More recently, in 1905, experiments have been made on stresses in dams by means of India-rubber models, by John Sigismund Wilson and William Gore, Assoc. M. M. Inst. C. E., who exhibited their model at the Institution in July of that year. A series of weights hung to the base of the model represented gravity, and other weights suspended from cords passing over pulleys and leading to bearings on the up-stream face represented water pressure. The models were made to represent dams with 125 feet of water against them and having a top width of 8 feet, at a height of 4.5 feet above the flow line.

These experimenters confirmed Messrs. Atcherley and Pearson in finding tensile stresses in the up-stream toe of the dam, notwithstanding that they were designed with the lines of pressure well within the middle third, and conclude that to eliminate tensile strains it is desirable to either give greater super-elevation, wider top width, or make the upstream face vertical, so as to bring the center of gravity nearer to the wetted face, or to increase the section materially and back the dam with an embankment of earth on the reservoir side.

Experiments with models of dams made of "plasticine," a kind of modelling clay, were recently made by Sir John W. Ottley, K.C.I.E., M. Inst. C. E., and Arthur W. Brightmore, D. Sc., M. Inst. C. E. The model was 30 inches high, with a base of 26 inches and a length of 12 inches. It was moulded in a frame with plate-glass sides, which were ruled vertically and horizontally with lines scratched on both the glass and the plasticine, and made to coincide. Slight clearance was given between the glass and the model, so that there was no lateral friction to support the clay. Actual water pressure was applied through a thin rubber bag made to fit the face of the dam.

The results of these experiments will shortly be published in the Proceedings Inst. C. E., but it may be stated that they confirm in a general way the conclusions reached by the experiments with rubber models.

These various investigations serve to emphasize the fact that the engineering profession is not fully satisfied with the profile types of dams as they have been evolved by previous mathematical computation, but is still striving to reach a more conclusive and satisfactory solution of the intricate and indeterminate problems of the stresses on masonry dams. Meanwhile the ultra conservative ones pile up masses of materials to greater and greater volumes, and a few of the bolder ones build daring structures that appear to defy all theories of stability.

AMERICAN DAMS.

Old Mission Dam, San Diego, Cal.—The first masonry dam built in California of which there is any record was erected in 1770 by the Jesuit Mission Fathers. It was constructed across the San Diego River, 13 miles above its mouth, at the lower end of El Cajon Valley, where the stream cuts through a dike of porphyry. It was built for impounding and diverting water for irrigation and domestic use at the San Diego mission 4 miles below. It was 244 feet in length, 13 feet in thickness, and about 15 to 18 feet high. Fig. 149 is a recent photograph of the old dam in its present condition, half buried in trees and driftwood. The view is taken below the main outlet-sluice. The water was conveyed to the mission through an open masonry conduit, lined with semicircular tile or half-pipes. The cement used in the dam was made from limestone possessing hydraulic properties, quarried near the dam. The dam, though still in existence, has been disused for half a century past. It shows evidence of having been damaged by floods and repaired at various times. The manual labor of construction was done by Indians, of whom no less than 1600 neophytes were at one time supported at the mission. Considering the quality of the materials and labor available, and the torrential nature of the river, which it has resisted, as evidenced in the photograph by the driftwood piled up against it, the masonry is of excellent grade.

El Molino Dam.—A few years after the erection of the Old Mission dam of San Diego the Jesuit Fathers constructed a masonry wall of similar size about 10 miles east of Los Angeles, the purpose of which was to control and raise the level of a natural lake and impound it for use in irrigation at the Mission San Gabriel. The dam is located on what is now known as El Molino rancho, the name being derived from the fact that the priests here built a mill, whose massive walls are still intact, for grinding corn and wheat, the power for which was derived from water gathered from springs that issued from the hillside and fed the lake. The mill was a little above the level of the crest of the dam, and the water from the wheels flowed into the reservoir, where it was caught for use in the valley below. The dam was straight in plan, about 200 feet long, and 15 feet high at the center. The masonry is of superior character and is still in perfect state of preservation, although it has not been in service as a dam for many years past.

The Sweetwater Dam.—This structure is located in the Sweetwater River, 7 miles above the mouth of the stream and 12 miles southeast of the city of San Diego, California, and was built in 1887–88 by the San Diego

Fig. 149.—Old Mission Dam, near San Diego, Cal. The First Irrigation Dam built in the United States.

Land and Town Company to impound water for the irrigation of lands bordering on the bay of San Diego and for the domestic supply of National City. The Sweetwater, like all the so-called rivers of San Diego County that empty into the Pacific Ocean, is a torrential stream, subject to violent floods in seasons of abundant rains, and dwindling to a diminutive brook within a few weeks or months after the rain ceases. During the summer and fall it ceases to flow, and on occasional years of low rainfall the run-off even in winter is practically nothing, so that it was essential to provide storage for at least two years' supply for the territory depending upon it. Prior to the beginning of work nothing was known of the probable run-off to be expected, further than that the watershed area of 186 square miles, having an extreme elevation of about 6000 feet, would probably receive a precipitation very greatly in excess of the recorded rainfall at San Diego, where the record has been maintained for nearly forty years, and that judging by this record the run-off from such a watershed should give an average supply adequate to the needs of the community to be provided, with a storage capacity of two years' supply in the reservoir. Subsequent experience has shown that the fluctuation in run-off has ranged from practically nothing for three consecutive years to 70,000 acre-feet in one year, or nearly four times the reservoir capacity, per annum. At the time the construction of the dam was begun in November, 1886, an active land "boom" was in progress in southern California, and the San Diego Land and Town Company, owning a large area of fertile lands, found them unsalable without water. It was essential, therefore, to obtain a certain portion of the supply quickly in order to market the lands. The dam was thus necessarily planned without the usual preliminary studies of its capacity for storage, or the volume of supply which would be required or could be made available.

As originally designed, the dam was to be a slender masonry or concrete structure, fashioned after the Bear Valley dam by the same engineer who built the latter, and was to be but 10 feet thick at base, 3 feet at top, and 50 feet high, backed on the water-face by an embankment of quicksand. When the wall had reached a height of 15 to 20 feet at the highest part, at an expenditure of $35,000, and its outline and design were fully realized by the management, the plan was disapproved and the author was engaged to construct a more substantial work on the same site, utilizing the masonry already in place. The new plan was drawn to have an extreme height of 60 feet, and the new work enveloped the old. This structure is shown nearly complete in Fig. 150, and its profile is shown in dotted lines in the middle section on Fig. 151. It was built in steps on the back with a view to adding to its height, as was subsequently done. The dam had a maximum thickness of 35 feet at

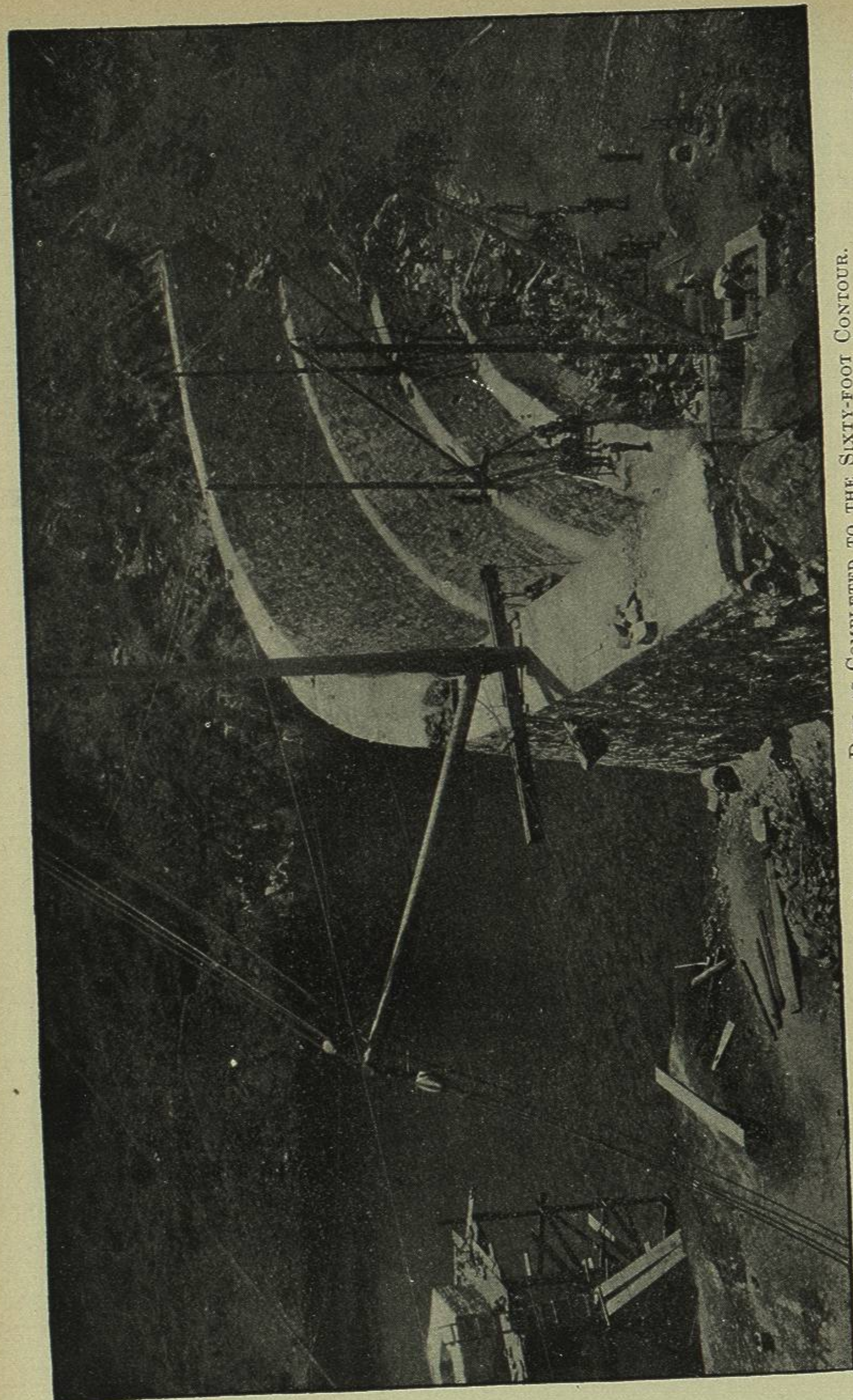

Fig. 150.—Original Sweetwater Dam as Completed to the Sixty-foot Contour.

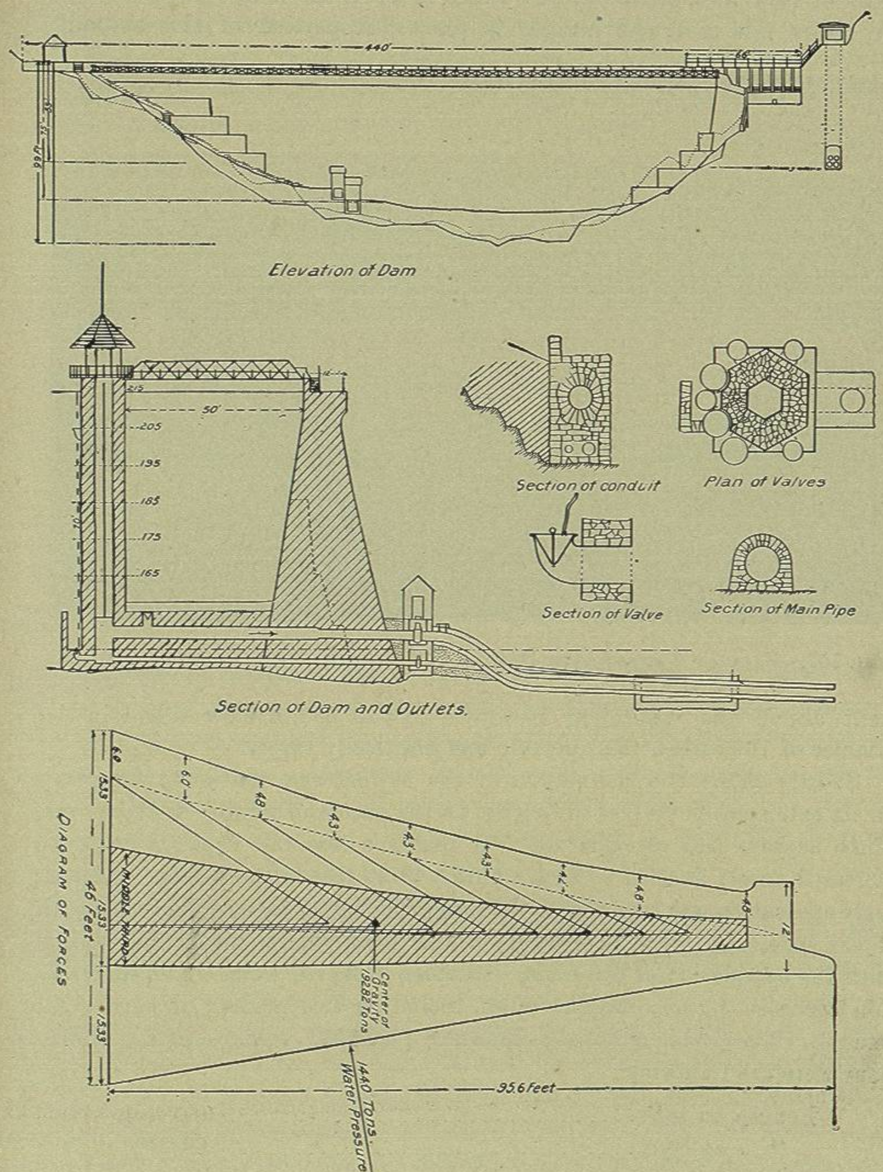

Fig. 151.—Elevation and Sections of Sweetwater Dam.

base, and was 5 feet thick at the top. It was fortified by an embankment of clay and gravel 50 feet wide, 10 to 15 feet high, placed against the upper side and well tamped in place. A portion of this embank-

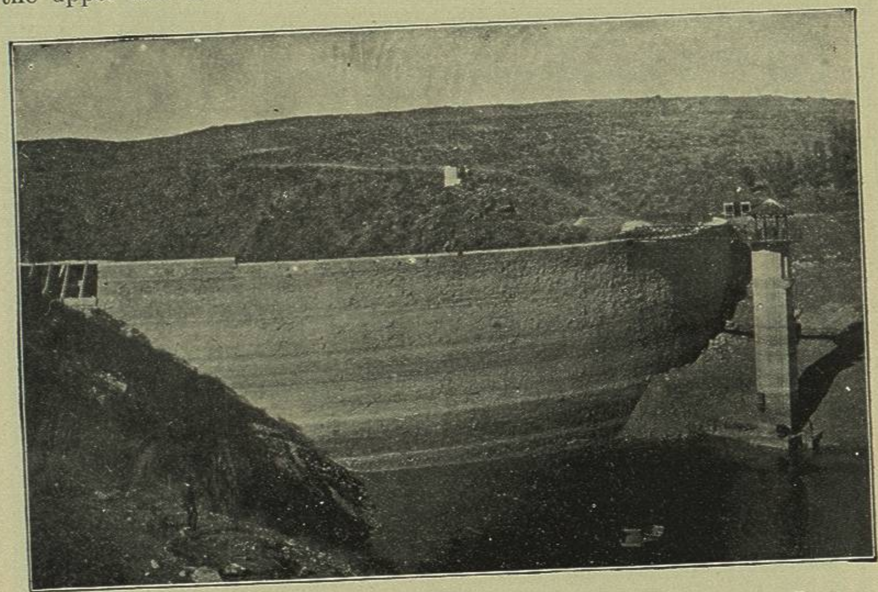

FIG. 152.—FACE OF SWEETWATER DAM IN 1899. AFTER TWO YEARS OF DROUTH.

ment above the water-line is shown in Fig. 152, a view taken in the summer of 1899 when the reservoir was practically empty.

Shortly before the completion of the 60-foot dam authority was given for its extension to 90 feet in height, on the recommendation of the writer, whose surveys had revealed the fact that the reservoir capacity could be increased nearly fivefold by such addition of 30 feet to the height. Accordingly excavation was renewed at the lower side for an extension of the width of the base, and work proceeded on the final plan without interruption until the completion of the entire structure in April, 1888. The construction occupied sixteen months in all, including two months of waiting for cement. The profile adopted is shown in Fig. 151. As finished the dimensions were the following:

Length on top	380 feet.
" at base	150 "
Thickness at base	46 "
" " top	12 "
Height on upper side exclusive of parapet	90 "
Height on lower side	98 "
Radius of arch	222 "

The up-stream face has a batter of 1 to 6 from base to within 6 feet of top; thence vertical. The lower slope has a batter of 1 in 3 for 28 feet, then 1 in 4 for 32 feet, and thence 1 in 6 to the coping.

Water is drawn from the reservoir through a tower of hexagonal form, placed 50 feet above the dam, near the center (see Fig. 153), and connected with the dam by a foot-bridge of iron (see Fig. 154).

It has seven inlet-valves which are placed at intervals of 10 feet in height from the top down. Two cast-iron outlet-pipes, 18 and 14 inches diameter respectively, lead from the tower to and through the dam. They lie in a trench cut in the bed-rock, and on top of them is built a masonry conduit from the tower to the dam, connecting with a third pipe, 36 inches diameter, of riveted wrought iron, ½ inch thick. All are carefully embedded in the masonry of the dam, and no leakage has ever taken place along them. Gate-valves control their flow below the dam. The tower valves are simple plates of cast iron fitting over elbows set in the masonry of the tower, and can only be moved when the lower gates are closed.

The stone used in construction was quarried from the cliffs on either side below the dam, within a distance of 800 feet, and was all hauled in wagons and stone-boats. Animal power was alone used for manipulating the derricks in the quarry and on the dam, as well as for mixing concrete. The stone was a blue and gray porphyry impregnated with iron, weighing 175 to 200 pounds per cubic foot. It quarried out with irregular cleavage, but generally presented one or two fairly good faces. The seams in the rock contained plastic red clay to such an extent that it was necessary to wash and scrub by hand every stone that went into the dam with good steel and fiber brushes. Imported English and German cement was used throughout the work, mixed with clean, sharp river sand in a revolving square box of wood, with a hollow shaft passing through two diagonally opposite corners, through which the water was introduced. The masonry weighed when tested 164 pounds per cubic foot.

The waste-weir is formed at the left bank as a part of the dam, and as first built consisted of seven bays, each 4 feet in clear width, closed with flash-boards, which could be opened to a depth of 5.7 feet below the crest of the dam. These bays were separated by masonry piers, each 2 feet in thickness. This wasteway and a 30-inch blow-off gate from the main pipe below had a combined capacity of 1800 second-feet, which was in excess of the maximum flood discharge as indicated by high-water marks, although a subsequent flood exceeded this capacity a little more than ten times.

The volume of masonry in the dam proper, including the parapet 3.5 feet high, 2 feet thick, was 19,269 cubic yards. The wasteway, inlet-tower, and other accessories required 1238 cubic yards additional, or a total of 20,507 cubic yards of masonry, in which were used 17,562 barrels of

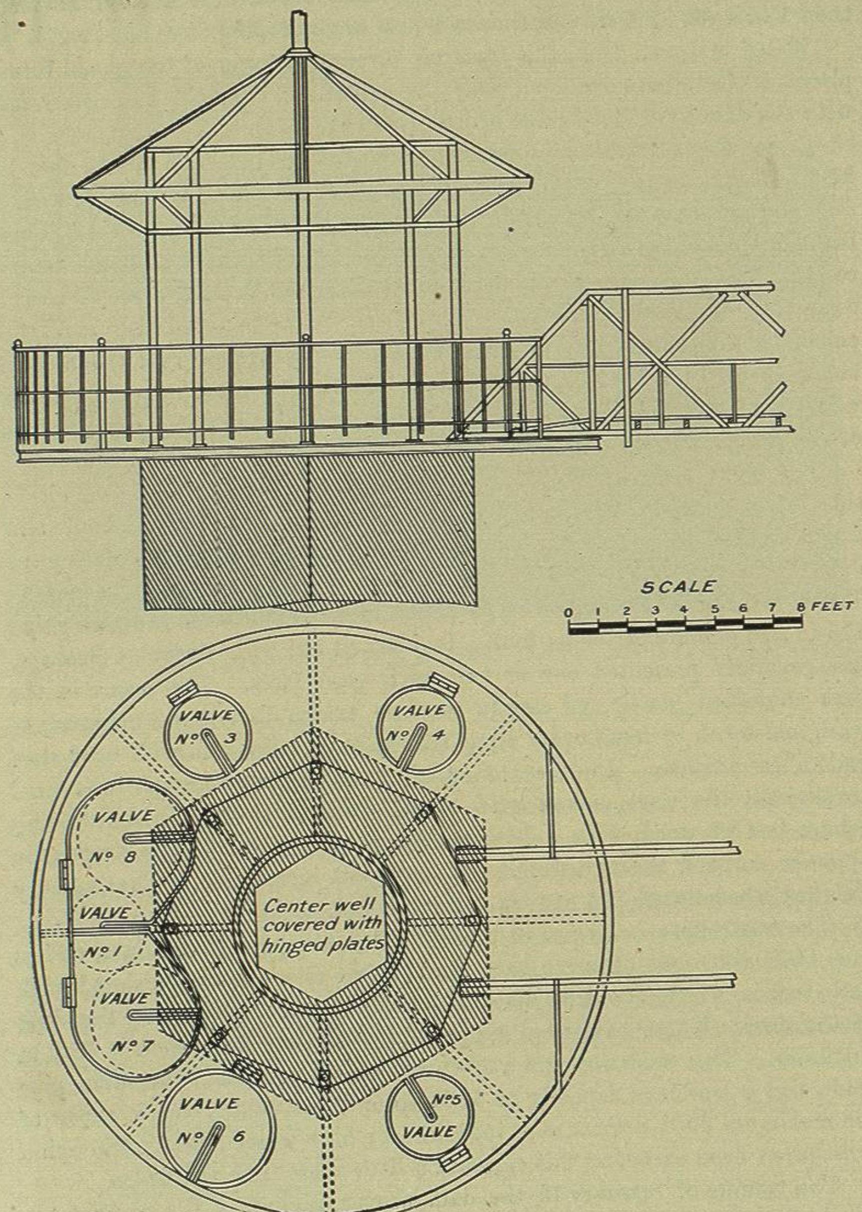

FIG. 153.—DETAILS OF TOWER OF SWEETWATER DAM.

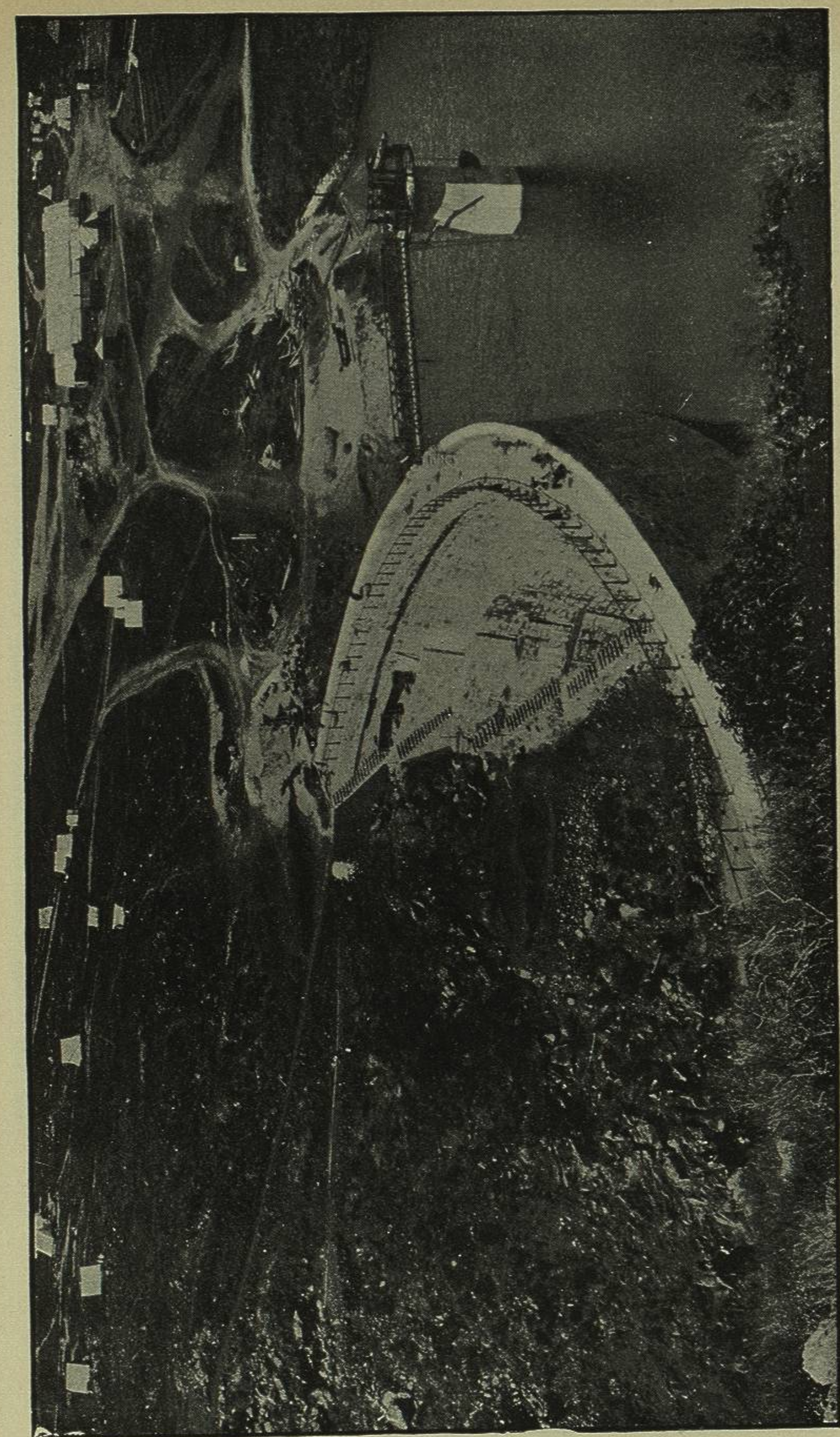

FIG. 154.—SWEETWATER DAM AS FINISHED, APRIL, 1888.