For a board floor, nailing strips are laid upon the concrete, or imbedded in it at right angles to the supporting beams. With cinder concrete the plan is sometimes followed of nailing the floor boards directly into the concrete. The objection to this is that the surface of the concrete must be leveled with great care, and it is difficult to relay the boards if a new floor is required because the concrete becomes so hard with age.

The cost of the labor of laying a concrete floor is dependent upon the character of the building. In a case under the observation of the authors where the floors consisted of cinder concrete resting upon steel I-beams, a gang of nine laborers, with a foreman (in addition to the engineman, who ran the elevator,) mixed concrete in the basement to supply a gang of eleven men, with foreman, who, on one of the upper floors, were placing

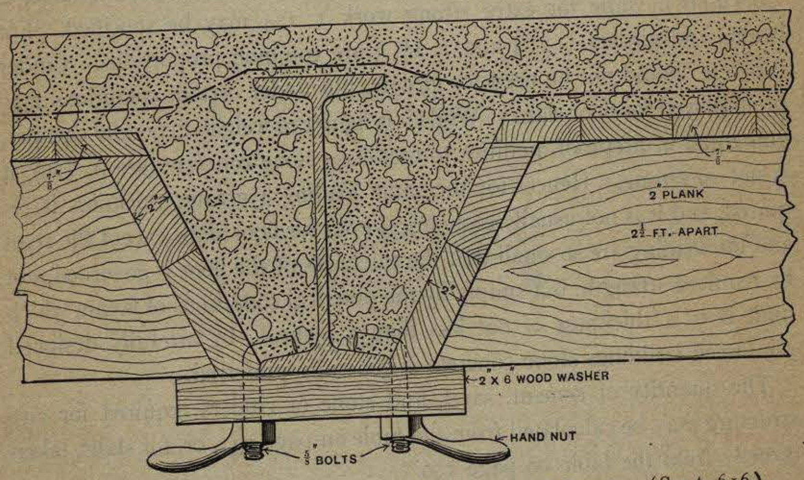

FIG. 193.—Form for Concrete Floor between Steel I-Beams. (*See p.* 616.)

metal, wheeling concrete, leveling it, and cleaning forms. Six carpenters, with foremen, were employed building the forms, which were supported from the girders, in advance of the concreters. This gang averaged 22 to 25 batches (corresponding to 17 to 19 cu. yd.) of 1 : 2 : 5½ cinder concrete in nine hours.

Floor Forms. In a large building the floor panels should if possible be so designed that the same forms may be used more than once, although they must not be removed until the concrete has attained sufficient strength to sustain its own weight and any loading which will come upon it.

If the floor slabs are supported by steel I-beams, the forms may be attached to the lower flanges, as shown in Fig. 193 a design of Mr. William F. Kearns. The steel, however, must be bent up further from the support than is shown in the drawing and carried nearer to the top of the slab to prevent cracking near the I-beam.

If the girders are also of concrete, the supports for the form must be heavy enough to carry the weight of the beam of concrete, as well as the floor slab and the men and materials upon it. The forms must be so tight as to prevent the water and thin mortar running away from the concrete and carrying off the cement. This may best be accomplished by tongued-and-grooved or bevel-edged boards, but it is often possible to use square-edged lumber if it is thoroughly wet to swell it before placing the concrete. Joints in the beam forms may be covered with cleats.

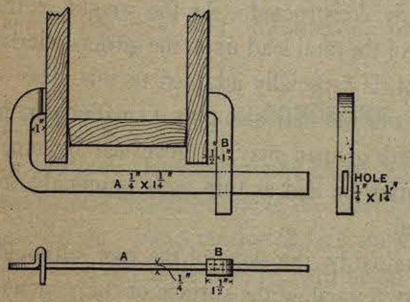

FIG. 194.—Clamp for Beam or Small Column Form. (*See p.* 617.)

A simple form of clamp for beam or small column forms, used originally in Europe, is shown in Fig. 194. The hook, *A*, is a plain piece of flat iron ¼ inch by 1¼ inches, with one end bent and curved as shown. The dog, *B*, is a square piece of iron, with the end slightly turned and a hole slightly larger than the flat iron, *A*, punched through it. This is tightened by hammering on its lower end. The outward pressure of the form boards upon its upper end causes it to bind, and prevents it from slipping back. If it fails to hold, in any case, a wooden wedge is readily driven in to assist in tightening.

CONCRETE STAIRS

The design of concrete stairs is a simple problem in reinforced concrete construction. A stairway may consist (1) of an inclined slab of reinforced concrete with the steps molded upon its upper surface, or (2) of two or, for a wide stairway, three inclined girders to form the stringers, with the stairs between them. The first method is suitable for short flights not over 8 or 10 feet in length measured on the slope, and the thickness and reinforcement are calculated as for a slab supported at the ends. (See pp. 512 to 515.) The principal reinforcement is of course in the direction of the length with occasional cross metal for stiffening. A slab 5 inches thick measured at the foot of the risers is suitable for a stairway half a story high.

When built with side girders, the dimensions of each of the latter may be calculated as a concrete beam with a longitudinal rod near the lower surface. A small rod also runs across from girder to girder at the foot of each riser so that the risers are practically reinforced beams. It is usually cheaper to construct the under side of the stairs as a slab than to build forms for each stair. The forms for the stringers may consist of planks notched for treads and risers, with boards nailed across as molds for the faces. If a fine finish is desired, the method of surfacing described for curbing may be followed. (See p. 602.)

CONCRETE ROOFS

Concrete roofs are designed and laid in much the same manner as are floors. The forms also are similarly constructed. As the weight of the roof itself forms a large proportion of the total load upon the girders, cinder concrete, because of its light weight, is especially adapted to this class of construction. The strength of the concrete may also play a smaller part in roofs than in floors, because the length of span may be governed by other conditions, and the concrete may often be laid as thin as is practicable to lay it and properly imbed the metal.

The wetness of the concrete is limited by the slope of the roof, although for a steep slope it may be necessary to confine the surface of the concrete by forms.

The proper thicknesses and reinforcement for different spans may be obtained from tables on page 512 or 515, selecting the weights from the data in the paragraphs which follow.

Roof Loads. A roof load is made up of the weights of the roof itself, the roof covering, the snow load, and the wind load.

The weight of the concrete may be obtained from the tables mentioned.

Prof. Mansfield Merriman* gives the following estimates for the weight of roof covering:

Tin, 1 lb. per square foot of roof surface.
Iron, 1 to 3 lb. per square foot of roof surface.
Slate, 10 lb. per square foot of roof surface.
Tiles, 12 to 25 lb. per square foot of roof surface.

Average may be taken at 12 lb. per square foot.

The snow load varies with the slope of the roof and the locality. Prof. Merriman allows for an approximate average 15 lb. per square foot of horizontal area.

The wind load, which acts horizontally, varies with the velocity of the wind, a usual pressure being assumed as 40 lb. per square foot of vertical surface. This pressure multiplied by the sine of the angle of slope of the roof gives the pressure normal to the surface.

In practice it is common to specify a minimum value for the roof load to

* Merriman's "Roofs and Bridges," p. 4.

include the weight of the roof covering, snow, wind and any moving loads which may come upon it. A usual value for this total is 30 pounds per square foot.

It is seldom advisable to build concrete roofs without an external covering, such as tar and gravel. However, small surfaces laid by expert workmen at one operation to avoid joints and designed with special reinforcement have given satisfaction.

Concrete is adapted to roofs of special design. One form is the dome, which is discussed and illustrated on page 626.

CONCRETE WALLS

If Portland cement concrete could be laid in thin walls as cheaply as in mass work it would be one of the most inexpensive materials for permanent construction. As a matter of fact, an experienced contractor can build a 6-inch wall of concrete which will be stronger, more durable, and no more expensive than a 12-inch wall of brick.

The chief cost in concrete wall construction is in the labor of building and raising the forms and of hoisting the concrete. The former varies with the method of construction and the number of angles in the wall. In the case of a large structure the concrete may be hoisted in elevator buckets* by power. If the building is small and the concrete is hauled up by hand in buckets to a height of, say, 15 feet, at least twice as many men will be required to fill pails, haul up, and carry to place as are needed for measuring and mixing the concrete on the platform below.

Methods of surfacing concrete walls are described on page 288. Plastering is unsatisfactory.

Cellar Walls. Cellar or basement walls adapted to withstand earth pressure may be thinner when of concrete than when built of stone, because laid as a continuous vertical slab supported at top and bottom.

For a wall of 1 : 2½ : 5 Portland cement concrete with a spreading base imbedded in the earth, a thickness of 10 inches will withstand without reinforcing metal a pressure of 6 feet of earth. If the top of the wall is strengthened by a wooden sill imbedded in or dogged to the concrete, and the sill is stiffened by floor joists, the wall becomes a slab supported at its bottom by the earth and at its top by the sill. A 6-inch wall 8 feet high will thus withstand the pressure against it of 6 feet of earth. However, ¼-inch rods, spaced about 2 feet apart in both directions, will greatly stiffen so thin a wall, and prevent cracks before the concrete is thoroughly hard. If desired, a coping of concrete wider than the wall itself may be formed at the top and a ½-inch rod placed horizontally in its inner face.

*Method used at the Ingalls Building is illustrated in *Engineering News*, July 30, 1903, p. 95

The earth must not be filled in against the back of the wall until three or four weeks after placing, unless portions of the interior forms are left in place and carefully braced.

Designs for reinforced concrete retaining walls are illustrated on page 666.

A simple form for a cellar or foundation wall is illustrated in Fig. 195. A ranger, *AA*, is lined, and lightly spiked to occasional studs whose pointed ends are driven into the ground, and kept in line by strips of wood running from it to stakes in the bank. In some cases it may be advisable also to set a lower ranger between the studs and the bank. Occasional stakes, *BB*, are driven in the ground, and a ranger, *CC*, for the inside row of studs,

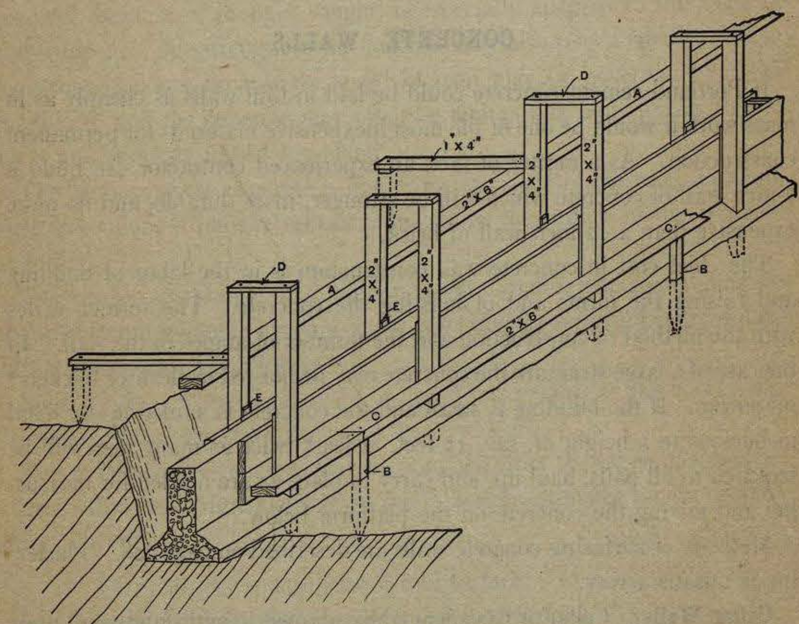

FIG. 195.—Form for Cellar Wall. (*See p.* 620.)

is laid on top of them, lined, and lightly spiked to them, while the upper ends of these studs are held by cleats, *DD*, run across to the inner row of studs. Vertical strips, *EE*, about ⅞ inch square, are placed inside of each stud for the form planks to rest against, and after a section of concrete is laid are easily knocked out, and the form planks raised to another level. The first layer of concrete is allowed to flow out under the lower plank to form a footing, above which the cellar floor is laid. The number of the laborers and the height of the forms should be such that the planks may be raised each morning, provided the concrete is hard enough to withstand the pressure of the thumb without indenting.

Walls for Buildings. Concrete walls are either of single thickness, or double with an air space between. The double wall has greater stability, and the air space renders the interior of the building less subject to changes in temperature and more completely moisture-proof. Moisture is likely to collect on the inside of a single wall.

A single concrete wall 4 inches thick with its base spread to provide a footing is at least equivalent to an 8-inch brick wall, and a 6-inch concrete is at least equivalent to 12 inches of brick. It is advisable to place small reinforcing rods, about ¼ inch in diameter, 12 inches to 2 feet apart in walls 6 inches thick or under, not only to increase their permanent strength, but to guard against accidents during or immediately after construction. Occasional projections or pilasters improve the appearance and add to the strength of a single wall.

Each face of a hollow wall is usually 3 to 4 inches thick, 3 or 3½ inches being the minimum thickness at which concrete can conveniently be placed.

The four-story factory building of the Pacific Coast Borax Company at Bayonne, N. J., designed by Mr. E. L. Ransome, is an excellent example of hollow wall construction. The thickness of both faces of the walls is 3½ inches. The walls of the first story are 16 inches from surface to surface, that is, the space between is 9 inches, while the walls of the upper stories are made thinner by reducing the width of the hollow space. The general construction of a hollow wall is illustrated in Fig. 197, page 623.

The walls of the Ingalls Building consist of concrete 8 inches in thickness, faced with brick or marble. They are supported by reinforced columns spaced about 16 feet on centers, and the portions of the wall at the floor lines, that is, between the top of the window of one story and the window-sill of the story above, are, in reality, concrete beams reinforced by two ½-inch bars placed 2 inches above the top of each tier of windows, with ¼-inch horizontal bars 2 feet apart over the remainder of the wall. In addition to the column reinforcement vertical bars are placed 2 inches from each window opening.

The marble facing is supported at each floor line by triangular projections in the concrete, and the brickwork in the stories above by square projections 3½ inches wide. The marble is also held at each horizontal joint by anchor bolts imbedded in the concrete, and the brickwork by ties of round, straight rods about 8 or 9 inches long and ¼ inch in diameter, placed through small holes in the outer forms before concreting so as to extend 5 inches into the concrete.

Wall Forms. A simple form for a cellar wall is illustrated and described on page 620. A form for a wall of single thickness is illustrated in Fig. 196 The concrete is first laid to the full height of the ribs, then the bolts are loosened, the ribs raised one-half their length, so that one-half of each still laps over the concrete to keep the wall true and straight, and the forms are again filled with concrete to the top. Two bolts to each pair of ribs are all that are required after the concreting is commenced. These are removed before the wall is hard, so that they need be simply greased and the holes filled solid full with mortar mixed in the same proportions as the

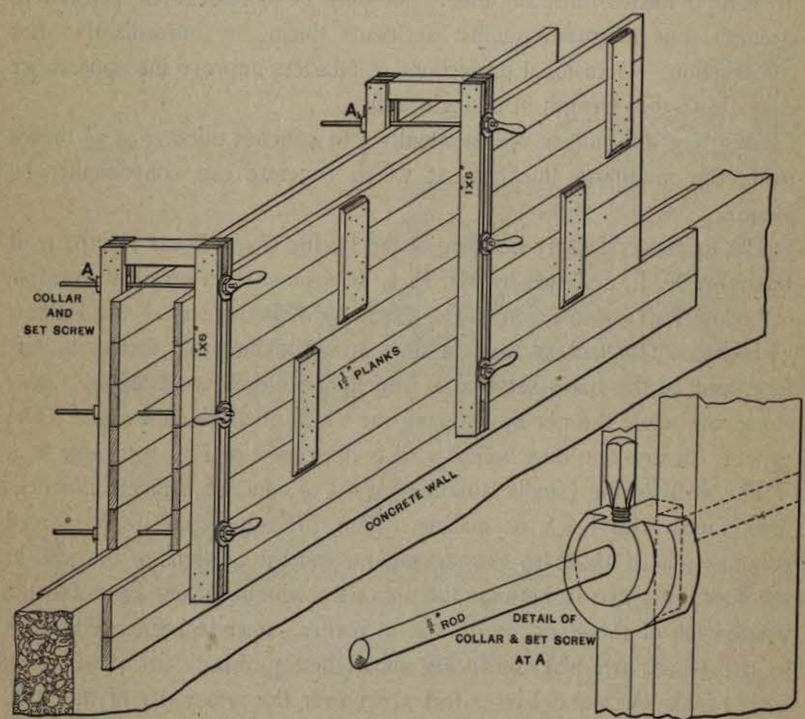

FIG. 196 —Ribs for Holding Form Plank. (*See p.* 622.)

mortar in the concrete. The collar and set screw shown in detail is convenient where the walls or columns are of various dimensions, although usually an ordinary threaded bolt with nut and washer may be used.

A design for a form for a hollow wall is shown in Fig. 197. The ribs and bolts are so arranged that the latter do not pass through the concrete, the form being raised when the concrete reaches their level. In the same figure is shown a style of tongued and grooved molding with edges slightly beveled, which may be used to form the horizontal joint instead of nailing

a triangular strip upon the planks. If the surface is finished as a monolith of course no moldings are required. The forms must be nearly watertight, to prevent the mortar running away from the stones.

Placing Concrete in Walls. For thin walls it is necessary to use mushy concrete, so soft that it must be handled quickly or it will run off the shovel. It should not, however, be so wet that the mortar is watery, or it will run away from the stones and leave pockets in the finished work. The concrete should be joggled rather than rammed, the chief object being to prevent collections of stones in one place, which will cause notice-

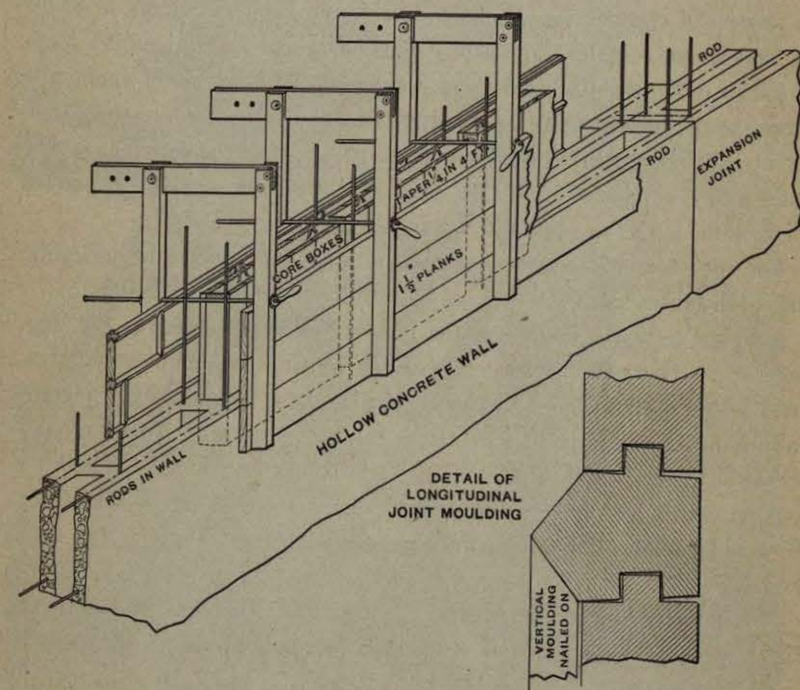

FIG. 197. — Forms for Hollow Walls. (*See p.* 622.)

able voids on the surface. The ramming of concrete is discussed on page 281, and methods of surfacing are described on page 288.

The size of stone for walls is sometimes limited to ¾ inch or one inch. However, a larger sized material, even up to 2 inches, has been used by Mr. Thompson in 4 and 6-inch walls with satisfactory results.

CONCRETE COLUMNS

Methods of design and allowable working stresses are recommended in Chapter XXI, page 488. Unless of very large diameter in proportion to the length, columns should be always reinforced, not only to strengthen them but to guard against possible emergencies. If the steel is not actually figured to take stress, $\frac{3}{4}$ or $\frac{7}{8}$ inch rods, one in each corner, are customary reinforcement. For wall columns or others where there is slight eccentricity, extra rods may be inserted on the side where there is the greatest stress. If the loading is appreciably eccentric, allowance must be made for it in the design, and the stresses and reinforcement may be computed from the analyses presented on pages 558 to 574.

The columns of the Harvard Stadium,* illustrated in our frontispiece in process of construction, range in size from 14 inches square to 24 by 33 inches, and contain $\frac{3}{8}$ and $\frac{1}{2}$-inch rods in the corners with square loops of $\frac{1}{4}$-inch rods placed around them horizontally at intervals of about fifty times the diameters of the loop rods. The allowable compressive stress for 1 : 3 : 6 concrete in columns was taken at 350 lb. per square inch. The outer wall is supported by hollow piers, 66 by 36 inches over all, 4 inches thick on the longer faces, and 6 to 8 inches thick on the ends.

The 1904 specifications of the Prussian Public Works place the horizontal rods at distances apart of not more than thirty times their diameters.

A typical section of column in the Ingalls Building is shown in Fig. 192, page 613. The rods designed to assist in bearing the compressive stress are 4 inches in diameter in the lower portion of the column, and are gradually reduced to one inch diameter at the upper stories. They are connected at the ends with pipe couplings and the joints grouted. The outer rods on each edge of the column are designed to resist the wind stresses. To avoid complication in the drawing, these are not shown at the floor level.

The construction of the molds for a concrete column is illustrated in Fig. 198, which shows a column of the Harvard Stadium under construction.

COST OF CONCRETE BUILDING CONSTRUCTION

So many factors enter into the cost of concrete buildings that it is impossible to give data which will apply to all conditions without specifying the character of the design, the size, height and shape of the building and the unit cost of materials and labor. Any structure must be accurately estimated, paying special attention to the cost of forms. A few general rules are given on page 26.

Mr. Emil Perrot† gives the following approximate average values per

* Described by Lewis J. Johnson in Journal Association Engineering Societies, June, 1904, p. 293.
† Proceedings National Cement Users' Association, 1909.

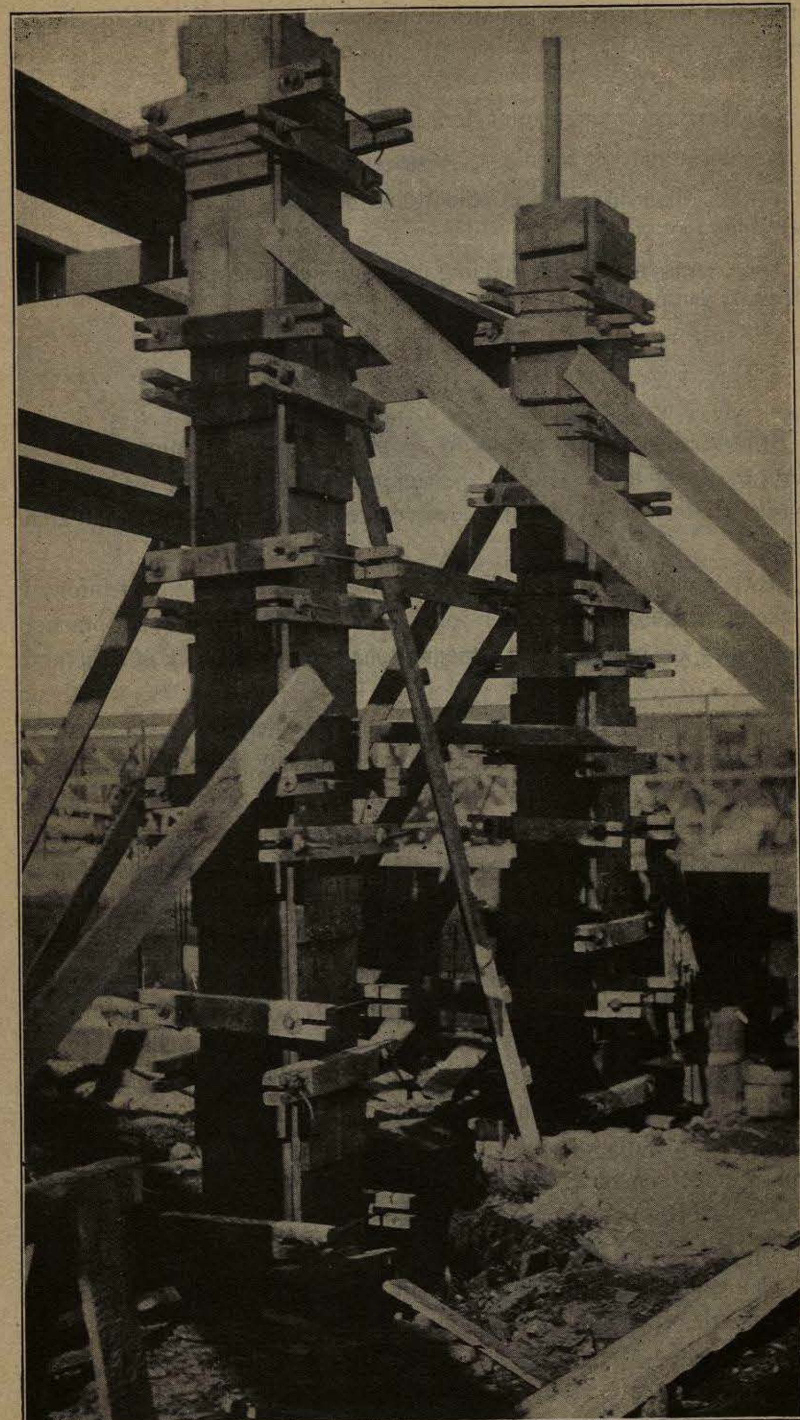

FIG. 198.— Molds for Columns at Harvard Stadium. (See p. 624.)

cubic foot for different types of buildings, which are useful for rough approximate estimates by the prospective builder:

1. Warehouses and manufactories. Cost, 8 to 11 cents per cubic foot.
2. Stores and loft buildings. Cost, 11 to 17 cents per cubic foot.
3. Miscellaneous, such as schools and hospitals. Cost, 15 to 20 cents per cubic foot.

These costs include the building complete, omitting power, heat, light, elevators and decorations or furnishings.

DOMES

Reinforced concrete is admirably adapted to the construction of domes, since the concrete can take all the compressive stresses, and the steel the tensile stresses developed in the lower curves of the dome and in the arch ring.

While a number of domes have been constructed entirely of reinforced concrete, in Europe up to over 70 foot spans, the more common practice in America has been to carry a concrete shell on a framework of structural steel.

Yale University Dome. An example of the latter type is the dome of one of the bi-centennial buildings at Yale University, New Haven, Conn., for example, 55 feet in diameter at the bottom and 34 feet high, consists of a skeleton of 24 8-inch I-beam ribs, supported at the top against a circular steel rim, with reinforcing metal imbedded in the 3½-inch thickness of concrete between them. The surface of the concrete was formed by "screeding" it with a curved templet whose length was the entire height of the arch.

Dome of Temple Adath Israel. A dome entirely of reinforced concrete is represented in cross section in Fig. 199, page 627. This is the main dome of the Temple Adath Israel at Boston, Mass., designed and built by Mr. O. W. Norcross, under the supervision of Mr. C. H. Blackall, Architect.

The dome proper, which has a span of 52 feet 9 inches, is 5 inches thick at the haunch and 3 inches thick at the crown, and is composed of 1 : 2 : 4 broken stone concrete. The reinforcement consists of expanded metal, 3-inch mesh No. 10 gage, from the tension ring to the angle of rupture, and 2-inch mesh No. 12 gage for the remainder of the section. The 5 by 4 by ½-inch angle tension ring is supported by 4 by 3 by ⅜ inch angle struts, one on each side of all the haunch windows, which in turn carry the weight of the dome to the steel girders of the roof below.

In designing the dome, the stresses were computed by Prof. William Cain's

analytical method,* the essential features being somewhat similar to the Habrich Construction as applied to domes in Europe.

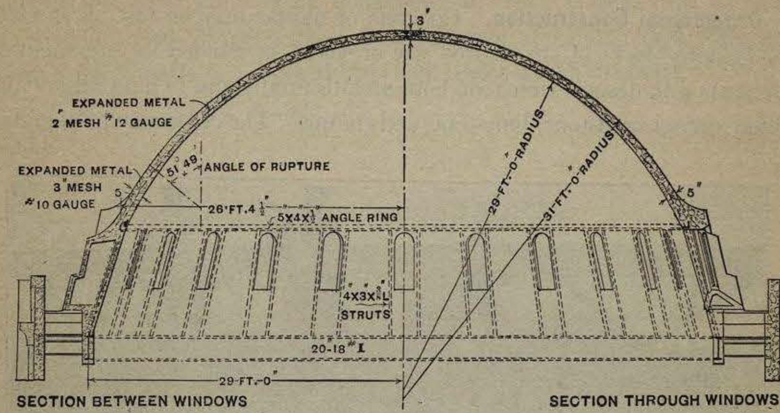

FIG. 199. Dome of Temple Adath Israel, Boston. (*See p.* 616.)

WALLS OF MORTAR PLASTERED UPON METAL LATH

Partitions of plaster from metal lathing are used extensively for fireproof office buildings and hotels, and are also adapted, when made with Portland cement mortar, to certain classes of outside walls.

For a one-story building, timber or steel posts may be set upon concrete foundations, and the walls constructed by using ¾-inch or 1-inch channel irons for studding, to which the metal lathing is attached, and then covered (on both sides) with Portland cement mortar about 2 inches thick, the studding being generally set from 12 to 16 inches on centers, the spacing depending on the height of wall. Such walls are also adapted for high buildings where steel frames are used, as the studding can be securely bolted to the steel work, and the metal lathing and cement applied in the same manner as for one-story buildings.

For curtain walls the first coat of mortar is usually mixed with one barrel of first-class Portland cement to three barrels of coarse sand, and one cask of lime putty, or paste, into which is mixed a small quantity of long cattle hair. The second coat, which is applied before the first coat is thoroughly dry, consists of one barrel of Portland cement to three barrels of sand with about a bucketful of lime putty, without hair. The finish coat is generally mixed in the proportions of one part Portland cement to two parts sand.

* Transactions American Society Civil Engineers, Vol. LV, p. 201.