicular blows merely roughen, while glancing strokes produce lineal markings. Tooling is a simple and effective means of dispelling the coldness of plain concrete surfaces. (See Fig. 84.)

Displayed Selected Aggregates.—For decorative effect and variety in

9

color and composition no treatment offers the architect a wider field
than that of exposed selected aggregates. A wealth of color is everywhere
at hand in the various marbles, burnt clays, gravels and granites, from
which he may make his selection of crushed aggregates (one or several)
and combine them on the mixing board in much the same manner as the
artist mixes his paints. Placed in the wall and treated so as to display
the beauty of the composition, very attractive and pleasing results are
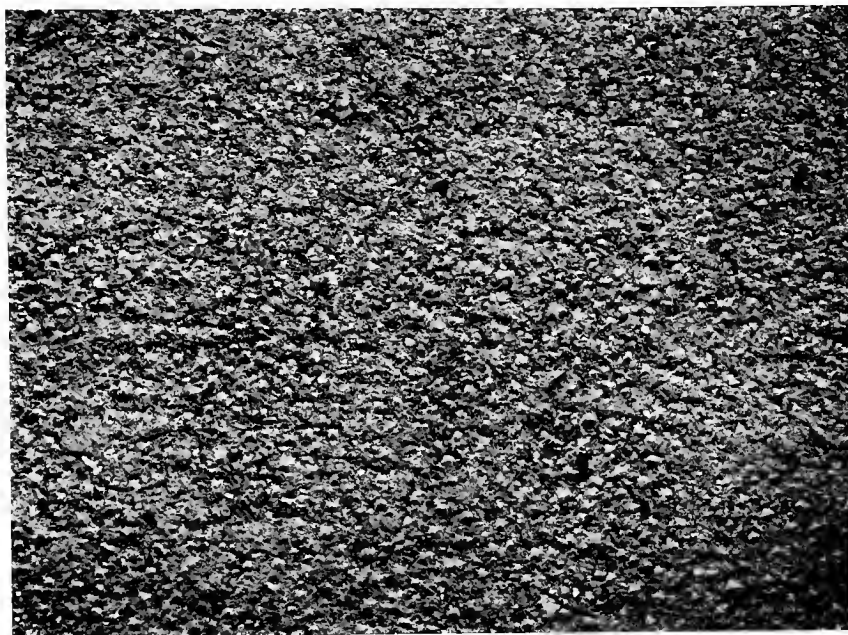

Fig. 84.

obtained. On account of the great range of possibility in this field
definite instruction cannot be given as to the selection, size, grading and
proportioning of the various aggregates. Such details depend on the
subject and the treatment proposed. After these factors have been de-
termined upon, the matter reduces itself to the ordinary problem of con-
crete construction. If two or more coarse aggregates are used they
should be thoroughly blended before being mixed with the sand and

Fig. 85.—Wall showing beauty of displayed selected aggregates.   Also a striking example of the harmony of concrete and tiles or mosaics in rather bold relief.

Residence of E. L. Ryerson, Lake Forest, Ill.

In this attractive residence the practicability of concrete is again shown in the construction of arches and balustrades as well as walls and floors.

cement to form a wet concrete. For such treatment a rich mixture, such as a 1:2:4 or a 1:2½:5 mix, is usually desirable. If it is advisable to economize in the matter of selected aggregates, this may be accomplished by the use of facing boards (see page 123) and by backing up the outside layer of selected aggregates with concrete made of ordinary materials.

Several methods are practised for removing the cement film and for displaying the color of the concrete. The forms may be taken down while the concrete is yet green and the face scrubbed or brushed. Likewise at the proper age the surface may be tooled. After the film of cement has been removed to brighten up the colors of the aggregate, the walls should be treated to one or more applications of a wash composed of 1 part commercial hydrochloric (muriatic) acid mixed with 5 to 10 parts of clear water, with an interval of several minutes between the applications. When the desired effects have been obtained, usually within half an hour, the walls are scrubbed down with a fiber brush and are afterward flushed with water to remove the acid thoroughly. Such treatment yields a surface rough in appearance and pleasing in color. (See Fig. 85.)

If a smooth surface is preferable to the rough appearance, a terrazzo effect may be obtained by dressing the surface with a carborundum stone, as described under "Abrased and Tooled Surfaces." By such means not only the outside cement film is removed, but the aggregates are also ground down smooth and given a polish. Light, portable, power grinding machines are now on the market which quickly and economically accomplish this work. The grinding and polishing bring out the beauty of each particle of aggregate and enhance the effect by leaving it in a setting of cement.

Colored Surfaces.—For decorative effect it is often desirable to produce a concrete of a shade which will harmonize with some general color scheme. This may be accomplished either by the use of mineral coloring matter or by selected aggregates of such a color that, when made into concrete, the desired results will be produced.

Artificial Colors.—The use of artificial colors in concrete is a matter which should be entered into only after careful and thorough experimen-

tation or upon advice of persons familiar with all factors in the case. Only mineral pigment should be used. For various reasons it is best to use a color facing-mortar only and to apply it by means of facing boards. Mix the colors dry with the cement, and in making concrete use this mixture in the usual way. Sometimes the coloring matter is added to the water. To produce even effects, it is essential to measure exactly and carefully mix every ingredient, including the water. Likewise it should be remembered that mortar when wet appears several shades darker than when it is dried out. By mixing 5 pounds of coloring matter with each bag of cement in an ordinary 1:2 sand mortar, the following colors will be approximately secured: brown—roasted iron oxide; buff to yellow —yellow ochre; blue—ultramarine; gray to dark slate—lampblack or carbon black; black—manganese oxide, eleven pounds per bag. By increasing or decreasing the proportion of coloring matter, various hues may be obtained.

Natural Colors.—Through the use of many natural materials, such as marbles, granites, sandstones, gravels, burnt clays, corals and sands, results far preferable to artificial colors can be obtained. These materials are crushed fine and are made into concrete in the customary manner. The surface coloring is brought out by exactly the same method used for displayed selected aggregates. For example, beautiful pinks may be obtained with red marble dust; a terrazzo effect may be obtained by incorporating with the red marble dust a few black and white marble chips; or a slightly different effect secured by using black and white marble screenings alone. Crushed granite or feldspar will give glitter to a surface, and so on an infinite number of effects may be produced.

Mosaic Decoration.—One of the most popular effects is obtained by ornamenting a concrete surface with colored tiles. In working out ornamentation two general methods of treatment are possible: the simple Roman plan of using tesserae, in which the design is formed from square or nearly square pieces, or the more modern way of cutting the clay into units of sundry shapes to conform to the potter's process and to delineate the design. This latter method is comparable to that used in stained-

Built by P. H. Bosworth

Fig. 86.—House at Evergreen Park, Mayfield, Cal., in which mosaic or inlay of tiles relieves an otherwise plain concrete wall.

glass windows. The cement joints correspond to the lead in the stained glass. Either plan is practicable.

Several methods of setting tiles are in use. In general, careful attention must be given to the correct lay-out of the design and to a means of fixing it securely until held permanently by the concrete. In walks and floors this is simply a matter of exact location. For walls and ceilings the entire figure is often molded complete or in sections in a concrete slab of the same texture as that of the wall proper and later set in place. With this and similiar schemes, a piece of heavy paper or felt is placed between the form and the face of the tiles to prevent them from being stained by liquid cement. Special adhesive substances can be bought or made by means of which the tiling can be glued in exact location on the forms and securely held there until backed up and fixed by the concrete. (See Fig. 86.) Later the application of water dissolves the glue and leaves the decorations permanently in place. Likewise space may be left for inserting the decorations later by lightly nailing to the inside of the form blocks of wood cut to the shape of the units composing the design. When the forms are removed, the concrete retains the wooden block, which should be left in position until the concrete surface has been given the desired finish. The block can then be removed and the ornament set in place with good cement mortar.

Chapter V

Calculations for Determining the Strength and Design of
Reinforced Concrete in House Construction

Built by Benjamin A. Howes, Engineer, New York

A service court, showing advantage of concrete where sanitary precautions are especially important.

Chapter V

Calculations for Determining the Strength and Design of Reinforced Concrete in House Construction

Principles of Reinforced Concrete.—Concrete, which usually consists of broken stone embedded in or cemented together with a mortar consisting of Portland cement mixed with gravel or sand, partakes of the nature of an artificial stone, and becomes monolithic upon the hardening of the cement. The broken stone is used as a filling material to save the cost of the more expensive cement, and is known as the "aggregate," while the cementing material is usually designated as the "matrix."

Concrete has great compressive resistance, but is deficient in tensile strength. The great discrepancy between the compressive resistance and tensile strength of concrete is as the ratio of 1 to 10—that is, plain concrete of the usual mixture used in construction work has for its compressive strength 10 times its strength under tension. When subjected to tensile stresses it is still further weakened and made unreliable by the possibility of cracks or flaws occurring on account of the shrinkage of the material. These defects, which sometimes are due to the pouring and setting of the concrete, would not decrease the compressive strength, from the fact that should such cracks or flaws occur they would, under a direct compressive stress, be brought together, and the two blocks would have, in spite of the defect, a perfect bearing one upon the other.

The Purpose of Steel Reinforcement in Concrete.—Any beam which is supported at its ends, and sustains weight either uniformly distributed or concentrated, is subjected to bending, and transverse stresses

are created. The transverse stresses in a beam consist of compressive stresses and tensile stresses. In the upper portion of the section of a simple beam, as shown in Fig. 87, the fibers are in compression, while in the lower portion the material is subjected to tension. An imaginary plane separating these two directly opposite kinds of stresses is always denominated the "neutral axis."

Since concrete has approximately ten times as much compressive resistance as tensile strength, it is quite evident that if a beam was made of plain concrete, the full value of the material in compression could never be developed, from the fact that it has such a low value in tension
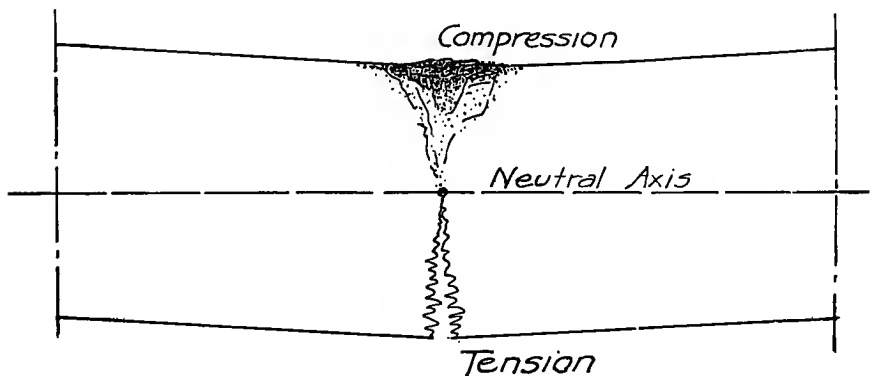

Fig. 87.—A concrete beam without reinforcement and stressed beyond elastic limit would fail as shown.

in that portion of the section below the neutral axis. In order to develop the full compressive resistance of concrete in the section of a beam above the neutral axis steel rods or bars are embedded in the concrete near the lower edge or soffit of the beam. Such a beam is said to be "reinforced," and is economically designed when sufficient steel is embedded in the concrete to develop the full compressive resistance of the concrete in the beam section above the neutral axis.

Steel reinforcement is also used in the construction of columns or posts of concrete to prevent these members from buckling or bending on account of their slender proportions, for all columns over 10 diameters are liable to transverse stresses corresponding with those created in the

beam. These stresses are developed by inequalities in the strength in the section or by eccentric loading. The steel reinforcing rods in a column also prevent the column from shearing along an oblique line, as the type of failure indicated in Fig. 88 is quite usual when reinforced concrete columns are tested to failure.

The Use of Shrinkage Rods and Bars.—Another reason for using steel embedded in concrete is for the purpose of tying the mass of concrete together so as to prevent any cracking from setting. Many materials are subjected to a reduction in size in setting or hardening, and such changes in the mass are apt, where other parts are held, to produce cracks. By binding together the mass of concrete, whether it be a column or floor slab, with steel rods at intervals, such shrinkage cracks are prevented.

The rods or bars placed in the concrete for this purpose are usually designated as "shrinkage rods." It is customary to introduce shrinkage rods in floor slabs and walls.

Fig. 88.—Line of failure in a concrete column when stressed beyond elastic limit.

Secondary Reinforcement.—There is also used in both columns and beams what is designated as "secondary reinforcement." In beams, vertical or oblique stirrups, as illustrated in Fig. 89, are usually introduced. These stirrups are primarily used to transmit the stresses from the main reinforcing rods or bars to the concrete in the upper section of the beam. They also prevent the beam from cracking along oblique lines, as illustrated in the figure. Such cracks are called "diagonal tension cracks."

It will be noticed from the illustration that these stirrups cross such lines of defects, and prevent them by giving additional tensile strength at right angles to the plane of these faults. In columns, the vertical rods, as illustrated in Fig. 90, are tied at intervals with light
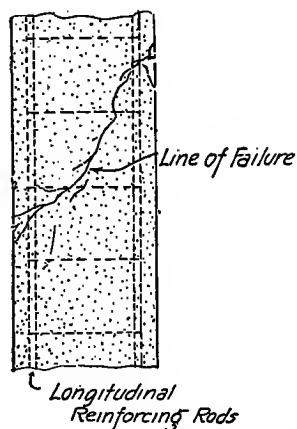
iron, looped wires, or other means, in much the same manner as the floor systems tie in the columns of a building. The purpose of the secondary
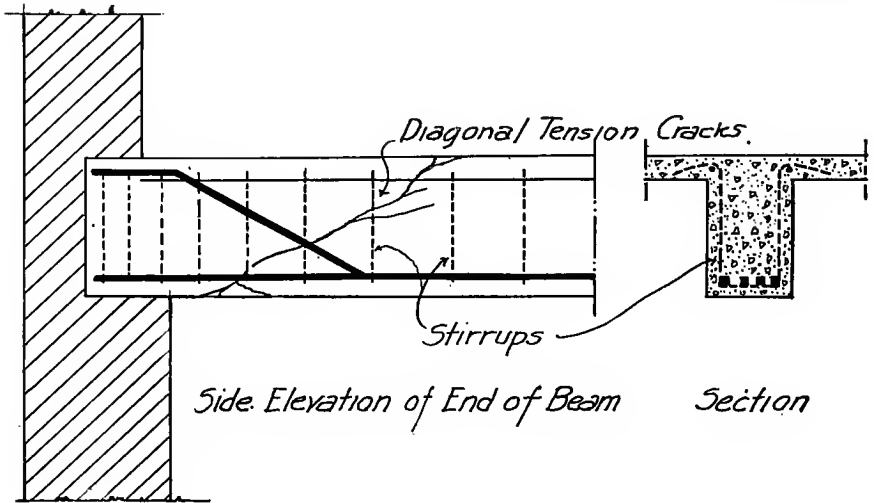

Fig. 89.—Arrangement of reinforcement in beams.

reinforcement in columns is to prevent the long longitudinal rods or bars from buckling under stress, and splitting or spalling the concrete of the column, as well as to tie together the mass of concrete in the column.
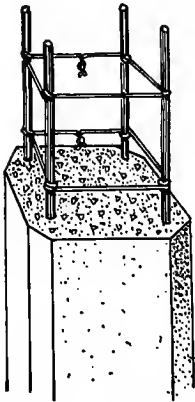

Fig. 90.—Position of reinforcement in columns.

Arrangement of Primary and Secondary Reinforcement.—There is illustrated in Fig. 91 a typical system of slab, beam, girder, and column construction of reinforced concrete. The rods or bars marked "a" in the figure are the main reinforcing rods, and it will be noticed that several of these rods or bars are bent up at the ends, and extend to the top of the beam near the points of support. This is done in order that there shall be additional resistance to longitudinal shear, and also to prevent the diagonal tension cracks near the abutments. Another reason for

bending some of the rods up in this manner is to provide tensile resistance at the top of the beam near the point of support, so as to resist what is called the "negative moment."

The negative moment, or contraflexture, is simply the changing of the stresses to opposite kinds where the ends of a beam are fixed, or held rigidly. When these bent-up rods lap over the points of support they tie the construction together, and give the beam the advantage of continuity. This reduces the bending moment considerably, although it is seldom taken into account in the design of concrete beams and girders.
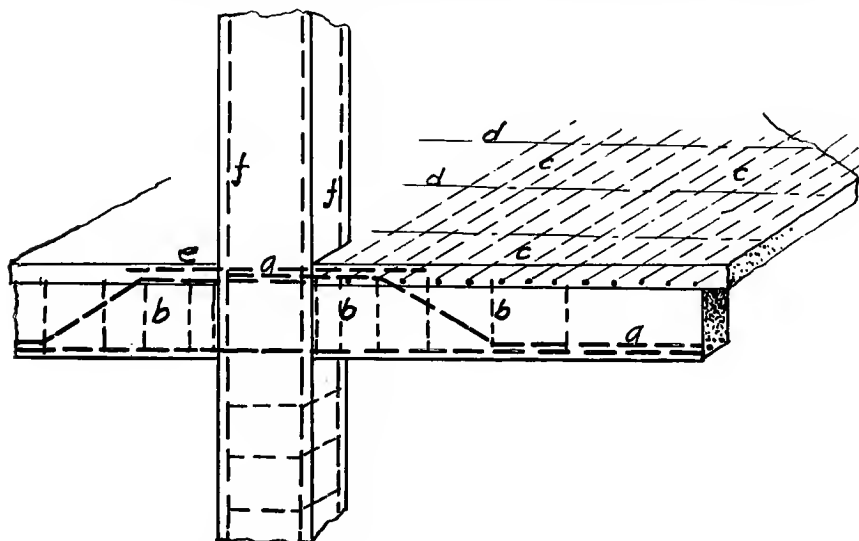

Fig. 91.—Arrangement of primary and secondary reinforcement.

At *b b* in the figure is shown the "secondary reinforcement." This secondary reinforcement consists of stirrups—usually of light bar iron, $\frac{1}{8}''$ x $1''$, or $\frac{1}{4}''$ or $\frac{3}{8}''$ round, bent in the form of U-shaped stirrups, which interlace with the main reinforcing bars and project into the upper part of the beam. When there is a slab, monolithic with the beam, these stirrups are carried to the upper part of the slab. The number of stirrups required and the proper spacing is given on page 187.

The rods or bars indicated at *c c* are known as the "slab rods,"

and extend at right angles to the beams, thus reinforcing the concrete slab. These bars are usually from $\frac{1}{4}''$ to $\frac{1}{2}''$ square or round, being spaced from 3″ to 8″ on centers, depending upon the amount of resistance necessary for the particular spans and loads.

It is usual in all slab reinforcement to provide shrinkage rods or bars, which are shown in the illustration at *d d*. These rods are generally very light bars, about $\frac{1}{4}''$ square or round, and it is the usual practice to place them about 24″ center to center.

Besides the slab reinforcement and shrinkage bars, it is considered good practice to provide what is known as "shear bars" over all main girders—"girders" being understood as the concrete supporting members which sustain the ends of the beams. These shear rods are intended to increase the resistance of the slab over the top of the girder, and are quite frequently made of the same-sized bars as the slab reinforcement. They are generally 5′ in length, and spaced 12″ center to center.

"Lap-rods" or "tie-bars" are placed over the junction of all beams and girders where the main reinforcing rods do not lap. Such tie-rods are made, as a rule, $\frac{3}{4}''$ square or round, and generally about 5′ in length. Sometimes two such rods are placed over the junction of girders, and one rod over the junction of beams. These rods are indicated in the illustration at *e*.

The longitudinal rods in columns are not, as a rule, decided upon with regard to their number and area by any fixed formula. The general practice is to put in enough steel to equal in area 1 to $1\frac{1}{2}\%$ of the sectional area of the concrete. Longitudinal column rods are shown in the figure at *f*, and it is never good practice to make these rods less than $\frac{1}{2}''$ in diameter. It is customary to extend these rods above the floor construction, so that the rods of superimposed columns may lap with them, the lap usually being made about 2′ 6″ in length.

The longitudinal rods of columns are always tied together at intervals with either $\frac{1}{4}''$ round ties, or else held in position with wire ties, or ties of bar iron punched so as to allow the rods to pass through. The practice is to make these ties a distance apart equal to the diameter of the column, never, however, exceeding an 18″ pitch or spacing.

Residence of Mrs. Gaston Davis, Ocean City, N. J.   *Grant M. Simon, Architect, Phila.*

A massive concrete fireplace and chimney built as an integral part of the house.   Surface untreated.

Strength of Concrete.—The concrete used in building construction is usually composed of a 1–2–4 mixture—that is, one part Portland cement, two parts sand or fine gravel, and four parts broken stone. Sometimes broken slag or clean boiler cinders are substituted for the broken stone, in which case the concrete is known as "slag" or "cinder" concrete, respectively. It is poor practice, however, to use either of these two for reinforced concrete for building construction, although cinder concrete is sometimes used for floor slabs supported on steel beams.

The contractor is not particularly interested in the ultimate strength of concrete, but he is interested in the allowable unit working stresses. These allowable unit stresses are different in the several cities, and are fixed by the building laws. Outside of the jurisdiction of the cities the judgment of the designer is the governing factor in deciding upon these values.

In all instances where allowable unit stresses are given, it is understood to mean the stress in pounds per square inch, which is allowed as a basis in figuring the safe working strength of the material. The following table gives the allowable compressive, shear, tensile and bond stresses for concrete and steel used by the best conservative practice in the design of reinforced concrete structures:

TABLE 4.—ALLOWABLE WORKING STRESSES FOR CONCRETE WHEN REINFORCED

(STRESSES ARE IN POUNDS PER SQUARE INCH)

Mixture 1–2–4	Compression under Transverse Stress	Compression under Direct Stress	Shearing Stress	Bond or Adhesive Stress
Stone Concrete	600	500	75	50
Slag Concrete	400	300	50	40
Cinder Concrete	250	150	25	15

The most important values in the table are the direct compressive values of reinforced concrete, used in figuring the strength of columns,

[147]

and also the unit compressive strength of concrete allowable in figuring the strength of beams and girders. The values of shear are of some use in figuring the shearing resistance of beams at their points of support. It is necessary sometimes to determine the adhesive strength of a steel bar or rod embedded in the concrete, and here the bonding stress or the grip of the concrete upon the steel is important.

These values will be used in some of the examples in design given in the following pages.

Strength of Beams and Girders.—There are shown in Fig. 92 at (a) and (b), diagrammatical figures which show the distribution of the stresses in reinforced concrete beams, based on usual assumptions employed by engineers in determining their strength. These assumptions are as follows:

(a)   (b)

Fig. 92.—Diagram showing distribution of stresses in reinforced concrete beam.

First: That the steel takes all of the tensile stress, while the concrete takes all of the compressive stress.
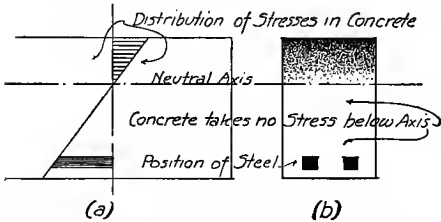
Second: That the relative amounts of the stresses upon the steel and concrete are in direct proportion to their ratio of moduli of elasticity.

Third: That the total compressive resistance of the concrete above the neutral axis must equal the total tensile resistance of the steel.

Fourth: That the stresses on the concrete vary directly from zero at the neutral axis, to maximum at the extreme fiber; thus the variation of stress in the section above the neutral axis is indicated by a triangle.

From the above it will be seen that reinforced concrete beams, being a composite material, differ from beam sections of a single material, for in the latter the neutral axis passes through the center of gravity of the section, whereas in reinforced concrete beams the neutral axis is constantly shifted by changes of the relative percentage of the steel and concrete in the section, and raises or lowers in order to adjust the direct

stresses above and below the neutral axis to comply with their differences in their relative stresses and strains. The one important thing, therefore, to determine before the strength of a beam section can be ascertained, is the position of the neutral axis.

Formula for Determining the Position of the Neutral Axis.—The location of the neutral axis in any reinforced concrete beam varies with the relative percentage of steel, with the quantity of the concrete, and with the quality of the concrete.

The formula for determining the position of the neutral axis is applicable to both rectangular beams and beams of T-section. This is true for all practical purposes because in beams of T-section the neutral axis lies so close to the bottom of the slab that the T-section may be considered as a rectangular beam of a width equal to the available extent of the slab in compression. This will be explained in conjunction with T-sections.

The formula for determining the distance k, or the percentage of the depth which the neutral axis is below the top of the beam, is as follows:

$$k = \sqrt{(pn)^2 + 2\,pn} - pn$$

The values in this formula are best understood by referring to Fig. 93 and the following notation:

k = Ratio of the depth of the neutral axis from the top of the beam to the effective depth d.

p = Ratio of the area of the steel to the area of the concrete in the portion of the beam above the center of action of the steel. This is true because the 2 or 3 inches of concrete below the steel is considered merely as fireproofing.

n = Ratio of the moduli of elasticity of the steel to the moduli of elasticity of the concrete. In the best practice this value for stone concrete is 12, and the values for slag and cinder concrete are, respectively, 15 and 30, though sometimes different values for these are used.

The formula given above is the basic formula for all reinforced concrete design, and as illustrating its application the following example is interesting:

Example: At what percentage of the distance from the top to the center of action of the steel reinforcement is the neutral axis located, providing the beam is of rectangular section and is reinforced with $\frac{6}{10}$ of one per cent, or .006 of steel? The ratio of the moduli of elasticity of the two materials is 1 to 12.

Solution: Referring to the formula $k = \sqrt{(pn)^2 + 2\,pn} - pn$ the values of p and n are respectively .006 and 12; then, by substitution the value of

$$k = \sqrt{(.006 \times 12)^2 + 2 \times .006 \times 12} - .006 \times 12$$

or, $k = \sqrt{.005184 + .144} - .072 = .314.$ Answer.

It is customary not to work out these formulas every time the distance k is desired for any particular percentage of steel reinforcement, but to refer to a table giving these values. Such a table is given on page 151.
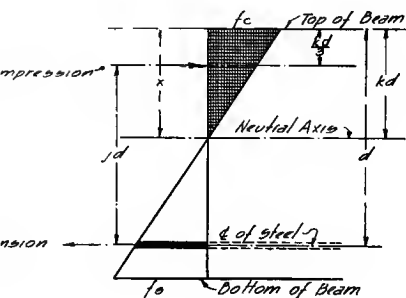

Fig. 93.

Determination of the Distance Jd.— The necessity for obtaining the distance from the top of a reinforced concrete beam to the neutral axis is to locate the center of gravity of the compressive stresses in the concrete above the neutral axis.

Referring to Fig. 93, it will be seen that the stress in the concrete varies from zero at the neutral axis to maximum at the extreme upper edge of the beam. As this variation is uniform under working stresses, the variation in the compressive stresses can be represented as a triangle. The center of action of the compressive stresses is, therefore, at the center of gravity of this triangle, and is consequently located at one-third of the altitude of the triangle from the base, or is equal to $\frac{kd}{3}$, when kd is the distance of the neutral axis from the top of the beam, and the lever arm with which the concrete and steel reacts can be designated as jd, and can be determined directly, when the neutral axis has been located. The value j varies, of course, with the variation in the value of

k. The value of k is determined by the ratio of the steel reinforcement and the ratios of the moduli of elasticity. Consequently, a table which gives the value of j, referring to Fig. 93, in ratio of the distance d, is valuable, as it gives the lever arm which determines the resisting moment of the steel reinforcing rods or bars used in the beam.

The values of j for different ratios of steel reinforcement and for different values of n, or the ratios of the moduli of elasticity of the steel and concrete, are given in the following table:

TABLE 5

Values of p	$N=10$ Values of k and j		$N=12$ Values of k and j		$N=15$ Values of k and j	
.001	k =.132	j =.956	k =.143	j =.952	k =.158	j =.947
.002	k =.181	j =.940	k =.196	j =.935	k =.215	j =.928
.003	k =.217	j =.927	k =.236	j =.922	k =.258	j =.914
.004	k =.246	j =.918	k =.266	j =.911	k =.291	j =.903
.005	k =.270	j =.910	k =.291	j =.903	k =.319	j =.894
.006	k =.292	j =.903	k =.314	j =.896	k =.343	j =.885
.007	k =.311	j =.896	k =.334	j =.889	k =.366	j =.878
.008	k =.328	j =.891	k =.352	j =.883	k =.384	j =.872
.009	k =.344	j =.885	k =.370	j =.877	k =.401	j =.866
.010	k =.358	j =.881	k =.384	j =.872	k =.417	j =.861
.012	k =.384	j =.872	k =.411	j =.863	k =.444	j =.852
.014	k =.407	j =.864	k =.435	j =.855	k =.470	j =.843
.016	k =.428	j =.857	k =.456	j =.848	k =.492	j =.836
.018	k =.446	j =.851	k =.476	j =.841	k =.513	j =.829
.020	k =.463	j =.844	k =.493	j =.836	k =.530	j =.823
.030	k =.531	j =.823	k =.561	j =.813	k =.600	j =.800
.040	k =.580	j =.807	k =.610	j =.796	k =.650	j =.784
.050	k =.618	j =.794	k =.650	j =.783	k =.686	j =.771

Resisting Moment of Rectangular Beams (Considering the Steel).— In order to determine the resisting moment of a reinforced concrete beam it is only necessary to find what percentage the area of the steel bears to the area of the concrete in the beam section, and select from the above, Table 5, the value of j. The product of the value j, the distance from the center of action of the steel to the top of the beam (d), and the total safe working stress of the steel (a s), will give the resisting moment of the beam. This can best be expressed by the formula

$$M_1 = j \, d \, a \, s$$

[151]

In this formula

M_1 = the resisting moment of the beam in inch-pounds;
d = the distance from the center of action of steel reinforcement to the top of the beam;
a = the total area of the steel reinforcing rods, and
s = the safe unit tensile stress of the steel, which is generally taken at 16,000 pounds.

In determining the ratio of the steel, in order to obtain the corresponding value j in the table, the area of the concrete is always
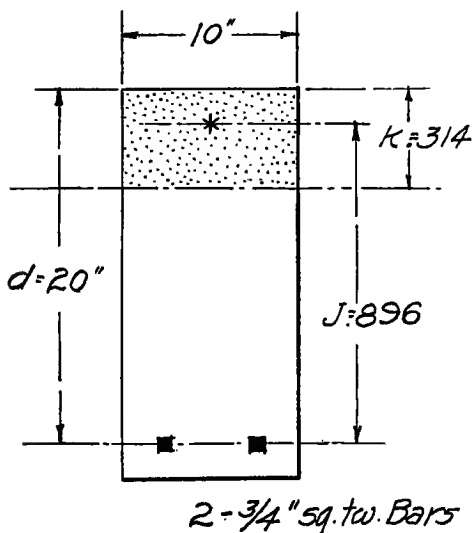

Fig. 94.

considered as the width of the beam multiplied by the distance from the top of the beam to the center of action of the steel, as the concrete below the reinforcing rods or bars is not a part of the theoretical beam, and acts only as fireproofing for the steel reinforcing rods.

Example: Determine the resisting moment of the rectangular reinforced concrete beam illustrated in Fig. 94.

Solution: The total area of the concrete from the center of action of the steel to the top edge is 10″ x 20″=200 square inches. As the reinforcing rods or bars are ¾″ square, the sectional area of one rod is .5625, and 2 rods or bars will have a sectional area of 1.125; hence the ratio of steel reinforcement in the section of the beam is

$$1.125 \div 200 = .0056$$

Assume that N = 12.
From Table 5 it will be seen that the ratio of the lever

Porch return constructed of solid concrete, which means elimination of
cost for up-keep.   Note untreated surface of house walls.

Porch at residence of Mrs. Gaston Daus, Ocean City, N. J.

Grant M. Simon, Architect, Phila.

arm, or j, for the ratio of steel reinforcement, or .006, is .896, so that in inches the lever arm with which the steel acts about the center of compression is

$$20 \times .896 = 17.9 \text{ inches} = jd.$$

The resisting moment of the reinforced concrete beam can be found by substitution in the formula $M_1 = j\, d\, a\, s$, so that

$$M_1 = 17.9 \times 1.125 \times 16,000 = 322,200 \text{ inch-pounds.}$$

Resisting Moment of a Rectangular Beam Section, Considering the Concrete.—In reinforced concrete beams of rectangular section the strength of the two materials must be considered—that is, the resisting moment of the steel reinforcement must be found, and if there is any doubt about the concrete in compression when stressed to its maximum working stress at the extreme fiber, then its resistance must be determined as well, and the least resisting moment considered as the one limiting the strength of the beam section.

In all reinforced concrete beams when the percentage of steel is such that the concrete and steel are of equal resistance, and both are fully stressed to their allowable unit working stresses when the beam section is developing its maximum allowable resistance, the beam is said to be reinforced with a *critical* percentage of steel. This critical percentage of steel is always the same for fixed unit stresses and moduli of elasticity, so that if the steel reinforcement is below the critical percentage, the strength of the concrete need not be questioned, and the resistance of the steel alone is considered.

The resisting moment of the concrete above the neutral axis may be found as simply in a rectangular beam as the resisting moment of the steel reinforcement, when once the neutral axis has been determined for the percentage of steel used as reinforcement.

In a rectangular reinforced concrete beam the intensity of stress at the neutral axis is zero, while at the extreme fiber it may be as high as the maximum allowable compressive stress for concrete in compression when subjected to transverse stress. The average is therefore one-half of the

maximum stress, so that if the maximum unit compressive strength of the concrete is taken at 600 pounds, the average stress will be 600 ÷ 2 = 300 pounds per square inch. In order therefore to determine the resistance of the concrete above the neutral axis all that is necessary to do is to multiply the area of the cross-section of the beam above the neutral axis by the average unit compressive resistance of the concrete, the product, in turn, being multiplied by the distance from the center of action of the steel reinforcement to the center of action of the compressive area of the concrete.

As previously stated, the location of the center of the compressive area is one-third of the distance from the top of the beam to the neutral axis, or $\frac{kd}{3}$, and the lever arm with which the concrete acts about the steel reinforcement is j d, so that the resisting moment of the beam section, with regard to the compressive resistance of the concrete, may be found by the following formula:

$$Mc = \frac{k\ j\ d^2\ b\ c}{2}$$

in which

Mc = the resisting moment with regard to the compressive resistance of the concrete.

k = ratio of the distance from the top of the beam to the neutral axis to the distance d.

j = ratio of the distance between the center of compression in the concrete and the center of action of the steel, to the distance d.

d = the distance from the center of action of the steel to the top of the beam.

b = the width of the beam.

c = the maximum unit allowable compressive resistance of the concrete.

Example: Determine the resisting moment of the reinforced concrete beam shown in Fig. 94, considering the concrete.

Solution: As found in the previous example, the ratio j = .896; and from Fig. 94 = d = 20″; b also is determined from the figure as being 10″; while k = .314, as also determined from Table 5. In this instance the allowable

compressive resistance of the concrete will be taken as 600 lbs. Therefore, by substitution in the formula

$$M_c = \frac{.314 \times .896 \times 20 \times 20 \times 10 \times 600}{2} = 337,612 \text{ inch-pounds.}$$

Beams of T-section.—Where reinforced concrete beams or girders support and are monolithic with a concrete floor slab, in analyzing the strength of the beam or girder it is considered as a T-section. The form of the beam section thus considered is shown in Fig. 95, and it will be seen that by the adoption of this section the available amount of the concrete in compression is greatly increased over that which would exist in a simple rectangular beam.

In the analysis of a beam of T-section to determine its strength or
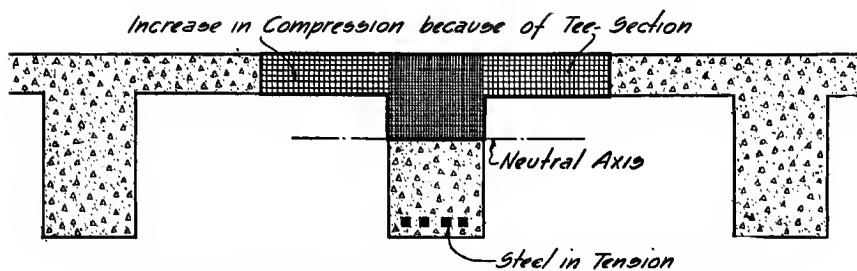

Fig. 95.—Increased area over which compressive stress acts when beam and slab are molded as a monolith.

resisting moment, it is a question as to what width of slab can be considered as acting homogeneously with the beam. A conservative rule is that the width of the T-section shall not be over 20 times the thickness of the slab. For instance, if the slab is 4″ in thickness, the width of the slab incorporated in the T-section would be 80 inches, provided, of course, that this distance does not extend the slab past the middle of the distance between the two beams. Where the beams are closer together than 20 times the thickness of the slab, the flange of the T-section is considered to extend a distance on each side of the beam equal to one-half the distance to the next beam.

In the recently prepared Building Laws of the city of New York

the width of the slab to be incorporated with the beam in forming the T-section is limited to one-sixth the span of the beam, but is not to be greater than six times the thickness of the slab on either side of the beam.

The important factor to determine in the analysis of a beam of T-section is, as with rectangular beams, the location of the neutral axis; but the extreme strength of a reinforced concrete beam of T-section can be very simply found by making an assumption, which is seldom much in error, and is consequently sufficiently safe for practical purposes, especially when it is realized that because of the assumptions made in calculating the bending moments, reinforced concrete construction has an actual factor of safety far above that used.
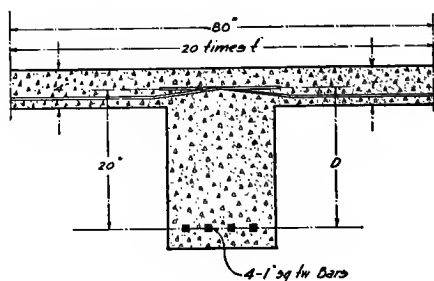

Fig. 96.

Approximate Determination of the Strength of the T-Section.—To determine approximately the resisting moment of a reinforced concrete beam of T-section, reference is made to Fig. 96. As previously stated, the reinforced concrete beam, being composed of two materials of different strength, it is necessary to find the resistance of each under the stresses due to the load, and to limit the load on the beam so that the allowable strength of the weaker material will not be exceeded. Nearly always in reinforced concrete beams of T-section—and it would be especially so in house construction—there is ample concrete in compression, and the steel is the limiting factor. Another assumption that is to be made in determining the approximate strength of T-sections is the location of the center of action of compression in the slab, and one which is, on an average, nearly always safe to make, is to assume the center of action to be at the center of the slab. When this assumption is made, the resisting moment of the steel may be expressed by the following formula:

$$M_s = a \ s \ D$$

[158]

In this formula

M_s = the resisting moment of the beam section in inch-pounds, considering the steel.

a   = the total area of the steel reinforcement.

s   = the safe unit fiber stress to which the steel is to be subjected.

D   = the distance from the center of action of the steel reinforcement to the center of the slab.

Example: Assume that the beam section shown in Fig. 96 is reinforced with four $1''$ square twisted bars, and that a safe unit stress on the steel of 16,000 pounds is to be considered as the working stress.   What will be the resisting moment, and what load, including weight of beam and slab, will the beam carry providing it has a span of 20 feet?

Solution: By substitution in the above formula

$M_s = 4 \times 16,000 \times 20 = 1,280,000$ inch-pounds.

If this is the resisting moment in inch-pounds, and the bending moment of any simple beam uniformly loaded is equal to $M = 1\frac{1}{2}\ W\ L$, where W is the total load per square foot and L is the span in feet, the total load that the beam will support can readily be found by the formula

$$W = \frac{M_s}{1\frac{1}{2}L} \text{ or } W = \frac{1,280,000}{1\frac{1}{2} \times 20} = 42,666 \text{ pounds.} \quad \text{Answer.}$$

To Determine Whether there is Sufficient Concrete in Compression, Approximately.—In conservative practice in the design of reinforced concrete work it is usual to stress the extreme fiber, or upper edge of the section in compression under transverse stress, to a working stress of 600 pounds.   It is also understood that the stress in the concrete at the neutral axis is zero.   In determining the approximate resistance of a T-section considering the steel reinforcement, as explained on page 158, the position of the center of action of the concrete in compression was assumed as at the center of the slab.   This assumption makes the neutral axis pass through the web of the beam at a distance below the slab equal to one-half the thickness of the slab.   The variation of the compressive stresses in the concrete is uniform from the neutral

axis to the extreme upper edge of the slab, so that the safe allowable unit stress at the bottom of the slab would be one-third of the maximum allowable, or 200 pounds, and the average allowable stress in the slab section would be equal to

$$\frac{600+200}{2}, \text{ or 400 pounds.}$$

One of the first principles of engineering is that, for every force acting in one direction in a body in equilibrium there must be a corresponding and equal force acting in the opposite direction; therefore the total resistance of the concrete must at least be equal to the total resistance of the steel. To determine, then, approximately, whether the beam has sufficient concrete in compression in a slab, all that is necessary to do is to compare the strength of the steel reinforcement with the direct resistance of the portion of the concrete considered as being in compression, or more directly, the average stress in the concrete must not exceed 400, so that the results obtained by the following formula must be within this limit: $c = \dfrac{a\ s}{b\ t}$;

in which b = the width of the slab in compression;

       t = the thickness.

    Example: Determine whether the concrete in the slab section shown in Fig. 96 is sufficient to give the full resistance of the steel at 16,000 pounds.

    Solution: The total area of the steel is 4 square inches, and the fiber stress, or safe unit tensile resistance, is 16,000 pounds. As the slab is 4 inches in thickness, the available width of slab is 4 × 20, or 80 inches. These values having been obtained, substitution can be made in the above formula as follows:

$$C = \frac{4 \times 16,000}{80 \times 4} = 200 \text{ pounds;}$$

showing that the concrete is only stressed up to one-half of its allowable compressive resistance and is perfectly safe.
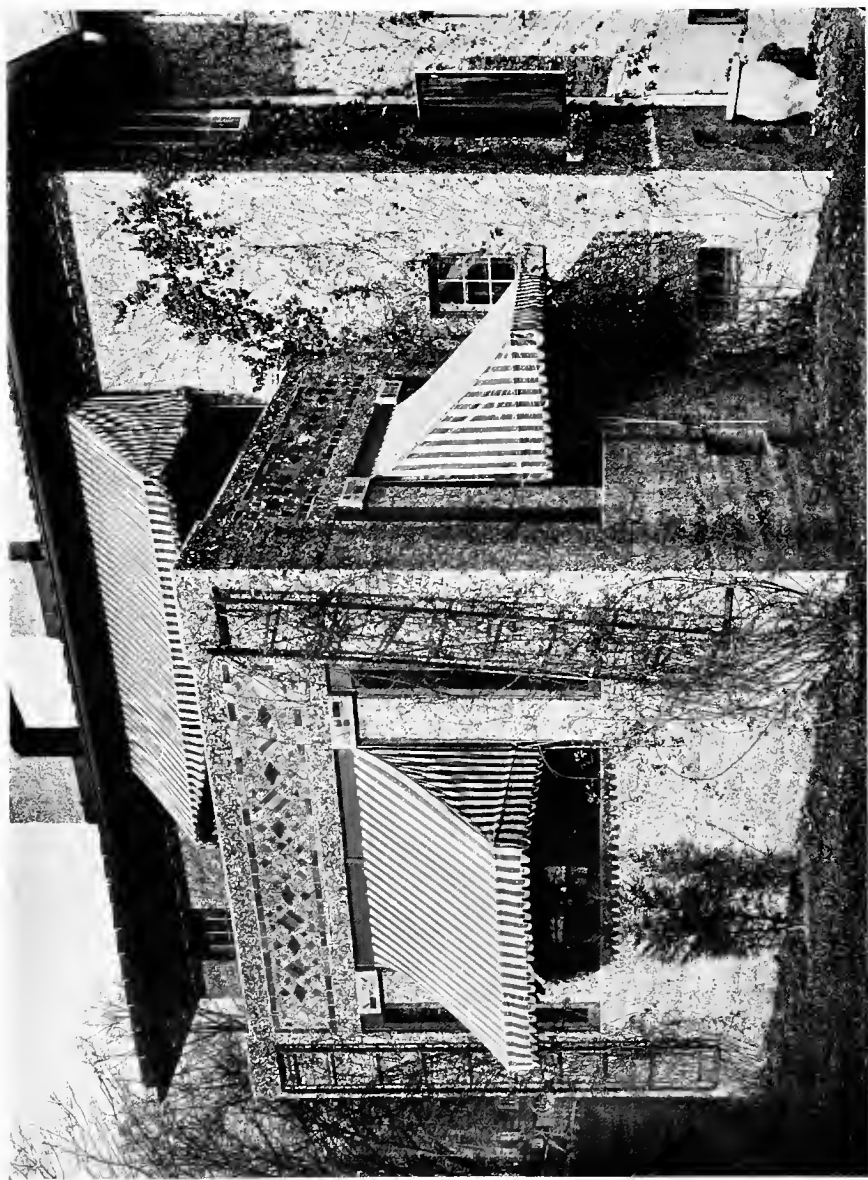
Detail in residence of Albert Moyer, South Orange, N. J.

Tracy & Swartout, Architects, New York

Second example of exposed selected aggregates relieved by border of Moravian mosaic or tile.

Example of the adaptability and economy of concrete in stairway construction.

More Accurate Method of Determining the Resisting Moment of T-sections (Considering the Steel).—In order to accurately determine the resisting moment of reinforced concrete beams of T-section, the location of the neutral axis x x, Fig. 96, must be determined.

It is a generally accepted practice in locating the neutral axis for beams of T-section, to consider that the beam is a rectangular beam, as included within the lines a, b, c, d. There is very little chance of error in this assumption, for the reason that the neutral axis quite frequently falls within the slab, and even though it should fall below the bottom of the slab, the small section of the concrete represented by the shaded areas can be practically included. The chance of error is particularly reduced because the portion of the concrete below the neutral axis is never taken into account in determining the strength factors of the section.

In finding the location of the neutral axis x x, or the distance kd, the same formula as that applied for the determination of the same distance in rectangular beams is used, namely:

$$k = \sqrt{(p\ n)^2 + 2\ p\ n} - p\ n.$$

Before applying this formula it will be necessary to determine upon the values p and n. If the T-section illustrated in Fig. 97 is taken as an example, the value p is equal to $\frac{8}{80 \times 22} = .00454$; the value of n is ordinarily taken, for stone concrete, at 12, so that by substitution in the formula

$$k = \sqrt{(.00454 \times 12)^2 + 2 \times .00454 \times 12} - .00454 \times 12 = .2801$$

As the distance d, Fig. 96, is 22 inches, the actual distance from the top of the slab to the neutral axis, or the line x x, is

$$.2801 \times 22 = 5.16 \text{ inches,}$$

showing that the neutral axis is a little over $1\frac{3}{16}$ inches below the bottom of the slab. The center of action of the concrete is always taken at one-third of the distance kd from the top, so this brings the center of the compressive area one-third of 5.16, or 1.72 inches from the top, and makes the distance D = 20.28 inches.

[163]

In order to determine the resisting moment of the beam with reference to the steel reinforcement, the formula

$$Ms = a \ s \ D$$

is used, and by substitution

$$Ms = 20.28 \times 8 \times 16,000 = 2,594,840 \text{ inch-pounds.}$$

More Accurate Method of Determining the Resistance of Concrete to Compression in a T-section.—After the neutral axis has been located in a T-section, as illustrated in Fig. 97, it is known that the minimum stress in the section is zero at the neutral axis, and maxi-
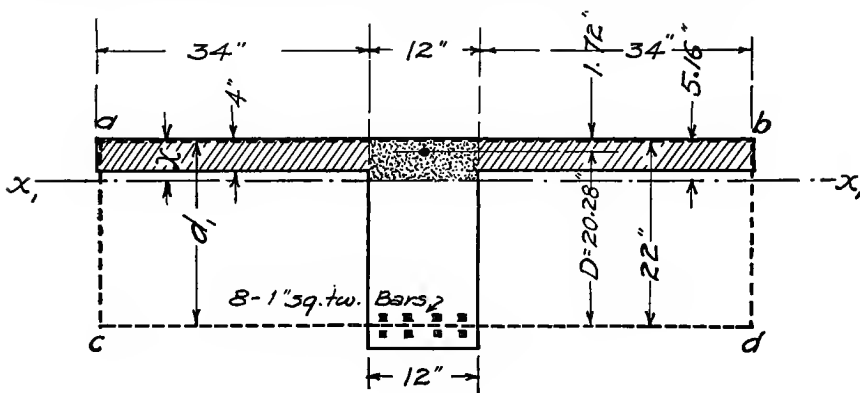

Fig. 97.

mum at the extreme top surface of the slab. The entire resistance of the portion of the concrete of the beam section in compression may then be found by taking the area, which is stippled in the figure, at the average stress of 300 pounds, and by taking the two side sections of the T, which are shown in the figure by the cross-section lining, at the average stress which exists in these sections. This average stress is greater than 300 pounds if the neutral axis falls below the bottom of the slab, and is equal to 300 pounds if the neutral axis coincides with the line of the bottom of the slab. Therefore, where the neutral axis falls below the bottom of the slab it is necessary to determine the average stress in the two side

sections of the T. The allowable maximum compression at the top of the slab is 600 pounds per square inch, and the total allowable compression at any section of the slab is in direct proportion as its distance varies from the top of the slab toward the neutral axis; so that the maximum allowable stress on any line between the neutral axis and the top of the slab may be determined by the proportion expressed in the following equation:

$$c_1 = \frac{k_1}{k} c$$

in which $c_1 =$ the unit stress at any line above the neutral axis.

   $k_1 =$ the ratio of the distance between the neutral axis and the line at which it is desired to obtain the stress, to the total depth of the beam.

   $k \ =$ the ratio of depth of neutral axis to effective depth of the beam.

   $c \ =$ the allowable unit stress at the extreme top edge of the beam.

From this the average stress, or c_a, for the two side sections of the T can be obtained by the formula

$$c_a = \frac{c \frac{k_1}{k} + c}{2}.$$

To illustrate the method by which it is determined whether there is sufficient concrete in compression, the following example is given:

Example: Determine whether there is sufficient concrete in compression, at the allowable unit stress of 600 pounds, in the beam section illustrated in Fig. 97, to equal the resistance of the steel when stressed to 16,000 pounds.

Solution: The conditions of the problem are illustrated in Fig. 97; the total compressive resistance of the portion of the rectangular section shown dotted above the neutral axis is equal to

$$5.16 \times 12 \times 300 = 18,576 \text{ pounds};$$

The average stress in the two side sections of the T, applying the above formula

$$c_a = \frac{c \frac{k_1}{k} + c}{2},$$

which by substitution becomes

$$c_a = \frac{600 \frac{1.16}{5.16} + 600}{2} = 367 \text{ pounds.}$$

The area of the two sections is 68×4, or 272 square inches, and their total resistance to compression is $272 \times 367 = 109{,}824$ pounds; then, by adding together the resistance of the portion of the rectangular section shown dotted, and the resistance of the two side sections shown cross-section, the total resistance of the concrete in compression when stressed up to the maximum of 600 pounds at the extreme top edge, is equal to $109{,}824 + 18{,}576$, or 128,400 pounds.

Comparing this resistance to direct stress in compression, with the allowable resistance of the steel, it will be seen that the 8 square inches of steel at 16,000 pounds has a resistance of 128,000 pounds, so that the concrete in compression is more than sufficient, and no further attention need be given to these portions of the problem.

It is usual in the design of reinforced concrete to have available tables which give the resisting moment of beams and girders of different depths, reinforced with different areas of steel, and monolithic with slabs of different thicknesses. From such tables it is very convenient to select a beam section which will give the required resistance. This can be done by inspection, and no calculation is required except to determine the bending moment on the beam. It is usual in such tables to show by a line running through the table the demarcation between the portion of the table wherein the resisting moments are limited by the steel from those values in the table which are limited by the concrete in compression. Still more convenient and desirable in the design of concrete houses are tables giving the resisting moments of slabs of different thicknesses, reinforced with bars and rods of different sizes and spacings.

Such tables and the accompanying explanations regarding their use are given on page 192.

Resistance of Concrete Posts or Columns.—From extensive experiments upon full-sized sections of reinforced concrete posts or columns it has been found that the use of longitudinal reinforcing rods properly tied in with wire ties add materially to the strength of the concrete, so that, while plain concrete in posts up to 15 diameters in length could not be considered as capable of supporting safely more than 350 pounds to the square inch, conservative practice concedes that reinforced concrete columns can safely sustain 500 pounds to the square inch of section.

In the several first-class cities the values allowed upon reinforced concrete columns vary considerably, but conservative practice allows the use of 500 pounds to the square inch when columns are reinforced with steel the area of which is from 1 to $1\frac{1}{2}\%$ of the area of the concrete for the longitudinal rods or bars for columns whose length does not exceed 15 diameters. It is seldom that concrete columns are used in building construction where the proportion of length is greater than this. If it should be, the safe strength per square inch should be reduced in proportion as the length exceeds the diameter of 15 to 1.

Plan

4 - 3/4" Sq. Longitudinal Bars & 3/16" or 1/4" round iron Loop ties
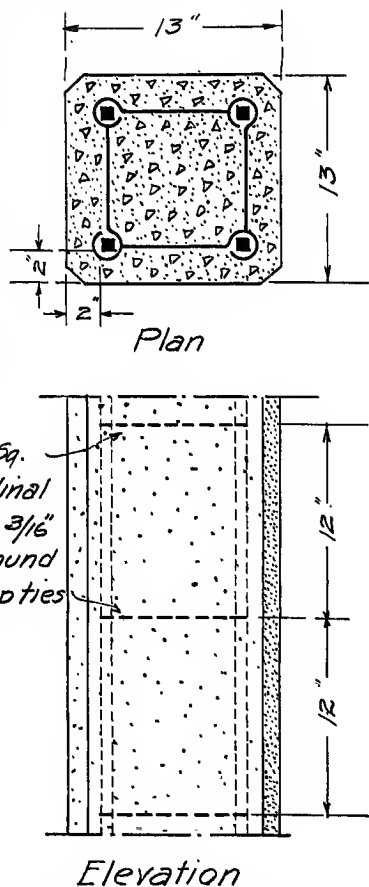
Elevation

Fig. 98.—Method of tying together vertical column reinforcing.

Example: Assume that it is desired to support a load of 80,000 pounds on a reinforced concrete column.

Solution: The safe unit stress is 500 pounds; therefore the area of column required equals

80,000 ÷ 500, or 160 square inches;

A column 13″ square would have a sectional area of 156 square inches, which is sufficiently close to the required result to be used.

To reinforce this column with 1% of steel would require a total sectional area of steel rods for longitudinal reinforcement equal to 1.56 square inches, which divided among 4 rods would give for the area of each rod or bar .39 square inch. The sectional area of a ¾-inch round rod is .45; therefore four rods of this size could be used and should be placed and tied together as indicated in Fig. 98.

In order that the strength of reinforced columns of any size may be conveniently found, the following table is given. This table gives the strength of the several sized columns for the allowable unit compressive stresses on reinforced concrete columns.

TABLE 6.—SAFE LOADS IN POUNDS FOR DIFFERENT UNIT STRESSES ON SQUARE REINFORCED CONCRETE COLUMNS

Size	Area in Sq. Inches of Column	350 pounds per sq. inch Load	500 pounds per sq. inch Load	650 pounds per sq. inch Load	750 pounds per sq. inch Load	Area of Steel in sq. inches	
						1%	1½%
8 x 8	64	22,400	32,000	41,200	48,000	.64	.96
9 x 9	81	28,400	40,500	52,700	61,000	.81	1.21
10 x 10	100	35,000	50,000	65,000	75,000	1.00	1.50
11 x 11	121	42,400	60,500	78,700	91,000	1.21	1.81
12 x 12	144	50,400	72,000	93,600	108,000	1.44	2.16
13 x 13	169	59,200	84,500	109,900	126,000	1.69	2.53
14 x 14	196	68,600	98,000	127,400	147,000	1.96	2.94
15 x 15	225	78.800	112,500	146,500	169,000	2.25	3.37
16 x 16	256	89,600	128,000	166,400	192,000	2.56	3.84
17 x 17	289	101,200	144,500	187,900	216,000	2.89	4.33
18 x 18	324	113,400	162,000	210,600	243,000	3.24	4.86
19 x 19	361	126,400	180,500	234,700	271,000	3.61	5.40
20 x 20	400	140,000	200,000	260,000	300,000	4.00	6.00
21 x 21	441	154,400	220,500	286,700	337,000	4.41	6.61
22 x 22	484	169,400	242,000	314,600	363,000	4.84	7.26

Strength of Steel Columns Considering the Resistance of the Reinforcement.—In some sections of the country it is the practice to

A California concrete house admirably suited to its environment.

Residence of Daniel Simonds, Fitchburg, Mass.   *William S. Covell, Architect, New York.*   *Benjamin A. Howes, Engineer and Builder, New York.*

A beautiful house of reinforced concrete which emphasizes the extreme utility of the material in the construction
of costly dwellings.

include in the calculations for determining the strength of reinforced concrete posts the strength of the steel in the longitudinal rods. Such formulas are based on the assumption that the steel is subjected to the corresponding stress due to its proportional deformation, fixed by the deformation of the concrete under its safe stress.

The relative strains and stresses for the two materials are expressed by the ratios of the moduli of elasticity, which for stone concrete is taken at from 12 to 15. The formula for the strength of columns on these assumptions is then as follows:

$$P = c (A - a) + a n c$$

In this formula

P = safe bearing strength of the column.
A = area of column section.
a = sectional area of all of the longitudinal reinforcing bars.
c = safe compressive strength of the concrete.
n = ratio of the moduli of the elasticity.

It is safe in using such a formula to take n at 12, and c at 500 pounds.

Example: Assume that it is desired to find the safe strength of a reinforced concrete column 14 inches square, reinforced with 4 1-inch round bars.

Solution: The total area of the column section is 14″ x 14″, or 196 sq. in., and the total area of the steel reinforcement is .78 × 4, or 3.12; by substitution in the above formula

P = 500 (196 − 3.12) + 3.12 × 12 × 500 = 115,160 pounds. Answer.

Live and Dead Loads.—In all buildings, whether dwelling houses or those of larger and heavier construction, the design of the floors and walls depends upon the weights or loads they will be required to sustain.

In dwelling houses walls of ordinary construction are generally of ample strength to carry the weight or load usually imposed. In the matter of floors and roofs, these can be directly proportioned and reinforced to their weights and the loads they are required to sustain.

The architectural designer has to do with two kinds of weights or loads, namely, the weight of the materials composing the structure

itself, and the weight or load applied or superimposed upon the floors. These two loads are designated as the dead and live loads respectively.

Dead Load.—The weight of the materials composing a floor or roof makes up the dead load, and it is generally the practice to reduce both the dead and live loads to the weight in pounds distributed over a square foot of surface, so that when either a "dead" or "live" load is mentioned it is understood to be the weight in pounds per square foot of floor area. There would, of course, be an exception where one was considering a load upon a column or post, in which case the aggregate dead and live loads might be meant.

In order to accurately determine the dead load the designer must know the weights of the materials entering into the construction, and these, for dwellings of reinforced concrete, would be as follows:

TABLE 7.—WEIGHT OF BUILDING MATERIALS

REINFORCED CONCRETE WEIGHS 150 POUNDS PER CUBIC FOOT
CINDER CONCRETE WEIGHS 90 POUNDS PER CUBIC FOOT

Reinforced Concrete Slab		Miscellaneous Material	
Thickness in Inches	Weight per Square Foot in Pounds	Material	Weight in Pounds per Square Foot
3	37½	2 Inch Cinder Concrete with Sleepers	14
3½	43¾	2 Inch Cement Top Coat	13
4	50	¼ Yellow Pine Flooring	3
4½	56¼	¼ Hardwood Flooring	4
5	62½	Slag Roof	6
..	..	Slate Roof	8 to 10
..	..	Metallic Lath and Cement Plaster	10
..	..	Sheet Copper Roofing	2
..	..	Interlocking Tile	18
..	..	Flat Promenade Tile	16

It is usually safe in house construction, where there are reinforced concrete beams and girders, to take the dead load of the floor construction at from 90 to 100 pounds per square foot, and for hollow terra-cotta

tile and concrete joist construction, to take the live load at from 75 to 80 pounds.

Live Load.—The live load in any building is an assumed weight per square foot of floor area which is considered to be the extreme possible limit of the superimposed floor loading, such as the weight of the people, furniture and merchandise, and, in some cases, even partitions, if there is a possibility that the location of these may be changed to suit the requirements of tenants.

In dwelling-houses the live load per square foot of floor surface is very little—probably not actually amounting, under ordinary conditions, to more than 10 or 15 pounds per square foot. In all dwelling-houses, however, there is the possibility of a great number of people being assembled on the floors, and consequently in the larger cities a live load of 70 lbs. is generally stipulated in building laws as being the proper superimposed weight for designing the floor construction. This load is rarely, if ever, realized and a load of 40 pounds per square foot is ample for the design of concrete houses not subjected to the requirement of municipal building laws.

The combination of the live and dead loads gives the total load per square foot of floor area. The average total floor load for a dwelling-house, considering a live load of 40 pounds, would seldom be over 120 to 130 pounds per square foot.

Roof Loads.—In modern structures of considerable size it is sometimes considered essential, in designing the roofs, to make allowance for snow and wind loads. Generally in the design of smaller buildings, which classification would include dwellings, even pretentious types, it is usual to combine the snow and wind loads, and to use a superimposed load on the roof of from 25 to 30 pounds per square foot. This load added to the weight of the roof construction gives the total roof load per square foot.

In climates comparatively temperate the load of 25 to 30 pounds could be reduced to from 15 to 20 pounds unless it was proposed to use

the roof as a promenade, when it would be safer to use a somewhat heavier superimposed load. Roofs that are very steep have, of course, little snow load, but on the other hand the wind pressure increases.

Weights on Floor Slabs, Beams, Girders, etc.—In the planning of floors the floor slab, if of concrete, must be designed first. The dead load of the floor slab alone is not as great as the dead load of the entire floor construction, so that in order to get a total load per square foot on a floor slab the live load is added to the actual weight of the floor slab and the finished floor, whatever that may be.

The total load per square foot upon a beam or girder must take into account the weight of the beam or girder itself, distributed over the floor area which it supports, and this dead load is, of course, somewhat more than the dead load of the slab itself. The total weight that a beam or girder supports is equal to the area of floor carried by it multiplied by the total floor load, which includes the dead and live loads, and in the same manner we calculate the load carried by a column or post, with the exception that if it carries more than one floor the aggregated weight from all floors which the column supports must be taken.

Usually the area supported by a beam or girder is equal to the span multiplied by the distance from center to center of these structural members, and where a girder supports a number of reinforced concrete beams it is usual to figure the girder as being uniformly loaded rather than as supporting a number of concentrated loads. This is owing to the monolithic character of the construction, the weight from the beams being well distributed over the girder.

Chapter VI
Calculating the Bending Moments for Reinforced
Concrete Beams and Slabs, and the Determina-
tion of Size and Reinforcement

Reinforced concrete dwelling
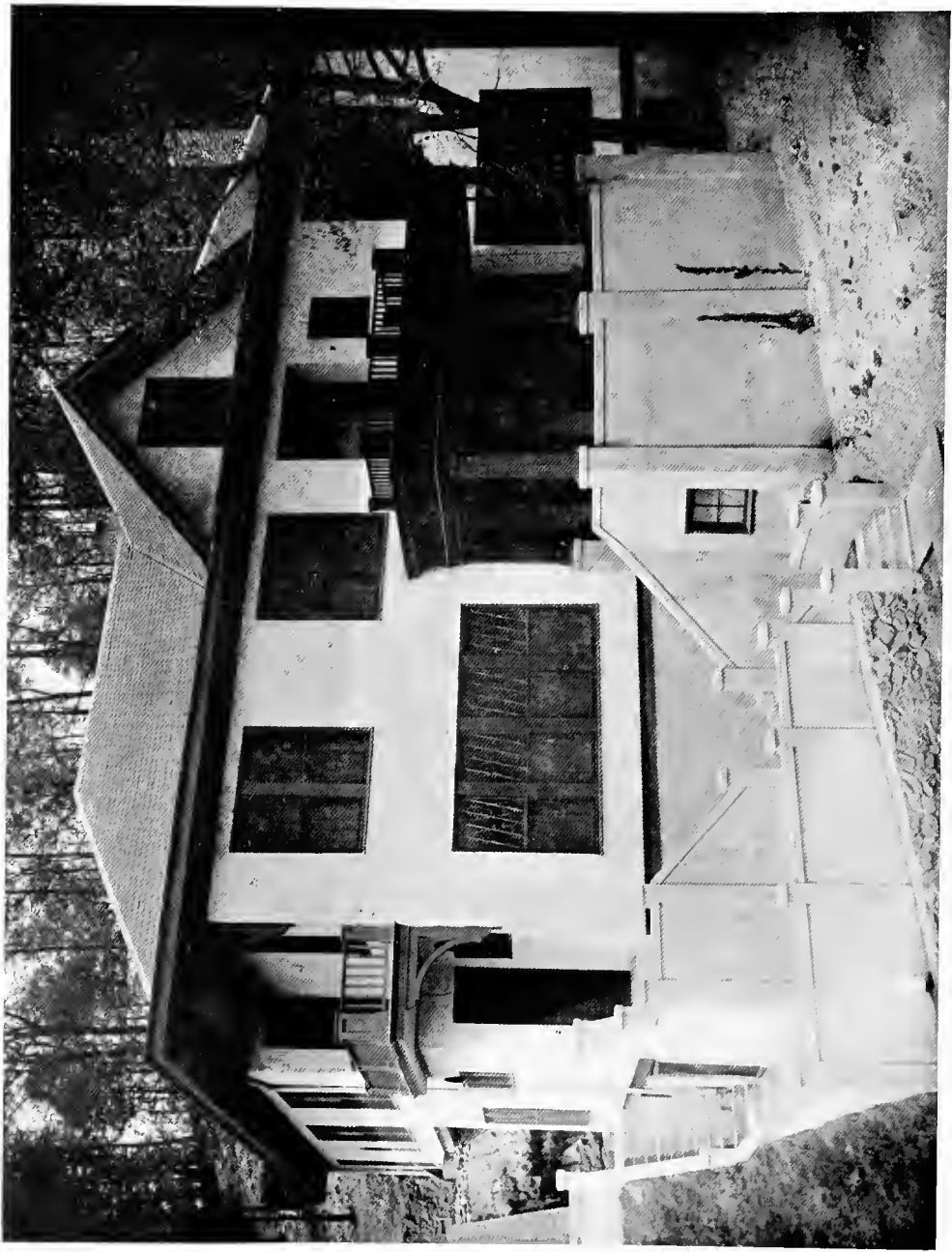
Chapter VI

Calculating the Bending Moments for Reinforced Concrete Beams and Slabs, and the Determination of Size and Reinforcement

Theory of Bending Moments.—The loads on a beam produce transverse stress on the material composing the beam. The loads and the reaction at the supports act about any point in the length of the beam through lever arms equal to the perpendicular distance from the line of action of the load or the reaction, and both the loads and the reactions produce moments about any point. These moments are either positive or negative, as they act together or in opposition to each other. It is evident, therefore, that the moments which act in the same direction may be added together, and that those which are opposed may be deducted from the sum. In this way the algebraic sum of the moments about any point in the length of a beam may be obtained, and the resultant moment is called the bending moment. This bending moment is resisted by the strength of the material of which the beam is composed, so that in order to determine whether a beam is of sufficient section to resist the action of the loads and the reactions, it is necessary to find the maximum or greatest bending moment to which the beam is subjected.

Formulas for Greatest Bending Moments on Simple Beams.—The greatest bending moment on any simple beam may be determined by finding the algebraic sum of the moments about the point at which the greatest bending moment occurs.

For convenience it is customary to use simple formulas, arranged in terms of the weight and span, for finding the bending moment on

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beams loaded with a uniformly distributed load, a load concentrated at the center, or a triangular shaped load such as the weight of brickwork on a lintel over an opening.

In the following tabulation a simple beam is considered as one supported at both ends, while a cantilever is a projecting beam or one supported at one end only. In the formulas the bending moment, M, is determined in inch-pounds, the weight, W, is taken in pounds, and the span in feet or inches as designated L or l, respectively.

FORMULAS FOR BENDING MOMENTS

Simple Beam, Uniform Load. . . . . $M = \dfrac{Wl}{8}$ or 1.5 WL

Simple Beam, Load Concentrated at the Center. . . . . $M = \dfrac{Wl}{4}$ or 3 WL

Simple Beam, Triangular Load, Apex at the Center. . . . . $M = \dfrac{Wl}{6}$ or 2 WL

Simple Beam, Uniform Load; Ends of Beam Fixed . . . . $M = \dfrac{Wl}{10}$ or 1.2 WL

Cantilever Beam, Uniform Load. . . . . $M = \dfrac{Wl}{2}$ or 6 WL

Cantilever Beam, Load Concentrated at End. . . . . $M = Wl$ or 12 WL

Example: What will be the greatest bending moment of a reinforced concrete floor beam which has a span of 20 feet, and where the distance from center to center of beam is 6 feet, and the total load 140 pounds per square foot? ·

Solution: The area of floor supported is equal to 6 × 20, or 120 square feet, and the total load on the beam consequently equals 120 × 140, or 16,800 pounds. Considering that the beam will be taken as fixed at the ends, the formula for a uniform load with the ends fixed will be applied. This formula gives the value of

$$M = \frac{Wl}{10}, \text{ or } 1.2\, WL,$$

so that by the substitution of the values in the formula

$$M = 1.2 \times 16,800 \times 20 = 403,200 \text{ inch-pounds.}$$

Application of Formulas to Reinforced Concrete Beams.—The factor of safety used for reinforced concrete is large—that is to say,

while in figuring the resistance of the material it is customary to use factors of safety of four, for the steel and concrete, there are certain assumptions made with reference to the method of figuring the bending moments which are so far within the safe limits that under any ordinary conditions of fair design and workmanship the actual bending moment is so reduced as to give a much greater factor of safety than is usual in

Load considered acting from face to face of Beams
use $\dfrac{Wl}{8}$

Fig. 99.

Load considered acting from centre to centre of Beams
use $\dfrac{Wl}{10}$

Fig. 100.

structures subjected to static loads. The principal reason for the increase in the factor of safety in reinforced concrete construction lies in the fact that the entire system of beams and girders, together with the floor slab, is usually monolithic, and the girders and beams, besides being continuous over several supports, act mutually in two directions, thus adding greatly to the strength of the floor system.   (See Fig. 99.)

The conservative practice in the design of reinforced concrete floor slabs is to figure the bending moment by the formula $\frac{Wl}{10}$ when the loads and spans are considered as acting over a distance equal to the distance from center to center of beams, and to use the formula $\frac{Wl}{8}$ when the clear span of the slab, or the distance from face to face of beam, is taken as the span, and the distance over which the load is distributed. These two assumptions are illustrated in Fig. 100. There is generally some economy gained by using the first formula, but when this formula is used, the reinforcing rods should be brought to the top of the slab over the beam bearings.

In the design of beams and girders it is undoubtedly safe to consider them as fixed at the ends, and to therefore figure the bending moment upon them by the formula $\frac{Wl}{10}$. Where this formula is used the span of the beam and girder should always be taken as the distance from center to center of supports, even though only the load which would be supported by the clear span is considered.

As in slab construction, the beams and girders should never be considered as fixed at the ends unless they are monolithic at the points of support with the floor construction, or else are securely built into the walls, and then only when the reinforcing rods are bent up toward the supports to form reinforcement for the change in the bending moment which takes place in continuous beams over supports. The method of figuring bending moments for slabs, beams, and girders, and the particular formula which may be used, is usually regulated by the building laws in cities of the first class. Outside of the scope of such laws the designer can use such modifications of these formulas as his judgment and experience may dictate. Where the material and workmanship are of first quality, the designer can certainly afford to use those assumptions which will give him the most economical results, and still be assured of having a secure and safe building, for the reasons stated above.

Minimum Depths of Slabs, Beams, and Girders.—In the design of reinforced concrete structures there are certain minimum thicknesses for slabs, and depths for beams and girders, which are uni-

A straightforward use of concrete which carries conviction as to its strength and durability.

Concrete house of simple and pleasing design. Material peculiarly adapted to a building site of this character.

versally adhered to. For instance, it is considered impractical to build a reinforced concrete slab between beams of less than 3 inches in total thickness, and it is best, in any case, not to make the slab less in thickness than two-fifths of an inch for each foot in span. For example, assume that the span of a slab between beams is 8 feet: if two-fifths of an inch is allowed for each foot of span, and the span is 8 feet, this would give a thickness of sixteen-fifths, which is $3\frac{1}{5}$ inches, and the slab would be made $3\frac{1}{2}$ inches in thickness.

It is customary in designing beams and girders to confine the minimum depth of the beam or girder, counting from the under side of the slab to the bottom of the member, as three-fifths of an inch for each foot in span. To illustrate, assume that a beam has a span of 20 feet; allowing three-fifths of an inch for each foot in span would make the minimum depth of the beam sixty-fifths, or 12 inches, which would be shallow enough for a beam of this span supporting any kind of a load.

In deciding on the depth of beams and girders the commercial width of lumber from which the forms are to be made should be taken into account, unless it is proposed to saw and work stock boards to the necessary width. It is only by such care that the best economy is attained in the construction of concrete dwellings.

The Minimum Width of Beams and Girders.—There are three factors which regulate the width of beams and girders of reinforced concrete:

First: The minimum space into which reinforcing rods can be placed and into which concrete may be poured and spaded or tamped.

Second: The minimum width that will allow the steel to be sufficiently fireproofed.

Third: The minimum amount of concrete around the reinforcing rods or bars that will develop their resistance.

It is seldom practical to make reinforced concrete beams less than 6 inches in width, and they may be as much wider as is needed to meet the requirements above stated, or as may be necessary for archi-

tectural appearances. In all instances there should be at least 1½ inches of concrete outside of the steel reinforcement on both sides and bottom of the beam to give the necessary protection in the way of fireproofing, and it is also considered good practice to allow a distance from center to center of the reinforcing rods or bars of at least 2½ times the diameter of the rod or bar.

Determining the Bending Moment on Square Slabs.—In figuring the bending moments on slabs, whether they span from wall to wall unsupported by beams, or are incorporated with beams and, being monolithic with them, form a T-section, it is always customary in figuring the load and the bending moment to consider a portion of the slab 1 foot in width.

The difference between slabs and beams and girders, with reference to the bending moment, exists in the fact that the slabs may be supported on four sides and be reinforced in two directions. Where it is possible to reinforce a slab in two directions, considerable economy can be exercised from the fact that the bending moment in either direction is materially reduced, and consequently the slab need not be so thick, and supporting beams may be omitted. Where the slab is square, and is supported on all four sides in a secure and fixed manner, then the bending moment on the slab may be found by the following formula:

$$M_{(foot\text{-}pounds)} = \frac{WL}{20}$$

or, if the span is in feet and the resulting bending moment is in inch-pounds,

$$M_{(inch\text{-}pounds)} = \frac{3WL}{5}.$$

To illustrate the application of this formula, assume that it is desired to find the bending moment created in a floor slab 12 feet square, and supporting a total uniformly distributed load of 125 pounds. The load on a portion of the slab 1 foot in width is equal to 12 × 125, or 1500 pounds. Applying the above formula, and substituting,

$$M = \frac{3WL}{5} = \frac{3 \times 1500 \times 12}{5} = 10,800 \text{ inch-pounds.}$$

By referring to Table 9 it will be observed that a slab with a total thickness of 5 inches, reinforced with ¼-inch square twisted bars, spaced 4 inches center to center, will give the required resistance; the reinforcement must, of course, extend in both directions.

Double Reinforcement in Rectangular Slabs.—Floor slabs which are supported on four sides, but which are rectangular instead of square, may be reinforced lengthwise and crosswise; the reinforcement running crosswise of the beam must be heavier than that running lengthwise, from the fact that the greater proportion of the load will be carried by the short span. This is best explained by the fact that the stress in steel or concrete, or in fact any material, is, within working stresses, always proportional to the amount of strain or deformation produced in the material. It is consequently evident that the greatest strain will be produced in the reinforcement running the short way of the slab when subjected to the same deflection, as the reinforcement running lengthwise. In rectangular slabs, therefore, it is necessary to figure the amount of reinforcement required in both directions, by figuring the bending moment created in the slab, with regard to both short and long span.

TABLE 8.—PROPORTION OF LOAD CARRIED IN BOTH DIRECTIONS BY RECTANGULAR FLOOR SLABS

Ratio of Length of Slab to Breadth	Proportion of Load Carried by Reinforcement of Short Span	Proportion of Load Carried by Long Span
1	.5	.5
1.1	.6	.4
1.2	.67	.33
1.3	.74	.26
1.4	.79	.21
1.5	.83	.17
1.6	.87	.13
1.7	.89	.11
1.8	.91	.09
1.9	.93	.07
2	.94	.06

The proportionate part of the total load on a rectangular floor slab which will be carried by the reinforcement extending the short way of the slab, can be found by the following formula:

$$L_p = \frac{l^4}{l^4 - w^4}$$

In this formula

Lp = the proportion of the load resisted by the reinforcement placed the short way of the slab.

l = the length of the slab.

w = the breadth of the slab.

the value Lp is the proportional part of the total load per square foot. In order to save calculation, the various values of Lp, or the proportional part of the load carried by the reinforcement extending the short way of the beam, may be determined from Table 8, which has been worked out for proportional parts of length to breadth, varying by tenths, from square slabs to rectangular slabs having a length equal to twice their breadth.

In order to explain the use of Table 8 and the method of calculating the amount of reinforcement required in a rectangular slab reinforced in two directions, the following example is given:

Example: Determine the amount of reinforcement required both crosswise and lengthwise, for a reinforced concrete slab, supported on four sides, having a width of 10 feet and a length of 12 feet.

Solution: The ratio of the length to the breadth is as

$$\frac{l}{w}, \text{ or } \frac{12}{10} = 1.2.$$

Referring to the above table, it will be found that the proportional part of the load carried by the reinforcement extending across the slab is .67; if therefore, the total load is 130 pounds per square foot, the proportional part of this load carried by the short span will equal 130 × .67 = 87 pounds per square foot. In figuring the bending moment in rectangular slabs, after the proportional part of the load is found for each span, the bending moment is figured by the formula

$$M = \frac{WL}{10};$$

therefore the bending moment in this instance will equal

$\frac{870 \times 10}{10} = 870$ foot-pounds, or 10,440 inch-pounds.

By referring to Table 9, a 4-inch slab with square bars, it will be found that ⅜-inch square bars spaced 5-inch centers will give a resisting moment of 10,650 pounds, which is only slightly in excess of the requirements, and is the correct size to use.

Stirrups.—All concrete beams, whether rectangular or T-section, should have secondary reinforcement in the form of stirrups, which extend from the main reinforcing rods or bars, vertically or diagonally, through the web of the beam to the top. These stirrups have several uses, namely, they help to transmit the stress in the reinforcing rods to the portion of the concrete in compression by resisting the horizontal shear; their greatest use, however, is to prevent what is known as diagonal tension cracks near the abutments, or points of support.

There are various formulas by which the number of stirrups can be figured, but designing engineers do not, as a rule, apply them in practice, and such formulas would be particularly useless in the design of concrete dwellings, where the loads are light. A very excellent rule, and one which is used almost universally by designing engineers of considerable experience, is to place in the beam or girder stirrups equal in number to the span in feet. As the stirrups are primarily shear members, and as the shear increases toward the points of support and is zero at the center of the span of a beam uniformly loaded, it is customary to place the stirrups close together at the abutments, and farther apart toward the center of the span. An excellent rule is to space the stirrups at the abutments according to the following tabulation:

> First three stirrups @ 4-inch center to center.
> Next two stirrups . @ 6-inch center to center.
> Next stirrup ...... @ 12-inch center to center.
> Next stirrup ...... @ 18-inch center to center.

The maximum distance for stirrups should not be over three feet apart at the center of the span.

Stirrups used as the secondary reinforcement for concrete beams and girders in house construction may be of ¼-inch diameter round rods, and this size of stirrup is sufficient if spaced according to the above schedule.

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A house in which the wall surface is typical of concrete.

Chapter VII
Tables for Designing Reinforced Concrete Construction and Their Use

Bungalow or cottage type of house for which concrete is better suited than any other material.

Chapter VII

Tables for Designing Reinforced Concrete Construction and their Use

The several formulas which have been given for finding the location of the neutral axis and the resistance of reinforced concrete beams, involve more or less lengthy calculations, so that it is usual to employ tables which give the results of many calculations based on the formulas.

One of the most valuable of these tables gives the resistance, or resisting moment, of reinforced concrete slabs. The resisting moments of reinforced concrete slabs one foot in width are given in inch-pounds in Table 9. The resisting moment selected from the table must equal the maximum bending moment due to the load on the slab taken in inch-pounds. An examination of this table shows that it gives the resisting moments for slabs from 3 inches to 6 inches in thickness, varying by the one-half inch, and reinforced with both square and round bars, ranging from $1\frac{1}{4}$ inch to $3\frac{3}{4}$ inch, and spaced from 2 inches to 12 inches center to center.

It will be observed that an irregular line passes through these tables. This line separates the values which are limited by the steel reinforcement from those values that are limited by the resistance of the concrete to compression. The values above the line are regulated by the strength of the steel reinforcement, while those below the line are determined by the resistance of the concrete.

The nearer the values approach the line, the more nearly are both the steel and the concrete subjected to their maximum working stresses.

A study of the table will show the values of the resisting moments below the line increasing in a much less ratio than the amount of steel used for the reinforcement, thus showing a loss of economy.

The values in the following table are based upon the strength values of stone concrete, composed of one part of Portland cement, two parts of clean gravel or sand, and four parts of good hard broken stone. The allowable working stress of the steel is taken at 16,000 pounds per square inch, and the allowable compressive stress on the concrete at the extreme fiber is 600 pounds per square inch. The ratio of the moduli of elasticity of the materials is taken at 12. Attention is also called to the fact that the fractional values in the first column of the table are the figures denoting the size of the bars—either the diameter of the round rods or the side of the square bars. The figures at the top over each column is the spacing of the rods in inches, or, as it is sometimes called, the "pitch."

It must be borne in mind in selecting values from the tables that the nearest value within 5% above or below the bending moment may be used, and it is generally considered best not to use the bars in sixteenth sizes, but rather to use those in the eighth size, such as ¼, ⅜, ½, and ⅝. It is good practice to use the same sized rods or bars throughout a job, and rather to use small bars at a reasonable spacing than the larger bars at 8″, 9″, or 10″ pitch.

TABLE 9.—RESISTING MOMENTS IN INCH-POUNDS. IN EVERY CASE CENTER OF STEEL IS ONE INCH FROM BOTTOM OF SLAB

[Figured for stone concrete 1–2–4 mixture 16,000 pounds on steel 600 pounds on concrete Phila. Law. Below line, steel is in excess of critical percentage and concrete is limiting factor.]

THREE-INCH CONCRETE SLABS.
ROUND RODS SPACED CENTER TO CENTER.

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
¼ inch.............	5155	4507	4078	3380	2818	2396	2112	1880	1690	1535	1409
5/16 "	5870	5222	4776	4411	4133	3742	3300	2927	2640	2400	2200
3/8 "	6432	5803	5332	4973	4709	4430	4262	4075	3802	3452	3168
7/16 "	..	6288	5837	5467	5189	4930	4738	4541	4377	4176	4118
½ "	..	6696	6265	5900	5606	5342	5150	4960	4810	4653	4500
9/16 "	..	..	6620	6280	5980	5730	5520	5332	5175	5011	4895
5/8 "	..	..	..	6605	6320	6058	5870	5673	5500	5342	5222
11/16 "	..	..	..	..	6615	6360	6172	5980	5822	5664	5520
¾ "	..	..	..	..	..	6635	6432	6265	6086	5937	5803

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
1/4 inch	5532	4900	4425	4105	3587	3050	2600	2382	2152	1955	1794
5/16 "	6260	5600	5140	4800	4493	4264	4066	3734	3360	3053	2800
3/8 "	6800	6187	5730	5360	5065	4840	4637	4430	4286	4138	4008
7/16 "	..	6658	6225	5865	5568	5304	5105	4930	4766	4600	4460
1/2 "	..	..	6630	6293	5990	5645	5534	5342	5189	5016	490C
9/16 "	..	..	..	6648	6365	6110	5918	5726	5554	5400	5265
5/8 "	..	..	..	..	6686	6437	6260	6058	5900	5750	5606
11/16 "	..	..	..	..	..	6710	6540	6355	6206	6038	5911
3/4 "	..	..	..	..	..	..	6800	6630	6460	6320	6190

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
1/4 inch	7515	6525	5284	4226	3525	2995	2640	2350	2115	1920	1760
5/16 "	8593	7620	6880	6320	5505	4680	4125	3660	3300	3000	2751
3/8 "	9510	8490	7770	7250	6810	6410	5940	5280	4755	4315	3960
7/16 "	10260	9270	8540	7990	7570	7150	6840	6580	6315	5876	5390
1/2 "	..	9930	9225	8660	8210	7790	7515	7215	6940	6735	6525
9/16 "	.	10490	9820	9260	8805	8385	8085	7770	7540	7300	7070
5/8 "	.	..	10330	9790	9330	8935	8595	8295	8055	7800	7620
11/16 "	..	..	..	10220	9800	9390	9100	8790	8510	8280	8075
3/4 "	..	..	..	10650	10215	9835	9510	8225	8970	8720	8500

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins
1/4 inch	8110	7090	6410	5380	4485	3815	3360	2975	2690	2445	2240
5/16 "	9210	8200	7500	6920	6505	5950	5250	4665	4200	3810	3500
3/8 "	10095	9110	8385	7825	7390	6975	6705	6410	6052	5500	5045
7/16 "	..	9870	9160	8595	8160	7735	7450	7150	6880	6675	6465
1/2 "	..	10500	9835	9270	8815	8405	8110	7790	7570	7305	7090
9/16 "	..	..	10380	9860	9400	9050	8680	8385	8140	7875	7690
5/8 "	..	..	..	10360	9915	9510	9210	8925	8650	8410	8200
11/16 "	..	..	..	..	10375	9980	9690	9390	9135	8895	8670
3/4 "	..	..	..	..	..	10400	10095	9835	9560	9315	9110

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FOUR-INCH CONCRETE SLABS.
ROUND RODS SPACED CENTER TO CENTER.

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
¼ inch	10130	8453	6430	5070	4225	3590	3165	2820	2535	2300	2115
5/16 "	11750	10290	9320	7925	6600	5610	4950	4390	3960	3600	3300
3/8 "	13055	11600	10580	9785	9170	8080	7100	6330	5680	5120	4735
7/16 "	14160	12700	11700	10900	10200	9700	9230	8610	7750	6975	6457
½ "	..	13640	12610	11810	11170	10620	10130	9850	9400	9070	8440
9/16 "	..	14460	13460	12680	12000	11430	11030	10590	10190	9860	9590
5/8 "	..	15190	14220	13400	12770	12215	11750	11300	10960	10570	10290
11/16 "	..	..	14880	14115	13455	12875	12420	11970	11630	11245	10995
¾ "	..	..	..	14646	14095	13500	13055	12635	12235	11890	11600

FOUR-INCH SLABS.
SQUARE BARS SPACED CENTER TO CENTER.

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
¼ inch	11030	9612	6070	6460	5380	4575	4033	3570	3230	2930	2690
5/16 "	12610	11150	10100	9370	8500	7140	6300	5600	5040	4580	4200
3/8 "	13920	12450	11390	10650	9970	9440	9018	8070	7260	6600	6025
7/16 "	15000	13590	12540	11750	11080	10530	10100	9580	9300	8990	8240
½ "	..	14500	13480	12700	12000	11430	11030	10600	10200	9880	9610
9/16 "	..	15310	14320	13540	12900	12290	11850	11390	11050	10740	10440
5/8 "	..	..	15030	14270	13630	13060	12610	12190	11800	11430	11150
11/16 "	..	..	..	14940	14310	13730	13300	12870	12500	12130	11830
¾ "	..	..	..		14915	14340	13920	13480	13130	12770	12450

FOUR AND ONE-HALF INCH CONCRETE SLABS.
ROUND RODS SPACED CENTER TO CENTER.

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
¼ inch	13135	9864	7400	5916	4932	4194	3700	3290	2960	2687	2465
5/16 "	15230	13320	11557	9246	7704	6550	5775	5123	4620	4200	3850
3/8 "	17010	15040	13625	12600	11090	9427	8317	7393	6655	6042	5545
7/16 "	18510	16510	15125	14070	13215	12435	11320	10065	9060	8225	7560
½ "	19770	17845	16405	15300	14495	13655	13125	12555	11833	10750	9860
9/16 "	20874	19035	17580	16480	15555	14860	14260	13625	13185	12715	12320
5/8 "	..	19980	18595	17520	16625	15845	15230	14700	14200	13655	13320
11/16 "	..	20874	19505	18435	17580	16745	16155	15550	15080	14635	14235
¾ "	..	..	20345	19300	18405	17655	17010	16405	15935	15405	15040

Four and One-half Inch Concrete Slabs.
Square Bars Spaced Center to Center.

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
¼ inch	14275	12350	9415	7535	6280	5340	4705	4170	3765	3420	3140
5/16 "	16360	14465	13100	11760	9805	8330	7350	6535	5880	5345	4900
3/8 "	18200	16195	14855	13700	12890	12000	10590	9415	8475	7700	7060
7/16 "	19800	17745	16330	15205	14360	13540	12995	12435	11535	10475	9610
½ "	..	19050	17655	16510	15605	14880	14275	13640	13215	12745	12350
9/16 "	..	20140	18755	17700	16780	15995	15345	14860	14330	13800	13420
5/8 "	..	..	19740	18685	17830	17010	16360	15846	15265	14920	14465
11/16 "	..	..	20640	19595	18740	17950	17345	16745	16230	15790	15330
¾ "	..	..	..	20420	19565	18800	18200	17655	17110	16625	16195

Five-Inch Concrete Slabs.
Round Rods Spaced Center to Center.

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
¼ inch	16310	11273	8455	6762	5637	4793	4225	3760	3380	3070	2818
5/16 "	19085	16550	13207	10567	8805	7485	6600	5854	5280	4800	4400
3/8 "	21330	18815	17050	15210	12674	10774	9505	8450	7605	6905	6337
7/16 "	23345	20755	18950	17530	16435	14665	12938	11503	10355	9402	8627
½ "	25056	22465	20485	19260	18010	17090	16300	15020	13523	12283	11267
9/16 "	26495	23925	22080	20700	19585	18565	17685	17050	16370	15550	14264
5/8 "	..	25285	23480	22000	20890	19835	19085	18315	17605	17105	16550
11/16 "	..	26455	24690	23250	22080	21045	20200	19545	18875	18220	17665
¾ "	..	..	25730	24345	23215	22155	21330	20620	19335	19390	18815

Five-Inch Concrete Slabs.
Square Bars Spaced Center to Center.

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
¼ inch	17720	14350	10763	8610	7175	6100	5380	4764	4305	3910	3590
5/16 "	20565	17970	16260	13445	11205	9520	8400	7470	6720	6110	5600
3/8 "	22945	20255	18545	17165	16030	13720	12105	10760	9685	8800	8070
7/16 "	24900	22270	20410	19065	17855	16935	16145	14650	13185	11975	10905
½ "	26515	23960	22140	20755	19605	18585	17720	17090	16415	15640	14350
9/16 "	..	25460	23675	22115	21060	19985	19295	18545	18000	17300	16740
5/8 "	..	26745	25035	23575	22425	21330	20565	19815	19200	18595	17990
11/16 "	..	..	26150	24805	23645	22580	21770	21045	20315	19755	19275
¾ "	..	..	27225	25845	24750	23710	22925	22140	21445	20890	20255

FIVE AND ONE-HALF INCH CONCRETE SLABS.
ROUND RODS SPACED CENTER TO CENTER.

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
1/4 inch	19024	12680	9510	7606	6340	5390	4750	4230	3800	3455	3170
5/16 "	23160	19810	14850	11880	9900	8400	7425	6590	5940	5400	4950
3/8 "	26080	22795	20630	17110	14260	12120	10700	9500	8550	7770	7125
7/16 "	28575	25260	22990	21285	19400	16500	14550	12940	11650	10589	9700
1/2 "	30705	27385	25120	23400	21990	20680	19000	17000	15210	13820	12680
9/16 "	32560	29380	27000	25175	23815	22455	21555	20630	19250	17500	16050
5/8 "	34215	31055	28745	26875	25420	24200	23160	22235	21480	20705	19810
11/16 "	..	32540	30255	28480	26975	25635	24740	23790	22865	22160	21555
3/4 "	..	33900	31710	29890	28455	27045	26075	25120	24350	23570	22795

FIVE AND ONE-HALF INCH SLABS.
SQUARE BARS SPACED CENTER TO CENTER.

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
1/4 inch	21630	16150	12110	9700	8075	6870	6050	5360	4840	4390	4040
5/16 "	25030	21920	18900	15110	12600	10720	9460	8400	7560	6870	6300
3/8 "	27800	24810	22430	20770	18160	15430	13620	12110	10890	9900	9080
7/16 "	30570	27240	24930	23130	21770	20510	18540	16470	14830	13360	12360
1/2 "	32670	29430	27045	25240	23760	22500	21630	20680	19390	17600	16150
9/16 "	34500	31300	29010	27170	25640	24470	23470	22430	21700	20920	20290
5/8 "	..	32930	30670	28920	27290	26100	25030	24200	23350	22525	21920
11/16 "	..	34500	32150	30400	28970	27630	26610	25635	24860	24100	23425
3/4 "	..	..	33560	31860	30330	29060	27945	27045	26270	25420	24810

SIX-INCH CONCRETE SLABS.
ROUND RODS SPACED CENTER TO CENTER.

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
1/4 inch	21140	14100	10570	8450	7050	5990	5275	4700	4230	3840	3520
5/16 "	27540	22000	16500	13210	11000	9330	8250	7320	6600	6000	5500
3/8 "	31110	27240	23760	19010	15800	13470	11880	10550	9510	8610	7900
7/16 "	34200	30270	27390	25290	21520	18330	16150	14230	12930	11750	10760
1/2 "	36900	32850	30060	27750	26190	23940	21130	18770	16900	15360	14090
9/16 "	39240	35220	32340	30165	28300	26840	25590	23770	21380	19380	17830
5/8 "	41280	37260	34380	32190	30470	28860	27540	26500	25485	24000	22000
11/16 "	..	39240	36360	34050	32310	30690	29430	28230	27300	26400	25560
3/4 "	..	40830	38040	35850	33900	32430	31125	30060	29010	27990	27240

Diameter of Rods	2 ins.	3 ins.	4 ins.	5 ins.	6 ins.	7 ins.	8 ins.	9 ins.	10 ins.	11 ins.	12 ins.
¼ inch	25650	17940	13450	10770	8970	7625	6720	5950	5390	4880	4480
$\frac{5}{16}$ "	30000	26040	21010	16800	14000	11910	10500	9330	8400	7640	7000
$\frac{3}{8}$ "	33540	29580	26820	24200	20180	17150	15140	13450	12100	11000	10090
$\frac{7}{16}$ "	36690	32640	29800	27540	25830	23350	20600	18300	16480	14840	13730
½ "	39330	35280	32430	30270	28350	26880	25650	23900	21525	19550	17940
$\frac{9}{16}$ "	41550	37530	34710	32560	30750	29130	27810	26820	25770	24750	22700
$\frac{5}{8}$ "	..	39660	36780	34590	32790	31440	30000	28830	27700	26900	26040
$\frac{11}{16}$ "	..	41520	38760	36540	34710	33060	31740	30690	29670	28710	27780
$\frac{3}{4}$ "	..	..	40380	38250	36480	34800	33510	32430	31230	30480	29580

To illustrate the use of Table 9, attention is called to the following example in which the slab is supported on two sides only:

Example: What size of slab and what reinforcement will be necessary for the reinforced concrete construction over a living-room in an all-concrete house? It is the intention to reinforce the concrete slab in one direction only and it is considered that the ends of the concrete slab are fixed. The distance between the concrete beams is 8 feet, and the live or superimposed load, exclusive of the weight of the construction, is 70 pounds per square foot. The floor is to be finished with a wood floor secured to sleepers embedded in 2 inches of cinder concrete.

Solution: The assumption is that a 4-inch slab will be sufficiently thick, so that the total floor load per square foot of slab will be made up as follows:

Live Load............................. 70 pounds
Weight of Slab......................... 50 pounds
Weight of Flooring..................... 4 pounds
Weight of Cinder Concrete.............. 15 pounds

139 pounds per square foot.

Considering a portion of the slab 1 foot in width, the total load on such a portion is equal to weight per square foot by the span of the slab in feet, or

$$139 \times 8 = 1,112 \text{ pounds.}$$

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The bending moment of the slab may be figured by the formula

$$\frac{WL}{10}$$

or, if the span is taken in feet and the result is desired in inch-pounds:

$$M = 1.2 \ WL.$$

If the weight $W = 1,112$ pounds, and the span in feet, or $L = 8$, then by substitution

$$M = 1.2 \times 1,112 \times 8 = 10,675 \text{ inch-pounds.}$$

Assuming that it is desired to use square twisted bars, refer to the portion of Table 9 relating to 4-inch slabs. It will be seen that $\frac{3}{8}$-inch square bars, spaced 5 inches from center to center, have a resistance of 10,650 inch-pounds, which is sufficiently close for practical purposes.

In order to illustrate further the use of Table 9, the following problem in the design of a rectangular slab supported on all four sides is given:

Example: A floor slab in a dwelling-house is supported on all four sides by outside and partition walls. The length of the slab is 14 feet, and the width is 10 feet, while the total load, including the weight of the slab, is 120 pounds per square foot. Determine the thickness and the reinforcement necessary for reinforcing the slab in both directions.

Solution: It is first necessary to find the ratio of the length of the slab to the breadth (as explained on page 185). This ratio, or

$$L_p = \frac{14}{10}, \text{ or } 1.4;$$

then, from Table 8, the proportion of the load carried by the short and the long span is found for the value of 1.4 to be .79 and .21 respectively. The load in pounds, therefore, to be carried by the short span would be

$$.79 \times 120 = 94.80 \text{ pounds per sq. foot,}$$

while for the long span the weight producing the bending moment would equal

$$.21 \times 120 = 25.20 \text{ pounds per sq. foot;}$$

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the next thing to find is the proportionate weight on the slab both ways for a strip of slab 1 foot in width, and these weights are as follows:

$$W_b = 10 \times 94.80 = 948 \text{ pounds},$$
$$W_l = 14 \times 25.20 = 353 \text{ pounds};$$

as the span and load are taken from center to center of supports the bending moment both the short way and the long way of the slab is then calculated by the formula

$$M = \frac{WL}{10},$$

or, using L in feet, and obtaining the results in inch-pounds,

$$M = 1.2 \ WL.$$

This calculation is as follows:

Bending Moment
    Short Way of Slab = $1.2 \times 948 \times 10 = 11{,}376$ in. lbs.
Bending Moment
    Long Way of Slab = $1.2 \times 352 \times 14 = 5{,}914$ in. lbs.

Table 9 may now be used for determining what slab and what reinforcement will be necessary to give the required resistance.

Note.—It is best in making selections from the table, where rectangular slabs are concerned, to use first the bending moment short way of the slab.

In above example the bending moment the short way of the slab is 11,376 inch-pounds. Referring to Table 9 it will be observed that a 4½-inch slab, reinforced with ⅜-inch square twisted bars placed 7 inches from center to center, has a resistance of 12,000 inch-pounds, and that if ¼-inch square twisted bars spaced 6 inches on centers are used the long way of the slab, the resistance will be 6,280 inch-pounds, which is in excess of the bending moment of 5,913 inch-pounds created in the slab lengthwise.

Resisting Moments of Rectangular Beams.—While the resisting moment of rectangular reinforced concrete beams may be found with little trouble when the percentage of the steel reinforcement and the location of the neutral axis have been found, nevertheless when the bending moment has to be calculated it is much more convenient to determine the actual size and reinforcement needed directly from a table giving resisting moments for rectangular beams of different depths and reinforced with different percentages of steel reinforcement. Consequently, the resisting moments in inch-pounds are given in Table 10. The values in this table are limited by an allowable unit fiber stress on the steel of 16,000 pounds, and an allowable unit compressive stress on the concrete at the extreme edge of 600 pounds, and a ratio of 12.

Referring to the table it will be observed that the resisting moments are given for beams reinforced with $\frac{5}{10}$ of one percent to 1 percent of steel, varying by one-tenth of one percent, and also for beams from 6 inches to $36\frac{1}{2}$ inches in depth. The large values in the columns are the resisting moments in inch-pounds for each inch in width of the beam, while the decimal values are the areas of the steel reinforcement required in square inches for each inch in width of the beam. It will also be noticed from the figure accompanying the table that the depth, or the distance d given in the column to the extreme left, is the distance from the center of action of the steel to the top of the beam, and is not the total depth of the beam.

The following example illustrates the use of the above table:

Example: A rectangular reinforced concrete beam supported on the columns of a portico, supports a tile roof which imposes a total load of 500 pounds per running foot; the span of the beam is 20 feet. Determine the size of the beam and the amount of reinforcement necessary to carry the weight.

Solution: The total load on the beam is 20×250, or 5,000 pounds, and as the beams are not fastened at the ends, the bending moment in inch-pounds is found by the formula

$$M = \frac{Wl}{8}, \text{ or, } 1\tfrac{1}{2} \text{ WL.}$$

Ratio of Steel Reinforcement.

d	.005		.006		.007		.008		.009		.01	
6	2601	.030	3036	.036	3214	.042	3365	.048	3505	.054	3616	.060
6½	3052	.033	3563	.039	3772	.046	3949	.052	4102	.059	4244	.065
7	3540	.035	4132	.042	4374	.049	4580	.056	4757	.063	4922	.070
7½	4064	.038	4743	.045	5022	.052	5257	.060	5461	.068	5651	.075
8	4623	.040	5397	.048	5714	.056	5982	.064	6213	.072	6429	.080
8½	5219	.043	6093	.051	6450	.060	6753	.068	7014	.077	7258	.085
9	5851	.045	6831	.054	7231	.063	7571	.072	7864	.081	8137	.090
9½	6520	.048	7611	.057	8057	.067	8435	.076	8762	.086	9066	.095
10	7224	.050	8433	.060	8927	.070	9347	.080	9708	.090	10045	.100
10½	7965	.053	9298	.063	9842	.074	10305	.084	10704	.095	11075	.105
11	8741	.055	10104	.066	10802	.077	11309	.088	11747	.099	12155	.110
11½	9554	.058	11153	.069	11806	.081	12361	.092	12839	.104	13285	.115
12	10403	.060	12144	.072	12855	.084	13459	.096	13980	.108	14465	.120
12½	11288	.063	13177	.075	13949	.088	14604	.100	15169	.113	15696	.125
13	12209	.065	14252	.078	15087	.091	15796	.104	16407	.117	16978	.130
13½	13166	.068	15370	.081	16270	.095	17034	.108	17694	.122	18308	.135
14	14159	.070	16530	.084	17498	.098	18319	.112	19028	.126	19689	.140
14½	15189	.073	17732	.087	18780	.102	19651	.116	20412	.131	21120	.145
15	16254	.075	18976	.090	20087	.105	21032	.120	21844	.135	22602	.150
15½	17355	.078	20262	.093	21448	.109	22455	.124	23324	.140	24134	.155
16	18493	.080	21590	.096	22854	.112	24127	.128	24854	.144	25716	.160
16½	19667	.083	22960	.099	24305	.116	25446	.132	26431	.149	27349	.165
17	20877	.085	24373	.102	25800	.119	27011	.136	28057	.153	29031	.170
17½	22124	.088	25828	.105	27340	.123	28624	.140	29732	.158	30764	.175
18	23406	.090	27325	.108	28925	.126	30283	.144	31455	.162	32547	.180
18½	24724	.093	28864	.111	30554	.130	31988	.148	33227	.167	34380	.185
19	26079	.095	30445	.114	32228	.133	33741	.152	35047	.171	36264	.190
19½	27469	.098	32069	.117	33946	.138	35540	.156	36916	.176	38198	.195
20	28896	.100	33740	.120	35710	.140	37386	.160	38834	.180	40182	.200
20½	30359	.103	35443	.123	37517	.144	39279	.164	40800	.185	42216	.205
21	31758	.105	37193	.126	39370	.147	41218	.168	42814	.189	44300	.210
21½	33493	.108	38985	.129	41267	.151	43204	.172	44877	.194	46435	.215
22	34964	.110	40819	.132	43209	.154	45237	.176	46989	.198	48620	.220
22½	36572	.113	42696	.135	45195	.158	47317	.180	49149	.203	50855	.225
23	38215	.115	44614	.138	47226	.161	49443	.184	51357	.207	53140	.230
23½	39895	.118	46575	.141	49302	.165	51616	.188	53615	.212	55476	.235
24	41610	.120	48578	.144	51422	.168	53836	.192	56115	.216	57862	.240
24½	43362	.123	50623	.147	53587	.172	56102	.196	58275	.221	60298	.245
25	45150	.125	52711	.150	55796	.175	58416	.200	60678	.225	62784	.250
25½	46974	.128	54840	.153	58050	.179	60777	.204	63129	.230	65320	.255
26	48834	.130	57011	.156	60349	.182	63182	.208	65639	.234	67907	.260
26½	50731	.133	59226	.159	62693	.186	65636	.212	68177	.239	70544	.265
27	52663	.135	61482	.162	65081	.189	68136	.216	70774	.243	73232	.270
27½	54632	.138	63779	.165	67513	.193	70683	.220	73420	.248	75968	.275
28	56636	.140	66120	.168	69990	.196	73277	.224	76114	.252	78756	.280
28½	58677	.143	68503	.171	72513	.200	75917	.228	78856	.257	81594	.285
29	60754	.145	70928	.174	75079	.203	78604	.232	81648	.261	84482	.290
29½	62867	.148	73395	.177	77691	.207	81338	.236	84487	.266	87420	.295
30	65016	.150	75903	.180	80347	.210	84119	.240	87376	.270	90409	.300
30½	67201	.153	78454	.183	83047	.214	86946	.244	90312	.275	93447	.305
31	69423	.155	81048	.186	85792	.217	89820	.248	93299	.279	96536	.310
31½	71680	.158	83683	.189	88582	.221	92740	.252	96332	.284	99676	.315
32	73974	.160	86361	.192	91418	.224	95708	.256	99414	.288	102865	.320
32½	76314	.163	89081	.195	94296	.228	98722	.260	102545	.293	106105	.325
33	78669	.165	91843	.198	97220	.231	101783	.264	105724	.297	109394	.330
33½	81071	.168	94647	.201	100188	.235	104891	.268	108953	.302	112735	.335
34	83509	.170	97494	.204	103200	.238	108046	.272	112229	.306	116125	.340
34½	85984	.173	100382	.207	106258	.241	111247	.276	115554	.311	119565	.345
35	88494	.175	103313	.210	109360	.245	114495	.280	118928	.315	123056	.350
35½	91040	.178	106286	.213	112508	.249	117790	.284	122350	.320	126597	.355
36	93623	.180	109300	.216	115700	.252	121130	.288	125821	.324	130188	.360
36½	96243	.183	112362	.219	118930	.256	124513	.292	129335	.329	133825	.365

so that by substitution

$$M = 1\tfrac{1}{2} \times 5{,}000 \times 20 = 150{,}000 \text{ inch-pounds.}$$

The width of rectangular beams is generally determined either by an architectural or structural requirement. The minimum width of beams on account of practicability of construction is usually 6 inches, and in house construction the maximum width would seldom exceed 12 inches. Assume that a beam 10 inches in width is to be used, the resistance for each inch in width would equal

$$150{,}000 \div 10, \text{ or } 15{,}000 \text{ inch-pounds;}$$

referring to Table 10, the column headed ".006," it will be seen that a beam from $13\tfrac{1}{2}$ inches to 14 inches in depth will answer, and that the total area of steel reinforcement will equal

$$.081 \times 10 = .81 \text{ square inch.}$$

Therefore two $\tfrac{5}{8}$-inch square twisted bars will be nearly enough, and two $\tfrac{3}{4}$-inch much more than is required for reinforcing the beam.

If the beam is designed as a rectangular section supporting the floor slab, the depth of the beam is considered from the top of the slab to the center of reinforcing in the beam. This must leave at least $1\tfrac{1}{2}$ inches of concrete under the steel, to act as fireproofing.

Chapter VIII
Concrete Block Houses

Residence of G. A. Maurer, Mishawaka, Ind.

H. H. Richards, Architect, Chicago

A concrete block of plain pattern and surface suitable for large dwellings or houses of moderate cost.

Chapter VIII
Concrete Block Houses

The demand for better homes, for more sanitary, permanent and fireproof houses of moderate cost, led to the enthusiastic reception accorded the concrete building block. In skilled, intelligent hands, many remarkably beautiful and satisfactory dwellings have been and are being built of this cement product. On the other hand, especially in the earlier days of the industry, not a few unsightly and unsatisfactory structures resulted. The fact that little or nothing is said of success, while great publicity is given to failure, has led many to believe that good houses cannot be built of concrete blocks. Such is far from the case: many of the best architects in the country have designed and built residences of concrete blocks, some of which have cost more than one hundred thousand dollars. From the smallest cottage to the palatial mansion, these structures are satisfactory in every detail—the combination of tasteful design with good workmanship.

Designing the Block.—With regard to the size and proportional dimensions of the block or blocks, little can be said other than that these details should be in perfect keeping with the general architectural style of the structure. The same holds true in the matter of surface finish of the block. Concrete, as concrete, has sufficient beauty in itself to make imitation of other materials not only unnecessary, but even reprehensible. Too frequently mechanics have designed and marketed block molds perfect mechanically but so bad esthetically that architects have often rightfully refused to use the product. With a simple mold of plain design, an artisan can produce a block of wonderful beauty and utility. To bring out the beauty of the concrete, the exterior of the block is

finished in accordance with any of the several methods given under "Surface Treatment," page 122.

Making the Block.—The selection, proportioning and mixing of the aggregate for concrete blocks are governed in general by the information covering these subjects on preceding pages. On account of the narrowness of the spaces of molds, the maximum size of stone permissible in a well-graded aggregate is usually $\frac{1}{2}$ to $\frac{3}{4}$ inch in diameter. The Portland cement, sand and crushed rock should be combined in such proportions as to form a dense, damp-proof block. This correct proportion is determined by methods previously described. For average conditions, with sand grading uniformly from o to $\frac{1}{4}$ inch and stone from $\frac{1}{8}$ to $\frac{1}{2}$ inch, the concrete is generally proportioned 1 part cement to $1\frac{1}{2}$ parts sand to 3 parts crushed rock or 1 part cement to 2 parts sand to 4 parts crushed rock. With clean, well-graded, crusher-run stone screenings or bank-run gravel, the proportions are most frequently 1 to 3 or 1 to 4. When sand alone is used, more cement is required. Such concrete is most often proportioned 1 to 2 or 1 to 3. In order to produce blocks similar in quality and appearance, all materials, including the water, should be accurately measured by volume.

It is highly important that an abundance of water be used in the concrete for blocks. The cement requires it, and in no other way can dense, damp-proof blocks be made. The quantity of water necessary to a given amount of dry materials varies. If the block is made by tamping, there should be at least sufficient water that liquid cement will flush to the surface when the concrete is rammed into the block mold. Frequently block manufacturers, in their efforts to turn out quantities of blocks with a minimum number of molds, have made the very serious mistake of mixing the concrete too dry, so that the blocks might be stripped of the molds more quickly. No amount of tamping will produce density in a concrete lacking sufficient water. Concrete for poured blocks is usually of the consistency known as "mushy" or "quaking."

Curing Cement Products.—To cure concrete products rapidly
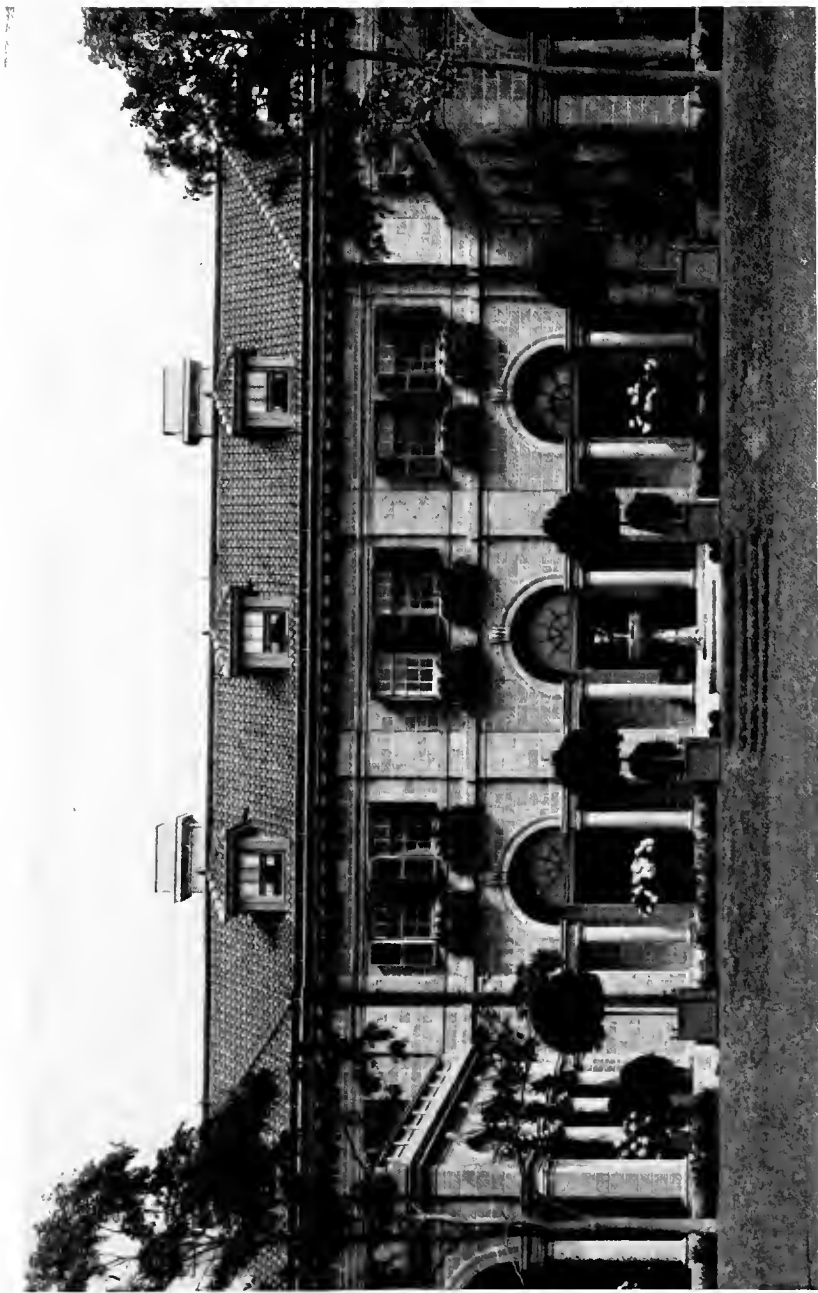
Residence of F. S. Harkness, New London, Conn.   *Lord & Hewlett, Architects*

A notable example of the utility of concrete blocks in the construction of costly dwellings. Gray blocks, green tile roof, white window frames, green shutters, and dark green flower-boxes.

Residence of J. R. Steers, Port Chester, N. Y.
Carrere & Hastings and Blake & Buler, Architects, New York

A costly mansion built of concrete blocks of simple pattern, but especially selected aggregates. This successful use of blocks represents the combined efforts of capable architects and engineers.

and with the best results, heat and moisture are essential. A thorough understanding and practice of these requirements enable the manufacturer not only to market his product sooner, but also to produce a superior article.

Sufficient water must be incorporated with the concrete previous to molding and must be conserved in the product until it is thoroughly cured. After the block is molded, precautions must be taken to protect it from sun, wind and frost until the cement has thoroughly set. (See instructions for protection of freshly placed concrete, page 117.) Openings to the curing room are closed by doors or canvas, so as to cut off all drafts, which tend to remove moisture from the concrete product. Moreover, as soon as possible without pitting the surface, the freshly molded units are sprinkled with water and the operation repeated at intervals of four to twenty-four hours for five to seven days. When seven days old, blocks may be piled in the open air. Even then an occasional wetting is beneficial. Ordinarily cured blocks should not be placed in the wall until they have attained the age of at least thirty days, as freshly made concrete contracts slightly until the cement has attained its full set, and small shrinkage cracks might appear at the mortar joints.

Portland cement sets up more quickly in warm weather than in cold. Within recent years many cement products manufacturers have been taking advantage of this characteristic of cement by installing steam-curing plants. With steam even at atmospheric pressure, it has been found that in a steam-tight kiln the concrete becomes sufficiently hard in the course of a few days to permit the shipping of the product.

Exhaustive tests made by the United States Bureau of Standards have deduced the fact that a compressive strength of concrete considerably in excess of that obtained normally after aging for six months can be obtained in two days by subjecting the product to steam under considerable pressure. Moreover, steam-cured products are lighter in color and much more uniform in appearance than concrete of the same aggregate cured by ordinary methods.

Advantage of Block Construction.—The concrete block is the simplest form of unit construction. Since it is a factory product, the same mold is used many times for many different structures, with a resulting small charge for forms. Each unit can be carefully inspected for quality and uniformity of appearance previous to erection in the house wall and all faulty pieces rejected. A concrete block house presents no unusual difficulties of construction. Masons of ordinary skill can build a residence with concrete blocks much more quickly and cheaply than with ordinary stone or brick. The floors and interior finish are the same as those usually given masonry structures.

The architect interested in concrete blocks may obtain them from manufacturers who make a standard pattern, or, if these are not satisfactory, he may select his own aggregates and surface finish, even to the extent of having special face molds made for machines used in the manufacture of ordinary blocks. This was done in the case of the Steers' residence, shown on another page. This large and costly dwelling was built of blocks cast in plain form on a machine of simple pattern, but with aggregates selected and mixed to give the required color and texture. This dwelling is an excellent example of the utility of the concrete block when in competent hands, as it represents the combined efforts of prominent architects and engineers.

Where the architect selects the block made by the manufacturer, he should make certain that it is of the very best quality as to density and strength. In the matter of porosity, however, it may be said that blocks which admit moisture when first erected sometimes become thoroughly water tight.

The concrete block is especially valuable in localities scarce in timber, where the cost of forms for poured or cast houses might be excessive. In some countries the block has taken precedence over reinforced concrete for house wall construction, notably in England, Scotland and Ireland. These countries have surpassed the United States in attractive block buildings, especially of the cottage type. They are usually constructed of the severely plain block, such as is shown in the accompanying illustrations. There has been no attempt at fantastic shapes or orna-

Residence of D. A. McLennen, Lake Forest, Ill.   Howard Shaw, Architect, Chicago

An attractive house of concrete blocks treated with stucco finish.
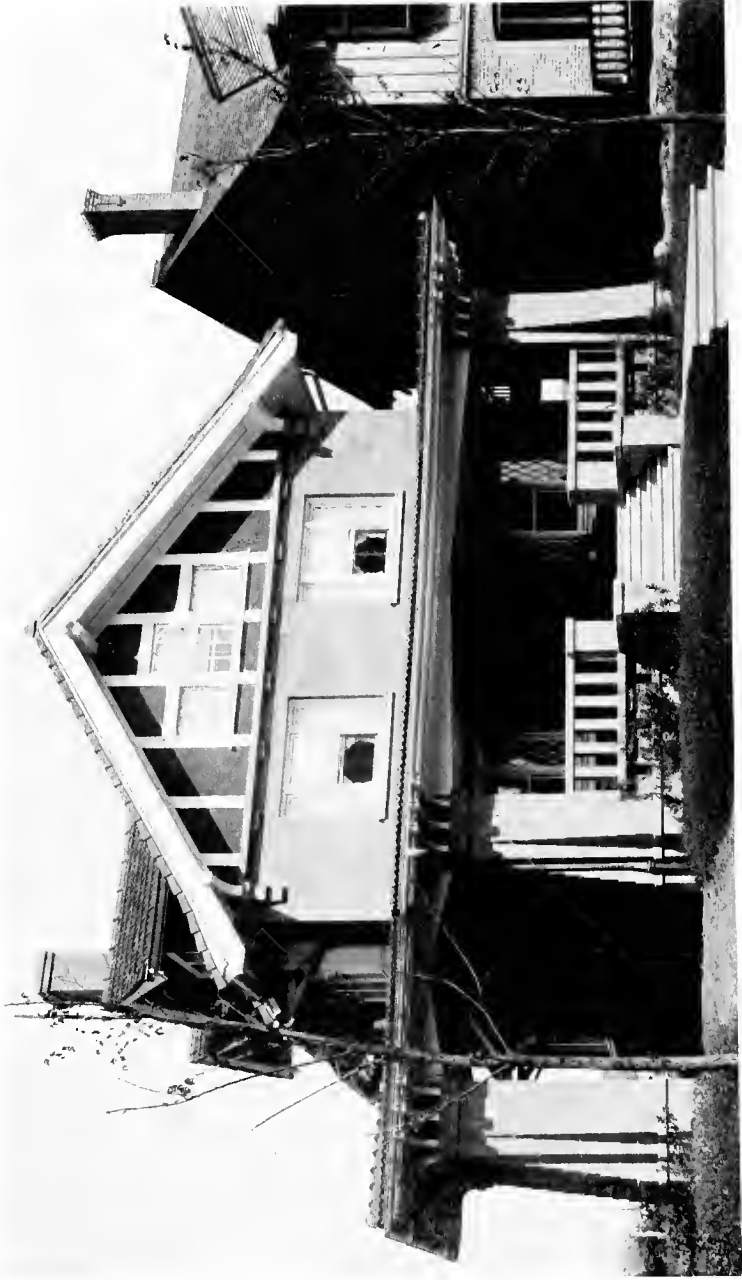
Residence of Joseph P. Sherer, Milwaukee   *H. J. Rotier, Architect, Milwaukee*

The plain surface concrete block as used in a dwelling of moderate size.   Note porch columns.

mentation, merely the substitution of the concrete block for plain, dressed stone.

The several illustrations of block houses show the attractive character of the material when used in the most direct and unpretentious manner.

The design of reinforced concrete buildings requires an understanding of at least such elementary principles of engineering as will insure safety to the structure, but with blocks the builder may, generally speaking, proceed as with brick or stone. As is the case with all materials used in unit construction, however, each requires special treatment, but the laying up of a block wall is not more difficult or complicated than the construction of a wall of brick or stone. In brief, the block is an excellent substitute for these materials, whether applied to dwellings or buildings of larger size.

Residence of Maitland F. Griggs, Ardsley on Hudson.

Benjamin A. Howes, Engineer, New York

A substantial concrete house of the sanitary and fire-resisting type.
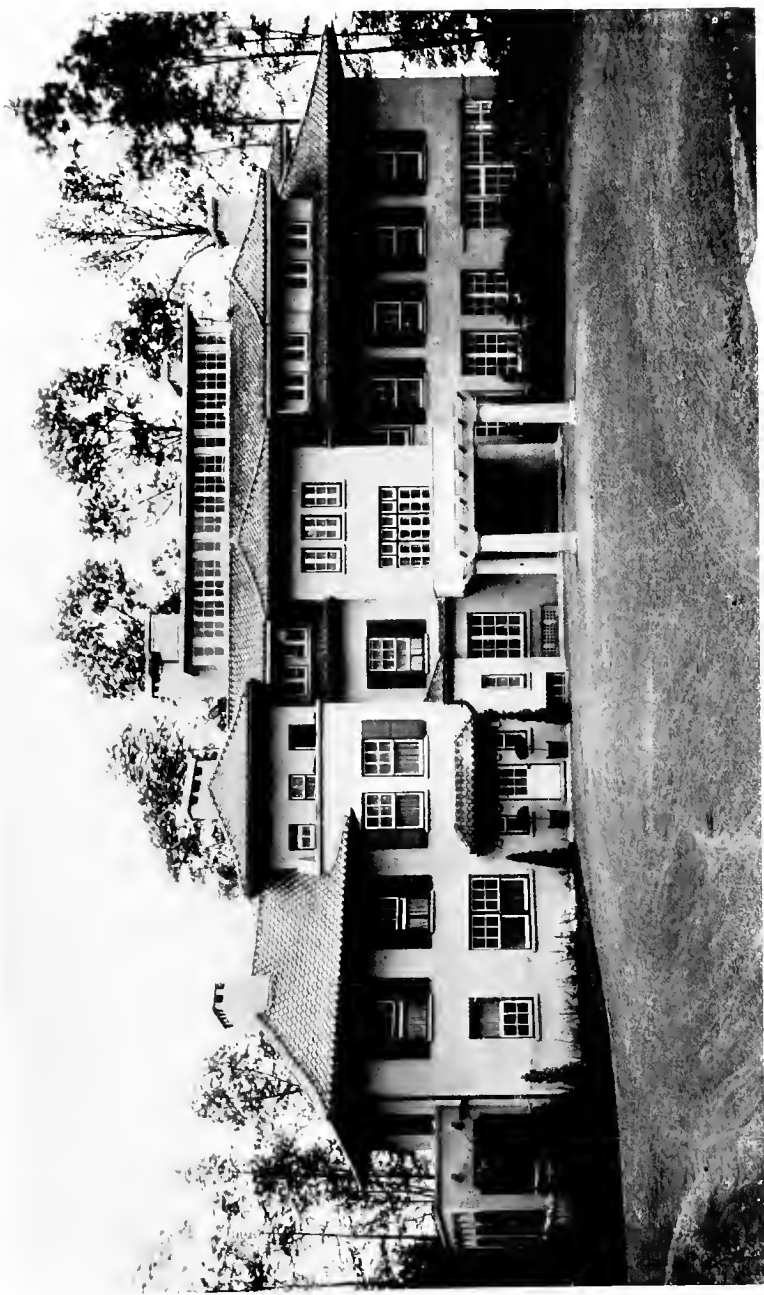
Residence of William C. DeLanoy, Short Hills, N. J.

Benjamin A. Howes, Engineer, New York

The fireproof properties of concrete make it especially desirable for the costly suburban or country house.

Administration Building, Washington Park, Chicago.

An especially interesting example of untreated surface.
(See pages 123 and 124.)

Alphabetical List of Architects, Engineers and Builders Whose Work is Represented in the Illustrations Contained in this Book*

ARCHITECTS

* In a few cases it was impossible to obtain names of architects and omissions were, therefore, unavoidable.

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Church Window, Lynn, Mass.   *Simpson Bros., Engineers, Boston*

Architectural detail cast in concrete.   Equals stone in strength and appearance
and costs much less.

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