are apparently firmly committed to the concrete or masonry core-wall as an essential element in the building of earth dams.

The Glenwild Dam, Amsterdam, New York.—The city of Amsterdam, New York, in 1902, built an earth dam 63.5 feet high, 450 feet long, 13 feet wide on top, with up-stream slope of 2 on 1, down-stream slope 2.5 on 1, to form a reservoir of 180 acres area, and having a capacity of 1,200,000,000 gallons (3675 acre-feet). The dam is curved up-stream with a radius of 708.6 feet, and has a core-wall of cement masonry in the center, reaching to a height of 1 foot above the flow line of the reservoir. The core-wall is 14.5 feet thick at the ground line, and extends 7 feet below the surface with a uniform thickness of 6 feet. Above the wide part of the base at the stripped surface it has a batter on one side of 3 inches to the foot. The wall is composed of broken bowlders, none of which exceed ½ cubic foot in size, laid by hand, and grouted with 1:3 cement mortar, in 16-inch courses.

The outlets consist of two 18-inch and one 12-inch cast-iron pipes laid side by side and bedded in rubble masonry, through the body of the dam. Where they passed through the core-wall, an arch was sprung over them, and the space between pipes and arch subsequently filled with cement grout poured in through three 1½-inch pipes reaching to the top in the interior of the wall, after all settlement had ceased.

The dam was designed by Mr. Stephen E. Babcock, of Utica, as consulting engineer. Its cost by contract was $47,360.

The Laramie River Dam, Wyoming.—The Wyoming Development Co., in 1900-01, constructed a dam across the Laramie river to form a storage reservoir covering an area of 6588 acres and having a storage capacity of 120,000 acre-feet, for the irrigation of 60,000 acres in the neighborhood of Wheatland, 90 miles north of Cheyenne, at an altitude of 4700 feet above sea level. The dam is 8000 feet in length, 34.5 feet maximum height, and contains 344,000 cubic yards. The up-stream slope is 3 on 1, outer slope 2 on 1, crest-width 15 feet at a height of 5 feet above the flow line of the reservoir. The dam is built as a homogeneous earth structure, the material being placed by horse-scrapers and carts. It has no core-wall, but for a distance of 1200 feet in the center, crossing the river channel, a row of wooden triple-lap sheet piles was driven to a depth of 10 to 12 feet below the surface.

The embankment is rip-rapped with large bowlders on the water-face, extended by an apron of the same material, 30 feet wide above the upper toe of the dam, requiring a total of 16,000 cubic yards of rock.

The dam was built by George Frederick Vollmer, Assoc. M. Inst. C.E.*

Cedar Grove Dams, Newark, N.J.—The city of Newark, New Jersey, in 1901-04, created a storage reservoir near Cedar Grove, seven miles from

* *Vide* Minutes of Proceedings, Institution of Civil Engineers, vol. 162, Nov., 1905.

the city, having a capacity of 700,000,000 gallons (2150 acre-feet) by building an earth dam 2700 feet long, across the main outlet of the basin, with dikes at each end of the reservoir, 650 feet and 825 feet in length respectively. All three dams have concrete core-walls, which extend up 2.5 feet higher than the full reservoir level, are 4 feet thick at top, and have a uniform batter of ½ inch to the foot on both sides, down to the original ground surface, below which the thickness is uniform to the bottom of the trenches in which they are built. The walls are plastered with ½ inch of 1:1 cement mortar on the water side, applied in the forms as the concrete was placed. The maximum height of the core-wall in the main dam is 102 feet, and the total volume of concrete in all the core-walls was 36,000 cubic yards. It was mixed in the proportion of 1 part of Rosendale cement, 2 of sand and 5 of crushed rock. The posts of the forms on each side of the wall were made to support a light railway the entire length of the dam, on which cars operated by a cable and winding engine were run, conveying concrete from the mixing plant at one end. This trestle was carried up in three bents or levels of 20 feet each on the main dam.

The maximum heights of the north and south dikes above the original surface are 26 and 25 feet respectively, the core-walls being 40 and 42 feet high. They are 12 feet wide on top, 6 feet above reservoir level, and have 2 on 1 slopes each side. The main, or west dam, is 18 feet wide on top, 5 feet above the water line, and has an 8-foot berm in each slope 20 feet below the top.

The core-wall trenches were refilled on the water side of the walls to the original ground surface, with clay puddle, and on the other side with selected material shoveled into water or well rammed.

The earth, a red clayey loam, was excavated by steam shovels and hauled to the dam in trains of 3½ yard cars by numbers of small saddle-tank locomotives. It was spread in 5-inch layers by scrapers, and compacted by steam rollers and traction engines.

This dam is to be noted as having one of the highest concrete core-walls in America, and the whole construction is typical of modern earth-dam work. The total amount of material borrowed, representing the approximate volume of the dams, was 400,000 cubic yards.

The total cost of the dams complete was $660,000. This includes cost of stripping of the reservoir to a depth of six inches, but does not include pipes or outlet tunnel. The outlet of the reservoir is through a tunnel, 300 feet long, on the opposite side of the reservoir from the main dam.

The works were designed and constructed by M. R. Sherrerd, M. Am. Soc. C. E.

Belle Fourche Dam, South Dakota.—The largest earth dam under construction by the United States Reclamation Service is to form a res-

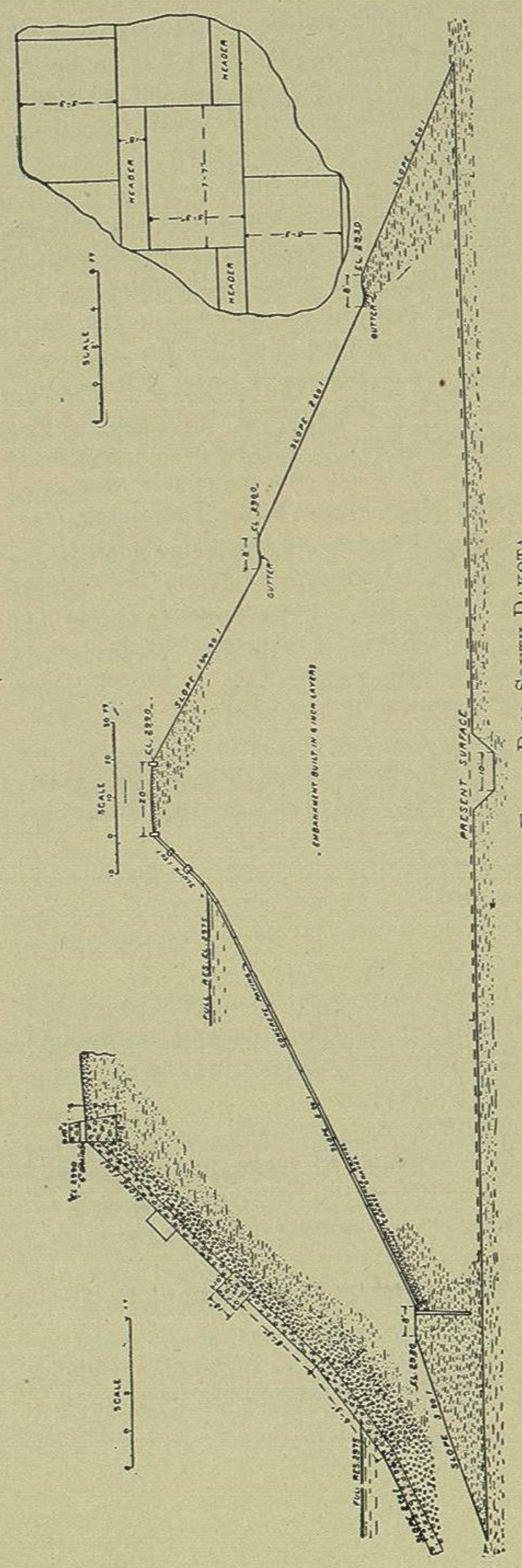

Fig. 292.—Section of Belle Fourche Earth Dam, South Dakota.

ervoir of 215,000 acre-feet capacity, for the irrigation of about 90,000 acres of arid land, largely public, situated south east of the Black Hills, South Dakota, by the diversion of the waters of the Belle Fourche and Redwater rivers, into a large basin east of the town of Belle Fourche, on Owl creek. The reservoir will be filled by a large feeder canal 6½ miles long, 40 feet wide on the bottom, carrying 10 feet depth of water.

The dam is to be 115 feet high, 6500 feet long and will contain 1,600,000 cubic yards. Its crest width will be 20 feet, at a height of 15 feet above the flow line or crest of spillway. The latter is 300 feet long, semi-circular in form.

A section of the dam is shown in Fig. 292.

The inside slope is 3 on 1 from the base up to near the water line, with an 8-foot berm near the bottom, 10 feet below low-water line at the foot of the pavement. Above the water the slope is 1 on 1. The facing of the dam is of concrete, made in large slabs, laid on 12 inches of screened gravel, overlying 12 inches of unscreened gravel. The slabs will be laid in the form of headers and stretchers, breaking

joints, the largest being 5 feet 3 inches × 7 feet 7 inches in size and 8 inches thick. The lower slope is 2 on 1, with two 8-feet berms. The dam contains no core-wall but consists of a heavy adobe clay, placed in 6 inch layers, sprinkled and rolled. The bulk of the earth was contracted for at a cost of 28 cents per cubic yard.

The contract was let to Orman & Crook, of Pueblo, Colorado, for a total of $879,164.25 or $4.09 per acre-foot of reservoir capacity. This does not include preliminary expenses, engineering, supervision, etc., amounting to perhaps 20% more.

The total volume of concrete in the work was estimated at 31,930 cubic yards, ranging in price from $6.50 to $7.00 per yard. It is understood that the financial embarrassments of the contractors were chiefly due to the losses on this work.

North Dike, Wachusett Dam, Mass.—One of the most difficult earth dam constructions and one of the largest reservoir embankments in the world, is the North Dike of the Wachusett reservoir, referred to in the account of the Wachusett dam. The dike is two miles long, 65 feet high at the deepest place to the water line, or 80 feet high to the top, with a maximum width on the base of 1930 feet. It covers an area of 135 acres, and contains 5,300,750 cubic yards. The down-stream slope of the dike varies from 3% to 6%, averaging less than one-tenth the usual slope given to reservoir banks.

To cut off percolation through porous substrata under the dike, a cut-off trench was excavated for a distance of 9505 feet, to a maximum depth of 60 feet, with a bottom width of 30 feet. For 3130 feet the excavation reached to bedrock. Over a distance of 5239 feet wooden sheet-piles 4 to 6 inches thick were driven in the bottom of the trench, to great depths, with the aid of the water jet, reaching at bottom to extremely fine sand. The cost of this work was about $125,000. Over 540,000 cubic yards were removed in the excavation of this trench, which was carefully replaced by selected soil from the reservoir stripping, placed in layers, sprinkled and rolled. The shrinkage of soil from the borrow pit to the finished dike after rolling was found to be 37.5%.

On April 11, 1907, a section of this dike in the highest place slid off into the reservoir over a length of 675 feet at a time when the water was 40 feet below the top of the dike. About 65,000 cubic yards moved bodily from 250 to 300 feet laterally. The dike was heavily riprapped with stone on the water-face, with 5 feet of coarse gravel and small stones, and overlying this was a layer of rock 10 feet thick, taken from the excavation and dumped on the slope. The embankment broke away to the crest, but caused no serious injury, and it is thought the safety of the dike was in no way affected. The slope was 1 on 2 on the water-face, and the embankment has a wide berm 30 feet below the top. The cause of the slide is not definitely known, but it seems evident that the angle of the slope was greater than the natural angle of repose of the materials used when saturated with water.

Druid Lake Dam, Baltimore, Md.—One of the highest earth dams in America was built in 1864 to 1870, with a maximum height of 119 feet, a crest width of 60 feet, at an elevation of 5 feet above the flow line, and with inner slope of 4 on 1, outer slope 2 on 1. The dam has a puddle clay core-wall in the center, having a base width of 36 feet, and a crown width of 17 feet, a little above the water line. In the construction of the dam, narrow embankments were first built up on each side of the core-wall to a height of 25 feet, the material being placed in layers well rolled. Then embankments of dumped material were built to the same height at the slopes, leaving basins between them and the center. These basins being filled with water the earth to fill the basins was dumped from the fill-banks over the edges into the water until the two basins were filled to the uniform height of the banks either side. Then the process was repeated by building up the core-wall, with supporting banks of rolled material, followed by dump-fills and the formation of pools of water or basins on either side into which the earth was subsequently dumped to fill them. This was a crude form of hydraulic fill, but it was an early recognition of the principle that earth settled under water is more cheaply compacted than would be possible of attainment by other means, while the proven stability of the dam after 37 years of service attests the efficiency of the process.

Cold Springs Dam, Oregon.—The Umatilla project of the United States Reclamation Service in Oregon is designed to irrigate about 20,000 acres from the Umatilla river. In connection with it the Cold Springs dam is being built in a small valley to form a storage reservoir of 50,000 acre-feet capacity. It is to be 3200 feet long, about 82 feet maximum height above the original surface, and will contain 620,000 cubic yards. Its width on the crest, 7 feet above the water line, will be 20 feet. The down-stream slope 2 on 1, up-stream slope 3 on 1. The diagram, Fig. 293, is a section of the dam showing the proposed arrangement of materials. The material immediately available for the construction of the dam consists of basalt rock, an extensive deposit of gravel on the northerly hillside below the dam, and fine surface soil, covering the entire country about. These were the most abundant, but in addition there is also available a deposit of pure volcanic ash, at infrequent intervals and scanty in quantity, an indurated clay at one end of the dam and sand and gravel underlying the surface soil, somewhat indurated and stratified. Prior to determining the choice of materials to be selected a series of interesting experiments were conducted under the direction of D. C. Henny, M. Am. Soc. C. E., supervising engineer, assisted by E. G. Hopson* the purpose of which

* *Engineering News*, March 7, 1907.

was to ascertain the permeability of the materials and the rates of percolation of water through them. These rates were determined by placing the materials in tanks similar to those used by the Massachusetts State Board of Health and by the Massachusetts Metropolitan Water Board in experimenting on the permeability of soils to be used in constructing the North Dike of Wachusett reservoir. The tanks were of galvanized iron, 18 inches in diameter, 5 feet deep. Two perforated pipes passed through the tanks horizontally, 3 feet apart, connected on the outside with glass gage tubes. The material to be tested was carefully rammed in a wet condition into the tanks between and around the perforated pipes. To prevent seepage of water following along the sides the interiors of the tanks were painted and sanded. Water was then put in on top of the material and maintained at a constant level. At regular intervals the outflow from the tubes was measured by weight. As the result of these it was found that the rate of percolation through surface soil was about 18,000 gallons per acre per day; through fine subsoil, 350,000; through gravel, 155,000,000; through volcanic ash, 400,000, and through coarse subsoil 650,000 gallons per acre per day. A mixture of 50% of fine subsoil with an equal amount of gravel showed a rate of but 20,000 gallons per acre per day. The experiments resulted in a material change in arrangement of materials in the dam from what had been the original design, and the selection and disposition have been made as shown in the diagram. This is such an intelligent and rational design of earth dam construction that the author considers it worthy of special commendation and study. The placing of coarse gravel on the down-stream side where it gives stability and drainage is directly in line with

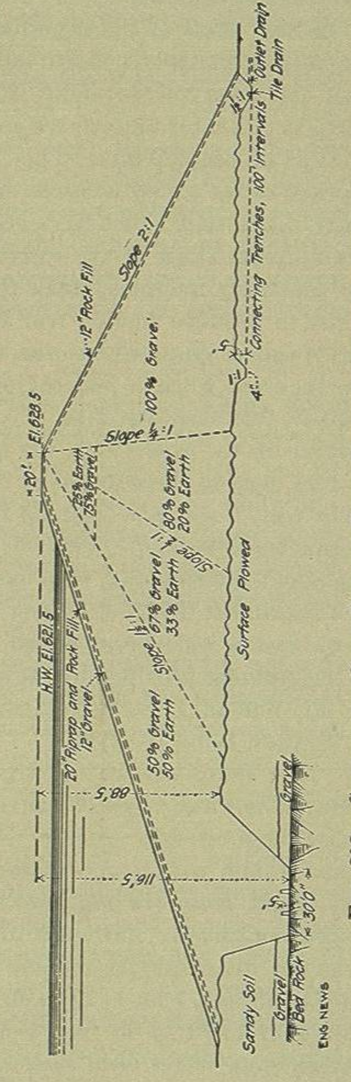

Fig. 293.—Section of Cold Springs Dam, Umatilla Project, Oregon.

the principles employed in hydraulic-fill dam construction. The position shown for the drain-pipes, considerably below the center, is more nearly correct than to carry them as far as the center. The absence of a core-wall will also be noted.

As the result of the experiments the engineers computed the possible loss by percolation through the dam when completed under this design with full reservoir, at about 20,000 gallons per day, or less than one-thirtieth of a cubic foot per second.

Slips in Earth Dams.—This experience with the Wachusett dike appears to be a very common one in the building of reservoirs in India, where many such slides have occurred, although almost invariably on the down-stream slope of the reservoir. These are doubtless largely due to the peculiarly unctious, black soils of that country, which lack in the elements to produce friction and stability, as well as drainage. In building the Waghad dam, which was to have been 95 feet high, an extensive slip occurred when it was completed to a height of 87 feet. The outside slope in this case was 2 on 1. The slope assumed by the slide from the bottom up for nearly half the height was about 3 on 1. It was repaired by first digging three drains at right angles to the axis of the dam. Then a few feet of soil was built up in the work of restoration, when a further motion was observed. This was only stopped after a large trench had been dug about 250 feet long, with base width of 30 feet and side slopes of 1 on 1, to a maximum depth of 40 feet down to rock. This was refilled with dry stone, and a wide berm added. The repair was effective, doubtless due to the drainage provided by the stone filling of the trench.

Mr. William L. Strange, Assoc. M. Inst. C. E., in a paper on "Reservoirs in Western India" * says:

"Low dams can be constructed with much steeper slopes than high ones. The water-faces of dams require a flatter slope than the rear ones. From these considerations it may be deduced that in an originally homogeneous dam with plane slopes, the resistance to slipping decreases with the height from the top, and that the proper section is one having the slopes continually flattened toward the base." On these principles he proposes an empirical section with the following slopes: Inner slope, base to 25 feet, 7 on 1; 25 to 40 feet, 6 on 1; 40 to 55 feet, 5 on 1; 55 to 70 feet, 4 on 1; 70 to 85 feet, 3 on 1; 85 to 100 feet, 2½ on 1. The down-stream slope of his ideal section starts with 5 on 1 to 25 feet, then 4¼, 3½, 3, 2½ and 2 on 1, respectively, for each change of 15 feet of height. The crest width of this section he shows as 10 feet at a height of 7 feet above the flow line, with a retaining wall nearly vertical on the water side for the 7 feet of superelevation.

* Minutes of Proceedings Institution of Civil Engineers, vol. 132.

For high earth dams in narrow gorges, where rock or "some non-viscous material is obtainable, he suggests a "compound dam," in which the two toe embankments for about one-third of the height are built up of rock, or presumably gravel if rock is not to be had, having the usual slopes of 3 on 1 on the water face and 2 on 1 outside, the inner batter of these toe walls to be steep; the space between these toe walls to be filled with earth, and the embankment to be continued above the top of the toe walls after the ordinary method of earth construction.

This "compound dam" is virtually based upon the same principles which have been set forth in the chapter on Hydraulic-fill Dams, as the leading advantage of the hydraulic-fill process of dam construction, which employs natural forces to segregate the coarse, "non-viscous material" from the soil, and deposit it in the form of massive toe walls on the slopes, confining the fine, unctuous, impervious materials in the center where they cannot escape or cause slips.

Soluble Salts as a Cause of Earth Slips.—As noted elsewhere in the foregoing pages, the slips which occurred in the Ashti and Ekruk dams were attributed to the fact that the black soil from which the dams were made, and which prevails over a large portion of India, contains impure lime and alkali in small nodules, which dissolve readily. In California, Colorado, and the Western States generally, these soils are of frequent occurrence, and cause great trouble in canal banks because of the seepage through the banks, which do not become firm and impervious until the soluble salts have been leached out of the soil in the course of years.

This class of soil when placed in a dam is subject to saturation not only from the rains but from percolation of water through the embankment from the reservoir. When so saturated the salts form a lubricant on which the embankment is apt to slide. Where the materials can be sluiced into the dam and deposited by the hydraulic process the water in transit must separate the insoluble materials, take up the salts in solution to a large degree, and finally carry them away as it drains off after leaving the earth. This is one of the advantages of the hydraulic process, which have not been dwelt upon in the chapter on Hydraulic-fill Dams, for the reason that this class of soil is the most undesirable, unfavorable and difficult to handle by this process, and therefore to be avoided. But where it has to be used for lack of better, it can certainly be made more stable by washing out its soluble contents by hydraulic sluicing, thus permitting of stable construction from otherwise unstable materials.

Various Modern Indian Dams.—In the paper referred to above, Mr. Strange gives a list of twelve earth dams built by English engineers in the Bombay Presidency, India, for irrigation storage, with the following data of dimensions and capacity:

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,