with ½-inch square steel rods, 12 inches apart, both vertically and horizontally, was built through the dam its entire length of 1050 feet. This reinforced section of the core-wall is 24 feet high from the top down, is 8 inches thick on top, 12 inches at bottom, and rests on a concrete base wall over a portion of the length, and for the remainder on top of a line of steel-sheet piling driven to bed-rock, a total depth of 65 feet below the crest, or 12 to 19 feet below the river-bed. The maximum length of these piles is 45 feet. They were driven where the depth of excavation through the old fill to reach bedrock would have been excessive and rendered an open trench for the core-wall inadvisable. The portion of the core-wall made of rubble masonry was 7 feet thick at the base, 3 feet thick at the top, and had a maximum height of 45 feet. The position of the core-wall is at the up-stream edge of the embankment roadway.

Lake McMillan Dam.—The Upper Pecos River reservoir is called Lake McMillan, and is formed by a rock-fill dam of the same general type as the lower one. This was built in 1893 under Mr. Louis D. Blauvelt as chief engineer. The dam has a top length of 1686 feet, and a maximum height of 52 feet. The rock-fill portion was made 14 feet wide at top, and the earth-fill 6 feet at top—making the total width 20 feet as in the lower dam, the slopes being the same, viz., 1½ to 1 on lower and 3.5 to 1 on upper side. The inner face of the rock-fill against which the earth rests has a batter of 0.5 to 1, the wall being laid up 2 feet thick by hand. The dam contains 102,400 cubic yards of rock, 103,600 yards of earth, 3800 yards of dry retaining wall, and 6200 yards of riprap. Its cost complete is stated to have been $200,000. An auxiliary embankment, 5200 feet long, 10 feet wide on top, 18.8 feet maximum height, with slopes of 1.5 to 1 and 3 to 1, and containing 78,400 cubic yards, was thrown up to close a gap in the ridge near the dam, at a cost of $10,000. It was made entirely of earth, paved with stone for a portion of its height on the water-side. When visited by the writer in the fall of 1895, and again in 1897, the dam showed no signs of leakage, or settlement, or any form of weakness, although the reservoir was more than half full. The works have never been completed to store more than 50,000 acre-feet, covering an area of 5500 acres, and it will be necessary to construct an expensive spillway before a material addition can be made to the volume of storage. At present the limit of storage is 17 feet below the crest of the dam, above which the water passes off through a gap of such dimensions as to carry 200,000 second-feet before the dam could be overtopped. The plan proposed is to close this gap with an embankment and excavate a small spillway through solid limestone on the right bank, with a capacity of 10,000 second-feet. When this is done the water-level will be raised 7 feet, or 10 feet below the crest, and the

volume of storage will be approximately 89,000 acre-feet, covering 8331 acres of surface.

Outlet.—The outlet for the water is provided by means of a canal 1100 feet long, cut through solid limestone at the east end of the dam, to a maximum depth of 35 feet below the crest. This is controlled by massive wooden headgates, placed on the line of the dam, six in number, each 4 feet wide, and arranged to open to a height of 8 feet by screws. Above these openings is a solid wooden bulkhead filling the cross-section of the canal. The gates are 6 inches thick, heavily ironed. The water issuing from the gates passes back into the channel of the river and thence flows to the lower reservoir. The canal is 30 feet wide, and required the excavation of 68,000 cubic yards of rock, solid measurement, all of which was used in making the rock-fill of the dam. The canal headworks cost $20,000.

The gates have a discharging capacity of 4400 second-feet when the depth of water over the floor of the canal is but 18 feet, and considerably in excess of this amount when the maximum depth of 25 feet is reached.

This type of rock-fill dam appears to possess every element of safety so long as sufficient spillway is provided to insure them from being overtopped. It seems particularly well adapted to the conditions found in the Pecos Valley, where ledges of limestone crossing the valley appear at the surface at intervals, affording reliable foundations for dams, and material for their construction; where an abundance of suitable earth is available for backing, and where dams of but moderate height are required to impound large volumes of water. Here also the country is so open as to make the work easily accessible from all sides. These conditions do not prevail in mountain canyons as a rule, and in such localities, where construction is cramped for room, and earth is scarce and hard to obtain, some other material for water-tight facing is cheaper and preferable to earth. For the special conditions existing where they were built these dams must be regarded as the best that could have been planned.

The total cost of the two reservoirs and the canal system depending upon them was $776,000, an average of about $7 per acre for the 110,000 acres of land commanded by the canals. The same company has built an expensive cut-stone masonry dam for power purposes at the town of Eddy, or Carlsbad as it was subsequently renamed, and another system of canals near the town of Roswell, 90 miles further up the valley. The dam is ogee in section, is 320 feet long, 6 feet high, with abutments 20 feet in height, and cost $22,000. It was nearly destroyed by the flood of 1893, when the Lake Avalon dam gave way, and was subsequently rebuilt. A canal leading from it on the east side, called the Hagerman Canal, covers about 5000 acres, of which 300 acres are irrigated. The Northern Canal, near Roswell, N. M., commands 59,000 acres, of which

4000 acres were irrigated in 1897. The canal is 38 miles long and has a capacity of 300 to 120 second-feet. It is fed directly from springs that form the sources of the Hondo River.

Water-supply.—The area of watershed drained by the Pecos River above the southern boundary of New Mexico is approximately 24,400 square miles, having a maximum elevation of about 11,892 feet. After leaving the main mountain range in Northern New Mexico, where it has its source, the Pecos enters upon a tortuous course across the great plateau of eastern New Mexico and western Texas, skirting to the eastward of the foothills of various mountain groups and isolated peaks, from which the river receives numerous important tributaries, but no feeders come to it from the east or the region of the "Staked Plains," whose drainage is caught in shallow pools, or sinks into the limestone formation underlying the plains. The maximum flow of the river is in the months of May, June, July, and August as the result of summer rains, more than 75% of the entire precipitation of the year falling in these months. Of the total watershed of the Pecos in New Mexico

5% has a mean precipitation exceeding 20 inches.
50% " " " from 15 to 20 "
20% " " " " 10 to 15 "
25% " " " under 10 "

These data are taken from the maps of the U. S. Weather Bureau, published in 1891, from which the following data as to mean and maximum precipitation at various stations within the Pecos watershed are compiled:

Station.	Mean Annual Precipitation. Inches.	Maximum Annual Precipitation. Inches.	Elevation above Sea-level. Feet.
Fort Stanton, N. M.	19.05	28.70	6154
" Sumner, "	15.01	27.27	4300
Puerto de Luna, "	16.29	16.70	4500
Gallinas Springs, "	17.08	27.82	4800
Fort Union, "	19.14	28.14	6750
Las Vegas, "	22.08	.....	6418
Roswell, "	.....	15.32	3857
Eddy, "	12.60	15.55	3140

The estimated discharge of the stream past the southern boundary of New Mexico was approximately 700,000 acre-feet in 1890, 1,300,000 acre-

feet in 1891, and 1,000,000 acre-feet in 1897. In 1893 the discharge exceeded that of 1891.

The minimum flow above Lake McMillan in August, 1891, was 202 second-feet, and in August, 1897, 225 second-feet. The maximum of 1893 was estimated at 42,500 second-feet, and that of 1904 at 82,000 second-feet. The total flow of the stream is thus seen to be from 10 to 15 times the combined capacity of the two reservoirs, a fact which suggests the probability of a somewhat rapid filling of the reservoirs by silt carried in suspension, and also emphasizes the necessity of ample spillway capacity. Furthermore it indicates that as the maximum flow is during a portion of the irrigation season, the reservoirs do not require to be drawn upon except at the lower stages of the river, and hence their duty promises to be unusually great. The great surplus of unappropriated water is also suggestive of the need for additional reservoirs on the stream above, where many desirable sites are known to exist.

The Walnut Grove Rock-fill Dam, Arizona.—Of all the rock-fill dams that have ever been built or projected in the West unquestionably the slenderest and most flimsily constructed was that erected across the Hassayampa River, 30 miles south of Prescott, Arizona, in 1887–88, the destruction of which by a flood on the night of February 22, 1890, was accompanied by the loss of 129 lives. This disastrous result was predicted when it was building by those familiar with its construction, as an event that was likely to occur, and the frightful consequences that ensued illustrate and emphasize the necessity and importance of governmental supervision of the plans and details of construction of all structures of that class, either by the State or Federal authorities. It should never have been permitted to be built of the dimensions given to it, and the manner of its building was a conspicuous display of criminal neglect of all requisite precautions to secure the safety of any dam, and particularly one of the rock-fill type.

The dam was 110 feet high, 10 feet thick at top, 138 feet thick at base, about 150 feet long at the bed of the stream, and 400 feet long on top. These dimensions would not have been excessive for an overfall dam of solid masonry laid up in Portland cement, but for a rock-fill the slopes were so much steeper than the natural angle of repose of loose rock (20 horizontal to 47 vertical on the upper side, and 70 horizontal to 108 vertical on the lower side) that it was really in danger of settling or sliding down to flatter slopes without the assistance of water-pressure against it. That it did not do so was solely due to the fact that the faces of the embankment were laid up as dry walls, each having a thickness of 14 feet at base and 4 feet at top, the center being a loose pile of random stone dumped in from a trestle. If these facing-walls had been carefully laid with large stones, on level beds, and an adequate spillway provided to carry the waste water around the dam and prevent it passing over the top, and if proper foundations had been laid for the entire structure, it might have been standing to-day. In a paper read before the Technical Society of the Pacific Coast, on October 5, 1888, eighteen months before the dam failed, Luther Wagoner, C.E., who was employed on the construction of the dam part of the time, called attention to "some very bad work" on the outer

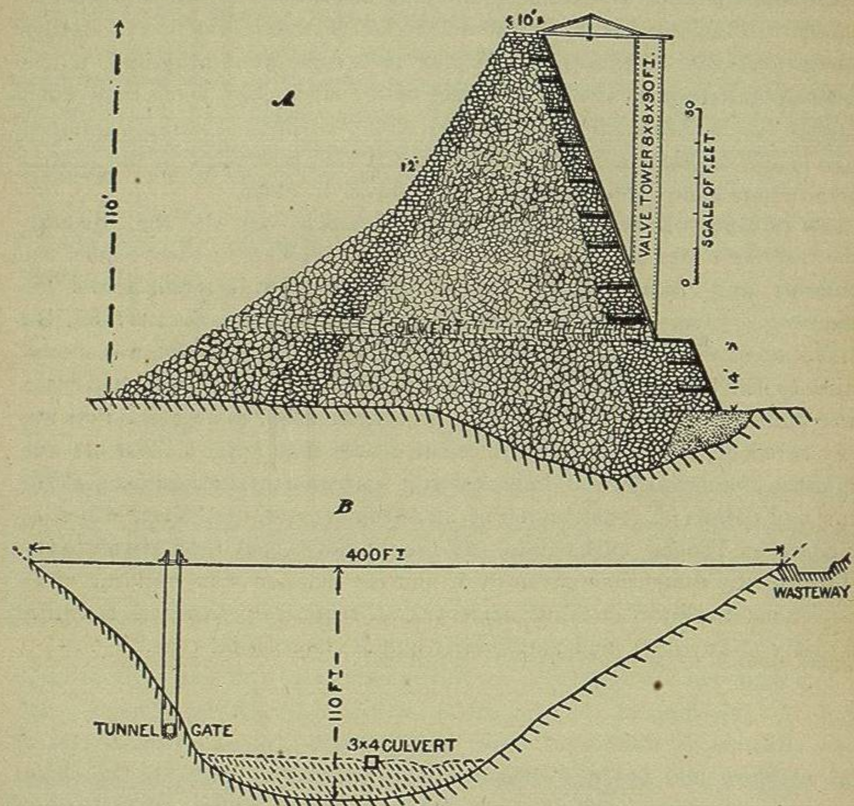

FIG. 40.—CROSS-SECTION AND ELEVATION OF WALNUT GROVE DAM, ARIZONA.

wall near the mid-height, and states that he "advised the company to cut a large wasteway and put the loose rock below the dam to strengthen this weak place." The following is extracted from Mr. Wagoner's paper: "The history of the construction of the dam is one full of blunders, mainly caused by the officers of the company in New York. Work was commenced on company account by Prof. W. P. Blake, who carried a wall across the

canyon to bed-rock through about 20 feet of sand and gravel. He was succeeded by Col. E. N. Robinson as chief engineer, and the work was contracted for by Nagle & Leonard of San Francisco. Under Col. Robinson the dam was commenced in the rear of the Blake wall, and was described in the specifications as being composed of front and back walls 14 feet at the base and 4 feet at the top, with loose rock-filling between, the dam to be made water-tight by a wooden skin or sheathing.

"Quarries were opened by the contractors upon both banks of the stream above the top of dam. 'Coyote' holes from 8 to 15 feet deep were charged with low-grade powder (4% nitro-glycerine), and the stone dislodged in large amounts. The stone was loaded up in cars, having the bed inclined at about 15°, and these were lowered onto the dam by a bull-wheel and

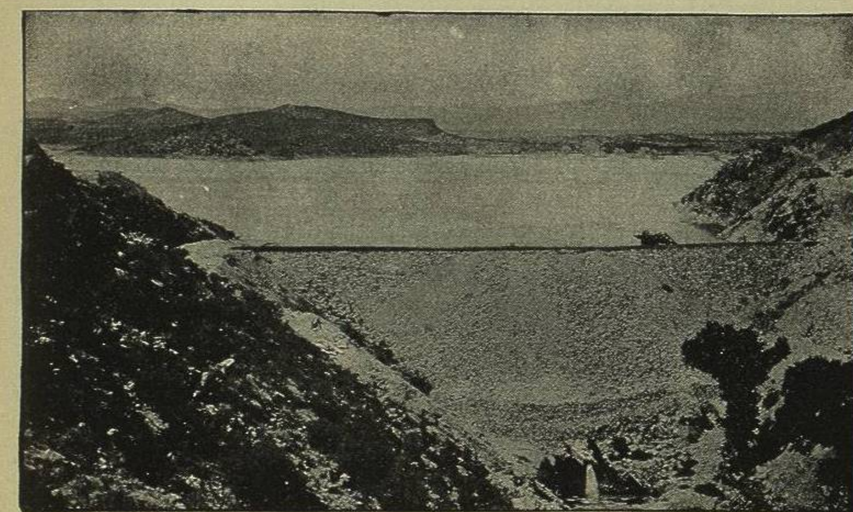

FIG. 41.—VIEW OF WALNUT GROVE DAM, ARIZONA.

brake, a three-rail railroad being laid on trestle across the dam, at a height of from 10 to 15 feet. On the slope midway was a turnout so as to allow the loaded car to pass the empty one. The loaded car was unhooked on the level and run out and dumped and returned above by the next loaded car. The legs of the trestle were left in the wall, only the caps and stringers being raised. During the first stages of construction derricks were used to distribute the larger stones; later the center was kept high and the stones from the wall were moved by bars. The effect of this upon the stability of the dam is bad, because it tends to form curved beds whose slope makes an acute angle with the direction of the resultant pressure.

"The company purchased a sawmill and cut the lumber for the dams, buildings, etc., and the skin was put on by contract. Cedar logs, 8 to 10 inches in diameter, 6 feet long, were built into the wall on the upper face, and projected out one foot. Vertical stringers, 6″ × 8″, of native pine, were bolted to the logs; the stringers were about 4 feet apart. At each joint of the stringers a cedar log was built into the wall about 2 inches above the joint, and two 4″ × 10″ spliced pieces, bolted through the log and spiked to the 6″ × 10″ pieces with galvanized-iron boat-spikes, completed the joint. Upon the main wall of the dam a double planking of 3-inch boards was laid horizontally, having a tarred paper put on with tacks between the planks. The outer row of planks was calked with oakum and painted with a heavy coat of paraffine paint,—refined asphaltum or maltha, dissolved in carbon bisulphide. The junction of the plank-skin and the bed-rock was secured by a Portland cement. Through the dam is a wooden culvert, 3 × 4 feet inside, about the level of the old creek channel; this is boarded with 3-inch plank inside and has a gate to draw off the water and waste it.

"The contract for the dam proper was for 46,000 cubic yards, lumped at $2.40 per cubic yard. The skin and cementing was extra. Lumber cost about $15 per M at the dam.

"With 70 feet of water above bed-rock the dam leaked 3.75 cubic feet per second. Various theories were advanced for the cause of the leak; one was that settlement of the dam had forced an opening of the junction of the inclined and horizontal skins; and another was that it leaked over the whole surface. The extreme right-hand skin below the bed of the stream is made of but one layer of plank. The machinery for draining the water was inadequate, and the men who did the cementing assured me that they worked in 4 feet of water, and that they did not go to the bed-rock. The probable cause of leakage, I believe, is due to all three of the reasons named."

The outlet provided for the reservoir was a culvert made partly in tunnels through a spur on the left bank, and partly as an arched masonry conduit, in which were laid two 20-inch iron pipes with gate-valves at the lower end below the dam. These pipes terminated above the dam in a square wooden tower 90 feet high built of 8″ × 8″ timbers, 8 feet long, notched one-half at each end, secured by a ⅝-inch rod through each corner, the joints calked with oakum, and the outside painted with paraffine paint. Two wooden valves were placed to admit water into this tower, one at the bottom and the other 20 feet higher. They were arranged to slide on wood, on the outside of the tower, with wooden valve-stems, 6 inches square, running up the outside to the top, where the operating device consisted of two pinions, a spur-wheel, and a rack. The openings were each about 15 square feet in area, against which the pressure with full reservoir

amounted to a resistance or load of nearly 40,000 lbs. (estimating the coefficient of friction of wood on wood at 0.40), while the lifting-device gave a maximum power of less than 1000 lbs. These were put in regardless of the protest of Mr. Wagoner, for the reason assigned that "they were designed by an engineer and must work."

This defect in outlet, however, in no way affected the stability of the dam, and even had it been possible to raise the gates at the approach of the flood, the relief which they would have afforded could not have averted the disaster, as the maximum capacity of the pipe was less than 200 second-feet, while the flood must have been several thousand second-feet for a considerable period.

Spillway.—The wasteway as built was 26 feet wide and 7 feet in depth, constructed at the right bank adjacent to the dam, the spill falling near or against its toe. Its maximum capacity when full was 1700 second-feet. As recommended by Mr. Wagoner, the material taken from this spillway was placed against the lower side of the dam, as a loose dump, increasing its bottom thickness to about 185 feet, and reaching nearly half-way up.

Mr. H. M. Wilson, hydrographer, U. S. Geological Survey, in an able review of the construction of this dam published in 1893,* says: "Mr. Robinson designed a wasteway 55 feet wide and 12 feet deep, cut through a ridge one-half mile north of the dam and spilling into a separate watercourse, which would in all probability have carried off the great flood of 1890. For some unaccountable reason a much smaller wasteway was ultimately constructed."

It is stated that the spillway was being enlarged at the very time of the destruction of the dam. Mr. Wilson further says: "One of the much-discussed points in connection with the construction of this dam was its foundation; it was intended that it should be founded on bed-rock. Witnesses before the courts, men who had taken part in its construction, claimed that the foundation did not reach bed-rock on the up-stream face. The body of the loose rock rested on the gravel bed of the river. The lower wall rested on bed-rock, but a portion of the upper wall rested only on river gravel. This fact was discovered during construction of the dam. An excavation was made under the dam and a masonry wall, 14 feet deep and about 14 feet wide, was laid, presumably to bed-rock, with another portion of this wall turning inward to the east on bed-rock. It was claimed, however, that this wall did not come within 5 feet of bed-rock, so that in fact, even after the alterations, the dam still rested on the gravel. The main up-stream wall of the dam rested for only 2½ feet on this secondary base which was built under it, the remainder of the thickness of

* "American Irrigation Engineering," page 298.

the wall resting on the buttress which inclined inward to bed-rock. The correctness of this view of the construction of the dam is indicated by the fact that considerable water passed under or through the dam in spite of its plank sheathing."

One year prior to the bursting of the dam, Prof. W. P. Blake prepared a paper describing it which was published in the Transactions of the American Institute of Mining Engineers, New York, in February, 1889, from which the following extract is taken:

"The reservoir was filled by the first floods and the water rose rapidly to and beyond the 80-foot contour-line. As to the effect upon the stream below there has been an agreeable surprise either from a partial opening of one of the gates or a leak. There has been a constant flow of water from the dam, and this has kept a constant stream through the valley, giving more water than usual along its course, so that instead of the owners of water-privileges denouncing the dam and asking for injunctions, they are hoping the dam will always leak to their advantage. *These results are of great value as to the demonstration of what the functions of such dams and reservoirs may be throughout the arid regions of the West;* even if not perfectly tight, they would be of immense value in catching the temporary floods and in equalizing the flow of such intermittent streams as the Hassayampa and many others."

It is remarkable that the designer of this dam should have looked upon the really enormous leakage developed in it in a spirit of exultation, as an achievement worthy of note, rather than as a source of alarm and danger. To write of such leakage as one of the results "of great value" requires unusual confidence in the stability of one's work.

None of the published descriptions of the construction of the dam have stated what disposition was made of the culvert under the center of the dam at the stream-bed, after construction was finished, or whether it was walled up or merely closed by a wooden gate.

The elevation of the dam-site is about 3000 feet above sea-level, while the drainage-basin of 311 square miles reaches to maximum altitudes of 8000 feet. The mean precipitation of the shed is estimated at 16 inches. The capacity of the reservoir to the spillway-level, 83 feet above the outlet tunnel, was about 10,000 acre-feet.

The water was intended to be used for placer-mining and irrigation. A diverting-dam, located some 20 miles down the canyon, was in process of construction at the time of the final catastrophe, under the supervision of Major Alex. O. Brodie (late Major of First Regiment U. S. Volunteer Cavalry, subsequently Governor of Arizona after distinguished services in the Spanish war), who barely escaped with his life.

East Canyon Creek Dam, Utah.—A modification of the Otay steel-core rock-fill dam was completed April 1, 1899, on East Canyon Creek, Utah, forming a reservoir of 8900 acre-feet capacity, to be used for irrigation, supplementary to the supply of the Davis and Weber Counties Canal Company.

The dam was originally built 68 feet high above the creek-bed, where the width of the canyon is but 50 feet. The length of the dam on top was 100 feet at that height.

A concrete wall, 15 feet thick, was carried down through the gravel bed of the canyon to bed-rock, a depth of 30 feet, and in the center of this wall the steel web-plates were anchored. These are $\frac{5}{16}$ inch thick for the lower 20 feet, $\frac{1}{4}$ inch for the middle 20 feet, and $\frac{3}{16}$ inch for the upper 28 feet. The rock-fill is given a slope of $\frac{2}{3}$ to 1, on upper side, and 2 to 1 on lower side, the top width being 15 feet. In construction all the rock necessary was thrown into the canyon after the concrete base was laid, by a series of heavy blasts, and the fill consists of masses that in some cases have a bulk of 100 cubic yards. The canyon walls rose to a height of more than 100 feet above the top of the dam on either side, and the material in falling packed very solidly together. After the rock-fill was thus thrown down in sufficient quantity an open cut was excavated in it down to the concrete wall, having a width of 15 feet at base, and as little slope on sides as possible. The steel core was then erected in the cut, and a wall of stone was laid up on either side, leaving a space of 4 inches each side of the plate, which was filled with asphalt concrete, consisting of 30% sand, 70% gravel, and sufficient asphalt to fill the voids, requiring 8 lbs. per cubic foot of the mass. The inner portion of the rock-fill was laid up as a substantial dry wall with headers and stretchers, reaching from the plate out to the water-face, the main rocks being placed with a derrick. Notwithstanding the care given in this construction the settlement of the wall as the water rose upon it to a height of 45 feet was so great as to draw the asphalt concrete away from the plate, an extreme distance of 5 feet at the top, bending towards the lake, and forming a curve from a point about 30 feet below the top, and finally the upper portion of the wall fell off, as indicated by the broken line in Fig. 42. The down-stream portion also settled somewhat, causing the concrete to part from the steel plates about 6 inches at the top.

This peculiar action is thought to have been caused by the adhesion of the asphalt to the stone wall, the bond being stronger with the stone than its adhesion to the steel plates. The rock used is a conglomerate with an admixture of red clay, which disintegrated when wet and produced the extreme settlement.

The dam cost $60,200 and required 23,000 cubic yards of rock; 810 cubic yards of cement concrete; 183 cubic yards of asphaltum concrete; 69,800 pounds of steel; and 50,500 feet B.M. of lumber.

The outlet to the reservoir is by means of a tunnel 200 feet long, the bottom of which is 10 feet above the original stream-bed. At the entrance to the tunnel two 30-inch riveted steel pipes $\frac{3}{8}$ inch thick are imbedded in concrete, controlled by 30-inch Ludlow valves bolted to them, operated from a platform projecting from the face of the cliff above. The valve-stems are $2\frac{1}{2}$-inch steel pipes. The main control of the outlet is by means of two other valves of the same size, placed at the bottom of a shaft, 50 feet back from the mouth of the tunnel, between two lengths of cast-iron pipe, the whole being imbedded in concrete which completely fills the tunnel. These are the working valves, the others being used only in emergency.

The spillway is at one end of the dam, and consists of a flume 6 feet deep, 27 feet wide, discharging below the toe of the dam. The available depth of the reservoir between the bottom of the spillway and the floor of the tunnel is 52 feet.

Mr. W. M. Bostaph was the engineer in charge, and Mr. Samuel Fortier was consulting engineer.

This account of the construction is an abstract of an article in *Engineering Record*, by M. S. Parker, M. Am. Soc. C. E. The writer is indebted to the *Record* for the loan of the cut illustrating the construction.

Theoretically the plan of imbedding the steel core in the center of a wall of asphalt concrete was an improvement upon that of the Otay dam, and had there been no settlement of the rock the construction would have been faultless. But in the Otay dam the steel core and the cement concrete either side of it are independent of the rock-fill, which is free to settle without pulling on the core. This is undoubtedly a superior plan, although the ultimate action of settlement when the reservoir is filled remains to be tested in the Otay dam, as up to the present writing it has never been filled. It has been feared that a rupture of the plates might be produced by the strains of unequal settlement.

During the winter of 1900–01, the dam was enlarged and increased to a maximum height of 93 feet, at a cost of $35,500, making the total cost of the work $95,700. The additional material required was 16,000 cubic yards of rock; 410 cubic yards of masonry; 370 cubic yards of concrete; 62,000 pounds of steel, and 20,000 feet B.M. of lumber. The area of the reservoir was increased to 262 acres, and its capacity increased from 3845 acre-feet to 8900 acre-feet. The dimensions at this height are: Length on top, 173 feet; width of crest, 10 feet, maximum width of base, 289 feet. The addition to the dam was made upon the down-stream side. The water-slope was extended to the new crest, but the sheet-steel core-wall was continued to the top as an exterior facing on the slope, laid at an angle of 30° from the vertical and backed by cement-concrete filling, between the plate and the dry stone wall of the dam. This filling is 1 foot thick, except at the sides of the canyon, where it is made 5 feet thick, and the plates are imbedded in a concrete block of triangular form, set in a trench 2 feet deep blasted out of the bed-rock.

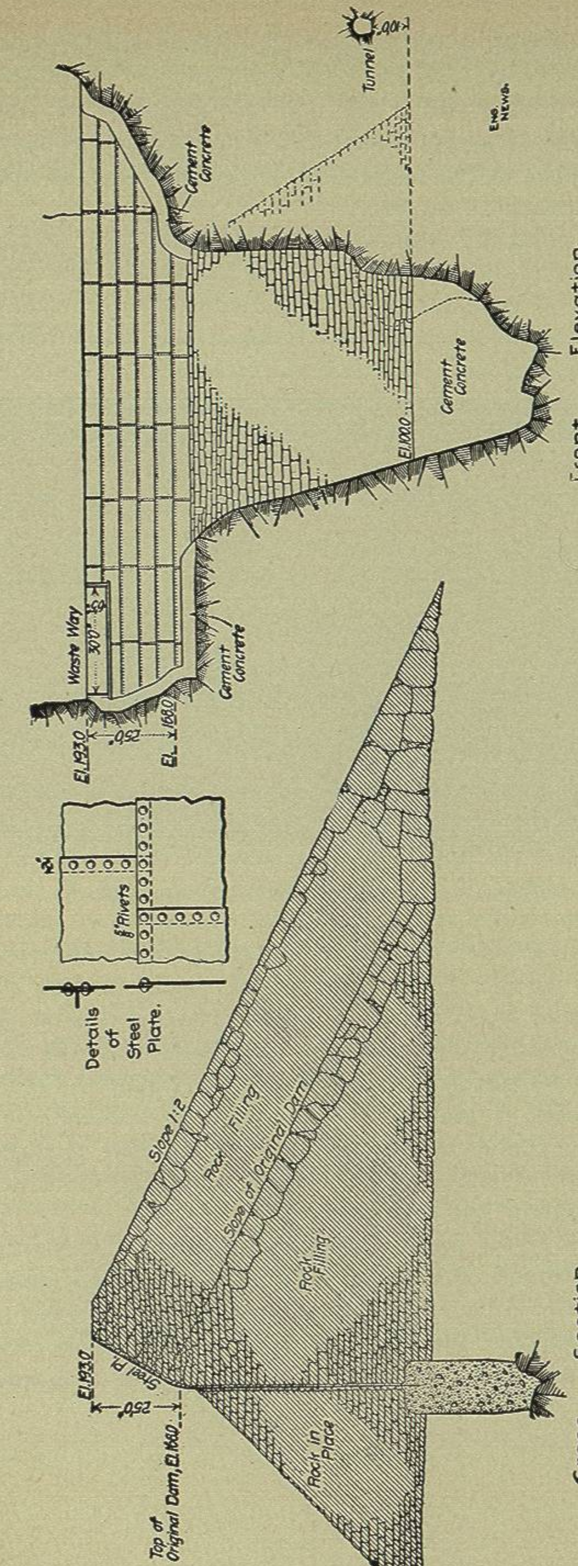

Fig. 42.—East Canyon Dam.