obviate this tendency to some extent, and to assist in closing the cracks as the reservoir filled, the curved form was adopted.

"It has been observed that the curved form does not render the structure altogether immune from cracking, and the cracks occur generally at about one-third of the length of the dam from the wings, commencing at the crest, first as a very fine crack and afterwards opening out and extending down the wall a distance of one-third to one-half of its height, and opening and closing as the reservoir empties or fills. It was thought that the introduction of an iron tie-bar in the crest of the dam to take the tensile stress due to contraction, would completely preserve the work from cracking. It has been proved in other works that the temperature in the heart of the dam, say 3 feet from the surface, is constant, from which it may be argued that in order to ensure safety from cracking it is only necessary to protect from tensile stress the upper or thinner part of the dam where the cracks invariably originate."

As a result of this reasoning three lines of 70-pound "T" rails were laid six inches below the level of the weir overflow, jointed with fish-plates and embedded in the concrete. The cost of the dam was £9566 ($44,500). The inner face for a thickness of 18 inches consisted of 1 of cement, 2.5 of sand and 3.5 of crushed stone to pass through a ring of ½ inch diameter, and the outer face for a thickness of 6 inches was made of concrete composed of 1 of cement, 3 of sand and 5 of crushed stone, passing a ring of 1½ inch diameter. The heart of the dam was built of blocks of stone, set in concrete, making what is locally known as "plum concrete," each stone having 6 inches of concrete all around, and no stone being laid nearer than 18 inches to the inner face, nor 6 inches to the outer face, nor 2 feet to the foundations. The stones were not larger than 16 cubic feet nor smaller than 2.5 cubic feet, roughly squared and placed with their longest dimensions normal to the axis of the dam. The proportion of "plums" was 33% of the whole.

Barossa Dam, South Australia.—One of the most remarkable of the recently constructed dams in Australia is that completed in February, 1903, by the South Australian Government at Barossa, for the domestic supply of the town of Gawler and surrounding farming district, including a small amount of irrigation, the total annual supply available being about 1,000,000,000 imperial gallons, or 3675 acre-feet. The dam is built entirely of concrete, as an arch, curved up-stream with a radius of 200 feet on the up-stream face (Fig. 262), the total length of the crest being 472 feet, the chord subtending the segment of a circle being 370 feet and the versed sine about 133 feet. The dam has a thickness at top of but 4.5 feet, and a maximum thickness at base of 45 feet, the extreme height being 113 feet, or 95 feet above the stream bed. The up-stream face is vertical, while the down-stream face has a batter of 37.14% from a point 27.34 feet below the

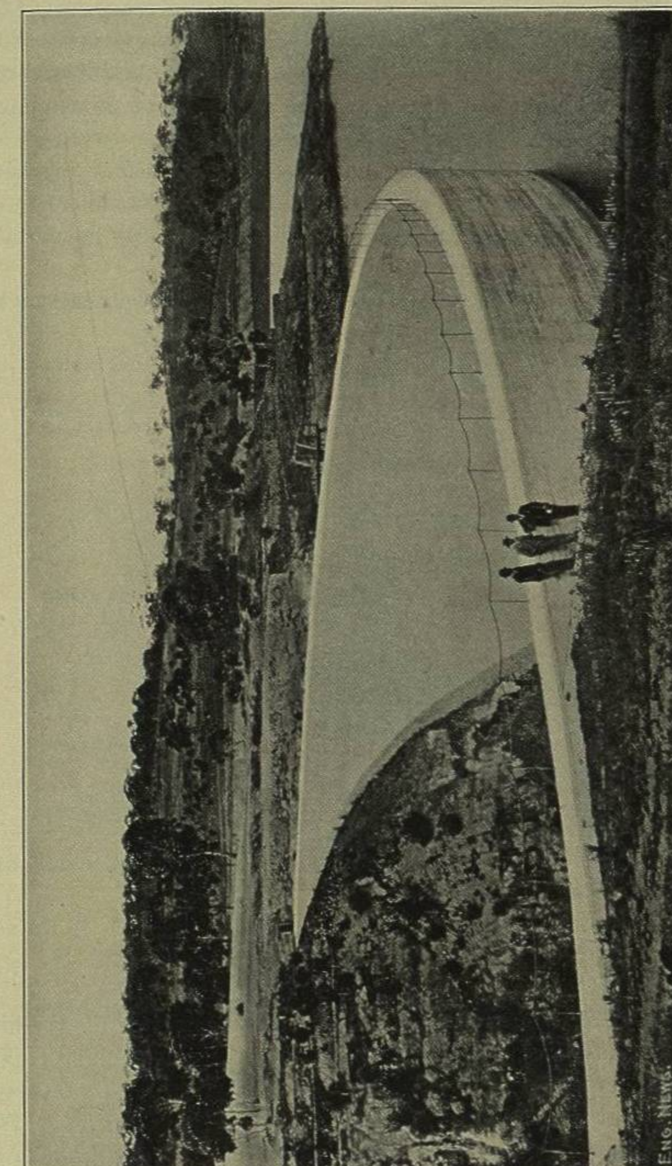

Fig. 262.—Barossa Dam.

top to the base. It contains 17,975 cubic yards of rubble concrete, of which 2215 yards, or 12.3%, are large stones or "plums." The average cost of the concrete was $9.30 per cubic yard, and the total cost £169,947 ($827,000). It was estimated that a saving of $217,000 was effected by the substitution of an arched concrete dam for a structure of gravity type as originally proposed.

The dam is built in a subsidiary basin of 3675 acre-feet capacity, supplied by a tunnel 7400 feet long from the Para River. By this arrangement only clear water is taken into the river after the muddy floods have passed.

The main outlet pipe is 22 to 18 inches diameter, 7 miles long to the

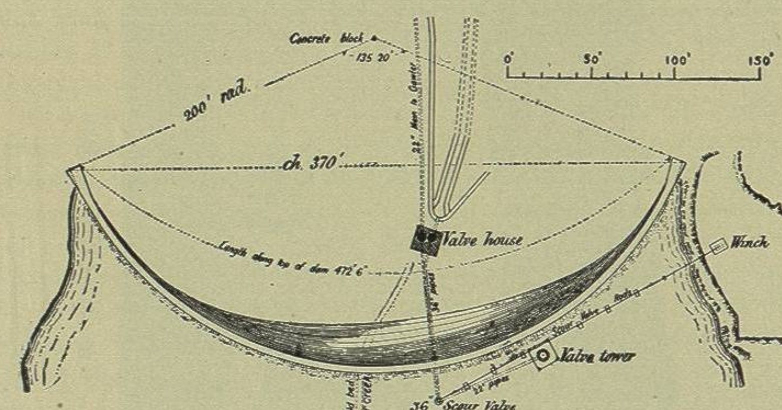

FIG. 263.—BAROSSA DAM.

town of Gawler, and is constructed of steel by the locking bar principle first used on the famous Coolgardie pipe line.

The top of the dam for the upper 20 feet is reinforced with 18 lines of 40-pound steel rails, joined with fish-plates, and imbedded in the concrete. The range of temperature during construction was from 30° to 168° F. Observations taken after completion during six days upon which equal extremes of 50° prevailed, the top of the dam was found to have moved up-stream to the extent of $\frac{7}{8}$-inch, showing an expansion of about 1.5 inch in the total length during the interval of the observation. This backward and forward movement of the dam appears to produce no cracking of the structure, which remains in an entirely satisfactory condition.

Coolgardie Dam, Helena River, Australia.—The daring and costly project for the supply of the desert mining region of Coolgardie, by pumping 5,000,000 imperial gallons daily through a pipe line 153.5 miles long, is

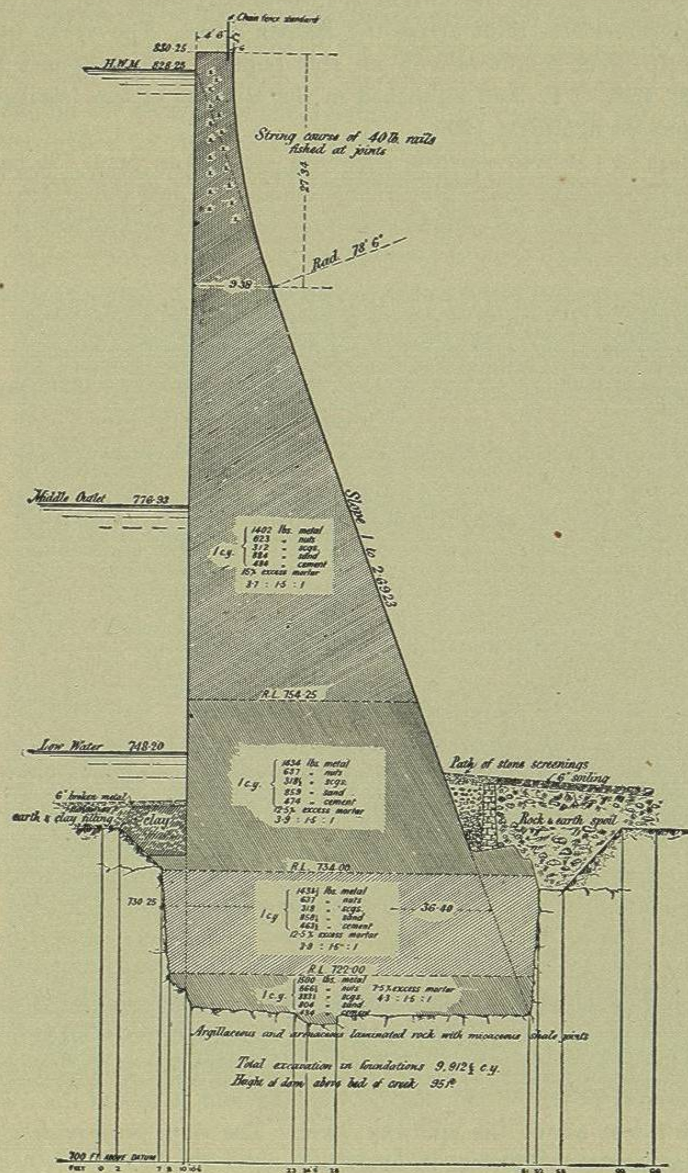

FIG. 264.—BAROSSA DAM.

better known to the engineering world than the fact that in connection with this project, and for the purpose of impounding water for it, a dam of large dimensions was built across the Helena river. The works were described with great minuteness in an able paper by Chas. Stuart Russell Palmer, M. Inst. C. E., and published in the Minutes of the Institution of Civil Engineers, in March, 1905.

The dam is a rubble concrete structure, straight in plan, 755 feet long on top, 100.5 feet high above the stream bed, and 197 feet in extreme height above lowest foundations. The width on top is 10 feet, and at 100 feet below 90 feet. The spillway is made over the crest of the dam for a length of 440 feet, spanned by a footbridge resting on seven piers. A water cushion has been provided at the base of the dam by an auxiliary weir below 100 feet long.

The crest of the dam is 426.75 feet above sea level, 6.75 feet above the lip of the spillway. The maximum depth of water is 97 feet.

The volume of concrete is not given, but there were used 76,418 barrels of cement, the mixture being in the proportion of 1 of cement, 2 of sand to 5 of crushed granite rock, passing a $2\frac{1}{2}$-inch ring.

The construction of the dam began in January, 1900, and was completed in June, 1902.

The reservoir covers an area of 800 acres, and has a capacity of 4,600,000,000 imperial gallons (16,900 acre-feet).

The pipe line to Coolgardie is 30 inches diameter, 351.5 miles long, and has a capacity of 5,600,000 gallons in 24 hours. It is of the lock-bar type. The total natural lift overcome by the eight pumps installed along the line is 1290 feet, but the total head pumped against including friction is 2700 feet, requiring an effective power of 3129 H. P. The power provided was 3642 H. P. The selling price fixed for the water to cover interest, depreciation and operating cost was 82 cents per 1000 gallons, equivalent to $5.10 per 1000 cubic feet, or $222 per acre-foot.

Cataract Dam, Australia.—The highest and most pretentious dam construction in Australia has been in progress of erection since 1902, to form a reservoir of 25,700,000,000 gallons (78,860 acre-feet) for the domestic supply of the city of Sydney, N. S. W. The dam is straight in plan, 811 feet long on top, 194 feet maximum height (40 feet below and 154 feet above the river-bed), 158 feet thick at the base, and 16 feet at the crest, at a height of 7 feet above the spillway level. The dam is provided with a spillway at one end, 730 feet in length.

It is formed of cyclopean rubble masonry of blocks of sandstone weighing 2 to 5 tons, set in cement mortar, and packed in with concrete, the blocks forming about 65% of the mass. (See Fig. 265.) The up-stream face consists of concrete blocks, 5×2.5×2 feet, set in place with cement

mortar, and backed with 3 feet of concrete, made of crushed basaltic stone and cement. The down-stream face is made of 6 feet of concrete, moulded in place. The total volume of the masonry and concrete is 144,610 cubic yards, and the entire cost of the structure is estimated at $1,585,000 including the clearing of the reservoir, which covers an area of 2145 acres. It is supplied by the run-off irom fifty square miles of watershed area.

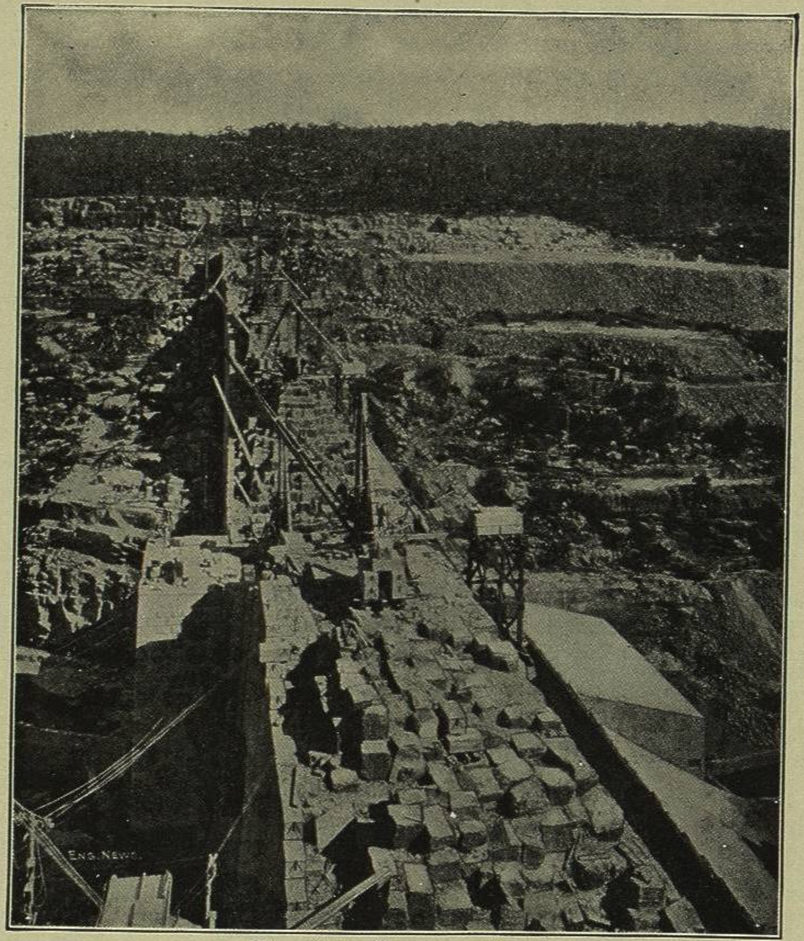

Fig. 265.—Cataract Dam.

The outlets of the dam consist of two 48-inch pipes, placed 147 feet below the spillway level. Two additional pipes of same size were also built through the dam for carrying the low-water flow during construction. When the dam was 76 feet high at its lowest part, a flood occurred during which water flowed 16 feet deep through a gap in the center of the work, 65 feet wide, without causing injury.

The dam was designed and built by L. A. B. Wade, M. Inst. C. E.

Belubula Dam, Australia (Fig. 266).—A dam consisting of a series of buttresses, or piers, with elliptical arches between them, was built on the Belubula river, N. S. W., for the Lyndhurst Goldfield Co., by Mr. Oscar Schulze, C. E., of Sydney, for the storage of water for power. The dam is of unusual design and construction, the base, or foundation, up to a height of 23 feet, consisting of concrete, above which the dam was built of brick a further height of 36.75 feet, in the form of six buttresses, 28 feet apart, center to center, each 40 feet long, 12 feet wide at the up-stream side and 5 feet thick at the outer end. These buttresses form piers for five brick arches, inclined at an angle of 30° from the vertical, and made 4 feet thick at bottom, 1 foot 7 inches thick at top. The spandrels between the arches were filled with concrete, which covered the crown of the arches to a depth of 12 inches, and joined the side walls of the dam, which are also of concrete. The total length of the dam, including the spillway section of 65 feet, is 431 feet. The dam contains almost 6000 cubic yards of concrete, and 500,000 bricks (1000 cubic yards) and the total cost was less than $45,000.

The storage in the upper 16 feet of the reservoir amounts to 87,120,000 cubic feet, and gives a head of 200 feet on the turbines located one-half mile below the dam.

The Beetaloo Dam, South Australia.—Like the Periyar dam in India and the San Mateo dam in California, this structure is composed entirely of concrete, of which about 60,000 cubic yards were used.

The dam was built in 1888-90, to form a reservoir of 2945 acre-feet capacity for irrigation and domestic water-supply.

The dam is 580 feet long on top, curved in plan, with a radius of 1414 feet, and designed after Prof. Rankine's logarithmic profile type. The maximum height is 110 feet, the base width being the same as the height. The thickness at top is 14 feet. The spillway is 200 feet long, 5 feet deep. The cost was $573,300.

Water is distributed entirely by pipes under pressure, some 255 miles of pipe from 2 to 18 inches diameter being required.

The dam was designed and built by Mr. J. C. B. Moncrieff, M.I.C.E., Chief Engineer.

The Geelong Dam, Australia.—This structure is also constructed wholly of concrete, made of broken sandstone and Portland cement, in the proportion of 1 of cement to $7\frac{1}{2}$ of aggregates.

The dam is 60 feet high, 39 feet thick at base, and 2.5 feet on crest. It is curved in plan on a radius of 300 feet from the water-face at crest. The coping is formed of heavy bluestone of large size, cut and set in cement. The work was carried up evenly in courses a few inches thick, and thoroughly rammed. The surface of the finished concrete was wetted and coated with cement grout before adding a fresh layer to it.

The dam forms a reservoir for the supply of the city of Victoria. Water

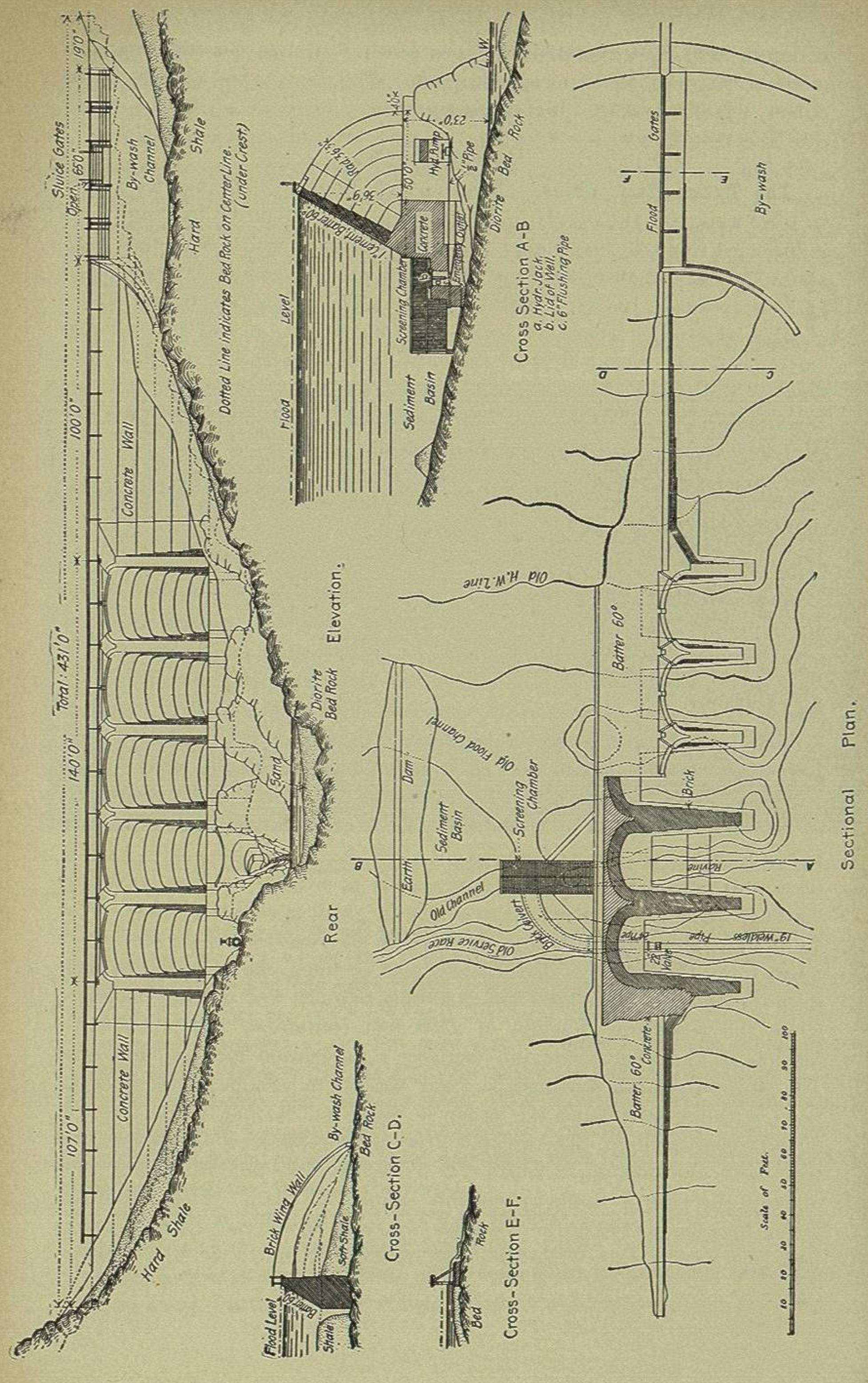

FIG. 266.—BELUBULA DAM.

is drawn from it by two 24-inch pipes passing through the masonry, one of which is used for scouring purposes. The dam leaked slightly at the outset, but this leakage quickly disappeared.

Dams in China.

The Tytam Dam, China.—This modern English structure was built to store water for the supply of Hong Kong. It is about 95 feet high, and is intended to go 20 feet higher. The present crest width is 21 feet, base about 65 feet. The water-face of the wall is almost vertical, the outer face being stepped in 10 feet vertical courses. The water-face is laid up in granite ashlar, the remainder being concrete, with stones of 2 to 6 cubic feet embedded. About 40% of the entire wall is composed of stone, and 60% of concrete. The screenings of crushed granite were used as sand, together with some river sand, which was scarce, and used without washing, as it was believed the rock dust and fine particles of soil would conduce to water-tightness. The strength of the mortar was less of a consideration than the securing of a water-tight wall.

Dams in Africa.

Assouan Dam, Egypt (Fig. 267).—No irrigation works of modern times are more notable and far-reaching in their beneficial results upon the industrial welfare of the people than the great storage dam erected by the Egyptian Government at Assouan, on the river Nile, 700 miles above its mouth. It creates a reservoir with a capacity of 863,000 acre-feet, its effect extending back up the river a distance of 140 miles, estimating its surface slope at 1:32,000. It will thus cover an area of over 40,000 acres, a large portion of which is not over 1000 feet wide. The dam which was begun in 1898 and completed in June, 1902, is of vast proportions, being 6400 feet in length, with a maximum height of 130 feet above the lowest foundations and containing 704,000 cubic yards of masonry. The maximum depth of water in the reservoir available for draft is about 60.8 feet at the dam. The elevation of high-water level in the reservoir is 348 feet above mean tide. The dam is divided into two sections, one of which extends from the east bank for 1800 feet as a solid masonry wall without openings, while the remaining portion of 4600 feet, containing 180 sluice-ways, reaches to the west bank, and includes a navigation lock on that side. The sluice-ways are designed to carry the entire volume of the river at flood, without permitting the water to reach higher than within 9.8 feet of the top of the dam. The width of crest of the eastern solid section is 17.8 feet, while the portion in which the sluice-ways are built is 23 feet wide on top, carrying a roadway entirely across the dam. The sluice-ways are in four levels, 140 of them on the two lower levels, each being 7 meters high by 2 meters wide, while the upper banks of 40 sluices are each 2 meters

wide by 3.5 meters high. The total discharging area thus provided, with all sluice-gates open, is 24,100 square feet. The maximum recorded discharge of the river was 494,500 second-feet (1878-79).

The sluices mostly are in groups of ten, with spaces of 5 meters of solid masonry between individual sluices, and 10 meters between two adjoining groups, where buttresses 26 feet wide, 3.8 feet thick, are built on each face at intervals of 240 feet. The openings or outlets being arranged at varying heights the reservoir may be drawn from near the top, without excessive head or friction to resist the opening of the gates. Sixty-five of them are placed near the bottom of the dam, with sills 70.7 feet below the floor of the roadway on top, of which forty are lined with plates of

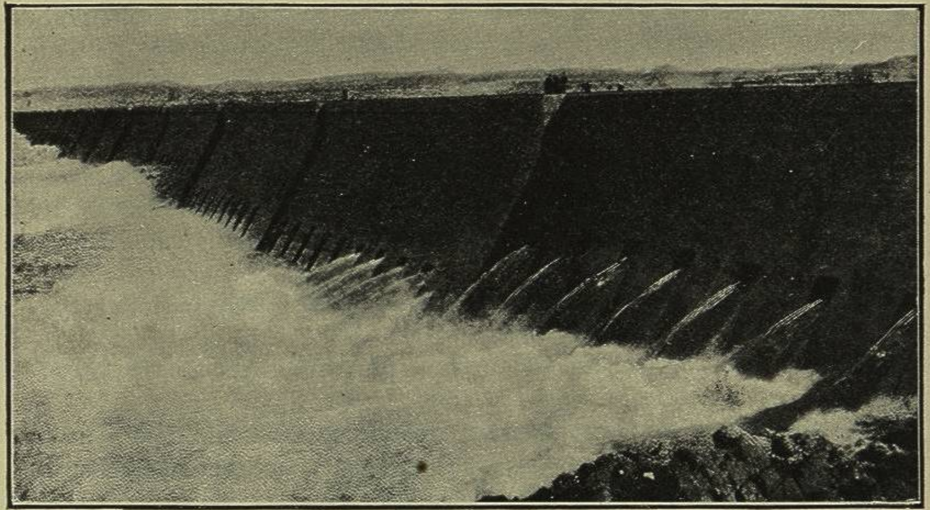

Fig. 267.—The Assouan Dam, Egypt. Showing Discharge through a Number of Sluices.

cast-iron, 1½ inches thick, having flanges or ribs embedded in the masonry, 12 inches deep, by which the plates are bolted together. Seventy-five sluices are placed at the next higher level, 55.8 feet below the crest, and of these one-third are provided with balanced gates of the Stoney roller type, easily operated under full pressure, if desired. Of the remaining sluices 18 are placed with sills 42.7 feet below the top of the dam, and 22 are 29.7 feet below the roadway level. The navigation pass around the dam consists of a canal, partly excavated in rock and partly in embankment witb 4 locks, making a total descent of 68.9 feet. The canal is 654 feet long, 49.2 feet wide on the base.

The dam is founded on a ledge of granite of very irregular surface, one narrow channel requiring a maximum height of 130 feet, but the average height is about 82 feet. The base width is about 85 feet. The down-stream batter is 1: 1.5, while that on the up-stream face is 1: 18.

The dam consists of rubble masonry laid in 1.4 cement mortar. It was said to be entirely water-tight when completed. The total excavation required was 824,000 cubic yards or double the estimate. This increased the masonry by 45% over what was anticipated, so that the final cost of the dam reached the sum of £2,450,000 ($11,907,000) or $13.80 per acre-foot of storage capacity. The plans for the dam were prepared originally by Sir Wm. Wilcocks, M. Inst. C. E., and executed by Frederick W. S. Stokes, M. Inst. C. E., and his successor, C. R. May, M. Inst. C. E. Sir Benjamin Baker, M. Inst. C. E., acted as consulting engineer for the Egyptian Government. The contractors were Sir John Aird & Co.

The original plans first proposed would have raised the water to such a height as would have inundated the ancient temple of Philæ, situated a mile above the dam on an island. Out of deference to public protest against the destruction of this archæological monument, the plans were modified so as to limit the flood level to the floor of the temple. In order to protect the portions of the temple resting on silt a great deal of work in underpinning was performed. Quite recently it has been decided that the temple must be sacrificed, as the importance of raising the dam to give increased storage has become paramount to all sentimental considerations. The capacity of the reservoir will be nearly doubled by the higher construction which has begun, and which will make it the largest reservoir in the world. It is reported that the increase of storage will add 1,000,000 acres to the irrigable area. Work has already begun on raising the dam, which will require three to four years to complete.

The Assiout Dam, Egypt.—In connection with the utilization of the water stored in the great Assouan reservoir, a diverting dam was constructed at the same time across the Nile, 339 miles below, to supply water to the Ibrahimia irrigation canals. The work is fully described in a paper prepared by George Henry Stephens, C. M. G., M. Inst. C. E., and published in Volume 153 of the Proceedings of the Institution of Civil Engineers, for March, 1904. Mr. Stephens had charge of the work from its commencement until its completion in 1902.

The dam is a masonry structure, 2691 feet long, built on a quicksand foundation and carrying a roadway on arches above the flood level. It consists of a series of 111 arched openings, each 16.5 feet wide, formed by masonry piers, each 6.56 feet thick, 51 feet wide, resting on a platform or base of concrete and rubble masonry, 87 feet wide, 9.8 feet thick having a row of cast-iron sheet piles, with tongued and grooved joints, driven 13 feet into the sand, on the upper and lower edges of the platform, as a cut-off against seepage under the dam. The roadway level on top is 41 feet above the floor of the structure. The maximum head of water against the dam is 34.5 feet.

The river bed is protected from erosion by a stone pavement, laid parallel with the dam entirely across the channel, 67 feet wide, placed on a bed of clay puddle, 4.6 feet deep, 46 feet wide on the up-stream side, with a similar pavement on the lower side, covering an inverted sand and gravel filter beneath to clarify percolating water and prevent wash.

One of the interesting special features of this work is the use of cast-iron sheet-piles in the foundations. These were each 16 feet long, 2 feet 3.5 inches wide, 1⅛ inch thick, and weighed about 2180 pounds. The tongues were 2½ inches deep, and the grooves enough deeper to admit of a ¾ inch O. D. pipe for carrying a water jet to facilitate driving, and subsequently to carry cement grout with which the grooves were filled and made water-tight. The work required 210,222 cubic yards rubble masonry and concrete, 11,472 cubic yards ashlar masonry, 1,626,660 cubic yards earthwork in excavation and embankment, and 642,370 cubic yards in temporary cofferdams. The navigation lock around the dam is 262 feet long, 52.5 feet wide, and capable of passing the largest steamers that ply on the Nile. The cost of the dam and locks was about $4,200,000, including the canal headworks, which cost about $660,000.

The irrigation under these extensive works is chiefly devoted to the production of cotton and sugar cane, and it was stated that the value of the crops produced the first year after their completion was in excess of the entire cost of the works constructed.

Sand River Dam, South Africa (Fig. 268).—A dam of rubble concrete was built in 1906 to store water for the supply of Port Elizabeth, Cape of Good Hope, South Africa, having a height of 55 feet, a length of 398 feet, and a base width of 38 feet. The overflow portion, 5 feet below the crest, is 151 feet long. The total cubic contents of the dam are about 9000 cubic yards. It is composed of concrete mixed in the proportion of 1 cement, 1.33 sand, and 5.5 stone, broken to pass a 1¼ inch ring, with "plums" of large quartzite rock and iron rods and rails embedded. The materials were conveyed to place by means of an aerial wire tramway. The dam is straight in plan. The cost was about $140,000. The works were planned and constructed by Mr. W. Ingham, Assoc. M. Inst. C. E.

The reservoir formed by the dam has a capacity of about 220,000,000 gallons (660 acre-feet).

Johannesburg Dam, South Africa.*—To supply the Rand mines with water for mining and domestic purposes, the Vierfontein Water Syndicate, in 1898, undertook the erection of a rubble masonry and concrete storage dam 120 feet in extreme height, located six miles south of Johannesburg. The dam was planned as a combination arch and tangent, the arched por-

* *Engineering Record*, January 7, 1899.