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.

Plant (one half cost) including pumps, piping, sheet steel flumes, hose, nozzle, etc.	$1871
Labor	3775
Teams, removing stumps, stones, hauling flumes, and timber	248
Straw	18
Oil, waste, pump repairs and sundries	119
Power, 92,000 K.W. hours at 1 cent	920
Motor rental	125
Total	$7076

FIG. 137.—CROTON HYDRAULIC-FILL DAM, MICHIGAN, DURING CONSTRUCTION.

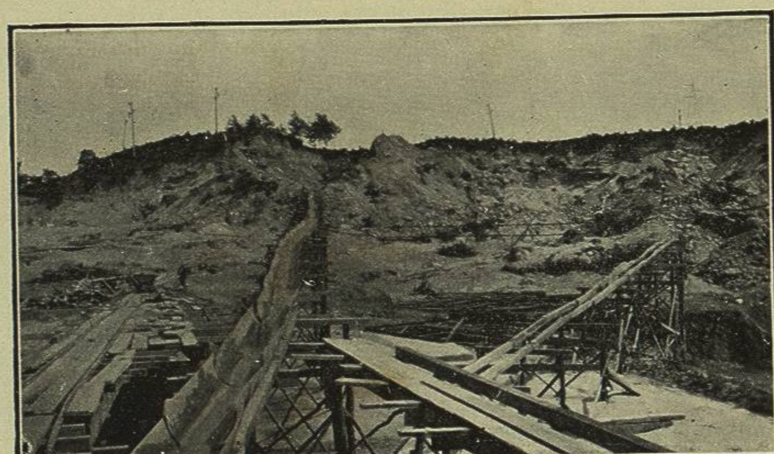

FIG. 138.—CROTON DAM, MICHIGAN, ILLUSTRATING FLUMES AND TRESTLE SUPPORTS USED IN HYDRAULIC SLUICING.

Seven Underwriter's rotary fire-pumps were used, all belt driven by electric motors, but on account of the severe service for which they were illy adapted an average of 50% of the pumps were out of service and undergoing repairs.

The material sluiced was fine yellow sand, common to all the pine country of northern Michigan, and was handled in semi-circular steel flumes, 30 inches diameter, in 10-foot sections, lapped 6 inches, and laid on 8% to 9% grades.

The river, flowing a minimum of 700 second-feet, was diverted through the spillway channel or waste-gate section of the dam by rock-filled timber cribs sunk across the channel to be occupied by the hydraulic-fill. A low fill of long, flat slope was then made under water on the up-stream side of the crib by hydraulically sluicing material into the channel from the bluff, 75 feet higher than the top of the dam at one side. The temporary closing cribs, when thus faced with a sluiced fill on the down-stream side, were made nearly tight under a head of 15 feet of water, demonstrating the possibility of making tight embankments with material deposited under water by hydraulic sluicing.

Prior to beginning the permanent embankment a continuous row of steel sheet piling was driven through sand and gravel 20 to 40 feet deep to and into a layer of hard-pan underlying. On top of this line of sheet piling a reinforced concrete core-wall, 12 inches thick, was built to the top through the embankment and 2 feet above the water surface to serve as a wave protection as well as a cut-off to prevent seepage through the fill.

The dam extends from the power-house located in the center of the channel to the highest bluff bank of the river at one side, a distance of 200 feet. It has slopes of 2½ on 1 to 6 on 1 on the up-stream side, and 2 on 1 to 4 on 1 on the down-stream side. The nozzles used at the face of the excavation were attached to 4-inch rubber hose and clamped to a 12-foot plank pivoted to a standard, by which two men could readily control its action. The nozzles tapered in 24 inches from 4 inches to 1½ inches. The greatest distance to which material was moved in the flumes was 800 feet. These flumes were supported on light pole trestles, easily erected and moved.

As an incident to the construction of the dam, a fill of 20,000 cubic yards was made by hydraulic sluicing for an approach to a highway bridge, just below the dam, using a 3-inch Gould rotary fire-pump, driven by 30 H.P. motor, the material being delivered into the fill in a sheet-iron flume 20 inches wide, 5 inches deep, on 15% grade. Cost data kept on 3000 cubic yards of this fill showed a total cost of 1.4 cents per cubic yard for labor.

The publication of the author's experience in similar work* a short time prior to the construction of the Croton dam doubtless encouraged the designers of this work to adopt the hydraulic method, then entirely new in Eastern practice.

Lyons Hydraulic-fill Dam, Michigan.—The Commonwealth Power Co., of Jackson, Mich., an ally of the Muskegon Grand Rapids Power Co., during 1906 and 1907 built a similar dam to that of the Croton dam, just described, for power development on Grand River near Lyons. The embankment extends from the penstock of the power-house 150 feet to a high clay bluff that forms the river bank on that side. The embankment contains 23,000 cubic yards of material placed by hydraulic sluicing during 45 days of December, January, and February under difficult conditions, owing to the severity of the weather. The cost of the plant, less salvage on sale, was $1200, or 5.13 cents per cubic yard. The labor cost was 27.3 cents per yard, a total of 32.40 cents per yard for the entire embankment. The material for the fill was taken from a clay bluff capped with 10 feet of sand and gravel. Owing to the tough character of the clay the overlying material alone was used, requiring high and expensive trestles to carry the flumes to the dump. Ice and freezing weather, necessitating the use of powder to break up the earth, made unusual difficulties and greatly increased the cost, but nevertheless there were no possible means of doing the work so cheaply by other methods under the conditions prevailing.

The construction of both the Croton and Lyons dams was carried out under the supervision of Mr. W. G. Fargo, hydraulic engineer, of Jackson, Mich., to whose courtesy the author is indebted for photographs illustrating the construction. (Figs. 136 and 137.)

Little Bear Valley Dam, California.—The dam which is under construction by the Arrowhead Reservoir and Power Co. in the San Bernardino Mountains on the headwaters of the Mojave River, is one in which the hydraulic-sluicing process is used to wash the fine materials from railway dumps in either slope to the center. The material is all excavated by steam-shovels, hauled in cars by locomotives and dumped into fills started at each toe of the embankment. Pipes are laid along the tracks from which outlets are provided for hose used for washing the materials as dumped. The water is supplied by steam-pumps. The dam is to have an extreme height of 200 feet from the stream-bed, and is built with a slope of 2 on 1 down-stream, and 2½ on 1 up-stream, the crest width to be 20 feet at a height of 15 feet above the flow line of the reservoir. A concrete core-wall is carried up a little in advance of the earth-

* Transactions American Society of Civil Engineers, Vol. LVIII, p. 196, "Recent Practice in Hydraulic-fill Dam Construction," by James D. Schuyler, M. Am. Soc. C. E.

Fig. 138a—Map of Little Bear Valley Reservoir.

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FIG. 139.—HYDRAULIC SLUICING ON THE CROTON DAM, SHOWING THE IMPROVISED NOZZLE CONTROL, OR HYDRAULIC MONITOR.

fill in the center of the dam. This is built in a trench 20 feet deep and is uniformly 20 feet thick up to the stream-bed, thence it batters to 3 feet at the water-line in 185 feet of height above stream-bed. The volume of concrete in the core-wall is to be about 30,000 cubic yards, while the earth will have a total volume of nearly $1\frac{1}{4}$ million cubic yards, two thirds of which was in place at the end of the working season of 1907, reaching to a height of about 110 feet.

The material in the dam consists chiefly of disintegrated granite, much of which has to be loosened by blasting before it can be handled by steam-shovel. It contains a variable percentage of clay, most of which is sluiced out and deposited by the water next to the core-wall.

The reservoir formed by the dam will cover an area of 884 acres and impound 60,179 acre-feet. The outlet to the reservoir is through a tunnel 4957 feet long, half a mile distant from the dam, lined throughout with concrete. An intake tower at the head of the tunnel is being built of reinforced concrete to a height of 180 feet, with an interior diameter of 9 feet.

The water of the reservoir which naturally flows to the desert on the north side of the range will be conveyed to the San Bernardino Valley by a series of long tunnels piercing the mountains, and dropping to the valley through pressure pipes by which power is to be developed. The water is to be used for irrigation and domestic supply.

The company has been at work on the system for more than 15 years.

Failure of Snake Ravine Dam, California, Illustrating Danger of Improper Use of Hydraulic Method.—The lessons to be learned from the failures of others are as valuable to the engineer as the record of successful construction, and for the purpose of illustrating how not to build hydraulic-fill dams the two disastrous attempts undertaken for the Turlock Irrigation District to construct a dam across Snake Ravine may be cited as conspicuous examples of the results of neglecting correct methods and principles. An interesting account of this work was prepared by J. B. Lippincott, M. Am. Soc. C.E.,* from which the following description has been compiled.

The dam was planned to be 64 feet high, 294 feet long on top, with crest width of 12 feet at a height of 4 feet above the water-line, and with side slopes between 1.5 on 1 and 2 on 1. Its purpose was to save the construction of 1500 feet of side-hill canal and flume in the line of the main canal of the Turlock Irrigation District. The capacity of this canal is 1500 second-feet and it was located to discharge into the basin above the dam, after passing through a ridge where a cut 50 feet

* *Engineering News*, October 20, 1898.

deep, 800 feet long, was required. The material of this cut was auriferous gravel, in size varying from 1 inch to 2 feet, imbedded in red clay with some sand. In its original position it is extremely firm and impervious, standing for years when mined in walls nearly vertical as high as 50 feet. A canal used for hydraulic mining, with a capacity of 24 second-feet, was already in existence 100 feet above the grade of the irrigation canal, and but one quarter of a mile distant. All these conditions were simply ideal for the cheap construction of a first-class dam by the hydraulic process. It was planned to build the dam by sluicing down the material out of the big cut, but no means were provided for conveying the sluiced material to the slopes of the embankment, and there separating the rock from the clay and sand, thus giving stability, friction, and drainage to the exterior sides of the fill. On the contrary, the material was turned loose down a natural ravine, and all the heavy bowlders and gravel were dropped on the way, while merely the fine silt and clay reached the dam. Thus the basin was filled with many hundreds of yards of the best material that never got down to the embankment.

The first attempt was made in 1893, but the dam, which was constantly shaky, vibrating and wet, without ability to drain itself to a condition of stable equilibrium, slid out when it reached the height of 30 feet. The second dam was built upon the wreck of the first, and, although greater care was given to provide drainage by an inclined box beneath the outer slope, so that it was completed to the full height, it was destroyed in the same manner when first tested by filling the basin, June 14, 1898. The embankment slid *en masse* down the ravine at a velocity of 6 to 10 feet per second, and after travelling a distance of over 1000 feet was thrown bodily into the Tuolumne River, creating a temporary dam 20 feet high. The superintendent and two dogs were on the dam when it gave way without the slightest warning. They were all carried entirely across the river and none of them hurt, though the man's shirt and pockets were filled with sand and mud on the trip.

The simplest and most elementary precautions in dam building appear to have been neglected, and no attempt was made to prepare the foundations by the removal of mining tailings in the bed of the ravine, the excavation of a trench to bed-rock, or the construction of any sort of core-wall or seepage barrier. A wooden culvert, $4' \times 4'$ in the clear, of 2-inch Oregon pine, was built through the dam at the bottom resting on 6×8-inch stringers. A shaft of wood was built up at the upper toe as an overflow for draining the reservoir during construction. Connecting with this box was an inclined wooden shaft $2' \times 4'$, laid parallel with the outer slope, 10 feet from the exterior surface, to take off the overflow from the pond on the dam. When the embankment