river-bed, and has a thickness of 134.5 feet at base and 78.7 feet at top. On this foundation the dam proper rests, with an offset of 3¼ feet on each side, making its thickness at bottom 72 feet, while at top the wall is 13 feet thick. Both faces are curved in parabolic form, presenting a graceful profile. The maximum pressures on the masonry are 6.1 tons per square foot.

The dam failed in part when first filled, and a breach of 130 feet was made in the wall, but it was immediately repaired. The failure occurred in winter. The dam is straight in plan.

The reservoir capacity behind the dam is about 13,000 acre-feet.

The Tlelat Dam, Algiers.—This masonry wall is 69 feet high, 325 feet long, 40 feet thick at bottom, 13 feet thick at top, and impounds 445 acre-feet, derived from a water-shed of 51 square miles. The dam was erected in 1869 on the Tlelat River to supply the town of Sante Barbe, 7½ miles below, and also for irrigation. The wall is vertical on the water-face, while the lower side has a vertical curve, the center of radius being 11.8 feet above the top of the dam.

The Djidionia Dam, Algiers, is 83.7 feet in extreme height, of which 28 feet is foundation below the river-bed level. The face is vertical, and the dam is straight in plan. The foundation is broader on top than the bottom of the dam, and will permit of an increased height in the structure by adding to the lower side from the foundation up. This has been decided upon, and 26 feet additional in height will be built. The reservoir will then have a capacity of about 4000 acre-feet. The dam was built in 1873–75, on the Djidionia River, to supply the towns of St. Aimé and Amadema with water. The masonry of this dam is slightly in tension on the water-face when the reservoir is filled, amounting to about 15 lbs. per square inch, but no injurious effect upon the masonry is apparent from this small tensile strain.

Dams in India.

The Tansa Dam, India.*—This great dam, forming a reservoir for the supply of Bombay, was begun in 1886, and completed in April, 1891. The work was done by contract and cost $988,000. It is straight in plan, the alignment consisting of two tangents, and it has a total length of 8800 feet, the maximum height being 118 feet. For a length of 1650 feet the dam is depressed 3 feet, to serve as a waste-weir. The thickness of the masonry at the base is 96.5 feet, and the entire section is made of sufficient

* See Proceedings Institution of Civil Engineers, vol. cxv. Paper by W. J. C. Clerke, M.I.C.E., on "The Tansa Works for the Water-supply of Bombay"; also, "Irrigation in India," by Herbert M. Wilson, 12th Annual Report U. S. Geological Survey.

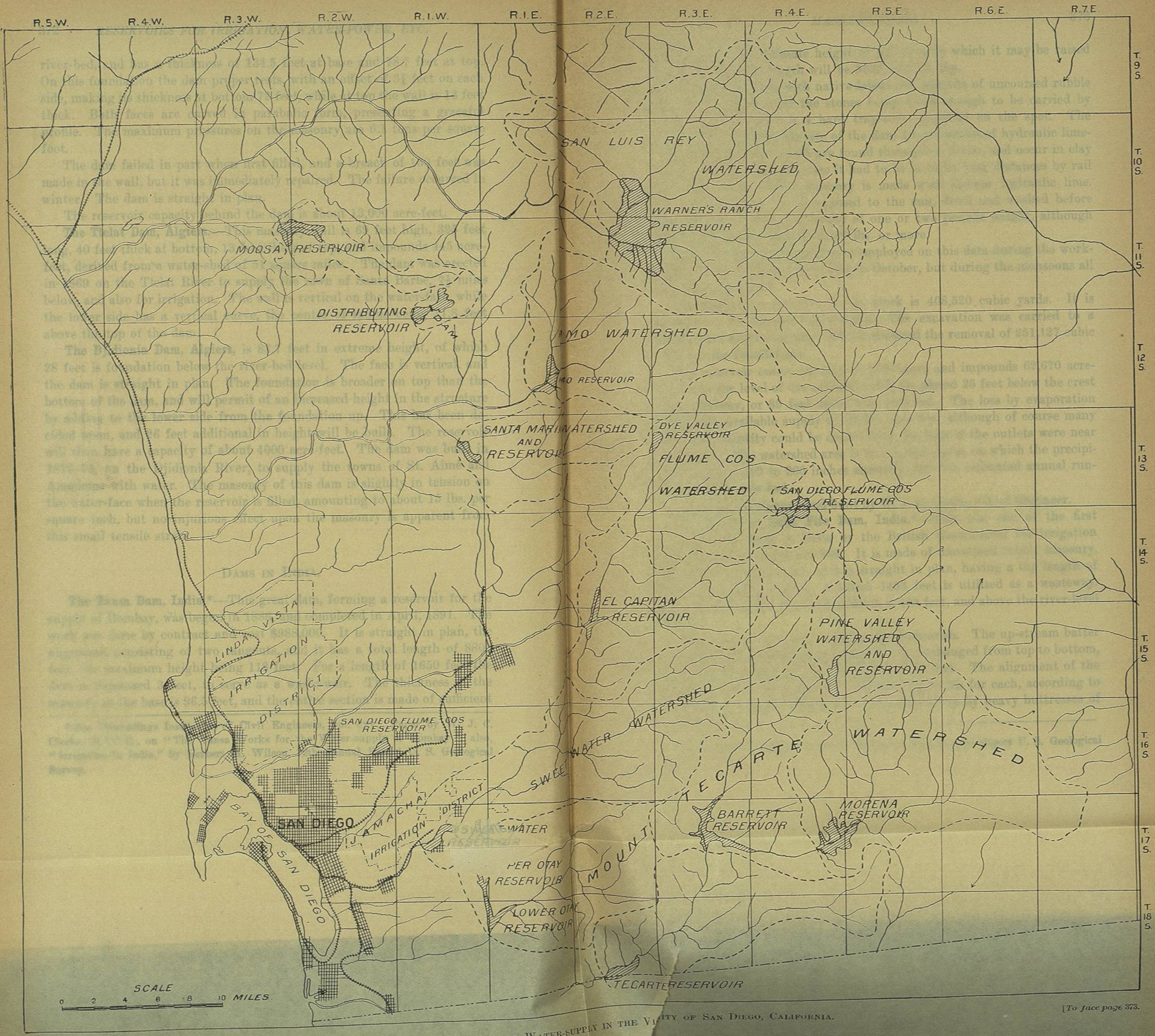

Fig. 176.—Map of Sources of Water-supply in the Vicinity of San Diego, California.

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dimensions for an ultimate height of 135 feet, to which it may be raised in future, when its length will be 9350 feet on top.

The dam was built with native labor, and consists of uncoursed rubble masonry throughout, all the stones being small enough to be carried by two men. The stone is a hard trap-rock, quarried on the spot. The cement was burned at the site of the dam from nodules of hydraulic limestone, called kunkur, which are found throughout India, and occur in clay deposits, although in this case it had to be brought long distances by rail and carts. Most Indian masonry is made with kunkur hydraulic lime. The nodules require to be exposed to the sun, dried and washed before being burned. They are usually of one or two pounds weight, although sometimes found in blocks of 100 lbs. or more.

From 9000 to 12,000 men were employed on this dam during the working season of each year, from May to October, but during the monsoons all work was suspended.

The volume of masonry in the work is 408,520 cubic yards. It is reported to be entirely water-tight. The excavation was carried to a considerable depth in places, and necessitated the removal of 251,127 cubic yards for the foundations.

The reservoir covers an area of 5120 acres and impounds 62,670 acre-feet above the level of the outlets, which are placed 25 feet below the crest of the spillway, or 89 feet above the river-bed. The loss by evaporation reduces the available supply to 15,870 acre-feet, although of course many times this quantity could be drawn from the lake if the outlets were near the bottom. The watershed area is 52.5 square miles, on which the precipitation is from 150 to 200 inches annually, and the estimated annual run-off is 267,000 acre-feet.

The dam was planned and built by W. J. C. Clerke, Chief Engineer.

The Poona or Lake Fife Dam, India.*—This was one of the first masonry dams built in India by the British Government for irrigation storage, and was begun in 1868. It is made of uncoursed rubble masonry, founded on solid bed-rock, and is straight in plan, having a top length of 5136 feet (nearly a mile), of which 1453 feet is utilized as a wasteway. Its maximum height above foundation is 108 feet, and above the river-level 98 feet.

The design of the dam is extremely amateurish. The up-stream batter is 1 in 20, and the down-stream slope 1 in 2, unchanged from top to bottom, the top width being 14 feet, and the base 61 feet. The alignment of the dam is in several tangents with different top width for each, according to its height, the points of junction being backed up by heavy buttresses of

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*** "Irrigation in India," by H. M. Wilson, in 12th Annual Report U. S. Geological Survey.**

masonry. When completed the dam showed signs of weakness and was strengthened by an embankment of earth, 60 feet wide on top, 30 feet high, piled up against the lower side.

The water is drawn from the reservoir 59 feet above the river-bed, and there is therefore available but 29 feet of the total depth of the reservoir. The amount available above this level is 75,500 acre-feet. The lake is 14 miles long and covers an area of 3681 acres.

The dam is located 10 miles west of the town of Poona, on the Mutha River. Its cost was $630,000, and it contains 360,000 cubic yards of masonry.

The canal on the right bank is 23 feet wide, 8 feet deep, and 99.5 miles long, drawing 412 second-feet from the reservoir and distributing it over 147,000 acres of land to be irrigated. At the town of Poona a drop of 2.8 feet is utilized for power by an undershot wheel, to pump water to supply the town. The left-bank canal is 14.5 miles long and carries 38 second-feet. The sluices from the reservoir are each 2 feet square, closed by iron gates operated by capstan and screw from the top of the dam. Ten of these supply the larger canal, and three discharge into the smaller one. Eight additional circular sluices, 30 inches in diameter, supply water to natives for mill-power and discharge into the larger canal.

The Bhatgur Dam, India.*—There are no masonry structures in the United States or Europe which surpass in size those of India which have been constructed for irrigation purposes by the British Government, in the attempt to render the great population of that country self-supporting and check the frightful famines by which it has been periodically devastated.

The Bhatgur dam, constructed on the Yelwand River, about 40 miles south of Poona, is one of the most notable of these great structures. Its length on top is 4067 feet, its extreme height above foundations is 127 feet, and it forms a reservoir 15 miles in length, having a capacity of 126,500 acre-feet. The extreme bottom width of the dam is 74 feet, and the crest is 12 feet wide, forming a roadway. The alignment of the dam curves in an irregular way across the valley, so as to follow the outcrop of bed-rock on which it is founded. The section of the dam was designed after a formula similar to that deduced by M. Bouvier, and all the calculations were worked out by Mr. A. Hill, M.I.C.E., who was afterwards assistant on the construction of the Tansa dam. The curve adopted for the lower face was a catenary, but the wall was actually built in a series of batters.

* "Irrigation in India," by H. M. Wilson, in 12th Annual Report, U. S. Geological Survey.

The three primary conditions of the design were:

1st. The intensity of the vertical pressure was nowhere to exceed 120 lbs. per square inch (8.64 tons per square foot);

2d. The resultant pressures were to fall within the middle third of the section; and

3d. The average weight of the masonry was assumed at 160 lbs. per cubic foot. The use of concrete was only permitted where the pressure was calculated not to exceed 60 lbs. per square inch, which gave a factor of safety of between 6 and 7.

The dam was designed and built by J. E. Whiting, M.I.C.E.

Waste-weirs at each end of the dam have a total length of 810 feet, and can carry 8 feet depth of water. The roadway is carried over these weirs on a series of 10-foot arches. Additional flood-discharge is given by twenty under-sluices, 4 × 8 feet in size (of which fifteen are located 60 feet below the crest), having a total capacity of 20,000 second-feet. These sluices are lined with cut stone, and closed by iron gates, operated from the top of the dam. The overflow wasteway is closed by a novel series of automatic gates that open in flood and rise up into position as the flood recedes, permitting the full storage of the additional 8 feet depth to be utilized. The gates are nicely balanced by counterweights that occupy pockets in the masonry. As the water rises to the top of the gate it fills these pockets, reducing the weight of the counterpoises, and the gate, being then heavier, will descend below the crest of the weir. When the level of the flood is reduced so that it no longer enters the pockets, the latter are emptied by small holes in the bottom, and the counterpoises overcome the weight of the gates, lifting them into place again.

The reservoir is used to supply the Nira Canal, which heads 19 miles below. This canal is 129 miles long, 23 feet wide, 7.5 feet deep, and carries 470 second-feet, supplying 300 square miles of land. The water is diverted to it by a masonry diverting-dam, known as the Vir weir, which is of itself an important structure, being 2340 feet long, 43.5 feet high, constructed of concrete faced with rubble masonry. Its top width is 9 feet. Maximum floods of 158,000 second-feet pass over its crest to a depth of 8 feet, coming from a watershed of 700 square miles. A secondary dam, forming a water-cushion, is located 2800 feet down-stream. This is 615 feet long, 24 feet high, built of masonry founded on bed-rock, and carries a roadway over its crest. During maximum floods the water is 32 feet deep in the cushion, when the water is 8 feet deep over the main dam.

The works were finished in 1890–91.

The Betwa Dam, India.*—This masonry structure forms a diversion-weir for turning the water of the Betwa River into a large irrigation-canal,

* See "Irrigation in India," by H. M. Wilson, in 12th Annual Report, U. S. Geological Survey.

and also serves for storage to the extent of 36,800 acre-feet, which is the capacity of the reservoir above the canal flow, although not all available.

The total length of the dam is 3296 feet, and its maximum height is 50 feet. It has an extremely heavy profile, being 15 feet thick at top and 61.5 feet at base. At its highest part the down-stream face is vertical, and a large block of masonry 15 feet thick reinforces the dam at its lower toe. It consists of rubble masonry laid in native hydraulic lime, with a coping of ashlar, 18 inches thick, laid in Portland-cement mortar.

In plan the dam is divided into three sections, of different lengths, by two islands, and is irregular in alignment.

The canal floor is placed 21.5 feet below the crest of the dam. A masonry subsidiary weir, 12 feet wide on top, 18 feet high, to form a water-cushion for the overflow of the dam, was built 1400 feet below, across the main channel, and a second subsidiary weir, 200 feet below the main weir, was made, to check the right-bank channel at the same level. The main dam and subsidiary weirs cost $160,000, not including the regulating and flushing sluices, which cost $10,000. The main canal is 19 miles long, and with its branches supplies 150,000 acres.

The Periyar Dam, India.—None of the modern structures for irrigation storage in India have presented greater difficulties than the great dam erected across the Periyar River, which was begun in 1888 and completed in 1897. The project, of which the dam was the basis, includes the construction of a wall to close the valley of the Periyar River to store 300,000 acre-feet of water; of the construction of a tunnel 6650 feet long, through the mountain-range dividing the valley of the Periyar from that of the Vigay River, for the purpose of drawing off the water of the reservoir, with the necessary sluices and subsidiary works for controlling the water on its way down a tributary of the Vigay; and finally the necessary works for the diversion, regulation, and distribution of the water for the irrigation of 140,000 acres in the Vigay valley, of which area the water-supply of the Vigay was only sufficient for irrigating 20,000 acres.

The dam is 155 feet high above the river-bed, with a parapet 5 feet higher, the foundations reaching to a depth of 173 feet below the crest. It is 12 feet thick at top and 114.7 feet at base, and is constructed throughout of concrete composed of 25 parts of hydraulic lime, 30 of sand, and 100 of broken stone. The water-face is plastered with equal parts of hydraulic lime and sand. The length of the dam on top is 1231 feet. Its cubic contents are about 185,000 cubic yards of masonry.

A wasteway has been excavated on each side of the dam, one of which is 420 feet long, and the other 500 feet long. The latter is partially formed by a masonry wall 403 feet long, filling a saddle-gap. The crests of these wasteways are 16 feet below the top of the parapet. The rock is a hard syenite. The maximum floods of the river reach 120,000 second-feet at

times. The drainage-area above the dam is 300 square miles, on which the rainfall is from 69 to 200 inches, averaging 125 inches per annum.

The river is one that is subject to violent and sudden floods, in an uninhabited tract of country, far even from a village, some 85 miles from the nearest railway, where there were no roads or even paths, in the midst of a range of hills covered with dense forests and jungles tenanted by wild beasts, where malaria of a malignant type is prevalent, where the commonest necessaries of life were unobtainable, and where the incessant rain for half the year prevented the importation of labor and rendered all work in the river-channel impossible for six months out of every twelve. During the first two years of construction watchmen with drums and blazing fires had to guard every camp at night against the curiosity of wild elephants that constantly visited the works, uprooting milestones, treading down embankments, breaking up fresh masonry, playing with cement-barrels, chewing bags of cement and blacksmith's bellows, kneeling on iron buckets, and doing everything that mischief could suggest and power perform.

The limestone for making the hydraulic lime was brought a distance of 16 miles; surmounting an elevation of 1300 feet by an endless wire rope, 3 miles long, to which the stone was brought by wagon-road. From the lower end of the ropeway the stone was carried on a short tramway to canal-boats plying on the river as far down as the dam, the stream having been made navigable for this purpose.

The sand used was dredged from the river-bed.

This brief summary of the unusual conditions under which the dam was built, gleaned from a paper written by Mr. A. T. Mackenzie, A.M.I.C.E., gives a general idea of the extraordinary difficulties which had to be overcome in constructing this great work, which is certainly one of the most notable of the many monuments to English engineering in India.

The total cost of all the works connected with the project amounted to about $3,220,000. The estimated net revenues were $260,000 annually.

The dam was designed and constructed by Col. Pennycuick, Chief Engineer. It is so designed (by M. Bouvier's formulæ) that the greatest pressure on front and back shall not exceed 9 tons per square foot, and the lines of pressure are kept within the middle third. Most modern dams of any magnitude have been built of uncoursed rubble masonry. Col. Pennycuick justifies the use of concrete in the Periyar dam in the following language, as quoted by Mr. Wilson: "Concrete is nothing more than uncoursed rubble masonry reduced to its simplest form, and as regards resistance to crushing or to percolation the value of the two materials is identical, unless it be considered as a point in favor of concrete that it must be solid, while rubble may, if the supervision be defective, contain void spaces not filled with mortar. The selection depends entirely upon their relative cost, the quantities of materials in both being practically identical."

In this opinion of the value of concrete he is less conservative than the engineers of the Tansa dam, who limited the use of concrete to the upper portion of the dam, where the limit of pressure did not exceed 60 lbs. per square inch.

While the full reservoir capacity is 305,300 acre-feet, the level of the outlet-tunnel is such that but 156,400 acre-feet can be utilized, although this may be supplied several times annually.

Meer Allum Dam, India.—Sometime prior to the year 1800, an extraordinary dam was built to form a reservoir for the supply of the city of

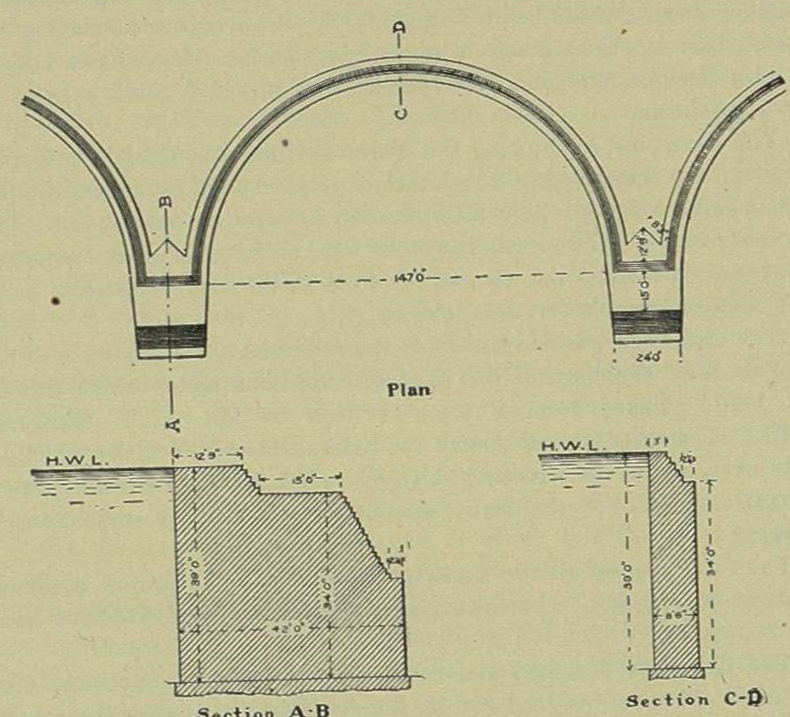

FIG. 261.—MEER ALLUM LAKE DAM, HYDERABAD, INDIA.

Hyderabad, in the form of a large arch, about half a mile in length, composed of 21 smaller arches, of semi-circular form, resembling scallops, with massive buttresses or piers between them. Fig. 261 shows the longest of the arches.

The spans between piers are of varying length, from 70 to 147 feet in the clear. The masonry of the arches, which is vertical on both faces, is 8.5 feet in thickness, and they transmit the pressure to the piers, which are 24 feet in thickness.

The reservoir formed by the dam is known as the Meer Allum lake, having an area of 900 acres, a maximum depth of 50 feet, and a capacity of 355,500,000 cubic feet (8168 acre-feet).

A spillway is provided at one end, but the water at times flows a few inches deep over the entire crest of the dam.*

DAMS IN AUSTRALIA.

Burraga Dam, N. S. W.—One of the slenderest concrete dams constructed in recent years in Australia, where several structures of extremely light type have been erected, was that built for the supply of the Lloyd Copper Company's mine, on Thompson's creek, New South Wales, forming a reservoir of 31 acres area, with a capacity of 13,500,000 cubic feet (310 acre-feet). The greatest height of the dam is 41 feet, the width at the crest being but 2 feet, and at the base 25.3 feet. Its length on top is 425.6 feet, of which 140 feet is used as an overflow waste-weir.

The work is described by John Hayden Cardew, Assoc. M. Inst. C. E., in a paper published June, 1903, in the Minutes of Proceedings of the Institute of Civil Engineers, from which the following quotation is taken:

"Although the greatest care was observed in the mixing of the concrete to secure a water-tight wall, it was recognized that the coarseness of the same would greatly militate against success in spite of the inner face of richer concrete, and it was found as the dam progressed and the water rose in the reservoir that a considerable leakage occurred, which appeared on the down-stream face of the dam like water coming from a very fine rose. To render the inner face with cement mortar made from such coarse sand would not improve matters; it was therefore decided to paint the inner face with neat cement mixed to a slurry, applied with stiff brushes, and well rubbed into the pores in three successive coats; this proved most effective, for when the water rose again in the reservoir the wall was found to be perfectly water-tight.

"The expansion and contraction in concrete dams when the reservoir is low is very great, and when the reservoir is full it is very unequal in different parts of the cross-section; this is especially the case in some parts of Australia, where hot days and cold nights are of frequent occurrence, giving a range of temperature of about 90° F., and on that account many of the concrete dams in this country are badly cracked. In order to

* *Engineering Record*, January 10, 1903.

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

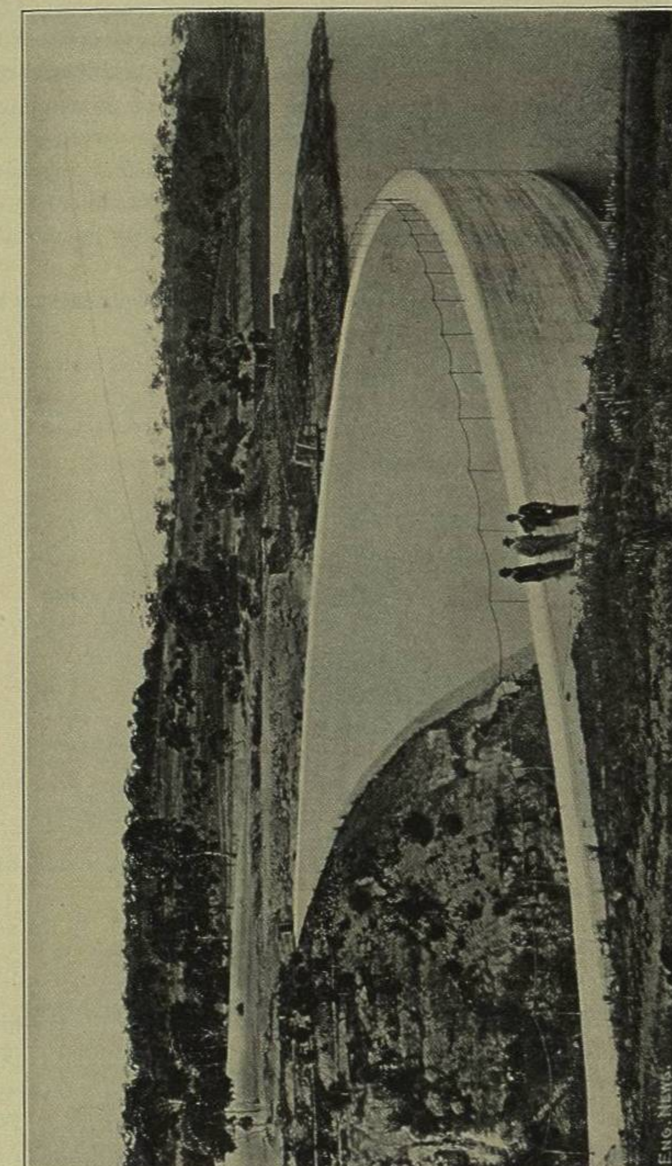

Fig. 262.—Barossa Dam.