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,

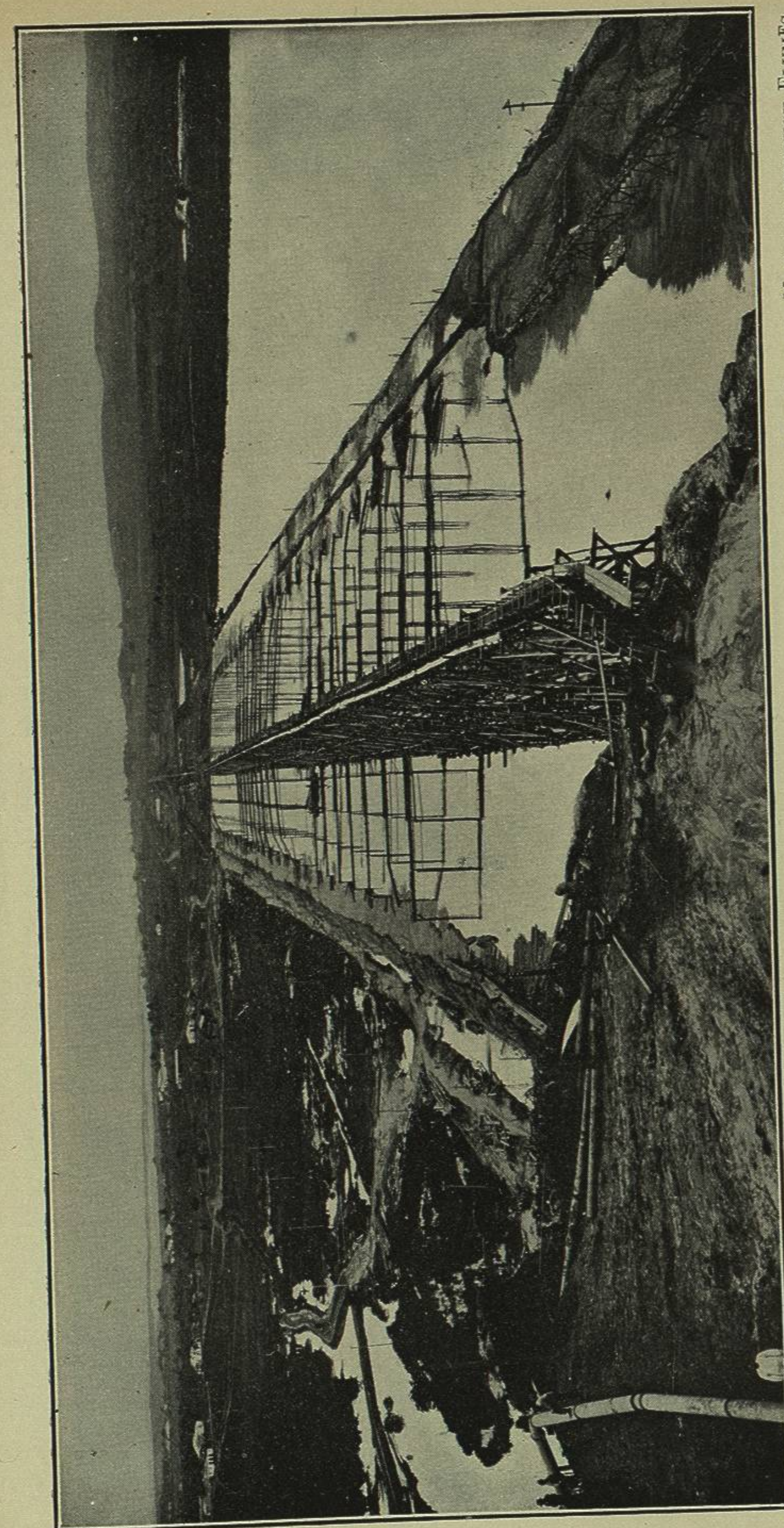

FIG. 108.—SANTO AMARO DAM, SAO PAULO, BRAZIL. (1 MILE LONG.) SHOWING METHOD OF DELIVERY OF SLUICED MATERIAL THROUGH FLUMES AND LATERALS.

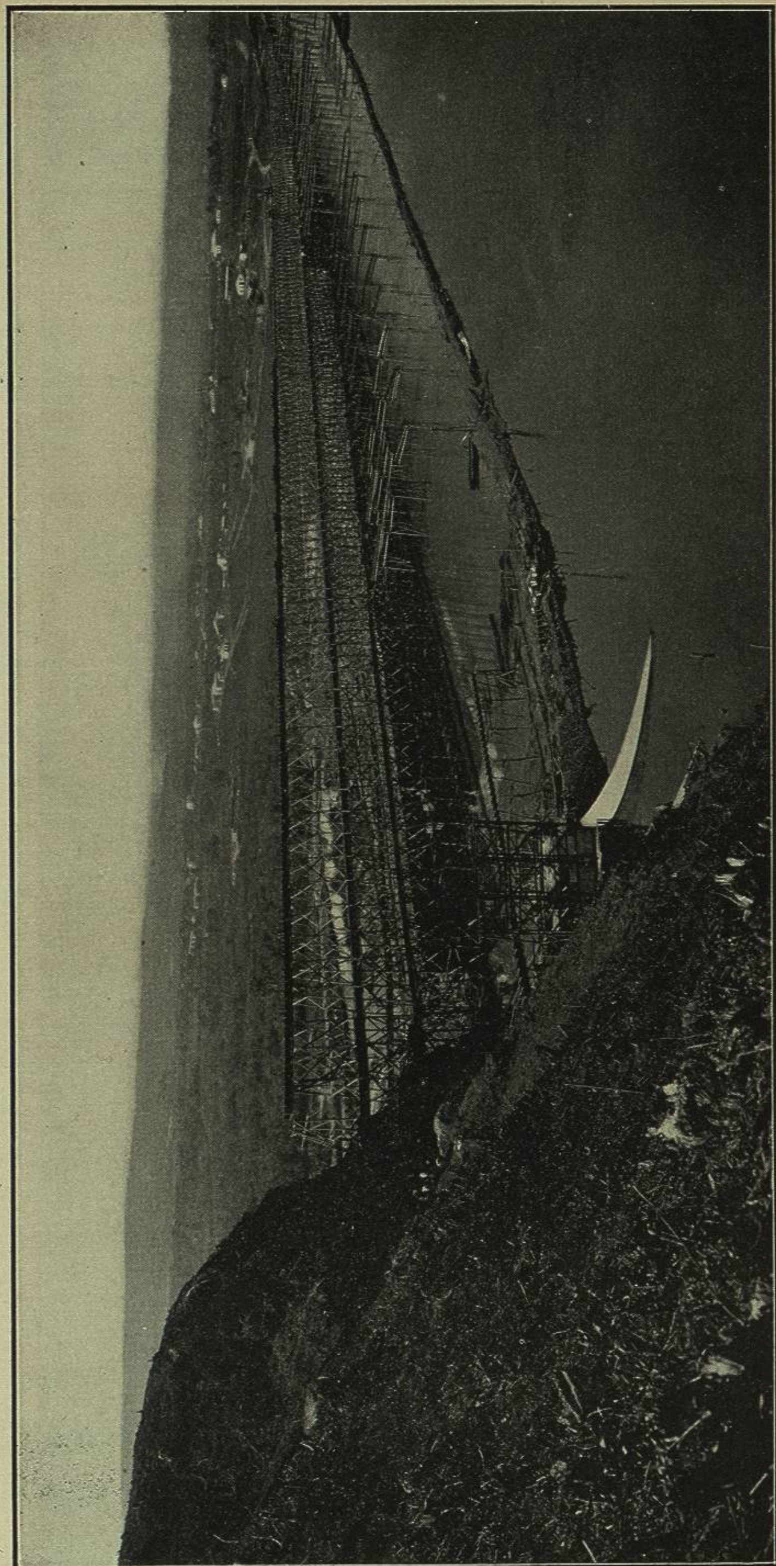

Fig. 109.—General View of Santo Amaro Dam, Brazil, Aug. 21, 1907. Showing Three Levels of Delivery on Central Trestle. Total Length 5300 Feet, Maximum Height 63 Feet.

F. S. Pearson, Dr.Sc., M. Am. Soc. C. E., has undertaken the construction of a dam 14 miles above the city, on a branch of the river known as the M'Boy Guassu. The dam will have a total length on the crest of about 5300 feet, a maximum height of 63 feet, and a volume of 715,000 cubic yards. The crest width will be 10 meters (32.8 feet) at a height of 3 meters above the spillway level. The up-stream slope is 3 on 1, down-stream slope 2 on 1. The dam is being built of clay and disintegrated granite obtained from a ridge 150 feet high at the west end of the dam, the materials being loosened by hydraulic jet under 75 pounds pressure at the nozzle of the monitor, with water supplied

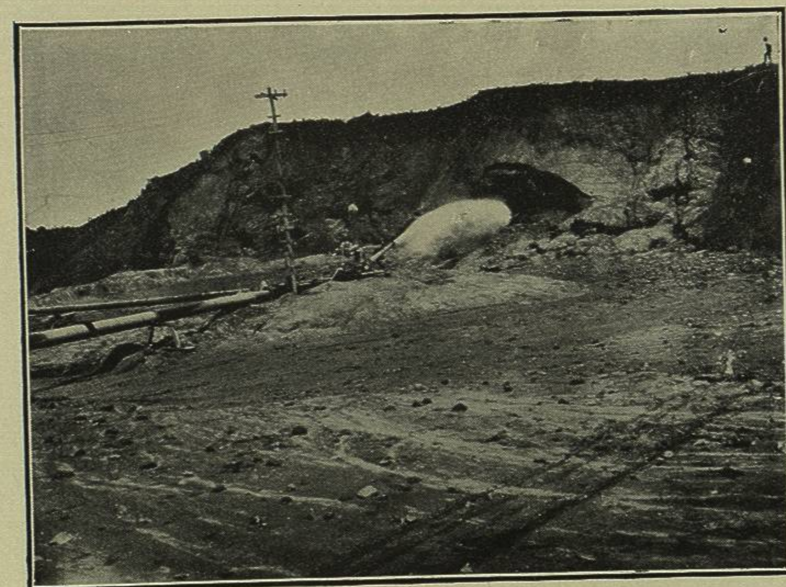

Fig. 110.—Santo Amaro Dam, Brazil, showing Hydraulic Monitor at Work, delivering 8 Second-feet under 85 Pounds Pressure through 4-inch Nozzle.

by a four-stage centrifugal pump, actuated by an electric motor, with current from the Parnahyba power-house.

The river here flows in a low-water channel, 80 feet wide, 8 feet deep, at the foot of the hills on the west side of the valley. At flood time, when the discharge exceeds 2500 second-feet, it spreads over the broad bottoms for nearly 2000 feet to the eastward. On the east of this level flat, the land rises gently for 3300 feet to the elevation of the crest of the dam. The bottom lands are swampy and covered with tropical grass and trees, and material for an earth dam could not have been obtained from borrow-pits at the sides. It was evident that the most suitable material was that of the high ridge to the west, and the simplest way of loosening and distributing it was by water pumped from the river and conveyed through flumes built lengthwise of the dam with lateral flumes at intervals leading to the slopes. The site of the dam was first stripped of sod, which was placed in the form of rectangular levees, 6 to 8 feet high, at or just outside the toe of the slope on either side. Hardwood triple-lap sheet piles were then driven to a depth of 10 to 15 feet over a distance of 2600 feet from the river bank easterly, beyond which similar piles were set in a deep trench and puddled in place for the remaining distance. Steel-sheet piles were driven in the channel section to a depth of 22 feet over a distance of 125 feet, connecting with

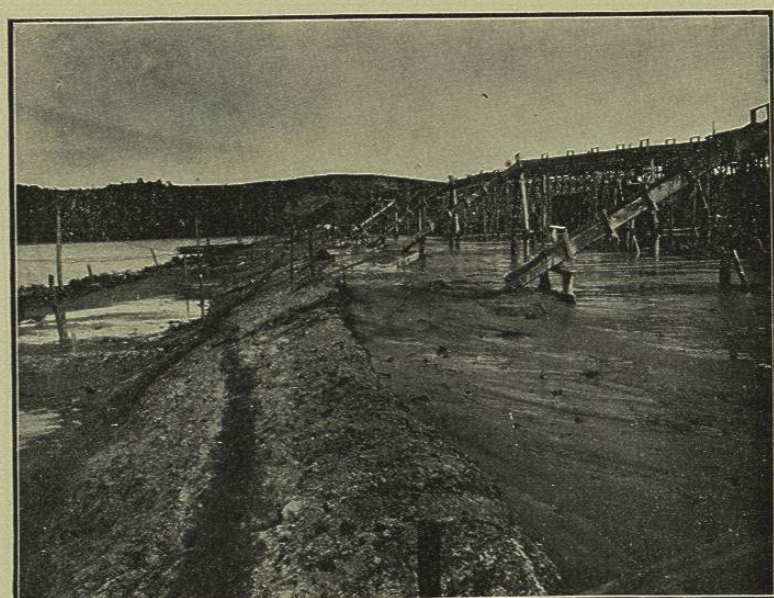

Fig. 111.—Upper Toe Filling on the Santo Amaro Hydraulic-fill Dam, Brazil, showing Lateral Flumes.

the concrete work of the outlet culverts, built at the foot of the high ridge, and founded on granite bed-rock. These piles penetrate the bed-rock 2 to 4 feet. The culverts are three in number, each 8 feet wide, 18 feet high, controlled by radial gates of steel at the down-stream end. The culverts are built in an excavation made in solid granite bed-rock, and have partition walls and abutments 6 feet thick. The thickness at the crown of the arches is 2 feet. About 5000 cubic yards of concrete were used in these culverts and the wing-approach walls. The stream has a low-water discharge of about 10 second-meters (353 second-feet), which was diverted through the culverts before work on sluicing began. The sheet piles referred to extend a few feet above

the stripped surface and are connected to a diaphragm of corrugated steel plates that reach above the water-line of the reservoir as a check to the burrowing of animals or ants. These plates are spiked to horizontal wale-pieces bolted to the center post of the main trestle supporting the sluice flumes.

The year 1906 and the first half of 1907 were consumed in the preliminary work of preparation, but finally the work of hydraulicking began in July, 1907. From that time until Dec. 1st, sluicing continued day and night for 128 days, during which the interruptions amounted to 39% of the total time. The work accomplished was the delivery of 381,000 cubic yards with an average volume of water of 7.94 second-feet, giving an average ratio of solids conveyed to water used of 19.2%. The main flume was placed on a grade of 3%, and reached a distance of 2000 feet from the west end of the dam. East of this point for 700 feet to the end of a dry earth levee built as the extension of the dam, where the height is less than 20 feet, the material was delivered by a booster pump, discharging through a closed flume.

The best work done was in the month of October, when a delivery of 156,000 cubic yards was accomplished with a mean of 8.35 second-feet. The interruptions amounted to but 18 hours during the month, or 2.4% of the total time. The cost of power at the rate charged of $\frac{1}{3}$ cent per K.W. did not exceed one cent per cubic yard for the month. The dam was to be completed by May, 1908. The construction since January, 1907, was in charge of Thos. Berry, C. E. The preliminary plans were prepared by the author after a visit to the site in October, 1905. The plans for the outlet-gates were drawn in the New York office of F. S. Pearson, Dr.Sc., M. Am. Soc. C. E.

Reservoir.—The reservoir formed by the dam covers a total area of 8320 acres, and has a capacity of 192,400,000 cubic meters (156,600 acre-feet). It therefore ranks among the largest reservoirs of the world.

The mean annual rainfall at São Paulo for 12 years, 1890 to 1901, was 1319 millimeters (54 inches) and the mean rainfall of the watershed was estimated at 2500 millimeters, with an average run-off of 50%. As the area is 244 square miles (63,200 hectares) the yearly run-off was computed at 780,000,000 cubic meters, or 4 times the reservoir capacity. During nine months, from March to November, 1907, the measured run-off was 419,515,000 cubic meters, with three months of rainy season to complete the year.

The power-plant at Parnahyba utilizes a total fall of 72 feet, and under full load requires 70 cubic meters per second (2470 second-feet). The function of the reservoir will be to supply a shortage in supply during the dry season, when a maximum deficit of 85,000,000 cubic meters in one such season has been experienced.

Hydraulic-fill Dams in Mexico.—The Mexican Light & Power Co., Ltd., a Canadian corporation, organized by F. S. Pearson, Dr.Sc., has installed a power-plant at the foot of the falls of the Necaxa River, State of Puebla, 100 miles northeast of the city of Mexico, where a maximum drop of 1400 feet is utilized, developing 40,000 H.P. which is transmitted to the capital of the Republic and to the mining camp at El Oro, a total distance of 170 miles. To equalize the flood flow of the streams and store water for use in the dry season, the company has been engaged since 1904 in the erection of five storage-reservoir dams of earth, which when completed will create an aggregate storage capacity of 123,000,000 cubic meters (100,000 acre-feet). Two of these dams, at Necaxa and Tezcapa, are to be of unprecedented height, and of enormous volume, 190 and 175 feet respectively, while a third, on the Los Reyes River, is to be 100 feet high. The hydraulic-fill process is being employed on all but one of these dams, for the adoption of which the responsibility rests with the author, who was called upon in January, 1905, to report on the subject, and has since been retained as consulting engineer to supervise their construction.

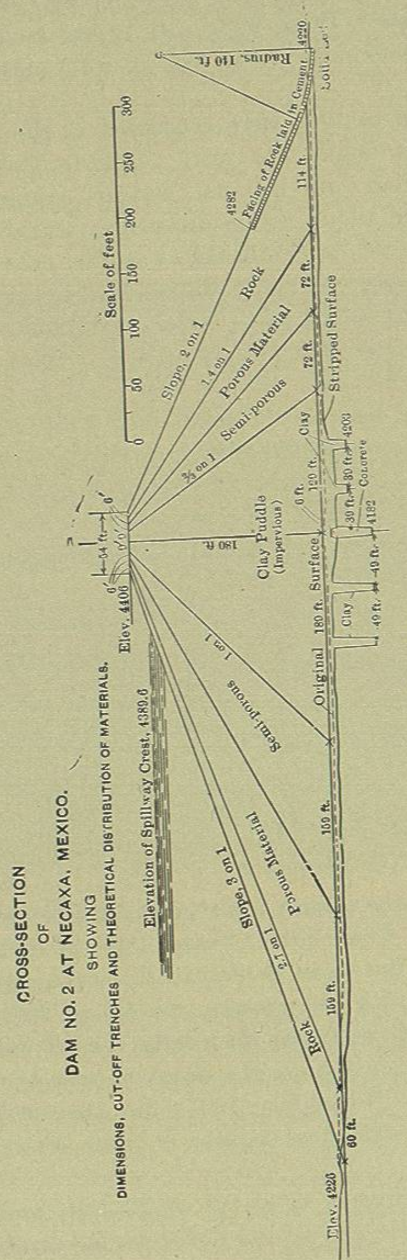

FIG. 112.

The highest and most important dam of the group is that at Necaxa, whose chief function is to serve as a penstock reservoir at the head of the pressure-pipes, and afford a storage of over 43,000,000 cubic meters (34,850 acre-feet) on the main Necaxa River, a stream which fluctuates between extremes of 2 and 200 cubic meters per second.