the site cost in addition $23,112.88, including clearing. The total cost was therefore $110,059.09, or $38.41 per acre-foot of capacity. The prices paid were unusually high for such work, and were the following per cubic yard: earth excavation, 30 cents; rock excavation, $1.10; rock-fill, $1.50; dry stone masonry, $3.75; rubble masonry in cement mortar, $8; concrete, $14; lumber, $50 per thousand feet board measure.

The detail of this work is given with special fullness, as it is the first rock-fill dam to be constructed in California for irrigation storage, and is of a type which is likely to be employed quite commonly in the future in localities better adapted for its use than in this particular case, where stone was comparatively scarce in the immediate vicinity of the dam.

The works of the district summarize in cost as follows:

Main feeder conduit	$116,328.60
Dam and reservoir	110,059.09
Distribution system	85,727.80
Total	$312,115.49

The catchment of the reservoir has been approximately as follows:

1895, 48	feet depth =	880 acre-feet
1896, 60	" " =	1925 "
1397, 74	" " =	3700 "
1898, 59.5	" " =	1000 "
1899, 47	" " =	830 "
Total		8335 acre-feet, or an average of 1667 per annum.

Lower Otay Rock-fill Steel-core Dam, California.—One of the most interesting of all the rock-fill types of dam yet constructed is located on Otay Creek, San Diego County, California, 22 miles southeast of San Diego, 10 miles back from the coast, and not more than 5 miles from the Mexican boundary-line. It forms the lower one of a series of four mammoth dams projected by the Southern California Mountain Water Company, to impound water for the municipalities of San Diego and Coronado and for the irrigation of an extensive area of frostless mesa lands adapted to citrus-fruit culture, reaching from the Mexican border northward to San Diego, including the peninsula of Coronado, and for the domestic supply of the villages and towns within reach of the distributing system to be built from the reservoir. The Lower Otay dam was completed in August, 1897.

The Otay Creek, at the point selected for the dam, cuts through the great dike of porphyry which traverses San Diego County from north to south nearly parallel with the coast-line. This dike in places is 10 miles or more in width, and at others less than 1 mile, and occupies the middle ground between the granite formation lying east of it, and the mesa forma-

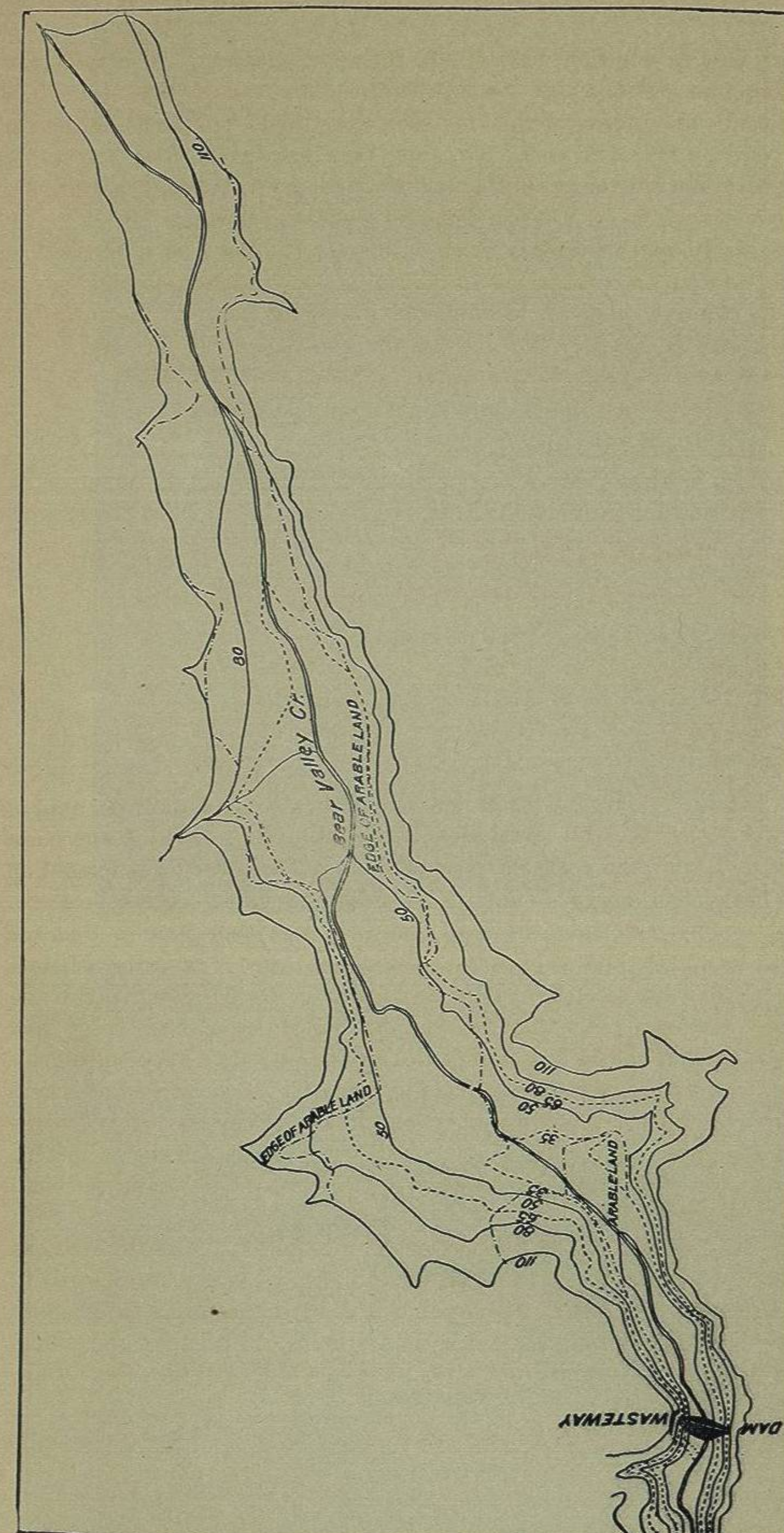

FIG. 8.—CONTOUR MAP OF RESERVOIR OF ESCONDIDO IRRIGATION DISTRICT.

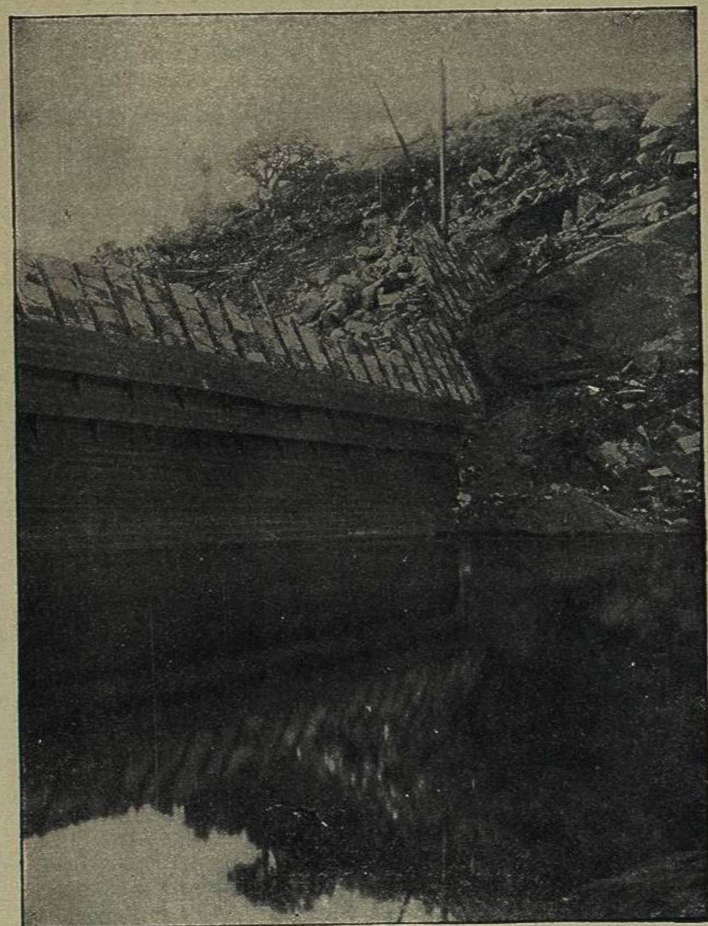

FIG 9.—CONSTRUCTION OF FACING OF ESCONDIDO DAM.

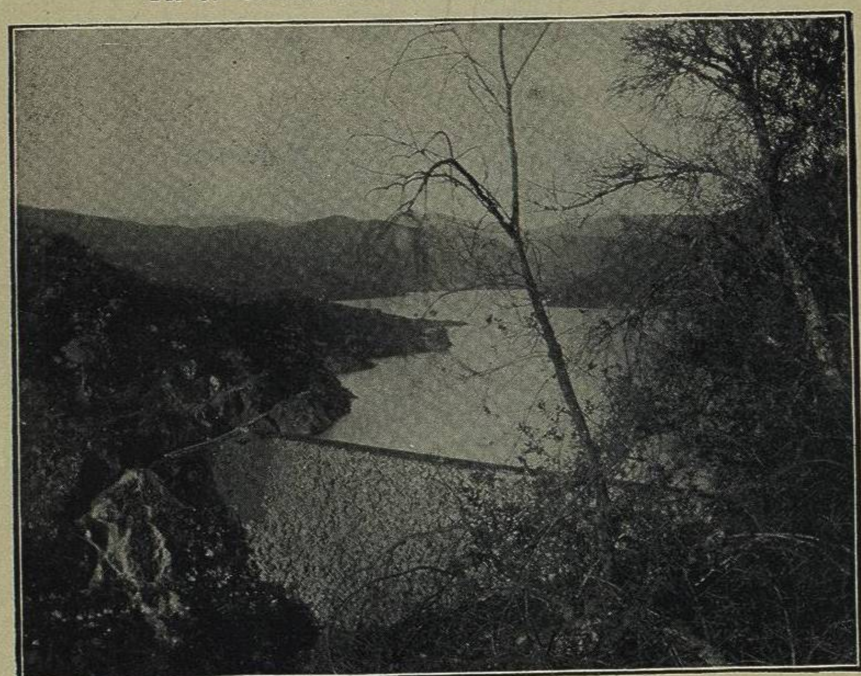

FIG. 10.—ESCONDIDO (CAL.) ROCK-FILL DAM. WOODEN LINING.

tion, which is an irregular strip of land, 10 to 15 miles wide, lying between the porphyry dike and the shore of the Pacific. The mesa formation is alluvial in origin; consisting of marl, indurated sand, gravel, cobbles, and all shades of soil from clay to sandy loam, but is devoid of hard rock, while the porphyry is an igneous rock, exceedingly tough, of high specific gravity, without regular cleavage, but broken by numerous fine seams with infiltration of reddish clay. The highest protrusions of the dike form the San Ysidro and San Miguel mountains, 2500 to 3000 feet in altitude. It is intersected by all the streams of the county that reach to the ocean, affording sites for the Lower Otay, the Upper Otay, the Sweetwater and La Mesa dams, and others further north that are projected. The Escondido dam is but a mile or two east of the dike in granite formation. The Otay dam is within a few hundred feet of the western limit of this dike, and in fact the outlet tunnel of the reservoir avoids it entirely and was excavated through the soft brown marl of the mesa formation.

The site of the Otay dam was an ideal one for a masonry structure, because of the satisfactory character of the bed-rock foundations, and the abundance of suitable rock and sand at the site, while its convenience to a port of entry rendered the cost of cement very moderate. The usual incentive for building rock-fill dams in preference to masonry, due to their remoteness and the high cost of freighting cement to the site was lacking in this case, and in fact the work was originally planned as a masonry dam. A foundation was laid for this purpose 65 feet thick at the base, reaching down to a depth of 31.4 feet below zero contour, and carried up to a height of 8.6 feet above zero, with a length on top of 85 feet. A view of the work is shown in Fig. 11.

Whether the change in plan from masonry to rock-fill with steel core has resulted in economy of first cost is difficult to determine, as the actual cost of construction has not been made public, or whether there may be grounds for regret that the change was made cannot be known until the stability of the structure is fully tested by the lapse of time. The reservoir has never filled since the completion of the dam, and until it is filled and remains full a considerable period without developing signs of weakness or extensive leakage, the success of the novel design cannot be known. Meantime the engineering profession will entertain the liveliest interest in the development of this novel type of dam, which, if successful, will certainly have wide application to other sites where the choice of material has a more limited range. The credit for originating the idea of making a rock-fill dam water-tight by inserting in its center a web-plate of steel, filling the entire cross-section of the canyon from side to side, and for putting it in application on a large scale, belongs to the former president of the water company, Mr. E. S. Babcock, of San Diego. When this plan was decided upon a heavy T iron was anchored to the top of the finished masonry foundation by 1-inch bolts, set in the masonry. The vertical leg of the T was punched with $\frac{5}{8}$-inch rivet-holes, spaced 3 inches center to center, and the bottom plates riveted to it. The plates were 5 feet wide, and 17.5 feet long, and the three bottom courses were 0.33 inch thick. From 28 to 50 feet high they are $\frac{1}{4}$ inch thick, and above 50 feet they are 8 feet wide, 20 feet long, and lessening in thickness as the top is approached. After riveting the

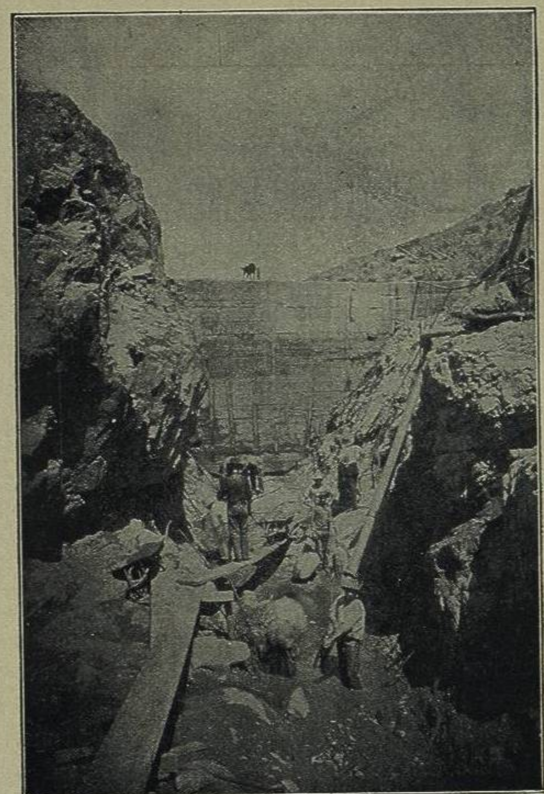

FIG. 11—MASONRY FOUNDATION OF LOWER OTAY DAM.

plates together with hot rivets they were chipped and calked on the side next to the water, and coated with Alcatraz asphalt, F grade, applied hot with brushes. Over this coat a layer of burlap was placed on each side of the plates, while the asphalt was still hot. This adhered tightly to the plate and served to hold the soft asphalt from flowing. A harder grade of asphalt was subsequently put on over the burlap, and the whole then encased in a rubble-masonry wall laid with Portland-cement concrete, 2 feet thick, the steel plate being in the centre. This wall at base is 6 feet thick,

tapering to 2 feet in a height of 8 feet. The moulds for the concrete, consisting of 1-inch boards laid horizontally and 2 × 6-inch vertical posts, were left in position permanently and the rock-fill built against them on either side. The steel core, or web-plate, was carried into the side walls of the canyon in a trench excavated to the depth necessary to reach solid rock and anchored with bolts leaded into the rock. The end plates were not trimmed to fit the irregular line of the rock cutting, but the masonry was widened to a maximum thickness of 20 feet at the sides, tapering from the normal thickness of 2 feet in a distance of about 20 feet. Fig. 14 shows the trench on the right bank about at the 40-foot contour. The function of the wall is to steady and stiffen the web-plate and protect it from injury from the loose rock piled against it, and as the wooden moulds were not removed the embankment is free to settle without injuring the concrete or the plates.

The expansion of the plates after they were riveted together, and the obtuse angle up-stream on which they were first started, which gradually was obliterated by an approach to a straight line toward the top of the dam, gave them a very irregular alignment, as will be seen in Fig. 13, which is a view looking along the top of the dam toward the left bank just before its completion.

The dam is a loose, rock-fill embankment, lying as it was dumped, without any portion of it, except the 2-foot core-wall, being laid by hand. In this respect it differs from its predecessors of the same type, which have been built with a considerable proportion of their slopes on the water-side laid up as a dry wall. It was designed to be 20 feet wide at top, with side slopes of $1\frac{1}{2}$ on 1 on each side. When work was suspended the up-stream slope, composed of the finer grades of materials coming from the quarry, had assumed about the slope stated, but the lower slope was steeper and stands about 1 to 1, while the top width is from 9 to 12 feet. When visited by the writer in September, 1899, the material excavated from the spillway cut was being dumped on the upper slope and the top width increased. The spillway is located some few hundred feet from the east end of the dam, and will consist of a channel 30 feet wide, 300 feet long, with a maximum depth of 30 feet, cut in the rock to a depth of 10 feet below the crest of the dam. The depth of water will be controlled by flash-boards resting at an angle of 30°, between channel-iron frames placed 5 feet apart. A wagon-bridge will be built over the top of these frames, from which full control of the flash-boards will be had. The discharge of the spillway will reach the creek channel several hundred feet below the toe of the embankment.

The entire volume of stone used in the work, approximately 180,000 cubic yards, was quarried immediately below the dam on the right bank, and was transported from the quarry by means of a Lidgerwood cableway, the cable having a diameter of $2\frac{1}{4}$ inches, and a span of 948 feet between