Lake Frances Hydraulic-fill Dam, California.—As an example of unusual difficulties and adverse conditions successfully overcome where other methods have failed, the repair and enlargement of the broken Lake Frances dam by the hydraulic method is perhaps the most conspicuous which could be selected.

This dam was originally built as an ordinary earth dam, by the Bay Counties Power Company, two miles above the Colgate Power House, on a little tributary of the Yuba River, called Dobbins Creek. It is located about 35 miles from Marysville, in the mountains of Yuba County, at an elevation of 1500 feet above sea-level. The watershed intercepted is but 6.5 square miles above the dam, from which the run-off fluctuates from a mere trickle of 3 or 4 miner's inches to an extreme flood flow of about 1000 second-feet. The dam was intended to form a small reservoir for emergency service, and is located 400 feet higher than the penstock of the power-house, which receives its water supply from the North Fork of Yuba River through a wooden flume nine miles long, built in the rocky canyon of that stream. The flume is subjected to occasional interruption from falling rocks, and in such an emergency the small reservoir storage of the Lake Frances reservoir is drawn upon for a few hours at a time to maintain the operation of the plant. It was originally planned to utilize the power at certain hours of the day when the demand was less than the output by pumping water from the flume up to the

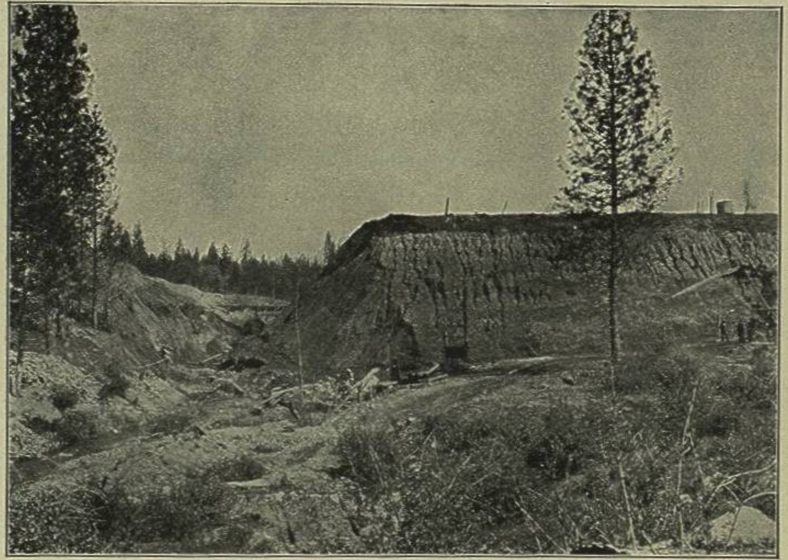

FIG. 84.—BREAK IN ORIGINAL LAKE FRANCES DAM. LOOKING UP STREAM.

higher reservoir, and a 4-stage 10-inch centrifugal pump was ordered built for this purpose. This plan was not carried out, but one-half the pump was subsequently finished up and used for the hydraulic-fill work which will be described.

The original dam built in 1899 had a maximum height of 50 feet, was 992 feet long, 16 feet wide on the crest, and was given slopes of 3 on 1 and 2 on 1, on the up-stream and down-stream sides respectively. It formed a reservoir of 42.67 acres area at the spillway level (4 feet below the crest), and gave a storage capacity of 30,545,000 cubic feet.

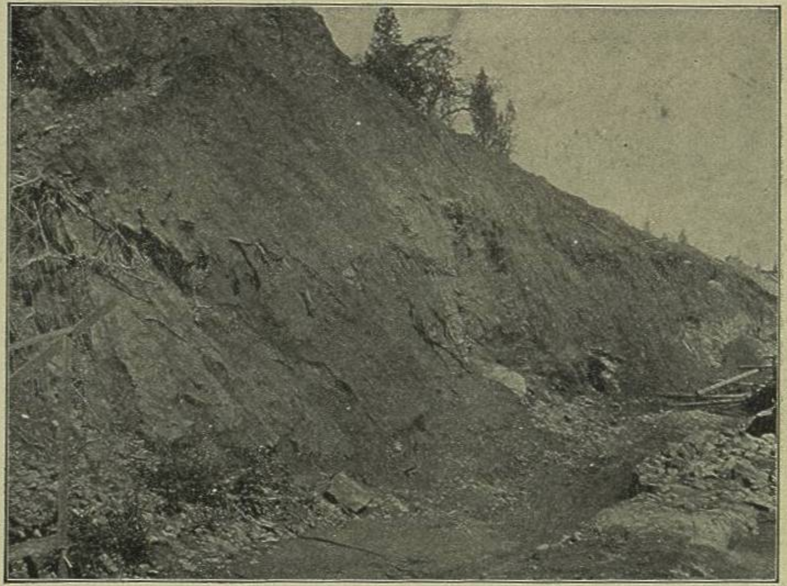

FIG. 85.—NEAR VIEW OF RIGHT SIDE OF BREAK IN EMBANKMENT OF LAKE FRANCES DAM SHOWING ROOTS EXPOSED BY THE BREAK.

The site of the dam as well as a large part of the reservoir-basin was covered with pine forest when construction began, and had to be cleared and grubbed to get at the material in the borrow-pits.

For two-thirds of its length from the east end where the embankment was lowest in height, it was built with slip and wheel scrapers, the earth being spread in layers of 6 and 8 inches depth and moistened and rolled as is customary. The remainder, covering the highest and most important portion of the dam on either side of the original stream channel, was built late in the season when the ground had dried out and the water-supply had practically failed. The rainy season was approaching and there was such haste in completing the dam that the earth was dumped in any way most convenient, as in an ordinary railway embankment, without any attempt at spreading in layers. The steep hill slope at the west end was not even cleared of stumps and roots over much of its surface, as the subsequent break revealed.

The material of the hillsides consisted of red clay and gray sandy soil, resulting from the disintegration of syenite rock, devoid of mica. In the valley proper the soil contained some gravel and enough vegetable mold to constitute a dark loam.

Rupture of Original Dam.—A few days after the fill had been completed, a rainfall of 9 inches in 36 hours caused the reservoir to fill rapidly, and when the water had risen to within six feet of the spillway level, at 11 A.M., Oct. 21, 1899, the dam was suddenly ruptured, and a hole washed through it 100 feet wide at top, extending down to and below the original stream-bed. The dam originally contained 80,265 cubic yards, of which 16,160 cubic yards, or about 20%, were washed away.

FIG. 86.—TOE LEVEE OF NORTH FACE, LAKE FRANCES DAM, AND INLET CRIB AT HEAD OF FIVE-FOOT OUTLET CULVERT.

Repair and Enlargement by Hydraulic Method.—During the summer following the break the writer was employed to report on the repair of the broken dam, and after examination recommended that the hydraulic sluicing method be employed. In the spring of 1901 he was placed in charge of construction, associating with him Mr. J. M. Howells, M. Am. Soc. C. E., who corroborated the writer's recommendation of the hydraulic-sluicing process as the most desirable means for reconstruction. It was decided that it would be unwise to repair the dam by simply filling the gap, as it would subject the remainder of the embankment, which had already failed at one point, to the possibility of a repetition of the same disaster, as well as subject the old and new parts to unequal settlement. It was therefore proposed to place a heavy layer of earth against the upper slope of the original fill of sufficient thickness to give an impervious core of selected fine clay between zones of porous, stable material. This added thickness was recommended to be 125 feet, measured horizontally, which, if carried out simply as a repair of the old dam, would have left it with a crest width of 141 feet. With this broad crest it was evidently safe to add 25 feet to the height of the dam. The filling of the break and the 125 feet facing required 133,782 cubic yards of material, while the increase in height proposed involved but 81,371 cubic yards additional for which the plant would have been already installed. As the storage would be increased three and one third times the extra cost was manifestly justifiable, and the work was ordered on that plan.

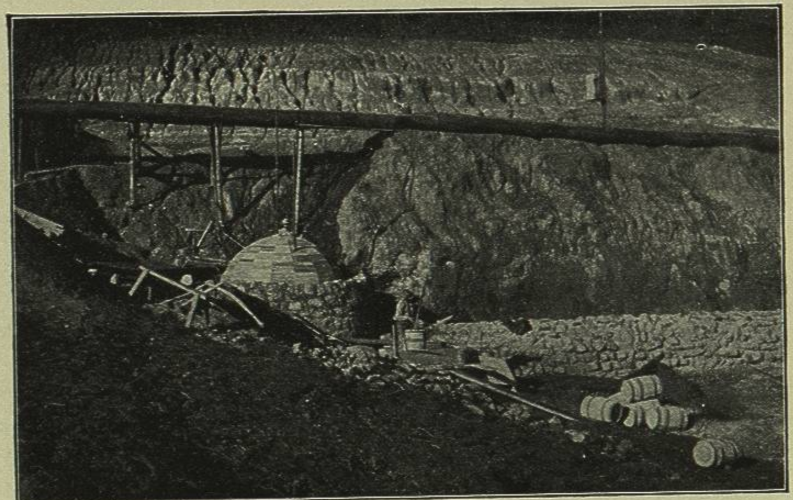

FIG. 87.—DOME ON GATE CHAMBER, LAKE FRANCES DAM; ALSO TWENTY-TWO-INCH SLUICE PIPE.

Sluicing with a Pump.—As a gravity water-supply was not obtainable it became necessary not only to pump the water for sluicing, but to build a small storage-reservoir below the dam to store up a supply and pump the water over and over again. Owing to delay in completing the two-stage tandem centrifugal pump (one half of the large pump referred to) on account of a machinists' strike in San Francisco, work was begun on a small scale May 10, 1901, with a 6-inch single-stage centrifugal pump, direct connected to a 30-H.P. motor, installed with electric current supplied from the Colgate Power House, two miles away. This pump delivered 1.76 second-feet under a head of 100 feet, and did very good service until June 15. By its use 4090 cubic yards were deposited in the repair of the break, at a cost of 18.27 cents per cubic yard. The larger pump was finally installed and put in service Aug. 30, 1901. It continued to supply the water for sluicing until the completion of the dam June 28, 1902.

The pump had a capacity for delivering 6 cubic feet per second, under a pressure of 120 pounds per square inch, through a line of 20-inch pipe, 300 to 700 feet long. The pump was belt-connected with a 350 H.P. synchronous motor, using alternating electric current at 2400 volts.

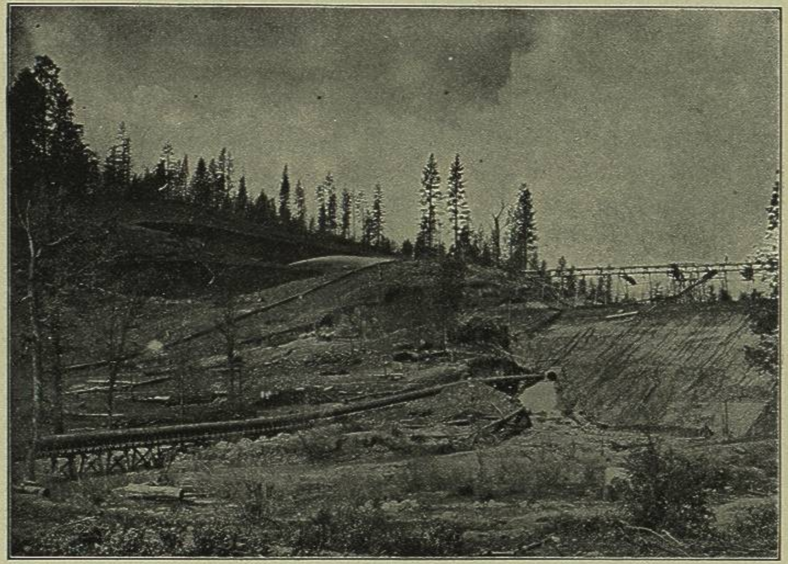

FIG. 88.—WEST END OF LAKE FRANCES DAM, SHOWING THE BREAK RESTORED, THE HIGHER DAM NEARLY COMPLETED, THE HYDRAULIC GIANT AT WORK, AND THE MAIN PIPE LINE SUPPLYING WATER TO THE PUMP.

A careful test of the plant made Feb. 5, 1902, showed the efficiency of the pump to be 61% to 63%, and the combined efficiency of pump and motor of 50% to 52%, when delivering 4.1 to 4.66 second-feet, under 104 pounds pressure.

The first work of the new plant was to complete the filling of the gap in the original dam by depositing the remaining 9620 cubic yards. This work was much hampered and delayed by the contracted area to which it was reduced, requiring frequent suspension of work to allow for proper settlement and drainage. Levees were maintained along the up-stream and down-stream slopes, one or two feet in height, composed of the most stable material brought down by the water, while the fine clay mud was deposited in the pond confined between these levees. The excess water was drained from this pond by flumes at one end, or by a pipe siphon, and returned to a pond at the north side of the dam. The sediment deposited from this overflow, together with one or more slides or slips from the slope, of the filling in the break, added 5220 cubic yards to the zone called the "North Face." These slips and sloughing down the slope were due to the lack of sufficient coarse gravel, rock, and sand to afford the desired friction and requisite freedom of drainage.

During all this filling of the break as well as in all subsequent work the water contained in the fine mud which composed the bulk of the interior of the dam was constantly being pressed out as settlement of the mass continued, and appeared as a continuous ooze over the entire face of the slopes. In fact this ooze was apparent for some months after the dam was completed.

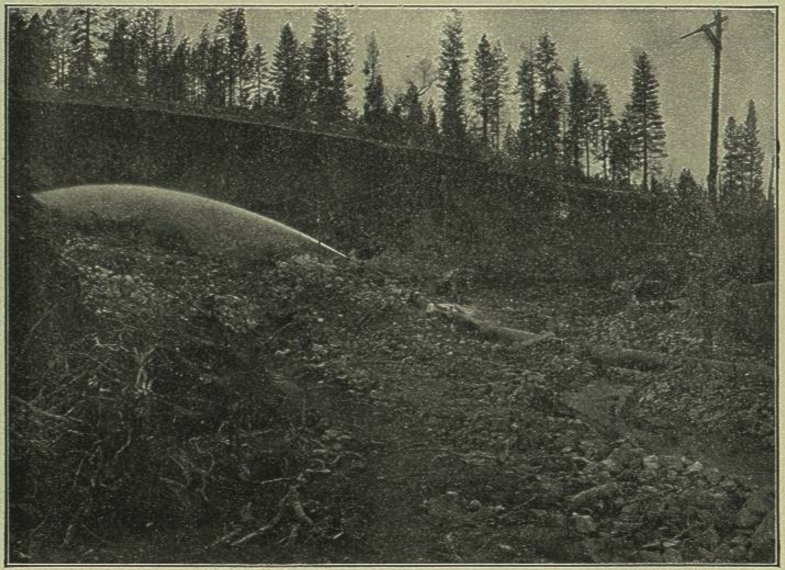

FIG. 89.—HYDRAULIC GIANT IN ACTION UNDERCUTTING THE BANK.

Owing to the great length of the dam (1300 feet on the crest) and the necessity for securing all the material of construction from one end, it was necessary to use gradients as low as possible, to avoid excessive height of trestle supporting the flume and pipe for delivering the material. The minimum was found to be 2.2%. For this reason it was not possible to transport much of the rock encountered in the borrow-pits, and there was constant lack of sufficient coarse material to maintain

the slopes, and prevent slides. It was finally found necessary to resort to the use of pine and cedar boughs and other brush 6 or 8 feet long laid into the slopes with the butts inside, to prevent the tendency to slip. This was effectual in knitting the mass together sufficiently to overcome the sliding and sloughing tendency.

The general plan of building the north face and the top embankment was to deliver the sluiced materials that had been loosened and washed out by the hydraulic giants, under pressure of 40 to 75 pounds per square inch at the nozzle, through a 22-inch riveted steel pipe, placed on a high trestle running parallel with the axis of the dam, and far enough inside the slope lines to make delivery through lateral flumes of moderate length, terminating at the edges of the rising embankment. They were of varying length, according to the height at which they were designed to deliver, and were made about 25 feet in average height. The longest trestle with which the additional height of 25 feet above the original dam was built was 1560 feet long, with 13 branch trestles, as shown in Fig. 92. The highest bent in this trestle was 40 feet high.

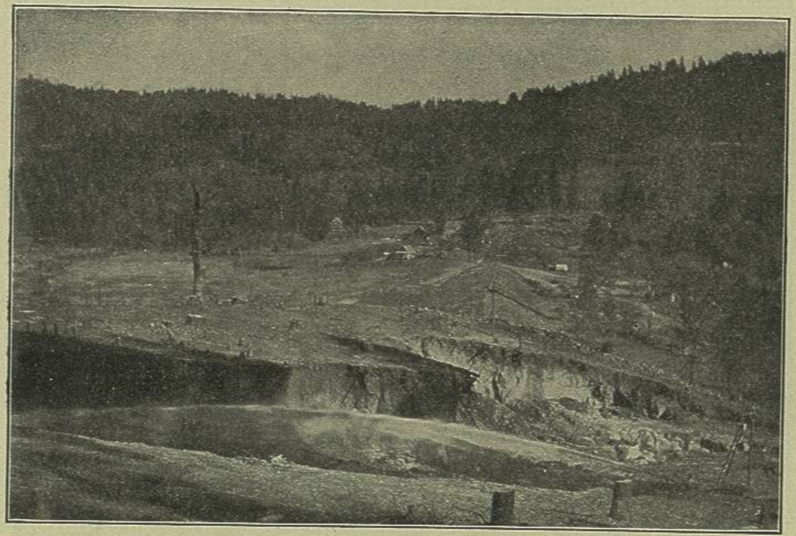

FIG. 90.—LAKE FRANCES DAM, NOVEMBER 6TH, 1901. FROM SOUTH BORROW-PIT, LOOKING ALONG AXIS OF ORIGINAL DAM.

The sections of pipe laid on the trestles were separated by a space of two to four feet, which space was filled by a loose curved plate or half pipe clamped over the joint with key bands that could be quickly unjointed by driving out a key and slipping off the band. Thus delivery of a part or the whole discharge of the pipe could be made at any point desired.

The volume in the completed dam is 280,700 cubic yards, of which amount 182,937 cubic yards were deposited by sluicing in the period of 253 days.

A record of the actual time of sluicing shows an aggregate during this period of 1581 working hours, or a little over 25% of the total time. Omitting Sundays and half the nights, the sluicing, in shifts of 10 hours per day, was carried on about one half the maximum available time. The other half was lost by reason of stoppages required for building trestles, and also from lack or shortage of power.

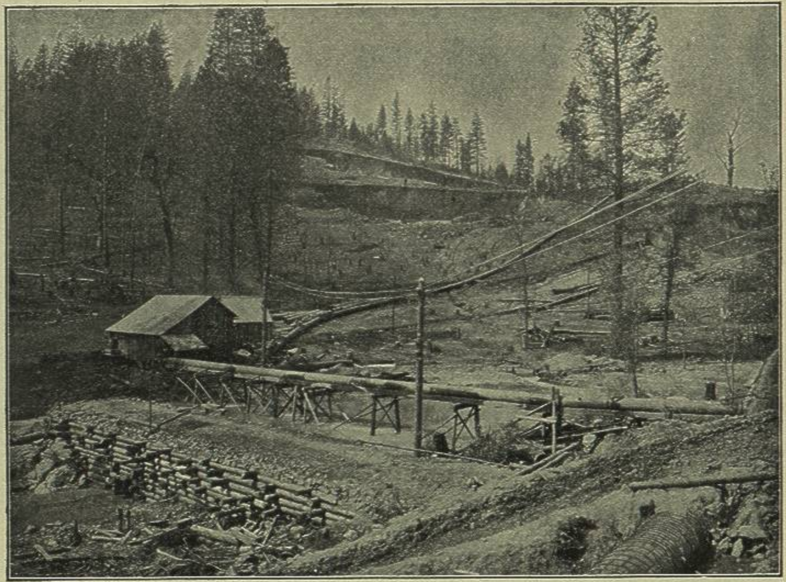

Fig. 91.—Lake Frances Dam Construction. Pumping Station, showing Suction Pipe connected to Tandem Centrifugal Pump. Crib Dam in Foreground built to store Water for earlier Operations.

The volume of water used was carefully measured and found to vary from 4.5 to 7.0 second-feet. The total water pumped was estimated at 30,740,000 cubic feet, while the total volume of solids transported and deposited in the dam amounted to 4,940,000 cubic feet, or 16.6% of the entire amount of water pumped. This was in addition to about 2% or 3% of silt carried in suspension and drained back into the reservoir.

The weekly percentages of solids carried by the water varied from a minimum of 6.1% to a maximum of 47.7%. With unlimited power, clear water, good material in the pit, a bank over 25 or 30 feet high and all conditions favorable, the material poured in rapidly and the ratio was maintained for several weeks from 32% to 38% of solids. A frequent cause of delay was due to accumulation of roots and stones in the borrow-pit, preventing a continuous flow of earth to the sluice ditch. Another cause was the occasional clogging of the delivery-pipe by reason of the light grade, and a momentary increase in percentage of solids carried. The best week's work was 22,350 cubic yards, deposited in 94.5 hours, an average of 236 cubic yards per hour with 6.5 second-feet of water, and a ratio of 27.2% solids. The power used averaged 236 H.P., showing a combined efficiency of pump and motor of 53.9%.

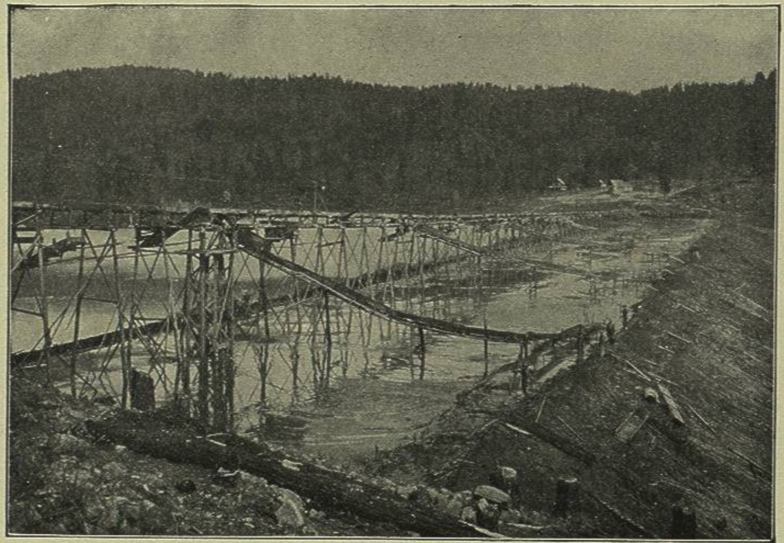

Fig. 92.—Lake Frances, Cal., Hydraulic-fill Dam Building. Showing Outer Levees Maintained with Brush, Deflecting Boards for Distributing Sluicings along Slope, gentle Slopes toward Center of Dam, and Gradual Movement of Drainage toward extreme End.

The total power used, at ½ cent per H.P.H., cost $2054, or about 1 cent per cubic yard moved.

The minimum cost for labor during any one week's run was 3.8 cents per cubic yard. The average labor cost was about 15 cents per cubic yard, and the total cost, including all power, materials, and plant, was probably less than 20 cents per cubic yard. Under more favorable conditions the work might have been done at an average of 3 to 5 cents per cubic yard.

These improved conditions, easily attainable for hydraulic-fill dam construction in many localities, may be outlined as follows:

(*a*) Constant, uninterrupted power amply sufficient to do the work required if the water has to be supplied by pumping, but preferably a gravity supply of 10 to 30 second-feet, giving greater carrying power and greatly increasing the output of material with the same force of attendants.

(*b*) Shorter top length of dam, permitting the use of steeper gradients in the sluice boxes and delivery-pipes, and consequently giving higher velocities and ability to move rock of considerable size for stability of slopes. In this case much rock was necessarily left in the pit where it was in the way and was a source of diminished efficiency, although greatly needed on the dam, because of lack of transporting power.

(*c*) Delivery from both ends of a dam simultaneously, instead of from one side alone, which would permit of increased gradients and more effective delivery of coarse material throughout the entire length of the slopes.

(*d*) A larger proportion of sand, gravel, or broken stone of less than 10 or 12 inches diameter, rendering the slopes stable without the use of brush, and avoiding the building of dry levees with teams.

Settlement.—The dam was constantly undergoing settlement as the water was being pressed out of it. This was observed by the distortion of the flumes and pipe trestles, and the slope boards on the slopes. The greatest amount of settlement measured on the posts of the last trestle used on the north face was 3.43 feet, or about 9% of the height. The original dam settled 2.5 feet vertically, notwithstanding the fact that it had been exposed to the rains of two previous winters, and was presumably solid.

Comparison of the volume of the dam with that taken from the borrow-pit (covering 7.12 acres, excavated to a mean depth of 21.5 feet) indicated that the former was but 84.6% of the latter, and estimating the silt carried off by the tail-water at 4.4%, the shrinkage of the soil from its natural condition in the bank to its compacted state in the dam was about 11%, a practical illustration of the solidifying action of water in building dams by this process. In fact, from the compact condition of hydraulic-fills generally, it appears certain that it is not possible to secure such density of earth by any other process, even at many times the cost.

Stratification.—The same means were used in this work to prevent or break up stratification across the center as were employed on the Crane Valley dam. The work of thrusting down paddles or planks was continuously kept up, the men working from boats or rafts floating in the pond of mud on top of the dam. Where any tendency was discovered for the formation of local stratification of sand streaks across or near to the center it was corrected by a change in the position of the dump and the grade from the sides toward the center.

Spillway.—The service outlet of the Lake Frances dam is a 30-inch cast-iron pipe, laid through the embankment and surrounded with masonry. Alongside of this pipe a masonry culvert was built for drawing off surplus water at will before the reservoir is filled to the spillway level. The spillway proper is 80 feet long, and is formed by a slab of concrete, 8 inches thick, reinforced with continuous sheets of expanded metal. Owing to the absence of rock this concrete slab, of Ogee form, was laid on the natural earth and discharges into a paved basin, from which a ditch leads to an isolated rock cliff, 500 feet away.

After the completion of the dam, during the winter of 1904–5, the lake was filled to overflowing, with the 5-foot culvert discharging its full capacity, and water ran 22 inches deep over the spillway. Evidently, the original spillway, 40 feet wide without an auxiliary discharge culvert, would have been totally inadequate, so that the first dam was doomed to ultimate destruction even had it not been breached as it was.

Hydraulic-filling of the Milner Dams on Snake River, Idaho.—In the foregoing chapter on rock-fill dams, a description was given of three combination rock-fill dams built on Snake River, Idaho, in 1904–5. The hydraulic filling was of a character quite distinct from that employed in the pure types of hydraulic-fill dams hitherto treated of in this chapter, and is deserving of further notice. The earth available for this work was of one class only, and consisted of fine white or grayish soil which covers the plains of that region to a depth varying from one to twenty feet or more. It is exceedingly fine in texture, an almost impalpable powder, free from grit and wonderfully uniform in quality. A test made by the writer showed that it was like finely-ground cement, as nearly 90% would pass through a sieve of 10,000 meshes per square inch. It is classed as *loess* or wind-borne soil, and is doubtless a fine volcanic ash. It absorbs water slowly in bulk, like flour, but when once wet packs very solidly and becomes as stable, as impervious, and as dense as clay, with this advantage that it does not shrink and crack in drying. Using this material as a backing for the rock-fill, it was very evident that the voids in the rock-fill above the wooden-core wall, described in the previous chapter, could only be filled by sluicing the earth in place with water. It was also considered that desired water-tightness of the mass could best be obtained by a thorough saturation during construction. The earth had to be obtained at a distance of 2000 to 8000 feet from the dam. A portion of it nearest to the dam was scraped into a box at the borrow-pit, by slip and wheel scrapers and dump wagons, and, water being pumped from the river to the box, the earth was thus sluiced through a flume to the point of discharge at the dam. The volume of water discharged by single