Conduits with Arch Top Only. The computation of the arch is similar to that for an arch bridge, and is given in Chapter XXII. The loads are carried to the sides of the arch conduit, which act as abutments. Experience indicates that it is not safe to count to a large extent upon the filling at the sides of the conduit to prevent them from cracking.

Longitudinal bars should be introduced to assist in providing for unequal settlement as well as to resist temperature stresses.

Circular Pipes. Under vertical forces the maximum positive moment acts at the top and bottom of the pipe and produces tension on the inside surface, and the maximum negative moment acts on the sides, causing tension on the outside surface*. Double reinforcement however is usually introduced.

Rectangular Conduits. Square and rectangular conduits† are designed as rigid frames loaded by weight of earth and live load acting on upper horizontal slab, reaction acting on lower horizontal slab, and earth pressure acting on sides of conduits. The stresses may be computed as in ordinary slabs (see page 421) after determining the moment by formulas given below.

Let

M_1 = negative moment at the four corners and at the center of vertical slabs, caused by vertical loads.

M_2 = positive moment in the center of the lower or upper slab, caused by vertical loads.

I_l, I_h = moment of inertia of horizontal and of vertical slabs, respectively.

l, h = span of horizontal and of vertical slabs, respectively.

w = uniformly distributed load.

Then

$$M_1 = \frac{wl^2}{12}\,\frac{lI_h}{lI_h + hI_l} \qquad (3) \qquad \text{and } M_2 = \frac{wl^2}{8} - M_1 \qquad (4)$$

The formulas apply to vertical loads as indicated above.

For earth pressure, assuming it as uniformly distributed, these same formulas may be used, but the earth pressure, which acts at right angles to the vertical load, causes positive moment, M_2, in center of vertical slabs and negative moment, M_1 at corners and also at center of horizontal slabs. For the earth pressure moments l and h must be transposed. The moments, M_1 and M_2, due to earth pressure must be computed separately and then may be combined with M_2 and M_1, respectively, due to vertical loads. The moments to be combined are of opposite signs and their sum may not represent the most unfavorable condition, which, of course, must be selected.

* See footnote † page 693.

† A table of dimensions and reinforcement for square and for rectangular conduits under different conditions is given by Sanford E. Thompson in "Concrete in Railroad Construction," published by the Atlas Portland Cement Co.

CHAPTER XXVIII

RESERVOIRS AND TANKS

A new field has been developed for concrete design in the building of covered reservoirs and filtration plants for water purification works. Plain or reinforced concrete is now commonly employed for the floors, columns, vaulted roofs, tanks, and filter basins. The Filtration Works at Little Falls, N. J.,* furnish a modern example of such construction. For open reservoirs, concrete is frequently substituted for stone masonry both in the retaining walls and core walls, and also is used for lining the bottom. Concrete tanks are used not only for water but for chemicals.

OPEN RESERVOIRS

The principles of design and construction of retaining walls have already been discussed in Chapter XXVI. The contraction cracks, which are almost certain to occur in long walls of any class of masonry, may be provided for by some form of expansion joint. Cut-off walls of clay† may be placed to prevent the passage of water through these vertical joints, or open wells‡ may be left at intervals in the walls, and after setting for a month or more filled with concrete. This concrete filling is placed preferably upon a cold day, when the contraction in the wall is greatest.

The lining for the bottom depends upon the character of the underlying soil or rock. Usually a layer of 1: 2½: 5 concrete 4 to 8 inches thick, if properly laid and troweled, will provide a lining sufficiently impervious for practical purposes.§

In small reservoirs, where earth and rock meet so as to present danger of unequal settlement and consequent serious leakage, a strip of reinforcing metal may be placed over the line of division.

COVERED RESERVOIRS

A common type of design for covered reservoirs consists of a concrete bottom, underlaid, where necessary, with 12 to 16 inches of clay puddle

*Transactions American Society of Civil Engineers, Vol. L, p. 394.

†See paper by Chas. W. Paine in Journal Association of Engineering Societies, October, 1902, p. 151.

‡Transactions American Society of Civil Engineers, Vol. L, p. 406.

§For other methods of lining see Chapter XIX on water-tightness.

and laid in the form of inverted groined arches. Piers of concrete or brick rest upon the thick haunches of the arches, and the roof is formed of groined arches supported by the piers and covered with a layer of earth. For the prevention of leakage, the principles already discussed in Chapter XIX, on Water-tightness, are applicable. The contraction of the concrete is a common source of cracks, but when comparing concrete with other kinds of masonry, it must be noted that concrete is no more liable to temperature contraction than brick and stone, the brick division walls, for instance, of the Albany Filtration Plant,* showing cracks similar in number and appearance to the cracks in the outside concrete walls.

Reservoir Walls.† Since the walls are supported at the top by a roof, there is less danger of overturning, and thinner sections may be used than for open reservoirs. This class of structure also presents opportunity for thin walls reinforced with steel.

Walls of plain concrete for shallow reservoirs or filter beds are frequently 2 feet to 2 feet 6 inches at the top, with a batter on the outside of 1 in 10.

The wall of a circular reservoir supporting a dome-shaped roof should be reinforced at the top with one or more rings of steel to resist the thrust.

Methods of forming expansion joints for open reservoir walls, described on page 695, are also applicable to covered reservoirs.

Reservoir Piers. The dimensions of the piers are readily calculated after designing the roof and determining its weight, and the weight of the earth covering. In concrete piers of dimensions suitable for reservoirs, a working pressure of 400 pounds per square inch may be safely allowed when the proportions of the concrete are 1 : 2½ : 5.

A floor of inverted groined arches will distribute the pressure of the piers if the soil is unstable. In some cases it may be necessary to place reinforcing steel in the footing (see design of column footings on page 644) to prevent unequal settlement.

In ordinary cases no reinforcing steel is needed in the piers. However, if the load upon them is extra heavy and the reduction of their dimensions is of importance, steel may be introduced to assist in carrying the compression. (See p. 489.) Also, if the columns are of considerable height, say, over 12 feet, a small rod near each corner, with occasional horizontal hoops, may be placed as described on page 624.

Reservoir Floors. The floor should be smooth, fairly impervious, and

*Transactions American Society of Civil Engineers, Vol. XLIII, p. 282.

†Methods of calculating the wall pressure, the amount of reinforcement required, as well as other tables and data relating to covered reservoir construction, are given in a paper on Covered Reservoirs and Their Design, by Freeman C. Coffin in Journal Association Engineering Societies, July, 1899, p. 1.

strong enough to resist the upward water pressure from the underlying soil when the reservoir is emptied. Mr. Coffin* considers a thickness of 3 or 4 inches sufficient when the soil is so compact that there is no danger, when empty, of pressure from without. In pervious earth he suggests 6 inches of concrete for heads as great as 20 feet.

Inverted groined arches for the floor not only distribute the pressure of the piers, but also present increased thickness of concrete around the piers where there is most danger of unequal settlement, give a minimum volume of concrete, and afford channels for the passage of the water when the reservoir is emptied.

The groined arches are laid in alternate diamonds before the piers are built, so that each pier will rest upon the corners of four diamonds. The method of laying the floor arches at the Albany Filtration Works† is illustrated in Fig. 227.

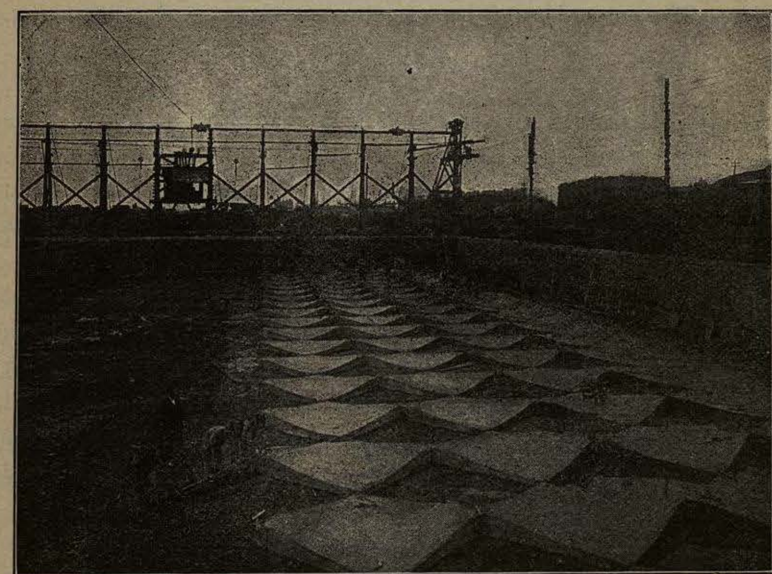

FIG. 227. — Reservoir Floor. (*See p.* 697.)

Before the concrete has set, the surface may be covered with a granolithic or mortar finish, as in sidewalk construction (see p. 600), or it may be simply troweled. Methods of treating joints between blocks and other means of waterproofing are discussed on page 346.

*See second footnote on p. 696.

†Allen Hazen in Transactions American Society of Civil Engineers, Vol. XLIII, p. 262.

Reservoir Roofs. Groined elliptic arches* are especially suited to reservoir roofs because requiring the minimum volume of concrete to support their own weight and the weight of the earth above them.

Mr. Coffin† says that the cost per cubic yard of groined arches of concrete is about one-half that of brick masonry. Although the centering costs more than brick because a tight surface is necessary, the brickwork is more expensive on account of the great amount of cutting required. He further states that "the cost of the centering, their supports, placing and removing them, is from 15 to 20 cents per square foot for the interior surface of the reservoir if it is all centered at once."‡

Mr. Leonard Metcalf has compiled a table§ of data relating to reservoirs in the United States covered with groined arches, which shows a range in span of arch from 10 feet 6 inches to 16 feet, a rise varying from one foot 6 inches to 4 feet, and a thickness at crown, in all cases but one, of 6 inches. The proportions of the concrete range from 1 : 2½ : 4 to 1 : 3 : 5.

TANKS

Reinforced concrete is cheaper for tanks than sheet steel, and more durable than wood. It is especially adapted for tanks used in paper and pulp mills to hold chemicals. When made of wood or other material which is affected by acid and bleach liquor, such tanks require constant repairs. Concrete not only furnishes a durable material, but one into which outlet castings may be readily built, and to which, if properly flanged so that the concrete cannot shrink away from the metal, the cement will adhere and form a tight joint. The gates and other connections, which are usually of brass or bronze, must be so heavy that the corrosion and wear upon them will not necessitate removal and therefore repairs to the concrete, since it is impossible to form a satisfactory joint between old and new concrete in a thin wall.

There are two distinct methods of concrete and mortar tank construction. In one, forms are built and the concrete is laid with metal reinforcement in the usual manner, and in the other, a framework of metal lathing, the shape of the tank, is constructed, and Portland cement mortar plastered upon it, as described on page 627.

*Methods of centering and placing the concrete of the vaulting are described in detail and illustrated in Mr. Hazen's paper in Transactions.

†See second footnote on p. 696.

‡Mr. Coffin also gives interesting diagrams showing quantities and costs of materials and labor for covered reservoirs.

§See Report of Annual Convention of the New England Water Works Association, 1903, *Engineering News*, September, 1903, p. 238.

Methods of Construction. The materials for the concrete must be very carefully proportioned so as to give a water-tight wall (see p. 339), and the stone should be of such size that a good surface can be readily obtained. The concrete should be mixed so wet that it will completely cover the metal reinforcement and flow against the form, and it is absolutely essential that the entire tank be built in one operation.

Mr. William B. Fuller's methods of constructing a thin wall require that the concrete be mixed very wet, so that after wheeling 25 feet it will settle down to a level in a wheelbarrow. The laborer shovels it from the barrow, throwing one shovelful in a place, and goes the entire length of the section or around the circumference, thus forming a very thin layer and preventing the separation of the ingredients.

The forms for the Little Falls tank described and illustrated on page 700 consisted of 2½ by ⅞-inch tongued and grooved boards, planed one side and placed vertically. Around the outside of the top of this cylinder of boards was placed a horizontal rib consisting of two sets of boards, 8 in each set, cut to a circle and laid in two thicknesses so as to break joints. Below this rib, a wire rope was wrapped around the forms spirally, so that the separate spirals were about one foot apart. The lower ends of the staves were held by the bottom portion already built, otherwise another rib would have been required at the bottom. The inside form consisted of three cylindrical centers built like ordinary sewer centers and placed upright one above the other, each about one foot 3 inches high. These were suspended so that the bottom of the lowest allowed for the 3-inch thickness of the concrete bottom. They were held temporarily in place sideways by pieces of board 3 inches long placed between them and the outside forms. As soon as the centers were fixed in position the concrete for the bottom was poured down through the middle of them and immediately afterward the walls were poured. This concrete flowed out slightly under the bottom center, but was easily removed after setting. There were no reinforcing angles between the bottom and the sides. The rods of the bottom extended very nearly to the outside lagging, and the side rods extended down almost to the lower surface of the concrete bottom. Two tanks were built at once, and the contract price of each was $100.

Examples of Tanks. The Filtration Plant at Little Falls, N. J., whose structural features were designed by Mr. Fuller, has a tank or well 41 feet high and 10 feet in diameter, which sustains the pressure of water either from within or from without. The walls are 15 inches thick at the bottom and 10 inches thick at the top. Rings of ½-inch Ransome twisted steel rods were placed about every 2 feet in the center of the wall, and vertical rods $\frac{3}{8}$ inch in diameter and about 5 feet apart were also set in the center of the wall, thus forming a series of hoops and posts.

On a platform in the same building is a tank 4 feet high and 4 feet in diameter. The walls are 3 inches thick, and contain rings of $\frac{1}{4}$-inch twisted rods placed about 6 inches apart, and $\frac{1}{2}$-inch vertical rods about 2 feet apart. The floor of the tank is also 3 inches thick, with $\frac{1}{8}$-inch rods spaced so as to make a 6-inch square mesh. This tank is shown in section in Fig. 228.

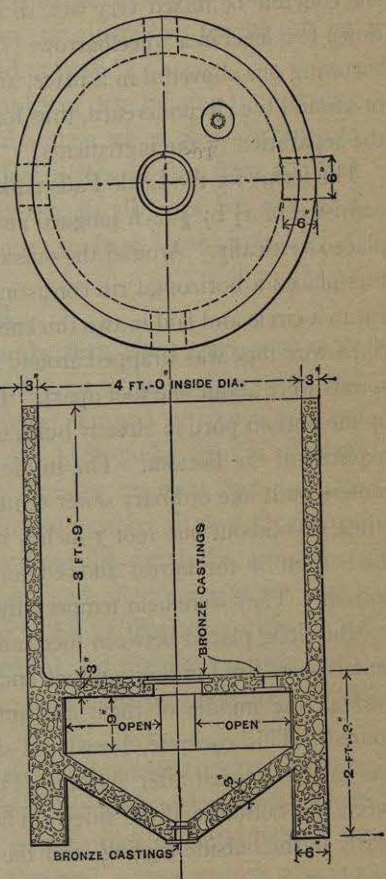

Fig. 228. — Concrete Feed Tank for Mechanical Filter at Little Falls, N. J. (*See p.* 700.)

The Illinois Steel Company, South Chicago, employ circular concrete tanks* for storing cement. These are 25 feet in diameter and 50 feet high, with walls 7 inches thick at the bottom and 5 inches thick at the top. The concrete is reinforced by rings spaced 4 inches apart and varying in diameter from one inch at the bottom to $\frac{3}{8}$ inch at the top.

At Milford, Ohio, is a stand-pipe† of reinforced mortar 80 feet high and $15\frac{1}{2}$ feet outside diameter. The thickness of the shell for the lower 30 feet is 9 inches, for the next 25 feet, 7 inches, and for the remaining 25 feet, 5 inches. The outside face is vertical. The concrete foundation is 20 feet in diameter and 6 feet thick. On top of this, T-bars, 1 by 1 by $\frac{1}{8}$ inch, were placed radially from the center to within 6 inches of the outer edge, and the shell was started directly from these. The horizontal base around and within the shell was then strengthened by a layer of 1:3 mortar 6 inches thick in the interior of the tank and 16 inches thick around the outside of it. The shell is of 1:3 mortar reinforced with T-bars 1 by 1 by $\frac{1}{8}$ inch, spaced 18 inches apart vertically and in horizontal rings varying from 2 inches

Engineering News, August, 1902, p. 148.

†See *Engineering News*, Feb. 1904, p. 184.

apart at the base to 3 inches at the top. T-shaped steel is not so suitable as round for reinforcement because of the lower adhesion. Stone with the sand would have produced a denser and cheaper mix.

STORAGE RESERVOIRS

Storage reservoirs for waterworks and other purposes are being built of reinforced concrete. The design of square or rectangular reservoirs involves problems similar to those met with in the design of retaining walls (see p. 659). In circular reservoirs, the thickness of the walls is usually based upon judgment to insure the proper placing of the concrete for water-tightness, while the horizontal reinforcement is designed to resist all the tension due to water pressure. The amount of horizontal reinforcement at various sections will vary with the water pressure, being zero at the top and increasing toward the bottom, and may be determined thus:

Let

H = height of reservoir in feet above section considered.

D = diameter of reservoir in feet.

A_h = area in square inches of horizontal steel per foot of height at section considered.

f_s = allowable unit stress in steel in pounds per square inch.

At any horizontal section the total tensile force, per foot of height, tending to rupture the reservoir on any diameter is $62.5\ HD$. Since the area of steel resisting this force is $2A_h$, we have $2A_hf_s = 62.5\ HD$, or

$$A_h = \frac{31.3\ HD}{f_s}$$

A comparatively low unit stress in the steel should be adopted, preferably not over 10 000 or 12 000 pounds per square inch, to prevent the formation of cracks in the concrete as it stretches.

Joints require special treatment to prevent leakage. (See page 284.)

In a high circular reservoir, the thickness of wall and vertical reinforcement should be considered as in chimney design (see p. 630).

Waltham Reservoir. The reservoir in Waltham, Mass., is 100 feet in diameter and 37 feet high, and the walls are 18 inches thick at the bottom and 12 inches at the top, the inside surface being vertical. The wall reinforcement consists of $1\frac{1}{8}$ inch round bars, simply lapped at the ends and varying in spacing from the bottom to the top, so as not to stress the steel beyond 12 000 pounds per square inch. The aggregates were especially graded according to the recommendation of one of the authors, and 5 per cent of hydrated lime, based on the weight of the cement, was added to increase the water-tightness.