CHAPTER IV.

EARTHEN DAMS.

The earliest constructions for water-storage of which there is historical record have been earthen dams erected to impound the water for irrigation. India and Ceylon afford examples of the industry of their inhabitants in the creation of storage-reservoirs in the earliest ages of civilization, which for number and size are almost inconceivable. Excepting the exaggerated dimensions of Lake Moeris in central Egypt, and the mysterious basin of "Al Aram," the bursting of whose embankment devastated the Arabian city of Mareb, no similar constructions formed by any race, whether ancient or modern, exceed in colossal magnitude the stupendous tanks of Ceylon. The reservoir of Koh-rud at Ispahan, Persia, the artificial lake of Ajmeer, or the tank of Hyder in Mysore, cannot be compared in extent or grandeur with the great Ceylonese tanks of Kalaweva or Padavil-colon. The first Ceylon tank of which there is historical record was built by King Panduwaasa in the year 504 B.C. The tank of Kalaweva was constructed A.D. 459, and was not less than 40 miles in circumference. The dam or embankment of earth which formed it was more than 12 miles in length, and the spillway of stone is described by the historian Tennent as "one of the most stupendous monuments of misapplied human labor on the island." The same author describes the tank of Padavil as follows:

"The tank itself is the basin of a broad and shallow valley, formed by two lines of low hills, which gradually sink into the plain as they approach the sea. The extreme breadth of the enclosed space may be 12 or 14 miles, narrowing to 11 at the spot where the retaining bund has been constructed across the valley. . . . The dam is a prodigious work, 11 miles in length, 30 feet broad at the top, and about 200 feet at the base, upwards of 70 feet high, and faced throughout its whole extent by layers of squared stone. . . . The existing sluice is remarkable for the ingenuity and excellence of its workmanship. It is built of hewn stones varying from 6 to 12 feet in length, and still exhibiting a sharp edge and every mark of the chisel. These rise into a ponderous wall immediately above the vents which regulated the escape of the water; and each layer of the work is kept in its place by the frequent insertion, endwise, of long plinths of

stone, whose extremities project beyond the surface, with a flange to key the several courses and prevent them from being forced out of their places. The ends of the retaining-stones are carved with elephants' heads and other devices, like the extremities of Gothic corbels; and numbers of similarly sculptured blocks are lying about in every direction. . . . On top of the great embankment itself, and close by the breach, there stands a tall sculptured stone with two engraved compartments, the possible record of its history, but the characters were in some language no longer understood by the people. The command of labor must have been extraordinary at the time when such a construction was successfully carried out, and the population enormous to whose use it was adapted. The number of cubic yards in the bund is upwards of 17,000,000, and at the ordinary value of labor in this country [England] it must have cost £1,300,000, without including the stone facing on the inner side of the bank. The same sum of money that would be absorbed in making the embankment of Padavil would be sufficient to form an English railway 120 miles long, and its completion would occupy 10,000 men for more than five years. Be it remembered, too, that in addition to 30 of these immense reservoirs in Ceylon, there are from 500 to 700 smaller tanks in ruins, but many still in serviceable order, and all susceptible of effectual restoration. . . . None of the great reservoirs of Ceylon have attracted so much attention as the stupendous work of the Giants' Tank (Kattucarré). The retaining-bund of the reservoir, which is 300 feet broad at the base, can be traced for more than 15 miles, and, as the country is level, the area which its waters were intended to cover would have been nearly equal to that of Lake Geneva, Switzerland (223 square miles). At the present day the bed of the tank is the site of ten populous villages, and of eight which are now deserted."

It was but recently discovered that the reason why the great reservoir was never utilized after having been built at such enormous expense, was an error in the original levels by which the canal from the Malwatte River, that was intended to feed the reservoir, ran up-hill.

Capt. R. Baird Smith, in his work on "Irrigation in the Madras Provinces," says:

"The extent to which tank irrigation has been developed in the Madras Presidency is extraordinary. An imperfect record of the number of tanks in fourteen districts shows them to amount to no less than 43,000 in repair and 10,000 out of repair, or 53,000 in all. It would be a moderate estimate to fix the length of embankment for each at half a mile, and the number of masonry works in sluices, waste-weirs, etc., would probably not be overrated at an average of six. These data, only assumed to give some definite idea of the system, would give close upon 30,000 miles of embankments (sufficient to put a girdle round the globe not less than 6 feet thick) and 300,000 separate masonry works. The whole of this gigantic ma-

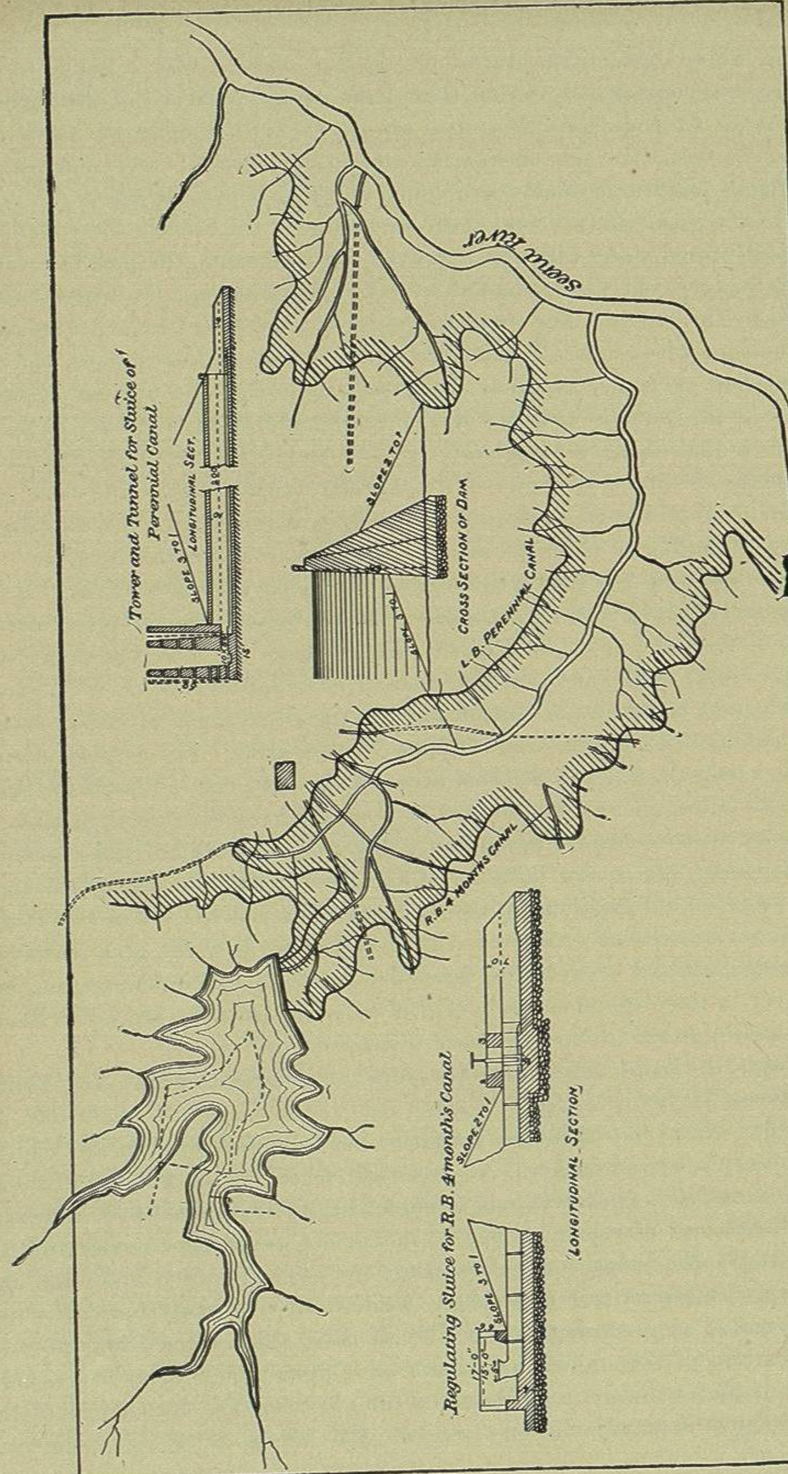

FIG. 283.—THE EKRUK TANK, BOMBAY. PLAN AND DETAILS OF DAM, ALSO SHOWING LANDS IRRIGATED.

chinery is of purely native origin, not one new tank having been made by the English. The revenue from existing works is roughly estimated at £1,500,000 sterling per annum, and the capital sunk at £15,000,000."

The same author described the Ponairy tank of Trichinopoly, now out of repair, as having an embankment 30 miles in length, and an area of 60 or 80 square miles. The Veeranum tank is very ancient, though still in service and yielding a revenue of $57,500 per annum. It has an embankment 12 miles long, and covers 35 square miles of area.

The Chumbrumbaukum tank has an embankment 19,200 feet in length, and forms a reservoir of 5730 acres, with a capacity of 63,780 acre-feet. The dam is 16 to 28 feet high. The water from the reservoir yielded an annual revenue to the government of $25,000 in 1853.

The Cauverypauk tank, in use from four hundred to five hundred years, has an embankment $3\frac{3}{4}$ miles long, revetted with a stone wall 6 feet thick at bottom, 3 feet at top, and 22 feet high, rising to within 5 or 6 feet of the top of the bank, which is uniformly 9 feet high above high-water mark. The embankment is nowhere less than 12 feet wide on top, with a front slope of $2\frac{1}{2}$ to 1, and a rear slope of $1\frac{1}{2}$ to 1. The whole outer surface is carefully turfed and planted with grass. Water is distributed from nine masonry sluices.

Mr. H. M. Wilson, in his work on "Irrigation in India," describes the abandoned tank of Mudduk Masur as having been built over four hundred years ago, when its capacity must have been 870,000 acre-feet of water. The restraining-dams were three in number; the main central dam, which is 91 to 108 feet high, and having a base of 945 to 1100 feet, is still intact, and the whole reservoir is capable of easy restoration. The lack of a spillway caused the destruction of the tank by the overtopping of one of the minor embankments. Mr. Wilson states that in the Mysore district of southern India there are 37,000 tanks, aside from the 53,000 enumerated in the Madras Presidency by Capt. R. Baird Smith. In the Mairwara District 2065 tanks have been built under English rule since the date of Capt. Smith's work, before quoted—1854.

Of the modern earthen dams built by English engineers in the employ of the Indian Government, two of the most interesting were recently constructed in the Bombay Presidency, the Ekruk tank near Sholapur, and the Ashti tank, on the Ashti river.

The Ekruk Tank (Fig. 283) impounds 76,500 acre-feet, and has a dam whose maximum height is 75.6 feet. The total length is 6940 feet, which included 2730 feet of masonry, of which 1400 feet is at the northern end and 1330 feet at the southern end. The cost of the dam was $666,000. The loss of water by evaporation during eight months is 7 feet in depth and amounts to 12,500 acre-feet, or 16% of the entire capacity.

The Ashti Tank (Fig. 284) is formed by an earth dam 12,709 feet long,

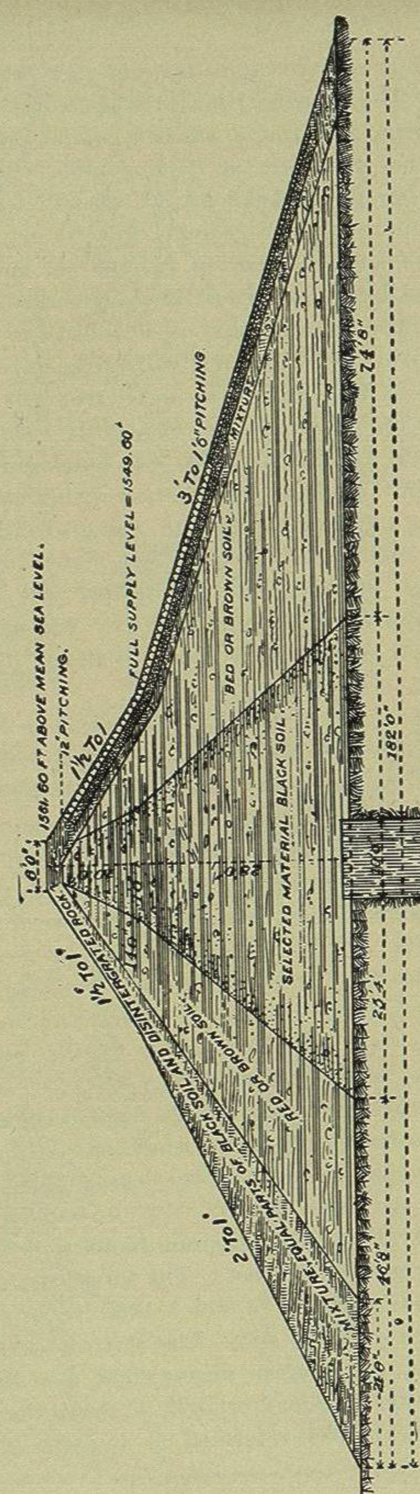

FIG. 284.—CROSS-SECTION OF THE ASHTI DAM, INDIA.

58 feet in maximum height, having slopes of 3 : 1 inside and 2 : 1 outside. The crest of the dam is 12 feet above high-water mark, and has a width of 6 feet. The interior slope is paved with stone. The storage capacity of the reservoir is 35,700 acre-feet, of which 9200 acre-feet, or 26%, is lost by evaporation. The reservoir has a surface area of 2870 acres. The following description of the construction of the dam is condensed from Mr. H. M. Wilson's "Irrigation in India":

The site of the dam was cleared of vegetation and top soil, so that the entire structure rests upon a sound and firm foundation. There is no puddle-wall proper, but a puddle-trench, 10 feet wide, was excavated down to a compact, impervious bed, the entire length of the dam, and was filled to one foot above the natural ground surface. This filling was composed of two parts sand and three parts black soil. The central third of the dam is built up of selected material of black soil, extending, as shown in the accompanying section, in a triangular section, 60 feet wide at the base, to the crest of the dam. Outside of this central section are two triangular sections of brown soil, faced with 1 to 15 feet of puddle of sand and black soil. On the inside a stone paving 6 inches thick is laid over the slope to resist wave-action. Across the river-bed a trench 5 feet wide was excavated along the entire length of the dam and extending 100 feet into the banks. On each side this trench was filled with concrete and connected with the puddle-trench. The puddle-trench was curved around the concrete wall and continued across the river at a distance of 20 feet from the concrete wall on the up-stream side. This work having been finished in dry weather, the sand of the river-bed was sluiced out of the way by confining the stream and directing it into narrow channels by loose rock spur-walls and piers.

The cross-section of the Ashti dam is considered amply strong, yet a more liberal section is believed to be advisable, especially in the matter of top width.

The wasteway of the Ashti reservoir consists of a channel 800 feet wide, cut through the ridge rock, the crest of which is level for 600 feet in length; thence the stream falls with a slope of 1% into a side channel. Its discharging capacity is 48,000 second-feet, causing the water to rise 7 feet above its sill, or to within 5 feet of the top of the dam.

In 1883 a serious slip occurred in the Ashti dam, causing a total settlement of 16 feet at the crest of the embankment, and causing the ground at the top of the dam to bulge upwards. The cause of this slip was attributed to the fact that for a considerable portion of the length of the dam it is founded on a clay soil containing nodules of impure lime and alkali, which render it semi-fluid when soaked with water. The slip occurred during or after excessive rains. It was corrected by digging drainage-trenches at the rear toe, which were filled with bowlders and broken stone, and by the addition of heavy berms or counterforts of earth, for 700 or 800 feet of its length, to weight the toe.

Similar slips occurred in the Ekruk dam, due to similar causes. These occurrences point to the value of thorough drainage to the outer toe of all earthen dams, and the desirability of the adoption of that form of combination of rock-fill and earth used so successfully in the Pecos dams, wherever rock can be obtained for the outer portion of such embankments.

Vallejo Dam, California.—Wherever earthen dams are constructed partially upon exposed bed-rock foundations, it is essential to provide free drainage to the water which seeks to follow along the bed-rock. An interesting application of this principle was made in the construction of a dam erected a few years since for the water-supply of Vallejo, California. The dam was built for storage purposes and formed a reservoir of 160 acres, 3 miles from the city. The bed-rock was exposed in the channel, and formed a low fall about the center line of the dam. Just above this fall a concrete wall was built upon the bed-rock some 6 feet high, with a drainage-pipe extending out to the lower toe of the embankment. A quantity of broken stone was placed above this wall, which formed a collecting-basin for any seepage that might pass through the embankment or that might creep along bed-rock, and the dam was then built over the wall in the ordinary way. This provision effectually prevents the saturation of the outer slope and keeps the dam well drained. The dam was planned and built by Hubert Vischer, C.E., with Mr. C. E. Grunsky acting as Consulting Engineer.

Earthen dams are usually constructed in one of the following ways:

(1) A homogeneous embankment of earth, in which all of the material is alike throughout;

(2) An embankment in which there is a central core of puddle consisting either of specially selected natural materials found on the site, or of a concrete of clay, sand, and gravel, mixed together in a pug-mill and rammed or rolled into position;

(3) An embankment in which the central core is a wall of masonry or concrete;

(4) An embankment having puddle or selected material placed upon its water-face;

(5) An embankment of earth resting against an embankment of loose rock;

(6) An embankment of earth, sand, and gravel, sluiced into position by flowing water—a form of construction described in the chapter on Hydraulic-fill Dams. Earthen dams have also been built with a facing of plank, made water-tight by preparations of asphaltum or tar. The choice of these various available plans is dependent upon local conditions at the site of the dam to be built, the materials available, and the predilection or education of the engineer planning the structure.

European engineers, judging from their works, lean toward the central puddle-core, and the greater number of the earth dams of the British Empire are constructed on this plan. American engineers appear to prefer the masonry core-wall, or the puddle facing on the inner slope of the embankment to the central puddle-core, as a means of cutting off percolation through the dam and thus securing water-tightness.

The natural slope of dry earth placed in embankment is about $1\frac{1}{2}$ to 1, but in practice it is customary to increase this to 2 to 1 on the exterior, and to 3 to 1 on the interior slopes. The necessary height of the embankment above the high-water mark depends to some extent upon the length and size of the reservoir, and the "reach" of the waves generated by winds, as well as upon the width of the spillway and the height to which water must rise in the reservoir during maximum floods to find full discharge through the spillway. Ample spillway capacity is of primary importance to the security of any earthen dam, unless it be one whose reservoir is filled by a canal or other controllable conduit from an adjacent stream. A lack of sufficient spillway is the cause of the greater number of the failures of earthen dams that have occurred, of which the most memorable case was that of the Johnstown dam, whose rupture caused the loss of two thousand lives and the destruction of many millions of dollars' worth of property. Had the spillway been of ample dimensions, this dam would have resisted any pressure that could have been brought to bear upon it and the disaster would, in all probability, never have occurred.

A common source of failure is in the doubtful practice of building the outlet-pipes through the body of the dam. These should either be laid in a tunnel at one side, or in a deep trench cut into the bed-rock or the solid impervious base of the dam, and the pipes surrounded by concrete, filling the entire trench.

In building earth dams of any type it is essential that the earth should be moist in order to pack solidly, and if not naturally moist it must be sprinkled slightly until it acquires the proper consistency. An excess of moisture is detrimental. It should be placed in thin layers, and thoroughly rolled or tamped, and the surface of each layer should be roughened by harrowing or plowing before the next layer is applied. Droves of cattle, sheep, or goats are often used with success as tamping-machines for earth embankments. They are led or driven across the fresh made ground, and the innumerable blows of their sharp hoofs pack the soil very thoroughly.

The Cuyamaca Dam.—One of the first earthen dams built in California for irrigation storage was the Cuyamaca reservoir-dam, erected in 1886 by the San Diego Flume Company. It is located in a summit valley between two of the Cuyamaca peaks, some 50 miles east of San Diego, at an elevation of 4800 feet. The dam is 635 feet long on top, 41.5 feet high,