floods draining the tributary watershed of 30 square miles of territory, from 5500 to 7500 feet in elevation, had the masonry been of reasonably good quality. The failure, therefore, was clearly due to poor workmanship and unsuitable materials. The dam was 150 feet long on crest, and was built with a central angle of about 165° opposed to the direction of the current, the up-stream face being vertical. The wall consisted of a thin facing of hand-laid masonry, not over one foot thick, the core being filled with a weak concrete of fine gravel, stone, spawls, and sand. The section of the dam as constructed is clearly seen from the photograph (Fig. 210). Considerable lime was used with the cement, which was of poor quality, and the concrete, though ten years old, possesses so little cohesion that it may be crumbled with a light touch. The cement used averaged but 1 barrel to 6 cubic yards of masonry. The failure of the dam, under all the circumstances, might have been anticipated. It is referred to here merely as an example to illustrate the natural consequences that must follow any carelessness or lack of attention to proper selection of materials and skill of construction in masonry or concrete dams that must withstand the erosive action of floods as well as normal water-pressure.

Concrete Dams of Portland, Oregon.—Among recent constructions of concrete masonry three dams designed and erected by the author for the water-works of Portland, Oregon, in 1894, may be classed as worthy of note. They were built for the purpose of forming distributing reservoirs, and were located across natural ravines, or embayments in the hills, the reservoir space being largely augmented by excavation, and the slopes covered with a lining of concrete. One of these dams, shown in Fig. 211, closes reservoir No. 1 on the side of Mount Tabor, and is 35 feet high, 300 feet long, with a base of 18 feet and top width of 6 feet. The reservoir capacity is 12,000,000 gallons. Behind the dam the material excavated from the reservoir was placed, forming a heavy embankment whose top width is 100 feet. This is such an immovable barrier that the chief function of the concrete wall is to act as a retaining-wall for the inner slope of the earth-fill, and to form a part of the reservoir lining. The reservoir receives the water delivered by a steel-pipe line 24 miles long, amounting at maximum capacity to 22,400,000 gallons daily, and distributes it to three other reservoirs, one of which is but 2000 feet distant, shown in the photograph Fig. 216, and the other two are five miles away, across the Willamette River, and designated as reservoirs 3 and 4 (Fig. 213). Reservoir No. 3, high service, has a dam 200 feet long which is arched up-stream with a radius of 300 feet. Its height is 60 feet, base 40 feet, top width 15.5 feet, carrying on its crest a driveway of the City Park, in which it is located. This is the only dam of the three which is curved, and the only one which does not exhibit some slight expansion-cracks. The dam forming reservoir No. 4, low service, is 50 feet high, 350 feet long, and 40 feet wide at base. The faces of these two dams, both of which are in the

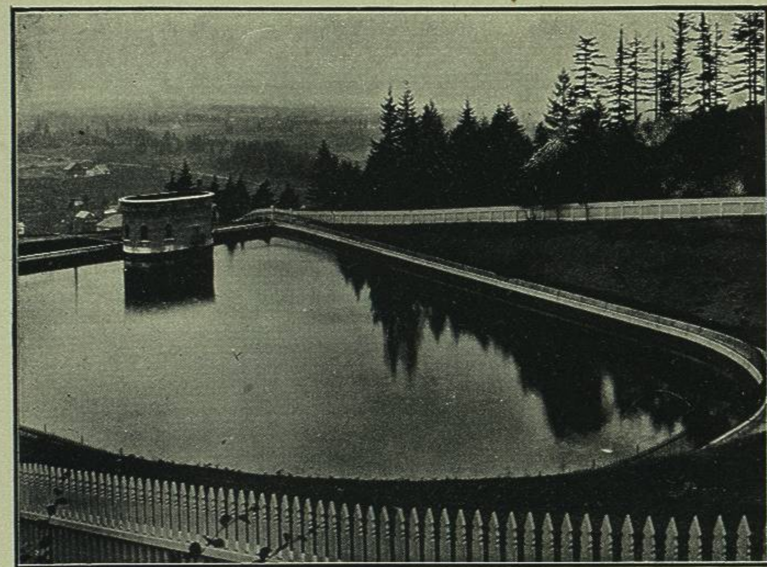

FIG. 211.—RESERVOIR NO. 1, PORTLAND, ORE., WATERWORKS. CONCRETE DAM WITH EARTH BACKING.

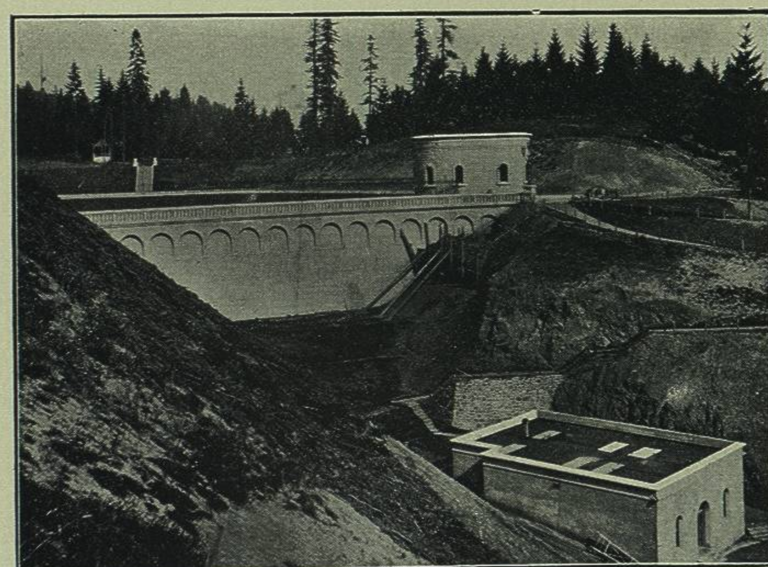

FIG. 212.—CONCRETE DAM, 60 FEET HIGH, AT RESERVOIR NO. 3, PORTLAND, ORE. POWER-HOUSE IN FOREGROUND.

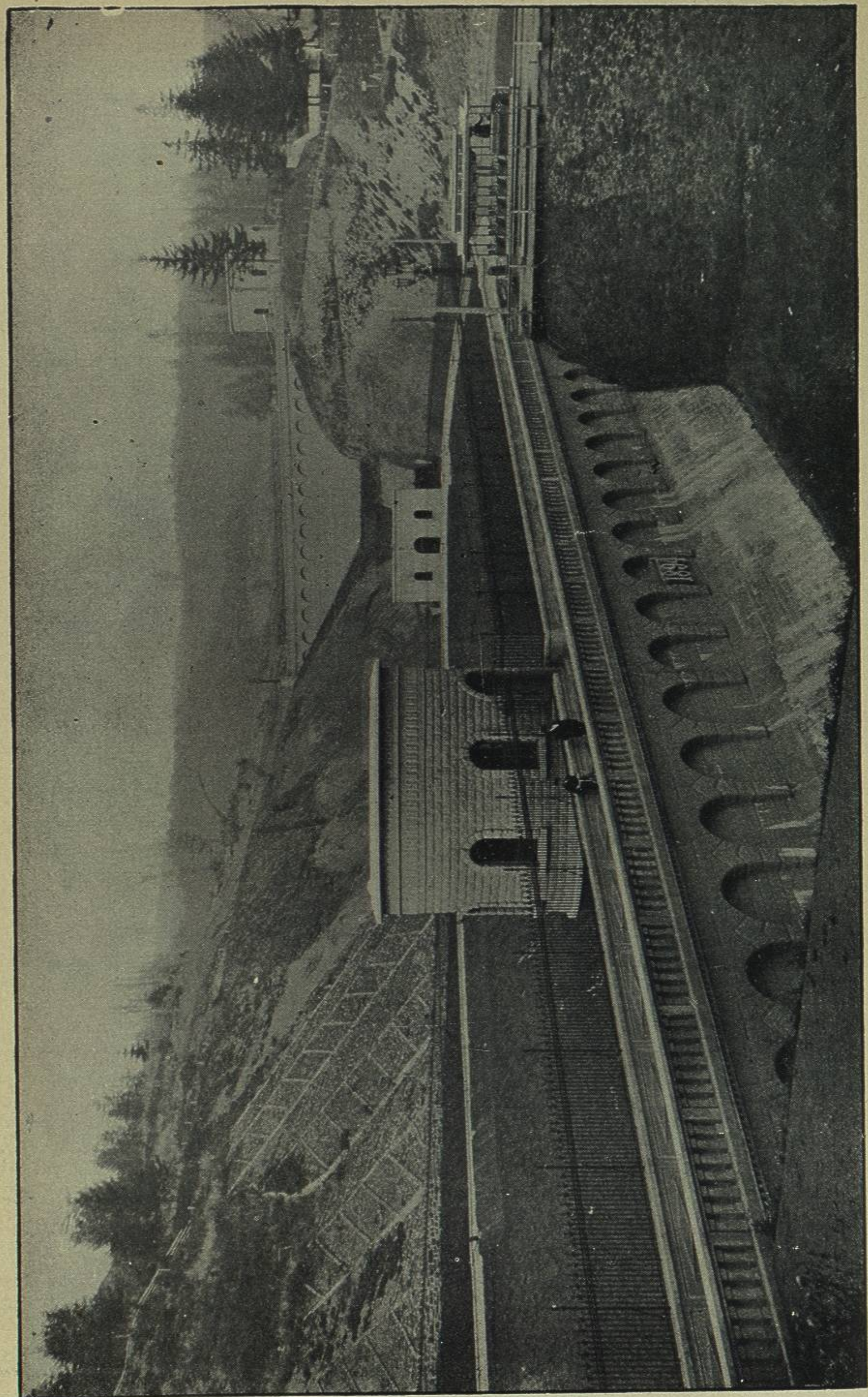

Fig. 213.—Exterior View of Reservoir Dams at Portland, Oregon.

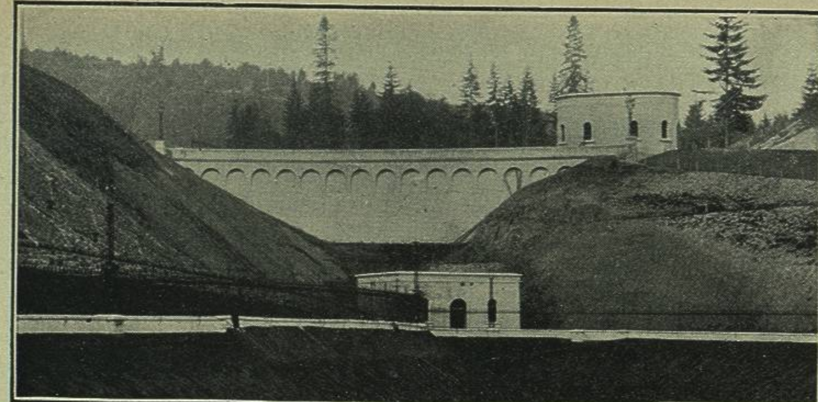

Fig. 214.—Concrete Dam at Reservoir No. 3, Portland, Oregon, Waterworks, showing Power-house below.

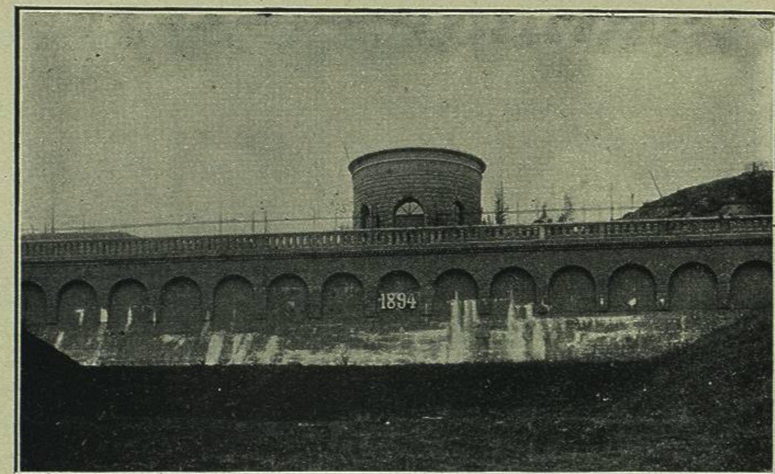

Fig. 215.—Concrete Dam of Reservoir No. 4, Portland, Oregon., Waterworks.

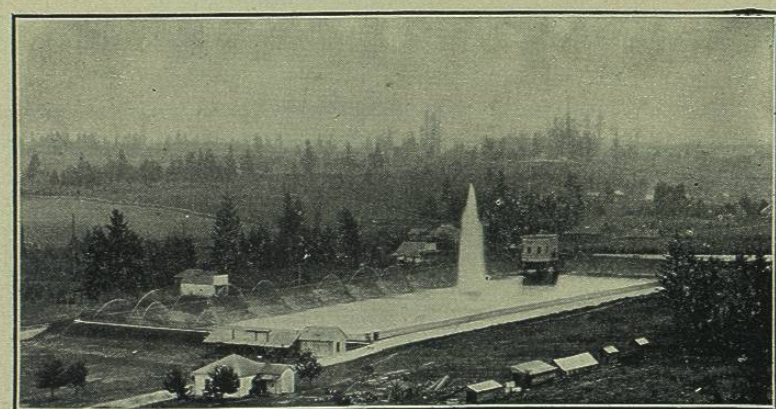

Fig. 216.—Reservoir No. 2, Portland, Oregon, Waterworks, showing Aeration Fountains.

City Park, are moulded and chiseled to resemble stone, and considerable ornamentation has been done on the parapets and about the gate-houses, as shown in Fig. 213, to which the concrete and iron construction lends itself to good advantage. It is needless to add that the dams of the dimensions given are of safe gravity profile, with ample factors of safety.

Basin Creek Dam, Montana.—This dam was built in 1893–95 to impound water for a portion of the domestic supply of the city of Butte, Montana, and is located 13 miles south of the city, on Basin Creek. It was designed by Chester B. Davis, M. Am. Soc. C. E., and constructed under direction of Eugene Carroll, C.E., Chief Engineer. The construction was described in *Engineering News*, December 17, 1892, Aug. 7, 1893, and Sept. 5, 1895, in communications prepared by these engineers, from which the following data have been taken. The dam is constructed of large stone, with spaces thoroughly filled with concrete, made of crushed granite 3 parts, sand 3 parts, and Yankton Portland cement 1 part. It was designed for an ultimate height of 120 feet above the lowest foundation, assumed to be at elevation 5780 feet above sea-level, or 30 feet below stream-bed, and was curved up-stream with a radius of 350 feet from its water-face. The thickness at base was to be 83 feet, and at top 10 feet; up-stream face vertical. At full height it would impound about 1,000,000,000 gallons (3069 acre-feet), covering an area of 130 acres to a mean depth of 23.6 feet. The dam was not completed higher than to the 5860-foot contour, or 40 feet below the projected crest, although its actual maximum height is 88 feet, of which 28 feet is below the stream-bed level, and it now can impound 200,000,000 gallons. The contents of the dam are 11,500 cubic yards of masonry. Its top length is 259 feet. Three 20-inch pipes are laid through the dam at its center, at the creek-bed level, two of which are used for blow-off. These pipes are controlled by plain cover-valves, resting on upturned elbows inside the dam, and raised by a windlass from the top. Gate-valves on the pipes below the dam give secondary control.

The materials of construction were hauled by a Lidgerwood cableway, with a clear span of 892 feet, the main cable being $2\frac{1}{4}$ inches diameter, suspended 60 feet higher than the 120-foot crest-line. This cableway crossed over the quarry, and was stretched on the chord of the inner face of the dam. The loads were swung either side of this line by using a single horse pulling from a rope attached to the load and leading back over a sheave to a snubbing-post. The limited space made the use of derricks for this purpose inconvenient. For a distance of 9 miles from the dam the main conduit to the city consists of a wooden-stave pipe, 24 inches in diameter, built by the Excelsior Wood-stave Pipe Co. of San Francisco, of which Mr. D. C. Henny, now supervising Engr. U. S. Rec. Service, was manager and engineer.

High Pressure Mining Dams.—A curiosity in the line of masonry dams is the one built in the Curry mine, at Norway, Michigan, to close

a drift 6 feet wide, $7\frac{1}{2}$ feet high, and thereby cut off a troublesome stream of water. It was built of sandstone, arched against the direction of the pressure, with a thickness of 10 feet, and laid in Hilton-cement mortar, in the proportion of 1 to 2 of sand. The dam (Fig. 217) is nearly 800 feet below the surface, and when the water fills behind it is subjected to a pressure of 277 lbs. to the square inch, equal to a static head of 640 feet, or a total pressure against the dam of over 800 tons. The dam was designed and built by Wm. Kelly, M. Am. Inst. M. E., and the most extraordi-

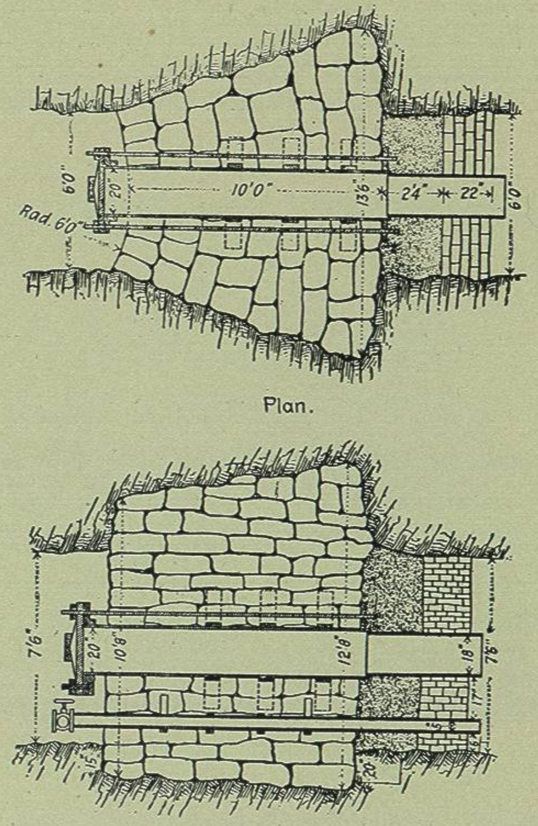

FIG. 217.—MASONRY DAM UNDER 640-FOOT HEAD, THE GREATEST RECORDED WATER-PRESSURE ON MASONRY.

nary precedent on record of masonry under such extremely high pressure. It was made practically water-tight by building a brick wall, 22 inches thick, 26 inches above the face of the dam, filling the intermediate space with concrete, and placing a quantity of horse-manure against the brick-work, which was held in position by a plank partition or bulkhead. When finally tested the leakage was but 7 gallons per minute. The dam cost \$484.27. (See *Engineering News*, Dec. 16, 1897.)

High-head Dams in Chapin Mine, Michigan.—Subsequent to the construction of this dam, two others of similar character and purpose, but under still higher pressure, were built in the Chapin Mine, Michigan.

One of these, on the east branch of the twelfth level, is at a depth of 960 feet from the surface, and resists a pressure of 355 pounds per square inch, equal to a head of 816 feet. The dam was made in the form of a circular arch, 6 feet in thickness, with an inner radius of 7.3 feet. It is set into deep skewbacks, cut into the walls of limestone surrounding it, and is formed of blocks of sandstone, laid in 1:2 cement mortar. This was backed up by concrete 5 feet in thickness on the crowning side of the arch. A 3-inch extra heavy pipe with gate-valve passes through the dam. The total load upon the dam is 1840 tons.

The second dam, in the west branch of the twelfth level tunnel, is under the same head, but being slightly higher withstands a total load of over 2500 tons. It is a simple plug of concrete, 20 feet long, about 10×10 feet in size, with an 8-inch outlet-pipe passing through it. The concrete is braced on the outer face by two heavy vertical girders of steel, behind five horizontal steel rails of heavy weight, all cemented into off-sets or recesses cut into the walls of the tunnel. The drift is 10 feet wide by about the same height.

The New Croton Dam, New York. (Fig. 218.)—It is perhaps appropriate that the commercial metropolis of the United States should have the highest dam in the world, embodying the most enormous mass of masonry in existence, and costing more money than any dam ever built. The dam occupied fourteen years in construction, having been begun September, 20, 1892, and completed January 1, 1907, at a total cost of $7,631,185.69, which included the construction of 20 miles of new highway and the reinforcing of 3 miles of the old Croton aqueduct.

The excavation for the foundations involved the removal of 1,821,400 cubic yards of earth and 400,250 cubic yards of rock. The masonry in the structure has a total volume of 855,000 cubic yards.

The dam has a maximum height of 297 feet above the lowest foundations, a base width of 296 feet at the level of 131 feet below the original river-bed, and a length of 2200 feet on the crest, including a masonry waste-weir 1000 feet in length. The width on the crest is 18 feet at a height of 14 feet above the spillway level, but a roadway 19.5 feet wide is carried over the top of the dam by corbeling out near the top to get the necessary width, which is accomplished by a series of ornamental arches, which greatly add to the architectural effect. The area of the reservoir formed by the dam is about 3360 acres, and its capacity is

about 180,000 acre-feet. The average cost per unit of storage is therefore about $42 per acre-foot.

The dam was designed by the late Alphonse Fteley, Past President Am. Soc. C. E., who carried on construction for nearly eight years, until January 1, 1900, when he resigned and was succeeded by W. R. Hill, M. Am. Soc. C. E. After the resignation of Mr. Hill as chief engineer of the Aqueduct Commission, J. Waldo Smith, M. Am. Soc. C. E., was appointed and served for two years, succeeded by Walter H. Sears,

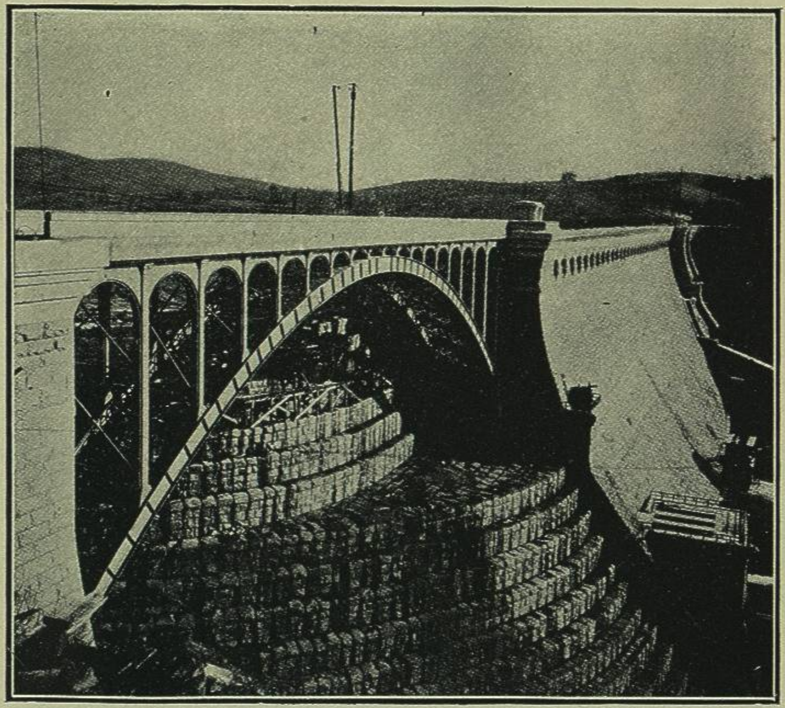

FIG. 218.—NEW CROTON DAM, N. Y. SPILLWAY IN FOREGROUND SPANNED BY BRIDGE.

M. Am. Soc. C. E. The work was directly supervised for the first twelve years by Chas. S. Gowen, M. Am. Soc. C. E., as division engineer.

The Cross River Dam, New York (Figs. 219 and 220).—The Aqueduct Commission of New York City have under construction and practically completed a high masonry dam for storage of water on Cross River, a branch of the Croton River, near Katonah, N. Y., to the extent of a total capacity of 9,000,000,000 gallons (27,540 acre-feet) at a cost under the contract awarded to MacArthur Bros. Company and Winston & Co. of $1,246,211.60.

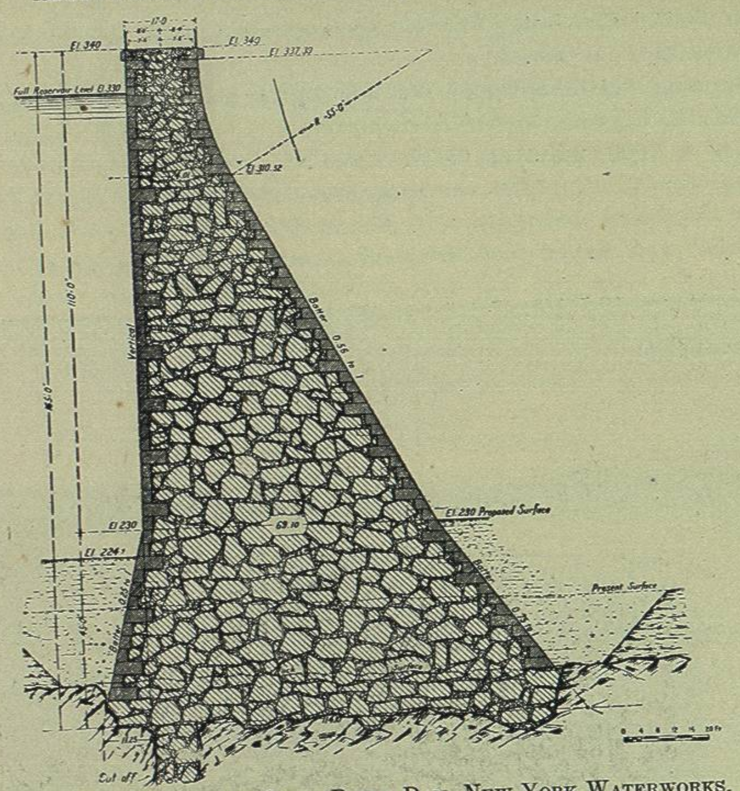

FIG. 219.—PROFILE OF CROSS RIVER DAM, NEW YORK WATERWORKS.

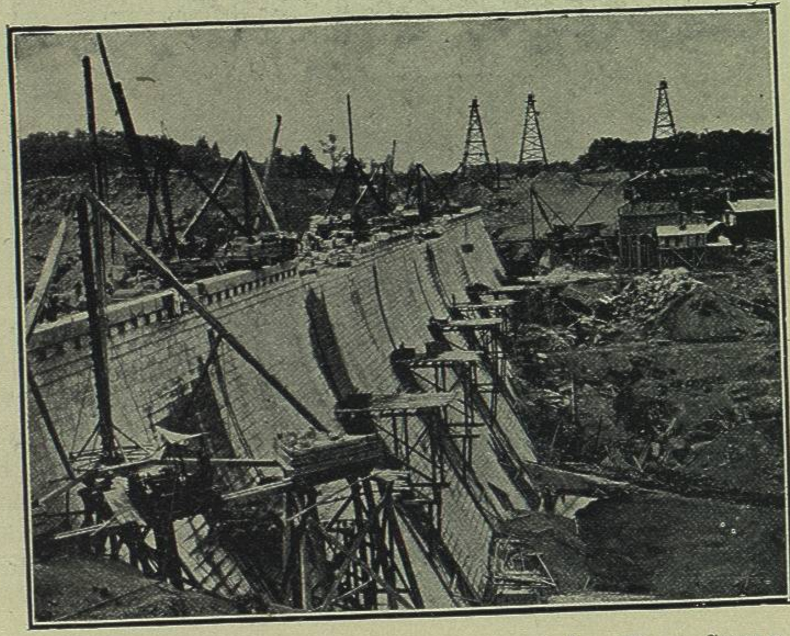

FIG. 220.—THE CROSS RIVER DAM FOR NEW YORK CITY WATER SUPPLY.

The dam will have a maximum height of 170 feet above the foundation, and a crest length of 772 feet. The width on top is 23 feet, and at base 127.7 feet. The total volume of the masonry is computed at 155,000 cubic yards. It consists of cyclopean rubble, laid between facing walls of concrete blocks, 2 to 3 feet wide, 3 feet in depth at bottom courses, diminishing to 2 feet at the top. The concrete of those blocks is mixed in the proportions of 1 of cement, 2.3 sand, and 4.7 broken stone, moulded in steel-faced moulds to produce a smooth surface. These blocks are set in rich mortar, consisting of 1 of cement to 2.5 of sand and pointed with 1:1 mortar. The blocks have a maximum weight of 6 tons. The concrete of the heart of the dam is mixed in the proportion of 1:3.2:5.8 into which large blocks of stone are imbedded.

The work was constructed under the charge of Walter H. Sears, M. Am. Soc. C. E. J. Waldo Smith, M. Am. Soc. C. E., is chief engineer of the Aqueduct Commission, Prof. Wm. H. Burr, consulting engineer.

The profile of the dam is shown on Plate No. 3. At its southerly end it is continued by an earth embankment with masonry core-wall 150 feet long, while at the northerly end is located a spillway constructed along the hillside a distance of 240 feet.

The Croton Falls Dam, New York.—Quite similar in design and height to the Cross River dam is the structure also being built by the Aqueduct Commission of New York City on the west branch of Croton River, near Croton Falls, N. Y. The dam will have the same profile and crest width, but its length will be 1095 feet, terminating at the north end with an abutment from which an earth dam with masonry core-wall will be continued 100 feet further. The spillway is to be 700 feet long, constructed along the hillside nearly at right angles to the direction of the dam.

Mr. Walter H. Sears is also chief engineer of this work. The reservoir will have a capacity of 14,000,000,000 gallons (42,840 acre-feet).

Spier Falls Dam, New York.—The Hudson River Water-Power Company in 1900 to 1905 constructed a high masonry dam across the Hudson River, 9 miles above Glen Falls, N. Y., having a height of 154 feet, a base width of 112 feet, and a thickness of 17 feet at top, which is 10 feet above the full reservoir level. At the original surface, which is 64 feet above the lowest foundation, the thickness is 74.1 feet. The up-stream side is vertical for 41 feet from the top, thence batters 5.7% to the bottom. On the down-stream side it is vertical for 4 feet, where a vertical curve of 81.74 feet radius continues 58.4 feet further, to where a batter of 1 to 1.045 begins. From the original ground level to the base the slope is 65%. The main dam, a section of which is shown in Plate III, extends across the river channel a length of 552 feet. This is continued by an overflow rollway weir section in masonry 817 feet long, 10 feet lower than the crest of the main dam. The total volume of masonry was 180,000 cubic yards. It is of the class known as cyclopean masonry, composed of large blocks of granite imbedded in a mortar of concrete, comprising about 30% of the mass.

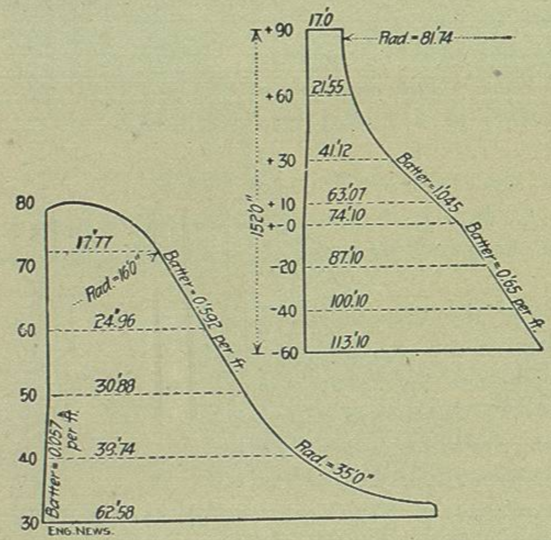

FIG. 221.—SPIER FALLS DAM, N. Y. PROFILES OF OVERFALL AND ABUTMENT SECTIONS.

The dam creates a reservoir 5.5 miles long, from which a power-head of 80 feet is derived, furnishing 20,000 H.P. at the minimum low water.

The dam was built under the supervision of Mr. Charles F. Parsons, chief engineer.

The Ithaca Dam, New York (Figs. 222 and 223).—One of the curiosities of recent dam construction is situated two miles from the city of Ithaca, on Six-Mile Creek, in a narrow rock gorge, with vertical walls but 90 feet apart. The dam was designed by Prof. Gardner S. Williams, M. Am. Soc. C. E., of Cornell University, who was inspired by the narrowness of the site to attempt a structure of most unusual slenderness and peculiar form.

It was intended to be 90 feet in height, with a radius of 57.75 feet on the down-stream face, in the shape of a section of a spherical shell, with overhanging crest. In deference to popular distrust of the safety of the structure, it was finally reduced to the height of 30 feet above

base, and finished off with an up-stream batter of 45° and a top thickness of 1 foot. The maximum thickness is 7.75 feet. The dam is composed of concrete, mixed in the proportion of 1 part cement, 2 parts sand, 2 parts gravel, and 2 parts broken stone, crushed to pass a 4-inch ring. The concrete was placed between thin walls of vitrified paving-brick, laid in a single course on each face, in cement mortar anchored into the body of the concrete by flat steel bolts, $1\frac{1}{2} \times \frac{1}{8} \times 7$ inches, turned up $\frac{1}{2}$ inch at each end and placed at every fifth brick in every fifth course.

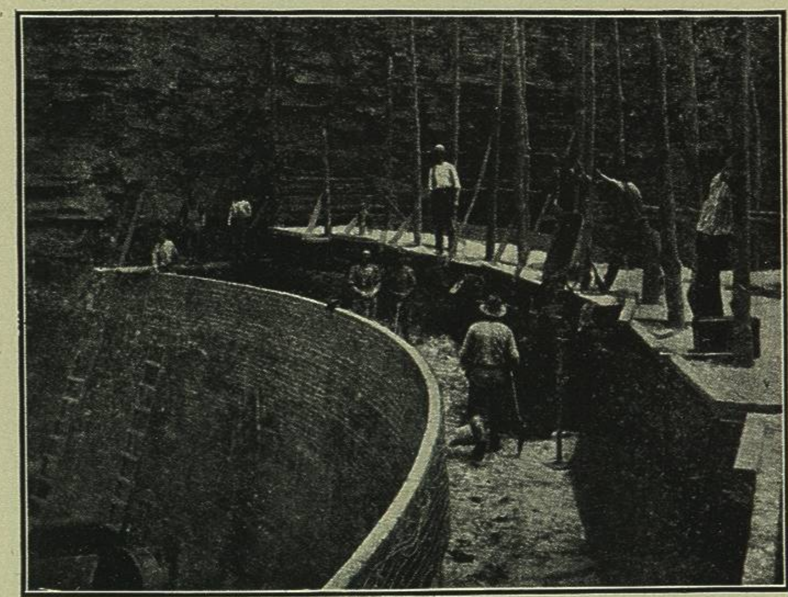

FIG. 222.—ITHACA DAM, NEW YORK, ILLUSTRATING CONCRETE CONSTRUCTION BETWEEN BRICK-FACING FORMS.

Inside the brick facings is a layer of rich cement mortar, 3 inches thick, in which are imbedded bands of steel, 3 inches wide, $\frac{3}{8}$ inch thick, placed 4 feet apart, extending entirely around the structure, and tied through the dam every 4 feet by $\frac{5}{8}$-inch steel rods, having a nut on each side of the bands. Over the steel frame thus formed is a wire netting with 4-inch mesh imbedded in the mortar.

The dam cost $25,000 and required the following quantities: Excavation, 500 cubic yards; concrete, 1000 cubic yards; brick, 120,000 (240 cubic yards); steel, 5000 pounds; cement, 1800 barrels. All concrete was put in very wet. The brick walls were laid flat, 3 to 4 feet in advance of the concrete and obviated the use of other forms.