the entire dam of earth by this method, and at much less cost, as the scarcity of rock and the distance from which it had to be gathered rendered the cost of the rock-fill excessive. The sole reason for its use was to secure drainage, and because it was considered that the soil composing the embankment, even though deposited under water, might not prove to be wholly impervious. The author is indebted to Mr. L. G. Kellogg, of Honolulu, for many of the photographs used in the illustrations, as well as for the data of methods of work employed under his superintendence.

The Nuuanu Dam, Honolulu.—The territorial government of Hawaii is engaged in the construction of a dam in the Nuuanu Valley, four miles from the city of Honolulu, for the storage of water for the domestic supply of the city and incidentally for the development of power, as the reservoir is over 1000 feet higher than the city, the water surface elevation being 1030 feet above the sea-level.

The area of watershed directly supplying the reservoir is but 930 acres, but as the mean observed rainfall for 15 years has been 136.3 inches the volume of run-off is very large, amounting to an average of over 11,000,000 gallons daily. The stream has been utilized to the extent of 4,490,000 gallons per day by a pipe line supplying three small reservoirs at a lower elevation. By the reservoir under construction, it will be possible to utilize a further amount, estimated at 3,300,000 gallons per day, which has now to be supplied by pumping from artesian wells at sea-level.

The dam is to have a maximum height of 77 feet above the bed of the stream, and a crest length of about 2100 feet. It is to be 10 feet wide on top, at a height of 6 feet above the spillway level, and will create a reservoir of 84.4 acres, impounding 629,340,000 gallons.

The dam was designed by S. G. Walker, M. Am. Soc. C. E., who intended it as an earth embankment with a central core-wall of wood, the material to be principally deposited by the hydraulic-sluicing method, and a contract was let in 1905, under specifications prepared by him. After the work had progressed a year, H. C. Kellogg, C.E., was called to consult on the plans and recommended a number of changes in design, among which was the substitution of a rock-fill on the down-stream side of the core-wall, over the channel section, about 150 feet in length. In 1907 the author was employed to report upon the work, and suggested raising the dam 10 feet higher to give 60% increase in capacity.

A core-wall trench was excavated throughout the entire length of the dam, from 10 to 45 feet in depth below the original surface, through successive layers of porous lava and volcanic ash material, to an impervious hardpan or bed-rock base, and in this trench a diaphragm of Oregon pine, consisting of double 2-inch planks, spiked to 4″×4″ uprights, was built. In the center section of 152 feet the trench was filled with a concrete wall, reaching from elevation 935 at the west end up to elevation 972, on top of which the diaphragm was continued with California redwood to the top. The deep trench either side of the diaphragm was refilled with clay. The rock-fill was laid on a slope of 1 on 1 on the down-stream side, as a hand-laid wall, the up-stream face being made vertical, 10 feet away from the wood core-wall, the space between being filled with clay. The volume of rock required was 17,000 cubic yards, which was brought by gravity from a quarry about 2500 feet distant, the empty cars being hauled up by a winding engine. The surface outlet of the reservoir is a 30-inch wood-stave pipe, heavily reinforced with concrete, 9 to 12 inches thick, extending through the embankment from a square valve tower placed at the up-stream toe of the dam. This pipe connects with the main leading to city distributing reservoir No. 1, a distance of 10,900 feet, of which the upper 3400 feet is wood-stave, the remainder being of lock-bar steel. A washout pipe of the same size and construction also passes through the dam.

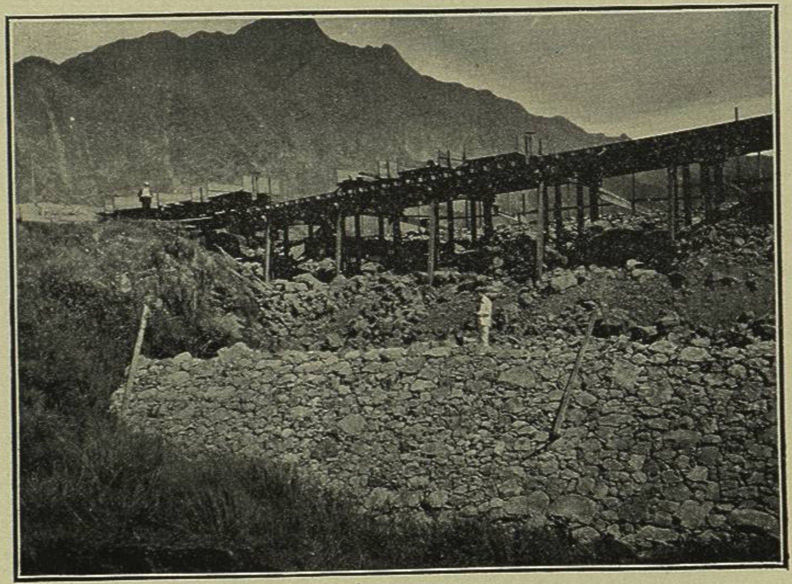

Fig. 100.—Nuuanu Dam, Honolulu, Showing Toe of Rock-fill Portion of Dam.

On account of the lack of sufficient water under gravity head with which to do hydraulic sluicing, a steam-pump with a capacity of 3.5 second-feet was installed with which about 170,000 cubic yards was expected to be deposited. The contract price for hydraulic-fill was

16 cents per cubic yard, while the portion of the embankment placed by other mechanical means was contracted for at 60 cents per yard, or nearly four times the cost of hydraulic filling, a ratio which may be taken as a fair one between the two classes of work on the average run of earthen dams.

The quality of earth available for sluicing was quite similar to that used in the Waialua dam, a clay soil produced from the decomposition of lava.

The original contract having expired by limitation, work was suspended for some time during the latter part of 1907. Meanwhile Judge Frear was appointed to succeed Mr. Carter as Governor of the Territory, and the new Governor appointed Marston Campbell as Superintendent of Public Works, to take the place of C. S. Holloway. New specifications were prepared at once for the completion of the dam, and in Febrnary, 1908, a second contract was let for finishing the structure for the following unit prices:

Earth filling	$0.314	per cubic yard.
Rock filling	1.73	" " "
Stone riprap	1.36	" square "
Broken stone under stone riprap	0.28	" " "
Concrete riprap	2.18	" " "
Broken stone under concrete riprap	0.14	" " "
Concrete in corewall	15.26	" cubic "
Concrete in spillway	20.41	" " "
Paving in spillway	2.50	" square "
Masonry wall in spillway	7.52	" cubic "
Lumber in corewall	56.32	" 1000 ft. B.M.
Excavation in corewall trench	0.54	" cubic yard.
Excavation in spillway	0.33	" " "
Clearing reservoir basin	259.00	" acre
Clearing dam site	450.00	" "

The new specifications called for the earth embankment to be "constructed by the method known as hydraulic sluicing" and required the contractor to designate the general plan of work and type of machinery he proposed to employ. The original contractor proved to be the lowest bidder on the new work. He proceeded to erect a pumping plant with two centrifugal pumps, driven by two gas engines of 125 H.P. capacity each, to lift 5 cubic feet per second from the pool behind the dam to a height of 150 feet, delivering the water into the suction side of duplicate pumps located at the upper station. These pumps are driven by engines

of equal size to those at the lower plant, and will force the water through hydraulic giants to excavate and disintegrate the earth in the mountain side under adequate pressure to do effective work.

The material so excavated is delivered to the dam through sheet steel flumes of prismoidal form, 10 inches deep, 27 inches wide on top, $13\frac{1}{2}$ inches wide on bottom, placed on 3% grade.

The cost of the work under the second contract is within the estimate made by the author.

Power.—The net head on the pipe at the lower reservoir, after deducting friction, is about 500 feet, which will produce 1100 H.P. during 8 hours daily, the capital value of which for city lighting, sewage pumping, etc., is safely estimated at $400,000. The saving in pumping the increased supply given by the reservoir will amount to $37,000 per annum.

Terrace Dam, Alamosa River, Colorado (Fig. 101).—The highest hydraulic-fill dam yet projected in the United States, in vertical height as well as in altitude above sea-level, has been under construction each summer since 1905, and is expected to be completed in the season of 1908 or 1909. It is designed for the storage of water for use in irrigation in the San Luis Valley. The location is at the head of the lower canyon of the Alamosa River, a few miles above the point where the river enters the valley. The dam-site is most unusual in its topography, as the lower 70 feet of the dam occupies a narrow, tortuous slit in the bed-rock from 20 to 60 feet wide, where the river had worn down through a ledge of hard trachyte, forming a canyon with vertical side walls.

Above this ledge the section across the canyon has a bowl-shaped form like the end of an ellipse. The dam was originally projected to a height of 180 feet and a tunnel 10 feet wide, 7 feet high, 725 feet long, was excavated through the solid rock on the north side of the canyon, discharging at the lower toe of the projected dam. This tunnel was intended to carry the stream during construction and subsequently serve as the only outlet to the reservoir. A shaft 75 feet deep was sunk at a point about 200 feet down stream from the crest of the dam, and gates for controlling the discharge of the tunnel were placed at the bottom of this shaft. After the first season's work it was decided to increase the height of the dam to 225 feet above the lower toe, which rendered an extension of the outlet tunnel necessary. The height at the center line will be 210 feet; crest width, 25 feet at an elevation of 20 feet above the high-water or spillway level; up-stream slope, 3 on 1; downstream slope, 2 on 1; length of crest, 605 feet. The change in height necessitated a removal of the crest-line of the dam down stream about 100 feet, the up-stream slope remaining unaltered. A concrete core-wall was built on the original center line, extending from the stream-

TERRACE RESERVOIR DAM
ALAMOSA RIVER, CONEJOS CO., COLORADO

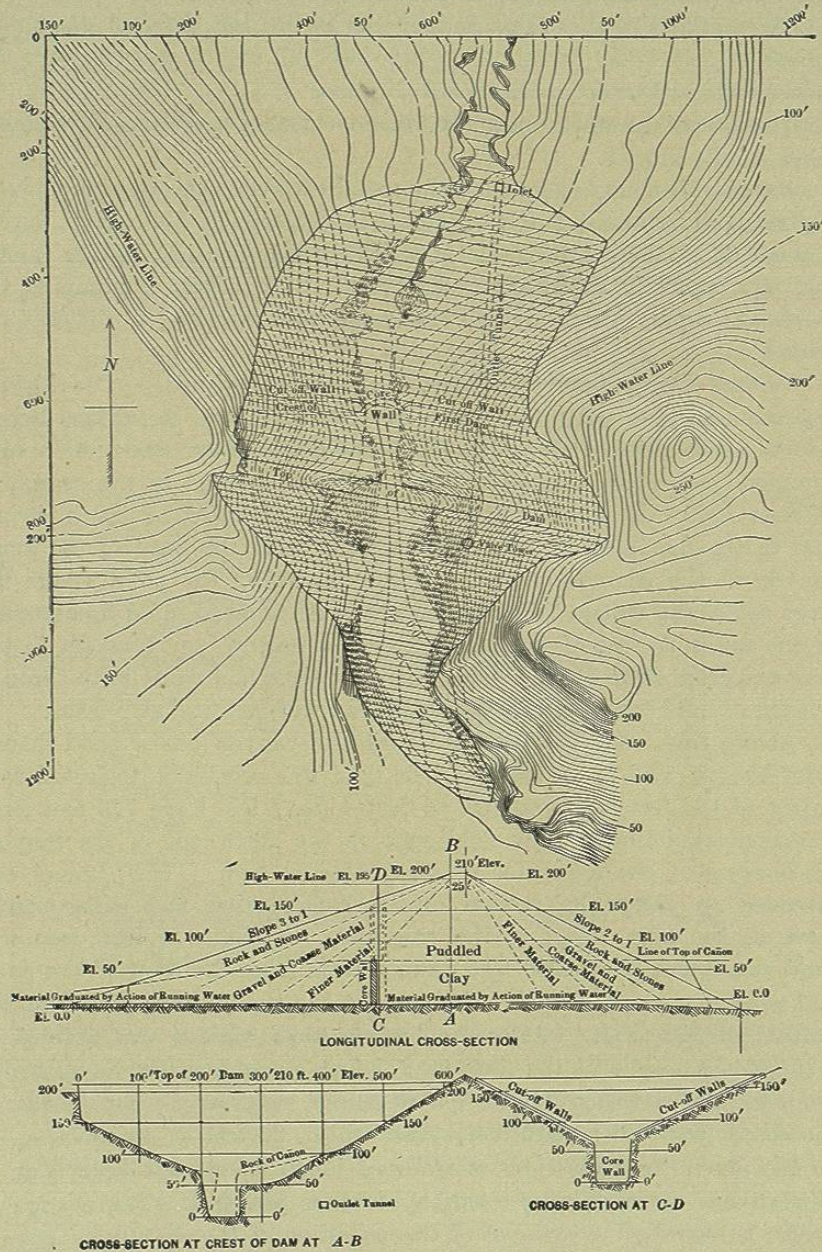

FIG. 101.

bed to the top of the narrow part of the canyon. This was made 15 feet thick throughout, curved on a radius of 50 feet.

Connecting with this wall and extending up the slopes, two parallel concrete walls were built 25 feet apart and reaching 2 feet above the

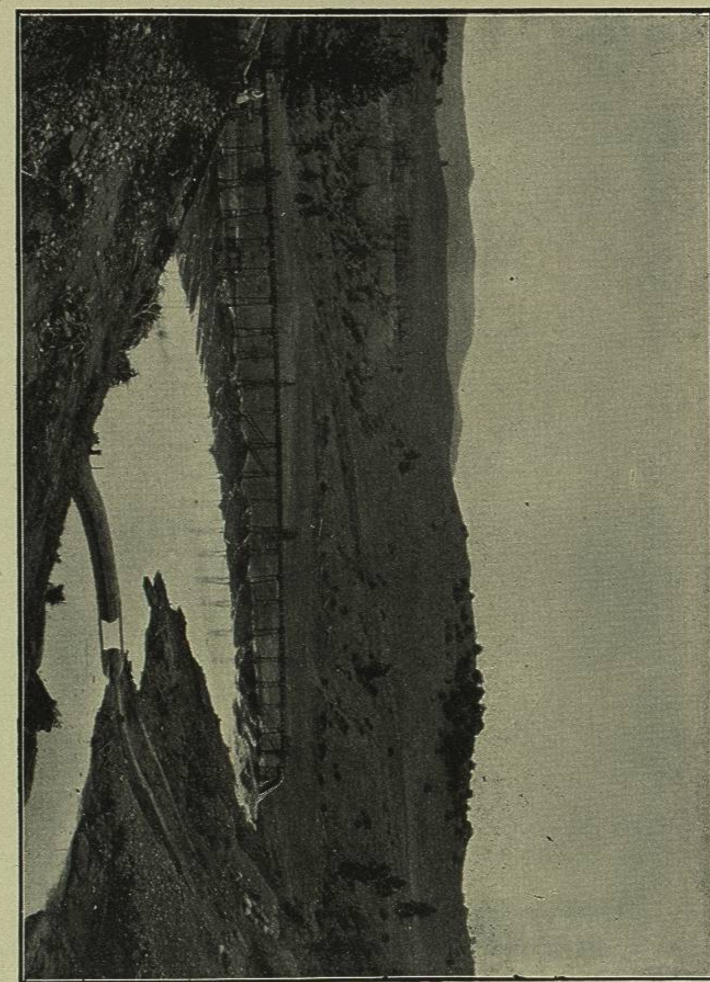

FIG. 102.—TERRACE DAM, COLO., SHOWING DEPOSIT OF SLUICED MATERIAL ON UP-STREAM TOE OF DAM. THE ABANDONED CORE-WALL, 70 FEET HIGH, SHOWS JUST OUT OF WATER.

original surface. These walls were all intended to be founded on hard bed-rock, and were designed to intercept seepage along the surface of the rock and be enveloped in the body of the puddle clay composing the center core of the dam. Unfortunately, they were built by contract under such careless supervision that subsequent examination proved them to be worthless and they were abandoned. They do not rest on bed-rock, and are composed of porous, rotten concrete. When this determination was reached, several cross trenches were made through the bowlders in the river-bed to the solid bed-rock, and these were refilled with the finest quality of puddle clay, upon which reliance will be placed for an impervious connection with bed-rock.

The method of building the dam by hydraulic sluicing was first suggested by Mr. T. W. Jaycox, M.A. Soc. C.E., State Engineer of Colorado, by whose recommendation the author was engaged to make an examination and report upon the project in June, 1905. At that time, a contract had been let for the entire work to one of the stock-

Fig. 103.—Hydraulic Sluicing on the Terrace Dam, Colorado.

holders of the company at a price of 18 cents per cubic yard, the contractor to furnish his own plant and materials. He first built a ditch and flume five miles in length, with a capacity of 40 second-feet, a sufficient elevation to deliver water to a penstock 325 feet higher than the crest of the dam, at the south end. The cost of the ditch and flume and all the pipe and plant for hydraulic sluicing, was $34,500. Two pressure-pipes of No. 16 riveted steel, each 15 inches in diameter, convey water from the penstock to hydraulic giants located in the sluice fields on the south side of the canyon. The ditch was completed too late in the fall of 1905 to begin sluicing, but in the following season about 120,000 cubic yards of material were sluiced in place from August 1st

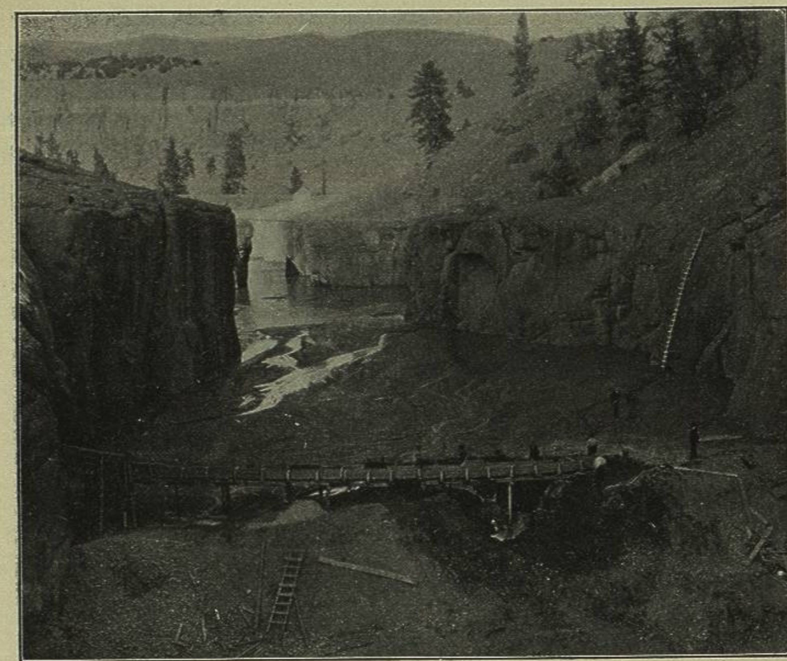

Fig. 104.—Terrace Dam, Colorado, looking Up-stream. Illustrating Gradation of Material toward the Center of the Dam from the Point of Deposit at the Slopes.

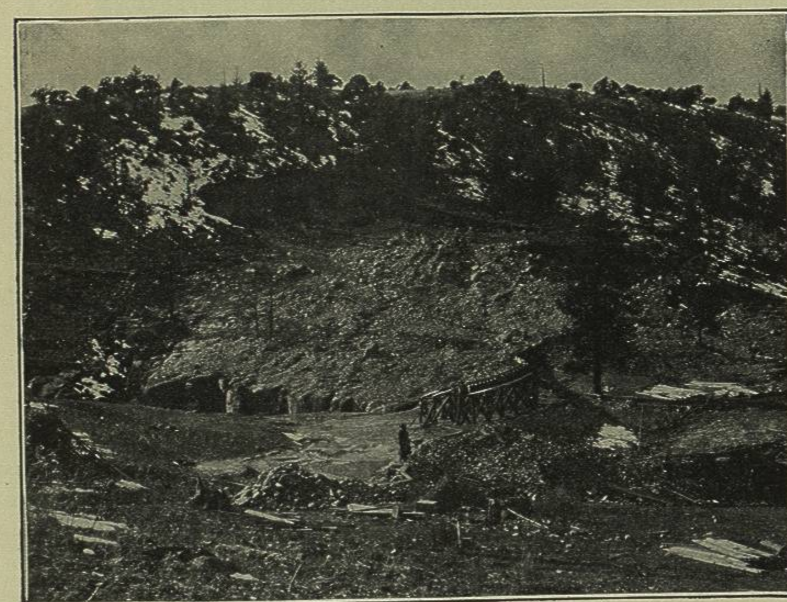

Fig. 105.—Terrace Dam. Deposit of Hydraulic Filling on the Upper Toe Slope.

to November 1st, when freezing weather forced a suspension of operations. The best average work for 30 days was 46,000 cubic yards delivered at a cost of 6.5 cents per cubic yard for labor.

The depth of filling at the down-stream toe was 55 feet, at the up-stream toe, 43 feet, and in the center, 18 feet. The material delivered

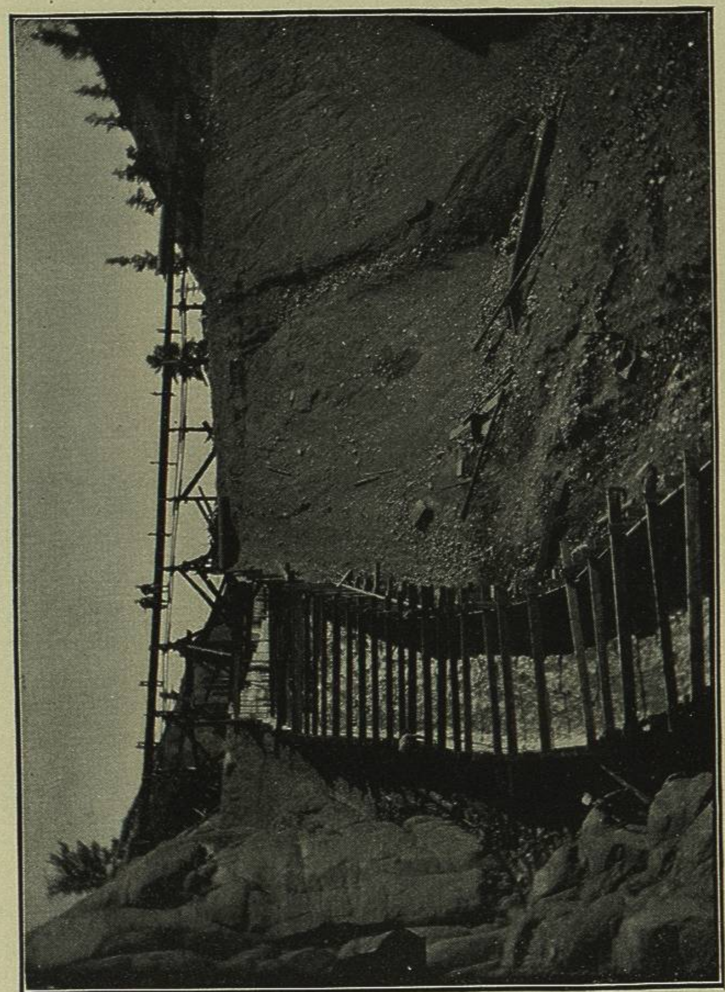

FIG. 106.—WASTEWAY FLUME FOR FLOOD DISCHARGE OVER LOWER SLOPE OF TERRACE DAM. SUMMER OF 1907.

at the two slopes was clean rock and gravel of all sizes up to about 2 cubic feet, while in the center the puddle clay was of fine texture, leaving little to be desired as an impervious core, whose base measurement exceeds 500 feet up and down stream. The material was delivered to the dam through square flumes, lined with slabs and round poles to take the wear, and laid on a grade of 7%. The volume of water used was about 26 second-feet.

As the depth of material in the borrow-pits has often been less than 6 feet considerable difficulty has been experienced in loosening it with sufficient rapidity to give fair efficiency to the carrying power of the water. Many flat, angular rocks were encountered which impeded the free flow of the approaches to the flumes and often necessitated

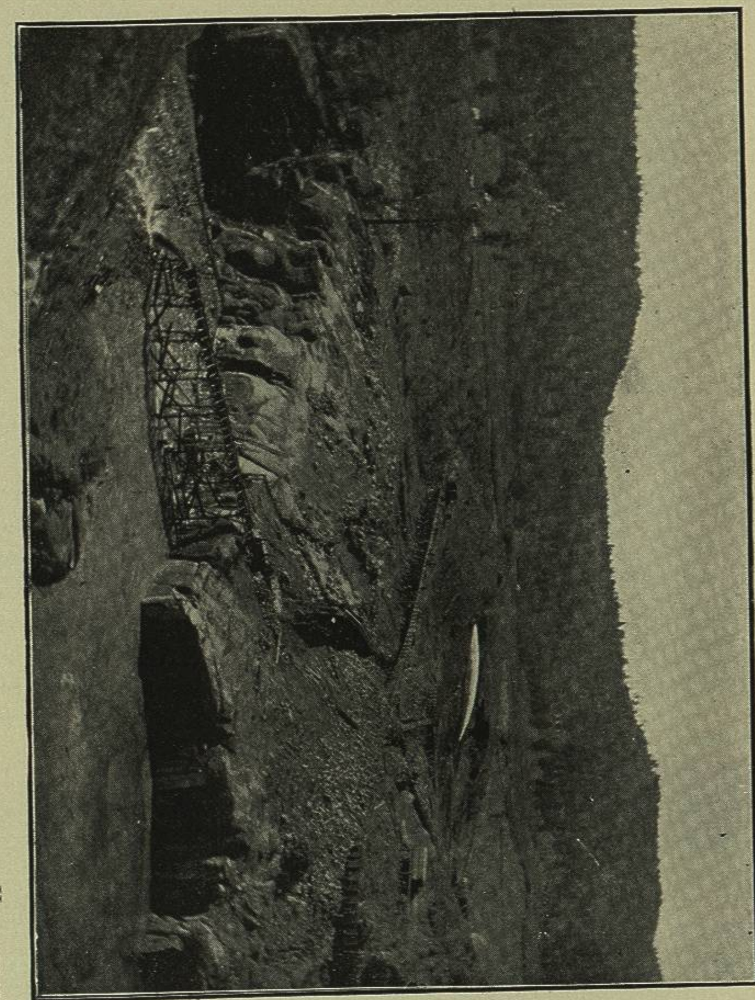

FIG. 107.—VIEW OF LOWER TOE FILLING, TERRACE DAM, COLORADO, SHOWING HYDRAULIC SLUICING IN BACKGROUND.

turning the monitors from the face of the bank to driving the material into the head of the flume.

At the opening of the season of 1907, the company took over the contractor's plant and continued work through the season on its own account. Owing to the small size of the outlet tunnel, it became necessary to build a large flume (Fig. 106) over the top of the unfinished dam and down the lower slope to care for the June freshet, an expedient which was successful, although sluicing could not be resumed until the river subsided to the capacity of the tunnel. This flume was 72 feet wide, 4 feet deep, and at times carried a flood discharge of 450 second-feet. The total volume of the dam will be approximately 500,000 cubic yards. The progress of the work was about as follows:

Prior to 1907	120,600	cubic yards
March and April, 1907	25,846	" "
May	15,654	" "
June and July	20,140	" "
August	11,435	" "
September	11,325	" "
Total	205,000	" "

At the close of the season of 1907 the dam had reached a height of 100 feet at the down-stream toe and 70 feet at the up-stream toe. With nearly 300,000 cubic yards yet to be deposited, it will be necessary to increase the rate of the past season about three times to complete the work in 1908.

The reservoir formed by the dam will have a storage capacity in excess of 25,000 acre-feet. The water will have high value, as the duty to be accomplished by it will be the irrigation of nearly one acre for each acre-foot of water impounded.

The Terrace Dam presented a situation where the cost of a masonry dam was prohibitive, where the materials for an earth dam of the usual type were not available because the earth is so intermingled with stone as to be practically inaccessible, and where the sole resource was to separate and deposit the materials at hand by the aid of water, which was to be had in abundance, under sufficient head or pressure to do the work. The results so far accomplished appear to the author to warrant the forecast that the dam when completed will be entirely successful. The work is under the general engineering direction of Mr. T. W. Jaycox, to whom the author is indebted for drawings and photographs used in illustration.

The Santo Amaro Dam, Brazil.—The São Paulo Tramway, Light & Power Company, Ltd. (a Canadian corporation) in 1895 erected a dam and installed a power-plant with a head of 70 feet at Parnahyba, on the Tieté River, in the State of São Paulo, Brazil, 22 miles below the thriving city of São Paulo, where 15,000 H.P. is generated and transmitted to the city for tramway service and for light and power. To partially equalize the flood flow and make up for shortage in dry seasons, the company, on the advice of its vice-president and consulting engineer,

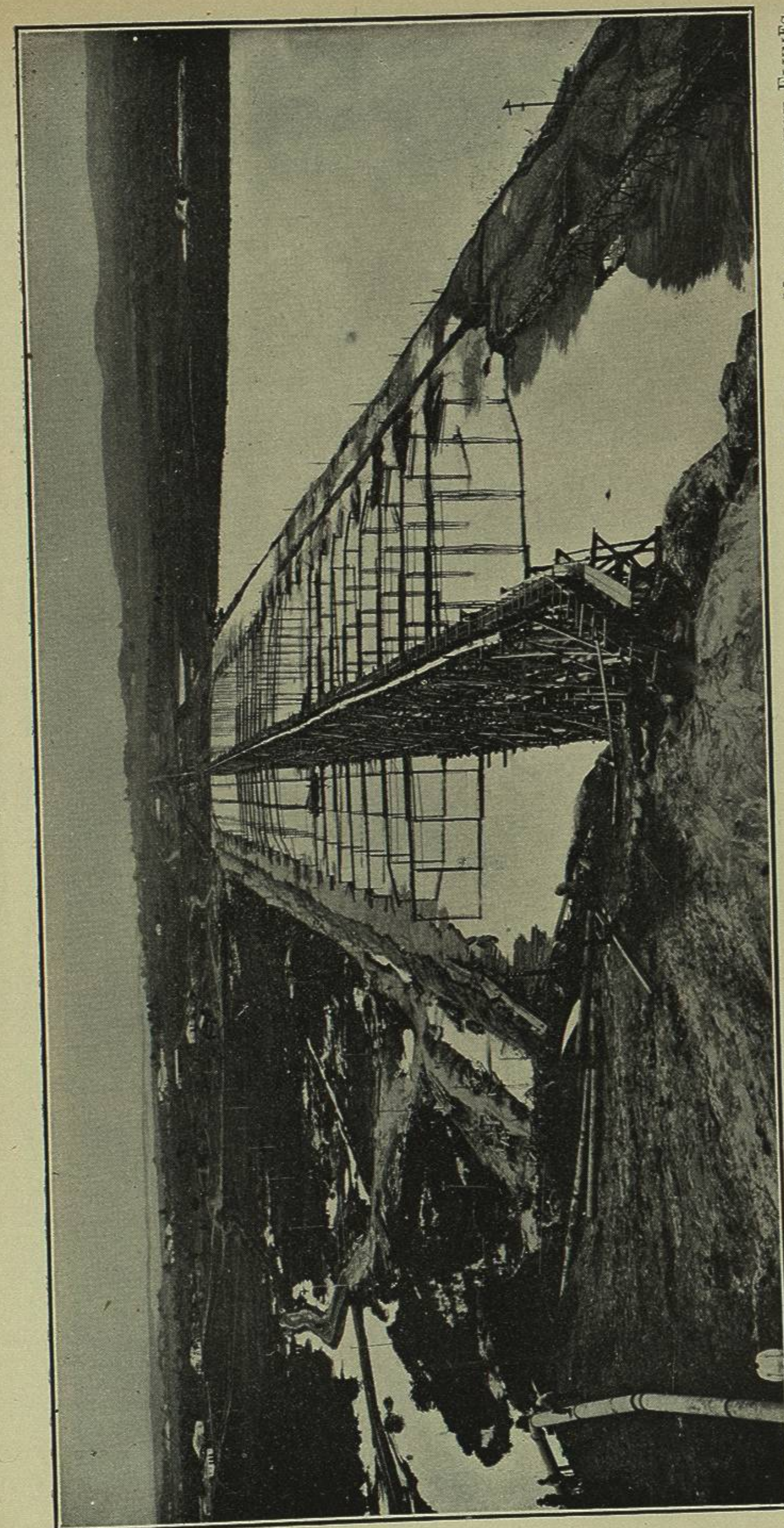

Fig. 108.—Santo Amaro Dam, Sao Paulo, Brazil. (1 Mile Long.) Showing Method of Delivery of Sluiced Material through Flumes and Laterals.