## TYPICAL SYSTEMS OF REINFORCED CONCRETE CONSTRUCTION.

Of the interesting features of modern civil engineering, interesting because of their extreme novelty and successful application, reinforced concrete is probably most noteworthy because of its unique adaptability. How striking is the influence of steel reinforcement is best exemplified by a reference to Fig. 1. There two beams are shown designed to carry ordinary floor loads, the one made entirely of concrete and the other of concrete with a sheet of expanded metal imbedded in the tensile portion of the beam. The saving in mere weight of concrete alone is apparent; and when we remember that the adoption of floor beams entirely of concrete means an increase of thickness of nine inches, or assuming five to eight floors, an increase in the total height of the building (with extra cost of higher and heavier walls, together with heavier foundations to carry them) of from four to six feet, we see that even as regards initial outlay for materials, the introduction of steel reinforcement into concrete construction is of importance.

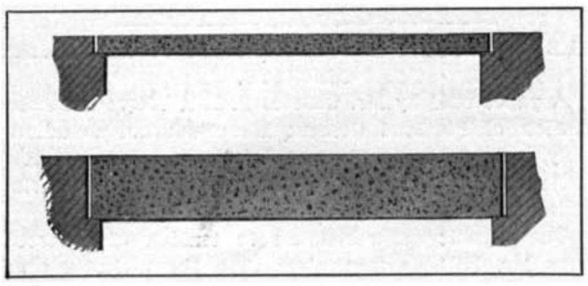

Fig. 1.—These Beams Are Designed to Carry the Same Load. The Upper is of Reinforced Concrete, the Lower of Plain Concrete.

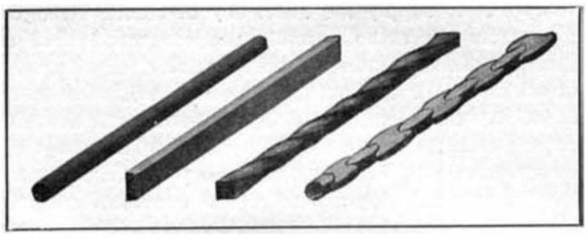

Fig. 2.—Types of Steel Reinforcing Rods.

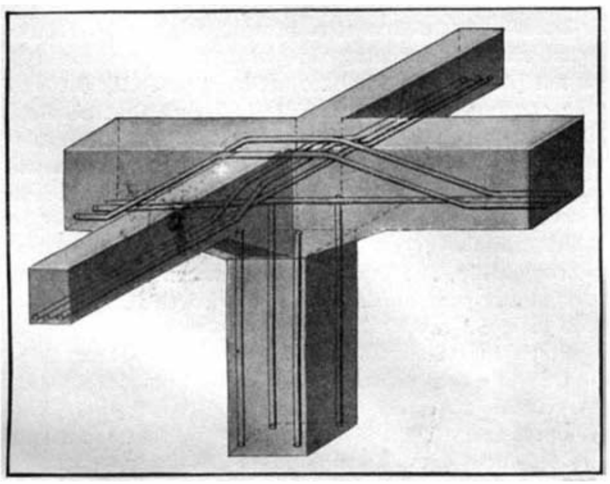

Fig. 3.—A Reinforced Concrete Pier for Railway Traffic.

So far as economy in initial cost of materials is concerned, reinforced concrete is undoubtedly cheaper than either concrete or steel alone. It is not very easy to demonstrate this economy except by comparative cost in individual cases, but an approach to a systematic comparison has been made by Mr. Walter Loring Webb, as follows: A cubic foot of steel weighs 490 pounds. Assume as an average price that it can be bought and placed for 4.5 cents per pound. The steel will therefore cost $22.05 per cubic foot. On the basis that concrete may be placed for $6 per cubic yard, the concrete will cost 22 cents per cubic foot, which is 1 per cent of the cost of the steel. Therefore, on this basis, if it is necessary to use as reinforcement an amount of steel whose volume is in excess of 1 per cent of the additional concrete which would do the same work, there is no economy in the reinforcement, even though the reinforcement is justified on account of the other considerations. Assuming 500 pounds per square inch as the working compressive strength of concrete, and 16,000 pounds as the permissible stress in steel, it requires 3.125 per cent of steel to furnish the same compressive stress as concrete. On the above basis of cost, the compression is evidently obtained much more cheaply in concrete than in steel—in fact, at less than one-third of the cost. On the other hand, even if we allow 50 pounds per square inch tension in the concrete and 16,000 pounds in the steel, it requires only 0.31 per cent of steel to furnish the same strength as the concrete, which shows that, no matter what may be the variation in the comparative price of concrete and steel, steel always furnishes tension at a far cheaper price than concrete, on the above basis, at less than one-third of the cost. The practical meaning of this is, on the one hand, that a beam composed wholly of concrete is usually inadvisable, since its low tensile strength makes it uneconomical, if not actually impracticable, for it may be readily shown that, beyond a comparatively short span, a concrete beam will not support its own weight. On the other hand, on account of the cheaper compressive stress furnished by concrete, an all-steel beam is not so economical as a beam in which the concrete furnishes the compressive stress and the steel furnishes the tensile stress. This statement has been very frequently verified when comparing the cost of the construction of floors designed by using steel I-beams supporting a fireproof concrete floor, and that of a concrete floor having a similar floor slab but making the beams as T-beams of reinforced concrete.

A good idea of reinforced concrete construction can be obtained from Fig. 3, which is an isometrical projection of a portion of a pier strong enough to carry the heaviest railway traffic. The disposition of the steel work is shown in the piles, the main girders, and beams; and the manner in which the steel rods running along the tensile or bottom side of the girders and beams are bent up over the top of the pile, which is here the tensile member (the beams being continuous), and then down again to the bottom of the girders and beams, is most instructive.

The sections of the steel employed vary in different systems, being round, flat, square, angle, and tee (Fig. 2). In all cases the simplest section is the best, as it costs less, and readily allows the concrete to be rammed into the closest contact with the entire surface of the armoring. In America the Ransome system is most extensively used—a system in which a bar of twisted steel is employed. Small sections are better than large ones, for by their use we obtain a more uniform distribution of stress in the steel; we can also readily bend and work them into any required shape; and finally, the most economical disposition of material is obtained, the metal being placed at the maximum distance from the neutral axis.

Expanded metal meshing (Fig. 6) is increasingly employed, more particularly in the lighter forms of construction. It consists of sheets of metal which have been mechanically slit and expanded, so as to produce a network. This type of reinforcement has many and obvious advantages. Its mere existence is proof of good steel, and it forms an excellent key for concrete too thin to permit reinforcement in the form of rods; thus it is very useful for concrete plaster, ceiling, and partition wall work. A good example of reinforced concrete in which expanded metal is used may be found in the Monier system (Fig. 5). An improvement on this system is the Clinton method (Fig. 11) of using an electrically welded wire netting in combination with

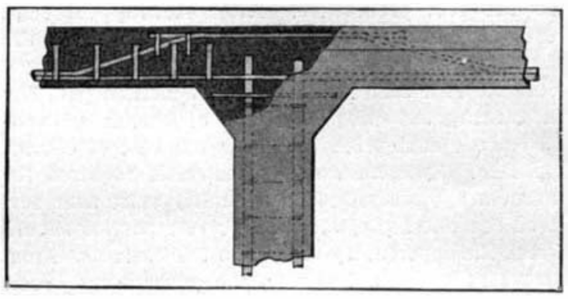

Fig. 4.—Method of Joining Columns and Floors.

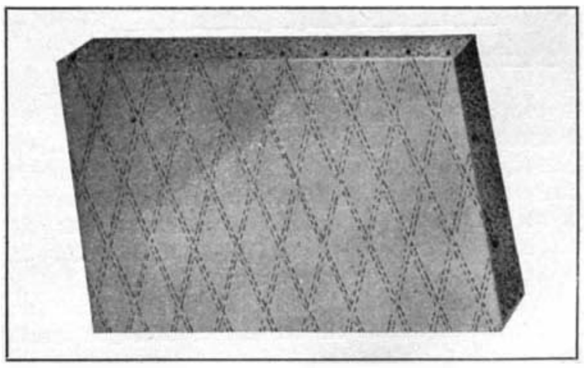

Fig. 5.—The Monier System.

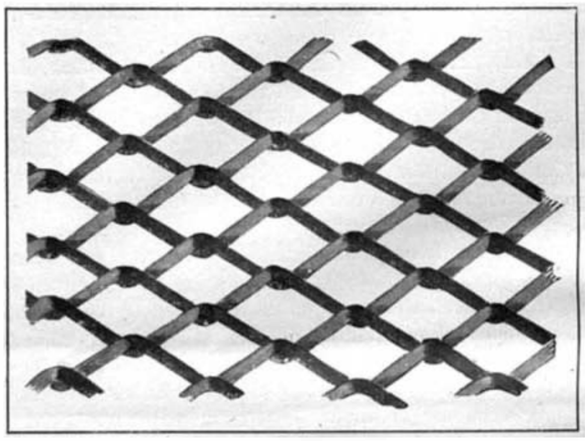

Fig. 6.—Expanded Metal.

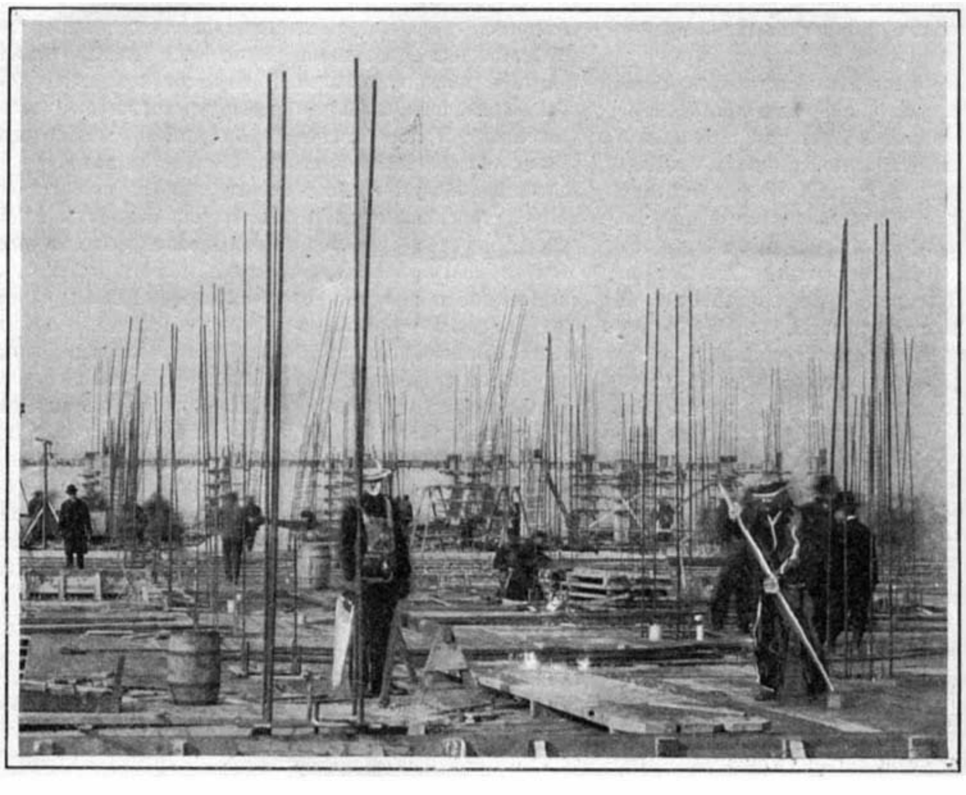

Fig. 7.—Ransome System of Erecting Columns.

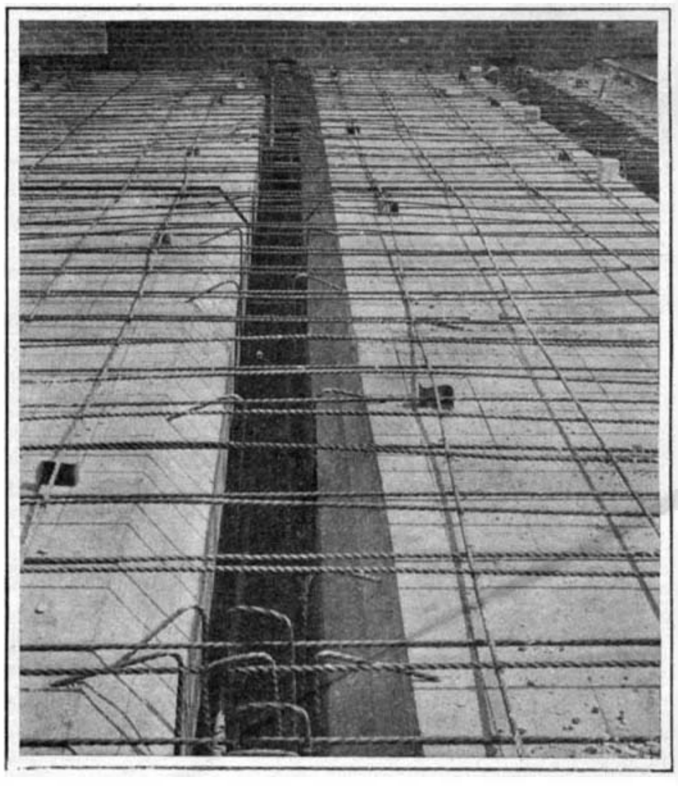

Fig. 8.—Wood Centering and Ransome Steel Bars for 50-foot Floor Span.

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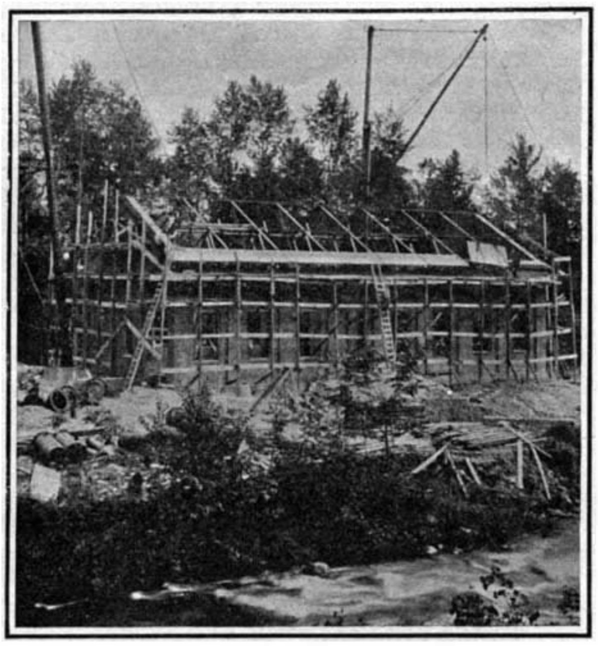


**Fig. 9.—Concrete Power Plant in Course of Construction.**

concrete. Clinton fabric consists of drawn wire of 6 to 10 gage, which may be made in lengths up to 300 feet. The system is therefore a continuous bond system, which prevents the entire collapse of a span unless the weight imposed is sufficient to break all the wires.

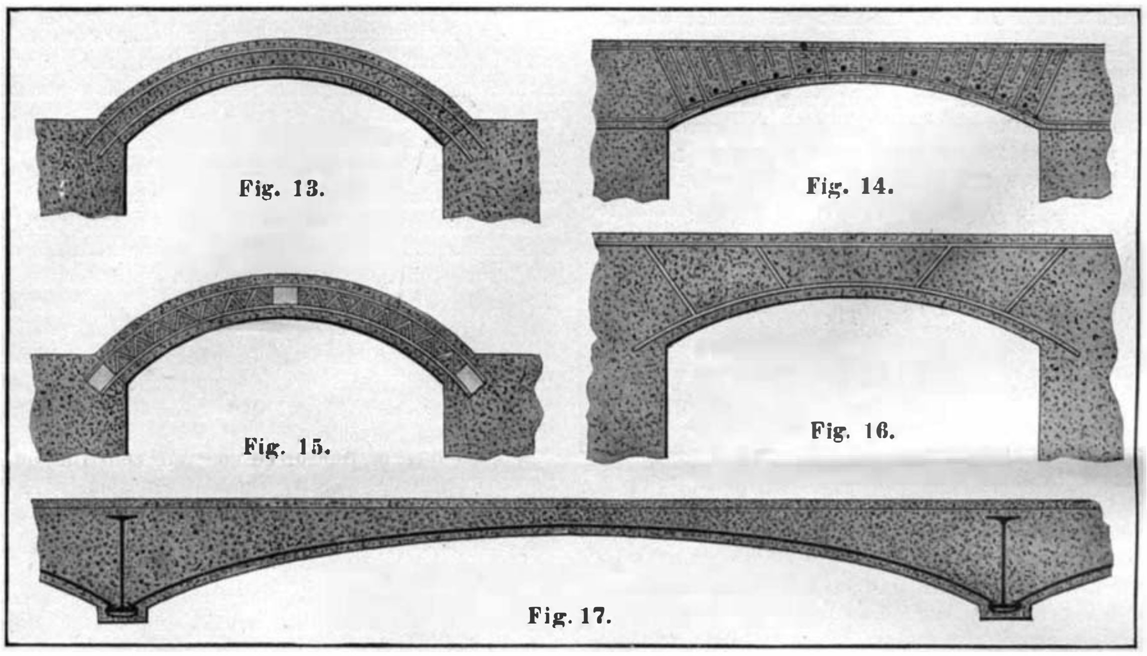
Columns and Piles.—Reinforced concrete columns are made with either square, rectangular, or circular sections. They are reinforced with from four to twenty rods, the diameters of which vary from ⅜ to 2½ inches. The rods are placed as nearly as practicable to the circumference of the column, so as to give the greatest radius of gyration for the section; but they are never placed so near the surface that they have not at least one or two inches protective covering. The steel so disposed is able to take up the tensile stresses which may be induced in the column by eccentric loading, lateral shock, wind pressure, and the pull of belting.

Columns and piles are made in wooden boxes, each consisting of three permanent sides and a fourth side which is temporary and removable. Under the patent rights of François Hennebique the reinforcing is placed in these boxes, and adjusted by gages to within one or two inches of the sides. The concrete is laid and rammed, about six inches at a time, with small hand rammers. The open side of the box is built up by battens fitting into grooves in the permanent sides, as the work proceeds; this enables inspection of the work to be made, and facilitates the placing of the ties at the proper positions. The ties are made of round wire 3-16 inch diameter and are dropped down over the top of the steel rods. They are spaced from two-inch centers at the bottom and top, to twelve-inch centers in the center of length of the column, and are intended to prevent the steel rods from spreading out under the action of longitudinal loads. Fig. 4 shows the method of joining columns to the floor.

In the Ransome columns as exemplified in a recently constructed factory building (Fig. 7) the vertical reinforcement consists of round rods with the connections made about 12 inches above the floor line. In order that these rods might be continuous the ends were threaded and connected with sleeve nuts, thereby developing the full strength of the rods. Horizontal reinforcement was also used, consisting of hoops formed by a spiral made from ¼-inch diameter soft wire, having a pitch or spacing of 4 inches in the basement columns, and gradually increasing to a pitch of 6 inches in the top story (Fig. 12).

According to Mr. Henry Longcope the first innovation in concrete piles was the sand pile, produced by driving a wooden form in the ground and withdrawing it, the hole being filled with moist sand well rammed. The next method adopted was to drive a metal form into the ground and after withdrawal to fill the hole with concrete. This was not successful, as it was open to the serious objection that on withdrawing the form, the ground would collapse before the concrete could be inserted. Still another method was introduced, which consisted in dropping a cone-shaped five-ton weight a number of times from a considerable height, in order to form a hole, which was afterward filled with concrete. This method never passed the experimental stage. Coming to more successful systems we may mention a method of molding a pile of concrete, allowing it to stand, and then driving it into the ground, a cap being used to protect the head.

Of modern systems which have proven successful Gilbreth's pile must first be recorded. Gilbreth uses a molded corrugated taper pile, cast with a core hole the entire length of the pile, which is jetted down by a water jet and finally settled by hammer blows.



**Types of Reinforced Concrete Arches.**

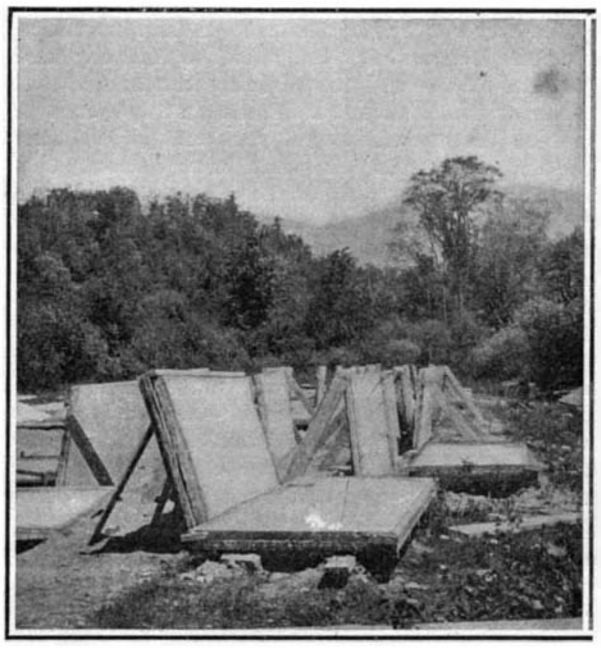


**Fig. 10.—Slabs of Concrete Ready for Roof.**

Features which recommend the Gilbreth piles are the opportunities for complete inspection before driving and the fact that they save time because they can be cast while excavation is going on. After being driven they can be loaded immediately. Naturally they present considerable skin friction. The making of these piles above the ground surface also does away with the possibility of their being damaged or squeezed out of shape by the jar occasioned by driving forms for adjoining piles.

Still another method is used by Raymond. Under this system piles are usually put in by either of two methods, the jetting method or the pile core method. The water jet system is used only where the material penetrated is sand, quicksand, or soft material that will dissolve and flow up inside the pile when the water is forced through the pipe, thus causing the shell to settle until it comes in contact with the next shell, and so on until the desired depth has been reached. The shells are filled with concrete simultaneously with the sinking process, and when necessary spreaders are attached to keep the hole in perfect line with the pipe. The ½-inch pipe is left in the center of the pile and gives it greatly increased lateral strength. If desired, the lateral strength may be further increased by inserting rods near the outer surface of the concrete. By this method, piles of any size up to two feet in diameter at the bottom and four feet at the top can be put through any depth of water and to a suitable penetration in sand or silt (water sediment).

The pile-core method is the one most generally used for foundation work and consists of a collapsible steel pile core, conical in shape, which is incased in a thin, tight-fitting metal shell. The core and shell are driven into the ground by means of a pile driver. The core is so constructed that when the desired depth has been reached it is collapsed and loses contact with the shell, so that it can be easily withdrawn, leaving the shell or casing in the ground, to act as a mold or form for the concrete. When the form is withdrawn, the shell or casing is filled with carefully mixed Portland cement concrete, which is thoroughly tamped during the filling process.

The simplex system uses another method in which the driving form consists of a strong steel tube, the lower end of which is fitted with powerful tooth jaws, which close together tightly, with a point capable of penetrating the soil when driven and also capable of

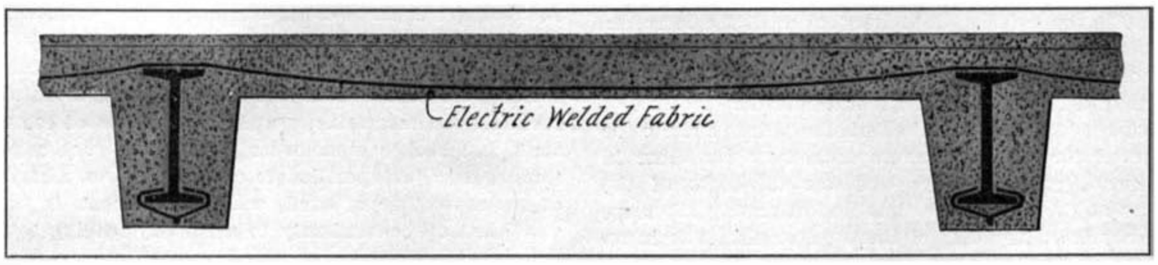


**Fig. 11.—Clinton System Using Electrically Welded Fabric.**

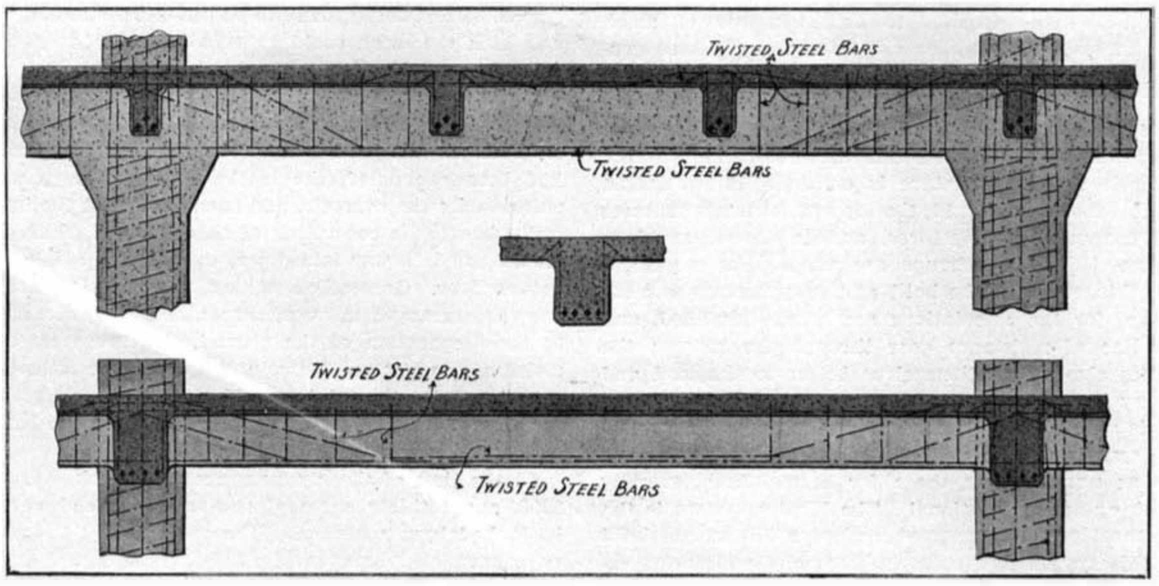


**Fig. 12.—Ransome Floor System With Beams.**

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opening automatically to the full diameter of the tube while being withdrawn. The point of the form closely resembles the jaws of an alligator. At the same time the form is being withdrawn, the concrete is deposited.

It is so evident that concrete is vastly superior to wood in the construction of piles that it is almost superfluous to mention the points of superiority. Concrete is not subject to rot or the ravages of the teredo worm, neither can the piles constructed of concrete be destroyed by fire, and no cost is attached for repairs. While it is not possible to give accurate statistics as to the life of a wooden pile, as it varies so much under different conditions, yet we know that in some cases a wooden pile is rendered worthless in a very few years, especially when the surrounding material is composed of rotted vegetation, or where the pile is exposed by the rise and fall of tides. It is also impossible to state the exact cost of a concrete pile, as it varies also according to conditions. Ordinarily speaking, a concrete pile will cost from one and one-half times to two times as much as a wooden pile; but in order to illustrate where a saving can be made, the following extract is given from a report on the piles driven at the United States Naval Academy at Annapolis, Md.:

"The original plans called for 3,200 wooden piles cut off below low water with a capping of concrete. To get down to the low water level required sheet piling, shoring and pumping, and the excavating of nearly 5,000 cubic yards of earth. By substituting concrete piles, the work was reduced to driving 850 concrete piles, excavating 1,000 cubic yards of earth and placing of 1,000 cubic yards of concrete."

In the work mentioned, the first estimate for wooden piles placed the cost at $9.50 each, while the estimate for concrete piles was placed afterward at $20 each, yet the estimate based on the use of wood piles aggregated $52,840, while the estimate based on the use of concrete piles was $25,403, or a total saving in favor of concrete of over $27,000.

In several instances piles have been uncovered to their full depth, and they were found to be perfectly sound in every particular. By surrounding the operation with the safeguards provided, it is almost impossible to make a faulty pile. The concrete is made as wet as good practice will allow. Constant ramming and dropping the concrete from a considerable height tend to the assurance of a solid mass, then the target on the ramming line or the introduction of an electric light into the form shows what is being done at the bottom of the form.

Floors, Slabs and Roofs.—The system of construction for floors, slabs, and roofs is determined by the extent of the work and the nature of the loads to be carried. If intended for small buildings and offices, the items can be made before erection (Figs. 9 and 10); but in the case of warehouses, factories, piers, and jetties, where live loads and vibratory stresses have to be borne, a monolithic structure is secured by building in molds directly on the site. For the lighter classes of monolithic structure, expanded metal is admirably suitable; it is also much used for the roofs of reservoirs, and for thin partition walls. The meshing is simply laid over the ribs or floor beams, which have been already erected, and the green concrete is applied to the required thickness, being supported from below by suitable supporting work, which is removed as soon as the concrete has set. In cold storage factories, the floor beams and ceilings are invariably erected first, the floor being laid afterward. The ceiling is then solid with the floor beams on their under side, and the floor is solid with them on their upper side, the air space between being a great aid to the maintenance of a low temperature for refrigeration.

In the Monier floors the reinforcement consists of round rods varying from ¼ inch to ⅝ inch diameter. The rods are spaced at about six times their diameter, and are crossed at right angles, being connected by iron wire bound round them. This artificial method of securing the rods takes considerable time, and is thus a somewhat costly process. To produce continuity of metal, the different lengths of rods are overlapped for about 8 to 16 inches, and bound with wire.

The Schlüter are similar to the Monier floors, but the rods are crossed diagonally, and the longitudinal rods are of the same size as the transverse ones. The Cottancin floors have their rods interlaced like the canes of a chair seat or a basket, and the Hyatt floors have square rods with holes through which small transverse rods pass. Over fifty systems of reinforcing are in use, and in most cases the only points of difference are the shape of the section and the method of attachment and adjustment.

Beams.—It is obvious that, as the span increases, a limit will soon be reached beyond which it is not economical to use plain floor slabs, for their dead weight becomes of such magnitude as to prohibit their use. We have thus to resort to a division of the main span by cross beams resting on columns, and the floor is laid on these beams, which are arranged to take as much of the load as to render it possible to reduce the thickness of the floor within reasonable limits. Reinforced concrete beams are typical of the type of construction in which the merits of two component materials are made to serve a common end; but in the particular case of steel and concrete, the actual part played by the steel is not at all well understood.

Speaking generally, beams do not differ in constructional details from floors. The same reinforcement is used in both, the only difference being, that as beams are usually deeper than floors, the shearing stresses become more pronounced, and greater provision has to be made for them by a liberal use of stirrups or vertical binding rods. In some systems the reinforcement consists entirely of straight rods, disposed in any part of the beam where tensile stresses are likely to be called into play. In others, specially bent rods are joined or welded to straight rods, and when welding has to be done it would appear that wrought iron is more suitable than steel.

It is usual to arrange the dimensions of the beams so that the whole of the compressive stresses are taken by that portion of the concrete on one side of the neutral axis; but in some cases, as with continuous beams or heavy beams of small depth, a proportion of the reinforcement is distributed along the compressed portion of the beam, the steel rods either taking up the excess of compressive stress over that at which the concrete can be safely worked, or else taking up the tensile stresses at the places where they occur over the supports. As a general rule we may take it that the economical depth for a reinforced concrete beam, freely supported at both ends, is one-twentieth the span, and is thus approximately the same as that of a steel girder of equal strength. Reinforced concrete beams are now made for spans up to 100 feet for buildings, and 150 feet for bridges. But for each class of work beyond this limit, the weight becomes excessive. Several arched ribs for much greater spans have, however, been successfully built.

The beams are made in much the same way as piles and columns; they can be made in sheds on the site, or in the actual position they are to occupy when finished. The ceiling and beams are erected first, the floor being afterward worked on the top of the beams. We thus obtain a very perfect monolithic structure in which any vibration set up by machinery, falling loads, etc., will be of much less extent than with an ordinary type of building, in which there is often a great want of rigidity, the beams and arches being loosely connected and able to vibrate independently of other parts of the structure.

Concrete being as weak in shear as in tension, provision is also required to take the shearing stresses. Some American designers have to this end patented special forms of reinforcement bar, in which each main tension bar has projecting upward from it ties inclined at an angle of 45 deg. (Kahn system). These extend to the top of the bar and take the tensile stresses arising from the shear. The corresponding compressive stress at right angles to this is carried by the concrete. The system is efficient, and on large spans, where weight must be reduced to a minimum, it has its advantages.

Thus in the Ransome system (Fig. 12) the shearing stresses at the ends of a beam are taken up by inclined reinforcing rods imbedded in the concrete at the junction of beam with column.

Arches.—Concrete has long had an extensive application in the building of arches, but until the introduction of reinforced concrete the arches that could be economically and safely constructed were limited to spans of a few feet. The general rule that the line of resistance fell within the middle third had to be observed for simple concrete arches, as for those in brickwork and masonry; and the thickness of the arches at the crown was thus approximately the same whether built in either of these materials. The introduction of steel reinforcement, however, made it possible not only to reduce the thickness of the ring for a given load-carrying capacity, but by suitably providing for the tensile stresses to enable arches of much greater span and smaller rise to be built. Some general types of arches in reinforced concrete are shown in Figs. 13, 14, 15, and 16. Fig. 13 shows an ordinary arch with top and bottom armature. In many cases where the tensile stresses can safely be carried by the concrete the top armature is omitted. In the Melan arches, shown in Fig. 14, the top and bottom armatures are connected by ligatures, and in the Hennebique arches (Fig. 15) stirrups are used. As a general rule, hinges should be built at the springings and the crown, for the calculations are much simplified, and the line of resistance goes through the hinges; the arches also adjust themselves better to the load and to any slow temperature changes, and when the centering is struck the arch can better take its bearings without cracking. The methods of calculation for arches are as numerous as those for beams, and generally speaking are as irrational. The Monier system is the one most generally adopted, and over 400 bridges built on this system now exist in Europe. In America expanded metal and Clinton electrically-welded fabric are often used. An example of the latter construction will be found in Fig. 17.

## CONCRETING THE JEROME PARK RESERVOIR.

The concreting of the westerly basin of the Jerome Park Reservoir, lying near the northerly limits of New York city, is, we believe, considerably the largest single job of concrete paving as yet undertaken. The total area of floor and side slopes of the basin is 101.25 acres, and the whole of this surface was coated with a layer of concrete, which varied in thickness from 6 inches on the floor to a maximum of 30 inches at the top of the slopes.

The figures of quantities involved are very striking. The work called for the use of 625 carloads, or 94,000 barrels, of Portland cement, 1,250 carloads of sand, and 3,125 carloads of crushed rock—a total of 5,000 carloads in all, which had to be hauled into the basin, distributed, mixed, and carefully laid in place. The task is further magnified by the fact that the preparatory leveling down and grading of the floor and slopes involved the taking out of the basin of another 5,000 carloads of excavated material.

The Jerome Park Reservoir was designed to act as a local storage and distributing reservoir within the city limits. It is divided by a central wall running approximately north and south, which divides it into a west basin (completed last year, and now in use with a maximum full capacity of 773,400,000 gallons) and an east basin, which is about 8/10 excavated and when completed will have a capacity of 1,130,000,000 gallons, or a total capacity of 1,903,400,000 gallons. The reservoir is supplied by the old and the new aqueducts, both of which lead from the great Croton Reservoir. At the northerly end of the basin is a large gatehouse, No. 7, through which the water can be discharged into either basin of the reservoir; or, if preferred, it may be taken through the conduits, which are built with the divisional wall, to the central gatehouse, No. 5, where the water can be let into either basin, or sent through the 48-inch pipe lines laid on the floor of the reservoirs (of a pair of which we present an engraving), across the reservoirs to gatehouses Nos. 2 and 3, on the westerly margin of the reservoir, or to gatehouse No. 4, on the easterly margin. From these gatehouses the water may be fed to the city mains, or returned into the basins for the better circulation of the reservoir. From gatehouse No. 4 a 48-inch pipe connects to supply the Jerome Avenue high-service station, or, if desired, the water can be passed on from central gatehouse, No. 5, south through one of two 11-foot circular conduits built in the division wall, to be discharged at the southerly end of either of the reservoirs for the purpose of thorough circulation.

The water received through the old aqueduct can be let into either basin at the northerly gatehouse, No. 7, or it may pass south through the division wall around gatehouse No. 5; or it can be diverted into this gatehouse and into the pipe lines or the reservoir basins.

It is evident that in carrying through a job of concreting on this great scale, the question of its cost was very largely dependent upon the judgment shown in disposing of the large force of labor and the enormous amount of raw material to the best working advantage. A gap was left in the central dividing wall of the reservoir, through which was laid a broad-gage track for hauling in the material. Speaking generally, the plan of operation was to lay approximately parallel tracks, north and south, as they were needed, spacing them 200 feet apart. Each track became a center from which the concreting was carried out on either side for a distance of 75 feet. Scattered along the tracks at distances which were found to be the most advantageous, were fourteen concrete mixers, and the supplies of cement, sand, and broken stone were hauled into such a position, that in juxtaposition to each mixer was a carload of stone, another of sand, while the cement, in bags, was piled up conveniently to a runway leading to the hopper of the mixer.

The concreting was laid in alternate strips about 12½ feet wide, extending 75 feet at right angles to the tracks, 75 feet being found to be the maximum distance at which the work could be economically done. The strips were laid with approximately 12½ foot spaces between them, and after the first strips laid had become hard or set, the intervening spaces were also concreted. As soon as the whole area controlled by one track had been completed, the tracks after ten days were shifted onto the concrete, and commencing at the inner end thereof, the concreting of the space on which the tracks had lain was laid down, thus giving a fair, unbroken floor. Generally speaking, the batteries of mixers were arranged in twos, threes, and fives, according to the preparation of the ground. The concrete consisted of one of cement, two of sand, and five of broken stone, and for the mixing of it there were altogether fourteen mixers employed on the bottom of the basin, and two on the northerly slope.

At the time of the commencement of work, April 1, 1905, about thirty acres of the southerly end of the basin had been concreted. The remaining 71.25 acres were completed between April 1 and October 1, 1905, by a maximum force of 1,200 men; and this in spite of the fact that one month's time was lost through a strike.