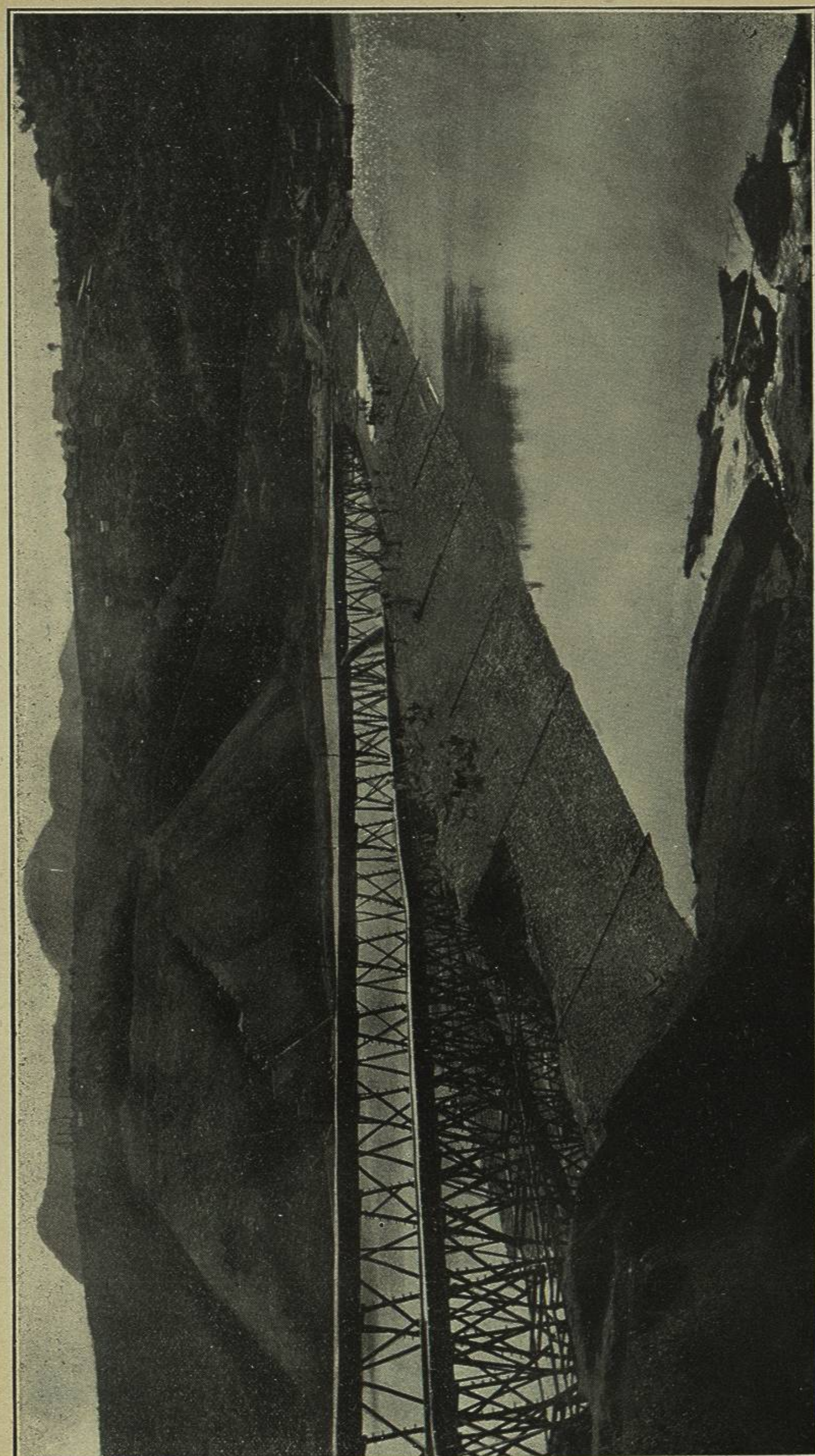

Fig. 129.—Up-stream Toe of Necaxa Hydraulic-fill Dam, Dec. 9, 1907, showing Delivery of Materials by Flumes. The Core-wall is shown in Center of Dam.

the line separating the central clay puddle, from the semi-porous mixture of clay and rock can be controlled, as it is found that the deposit drops off under water at a slope of 1 on 1. Under the water of the pond, the fine clay is deposited almost absolutely level. The water in the pond is usually from 12 to 15 feet deep over the bed of clay beneath. In this manner two stable dams of rock are being built up with an enormous core of clay, having a maximum thickness of 500 to 600 feet between them.

Dam No. 1, at Acatlan.—This structure was completed in June, 1906. It serves as a diverting weir to turn the water of the Tenango River to the Necaxa, through a 3000 foot tunnel. Its extreme height is about 30 feet and it was built of earth by the ground-sluice method, with water taken from the stream through a short ditch. Figs. 130, 131, and 132 illustrate the construction of the dam, and Fig. 133 shows the finished dam viewed from the tunnel portal. It is divided into two sections by a concrete weir located in the stream channel at the deepest portion. When examined with an earth auger to a depth of 20 feet below the crest six months after completion the core material was found in a plastic but compact condition. The dam has shown no sign of leakage or seepage and but very slight settlement.

Dam No. 3, at Tezcapa.—This dam, the second in height of the series, is located six miles above Necaxa, and will form a reservoir of 19,000,000 cubic meters, or less than half the capacity of Necaxa reservoir. After the site had been partially stripped, work was suspended pending the completion of the Laguna and Los Reyes Dams, Nos. 4 and 5, where subsequent surveys proved that greater storage can be secured at less cost and in shorter time. For this reason it will probably be the last of the group to be finished. In many respects it will present fewer difficulties of construction than any of the others, and can be completed with the plant in use at the Necaxa dam.

Laguna Dam.—A large natural basin near the end of one of the tributaries of the Necaxa River was acquired by the company and utilized as a storage-reservoir by building a long low dam across its outlet. It is fed by a 5-mile canal of 10 second-meters capacity from Necaxa River. This site is 20 miles distant from Necaxa, and 3000 feet higher. The dam was planned to have an ultimate height of 66 feet with a crest width of 25 feet and slopes of 3 on 1 and 2 on 1 respectively, and was to have been made as a hydraulic-fill, with water pumped from the lake. The urgent necessity for securing a storage of 12 to 15,000,000 cubic meters in the shortest possible time, led to the adoption of a plan for building the up-stream toe of the large dam to the height of 40 feet of the material chiefly obtained from stripping the middle third of the main dam. As there was a large amount of loose

FIG. 130.—LIQUID EARTH BEING DEPOSITED THROUGH PIPES ON OUTER SLOPES OF DAM NO. 1, TENANGO RIVER.

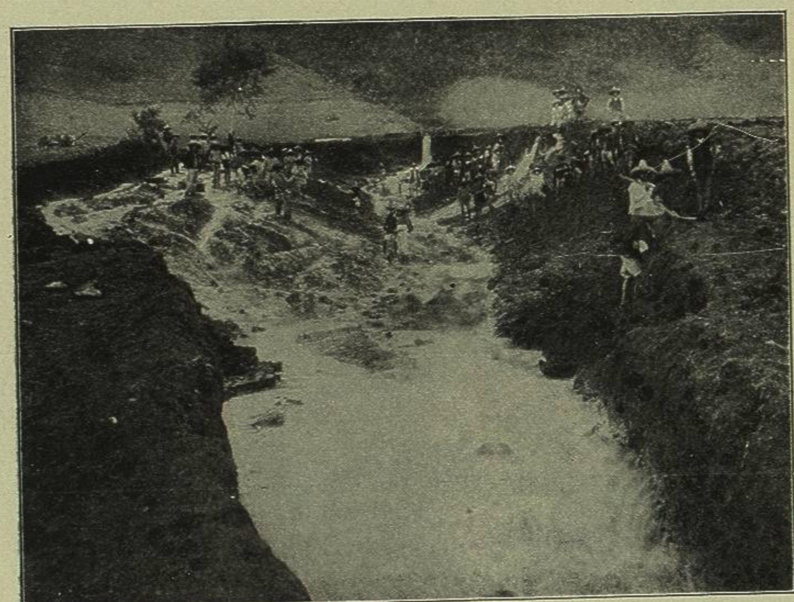

FIG. 131.—GROUND-SLUICING ON DAM NO. 1, TENANGO RIVER.

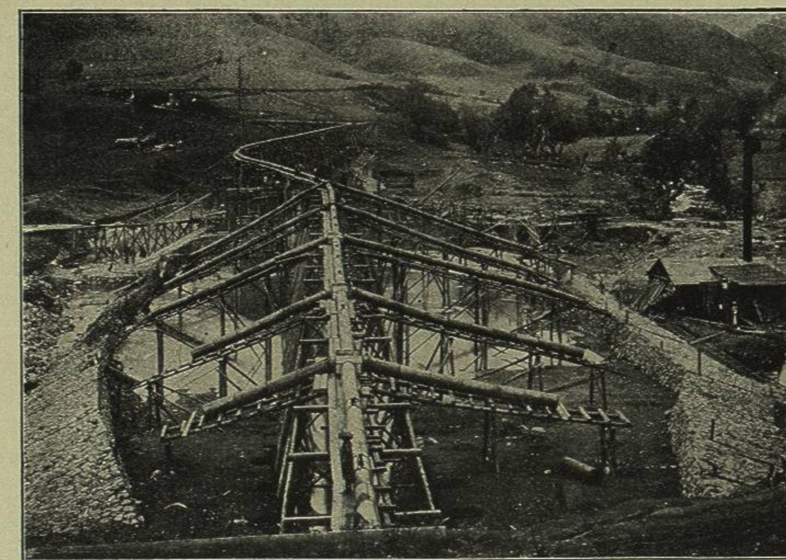

FIG. 132.—METHOD OF DISTRIBUTING SLUICED MATERIALS THROUGH PIPES, DAM NO. 1, AT ACATLAN, TENANGO RIVER.

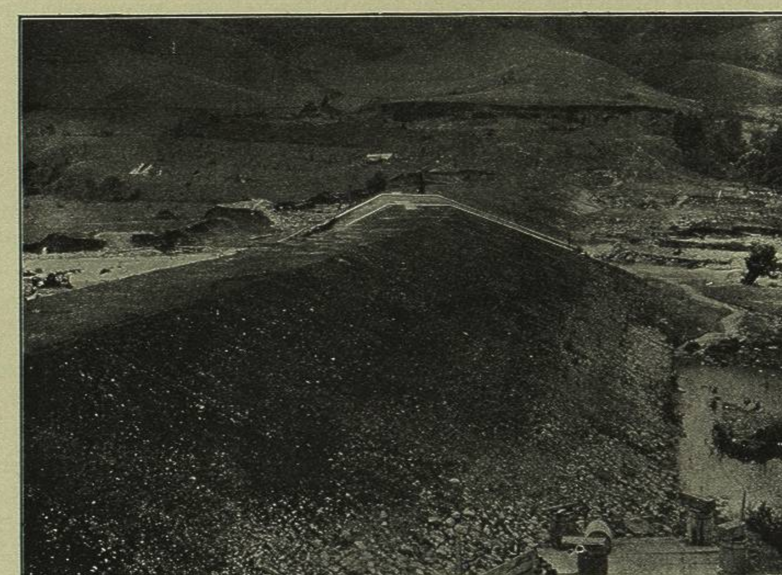

FIG. 133.—DAM NO. 1, AT ACATLAN, TENANGO RIVER, COMPLETED JULY, 1906. THE MATERIALS FOR THE DAM WERE GROUND-SLUICED FROM THE BORROW-PITS IN THE BACKGROUND.

rock in this stripping, it was decided to build the lower half of the dam as a loose rock-fill, with down-stream slope of 1 on 1, and crest width of 2 meters, while the up-stream half was to be of earth. Between the two materials a diaphragm of double 2-inch pine planks spiked to round poles set vertically was built, backed by a layer of choice puddle clay 2 meters thick, on the up-stream side. This diaphragm was started in the bottom of a trench in the bowlder and tepetate formation beneath the surface soil, the trench being 2 to 5 meters deep. Considerable water was developed in the trench but was drained off without difficulty. All the material in the dam was put in place by peon laborers with "chiquihuites," or baskets which they carry upon their backs with a leather strap passing across the forehead. The earth was moist enough to pack well under the thousands of trampling feet, and though no roller was ever placed upon it, the dam has shown no perceptible settlement. The dam was completed before the end of the rainy season of 1905 sufficiently to store the desired volume of 10,000,000 cubic meters, and proved to be entirely tight with the exception of one rather serious leak near the outlet-pipe, which was shut off by driving sheet-piling in the clay puddle. The reservoir proved to be so useful that it was resolved in January, 1907, to enlarge it as quickly as possible by the addition of 4 meters to the height of the dam, giving a capacity of 44,000,000 cubic meters to the lake. To make this enlargement most economically it seemed best to change the center line to that of the temporary core-wall and build a permanent core-wall of concrete, 1 meter thick, on the up-stream side of the plank diaphragm. This was done by excavating one half of the clay puddle and bracing the trench from the diaphragm to planking placed on the opposite side. This was done and the trench solidly filled between the forms which were not removed. The up-stream slope was changed to 2 on 1 and covered with a blanket of selected clay puddle 1 meter thick. The slope of the down-stream half was increased to 2 on 1 and the filling made of the best material available, well under-drained from the interior rock-fill by trenches filled with rock reaching to the lower toe, at intervals of 20 meters.

Cost of Basket Earthwork.—To those who are unfamiliar with methods in vogue in parts of Mexico in handling of earth and rock on men's backs by baskets and other home-made receptacles, a brief account of it may be of interest. In northern and western Mexico the peons use a basket made of raw hide, while in the central and southern portions the basket is made of bamboo about 19 inches deep, 17½ inches in diameter at top, 7½ inches at the bottom, and containing 1.4 cubic feet. These cost 40 cents (Mexican) each, and unless reinforced will not wear longer than 3 or 4 weeks. By stringing wires through them or putting rawhide over the outside, they are made to last two to four

times as long. These are carried on men's backs with a loop of leather or fiber passing over the basket and across the forehead. The most satisfactory method of working the laborers is to give them a task of a certain measured quantity to be excavated, loaded in baskets and delivered as a day's work. This varies from 2 to 5 cubic meters, according to the distance. The average wage is 75 cents per day. With a "tarea" of 3 cubic meters carried a distance of 150 meters from the pit, up a 2 on 1 slope a part of the way, which is a fair day's work, the cost would amount to 9.5 cents gold per cubic yard, pit measurement, or about 12 cents per cubic yard measured in the settled embankment. With such cheap labor as is available in Mexico the economy of hydraulic-fill construction is not so pronounced as elsewhere, and it is to be preferred chiefly on the ground of the superior quality of the embankment produced by the process.

Los Reyes Dam.—The fifth dam of the system is located on a stream to the north of Laguna, and not tributary to the Necaxa River. A tunnel through the intervening ridge was required to make its water available to the power-plant. This diversion was made before the work on the dam was begun. The site is a favorable one for a dam of 100 feet height, forming a reservoir of 28,000,000 cubic meters capacity. The gorge is narrow, and the volume of material required for an earth dam is but 183,000 cubic meters, which is small in comparison with the storage secured. Here, too, the emergency of maintaining a water-supply to the power-plant, already taxed to its limit, necessitated the employment of the temporary expedient of building a toe dam while the foundations of the larger structure were being prepared. This was made in a similar manner to the Laguna Dam with a combination of rock-fill, wood core-wall and earth-fill on the up-stream side, with a much thicker clay puddle against the diaphragm.

The concrete core-wall in the center of the main dam is being carried down through soft, seamy sandstone to a maximum depth of 60 feet. When finished up to the top above the stripped surface, it will be enveloped in clay puddle sluiced in by water supplied by a larger pump capable of delivering water under sufficient head to afford a cutting stream for loosening the earth and then do away with handwork. The down-stream slope will be composed of loose rock 50 feet thick at base, 5 feet at the top, resting against the clay puddle and affording the requisite stability and drainage.

In building the toe dam the principal part of the earth was put in place with baskets, and a plant was not installed for sluicing until the work was two thirds completed. Then a couple of Cameron steam-pumps, with combined capacity of 500 gallons per minute, were coupled together and water to the amount of about 300 gallons per minute was pumped from the pond above the dam to the head of a 10-inch V-flume laid on 10% grade, terminating on the dam above the wood core-wall. Earth was brought in baskets and dumped into a box at the head of the flume, whence the water carried it to the dam. The maximum work of this crude apparatus was 540 cubic meters (700 cubic yards) delivered in 10 hours, with a ratio of 75% of solids carried by the water. The cost of earthwork done in this manner during the month of December, including basket delivery of earth not sluiced, was under 11 cents gold per cubic yard.

These various works are being executed under the control of R. F. Hayward, M. Am. Soc. C. E., general manager, by Mr. F. S. Hyde, chief engineer.

The Yorba Hydraulic-fill Dam, California.—H. Clay Kellogg, C.E., of Santa Ana, Cal., who built the Waialua combination dam near Honolulu, described in the foregoing pages, has constructed an earth dam chiefly by the hydraulic process near Yorba Station, 30 miles south of Los Angeles, which has many interesting features and illustrates the adaptability of the method to conditions apparently unfavorable. The dam is 47 feet high, 800 feet long on the crest, having a slope of 3.5 on 1 on the water-face and 2 on 1 outside, with a crest width of 16 feet. Its contents are about 100,000 cubic yards, of which 80% was excavated, conveyed, and placed by the agency of water. The dam is located at the edge of a mesa, where it breaks off at the side of the valley of the Santa Ana River, and the top of the dam is but little lower than the level of the mesa. It closes the outlet of a small valley in the mesa, and forms a reservoir of 51,000,000 cubic feet capacity (1170 acre-feet) to be used for irrigation as an adjunct of the main canal of the Anaheim Union Water Co. This canal, from the Santa Ana River, feeds the reservoir and passes around it at an elevation but a few feet higher than the top of the dam, and the water used in sluicing was that supplied by this canal. The work was begun in February and completed in November, 1907, with a small force.

Owing to the lack of head for hydraulicking under pressure, the lower half of the dam was built up by the ground-sluicing method, the materials being loosened by plows, picks, and bars and washed into the dam through flumes, one on each side, laid on grades of 4% to 7% and using 3 to 4 second-feet in each flume. The side levees were built up at the beginning 4 to 8 feet high, with earth scraped from the center. Subsequently they were maintained by earth brought in from either end by cars and scrapers. The average cost of ground sluicing was about eight cents per cubic yard.

July 1st, when the dam reached a height above which it was no longer possible to secure the required gradients for conveying the mate-

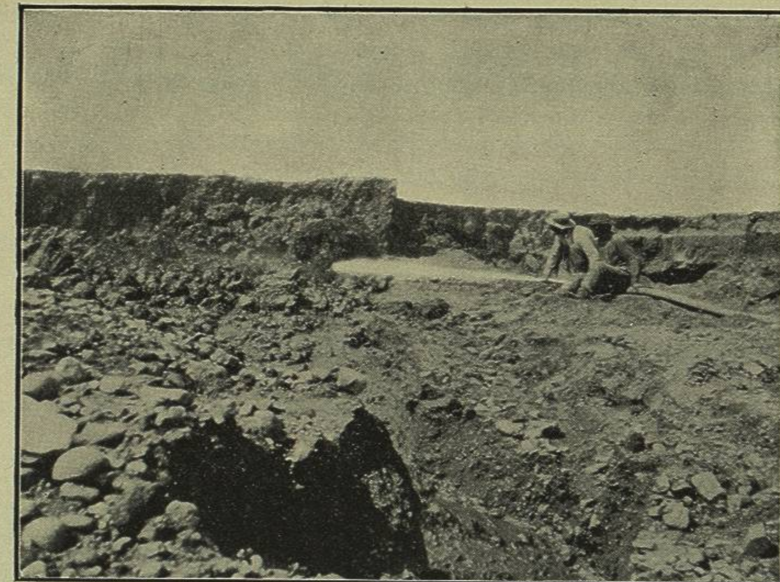

Fig. 134.—Yorba Dam, California. Hydraulicking an Earth Bank with Water Pumped through 1-inch Nozzle under 25 Pounds Pressure.

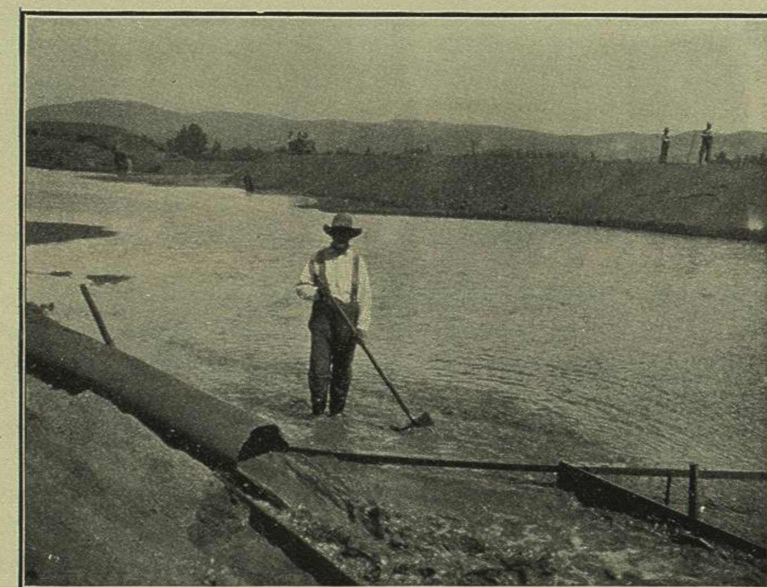

Fig. 135.—Yorba Dam, California. Showing Discharge of Pumped Material, along Up-stream Toe Levee.

rial by gravity, a single stage centrifugal pump, operated by gasoline engine of 60 H.P., was installed to deliver sluiced material through an 8-inch pipe to and along the dam, a maximum distance of 800 feet from the pump. The latter was located at one end 20 feet below the crest height of the dam, and had a capacity of 3 cubic feet per second. A second centrifugal pump, with a capacity of 0.5 second-foot, was installed near the ditch for supplying the hydraulic stream used for cutting the earth bank, delivering the water through a nozzle 1 inch in diameter at the end of a 2-inch hose, under a pressure of 35 pounds per square inch. This small stream, easily controlled by two men, sufficed to do the mining, clear water being added to the extent of 2.5 second-feet to convey the loosened earth to the lower pump. In this manner about 600 cubic yards was delivered daily in 10 hours, at a total cost of about 12 cents per cubic yard.

The material consisted of adobe clay soil, sand and gravel. A goodly proportion of the material is gravel ½ inch to 4 inches in size. The average ratio of solids delivered to water pumped is about 15%. The dam has no core-wall, but has a deep puddle trench excavated through the top-soil into hard blue clay. This trench is refilled with fine clay segregated from the soil in the sluicing operation, which constitutes so large a proportion of the heart of the dam as to insure water-tightness of the structure. The material left on the slopes is coarse enough to afford good drainage during construction and insure the exterior of the dam from future super-saturation.

Fig. 134 shows the operation of hydraulic sluicing, and Fig. 135 illustrates the method of delivery of earth upon the dam. The surplus water was drained from the pond through stand-pipes built up in successive layers and connecting with the main outlet-pipe through which the water was fed into the reservoir. The entire cost of the dam was about $38,000.

Silver Lake Dam, Los Angeles.—In constructing an earth dam in the city limits of Los Angeles, for storage and domestic distribution service, Mr. Wm. Mulholland, M. Am. Soc. C. E., superintendent of the city waterworks, made notable use of the hydraulic system in somewhat novel ways which further illustrate the flexibility of the sluicing method of dam building, and the fact that it is not essential to go outside the limits of the reservoir or above the high-water line to secure material for a hydraulic-fill dam. The dam is 900 feet long on the crest, 56 feet maximum height, and contains 146,000 cubic yards, all of which was taken from the reservoir basin and the greater portion of which was handled with pumps through the medium of water. The elevation of the crest of the dam is 450 feet above sea-level. The reservoir is fed

by a conduit from Los Angeles River, and has a storage capacity of 156,000,000 gallons (479 acre-feet).

For the purpose of cutting off percolation underneath the dam a trench was excavated to bed-rock on the central axis of the embankment, throughout its entire length, reaching a depth of 40 feet below the original surface in the center of the valley. This trench was filled with a concrete core-wall, which was carried up into the body of the dam a height of 3 to 6 feet above the original surface. In the deepest part, for a considerable distance, this wall was built between parallel lines

Fig. 136.—Silver Lake Dam, Los Angeles. The Earth, Loosened by the Hydraulic Jet, is Conveyed to the Pumping Station Shown and Pumped to the Dam.

of steel sheet-piling about 6 feet apart, driven into the sandstone bedrock in advance of the excavation of the earth between them.

At the lower levels the material used to build the dam was loosened and dissolved by ground sluicing with water taken from a grade-line pipe passing through the reservoir. The liquefied earth flowed by gravity down the slope to a sump whence a centrifugal pump forced it through a pipe to the dam, where it was distributed by flumes and lateral branch pipes. At a later stage the hydraulic jet was used for loosening the earth, the water being pumped by a single-stage centrifugal pump through 4-inch pipe, and delivered under pressure of 70 to 100 pounds through 2-inch nozzles, controlled by a local modification of the more expensive hydraulic monitor used in the mines.

When the material within 2000 feet of the dam was exhausted on one side the plant was removed to the other, and successive settings of the pumps were made, retreating further away each time, until before the dam was finished the material was being forced through 4000 feet of 8-inch pipe, with the main pump working under 40 pounds pressure, and a "booster" pump, located midway on the line, operating under 12 to 15 pounds per square inch. The actual lift represented only about 20% of the total head pumped against, the remainder being the friction in the pipes. During the later stage of the work the water used was about 2.5 second-feet, and the rate of delivery of material was about 500 cubic yards in 9 hours. The ratio of solids to water was therefore about 17%. At the earlier stages this ratio was as high as 28%. When the material was being delivered through 1500 feet of pipe, a careful summary of the data showed the cost to average 11 cents per cubic yard. Toward the end of the work, a careful account of cost on the delivery of 8000 cubic yards showed the average to be 16 cents per cubic yard, including all labor, materials, fuel, etc., including the work of building up the side levees by shovelling.

The water used was returned to the reservoir, which was half filled before the dam was finished. The main pump was always located at the water edge, where it could take additional water to dilute the stream of mud from the jets.

The material consisted solely of surface-soil, 3 to 4 feet deep (overlying hard-pan), of a heavy sandy loam quality, containing a considerable percentage of clay, which was carefully separated and placed in the center of the dam by the action of water, the sand being left on the sides of the embankment.

To prevent a slipping of the outer slope while it was saturated from the pond on top of the dam, six 2-inch drain-pipes were driven horizontally into the down-stream face of the embankment, a distance of 60 feet. Each was provided with a well-point and strainer at the inner end. They were about evenly spaced over a length of 200 feet of the highest part of the dam, and 6 to 10 feet above the surface. The greatest amount of seepage from any one of these drain-pipes measured two gallons per minute, which diminished to one fourth in a few weeks. These drains were effective in keeping the face of the dam dry and stable.

This dam is of special interest as a demonstration of what can be done with a cheap "pick-up" plant in gathering low-lying material from a distance, and forming a dam of superior compactness at moderate cost.

Swink Hydraulic-fill Dam, Colorado.—The Apishapa River is a torrential stream, which drains an area of 837 square miles, ranging in elevation from 4600 to 14,000 feet, and enters the Arkansas River

from the south a few miles above Rocky Ford. Its mean annual run-off is from 80,000 to 100,000 acre-feet, but it is so irregular and flashy in flow as to require storage to utilize it for irrigation. Owing to the absence of good storage-sites on the stream, the plan formed by Senator G. W. Swink, of Rocky Ford, for impounding the water is to build a diverting canal, 24 miles long, 31 feet wide on bottom, 6 feet deep, with a capacity of 1100 second-feet, from the stream to a flat basin in Patterson Hollow, where he designs to construct a reservoir covering an area of 2300 acres, with a capacity of over 46,000 acre-feet, by means of a dam 7150 feet long, 40 feet high, with inner slope of 9 on 1, outer slope 2 on 1, crest width 200 feet, and cubic contents of 2,800,000 cubic yards.

The materials for this huge dam are to be brought to it by the canal in its descent from the crest of the ridge between the valley of the Apishapa and that of the reservoir, a distance of 7 miles, where the fall is 147 feet to the top of the dam.

The soil is an extremely fine sand which has great cohesion when compacted under water. The depth to shale bed-rock over the area to be sluiced is from 8 to 15 feet. The canal will speedily cut down to bed-rock, and the soil must be carried forward to the dam. The dam slope levees were built to a height of 12 feet by scraping from the space between them. They are 644 feet apart from out to out. The canal will flow the entire length of the dam between these levees and discharge into the reservoir at the far end. The plan is quite unique, and the scale of the work is so ambitious that much time may be required to complete it, although the cost should be very moderate, and will chiefly consist in building up of the side levees from time to time, as the canal will only need intelligent guidance to excavate all the material it can carry. The construction will, in a measure, be automatic.

The reservoir will have 16 outlet-pipes through the dam at varying levels, in 8 pairs on either side.

The dam is estimated to cost about $100,000.

Croton Hydraulic-fill Dam, Michigan.—In constructing a power-plant on the Muskegon River, at Croton, Mich., in the winter of 1906–7, the Grand Rapids-Muskegon Power Co. employed the hydraulic-sluicing process most effectively and economically for the erection of an earth embankment 200 feet long, 40 to 60 feet high, containing 104,000 cubic yards. The total cost of the work* averaged but 6.8 cents per cubic yard, including all expense for plant, materials, supplies, labor, power, etc. The detail of cost was as follows:

* See *Engineering News*, of Oct. 14, 1907, illustrated article, by W. G. Fargo, C.E.