30% in sand. Sharp sand does not flow as readily as rounded sand or gravel, and is improved in delivery by an admixture of clay and stones. In this case the clay acted as a lubricant, which served to increase the carrying capacity of the water.

The entire volume of water pumped in building the dam, if computed by the percentages of solids given, must have been less than 20,000,000 gallons, although it is unlikely that these percentages were maintained throughout. The volume discharged through the nozzle under the stated pressure must have been about 1.4 second-feet, which is a very small sluicing-head. The nozzle velocity was 115 feet per second. The limitation of the nozzle pressure to 100 lbs. per square inch restricted the delivery of water and its effective power in disintegrating and transporting the soil to considerably less than might have been accomplished with higher pressure.

The entire cost of the dam with all its accessories is said to have been but $1140, which must be regarded as a marvel of cheapness for a structure of the size of this one and performing the function of an impounding dam of its magnitude. Another interesting feature connected with it was that the construction of the reservoir permitted the new pumping-station supplying the city of Tyler to be located on the border of the pond so much nearer to the town than the location of the original pumping-plant, which was at the site of the dam, as actually to save the cost of the dam in the length of main pipe that was thereby dispensed with.

The average cost per acre-foot of storage capacity in the reservoir formed by the dam was but $0.65. The dam is reported to have no apparent defects and gives satisfactory service. Mr. L. W. Wells was engineer and foreman in charge of the works, from whose memoranda, furnished by courtesy of Mr. Howells, consulting engineer, the foregoing description has been compiled. The accompanying illustrations were obtained through the courtesy of Mr. Ben R. Cain, of the Tyler Water Company.

La Mesa Dam, California.—In the spring of 1895 the San Diego Flume Company, which supplies the city of San Diego, California, with domestic water and furnishes an extensive territory of agricultural land with an irrigation-supply through a long line of flume, built an impounding-reservoir on the Mesa, or tableland, 8 miles northeast of San Diego, near the terminus of the flume, for the purpose of impounding the tail-water of the flume and the surplus accumulating at night, as well as to store the flood-water of the San Diego River in winter to the extent of the unused capacity of the flume. The dam (see Figs. 70 and 72) was designed and constructed by J. M. Howells, C.E., who was then president of the Flume Company.

With the successful experience obtained with hydraulic dam-construction at Tyler, Texas, the previous year, Mr. Howells applied the same

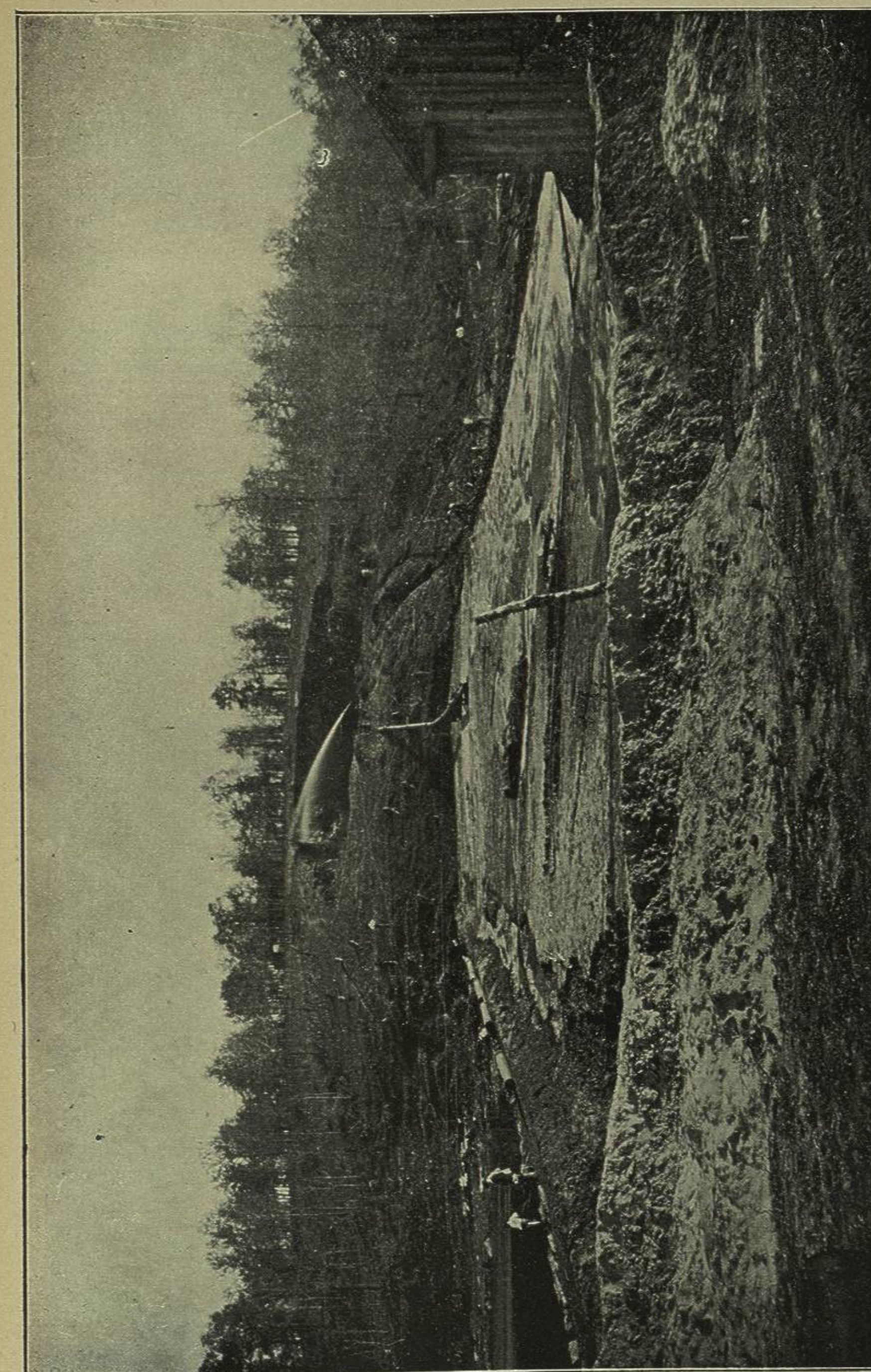

Fig. 69.—Hydraulic-fill Dam, at Tyler, Texas, in Process of Construction.
Water supplied by pump in building at right of picture.

FIG. 70.—VIEW OF FINISHED DAM AND WASTEWAY OF LA MESA RESERVOIR.

FIG. 71.—LA MESA (CAL.) DAM IN COURSE OF CONSTRUCTION BY THE HYDRAULIC PROCESS.

Showing method of loosening earth to get it in suspension before taking it into carrying conduit. The conduit was built in 20-foot sections, which could be and were frequently taken apart and moved as conditions required.

methods in a modified form to the erection of La Mesa dam. The situation and materials available were less favorable than at Tyler, and it was not possible to obtain water under pressure for disintegrating the soil. Hence it was necessary to resort to ground-sluicing alone.

The dam-site is in a narrow gorge cut through hard porphyry, whose walls are but 40 feet apart at the stream-bed, and stand nearly vertical on one side for 40 feet in height, from which elevation the ground slopes gently upward on both sides. The site had been regarded as particularly suitable for a masonry or rock-fill dam, as the foundations were of the best character and the materials at hand all that could be desired. With these advantages in view the first plans made were for a rock-fill with plank facing, of the following dimensions: height, 55 feet; length on top, 470 feet; thickness at base, 110 feet; at top, 12 feet; upper slope, ½ to 1; lower slope, 1 to 1; volume, 15,000 cubic yards. Bids were received on these plans, the lowest of which called for 99 cents per cubic yard for the rock-fill, and $2.08 for dry rubble wall. These prices are but 55% to 66% of the contract prices paid for the Escondido dam. The total cost under these bids would have been $20,260, exclusive of the plank facing and the outlet-gates and pipes. The hydraulic-fill dam proposed by Mr. Howells was given the preference by the company on a guarantee of a material reduction of cost below the bids for the rock-fill dam, and, although numerous difficulties were encountered, it was finally completed for about $17,000, including plant, excavations for foundations and spillway, outlet-gates, culvert and stand-pipes, paving of slopes, and all accessories, and furthermore it was built to a height of 66 feet, or 11 feet higher than the proposed rock-fill. It was made 20 feet wide on top, with a base width of 251.5 feet. All of the dam except a few feet on top, which had to be finished out with wagons, was put in place by flowing water. The surplus water from the flume was used at a time when little or no irrigation was going on, and at the same time the water was stored in the reservoir as it was being formed back of the dam.

The total volume of material handled was 38,000 cubic yards, some of which was transported an extreme distance of 2200 feet, and taken from an area of 11.5 acres, which was stripped to a mean depth of 2 feet. Had the material been as abundant and as accessible throughout the construction as it was up to the time one-fourth of the dam was in place, the entire structure could have been finished for 25% to 30% of its ultimate cost, but unfortunately it was found that below a depth of 2 feet from the surface the gravel and cobblestones of the mesa were cemented together so hard as to resist further washing, and this condition necessitated the employment of horses and scrapers to bring much of the material used to the sluiceways, at greatly increased cost. The results, considering all the unfavorable conditions, are an indication of what can be accomplished by this process where

surrounding conditions are more auspicious. The surface soil and sand contained in the coarse gravel constituted less than one-third of the mass, and consequently the dam can properly be termed a rock-fill with an earth core. The deposit on the dam being always near the outer slopes, the larger stones were naturally dropped there, while the finer materials shaded off towards the center. The gravel is of all grades, from egg size to large cobbles, 8 to 10 inches in diameter. On the outer slopes the largest of these were laid up in a dry wall of uniform slope and surface.

In beginning the work a trench was excavated in bed-rock, as shown in Fig. 72, from 2 to 5 feet deep, 20 feet wide at center and tapering to 5 feet at the ends. At right angles to this trench in the bed of the gulch a culvert was built to reach entirely through the dam at its widest point. This culvert, whose details are shown in Fig. 73, consisted of a concrete conduit, 48 inches wide, 30 inches high, extending from the inner face of the dam outward 180 feet, to a point 72 feet from the lower toe, where it connects with two 24-inch cast-iron pipes, that form the outlet to the reservoir. One of these pipes connects with a wood-stave pipe supplying water to San Diego, and the other is used as a waste, or clean-out, pipe. Both are controlled by gate-valves at the toe of the dam. The walls of the concrete culvert are 12 inches in thickness, and four vertical stand-pipes connect with the culvert at intervals of 35 feet from the inside end. These stand-pipes consist of 24-inch vitrified pipes, surrounded with concrete, which pass upward through the body of the dam, and are now used as outlet-pipes to the reservoir at four different levels. During construction they performed the important function of conveying the water into the reservoir after it had dropped its load of gravel and sediment on to the surrounding embankment. They were built up a joint at a time in 2-foot sections, as the work progressed, and were finished off at the top with brass ring and flap-valve, the latter being controlled by rods reaching up the slope through the water to the surface. (See Fig. 70.) These flap-valves can only be opened when pressure is relieved by closing the gate-valves below.

The volume of water used in constructing the dam was from 300 to 400 miner's inches—6 to 8 second-feet, which was all that could be spared from the flume after supplying the domestic consumption in San Diego and along the line, and the little irrigation which is kept up, even in winter, when the rains do not come just right. From the end of the 37-mile flume, which terminates on the mesa 10 miles from San Diego, the water was siphoned across a deep ravine by a 36-inch wood-stave pipe, 3000 feet long, discharging into a ditch which carried the water 1.5 miles to the top of the ridge overlooking the dam-site on the south. From this main ditch at various points laterals were carried down the slope of the hill towards the dam on a grade of 6%, dividing the ground into irregular zones of 50 to 100 feet in width, by several hundred feet in length. In sluicing these divisions

Fig. 72.—La Mesa Reservoir. Beginning of the Construction of Hydraulic-fill Dam.

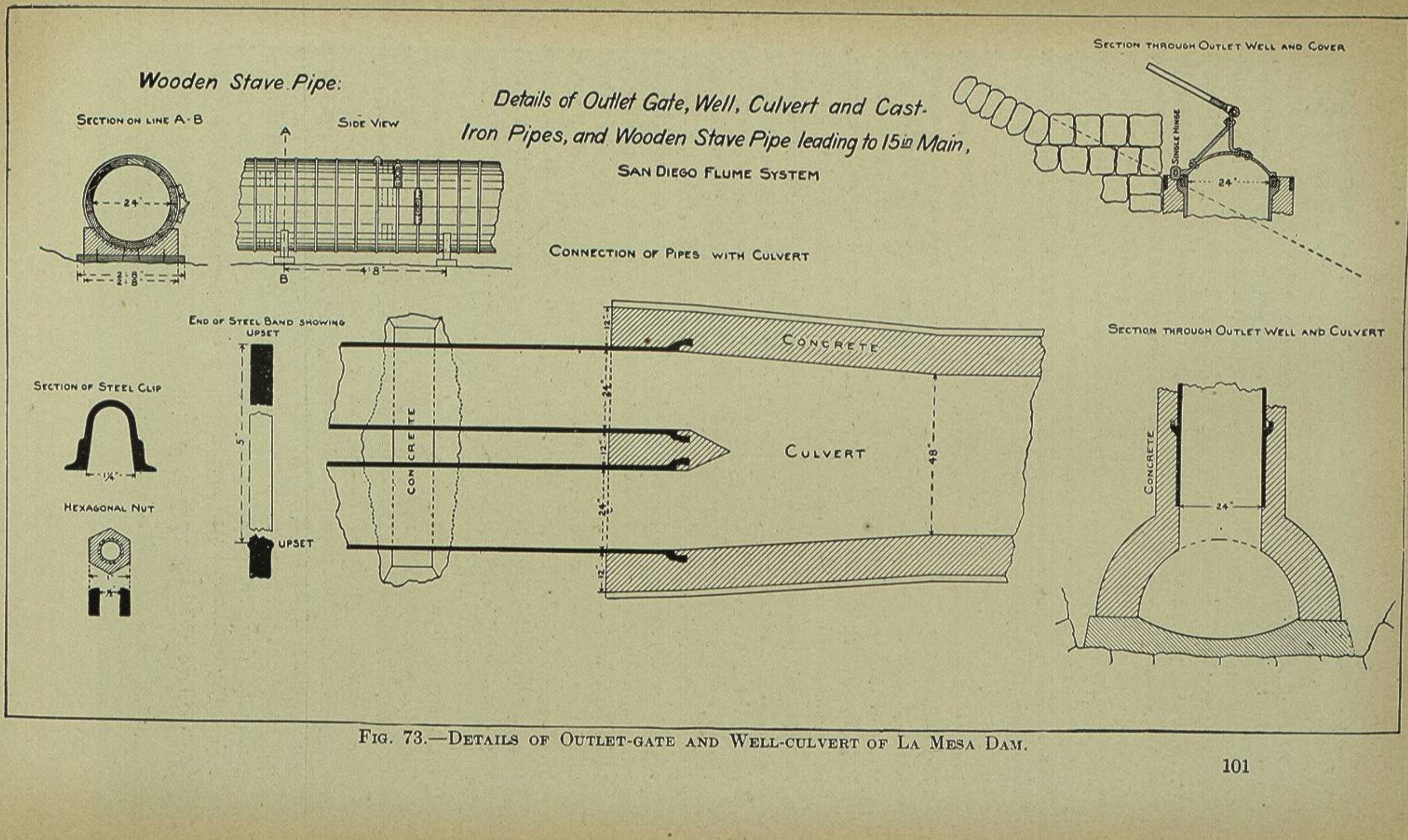

Fig. 73.—Details of Outlet-gate and Well-culvert of La Mesa Dam.

were stripped off clean to the cemented gravel bed-rock, beginning next to the head ditch and working downward toward the dam across the end of the strip. The fall from the upper-line ditch to the lower side of the zone was as great as the slope of the ground would admit,—the greater the fall the more rapidly the sluicing was done. The work accomplished was satisfactory as long as this slope was not flatter than about 25%, but as the hill from which the material was taken rounded off toward the top the velocity of the water in the cross-ditches became lessened, until it was insufficient to erode the material from its bed, and the process had to be assisted by the use of picks or plows, where the ground was not too soft for teams to get over it. This additional labor of loosening materially increased the cost. All of the material was obtained from one side of the dam, which was a further disadvantage.

As the stream secured its load of earth or gravel it was conveyed along the line of the lower ditch by 24-inch wood-stave pipes until deposited on the embankment. About 2000 feet of this piping was used in the work, the first cost of which was 90 cents per foot, exclusive of the lining of strips of tire-steel subsequently added to resist wear and tear. It was made in sections of 10 to 14 feet, loosely placed together and connected by strips of canvas wound around the ends of abutting joints and held in place by an ingenious tourniquet of tarred rope placed back of the last round band on the end of each section, the twist on one being made by a long nail, and on the other by an 8-inch piece of $\frac{1}{4}$-inch gas-pipe, the nail slipping into the gas-pipe and so preventing both ropes from loosening or untwisting. During a portion of this work the pipes were supported to the desired grade-line on the dam by trestle-work. A wire cable was also used for this purpose, although the latter did not give satisfactory results. Fig. 74 illustrates both methods of suspending the pipes, and shows the dam when about 30 feet high. The necessity of frequently unjointing the pipe on the dam for distributing the material evenly over the line from side to side made the use of a canvas joint over that portion of the pipe inconvenient, and it was replaced by loose straps of iron bolted to the pipes on the sides, which kept them in line, and the water would shoot across the joint without material loss. These joints were easily taken apart when desired. The pipes were found to wear very rapidly, and were lined, first with strips of wood, and later with strap-iron or tire-steel. Cast-iron pipe or open flumes would be preferable for this sort of service.

The work on the dam began February 14, 1895, and during the first thirty working-days, of 24 hours each, 21,000 cubic yards, or 55% of the entire dam, were put in place—an average of 700 cubic yards per day, although at times more than double this amount was moved in 24 hours. The ratio of solid embankment to water used during this period was about 3.3%. The force of men employed varied from 27 to 45, working in eight-hour shifts.

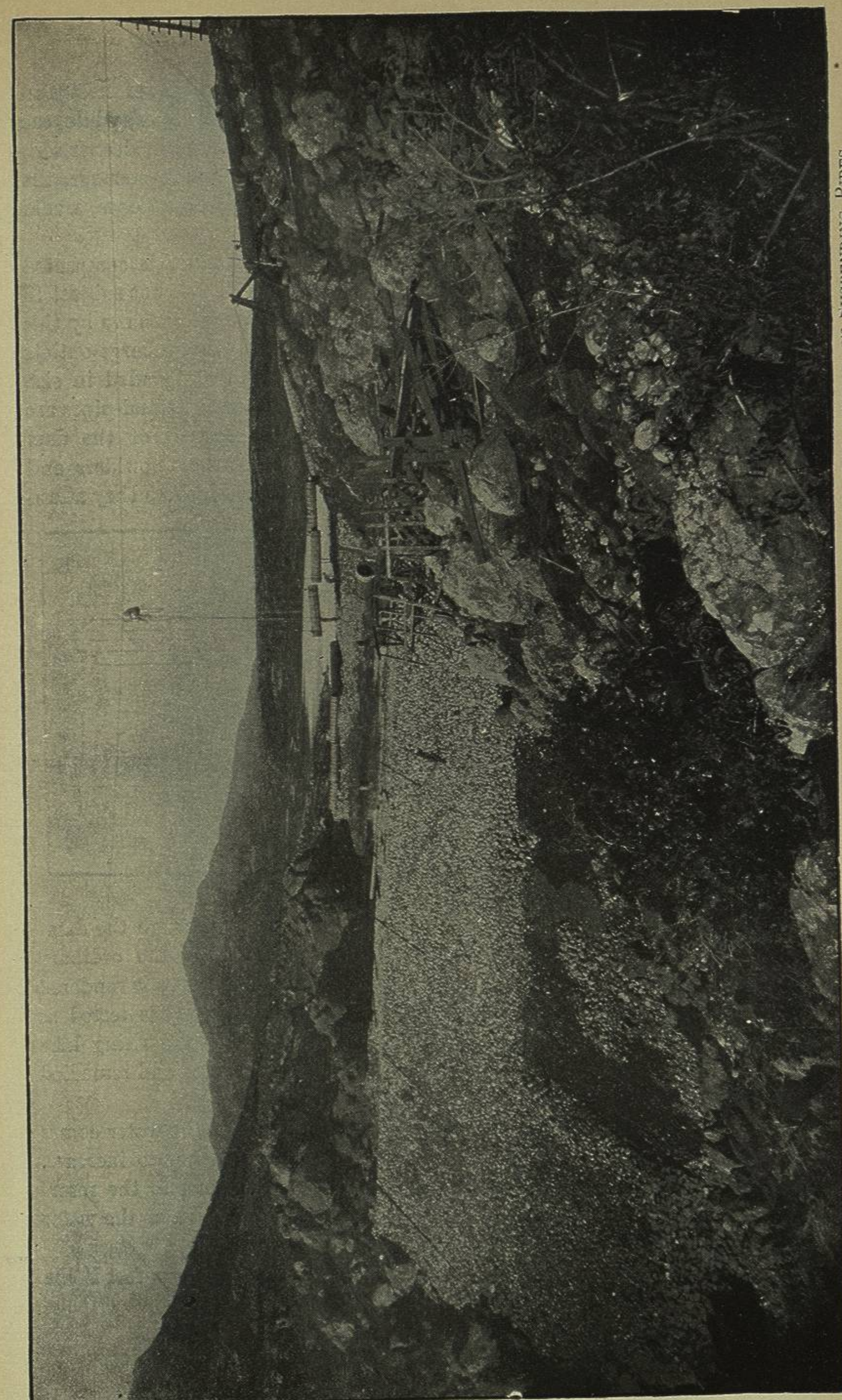

Fig. 74.—Construction of Hydraulic Dam, La Mesa Reservoir, illustrating the method of suspending Pipes.

Two men were kept on the dump directing the stream of material and building up the outer edges of the slopes to the proper lines, while the others were chiefly engaged in ground-sluicing. With looser or deeper soil, or under conditions permitting the use of a jet of water under pressure, the cost of loosening, which in this case was the chief item of expense, would be reduced to a nominal amount.

It is apparent that an embankment built in this manner is compacted as thoroughly as it could be by any process of rolling and is not subject to further settlement. It is also manifest that the finer materials are by this process precipitated in the interior of the fill, next to the discharge-outlets for the water, and that the particles are in a general way graded in size from the outside toward the center. In this dam all of the stand-pipes are placed inside of the center line, as shown by the section of the dam (Fig. 75), and therefore more of the coarse and permeable bowlders and gravel are placed on the outer half of the embankment, where they afford

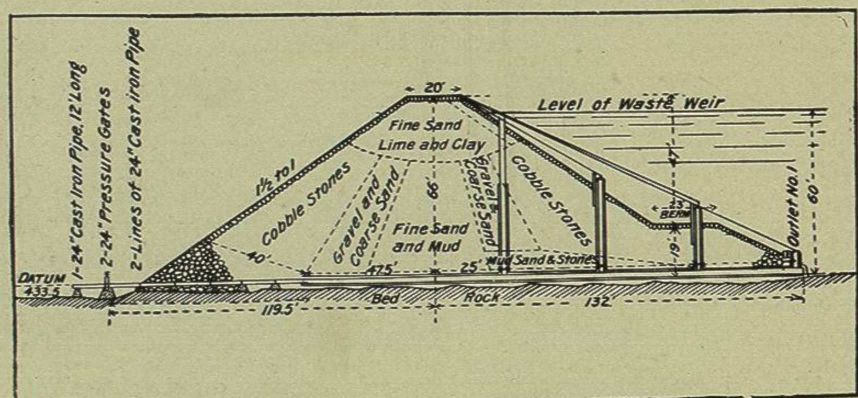

FIG. 75.—CROSS-SECTION OF LA MESA DAM.

ready drainage to the percolation that might find its way through the dam. (See Fig. 75.) Thus the failure of the structure through the ordinary process of supersaturation and the sloughing of the outer slopes is rendered highly improbable if not impossible. A dam built in this way is tested as it grows by the pond of water standing on top of it and the rising lake behind it, and if any weakness exists it is sure to be discovered and remedied by the operation of natural laws.

This dam is not entirely free from leakage, although as the water comes through quite clear it causes no anxiety and shows no tendency to increase. The leakage measures 100 gallons per minute when the water in the reservoir stands at the 54-foot level, and 23 gallons per minute when the water stands at 46 feet.

The reservoir-basin is large enough to impound 18,890 acre-feet if the

dam be raised to the 140-foot contour. Such a dam, of safe dimensions, would contain 682,000 cubic yards, and its construction has been seriously considered, the material to be obtained by excavating the interior of the basin, conveying it to the dam by the hydraulic method and then hoisting it in place by mechanical means.

The elevation of the base of the dam is 433.5 feet above sea-level, and a 24-inch wood-stave pipe, 6500 feet long, banded to withstand 180 feet maximum pressure, connects it with a 15-inch steel main that is laid from the end of the main flume to San Diego. The location and elevation of the connection of these pipes has practically determined the 43-foot contour in

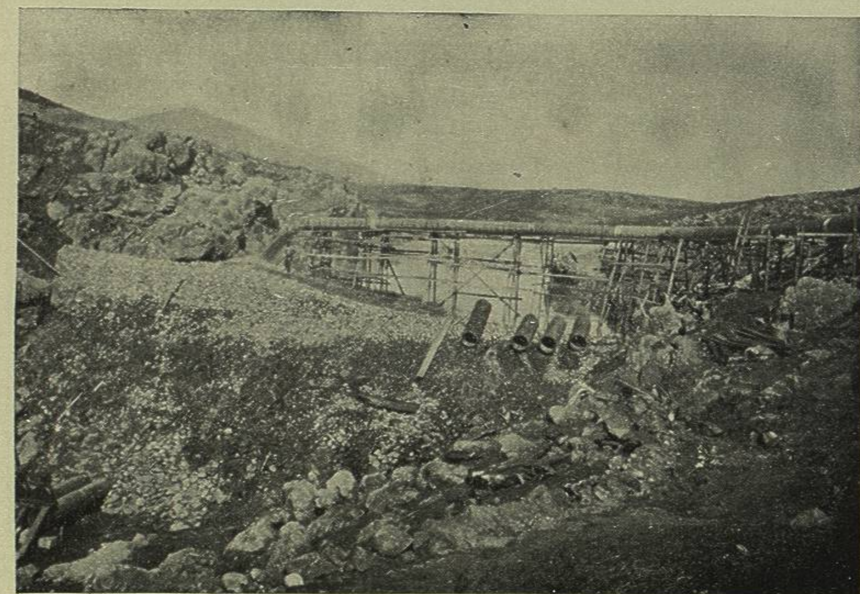

FIG. 76.—LA MESA HYDRAULIC-FILL DAM, SHOWING PIPE DISCHARGING MATERIAL ON THE DAM.

the reservoir as the lowest level to which the water will ordinarily be drawn when used for city service, unless a more direct connection be made. In times of scarcity the water below the 43-foot level has been pumped from the reservoir.

Crane Valley Hydraulic-fill Dam, California.—Some years ago the San Joaquin Electric Company erected a power-plant on the San Joaquin River, 34 miles north of Fresno, to utilize water brought from the North Fork of the San Joaquin to the power station. The power-drop at this place is 1410 feet, and the plant is remarkable as one of the first to make use of so high a drop, as well as for the long distance of the transmission of power, as the company deliver electricity to Hanford, a distance of 70 miles, as well