The dry years which have occurred since 1895 must undoubtedly reduce this mean very considerably, although the record has not been made public. In 1891 the run-off from the watershed was computed by Wm. Ham. Hall from the records of catchment, as follows, beginning with the completion of the dam:

Season.	Run-off. Acre-feet.	Season.	Run-off. Acre-feet.
1883–84........	236,000	1887–88........	132,400
1884–85........	21,600	1888–89........	70,400
1885–86........	142,400	1889–90........	211,600
1886–87........	8,000	1890–91........	186,800
		Mean........	126,150

This estimate is so large as to be decidedly questionable. Mr. J. B. Lippincott, Hydrographer U. S. Geological Survey,* estimates, by comparison of observations in other parts of the State, that the probable maximum run-off of the shed is about 100,000 acre-feet, and the mean about 28,500. The minimum was doubtless reached in 1895–99. The irrigation season of 1899 began with but 1560 acre-feet in the reservoir, a small portion of which was held over from the previous year. This was entirely exhausted early in the season, and an attempt was made to maintain the supply by pumping from shallow wells in the bed of the reservoir, although with indifferent success. Four to six acre-feet per day were obtained for a time, but it was largely dissipated by evaporation in passing down the canyon.

The loss to be anticipated from this reservoir by evaporation is a subject of much interest. It is at an altitude of 6200 feet, and well sheltered from winds by surrounding mountains, favoring minimum loss. On the other hand the water is shallow and spread out over a large area. Observations made at the gate-house of the Arrowhead Reservoir Company in Little Bear Valley, in the same mountain-range, but at lower elevation (5160 feet above sea-level), indicate that the evaporation from water-surface is about 36 inches per annum in that locality, of which about 90% occurs in the eight months from March to November, inclusive. This rate of loss applied to Bear Valley reservoir when full would indicate a probable loss of over 20% per annum if no water were drawn out, or about 14% per annum if a uniform draft of 2500 acre-feet per month were made during the period from March to November, inclusive.

The general form of the reservoir is shown in Fig. 177.

La Grange Dam, California.—There is something quite unusual in a masonry dam 125 feet high which is erected for the sole purpose of diverting water from a stream for irrigation purposes, and this is the character of structure that was built on the Tuolumne River, 1½ miles above the town

* Nineteenth Annual Report for 1897, U. S. Geol. Sur., Part IV., p. 585.

of La Grange, California, in 1891–94, by the Turlock and Modesto irrigation districts jointly. The Tuolumne River, as it leaves the mountains, on its way across the San Joaquin Valley, is cut down so deeply below the general level of the plain as to require a high dam to raise the water sufficiently to get it out on the irrigable lands. The dam is located at the mouth of a narrow box canyon and is in no sense designed or used for storage. It is 125 feet high on the up-stream face, 129 feet on the down-stream side, 90 feet in thickness at bottom, 24 feet at crest, and but 310 feet long on top. The wall is built as the segment of a circle of 300 feet radius, the arch being opposed to the direction of the water-pressure, although its profile is of purely gravity type, in which the lines of pressure are well within the middle third. On the water-face the dam is vertical for 70 feet below the top, and thence to the foundation has a batter of 1 in 20. The edges of the crest are rounded off on a radius of 3 feet on upper side, and 17.5 feet on lower side, leaving 6 feet of the crest level. At 6 feet below the crest the dam is 24.13 feet thick; at 69 feet below it is 52 feet thick; at 89 feet it is 66.25 feet; and at 97 feet, the top of the foundation masonry, it is 84 feet thick. The extreme bottom width at the highest point of the dam is 90 feet. The lower face has a batter of ½ to 1, from 70 feet below the crest, where a compound curve of 63 and 23 feet radii commences, which carries the face to its intersection with the battered face of the foundation masonry about 3 feet above low water. From this point the foundation batter is 1 in 7, to the bottom, about 32 feet in the deepest place. These dimensions give practically an ogee form to the down-stream face, which permits the water to follow the masonry without leaving its face in its descent, provided the depth be not more than 4 to 5 feet, and gives it a horizontal direction at the bottom. The curvature of the dam and the fact that the canyon is but 80 feet wide at the base of the dam, or top of foundations, so concentrate the stream that some erosion may be anticipated at the base, although nothing serious in that line has been reported.

The dam contains 39,500 cubic yards of masonry and cost $550,009. It is built throughout of rough, uncoursed rubble masonry, laid in Portland-cement concrete, in practically the same manner as that described in the construction of the Hemet dam. The work was done by contract, at $10.39 per cubic yard, including the excavation for foundations, but not including cement, which was furnished by the districts. The cement cost $4.50 per barrel delivered, and 31,500 barrels were used in the work.

It is believed to be the highest overflow dam in the United States, if not in the world. The volume of water passing over it may in extreme floods amount to 100,000 second-feet. The maximum flood that has yet gone over the dam was about 46,000 second-feet in volume, the depth on crest being 12 feet.

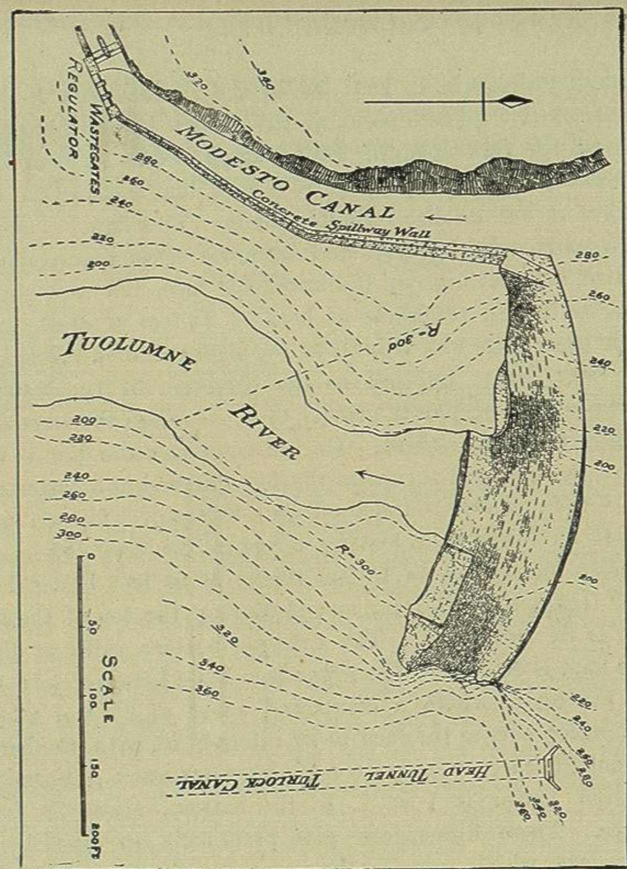

Fig. 178.—Plan of La Grange Dam, California.

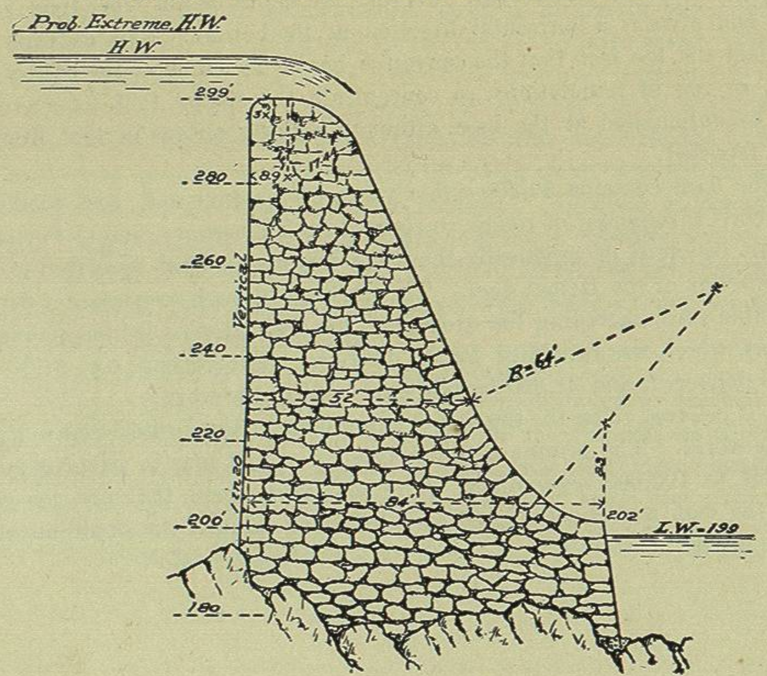

Fig. 179.—Profile of La Grange Dam, California.

During construction the low-water discharge was carried past the work in a flume the first year, and subsequently through two culverts, one at low-water level, and a second 10 feet higher. These were 4 feet wide, 6 feet high.

The Modesto Canal takes water through an open cut from the dam, on the right bank, and has a capacity of 750 second-feet. The Turlock Canal reaches the reservoir above the dam by means of a tunnel 560 feet long, 12 feet wide, 11 feet high, with regulating-gate at the head.

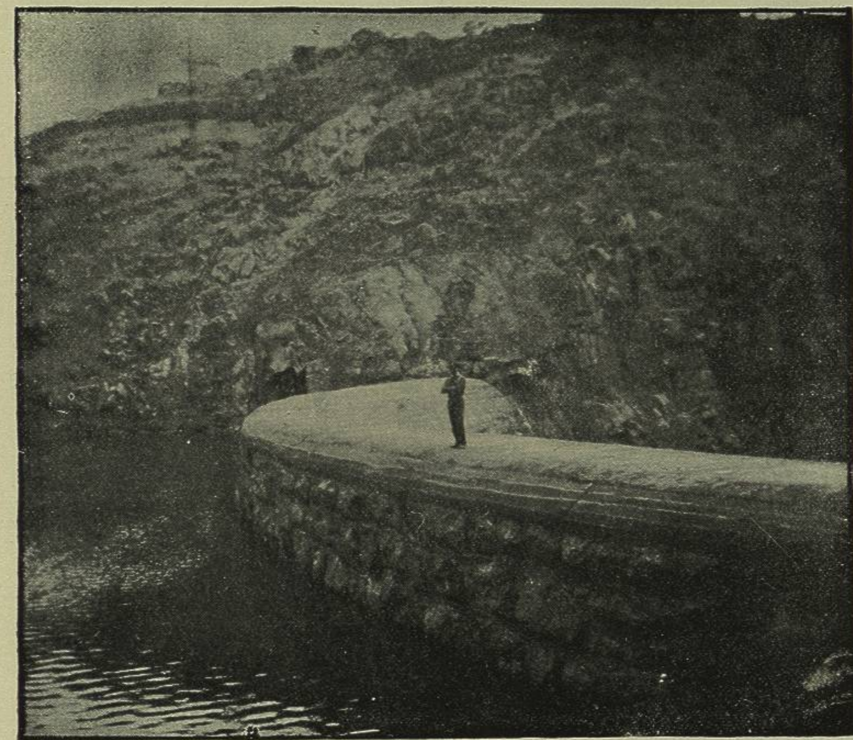
Fig. 180.—Upper Face of La Grange Dam.

In construction of the dam three lines of cableway were used, spanning the canyon, for hauling the materials.

The excessive cost of the work was doubtless due to the uncertainty as to the value of the bonds of the irrigation districts, which created a temerity among contractors, and there were few bidders. The contractor was obliged to buy the bonds at not less than 90% of their face value, and dispose of them at a figure from which he could obtain a profit on his work. Under ordinary conditions of prompt payments in cash the construction should have been done for one-half the actual cost.

The dam was designed by Luther Wagoner, C.E., who resigned

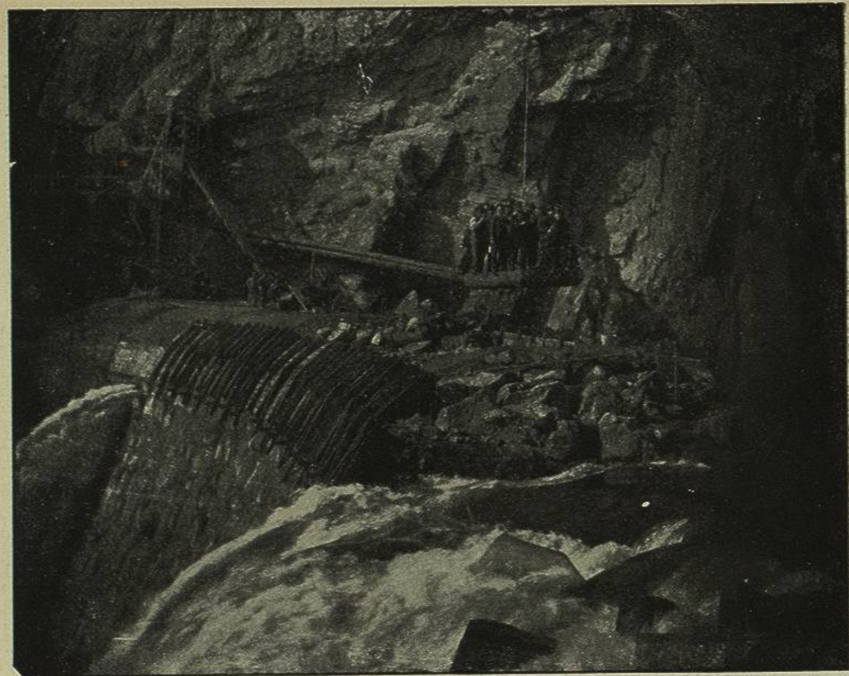

Fig. 181.—La Grange Dam, California, during Construction—finishing the Crest.

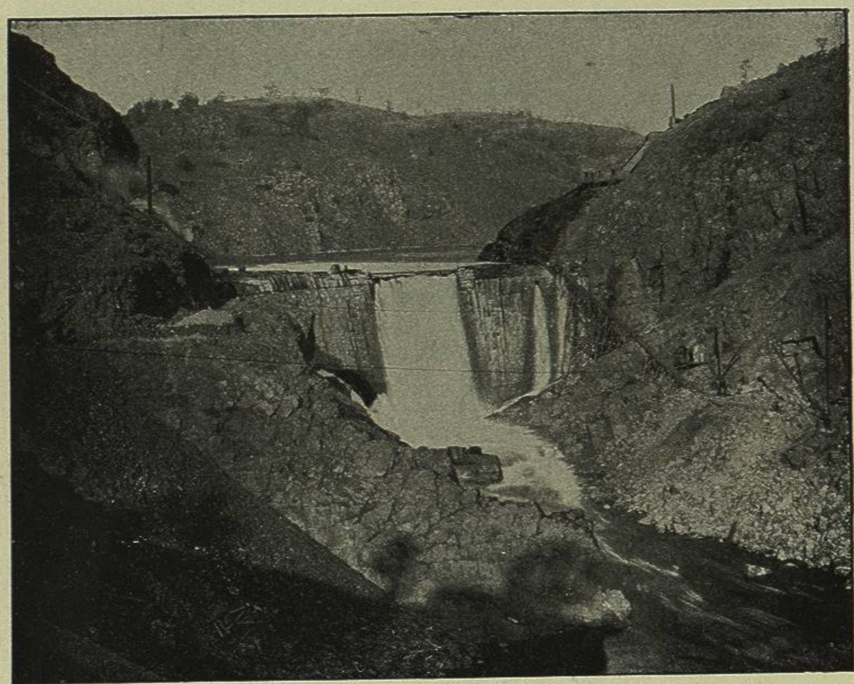

Fig. 182.—La Grange Dam, California.

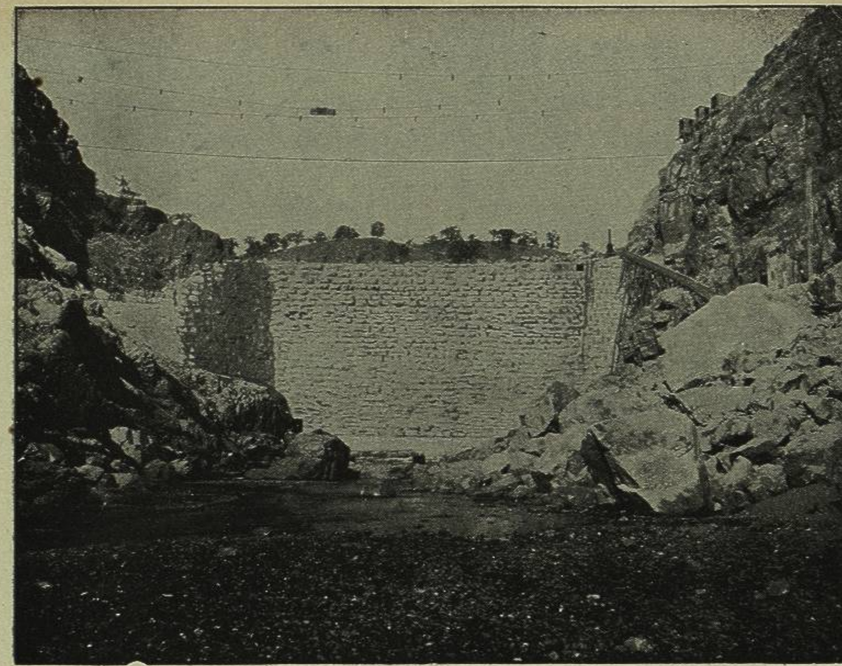

Fig. 183.—La Grange Dam, California

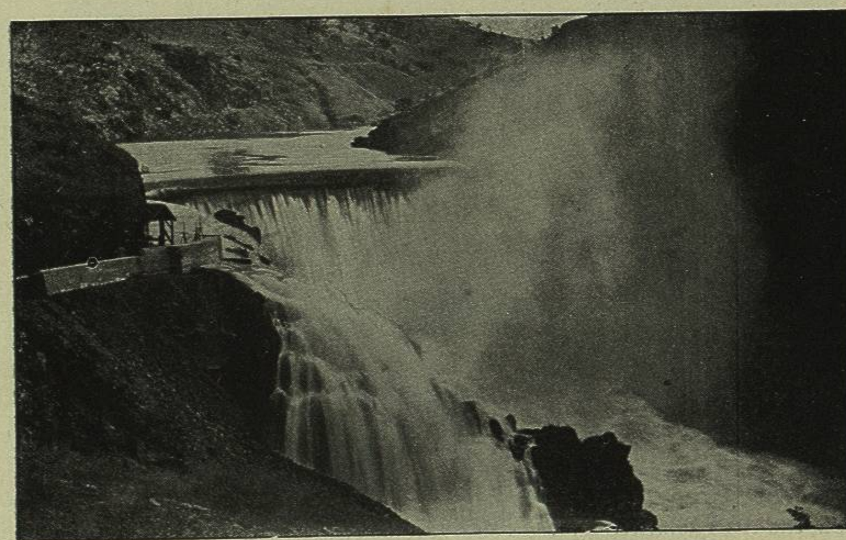

Fig. 184.—La Grange Dam, California, during Flood.

shortly after work began, and construction was completed under charge of E. H. Barton, engineer for the Turlock district, and H. S. Crowe, representing the Modesto district.

The elevation of the crest of the dam is 299.3 feet above sea-level, and the canal grade is 8.3 feet lower.

The Turlock irrigation district embraces 176,210 acres, and the canal supplying it has a reported capacity of 1500 second-feet. The main canal is 18 miles long, feeding five laterals of an aggregate length of 80 miles.

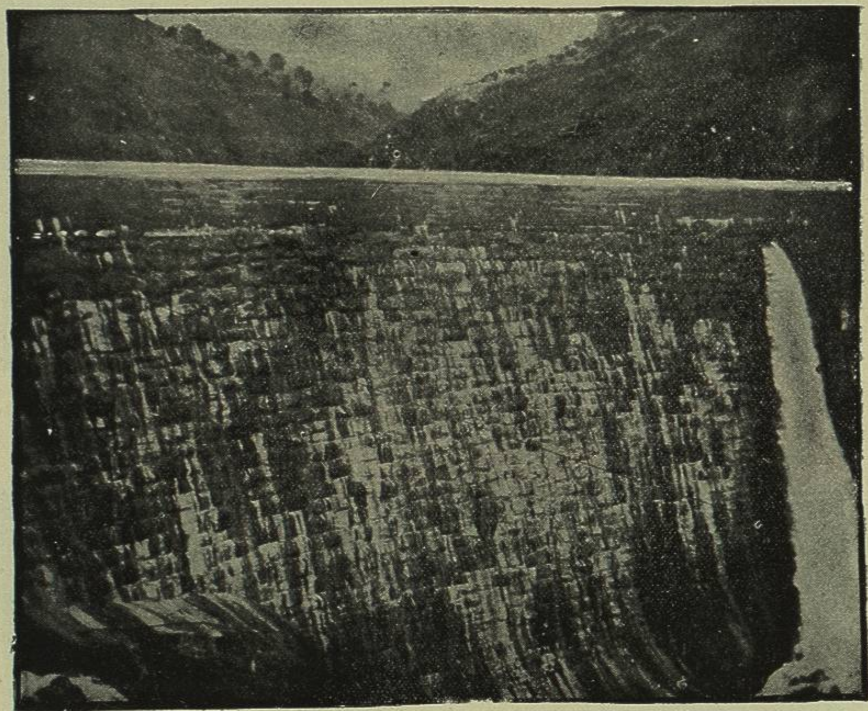

Fig. 185.—Lower Face of La Grange dam.

The Modesto district covers 81,500 acres, with a main canal 22.75 miles long before reaching the district, having a capacity of 640 second-feet. The entire irrigation system when fully completed will be the largest and most comprehensive one in California. and the dam upon which its success depends has been wisely constructed of such dimensions as to be of unquestionable stability. Figs. 180 to 185 are views of the structure.

Folsom Dam, California.—There are many features of the Folsom dam, on the American River, California, which give it special interest to engineers and all others who have seen it, one of which is that it was built by the State of California entirely with convict labor, incidentally to give employment to the inmates of one of the State prisons, but primarily to

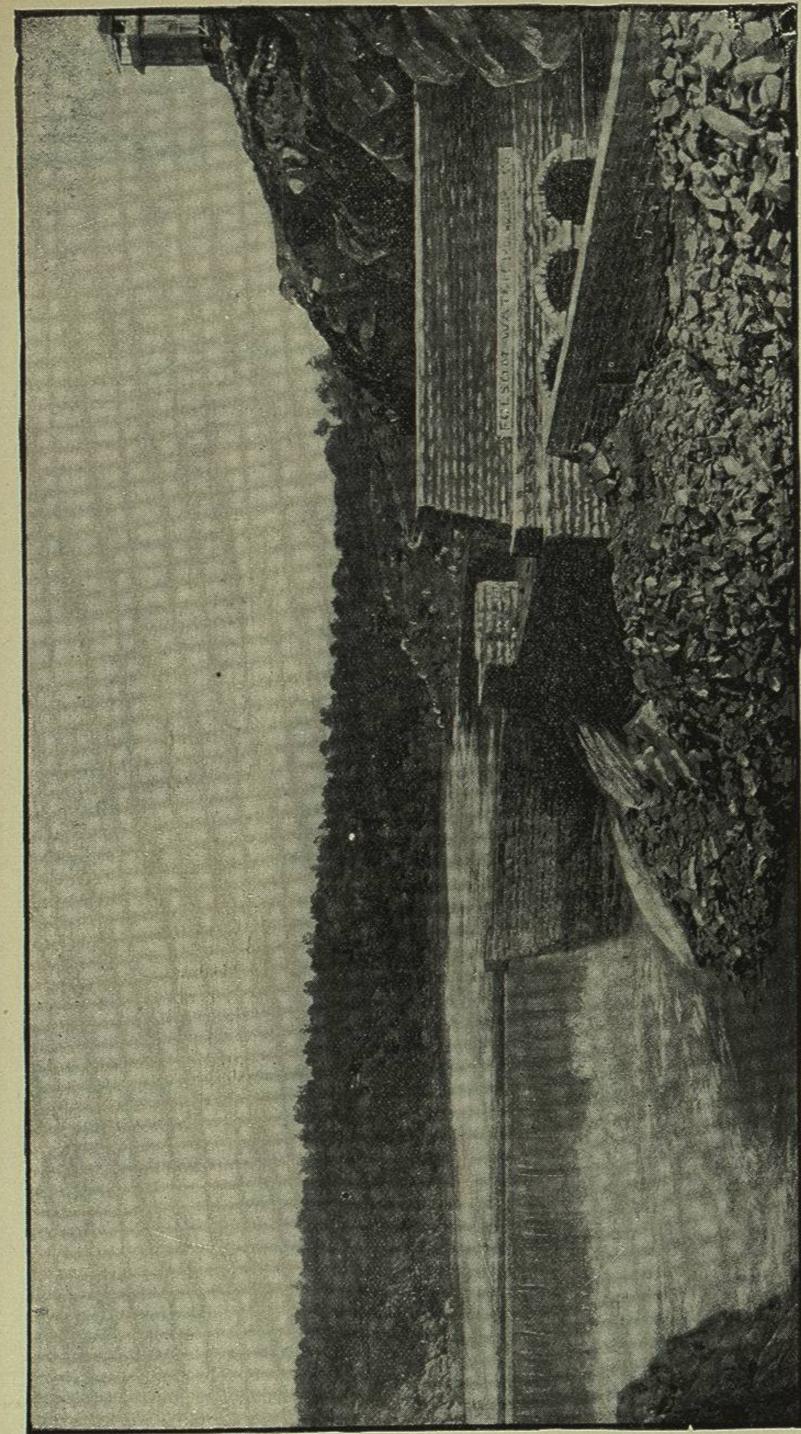

Fig. 186.—View of Masonry Dam on American River, California, at the Folsom State Prison, showing Canal Head-gates. Dam built by prison labor.

develop water-power for use in various industries about the prison and for transmission to other localities. A further purpose is served by the dam in the diversion of water from the American River out upon the plains of the Sacramento Valley for irrigation. The plan, profile, and section of the dam are shown in Fig. 187, and a photograph taken by a convict during construction is given in Fig. 188.

The dam is of the same general character as the La Grange dam, serving no purpose of storage, but designed solely for the diversion of the stream and so constructed as to permit flood-water to pass freely over its crest.

It is located at the top of a natural fall in the bed-rock of the stream, its height at the up-stream toe being 69.5 feet, while at the down-stream footing the height is 98 feet to the crest-line. The top thickness is 24 feet; base 87 feet. A movable shutter, 180 feet long, is placed in the center of the dam for raising the normal water-level at low stages. This shutter is placed in a depression, 6 feet in depth, below the general level of the dam, and is lowered during floods to allow the passage of extreme freshets over the dam. At low water the shutter is raised to a nearly vertical position by means of hydraulic jacks, as shown in Fig. 189, which are operated from the prison power-house. The entire crest length of the dam is 650 feet, including the curved approach to the canal head-gates.

The main dam is straight in plan. The construction of the dam was begun in 1886 and completed in 1891. It contains 48,590 cubic yards of masonry in the dam proper, while the retaining-wall of the canal has 27,000 cubic yards and the power-house 13,700 cubic yards of granite masonry, all laid in Portland-cement mortar. The dam is a very massive and substantial piece of masonry, composed of rough granite ashlar in large blocks of 10 tons or more in weight. The quarry, which determined the location of the State prison, affords an unlimited quantity of excellent granite which has a fine cleavage and is readily quarried into blocks of any desired size. The excavation of the canal along the granite cliff gave all the material needed for the dam. The stone was delivered to the dam by a cableway of unusual construction, in that two cables were used side by side like a suspended railway-track, and the trolley was a four-wheeled carriage from which the loads were hoisted and suspended. There are many disadvantages to this form of cableway, and no special features to recommend it as preferable to the single cable. The latter admits of dragging rocks from either side of the line of the cable for a considerable distance, an operation which would tend to derail the trolley of a double cableway.

The canal taken from the left side of the dam passes through the prison grounds and thence to the town of Folsom, one and one-half miles below, where the main power-drop of 85 feet is utilized for generation of power, which is transmitted electrically to Sacramento, 22 miles distant.

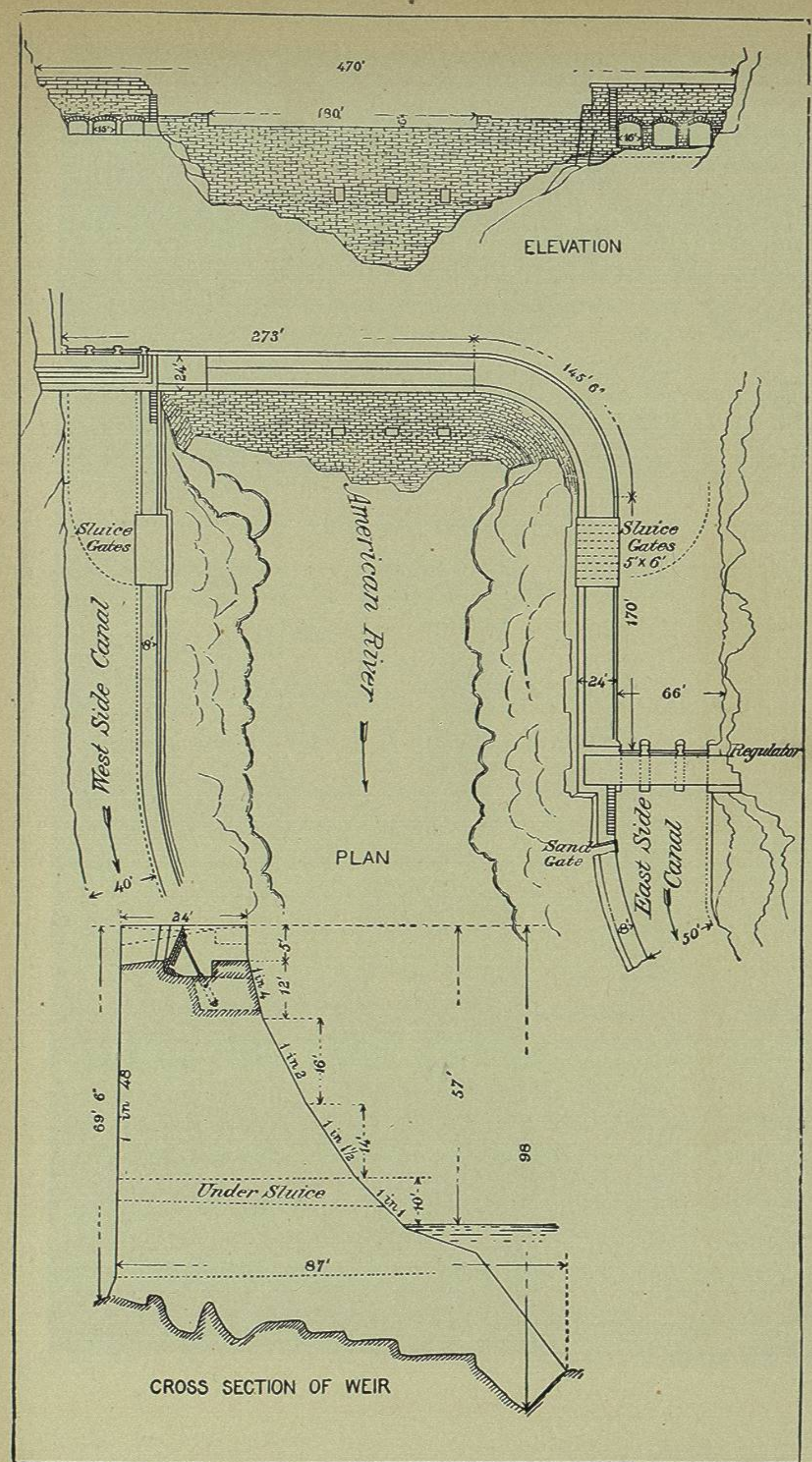

Fig. 187.—Plan, Cross-section, and Elevation of Weir and Headworks of Folsom Canal.

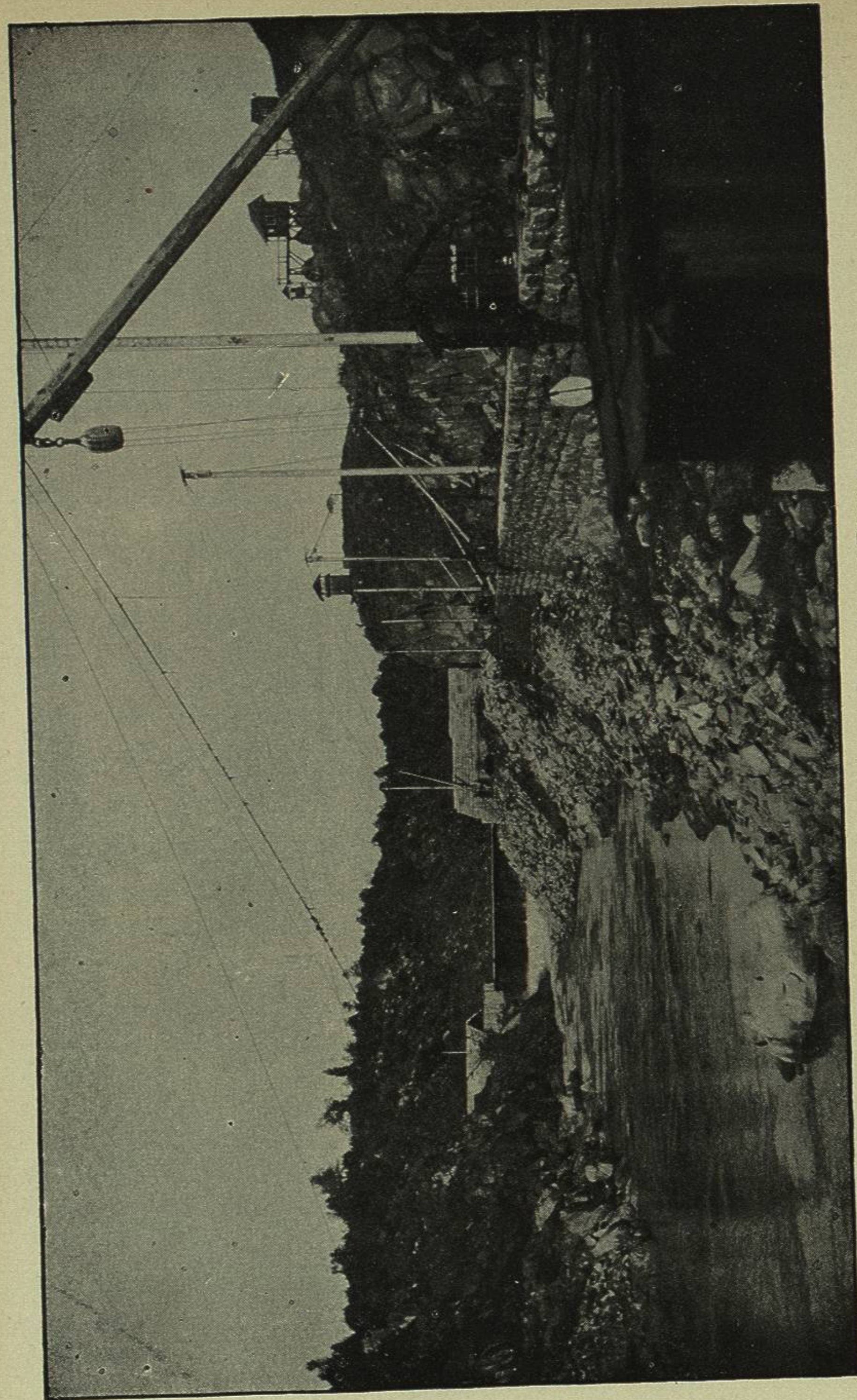

Fig. 188.—American River Dam at Folsom.

In passing the prison power-house a drop of 7.5 feet is utilized by six 87-inch Leffel turbines of the double improved type, and about 800 H.P. are developed at the maximum. The canal is 8 feet in depth throughout, the width below the prison power-house being 30 feet on bottom, 40 feet on top. Above the power-house the width is 10 feet greater. The grade is 1:2000, and the capacity of the canal about 1000 second-feet.

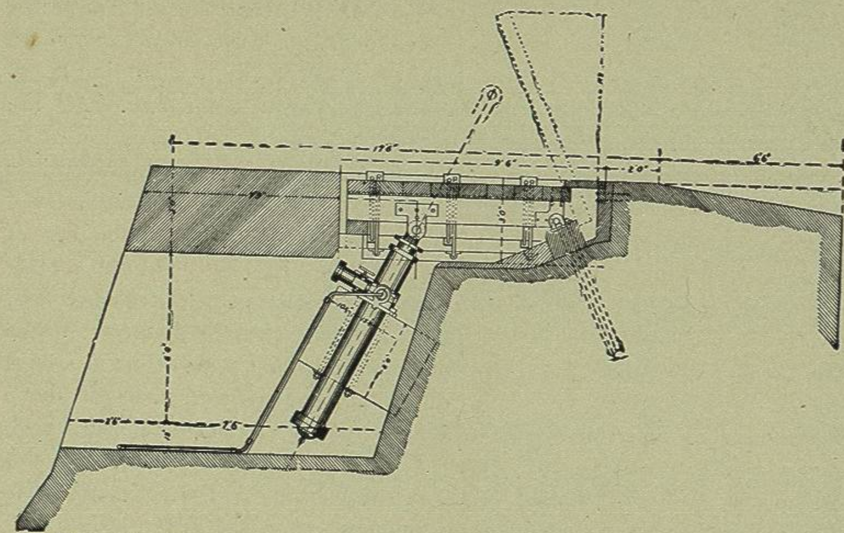

Fig. 189.—Hydraulic Jacks for raising Shutter on Folsom Dam.

The San Mateo Dam, California.—Doubtless the most enormous mass of masonry of any sort in the West, if not in the entire United States, is the great concrete dam erected on San Mateo Creek, 6 miles above the village of San Mateo, California, by the Spring Valley Water-works of San Francisco, to impound water for the supply of that city. The dam ranks among the highest and most costly of the world, and was erected in 1887 and 1888.

It was projected to reach to a height of 170 feet, at which the top width was to be 25 feet and base width 176 feet, but construction was suspended at the height of 146 feet, or 34 feet below the ultimate height. When finished the top length will be 680 feet. It has a uniform batter of 4 to 1 on the up-stream face, while the lower slope, beginning with a batter of $2\frac{1}{3}$ on 1 near the top, curves with a radius of 258 feet to near the bottom, where the batter is 1 to 1. The dam is arched up-stream with a radius of 637 feet.

It is built throughout with concrete, made of broken stone, beach sand, and Portland cement. This material was chosen because of the difficulty of securing rock in the vicinity suitable for rubble masonry. The stone was quarried in the immediate vicinity, and occurred in small irregular nodules,