Name of Dam.	Length, Feet.	Height, Feet.	Top Width, Feet.	Reservoir Area, Acres.	Reservoir Capacity, Acre-feet.
Ashti	12,700	58	6	2600	35,700
Ekruk	6,940	75.7	6	4550	76,500
Kas	718	56.4	10	75	
Maini	3,370	57.3	5	180	4,500
Medleri	2,250	41	6	169	1,430
Mhaswad	7,950	79.8	8	4020	71,000
Makti	3,000	65	10	505	7,850
Nehr	4,820	74	8	675	12,000
Parsul	2,770	62.3	6 to 8	152	2,870
Waghad	4,162	95	6	778	14,300
Malavedi	4,445	114	10	3550	118,000
Tarla	3,120	94	10	815	19,600

Talla Dam, Edinburgh, Scotland.—In 1897-1904, the city of Edinburgh, Scotland, built a storage reservoir dam on the Talla, a branch of the river Tweed, from which a conduit 32 miles long conveys water to the city. As an example of the latest type of earth dam as built in Great Britain, this dam is particularly interesting. It is 78 feet high above the original surface, and 1030 feet long on top. The crest width is 20 feet at a height of 7 feet above the flow line of the reservoir. The puddle trench was 50 feet or more in depth, excavated into slaty rock a maximum depth of 30 feet. The width at bottom was about 12 feet, with nearly vertical sides for 15 feet, above which it widened to 30 feet in the next 20 feet of height. From this point up the puddle core was given a batter of 1 in 8 on each side to the top, where it is 20 feet wide. On either side of the core-wall the middle third of the dam, or a little less, was made of "clayey or adhesive material in layers 9 inches thick." Outside of this zone, the construction was of "stony or open material in layers 18 inches thick." The inner slope was 4 on 1, the outer 3 on 1. The total volume of the dam is about 500,000 cubic yards.

From the description of the materials given* the dam is as perfect an imitation of the modern hydraulic-fill dam as could be made with the old and more expensive methods necessarily employed for handling the materials, although it may be doubted if the construction is any more satisfactory or has any higher factor of safety than if it had been built by the hydraulic process. The leading idea of the design is practically identical, viz.: a body of clay forming the heart of the dam to the extent of nearly one-third, with porous, rocky materials on the two slopes giving drainage. The so-called "compound dam" suggested by Mr. Strange is on the same general design, or aims at the same result.

* Paper by Wm. A. P. Tait, M. Inst. C E., in vol. 167, Proceedings Institution of Civil Engineers.

Illustrations of Typical Earth Dams.—Plates 4, 5, and 6 have been taken from the valuable work of Wm. Ham Hall, Am. Soc. C. E., published in 1888, entitled "Irrigation in California," to illustrate a few standard types of high earth dams with clay puddle core-wall. Plate 4 shows longitudinal and cross-sections of the Pilarcitos and San Andrés dams, and a longitudinal section of the Old or Upper Crystal Springs dam, all pertaining to the waterworks of San Francisco.

On Plate 5 are similar sections of the Llannefydd dam, Wales, in which the maximum depth of excavation for the core-wall was 122 feet; of the Dodder river dam, Ireland, where the excavation was comparatively small; of the Yarrow dam, Liverpool, England, 90 feet high, with a puddle core reaching down to 175 feet below the crest; and of the Vehar dam, Bombay, India, having a height of 84 feet.

On Plate 6 are sections of the Stubden, Leeming and Loch Island Reavy dams in Ireland, the Rotten Park dam, the Ulley dam, and the Vale House dam in England, and two dams in France, built without puddle cores. The Vale House dam is a part of the waterworks of Manchester, and has a puddle extending to a depth of 50 feet below the surface, with a base of concrete on the bottom of the puddle, filling the core-trench on bedrock —a common practice with English engineers.

Core-walls for Earth Dams.—The recent invention of steel sheet-piling which can be made practically water-tight, as a substitute for wooden sheet-piles, which are never entirely satisfactory, has greatly simplified the matter of securing a foundation for core-walls of earth dams. The construction of a satisfactory cut-off in quick-sand, gravel, soft rock or alternating strata of porous material, can now be made in many locations by the driving of steel piles without the necessity for excavating, bracing, pumping, etc., all of which is slow and difficult. Unless large bowlders are encountered, steel piles can be driven to as great a depth as is generally necessary to go down for a foundation. Time is often of vital consideration, and the use of piles of this class will frequently be the means of rapidly completing a job which would otherwise be delayed indefinitely waiting for the completion of the final excavation of foundations.

This use of steel piles as a cut-off and for foundation of the concrete core-wall may be cited in the building of the Big Rapids dam, Mich., in 1907, by William G. Fargo, hydraulic engineer, of Jackson, Mich., where sheet-piles were driven as deep as 56 feet through sand and gravel into hardpan. On top of this row of piles a thin reinforced concrete core-wall was built up through the dam, to the top, so located that the line of the wall coincided with the water line of the reservoir. In this way the continuation of the core-wall was made to act as a retaining wall, and the finishing of the riprap on the face of the dam.

The notable feature of this construction and that of the Lyons dam, built by the same engineer, is not alone the use of steel piling, but the extreme thinness of the core-wall, which is but 10 inches thick throughout. The wall is therefore merely a curtain, or diaphragm, of no stability unsupported, but having a certain amount of flexibility. It will therefore accommodate itself to unevenness of settlement in the embankment on either side with less danger of serious rupture than a rigid wall would undergo.

This use of a flexible, reinforced concrete core-wall or diaphragm for earth dams was first suggested by Mr. H. M. Wilson, M. Am. Soc. C. E.,* who wrote that in his opinion "such a diaphragm would be impervious, tough and flexible if not too thick," and suggested a thickness of 4 to 6 inches throughout, "firmly anchored in cement masonry at the foundation and up the abutment."

The only example of the use of cast-iron sheet piles as a foundation for a dam on record is that of the Assiout dam, Egypt, described in Chapter III on Masonry Dams.

The steel-plate diaphragm of the Chollas Heights dam of San Diego, Cal., heretofore described, is another notable instance of the use of a flexible diaphragm as a core-wall.

These are in striking contrast to the heavy masonry and concrete core-walls built in earth dams in the Eastern States, to which British engineers so seriously object. Mr. Reginald E. Middleton, M. Inst. C. E., says on this subject: †

"Where masonry alone is used, should there be any movement in the bank, the wall will be fractured, serious leakage may take place and the dam may be so much weakened thereby that its unforeseen destruction may result, and it is exceedingly difficult to make a thin or even a thick masonry wall perfectly water-tight."

British engineers adhere to clay puddle core-walls, and are not to be convinced that it can be considered good practice to attempt to support a rigid material such as masonry with a plastic material such as earthwork. The introduction of a thin, strong diaphgram, having a certain amount of flexibility and capable of yielding to pressure without injury, would seem to solve the objections raised toward the standard American type of core-wall as hitherto established, although as yet not sufficiently tested to establish their reliability.

The recognition of the desirability of building core-walls with flexibility combined with water-tightness, led to a suggestion by the editor of *Engineering News* ‡ that the core-walls of earth dams be built of brick, 16 inches thick, laid in hot asphaltum, in such a way as to hold a center diaphragm of pure bitumen between walls of brick. In this situation,

* *Engineering News*, July 16, 1903.
† *Engineering Record*, vol. 54, page 304.
‡ *Engineering News*, February 20, 1902.

in the heart of the dam, the asphaltum would be forever protected from oxidation or volatilization, and its water-tight properties preserved indefinitely. At the same time it could yield to uneven settlement without injury. The suggestion does not appear to have been adopted as yet, as far as the author is aware.

The editor of that journal * also suggests the use of stone macadam as a substitute for more expensive concrete in core-walls for earth dams. By this plan the macadam would consist of crushed rock, with an extra quantity of fine rock dust, to be spread in layers, thoroughly wetted and rolled or tamped in position, the finer dust to be obtained by recrushing and rebolting and passing through rolls a portion of the medium product of the rock crusher, in order to fill the voids in the rock. The editor calls attention to the high cementation value possessed by the dust of limestone, felsite, and even quartzite when saturated and pressed together under heavy rollers.

This suggestion would appear to be quite as applicable to the building of a core or facing for a rock-fill dam, in localities where cement is costly and difficult to obtain.

Special attention of engineers throughout the world was called to the discoveries made by a board of engineers called in 1901 to report upon the safety of the proposed earth extension of the New Croton dam. This board consisted of three prominent members of the American Society of Civil Engineers, Messrs. J. J. R. Croes, Edwin F. Smith, and Elnathan Sweet. Under their direction borings were made in a number of high earthen dams with masonry and concrete core-walls, at right angles to the axis, and at such intervals as to determine that in almost every case there was a continuous water-plane extending from the water surface of the reservoir to the core-wall, and on the down-stream side to the lower toe, having an inclination of 17% to 20% and indicating that the dams were saturated below this plane. The inference was plain that the core-walls were not water-tight and not effective in preventing water from passing through the dam. Their stability therefore depends in little or no degree upon the core-wall, but rather upon the compactness of the earth and the fineness of the particles composing the embankment, through the medium of which the movement of water on the plane of saturation is so exceedingly slow as to have no power to remove any particles from the dam.

The result of the investigation by the board was to recommend that the proposed earth section of the dam, which required a masonry core-wall of over 180 feet maximum height, be substituted by a solid masonry dam. These findings were generally approved by the engineering profession and the change was made.

* *Engineering News*, June 25, 1903.

If a concrete core-wall is not water-tight its only function in a dam must be as a stop against the ravages of burrowing animals. For this purpose it is customary with English engineers to spread a layer of broken stone over the outer slope, and then put six inches of soil above it. This simple treatment is found quite effective.

As noted in Chapter I on Rock-fill Dams, a core-wall of reinforced concrete but six inches thick at the top, 12 inches at bottom, 24 feet high, was built into the Avalon dam, New Mexico, in the reconstruction of the dam by B. M. Hall, engineer for the United States Reclamation Service. In an article written on this subject * Mr. Hall says:

"It is a well recognized fact that a durable core-wall or diaphragm of some kind should be placed in every earth dam to prevent burrowing animals from making tunnels through the dam that will enlarge rapidly as soon as a stream of water begins running through, and to prevent definite water channels through the dam from any other cause. So far as the writer is informed, no advocate of core-walls has ever claimed that even the heaviest walls in use are intended to add anything to the strength of the earth dam, or that the section of an earth dam could be safely reduced on account of having a masonry or concrete core-wall in it. This being the case, it is evident that a diaphragm made of imperishable materials, and having a certain amount of flexibility, will fulfill all the requirements of the ordinary core-wall, and will have the additional advantage of being able to accommodate itself to slight inequalities of settlement in the dam."

He states that he has designed an earth dam for the proposed Carite reservoir in the island of Porto Rico, in which it is planned to use a vertical diaphragm of concrete 6 inches thick, reinforced with $\frac{1}{2}$-inch steel rods spaced one foot apart both vertically and horizontally. The dam will be 92 feet high and the diaphragm will extend from the bedrock to the crest of the dam, 12 feet above the high water level of the reservoir. The earth will be puddled against the wall on each side as it is built up.

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* *Engineering News*, February 6, 1908, "Reinforced Concrete Diaphragm for Earth Dams," by B. M. Hall, M. Am. Soc. C. E.

CHAPTER V.

STEEL DAMS.

The Ash Fork Steel Dam.—This structure is the first one of its class that has ever been erected, and has so many novel features of an experimental character that it is specially interesting and instructive to the engineering profession. It was designed by F. H. Bainbridge, C.E., of Chicago, and was erected in 1897 on Johnson Canyon, at a point 4.3 miles east of Ash Fork, the junction of the Santa Fé Pacific with the Santa Fé, Prescott and Phœnix railroad. The dam is one mile south of the track of the former road. The steel portion of the dam is 184 feet long, 46 feet maximum height for 60 feet in center. This steel structure connects with masonry walls at each end, which complete the dam across the gorge to a total length of 300 feet on top. The steel structure consists of a series of twenty-four triangular bents or frames, standing vertically on the lower side, with a batter of 1 to 1 on the upper. These frames are composed of heavy I beams, with diagonal struts and braces, resting on concrete foundations, and placed 8 feet apart, center to center, all well anchored into the bed-rock on the concrete base, and braced laterally in pairs. The dimensions of the bents vary with their height. The end bents are 12 to 21 feet in height, nine in number; four of the bents are 33 feet high, and the remainder from 33 feet to 41 feet 10 inches high. The batter-posts, to which the face-plates are riveted, are of 20-inch I beams, the longest being 66.5 feet. The face of the dam is composed of curved plates of steel, $\frac{3}{8}$ inch thick, 8′ 10$\frac{5}{8}$″ wide, and 8 feet long, the concave side being placed towards the water. They thus present the appearance of a series of troughs or channels between the supports. The bent plates do not extend into the concrete at the base, but the bottom course consists of flat plates, and the course next to the bottom is dished in the form of a segment of a sphere, making the transition between the curved and straight form. The edges of the plates are beveled for calking, and riveted together with soft iron rivets. The joint between the steel and masonry structures at the ends is formed by embedding flat plates into the concrete, the face of which has the same slope as the face of