concrete through the base of the dam and extending into the reservoir for 240 feet. The reservoir formed by the dam covers an area of 130 acres, with a capacity of 102,000,000 cubic feet (2340 acre-feet). The surface elevation of the water is 9018 feet, giving a maximum depth of 63 feet to be drawn upon.

The dam was designed and built by Mr. R. M. Jones, Engineer and General Superintendent of the company.

Power generated with a drop of 1160 feet to the extent of 1600 K.W. is transmitted to Victor over a line of 8 miles in length. The wood-stave pressure-pipe is 23,400 feet long, the limit of pressure being 220 feet, below which a 29-inch steel pipe, ¼ inch to ¾ inch thick, 2900 feet long, is laid to the power-house.

The Animas Dam, Colorado.—In 1906 a large rock-fill and timber crib dam with plank facing was built for the creation of a storage reservoir of 960 acres, to be utilized for power development in San Juan County, Colorado, 25 miles from the city of Durango, by the Animas Canal Reservoir and Water Power Investment Company. The dam is 750 feet long, 55 feet high above the original surface, the foundation being carried down a depth of 33 feet through loose material to bed-rock. The cribs on the down-stream side are stepped in five benches or steps, from the bottom up, formed of logs and filled with rock. The dam is to be replaced eventually by a concrete dam, 100 feet high, 1400 feet long, increasing the reservoir to 1161 acres. Water is fed to the reservoir by a flume, 6×8 feet, 3½ miles long, leading from Cascade Creek. Water from this reservoir is conveyed through a flume 8800 feet long to a penstock reservoir, formed by a small earth dam with concrete core, 30 feet high, from which a riveted steel pressure-pipe 2844 feet long leads to the power-house, where an effective head of 960 feet is utilized. Power is transmitted to Durango and Silverton at 50,000 volts pressure. The works were built by Geo. M. Peek, M. Am. Soc. C. E.

CHAPTER II.

HYDRAULIC-FILL DAMS.

THE forces employed in hydraulic mining for tearing down banks of sand, gravel and rock, by means of a large volume of water issuing at great velocity from a nozzle under high pressure, have been utilized in the evolution of a novel and interesting type of dam-construction, called the "hydraulic-fill dam," which is becoming recognized as the most economical method of handling earth, as well as the most positive and satisfactory means of compacting it in a solid and immovable mass. By the skillful direction of the currents of water by which the material is conveyed, the disintegrated earth is assorted and deposited where it is desired to perform the required functions of stability and water-tightness in the dam, thus reversing the destructive process of mining and converting it into an upbuilding of great structures serviceable to mankind.

This development of hydraulic mining doubtless originated in the Pacific Coast, where many new and peculiar methods of mining auriferous gravel on a large scale were evolved by necessity, and the ready inventive genius of American miners. It was first employed for making small storage reservoir dams in and around the mines, with the detritus from which the contained placer gold had been washed. These dams were used either for impounding mining tailings, or for water.

Subsequently the principles involved in the utilizing of water of varying velocity for loosening, conveying, assorting, distributing, depositing and consolidating the materials were more carefully studied and scientifically employed in the design and construction of higher and more important dams. These principles are adaptable to the building of dams of any desired height, provided suitable materials are available and the conditions permit of economical construction.

The only limit of feasible height for dams of this class is one which is fixed by the cost, for if the embankment to resist water pressure be made sufficiently wide and massive, and with materials which may be so consolidated as to become impervious to water, there is no reason why dams of 300 feet or more in height should not be built, if justified by the cost. There are innumerable instances in different parts of the world where nature has built hydraulic-fill dams, which form lakes of great depth. The dimensions of such dams, built as glacial moraines, with bowlders, gravel, sand and rock-dust, are usually very much greater than any artificial structure would need to be for absolute safety.

Requisite conditions for the proper design of hydraulic-fill dams are the following:

First. They require to be located on a stable and impermeable foundation, whether it be clay, gravel, rock, or other material which is or which can be made impermeable to water under pressure.

Second. They must be formed of materials, which when packed in the mass of the embankment, are practically water-tight throughout the whole or a large proportion of their entire cross-section.

Third. They must have slopes sufficiently flat to render the structure stable under all conditions of saturation from the water in the reservoir or from soaking rains, or both combined.

Fourth. The elevation of the crest above the highest possible level of water in the reservoir must be sufficient, in connection with unobstructed spillways of ample dimensions, to insure against the possibility of the dam ever being overtopped by extraordinary freshets due to cloudbursts, or by waves driven up the slope by gales of wind or by any combination of such contingencies.

Fifth. They must be so constructed that after completion they shall not settle or crack or show any material sign of movement or change in form or position.

This latter requirement implies a radical change during construction from a condition of liquid mud and unstable equilibrium to one of solidity and absolute stability under all vicissitudes of time and change. Such changes of form and adjustment of the particles composing the mass by the pressing out of the water contained in the voids, is a slow process, particularly if the materials contain a large percentage of clay.

To secure stability and perfect drainage it is essential that the outer slopes of the embankment, composing about one third of the mass, equally divided between the up-stream and down-stream slopes, shall be composed of rock, gravel, or sand, which will afford friction and stability, as well as drainage to the interior of the dam. This interior two thirds is the water-tight section, composed of the finest clay or silt as segregated from the other material. It is at first thoroughly unstable and would slide from its position if unsupported by the stable sections on either side. With the slow settlement following gradual drainage and the pressing of the water from its voids, it becomes more and more dense, and finally assumes a condition of mature solidity and impermeability that fits it to resist the pressure of the water in the reservoir behind it. The best practice in hydraulic-fill dam construction is to test the structure at all stages of its growth, by permitting the reservoir to follow up the rising dam, always 10 to 15 feet below the top (at the same time maintaining a pond of water on top of the embankment), although this is not always feasible. When such a water-level is maintained against the dam as near the top as possible, the principal drainage of the interior mass of the dam will be out through the down-stream zone of permeable material, permitting of partial filling of the voids in the up-stream permeable zone with fine silt.

The conditions best suited for the economical employment of hydraulic-dam construction are:

1st. The existence of an abundance of water at the proper elevation to form a sufficient "sluicing-head"; and,

2d. An abundant deposit of materials for forming the dam, convenient to either end, and high enough above the top of the proposed structure to permit of the requisite grades for carrying the material.

The volume of water necessary for a "sluicing-head" should be from 5 to 20 cubic feet per second, although smaller heads may be used. Twenty to thirty second-feet may be readily handled in one head, and is more effective proportionally than smaller heads. The duty of water in hydraulic mining in California per miner's inch per 24 hours, ranges from 2 to 5 cubic yards of solid bank measure loosened and washed down. This is equivalent to a duty of from 80 to 200 cubic yards removed in 24 hours per second-foot of water. The ratio of water to solids would thus be from 2.5% to 6.25%. In hydraulic gold-mining it is essential to keep the percentage of solids quite low to permit the gold to drop freely to the bottom of the sluice-boxes, where it is caught by quicksilver. In dam-construction, on the contrary, it is desirable to maintain as high a precentage of solids as the water will transport. With sluice grades of 6% to 10%, the volume which may be transported by a sluicing-head of 10 second-feet is 3000 to 8000 cubic yards per 24 hours.

The most suitable material is an admixture of soil, clay, sand, and gravel of all sizes. Angular stones, not exceeding 2000 lbs. weight may be carried through the sluice-boxes with a sufficient amount of sandy soil or unctuous clay to enable it to flow well. It is customary to deposit the materials on the dam on the lines of the two slopes, which are studiously kept higher than the center of the embankment. The larger stones are here dropped, while the finer materials are carried towards the center where the water is drawn off through stand-pipes which lead back into the reservoir or which conduct it to a flume or pipe by which it may be wasted below the dam.

The material for this class of construction may either be loosened by a hydraulic jet of water issuing under pressure and playing against the bank, which is the cheaper and more rapid method, or if pressure is not available it may be plowed or picked and ground-sluiced.

The Hydraulic Giant.—The latest improved form of hydraulic monitor or "giant," as developed in the mines of California, is shown in Fig. 64.

The weight of the nozzle is counterbalanced as required by filling the wooden box with stone. The vertical movement of the nozzle is made by a ball and socket joint. The horizontal movement is on the ball-bearing joint between the two elbows around a center.

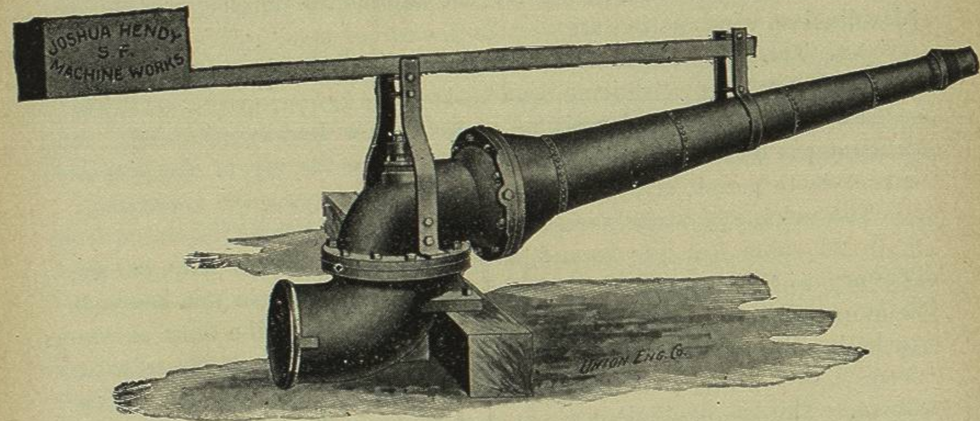

Fig. 64.—Double-jointed Hydraulic Giant.

To enable the operator to handle the giant with ease and change the direction of the stream quickly, a device called the "deflecting nozzle" is placed at the end of the nozzle of the giant, by means of which the power of the issuing stream is controlled to move the entire machine.

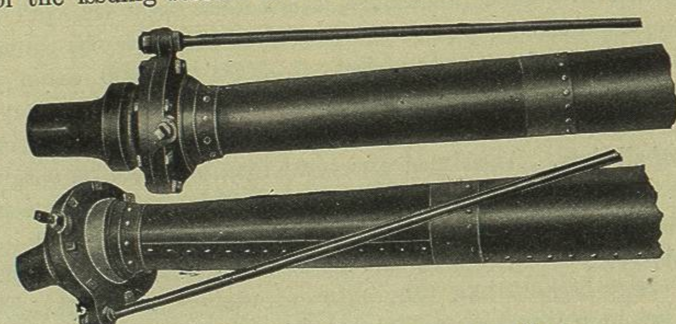

Fig. 65.—The Deflecting Nozzle of Giant.

When this nozzle is pressed slightly against the jet, the giant is moved in the opposite direction. By means of the lever this movement can be effected by a child, and a column of water weighing many tons can be thrown instantly through an arc of 180° or more. (Fig. 65.)

The earliest form of hydraulic giant is known as the single-jointed monitor, in which the movement is confined to one direction in a ver-

tical plane, and the machine had to be shifted by bars to change the horizontal direction.

Streams of water of all sizes requiring nozzles from 2 to 10 inches in diameter, and working under heads from 100 to 600 feet or more, have been used. To prevent a scattering or rotary motion of the water after it has issued from the nozzle all the taper pieces are fitted on the inner side with guide-vanes, and the jet is thus discharged in as solid and columnar form as possible thereby increasing its effectiveness.

San Leandro and Temescal Hydraulic-fill Dams, California.—This process of building up reservoir-embankments has been in vogue in a small way in the mines of California from the earliest days of hydraulic mining, but the first application of it on a large scale was made by Mr. A. Chabot, in the construction of the reservoir-dams for the water-supply of Oakland, California, a city of 60,000 inhabitants.

These dams were planned and built by Mr. A. Chabot, who, though not an engineer, had had years of experience as a practical hydraulic miner and was the principal owner of the water-works. They are both earthen dams, of which the central portion, including the puddle-core, were built up with scraper teams and rollers in the ordinary way, but extensive additions to their slopes and height were made by hydraulic sluicing.

The Temescal dam was built in 1868. It is 105 feet high, 18 feet wide on top, with original slopes of $2\frac{1}{2}$ to 1, which have been greatly increased by the material sluiced in from year to year subsequently. The water available being limited in supply to a few days each season after storms, the work was continued for a number of seasons as an economical method of increasing the bulk of the dam. It forms a reservoir of 18.5 acres, with a capacity of 188,000,000 gallons.

The San Leandro dam was built in 1874–75, and has a height of 125 feet above the stream-bed. It is located 9.5 miles east from Oakland, 1.5 miles above the village of San Leandro, at an elevation at base of 115 feet above tide. The dam is 500 feet long on the crest and 28 feet in width. The width of base from toe to toe of slopes is 1700 feet. The original slopes were $2\frac{1}{2}$ to 1 on the down-stream side, and 3 to 1 on the reservoir side. Subsequent additions to these slopes were made by hydraulic sluicing. The extreme depth of puddle core is 30 feet, making the total height of dam from bottom of puddle core to crest, 155 feet. The total volume of the dam is 542,700 cubic yards, of which about 160,000 yards were deposited by the hydraulic process. The water was brought 4 miles in a ditch, and the sluiced materials were conveyed in a flume, lined with sheet-iron plates and laid on a grade of 4% to 6%. The water used was 10 to 15 second-feet, and the ground-sluicing method was alone employed, as it was not convenient to get water under pressure. The cost was estimated at one-fourth to one-fifth that of putting the earth in place with carts or scrapers. The entire cost of the dam proper was about

$525,000, but the outlets, wasteway-tunnels, and improvements of various kinds about the reservoir have increased the total to over $900,000, or about $68 per acre-foot of storage capacity. The reservoir covers an area of 335 acres and has a maximum capacity of 13,270 acre-feet, or 4,323,446,000 gallons. The area of the watershed tributary to the San Leandro dam is 50 square miles, from which the run-off is ordinarily in excess of the storage capacity, and considerable difficulty was experienced in disposing of the surplus, without washing away the dam, until a waste-tunnel, 1100 feet long, with a capacity of 2000 second-feet, was constructed in 1888, discharging into the stream half a mile below the dam.

The plans and sections of these dams are shown in Fig. 66, in which are

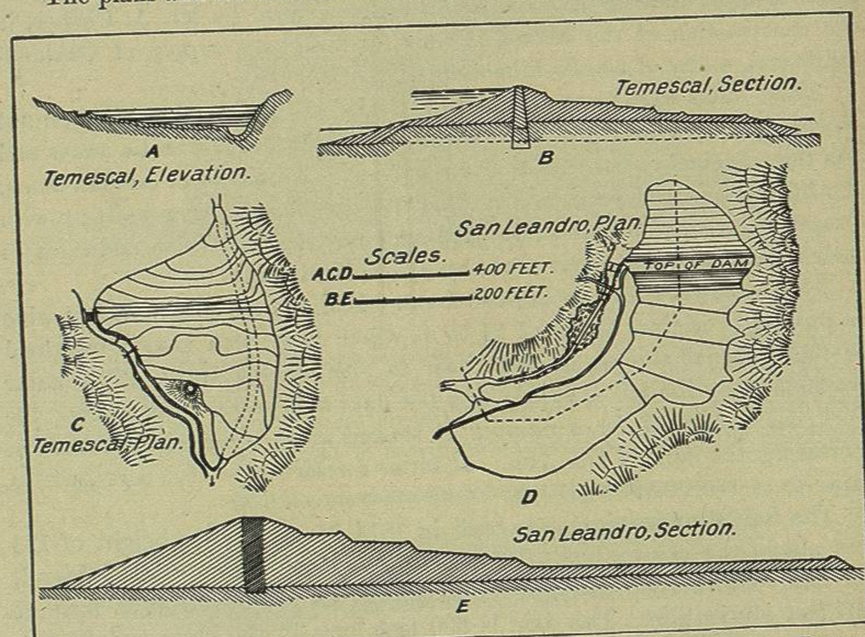

FIG. 66.—PLANS AND CROSS-SECTIONS OF SAN LEANDRO AND TEMESCAL DAMS.

represented the restraining levees for holding the sluiced material in terraces, as it was deposited on the outer slopes. The deposit on the inside was made by simply dumping the contents of the flume into the water and allowing it to assume its own slope on the surface of the embankment.

Hydraulic-fill Dam at Tyler, Texas.—In projecting improvements to the water-works of Tyler, Smith County, Texas, in May, 1894, the engineer of the company, J. M. Howells, C.E., conceived the idea of creating an impounding-reservoir by means of a dam to be constructed by the hydraulic-jet and sluicing method. The only means of getting water to the works was to pump it, and all the materials used in the dam were sluiced in from a neighboring hill. The total cost of the work, including the plant and all the appurtenances of the reservoir in the way of gates, outlet-pipes, etc.,

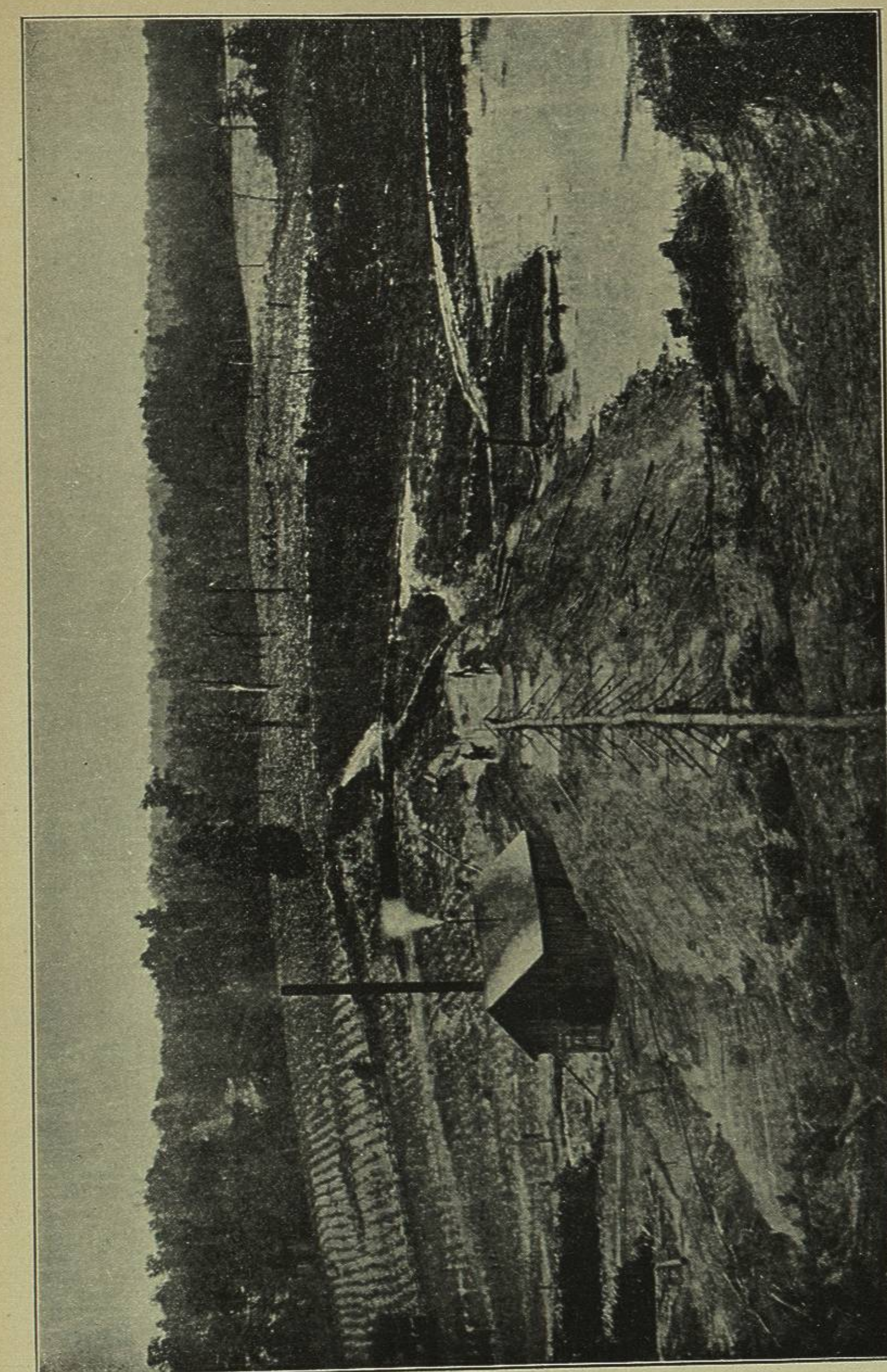

FIG. 67.—HYDRAULIC-FILL DAM AT TYLER, TEXAS, SHOWING DELIVERY-PIPE SUPPORTED ON A GRADE LINE, CARRYING MATERIAL TO OPPOSITE SIDE, AND SPILL-WAY CUT MADE BY SLUICING THE EARTH INTO BASE OF DAM.

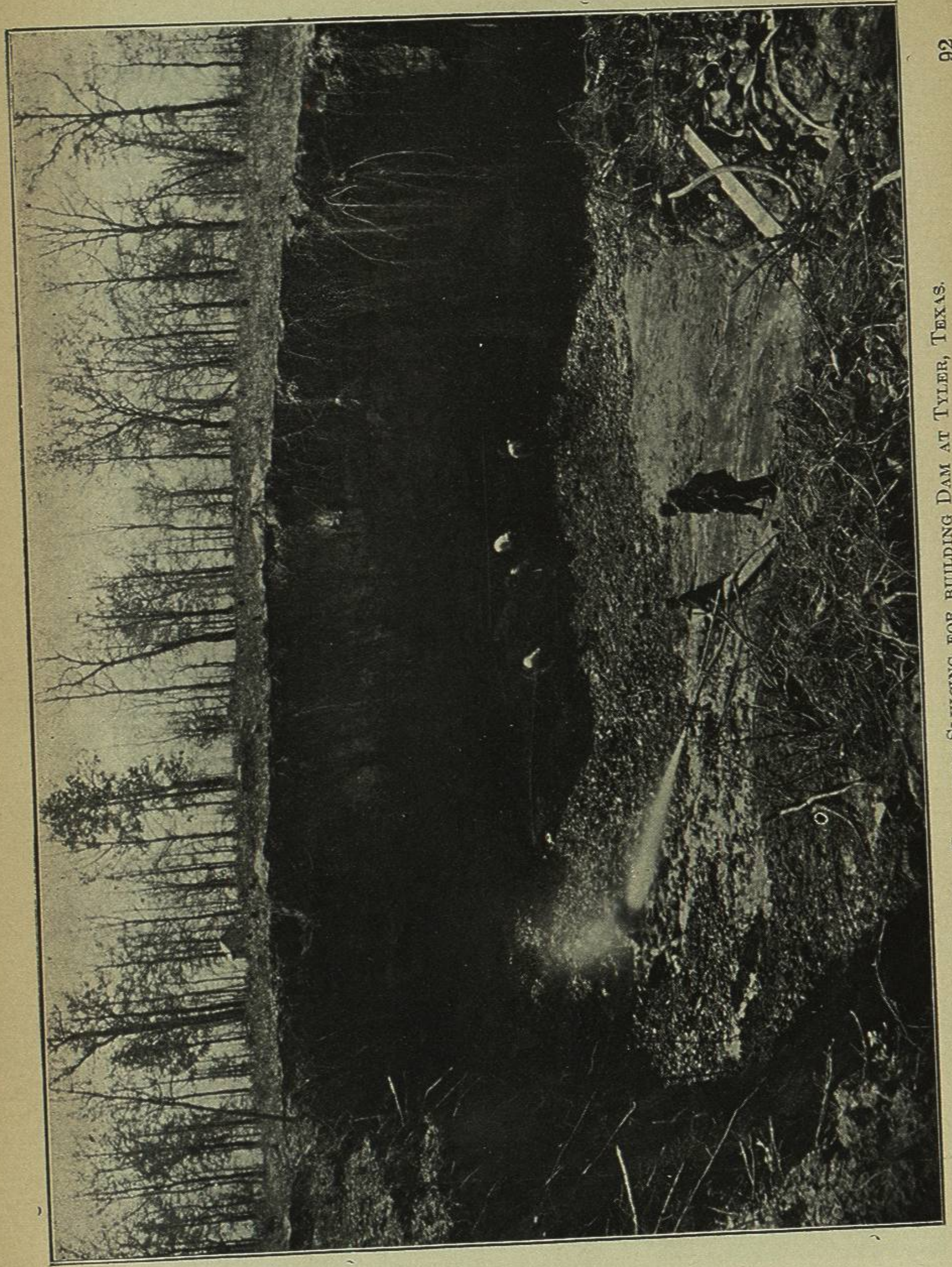

Fig. 68.—Hydraulic Sluicing for building Dam at Tyler, Texas.

was but $4\frac{3}{4}$ cents per cubic yard. The dam, Fig. 67, is 575 feet long on top, 32 feet high, and contains 24,000 cubic yards, the inner slopes being 3 on 1, and the outer 2 on 1, with a 4-foot berm on the inside 10 feet below the top. The maximum depth of water is 26 feet; the reservoir covers 177 acres and impounds 576,800,000 gallons, or 1770 acre-feet. The water used in sluicing was forced through a 6-inch pipe by a Worthington steam-pump of 750,000 gallons daily capacity, belonging to the old city pumping-station situated on the opposite side of the valley from the hill which supplied the material. This hill is 150 feet high, and the pipe terminated about half-way up from its base, where a common fire-hydrant was placed to which was attached an ordinary $2\frac{1}{2}$-inch fire-hose, with a nozzle of $1\frac{1}{2}$ inches diameter. From this nozzle the stream was directed against the face of the hill under a pressure limited to 100 lbs. per square inch (Fig. 68). The washing was carried rapidly into the hill on a 3% up-grade which soon gave a working face of 10 feet or more, increasing gradually to 36 feet vertical height. By maintaining the jet at the foot of the cliff the latter was undermined as rapidly as the earth could be broken up and carried away by the water. The material found in the hill consisted of a soft, friable sandstone infiltrated with ocher of varying shades of yellow, brown, and red, alternating with clay and sand, the whole overlaid by a surface soil of sandy loam, 2 to 6 feet deep. Experiment and observation led to the conclusion that 65% of the entire mass washed into the dam was sand, and 35% was clay.

In beginning the work a trench 4 feet wide was excavated through the surface soil down into clay subsoil, a depth of several feet, and this trench was refilled with selected puddle-clay sluiced in by the stream. Then the form of the dam was outlined by throwing up low sand ridges at the slope-lines, which were maintained as the dam rose in height, in the form of levees by men with hoes (Fig. 69). A shallow stream of water was thus maintained over the top of the embankment, the water being drawn off from time to time, either into the reservoir or outside, as preferred. As the embankment rose it assumed a grade-line from the side nearest to the source of supply to the opposite side. The material was transported from the bank in a 13-inch sheet-iron pipe, put together with loose joints, stove-pipe fashion. This pipe extended from near the face of the bluff, where the jet was operating, across the center line of the dam, and was so arranged as to be easily uncoupled at any point, so as to direct the deposit where required to build up the embankment uniformly. When the end of the dam nearest the bank reached the full height the pipe was raised on a trestle to give it grade for transporting the sand to the opposite side. A spillway was cut out by the same sluicing process, at the end of the dam farthest from the side where the main sluicing operation was conducted, and the earth from it was also placed in the dam. It was found that the quantity of solids brought down by the water varied from 18% in clay to

30% in sand. Sharp sand does not flow as readily as rounded sand or gravel, and is improved in delivery by an admixture of clay and stones. In this case the clay acted as a lubricant, which served to increase the carrying capacity of the water.

The entire volume of water pumped in building the dam, if computed by the percentages of solids given, must have been less than 20,000,000 gallons, although it is unlikely that these percentages were maintained throughout. The volume discharged through the nozzle under the stated pressure must have been about 1.4 second-feet, which is a very small sluicing-head. The nozzle velocity was 115 feet per second. The limitation of the nozzle pressure to 100 lbs. per square inch restricted the delivery of water and its effective power in disintegrating and transporting the soil to considerably less than might have been accomplished with higher pressure.

The entire cost of the dam with all its accessories is said to have been but $1140, which must be regarded as a marvel of cheapness for a structure of the size of this one and performing the function of an impounding dam of its magnitude. Another interesting feature connected with it was that the construction of the reservoir permitted the new pumping-station supplying the city of Tyler to be located on the border of the pond so much nearer to the town than the location of the original pumping-plant, which was at the site of the dam, as actually to save the cost of the dam in the length of main pipe that was thereby dispensed with.

The average cost per acre-foot of storage capacity in the reservoir formed by the dam was but $0.65. The dam is reported to have no apparent defects and gives satisfactory service. Mr. L. W. Wells was engineer and foreman in charge of the works, from whose memoranda, furnished by courtesy of Mr. Howells, consulting engineer, the foregoing description has been compiled. The accompanying illustrations were obtained through the courtesy of Mr. Ben R. Cain, of the Tyler Water Company.

La Mesa Dam, California.—In the spring of 1895 the San Diego Flume Company, which supplies the city of San Diego, California, with domestic water and furnishes an extensive territory of agricultural land with an irrigation-supply through a long line of flume, built an impounding-reservoir on the Mesa, or tableland, 8 miles northeast of San Diego, near the terminus of the flume, for the purpose of impounding the tail-water of the flume and the surplus accumulating at night, as well as to store the flood-water of the San Diego River in winter to the extent of the unused capacity of the flume. The dam (see Figs. 70 and 72) was designed and constructed by J. M. Howells, C.E., who was then president of the Flume Company.

With the successful experience obtained with hydraulic dam-construction at Tyler, Texas, the previous year, Mr. Howells applied the same

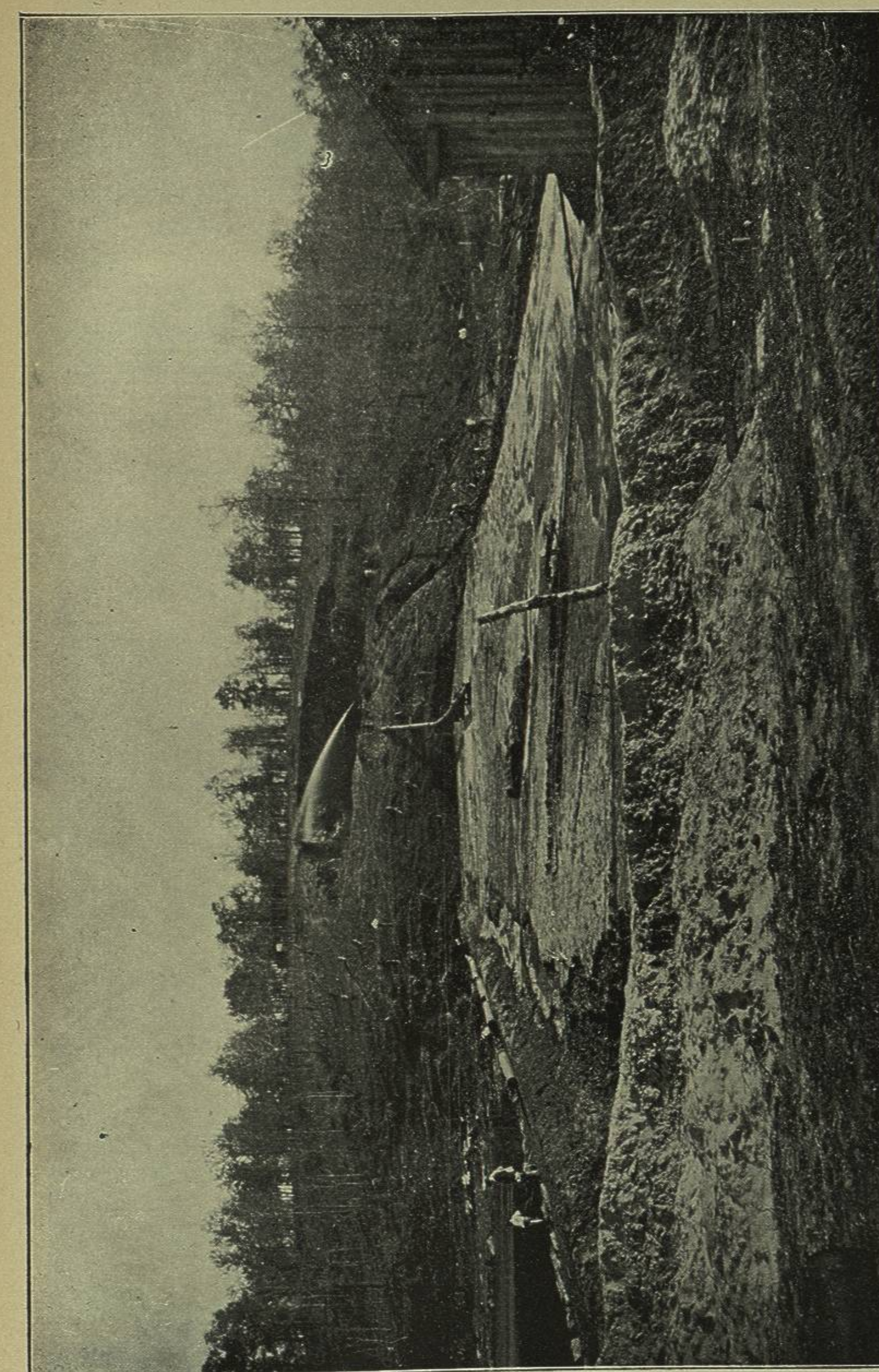

Fig. 69.—Hydraulic-fill Dam, at Tyler, Texas, in Process of Construction.
Water supplied by pump in building at right of picture.