in thickness, with Portland cement at about $2.00 per barrel, varies from $0.22 to $0.30 per square foot. The cost of curbing runs about $0.75 to $1.00 per linear foot without a metal strip, and 25 to 50 cents higher with it.

DRIVEWAYS

For driveways the concrete is laid similarly to that in sidewalk construction. The total thickness may be 5 inches for light travel, or 6 to 7 inches for heavy teaming. Grooving the surface in 6-inch squares affords foothold for the horses.

CONCRETE STREET PAVEMENTS

Concrete pavements in alley ways, constructed like sidewalks except marked off into small blocks, have been in successful use in Boston and elsewhere, since 1894. In 1896 a street pavement built in Richmond, Ind., by Mr. H. L. Weber, proved so successful that many other concrete pavements have been laid there, and the use has been extended to other cities. Results have been satisfactory where traffic is not too heavy, and where the very best of materials and workmanship have been employed.

The construction of concrete street pavements is similar to sidewalk construction but even greater care must be used to be sure that it is monolithic from top to bottom so that there can be no separation of layers. Unless the soil is very porous so as to drain off the water and at the same time form a non-compressible foundation, a porous material like broken stone or screened gravel thoroughly compacted and rolled should be laid for a depth of about 5 to 6 inches. Sometimes a 6-inch concrete foundation is also advisable. After laying the foundation a concrete base 4 inches to 6 inches thick is laid in proportions of about 1 : 2½ : 5 and the wearing surface must be placed at the same time or immediately following it so as to make one solid layer. The construction of the wearing surface is the most critical part of the work, for upon it depends the durability of the pavement. The best aggregate is crushed granite or trap or a mixture of this and sand. It must be free from dust and a considerable proportion of it should be as large as ¼ in. in size. Instead of using 1 : 1½ or 1 : 2 mortar, it is still better to form a true concrete, using proportions of about one part cement to one and one-half parts sand to two parts of crushed screenings. This is laid wet and may be troweled and divided into small blocks, or may be given a rough finish to afford a good foothold for horses. Expansion joints should be made along the curbs and across the street about every 30 feet apart.

CHAPTER XXIV

CONCRETE BUILDING CONSTRUCTION

The rapid development of the use of concrete both in the United States and Europe is the best evidence of its adaptability for a building material. This is exemplified in numerous structures which, not only from an engineering standpoint but architecturally as well, are models of the builder's art.

In work above ground, concrete is most extensively employed in the building of floors and roofs. Its especial availability for this class of construction has been made possible by the introduction of numerous systems of metal reinforcement, the application of which has resulted in the reduction of the thickness and brittleness of the slabs.

The fire-resisting qualities of Portland cement concrete when composed of first-class materials, such as sand, and gravel, hard broken stone, or cinders, appear both from experimental and actual fire tests to be equal or superior to those by any other material. (See Chapter XVIII, p. 327.) Moreover, its strength and permanence, when it is carefully laid and properly reinforced, are unquestioned, and by employing a wet mixture the mortar in the concrete surrounds and effectually prevents the corrosion of the metal with which it is reinforced.

Its fire-resisting quality has led to the adoption of reinforced concrete for stairways, for columns and girders, and finally for entire buildings. The growing confidence in its utility for office buildings seems to promise for it successful competition with steel fireproof construction and a wide use in this class of structures. The cost of the reinforced concrete for an office building built of this material in 1904, based on actual construction records, with cement at $2.00 per barrel delivered on the work, was about 20% less than the estimated cost of the steel and tile of ordinary fireproof construction. As the concrete portion constituted about one-fifth of the total cost of the building, the net saving is reduced to about 4%, a very considerable sum, however, when figured on a fifteen-story office building. There is also an additional saving in other materials due to the reduction in height of the building because of the thin concrete floors, and to the fewer coats of plaster, with omission of furring, on walls and ceilings.

The Ingalls Building, designed by the Ferro-Concrete Construction Company and erected in Cincinnati, O., in 1903, was the first notable example of a concrete office building in the United States. Sixteen stories high, it is entirely of concrete, with the exception of the facing of the exterior walls.

For factory building reinforced concrete is gradually superseding "slow-burning" mill construction with its brick walls and timber beams and columns. In certain cases the concrete has been found actually cheaper than the wood, three 6 story factory buildings in Cambridge, Mass., for example, being erected in 1908 at a lower cost than competitive estimates for wood and brick construction. Even if the cost for reinforced concrete runs from 8% to 10% higher than the estimate for brick walls, timber columns and girders, and plank floors since the concrete portion is only about one-half the total contract, the increased cost of the entire building is only 4% to 5%. The concrete building has greater durability and is fireproof, thus reducing running expenses and affording lower insurance rates.

For dwellings and other small buildings the cost of the forms alone may exceed that of the materials and labor on the concrete. In estimating the labor, allowance must be made for the time which is often necessarily lost in waiting for the cement to harden or the forms to be removed. For these reasons it may be more economical to work with a small gang, taking an entire day to lay the concrete to the height of one section of forms.

For the cellar and foundation walls of frame or brick houses (see p. 619), concrete is usually cheaper than rubble masonry.

A method of construction of light curtain or division walls consists in plastering Portland cement mortar upon metal lathing. A 2-inch wall thus made forms a permanent and fire-resisting partition. (See p. 627.)

Molded blocks of mortar or concrete (see p. 629), or concrete tile (see p. 629), are adapted to certain classes of structures. Under favorable conditions the cost may be less than that of a brick wall of equivalent thickness.

CONCRETE FLOORS

Concrete floor slabs are supported by steel or sometimes by timber girders, or are formed in combination with reinforced concrete girders. The metal reinforcement which is universally adopted for the slab not only reduces the thickness and weight of the floor, but prevents sudden failure, an extremely important consideration in this class of structures.

Concrete floor panels between steel girders must compete chiefly with porous tiling and brick arches. The relative cost of these three materials, while dependent upon the location of the work and market prices, is usually, all things considered, in favor of concrete. The encasing of the steel I-beams with fine concrete or mortar affords fire protection to the girders and, if desired, a continuous surface for plastering.

Design of Concrete Floors. The design of a complete floor system with reinforced concrete beams, girders and slabs is illustrated in the example, pages 468 to 474. The details of the design are also treated in Chapter XXI and the tables in the same chapter, pages 507 to 526, give means to determine very quickly the dimensions and reinforcement for different spans and loadings. Reinforced floors are strongest when made continuous over several bays provided they are properly reinforced at the top over the supports as well as in the bottom at the center. It is essential that the beam and slab shall be laid at the same operation. Slabs laid between steel I-beams, as in Fig. 193, page 616, are not so strong as when built in with reinforced concrete beams.

The arrangement of the floor beams and girders in a building of reinforced concrete depends upon so many considerations that special study is required in each case.

The smallest quantity of material is required with floor panels of short span and frequent floor beams to support them. However, very thin slabs and beams of concrete are not easy to construct properly, and there is difficulty in imbedding the metal, so that we may, in general, limit the thickness of both to not less than 3 inches. For the slabs this minimum should be raised where a floor is liable to sudden strains, such as the falling of a load, which tend to punch a hole through the floor. For beams a more practical minimum width is usually 5 or 6 inches, since the cost of the form, which is but slightly more for a large than for a small beam, is a considerable item, and a deep, thin beam is in danger of buckling and requires frequent cross beams or stiffeners.

The spacing of the beams may, therefore, be governed in some cases by the required thickness of the floor slabs and in others by their own economical construction. Similar considerations, applied to column and foundation construction, govern the design of the principal girders.

The Ingalls Building* presents an example of slabs of long span supported by heavy girders, and the factory of the Pacific Coast Borax Company† an example of thin floor slabs with frequent deep but narrow concrete beams.

In simple cases the dimensions and reinforcements of concrete floor girders may be obtained directly from the tables, pp. 509–511. More difficult problems require mathematical calculation as treated in Chapter XXI. Not only must the size of the tension rods in the bottom of the beam be considered, but also the size and location of the U-bars, the reinforcement

*See page 611.
†See page 621, also *Engineering Record*, July 30, 1898.

in the top of the beam, if required, and the proper connection with the columns. The girder illustrated in Fig. 192, page 613, is a typical design for a concrete beam supporting a heavy load, although the dimensions and reinforcement apply, of course, to a particular piece of construction.*

There are several methods of laying floors supported by steel girders, one of the most common of which is illustrated in Fig. 193, page 616. The haunches of the slab are carried down to the lower flange of the I-beam, the under surface of which may be covered with metal lathing for fire protection and plastering. The I-beam may be entirely enclosed in the concrete, but it is difficult to place the material under the lower flange. Where head room is very valuable, the top of the slab is laid flush with the top of the beams and the metal is placed between the beams instead of running over them. In either case the outline of the concrete may form the ceiling, the plastering being placed directly upon it so as to form panels, or the ceiling may be suspended from the I-beams on metal lathing.

Floors are sometimes laid as continuous slabs, imbedding simply the upper flange of the I-beams in the concrete. The forms are cheaper to construct, but the strength is less than with the haunches, and the web of the I-beam is not protected from fire. For ceilings, separate slabs may be formed resting upon the lower flanges of the I-beams. Still another type of floor consists of concrete arches sprung between the lower flanges of the I-beams, just as brick arches are formed, and filled to the floor level with cinders. They do not necessarily require reinforcement.

The metal reinforcement in a floor slab should be as near to the under surface as is consistent with durability and fire resistance. For a strictly fireproof building it is safest to allow at least an inch of concrete below the metal, but under ordinary conditions this may be reduced to ¾ inch or ½ inch, provided the concrete is mixed wet and carefully placed around and under it. If plain rods are used, they must be prevented from slipping by selecting very long lengths or by anchoring the ends, or both. If the ends are bent for this purpose, there must be a considerable thickness of concrete beyond the bend to prevent the tendency under load to straighten out and thrust through the concrete.

Safe Floor Loads. The following loading for floors, suggested for the Boston building laws by a committee of the Boston Society of Civil Engineers in 1904, represents first-class modern practice:

All new or renewed floors shall be so constructed as to carry safely the weight to which the proposed use of the building will subject them, and every permit granted shall state for what purpose the building is designed

*See also designs suggested, page 453.

to be used; but the least capacity per superficial square foot, exclusive of materials, shall be:

For floors of dwellings and for apartment floors of apartment and public hotels, fifty pounds.

For office floors and for public rooms of apartment and public hotels, one hundred pounds.

For floors of retail stores and public buildings, except schoolhouses, one hundred and twenty-five pounds.

For floors of schoolhouses, other than floors of assembly rooms, eighty pounds, and for floors of assembly rooms, one hundred and twenty-five pounds.

For floors of drill rooms, dance halls and riding schools, two hundred pounds.

For floors of warehouses and mercantile buildings, at least two hundred and fifty pounds.

The loads for floors not included in this classification shall be determined by the Commissioner, subject to appeal, as provided by law.

The full floor load specified in this section shall be included in proportioning all parts of buildings designed for dwellings, hotels, schoolhouses, warehouses, or for heavy mercantile and manufacturing purposes. In other buildings, however, certain reductions may be allowed, as follows: In girders carrying more than 100 square feet of floor, the live load may be reduced by 10 per cent. In columns, piers, walls, and other parts carrying two floors, a reduction of 15 per cent of the total live load may be made; where three floors are carried, the total live load may be reduced by 20 per cent; four floors, 25 per cent; five floors, 30 per cent; six floors, 35 per cent; seven floors, 40 per cent; eight floors, 45 per cent; nine or more floors, 50 per cent.

Weight of Concrete in Floors and Girders. The following table is based on an average weight of broken stone or gravel concrete of 150 lb. per cubic foot, and of cinder concrete of 112 lb. per cubic foot, to each of which has been added the weight of 4 lb. per cubic foot to provide for maximum weight of about 1% of reinforcing steel.

The weight of stone concrete varies not only with the proportions of the mixture (see p. 361) but also with the specific gravity of the aggregate, and for particular cases, the weights on page 3, which are based on tests made at the Watertown Arsenal and Washington University and checked by calculation from the specific gravity of different materials, may be used instead of the table. The table, however, is sufficiently exact for ordinary practical purposes.

Floors in the Ingalls Building. In the Ingalls Building at Cincinnati, Ohio, whose floors above the second floor were designed for a live loading of 60 pounds per square foot, the principal panels, which are about 16 feet square, are 5 inches in thickness, and reinforced with ¾-inch rods. Smaller panels of 3 to 6 feet in length are about 3 inches thick with ½-inch bars. The spacing of the rods varies with the length of the span. Where the panels are approximately square, the tension rods run in two directions, and where the panels are long and narrow, the tension rods run across the panel, with ¼-inch rods about 3 feet apart running lengthwise of the panel, to prevent contraction cracks. The principal girders are 32 feet long between centers of columns, and 27 inches in depth (measured to surface of concrete floor), and of width varying from 20 inches at the lower floors to 16 inches at the upper floors. Cross girders about 16 feet in length and 18 inches deep, of widths varying from 12 to 9 inches, are placed in the center of the span of the main girder, thus dividing the floor into slabs

Weight of Reinforced Concrete in Slabs and Beams. (*See p.* 611.)

Weight of Reinforced Slabs per Square Foot.			Weight of Reinforced Beam one inch wide per foot of length.	
Thickness in	Stone Concrete lb.	Cinder Concrete lb.	Depth of Beam in.	Stone Concrete* lb.
2	26	19	6	6.4
2½	32	24	7	7.5
3	38	29	8	8.6
3½	45	34	9	9.6
4	51	39	10	10.7
4½	58	43	12	12.8
5	64	48	14	15.0
5½	70	53	16	17.1
6	77	58	18	19.2
7	90	68	20	21.4
8	103	77	25	26.8
9	115	87	30	32.1
10	128	97	35	37.4

* Multiply by the length of beam in feet times its width in inches.

about 16 feet square. Fig. 192, page 613, is an isometric view showing the dimensions and reinforcement of the floor, main girder, cross girder, wall column, and wall in the fourth and fifth floors. The total distributed loading on the main girder is about 15 tons live load in addition to the weight of the reinforced concrete.

Materials for Floors. A first-class Portland cement which will meet the standard specifications given on page 29 must be selected. The rules for the selection of the aggregate are the same as for other classes of concrete. The size of the coarsest aggregate is often limited to one inch, but if well graded, so that the larger particles will not collect and prevent the flow of the mortar around the steel, the limit of size for beams, say,

FIG. 192. TYPICAL REINFORCING IN BUILDING CONSTRUCTION

(See p. 612)

panels of 3 to 6 feet in length are about 3 inches thick with $\frac{1}{2}$-inch bars. The spacing of the rods varies with the length of the span. Where the panels are approximately square, the tension rods run in two directions, and where the panels are long and narrow, the tension rods run across the panel, with $\frac{1}{4}$-inch rods about 3 feet apart running lengthwise of the panel, to prevent contraction cracks. The principal girders are 32 feet long between centers of columns, and 27 inches in depth (measured to surface of concrete floor), and of width varying from 20 inches at the lower floors to 16 inches at the upper floors. Cross girders about 16 feet in length and 18 inches deep, of widths varying from 12 to 9 inches, are placed in the center of the span of the main girder, thus dividing the floor into slabs

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Thickness in	Stone Concrete lb.	Cinder Concrete lb.	Depth of Beam in.	Stone Concrete* lb.
2	26	19	6	6.4
2½	32	24	7	7.5
3	38	29	8	8.6
3½	45	34	9	9.6
4	51	39	10	10.7
4½	58	43	12	12.8
5	64	48	14	15.0
5½	70	53	16	17.1
6	77	58	18	19.2
7	90	68	20	21.4
8	103	77	25	26.8
9	115	87	30	32.1
10	128	97	35	37.4

* Multiply by the length of beam in feet times its width in inches.

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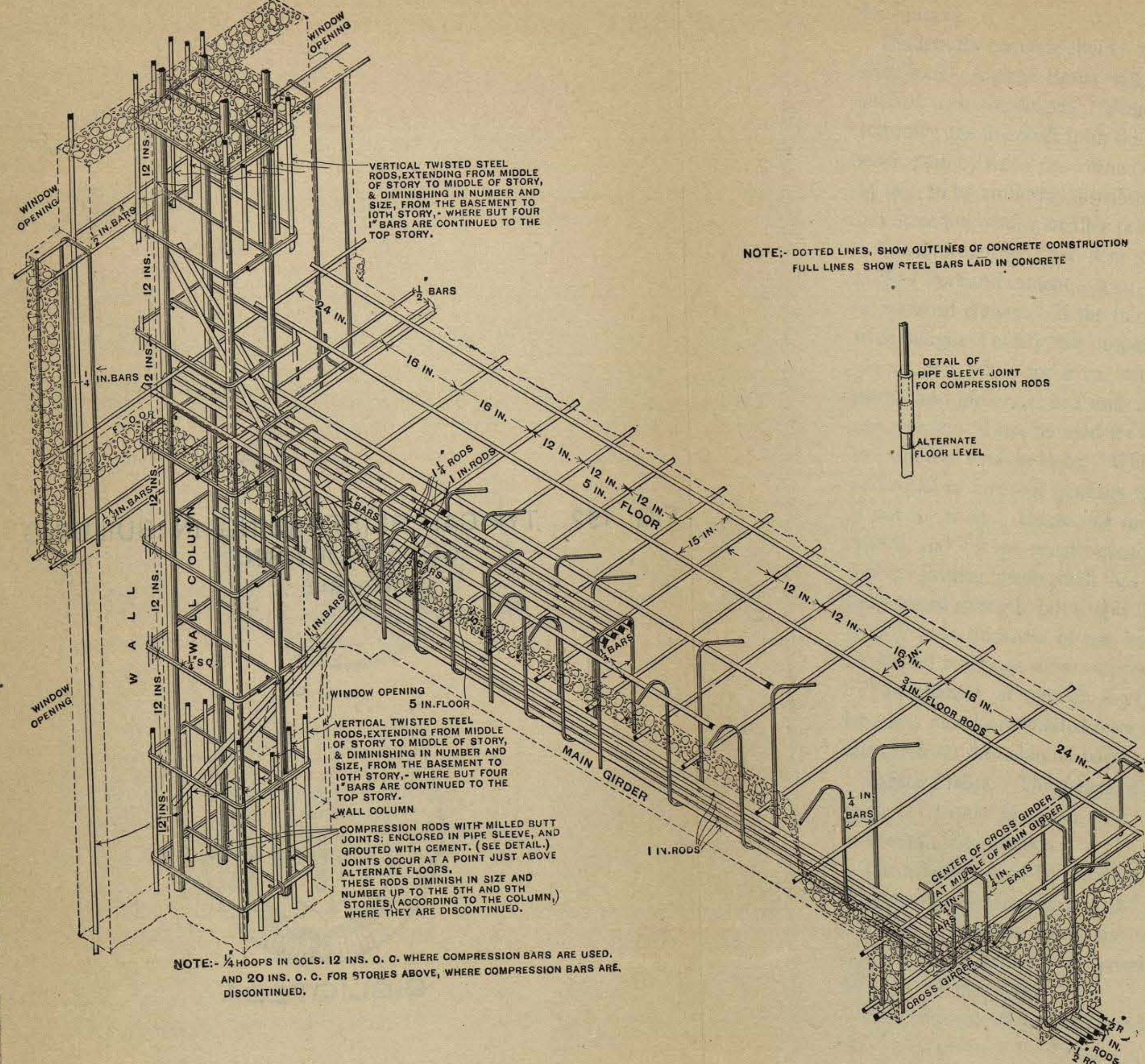

FIG. 192.—Typical Reinforcing in Building Construction, showing one-half of a main Girder, Floor and Wall Column. (*See p.* 612.)

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5 inches in width and floors not less than 4 inches thick may be as high as $1\frac{1}{2}$ inches.

Cinders for concrete should contain but little unburned coal and be free from soot. A clean cinder will not discolor the palm when held in it and rubbed with the fingers. Usually a better mixture can be obtained by screening the fine stuff from the cinders, and then, if gritty, mixing it with sand, than by using unscreened material, although if the fine stuff is found by tests to be uniformly distributed through the mass, it may be used without screening and a smaller proportion of sand added.

Usual proportions for floor concrete are $1:2\frac{1}{2}:5$, that is, one barrel packed Portland cement, 9.5 cu. ft. sand, and 19.0 cu. ft. of screened stone or screened cinders. If the thickness of the floor is such as to provide a wide margin of safety, the proportions may be $1:3:6$ (based on a barrel of 3.8 cu. ft.), while for extra strong work $1:2:4$ may be specified. For beams and girders $1:2:4$ and $1:2\frac{1}{2}:5$ are common proportions. Cinder concrete should not be used for girders, but under certain conditions may be employed for floor slabs. While it is lighter in weight, generally cheaper, and equal in fireproof qualities to first-class stone concrete (see p. 329), it is not so strong. Hence, for the same loading a greater thickness is required, and it is not usually economical even for floor slabs except the span and the loading are so small that the thickness of the floor is governed, not by required strength, but simply by the practical conditions of laying which limit it to a thickness of not less than 3 inches. In carefully designed reinforced buildings stone concrete is generally preferred.

The quantity of cement, sand, and stone or cinders required for any structure may be calculated from the table on page 231, or, for slabs, taken directly from the table on page 596.

Laying Floors. The general directions for mixing and placing concrete, given in Chapter II, p. 20, and Chapters XIV, and XV, are applicable to building construction.

The concrete must be mixed wetter than in sidewalk or basement floor construction, as described in the preceding chapter, so that the mortar may flow around the metal and thoroughly coat and protect it from rust and fire. The criterion of wetness may be that unless handled quickly it will flow off the shovel.

If the concrete floor is to provide a wearing surface, a granolithic finish may be given to it by laying a mortar wearing surface before the lower portion has set, as described for sidewalks in the preceding chapter, or the concrete may be troweled without the coating of mortar. The latter plan is amply sufficient for floors which are not subjected to excessive wear.