*Reservoirs for irrigation, water-power, and domestic ...*

James Dix Schuyler

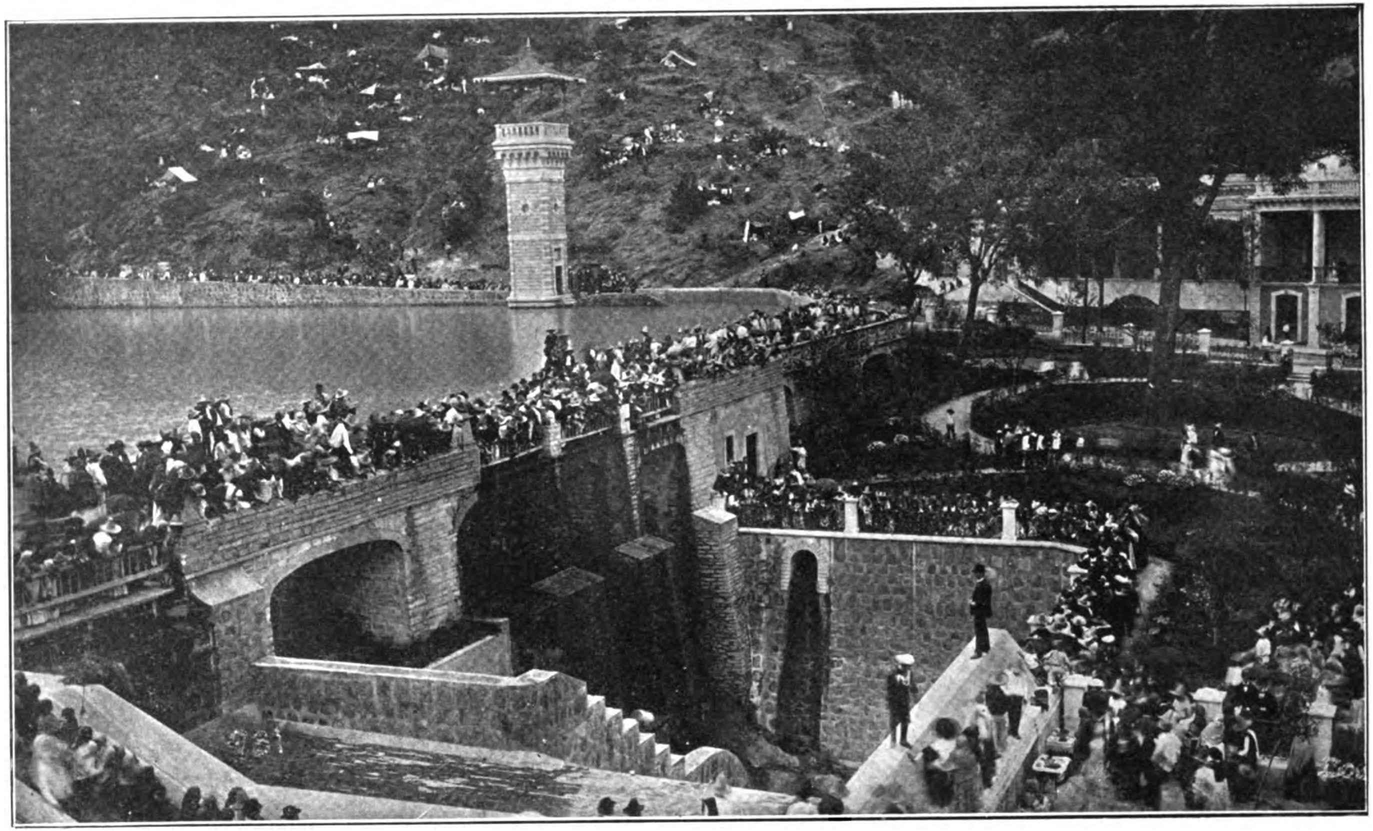

FIG. 125—LOWER DAM, OR "PRESA DE LA OLLA," GUANAJUATO, MEXICO. VIEW TAKEN DURING THE FEAST DAY WHEN THE GATES ARE RAISED AND THE RESERVOIR EMPTIED.

[*Frontispiece.*

# RESERVOIRS

## FOR IRRIGATION, WATER-POWER,

AND

## DOMESTIC WATER-SUPPLY.



WITH

AN ACCOUNT OF VARIOUS TYPES OF DAMS AND THE METHODS AND PLANS OF THEIR CONSTRUCTION.

TOGETHER WITH

***A DISCUSSION OF THE AVAILABLE WATER-SUPPLY FOR IRRIGATION IN VARIOUS SECTIONS OF ARID AMERICA; THE DISTRIBUTION, APPLICATION, AND USE OF WATER; THE RAINFALL AND RUN-OFF, THE EVAPORATION FROM RESERVOIRS; THE EFFECT OF SILT UPON RESERVOIRS, ETC.***

BY

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***FIRST EDITION.***

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# PREFACE.

In 1896 the author was requested to prepare a brief descriptive account of such of the principal dams and reservoirs as had come under his observation in the course of his professional practice in the arid region of the United States, for publication among other Water-supply and Irrigation Papers issued by the U. S. Geological Survey for the general information of the public on topics of popular interest.

In compliance with this request a paper was written somewhat hastily in the rare leisure intervals of a busy season, which was printed and circulated as a portion of the 18th Annual Report of the Geological Survey, in a more pretentious form than had been anticipated when the manuscript was prepared. The rapidity with which the edition of the paper was exhausted testified to the existence of a widespread interest in the subject of water-storage in the West, and a general demand for the facts regarding the works which have been built and those which are projected. This has encouraged the author to republish the paper in another form, revising and adding to it as the material has become available. The work does not pretend to be an exhaustive treatise on the subject of dam-construction in western America, nor does it assume to cover the field by an account of all the important dams which have been built. It is chiefly a straightforward description of those works with which the author has become familiar, either as a consulting engineer, or as designer and constructor, or merely as an interested observer of the development of the ideas of other engineers. The field is too great to be completely covered by any one work, and new projects are developing with such rapidity as to render the task of enumerating them all quite beyond the power of any one individual.

For what it may be worth in the way of information or suggestion to the fellow members of his profession, or to others interested in the storage of water, the volume is modestly presented, craving indulgence for all errors of omission or commission.

JAMES D. SCHUYLER.

OCTOBER, 1900.

# INTRODUCTION.

THE development of a water-supply for irrigation in the arid West sooner or later reaches a stage where the construction of storage-reservoirs becomes a necessity. If the stream is one of considerable volume, numerous irrigation-canals will be constructed from it at all convenient points, and its entire normal flow will be utilized before the impounding of flood-volumes is thought of as a possibility. But with the varying seasons there will occasionally come a year when the best of streams are so shrunken below the normal as to limit sharply the area which can be irrigated from it, and emphasize the regret that some means had not been provided for holding back the wealth of water which at times pours into the sea without benefit to any one, so as to render it available in the drier part of the year. Other streams there are, which drain very large districts and at certain times of the year are formidable and almost impassable rivers, that in the summer and fall are dry for months at a time. If these sources are to be rendered servicable storage-reservoirs must be built as the initial step in irrigation development.

All streams, except they be regulated by nature by means of lakes or subterranean reservoirs, are subject to great fluctuation. It is the function of artificial reservoirs to equalize in a measure these variations in flow, impounding the floods for use in the season when irrigation is necessary. Were it possible to conceive of a stream flowing throughout the year without change in volume, such a stream would not have its fullest measure of usefulness without storage of the water flowing during the period of the year when irrigation is not needed.

Inasmuch as the total available water-supply of the arid region is vastly short of the quantity needed for irrigating all the land requiring artificial watering, it is evident that, under every condition and with every class of stream, storage-reservoirs are needed to develop the fullest measure of usefulness of the existing supply.

Unfortunately it is beyond the possibility of hope that all the water flowing can be stored or utilized. There is such a wide range in the total run-off of every stream from one season to another that it would rarely be possible to find storage capaicty for the extremes of flow. On large rivers the ratio between maximum and minimum years may vary as 12 to 1, while on smaller streams the total flow one year may be one hundred times as much as that of the next year. Hence the reservoirs which might be provided to catch all the flow of average years would occasionally be overwhelmed by freshets so extraordinary as to fill them several times over. This condition has an important bearing on the design of every reservoir located in the path of floods, first, in emphasizing the necessity for providing ample spillway capacity, large enough to carry safely the greatest possible or probable flow, and, second, in fixing the proportion which the capacity of the reservoir may bear to the total annual run-off of the stream, so as to minimize the ratio of silt deposited to the total volume of water impounded. It may be accepted as true that the destiny of every reservoir is to be filled with silt sooner or later. If a reservoir were created on a stream carrying silt to the extent of 1% of its volume on an average (although few actually carry so much as 1%), and the average annual flow of the stream were, for an extreme example, fifty times as great as the capacity of the reservoir, the latter would be filled and become unserviceable in two years, assuming that the greater portion of the silt carried was deposited in the reservoir. It would evidently, therefore, be unprofitable to construct such a reservoir unless provision were made for an immediate increase in height of dam, for diverting the river around the reservoir, which is usually impracticable, or for sluicing or dredging the silt from the reservoir, a process involving great expense. If, on the other hand, the reservoir capacity was made great enough to store rather more than the usual average flow for one year, the period of usefulness of the works would be vastly increased, and the consideration of the problem of silt disposal would be left for future generations to solve.

The importance of reservoir-construction and water-storage for irrigation was not so generally recognized in the arid region prior to about the year 1885 as it has been subsequent to that time, and it is only within a comparatively recent period that capital has been extensively enlisted in such works except for the storage of water for cities and towns. With a few prominent examples of successful achievement in that line as precedents, however, the subject of water-storage has awakened wide-spread attention, and each year it appears to be attracting deeper public interest. Capital has been slow to undertake the largest and most important works of this character, because of the difficulty of realizing immediate returns upon the investment. The development of a new section upon which water is but recently introduced, the construction of distributing canals, ditches, and pipes, the cultivation of the land and the planting of orchards—in fact the conversion of a desert to a condition of profitable productiveness, is the work of time, which cannot be begun until the irrigation-works are actually completed, and when begun is slow of full development. Meantime, however, the interest account accumulates, and often is so far in excess of possible revenues as to bring discouragement, and sometimes actual bankruptcy, before a paying basis is reached. The uncertainty of the laws of the different States governing water rights in reservoirs, the difficulty of establishing fixed rates for water that will be high enough to afford an adequate revenue to the capital involved and low enough to enable the farmer to pay for the water he requires and make a living while developing his farm, and the responsibilities involved in the risk from floods, accidents, and dry seasons, have been potent in deterring capitalists from investing in the business of storing and selling water, *per se*, unless it were coupled with the ownership of the lands to be irrigated, or with the domestic supply of a growing town, or with the possibilities of generating water-power.

The recent development of electrical machinery, by which power may profitably be transmitted long distances with comparatively small loss, has indirectly benefited the irrigation development of the country by adding an incentive to the construction of storage-reservoirs for the primary and more profitable purpose of generating power. Many reservoirs are being favorably considered by capitalists for the power which they will afford that would otherwise be regarded as comparatively valueless or unprofitable investments for irrigation alone. As the great bulk of precipitation in the arid region occurs in the mountains, where it increases with some degree of uniformity with every foot of increased altitude, the mountains are coming to be regarded as indispensable to the wealth of the country, valuable not only for their precious metals, stone, and timber, but for the store of water which they are able to supply to the thirsty plains below. The mountains not only supply the water, but they usually afford the best sites for reservoirs to impound it, in ancient lake-beds, and high, cool, deep valleys, surrounded by forests; while the latter fulfil a most important function and attain a value far higher than the mere commercial one to be derived from their lumber and firewood, by serving to retard the rapid run-off of the water-supply. Forest growth is of primary importance in the preservation of the source of streams, in preventing the mountains from being washed down with destructive force to the valleys and the sea, and in creating natural reservoirs on every square mile of their surface.

That storage-reservoirs are a necessary and indispensable adjunct to irrigation development, as well as to the utilization of power, requires no argument to prove. That they will continue to become more and more necessary to our Western civilization is equally sure and certain; but the signs of the times seem to point to the inevitable necessity of governmental control in their construction, ownership, and administration. Those which private capital may undertake should only be permitted to be erected under the most rigid governmental supervision, to assure their absolute safety. Many reservoirs are needed for the development of the arid regions which are of too great a magnitude to be undertaken by private capital or organized individual effort. In every other country such works are undertaken by the national government. In general it may be said that the lands which would be benefited by such works in arid America belong to the government. To make these lands productive and capable of sustaining population, the government of the United States should undertake their reclamation and construct and administer the reservoirs. That such a policy will ere long be inaugurated seems inevitable. The purpose of this work is to familiarize the public with the details of construction and the general features of interest appertaining to the principal reservoirs constructed or projected in the Western States and Territories which have come within the knowledge or observation of the writer, describing in a popular way their characteristics, their water-supply, the results accomplished or sought to be accomplished by them, and the methods and materials employed in the construction of the dams which form them.

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## CHAPTER I.

### ROCK-FILL DAMS.

THE natural fertility of resource in the American people has led to many novel experiments in the construction of dams to adapt them to the materials most conveniently available, and this has resulted in the development of numerous interesting types. Among these the most conspicuous are the rock-fill dams, which may be said to have originated forty to fifty years ago in the mining region of California, where dams were built in remote and almost inaccessible locations, to which the transportation of cement was impracticable. These were considered to be of a temporary nature, where dams of permanent masonry were not warranted, but where a water-supply for mining purposes needed to be impounded. They began with timber or log cribs filled with loose stone. Their next stage was an embankment of loose stone a portion of which was laid up as a dry wall, with a facing of two or more thicknesses of plank to secure water-tightness. The latter type has proven so serviceable that it is still regarded as one of the most desirable classes of dam that can be built, where economy is of prime consideration. In the attempt to secure a greater degree of durability other types have been developed as follows:

1. Rock-fill dams with facing of asphalt concrete laid on a sloping dry wall.
2. Rock-fill dams with a central core of steel plates, and without hand-laid facing-walls.
3. Rock-fill dams with facing of Portland-cement concrete laid on dry wall.
4. Rock-fill dams with facing of masonry, built vertically, backed with earth, and covered on the lower side with blocks of stone laid in mortar.

5. Rock-fill dams with facing of steel plates laid on the sloping interior surface on a dry hand-laid wall.

6. Rock-fill dams with facing of earth.

Existing examples of these various types and the irrigation systems supplied by them will be considered in the following pages.

**The Escondido District Dam, California.**—Few of the irrigation districts organized in California under the well-known Wright law have been suc-

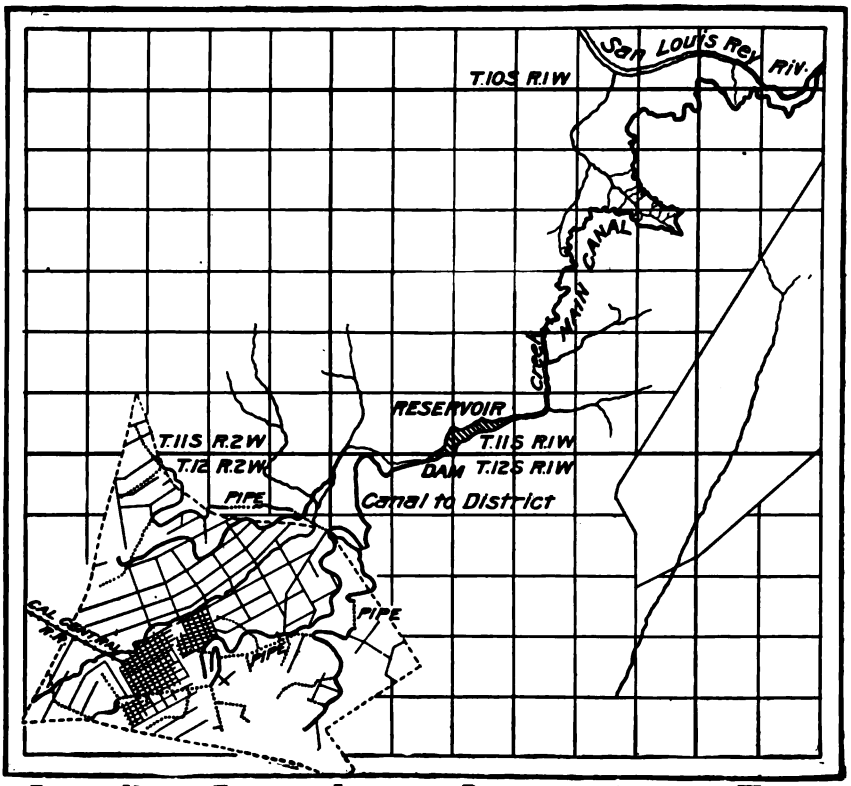


FIG. 1.—MAP OF ESCONDIDO IRRIGATION DISTRICT AND SYSTEM OF WORKS.

cessful in accomplishing the purpose of their organization, and many disastrous and lamentable failures have to be recorded in the practical operation of a law which, at one time, was looked upon as a wise and feasible measure for the general irrigation of the arid lands of the States. Among the very few that succeeded in selling bonds and constructing a storage-reservoir and distributory system is the Escondido district in the northern portion of San Diego County. The district (Fig. 1) is in a valley whose description is implied by its Spanish name, Escondido—hidden. It is surrounded by mountains and embraces 13,000 acres. The storage-dam supplying the district is located on the Von Segern branch of San Elijo

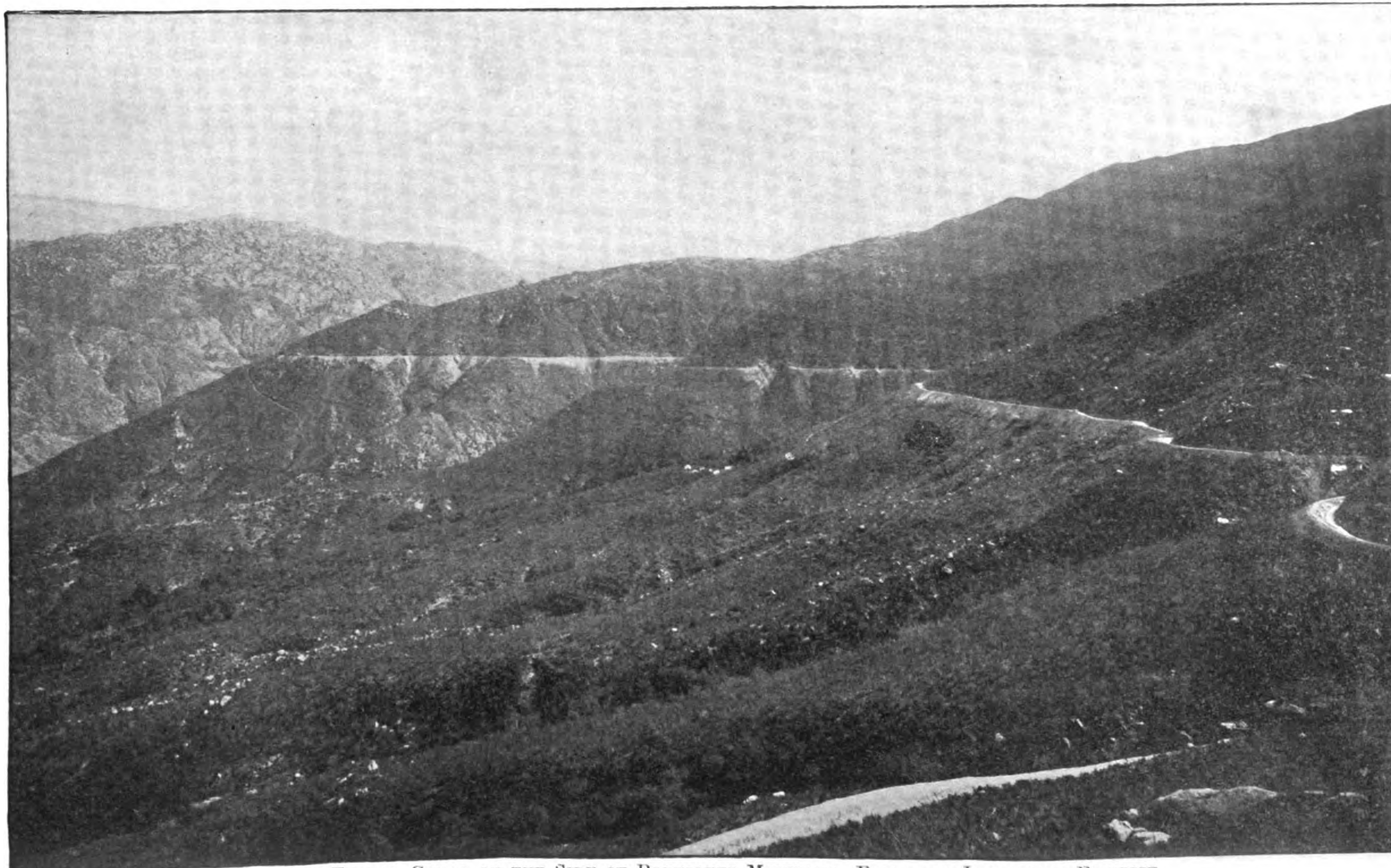

FIG. 2.—FEEDER CANAL ON THE SIDE OF RODRIGUEZ MOUNTAIN, ESCONDIDO IRRIGATION DISTRICT.

Creek, which passes through the town of Escondido. It is about two miles east of the district at its nearest point, and at an elevation of 1300 feet above sea-level, or about 650 feet above the town.

The immediate watershed tributary to the reservoir measures about 8 square miles, which in that region affords insufficient run-off to fill the reservoir, although adding materially to it at times of heavy rainfall. Hence the main supply had to be brought to it from the San Luis Rey River, the nearest stream to the north, by a conduit which taps the river at an altitude of 1600 feet, in a wild, rocky canyon, which is almost inaccessible by reason of its roughness. The conduit has a capacity of 28 second-feet, and is 5.6 miles long, consisting of 67,287 feet of ditch built along the rugged mountain-side (see Fig. 2), 14,142 feet of flume, and 806 feet of tunnel. The intake is made by a tunnel 356 feet long, heading in the river 3 feet below low-water level, while at the other end the rim of the reservoir-basin is pierced by a second tunnel 450 feet long. This tunnel discharges into a ravine leading down to the dam, 3½ miles below. The intake tunnel is cut through solid granite, which is excavated below grade at its lower end to form a settling-basin, in which sand accumulates at the rate of about 1000 cubic feet daily. This is sluiced back into the river by the opening of a side outlet-gate. By this means the water of the conduit is kept comparatively clear and but little sediment has accumulated in the reservoir.

The upper 8000 feet of the conduit consists of a flume (Fig. 3), supported on posts on the sides of a rugged canyon, which in places presents a vertical face of considerable height. The lumber of this flume was hauled by a roundabout road to a bluff on the opposite side and 600 feet above the river-bed, whence it was transported by a wire cable with a span of 1500 feet by means of a trolley manipulated by hand windlass and rope. At other points the lumber was hoisted to the line by horse-power, by means of a car and portable track several hundred feet in height. The flumes are mainly 4 feet wide by 3 feet deep, and the ditch is excavated with a bottom width of 5 feet and side slopes of 1 on 1, the minimum excavation on the lower side being about 3 feet. The formation throughout that region is granitic, partially decomposed, the disintegration of the rock forming a few feet of soil, from which protrude large bowlders of very hard granite embedded in softer rock *in situ.*

The total cost of the conduit was $116,328.60, or $1.29 per foot for construction and engineering, and 12 cents per foot for right of way, commissions, etc. The conduit is capable of filling the reservoir to its present capacity in a little over sixty days when running to its full capacity. Should the dam be completed to the height of 110 feet as it has been projected, the conduit would require to run full for rather more than six months to fill the enlarged reservoir.

In seasons when the precipitation exceeds 20 inches the run-off from the immediate watershed above the dam is alone expected to fill the reservoir as at present constructed. For the preservation of the main conduit, of which nearly 20% is wooden flume which should be kept wet for proper maintenance, it would be desirable to maintain a flow of water through it the entire season. For this purpose the construction of an auxiliary reser-

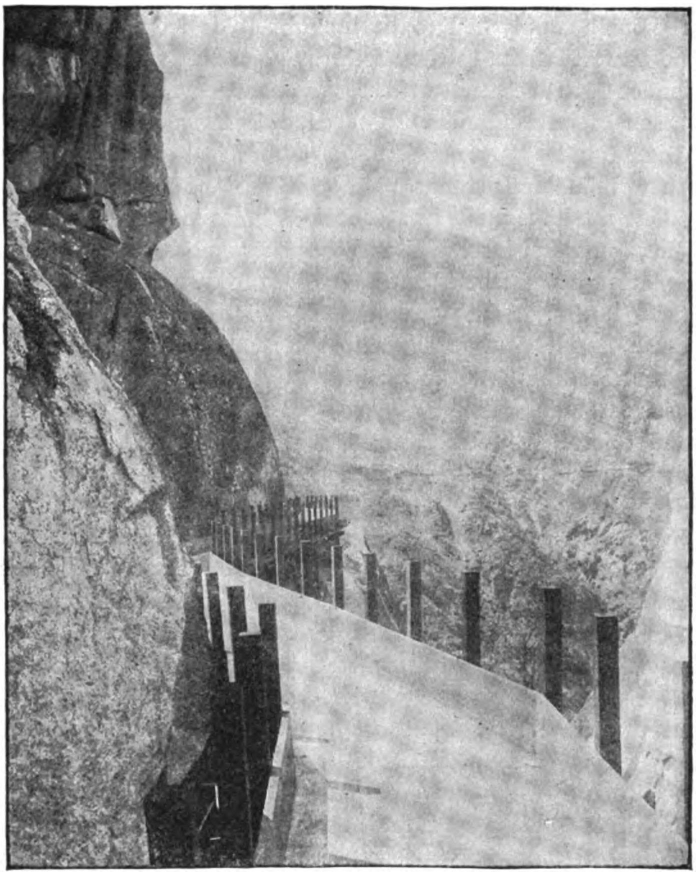

FIG. 3.—FEEDER CONDUIT OF ESCONDIDO IRRIGATION DISTRICT.

voir at the head of the conduit is regarded as one of the most desirable of the projected improvements to the system. A very capacious reservoir-site exists at Warner's Ranch, 15 miles above the head of the canal, where the drainage of 210 square miles of watershed may be impounded. A much greater volume of water can here be stored than would be needed by the district. In fact the capacity of a reservoir with a dam 100 feet high at this point would be 193,200 acre-feet, covering 5535 acres, which is far beyond the probable yield of the watershed in years of maximum rainfall.

A cross-section of the dam-site is shown in Fig. 6 , where the width of the site at 100 feet is seen to be but 590 feet. A more modest dam of earth, 36 feet high, to hold 30 feet depth of water and to impound 6400 acre-feet in a reservoir covering 740 acres, would serve all the requirements of the

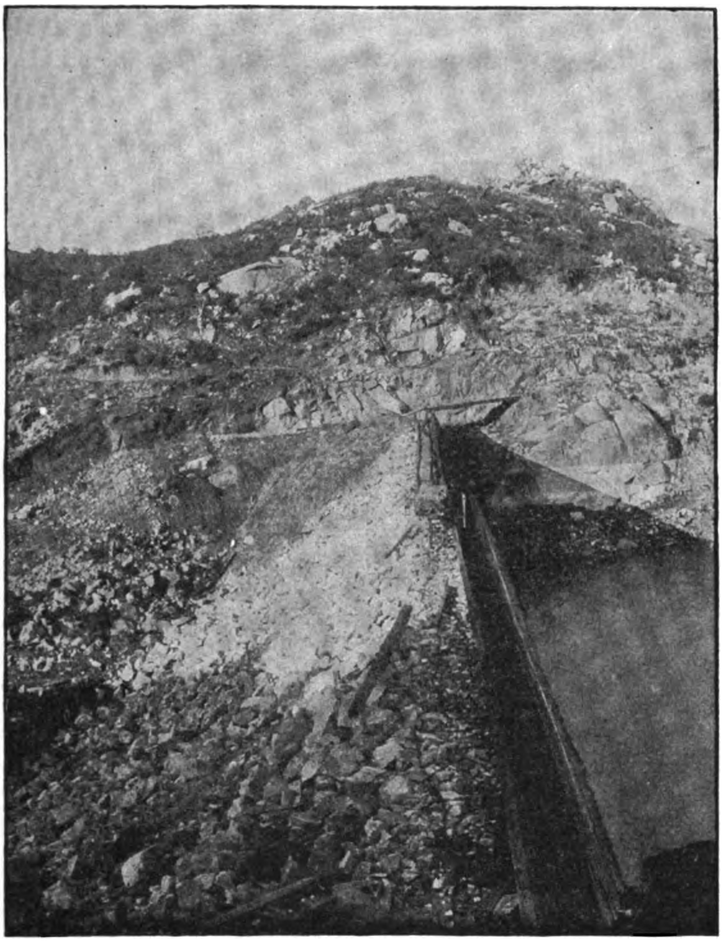

FIG. 4.—ESCONDIDO IRRIGATION DAM, LOOKING NORTH, SHOWING SPILLWAY.

district and at moderate cost, provided the land is obtained at reasonable rates.

The Escondido dam is of the ordinary type of rock-fill, with facing of redwood plank. In this respect it resembles the mining dams of northern California, although the use of redwood has given the facing a longer life than the more perishable pine used in the North. This structure appears to have been built with unusual care, and though ragged and unfinished in appearance, it is of ample dimensions for the pressures it withstands and is reasonably water-tight. It is 76 feet high, 380 feet long on top, 100 feet on bottom, with a base of 140 feet, and a thickness at the crest of 10 feet. A spillway has been excavated at the north end on the right bank of the reservoir, in solid rock, 25 feet wide, its bottom being at the 71-foot contour, or 5 feet below the crest of the dam. This is left open and unobstructed, although it has been customary near the end of the rainy season to build a barrier of sand-bags across it in order to impound a greater depth of water, after the danger of floods is presumed to be over.

The slopes of the dam are ½ to 1 on the water-face, and on the back 1 to 1 for half the height, flattening to 1¼ to 1 from mid-height to base. The cubical contents are 37,159 cubic yards, of which 6000 yards were hand-laid in courses of dry rubble on the face, the thickness of the wall being 15 feet at bottom, and 5 feet at top. The remainder consists of loose, angular blocks of granite, of all sizes up to 4 tons weight (Fig. 5), which were loosely dumped from cars and placed to some extent with derricks. No small quarry-spawls or earth were used, and the result is a clean rock-fill, which has not settled more than three inches since its final completion. No large ledges affording well-defined quarries of any considerable extent were uncovered in the course of construction, but all the material was taken from scattered bowlders and rock-masses protruding on either side of the canyon above and below the dam for a distance of 800 feet. Temporary tramways were built at different levels on either side, as the dam rose in height, so arranged as to permit the cars to run to the dam by gravity, the empty cars being hauled back by horses. These tracks were carried across the dam on elevated trestles, the posts of which remain buried in the embankment. This arrangement involved the pushing of the cars across the trestle by hand, which was a slow and expensive process. The entire method of work was costly and inconvenient compared with the modern systems of cableway transportation of such materials.

In stripping the foundations bed-rock was found about 4 feet below the bed of the creek, nearly level across the canyon from side to side. The top soil was removed over the entire base of the dam and the filling of rock placed directly upon the granite foundation. The bed-rock was of the formation described as prevailing along the main conduit, which is a common characteristic of southern California, and consists of disintegrated granite holding hard bowlders indiscriminately through it. The formation is not impervious to water, and for that reason is not considered a desirable or satisfactory foundation for a heavy masonry dam because of the resultant upward pressure on the base due to that condition, but for a rock-fill structure of this class it is unobjectionable. Into this bed-rock a trench was excavated at the upper toe of the dam, from 3 to 12 feet deep, which was refilled with rubble masonry 5 feet thick, laid in Portland-cement mortar. Into this masonry was embedded the plank facing, which was thus

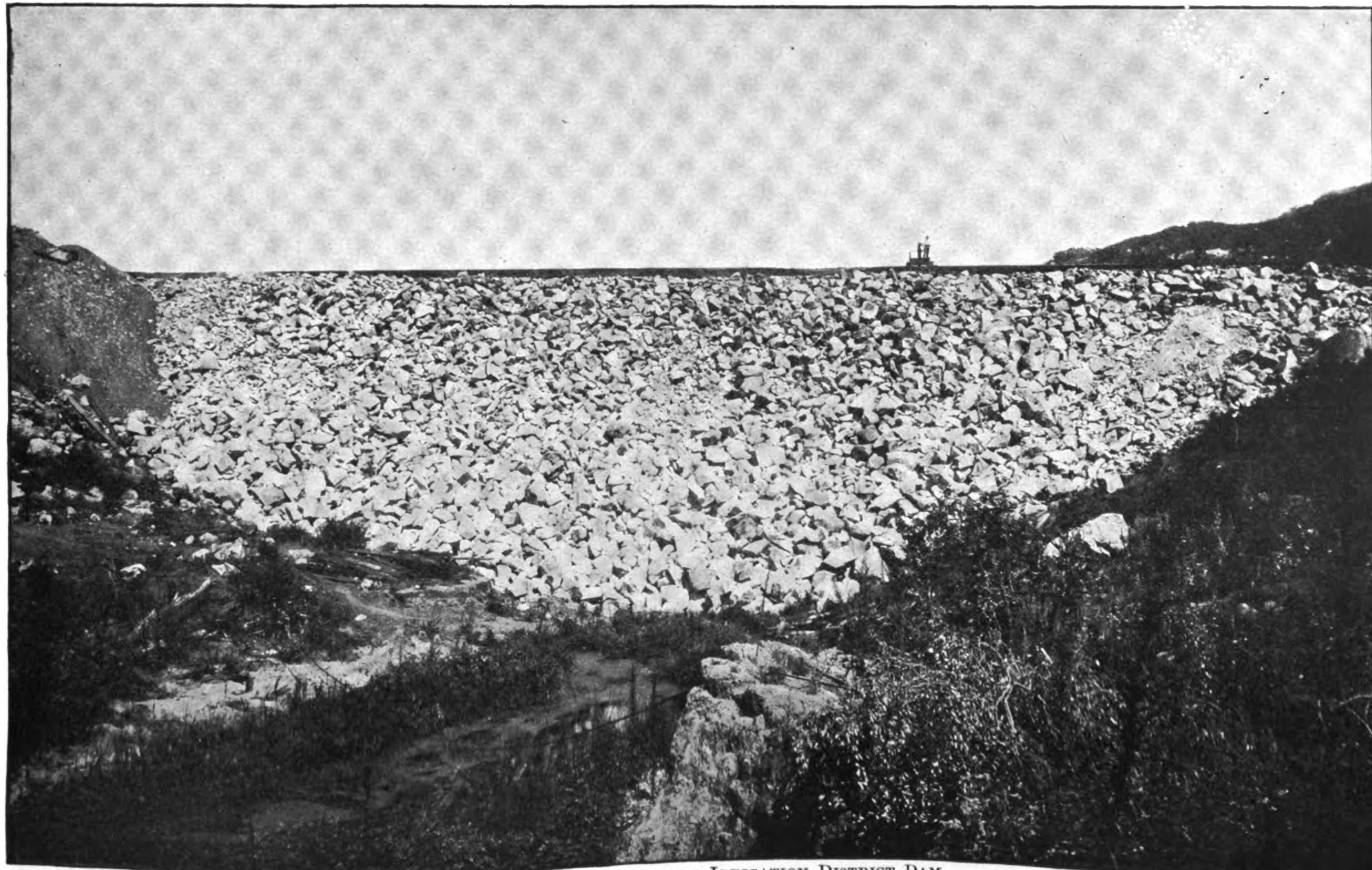

FIG. 5.—BACK OF ESCONDIDO IRRIGATION DISTRICT DAM.

connected all around the toe with the canyon walls and bed. The dry wall forming the upper face of the dam was so laid as to embed in its surface a series of redwood timbers, 6″ × 6″ in size, placed in vertical parallel lines, 5 feet 4 inches apart between centers. These timbers projected 2 inches beyond the face of the wall, and the planks were spiked to them. As each row of plank was put in position, beginning at the bottom, concrete was rammed into the 2-inch space between the plank and the face of the wall, giving a full bearing for the plank throughout. This provision was certainly a wise one, and so far as the writer is informed was never employed before in the dams of this class previously constructed. On the lower third of the dam the facing plank are 3 inches thick, on the middle third 2 inches, and on the upper third 1½ inches, all being doubled throughout. Joints were broken as far as possible, both at the vertical and the horizontal seams, by the second layer, and they were calked with oakum and smeared with hot asphaltum.

Springs of water were developed in the excavation of the foundation to the extent of 30,000 to 40,000 gallons per day, constant flow. These were led out by pipes to the outer toe. The leakage through the dam when filled to the 47-foot level was found to be 130,000 gallons daily, exclusive of the springs. This increased to 450,000 gallons daily when the reservoir filled to the top. It is not known whether this leakage comes through the joints of the facing or percolates through the disintegrated granite beneath the dam. Whatever may be its origin, it is entirely harmless as far as can be observed, and is not a source of anxiety. In the winter months when irrigation is not required this leakage-water is used for domestic service, and the whole of it is at all times picked up by the diverting-dam and carried into the distributing system. Hence it occasions no direct loss of water. While this amount of leakage would be dangerous to an earth dam, and even in a masonry structure would indicate the existence of an upward pressure that might endanger its stability if the section were too light, yet in a work of this nature the drainage through the open, loose rock is so perfect that the gravity of the mass is not lessened or disturbed by it, and no serious consequence can be anticipated.

The facing-planks have been carried up 3 feet higher than the top of the rock-fill as a wave protection, so that the extreme crest is 9 feet above the floor of the spillway as shown by the section illustrated in Fig. 6.

The outlet was originally designed to be controlled by means of a tower, the foundations of which were laid at the upper toe of the dam near the south end, but the plan was changed and a grating placed over the base of the unfinished tower a few feet above the gate covering the outlet. The gate is of cast iron with brass facings, set in a frame, also faced with brass, and bolted to the cast-iron outlet. It is set at the incline of the upper slope and is controlled by a long rod resting in guides at frequent intervals,

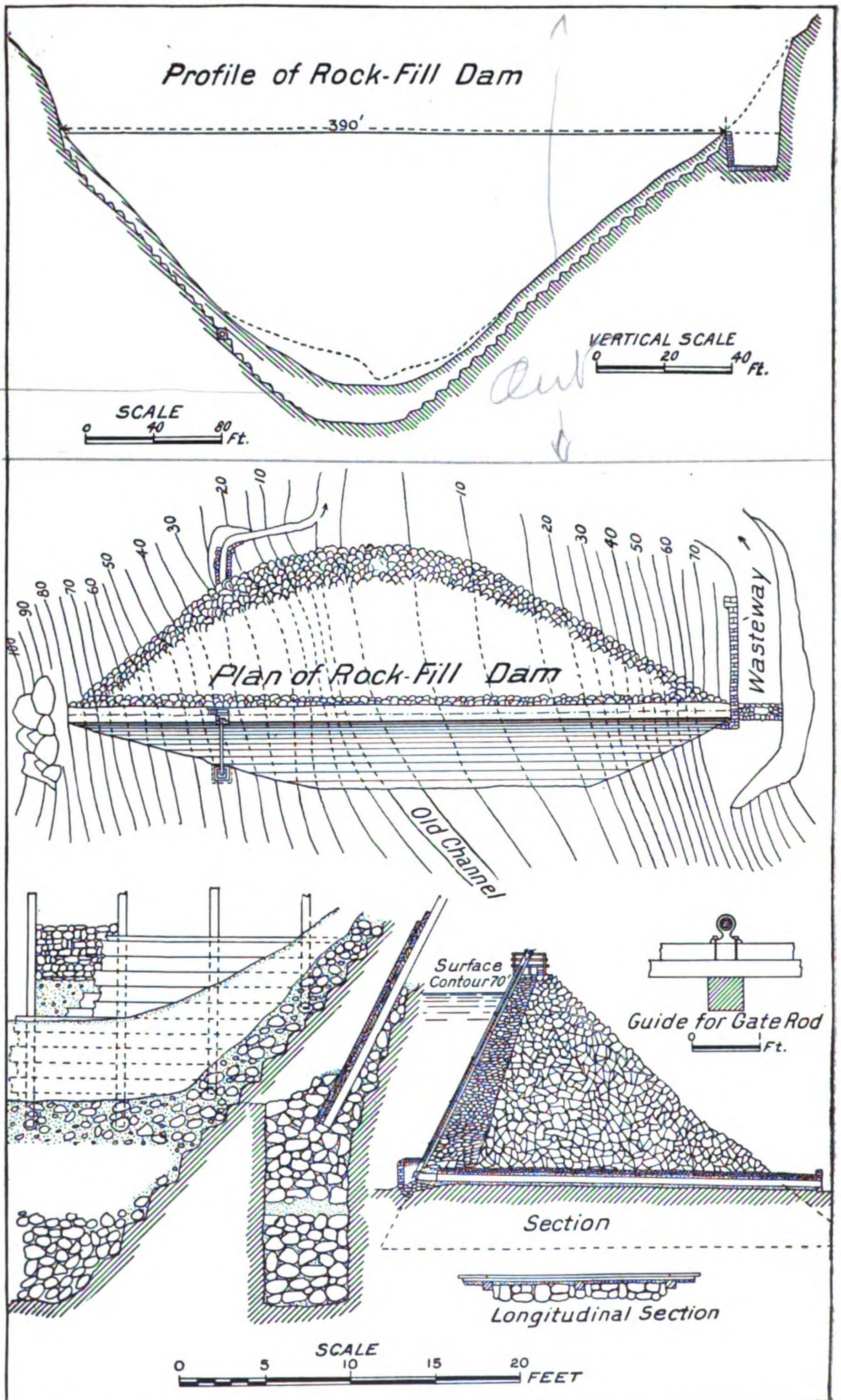




FIG. 6.—PLANS AND PROFILES OF ESCONDIDO DAM.

fastened to the wooden facing, and leading to a worm-gear placed at a convenient height above the top of the dam (Fig. 7). The outlet-pipe is 24 inches in diameter, consisting of a cast-iron elbow connecting with vitrified

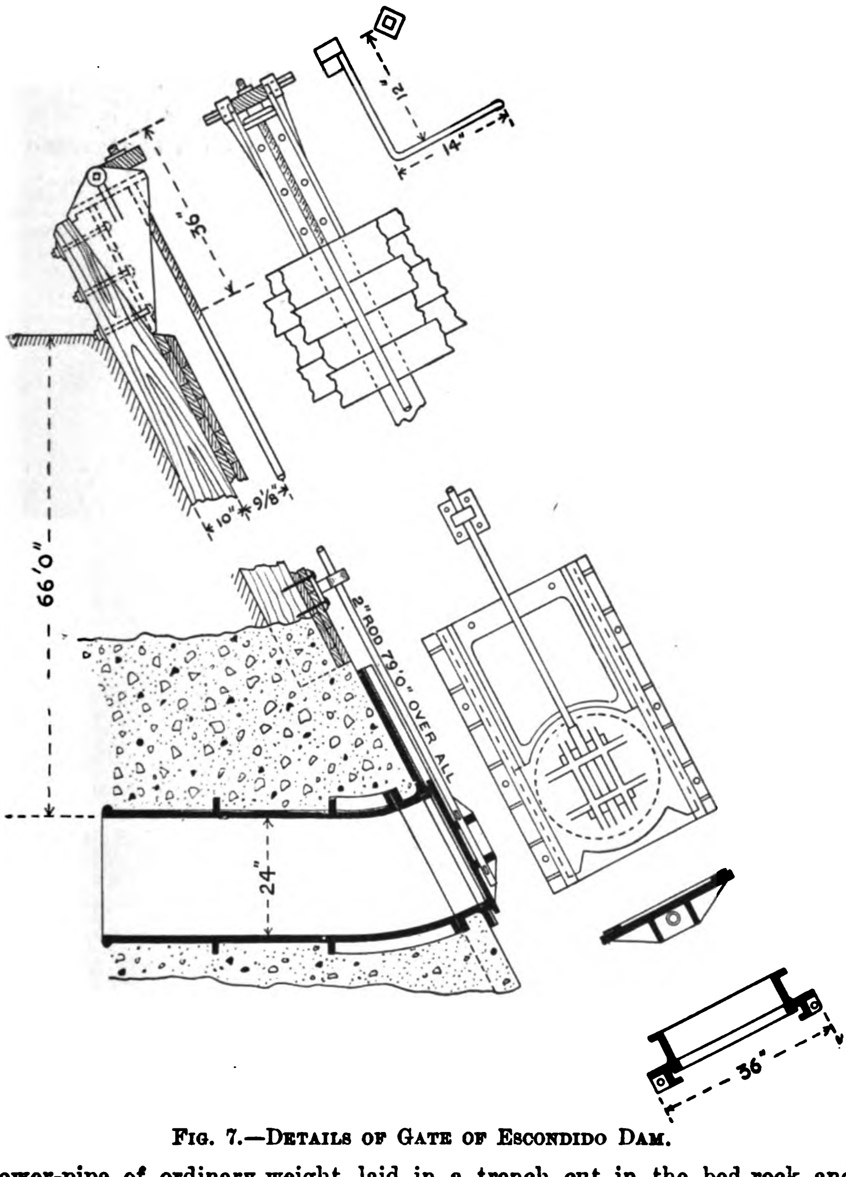


FIG. 7.—DETAILS OF GATE OF ESCONDIDO DAM.

sewer-pipe of ordinary weight, laid in a trench cut in the bed-rock and embedded in concrete, which covers it fully 12 inches in depth.

The total cost of the dam under the contract was $86,946.21, or $27.82 per acre-foot of reservoir capacity below the spillway level. The land for this conduit have capacities of from 1 to 10 second-feet. When completed in 1895 the distributing system consisted of 14.5 miles of riveted steel pipes, 3 to 20 inches in diameter, 2 miles of flumes, 1.5 miles of vitrified clay and cement pipes, and 13.5 miles of open ditches in earth—a total of 31.5 miles. During 1897, '98, and '99 about 11 miles of the open ditches in earth have been lined with cement to prevent loss of water by leakage; 4¼ miles of vitrified pipe from 5 to 14 inches in diameter have been laid, also 1.15 miles of 4- and 6-inch cement pipe, 0.87 mile of 2-, 3-, and 4-inch iron pipes, and 0.16 mile of 8-inch wood pipe. In addition to this are 15 miles of 2- and 4-inch pipes that formed the domestic-supply system of the town of Escondido, which is a part of the irrigation district, and is provided with domestic water by the district in the same proportion as a similar area of farming lands. This town-distributing system was in private ownership prior to the organization of the district, and was supplied by wells and pumps. It was purchased by the district for $9000 in bonds, and there was included in the purchase a lined and covered reservoir of 800,000 gallons capacity, a Worthington steam-pump of 500,000 gallons daily capacity, three 20-foot brick-lined wells, 20 feet deep, and twenty 2-inch driven wells, all connected by suction-pipes to the main pump. This auxiliary pumping supply, though small in amount, is very convenient to draw upon for domestic service in the late summer and fall when the water in the reservoir becomes foul and unfit for domestic use. The entire first cost of the distributing system was $85,727.80.

The works of the district summarize in cost as follows:

| | |
|---|---|
| Main feeder conduit | $116,328.60 |
| Dam and reservoir | 110,059.09 |
| Distribution system | 85,727.80 |
| Total | $312,115.49 |

The first issue of bonds by the district, out of the total amount of $350,000 authorized, was $344,500, which realized in cash or its equivalent $313,750, all of which was expended on first construction. The proceeds of the remaining $5500 of bonds, together with $2500 additional raised by taxation, were expended in the early part of 1897 in lining the main distributing ditches with cement plaster.

The irrigators using water in 1897 were 225 in number, cultivating 1575 acres, chiefly planted to citrus fruits. In addition to these the taps on the distributing system in the town numbered 204.

The annual expense of operating the system, is about $4000, while the interest on the bonds at 6% amounts to $21,000 per annum. The bonds run for twenty years, but their retirement begins on the tenth year from their issuance, and are payable thereafter at the rate of one-tenth each year. The total annual expense for salaries and interest divided by the number of

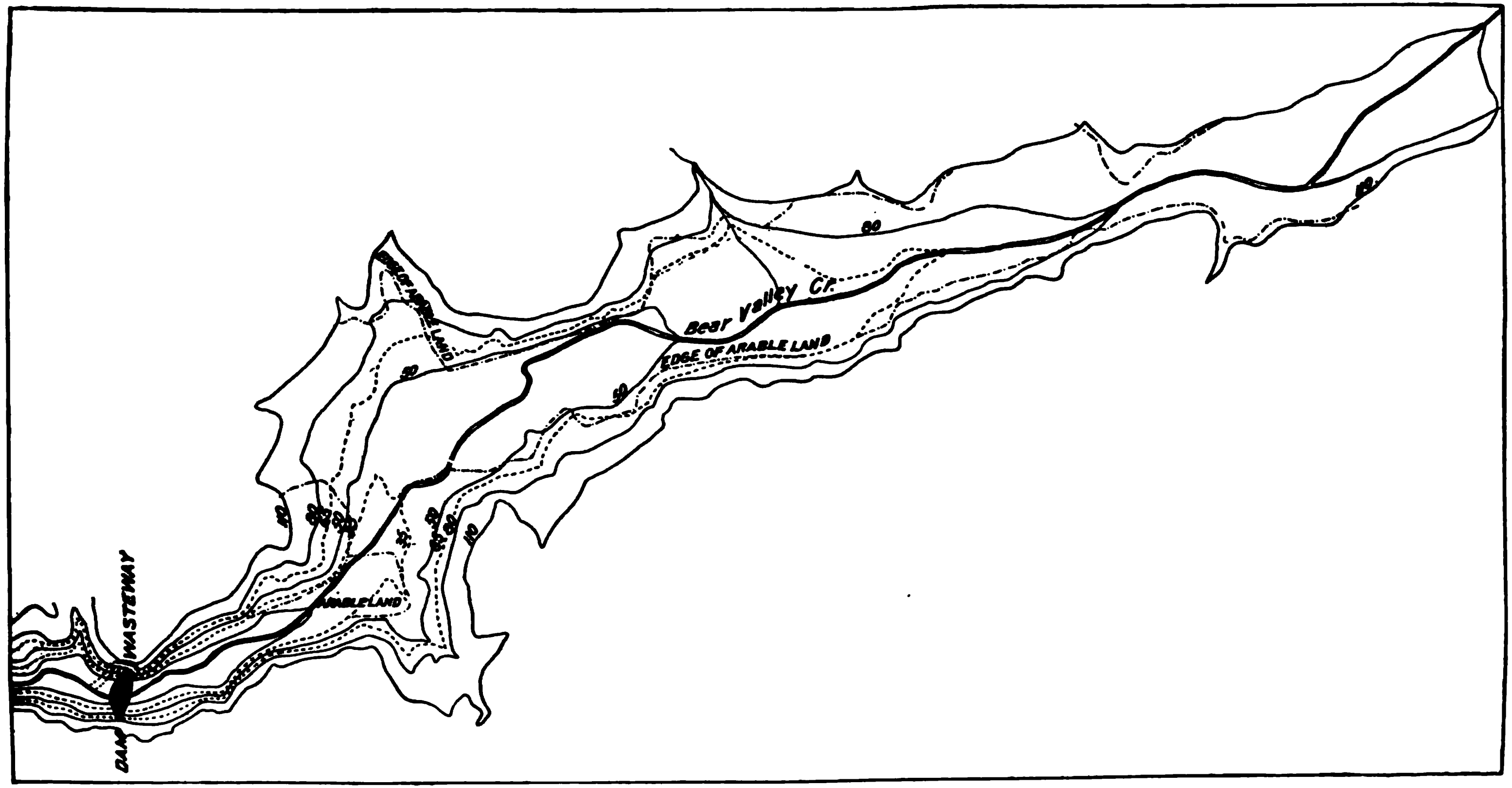


FIG. 9.—CONTOUR MAP OF RESERVOIR OF ESCONDIDO IRRIGATION DISTRICT.

acre-feet of reservoir capacity brings the annual cost per acre-foot of available water to about $8. Taking into account, however, the losses by evaporation in the reservoir and leakage from the ditches and flumes in transit, the cost of water actually available for use on the lands is not far from $12.50 per acre-foot, or nearly 4 cents per 1000 gallons. The average requirement for adequate irrigation is estimated at about 12 inches in depth,

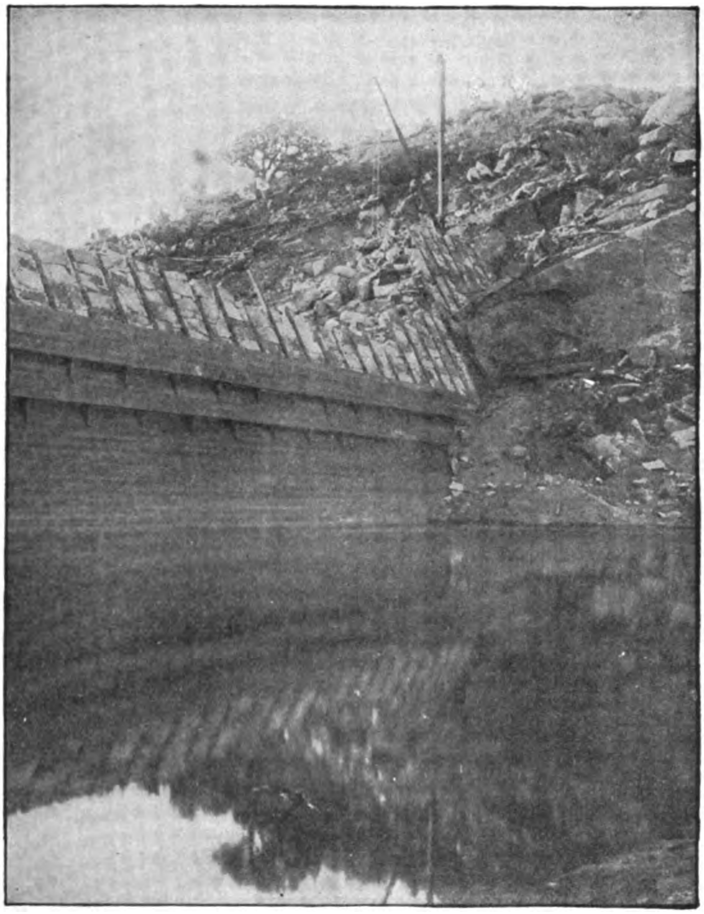

FIG. 10.—CONSTRUCTION OF FACING OF ESCONDIDO DAM.

or 1 acre-foot per acre. At this rate the district when fully irrigated would need 13,000 acre-feet, or nearly four times the present capacity of the reservoir. The total annual expenses divided by the total area of the district gives an average of about $1.80 per acre. The assessed valuation of the district in 1897 was $677,500, and the tax-rate assessed by the directors for irrigation expenses was $3.69 per $100. As the best land was assessed at $40 per acre, it was shown on that basis that the average cost to the owner was but $1.48 an acre, which is a low rate, provided the payment of the tax would insure him a sufficient supply for the irrigation of his land; but as the provision thus far made for the district in water-supply is less than one-fourth of what will ultimately be required to irrigate the whole district, and as the water available is apportioned to the irrigator pro rata to the amount of tax he pays, his annual rate must necessarily be higher than the amount stated if he receives the water he actually requires.

The apportionment is made in regular runs, once each month, beginning at the head of the system, and in order to accomplish the satisfactory irrigation of their tracts the orchardists are obliged to buy what water they lack of full supply from such of the neighboring taxpayers as do not yet use the water to which they are legally entitled. This assigned water is sold at about 10 cents per miner's inch for 24 hours' run, which is about one-third cost. During 1897 the water thus transferred was about 9488 inches for 24 hours. A toll of 1 cent per 24-hour inch, or 25 cents as a minimum, is charged as a gate-tax for zanjero's* fees for turning water on and off, which brings in a revenue of about $80 per month during the irrigating season, and $60 per month during the rest of the year. This toll was increased in 1899 to 40 cents, which covers all costs of operating.

The selling-price of water has steadily advanced during the late years of drought. In 1897 it was sold at 5 to 20 cents per miner's inch for 24 hours (12,960 gallons). In 1898 the rates were increased to 25 to 35 cents per inch, and in 1899 they were 50 to 60 cents per inch. The catchment of the reservoir has been approximately as follows:

| | | | | |
|---|---|---|---|---|
| 1895, 48 | feet depth | = | 880 | acre-feet |
| 1896, 60 | " " | = | 1925 | " |
| 1897, 74 | " " | = | 3700 | " |
| 1898, 59.5 | " " | = | 1000 | " |
| 1899, 47 | " " | = | 830 | " |
| Total........... | | | 8335 | acre-feet, or an average of 1667 per annum. |

A large number of orchards had been started and were being irrigated by water pumped from wells by windmills and gasoline engines before the completion of the works of the district. The cost of pumping by the various methods employed ranged from 3 to 8 cents per 1000 gallons ($10 to $26 per acre-foot), and this high cost, coupled with a very moderate and inadequate supply, caused many of the landowners whose property was not incorporated in the district to seek admission on equal terms with those inside. Several hundred acres were thus taken in after the works had been completed to the present stage upon payment of all back charges pro rata.

* From the Spanish, meaning ditch-tender.

FIG. 10a.—ESCONDIDO (CAL.) ROCK-FILL DAM. WOODEN LINING.

[To face page 18.

The residents of the district realize that their works are in an incomplete stage, and that to secure an adequate supply it is necessary to carry the storage-dam 40 feet higher, giving it a capacity of 11,355 acre-feet. This can readily be done at a cost not to exceed $110,000. The land purchased for the reservoir covers the enlarged area proposed, and it is only necessary to continue the embankment higher, adding the necessary width of base to give the same safe slopes which the present embankment possesses, and extending the wood-facing. With this improvement, and the addition of the smaller regulating reservoir on the river before mentioned, it is believed that the district will have an ample supply for its needs at a total outlay of about $40 per acre, and an average annual expense of $2.50 to $3 per acre.

During the fall of 1897 the validity of the bond issue was questioned by a portion of the landowners, many of whom ceased paying the tax levied to meet the interest on the bonds. In March, 1899, the bondholders requested the trustee, the Farmers and Merchants' Bank of San Diego, to take charge of the system according to the terms of the trust deed, and as provided by the Wright Act under which the district is organized. This was done, and the former superintendent was continued as manager.

**Lower Otay Rock-fill Steel-core Dam, California.**—One of the most interesting of all the rock-fill types of dam yet constructed is located on Otay Creek, San Diego County, California, 22 miles southeast of San Diego, 10 miles back from the coast, and not more than 5 miles from the Mexican boundary-line. It forms the lower one of a series of four mammoth dams projected by the Southern California Mountain Water Company, to impound water for the municipalities of San Diego and Coronado and for the irrigation of an extensive area of frostless mesa lands adapted to citrus-fruit culture, reaching from the Mexican border northward to San Diego, including the peninsula of Coronado, and for the domestic supply of the villages and towns within reach of the distributing system to be built from the reservoir. This system of reservoirs and conduits is the most comprehensive one yet projected in California for irrigation purposes, and when completed in its entirety it must add so greatly to the productive area and population of the region in the vicinity of the Bay of San Diego as to bring that port into the prominence in the world's commerce which its general excellence as a harbor has long deserved. The Lower Otay dam was completed in August, 1897, and the Morena and Barrett dams, the other two of the series, have been under construction since that time, although both are still far from completion.

The Otay Creek, at the point selected for the dam, cuts through the great dike of porphyry which traverses San Diego County from north to south nearly parallel with the coast-line. This dike in places is 10 miles or more in width, and at others less than 1 mile, and occupies the middle ground between the granite formation lying east of it, and the mesa formation, which is an irregular strip of land, 10 to 15 miles wide, lying between the porphyry dike and the shore of the Pacific. The mesa formation is alluvial in origin; consisting of marl, indurated sand, gravel, cobbles, and all shades of soil from clay to sandy loam, but is devoid of hard rock, while the porphyry is an igneous rock, exceedingly tough, of high specific gravity, without regular cleavage, but broken by numerous fine seams with infiltration of reddish clay. The highest protrusions of the dike form the San Ysidro and San Miguel mountains, 2500 to 3000 feet in altitude. It is intersected by all the streams of the county that reach to the ocean, affording sites for the Lower Otay, the Upper Otay, the Sweetwater and La Mesa dams, and others further north that are projected. The Escondido dam is but a mile or two east of the dike in granite formation. The Otay dam is within a few hundred feet of the western limit of this dike, and in fact the outlet tunnel of the reservoir avoids it entirely and was excavated through the soft brown marl of the mesa formation.

The site of the Otay dam was an ideal one for a masonry structure, because of the satisfactory character of the bed-rock foundations, and the abundance of suitable rock and sand at the site, while its convenience to a port of entry rendered the cost of cement very moderate. The usual incentive for building rock-fill dams in preference to masonry, due to their remoteness and the high cost of freighting cement to the site was lacking in this case, and in fact the work was originally planned as a masonry dam. A foundation was laid for this purpose 65 feet thick at the base, reaching down to a depth of 31.4 feet below zero contour, and carried up to a height of 8.6 feet above zero, with a length on top of 85 feet. A view of the work is shown in Fig. 11.

Whether the change in plan from masonry to rock-fill with steel core has resulted in economy of first cost is difficult to determine, as the actual cost of construction has not been made public, or whether there may be grounds for regret that the change was made cannot be known until the stability of the structure is fully tested by the lapse of time. The reservoir has never filled above the 60-foot contour since the completion of the dam up to the fall of 1900, and until the reservoir is filled and remains full a considerable period without developing signs of weakness or extensive leakage the success of the novel design cannot be known. Meantime the engineering profession will entertain the liveliest interest in the development of this novel type of dam, which, if successful, will certainly have wide application to other sites where the choice of material has a more limited range. The credit for originating the idea of making a rock-fill dam water-tight by inserting in its center a web-plate of steel, filling the entire cross-section of the canyon from side to side, and for putting it in application on a large scale, belongs to the president of the water company, Mr. E. S. Babcock, of Coronado. When this plan was decided upon a heavy T iron was anchored to the top of the finished masonry foundation by 1-inch bolts, set in the masonry. The vertical leg of the T was punched with ⅝-inch rivet-holes, spaced 3 inches center to center, and the bottom plates riveted to it. The plates were 5 feet wide, and 17.5 feet long, and the three bottom courses were 0.33 inch thick. From 28 to 50 feet high they are ¼ inch thick, and above 50 feet they are 8 feet wide, 20 feet long, and lessening in thickness as the top is approached. After riveting the

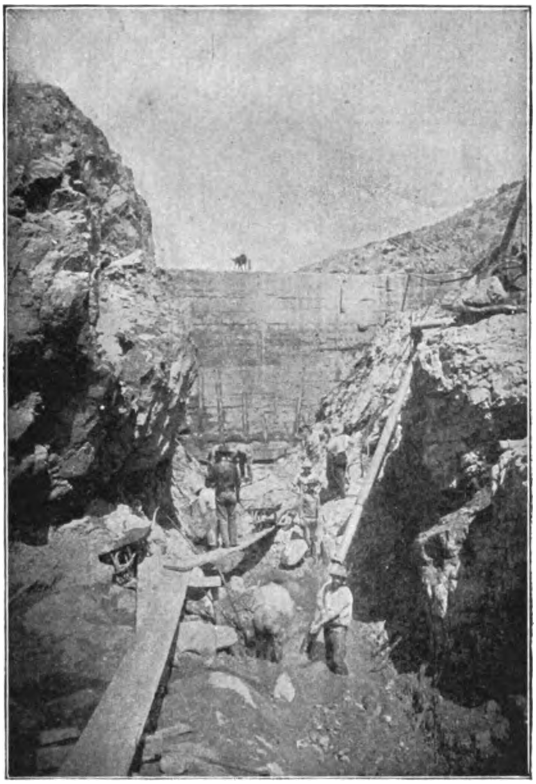

FIG. 11 —MASONRY FOUNDATION OF LOWER OTAY DAM.

plates together with hot rivets they were chipped and calked on the side next to the water, and coated with Alcatraz asphalt, F grade, applied hot with brushes. Over this coat a layer of burlap was placed on each side of the plates, while the asphalt was still hot. This adhered tightly to the plate and served to hold the soft asphalt from flowing. A harder grade of asphalt was subsequently put on over the burlap, and the whole then encased in a rubble-masonry wall laid with Portland-cement concrete, 2 feet thick, the steel plate being in the centre. This wall at base is 6 feet thick, tapering to 2 feet in a height of 8 feet. The moulds for the concrete, consisting of 1-inch boards laid horizontally and 2 × 6-inch vertical posts, were left in position permanently and the rock-fill built against them on either side. The steel core, or web-plate, was carried into the side walls of the canyon in a trench excavated to the depth necessary to reach solid rock and anchored with bolts leaded into the rock. The end plates were not trimmed to fit the irregular line of the rock cutting, but the masonry was widened to a maximum thickness of 20 feet at the sides, tapering from the normal thickness of 2 feet in a distance of about 20 feet. Fig. 12 shows the trench on the right bank about at the 40-foot contour. The function of the wall is to steady and stiffen the web-plate and protect it from injury from the loose rock piled against it, and as the wooden moulds were not removed the embankment is free to settle without injuring the concrete or the plates.

The expansion of the plates after they were riveted together, and the obtuse angle up-stream on which they were first started, which gradually was obliterated by an approach to a straight line toward the top of the dam, gave them a very irregular alignment, as will be seen in Fig. 13, which is a view looking along the top of the dam toward the left bank just before its completion.

The dam is a loose, rock-fill embankment, lying as it was dumped, without any portion of it, except the 2-foot core-wall, being laid by hand. In this respect it differs from its predecessors of the same type, which have been built with a considerable proportion of their slopes on the water-side laid up as a dry wall. It was designed to be 20 feet wide at top, with side slopes of 1½ on 1 on each side. When work was suspended the up-stream slope, composed of the finer grades of materials coming from the quarry, had assumed about the slope stated, but the lower slope was steeper and stands about 1 to 1, while the top width is from 9 to 12 feet. When visited by the writer in September, 1899, the material excavated from the spillway cut was being dumped on the upper slope and the top width increased. The spillway is located some few hundred feet from the east end of the dam, and will consist of a channel 30 feet wide, 300 feet long, with a maximum depth of 30 feet, cut in the rock to a depth of 10 feet below the crest of the dam. The depth of water will be controlled by flash-boards resting at an angle of 30°, between channel-iron frames placed 5 feet apart. A wagon-bridge will be built over the top of these frames, from which full control of the flash-boards will be had. The discharge of the spillway will reach the creek channel several hundred feet below the toe of the embankment.

The entire volume of stone used in the work, approximately 180,000 cubic yards, was quarried immediately below the dam on the right bank, and was transported from the quarry by means of a Lidgerwood cableway, the cable having a diameter of 2¼ inches, and a span of 948 feet between

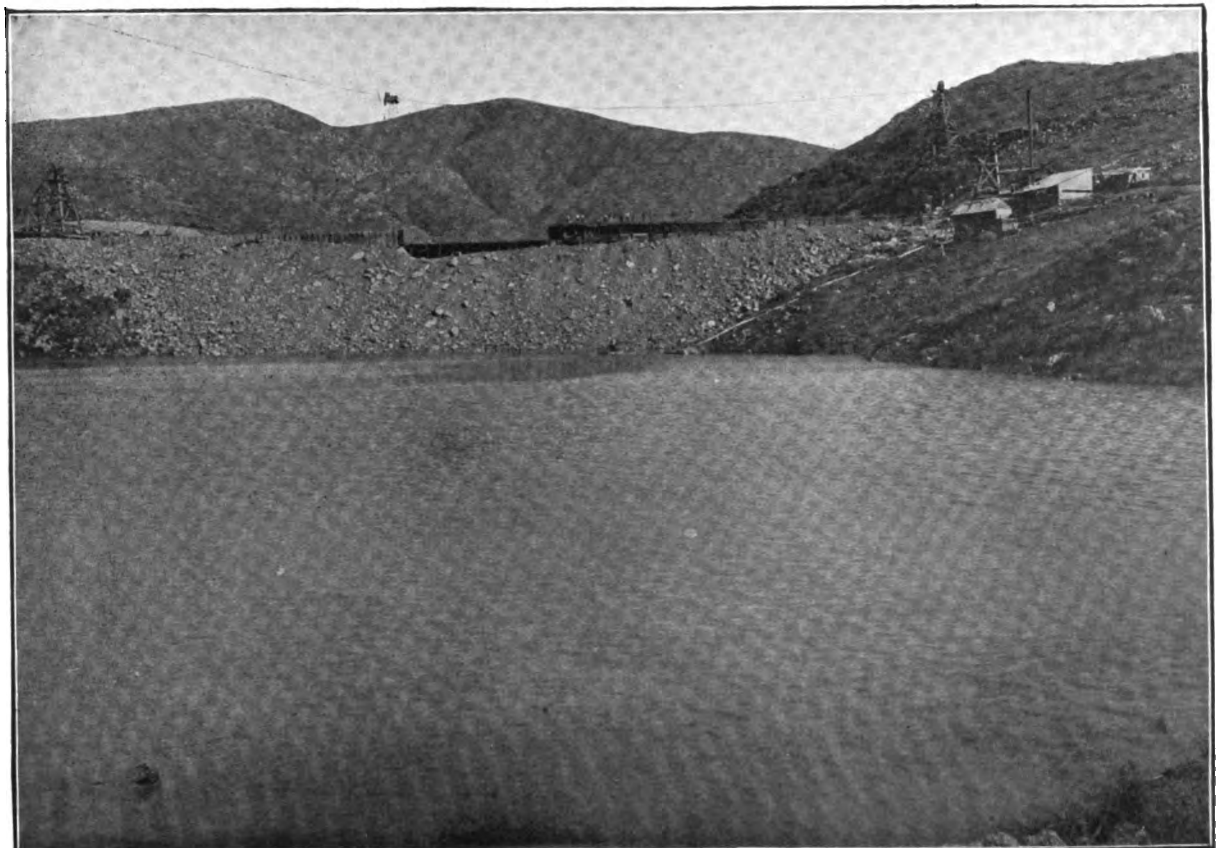

FIG. 11a.—OTAY (CAL.) ROCK-FILL DAM—STEEL CORE.

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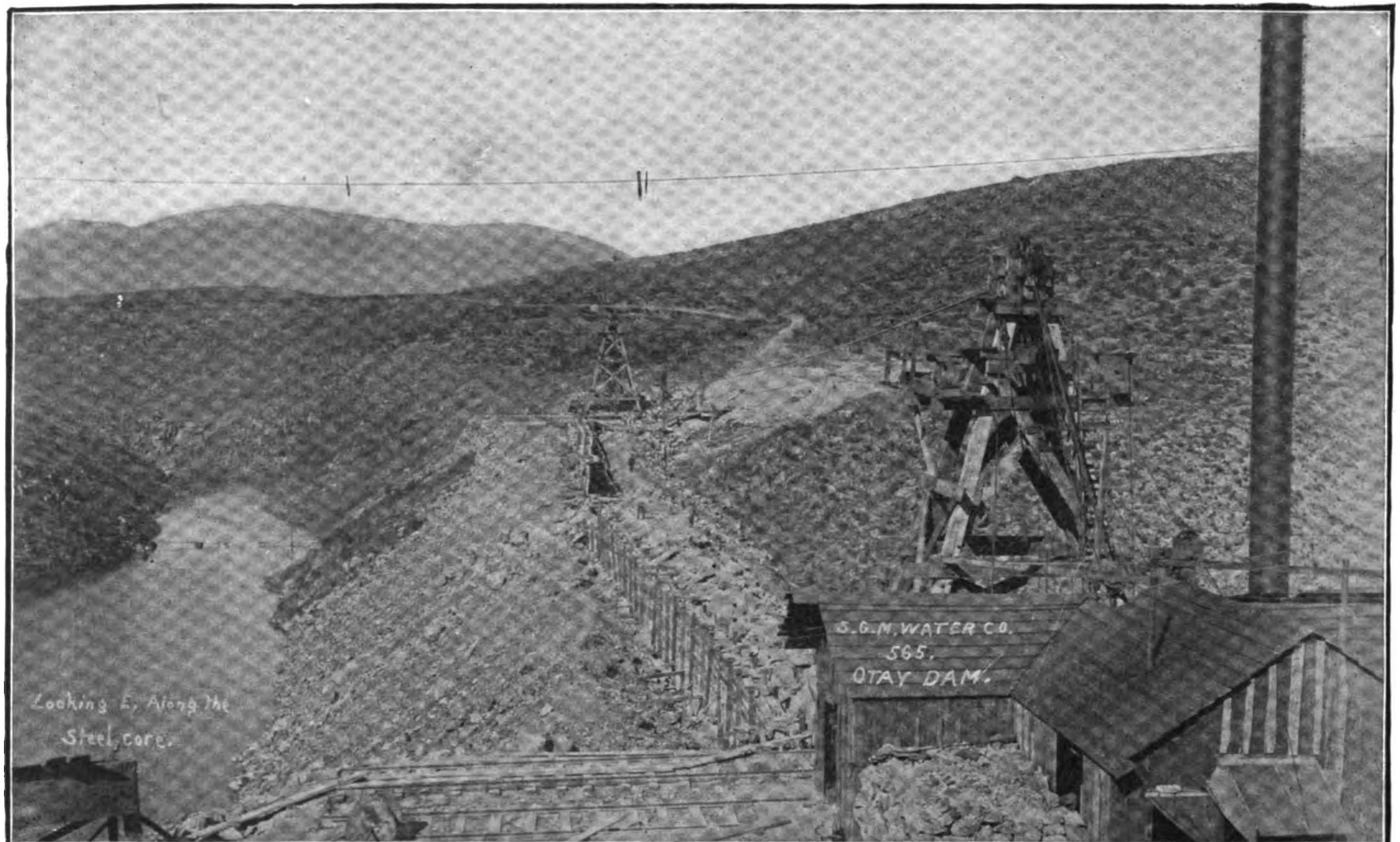


Fig. 11*b*.—Otay (Cal.) Rock-fill Dam—Steel Core.

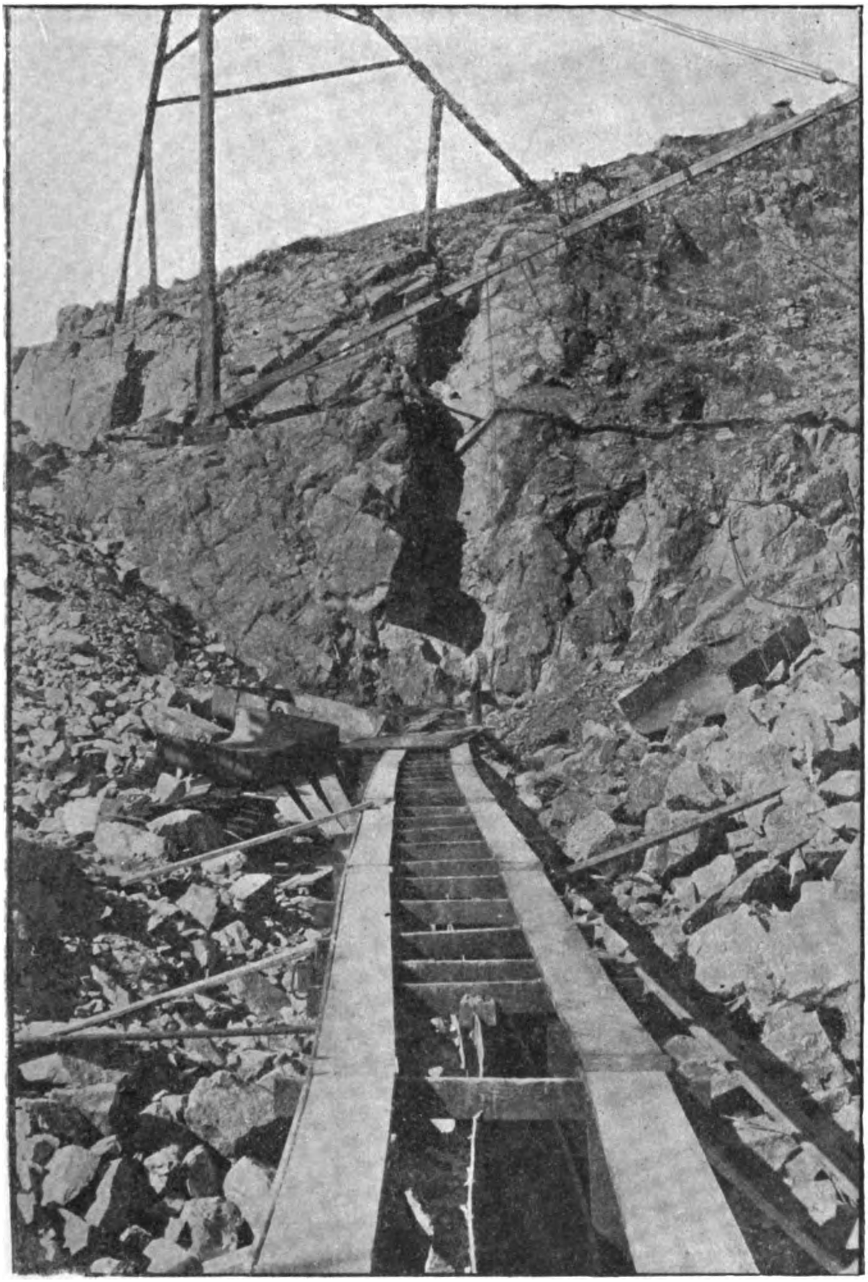

Fig. 12.—Steel Web-plate and Anchor-trench at West End of Lower Otay Dam.


FIG. 12*a*.—OTAY (CAL.) ROCK-FILL DAM—STEEL CORE.

[*To face page* 25.

towers, crossing the canyon diagonally, at an angle of about 60° with the axis of the dam. The head tower was 130 feet high, the tail tower down-stream 60 feet high, the tops being practically level, and a direct line between them crossed the axis of the dam 260 feet above the bed of the stream. The cableway had a guaranteed capacity of 10 tons, center load, under which its deflection was 88 feet, or 42 feet higher than the top of the

FIG. 18.—CREST OF LOWER OTAY DAM, SHOWING WEB-PLATE OF STEEL EMBEDDED IN CONCRETE. DAM NEARING COMPLETION.

dam. Up to the height of 75 feet the rock dumped under the line of the cable was distributed by means of derricks, but subsequently a secondary cableway was erected parallel with the line of the dam, underneath the main cable. This was anchored at each end to heavily ballasted cars resting on tracks, which permitted the cable to be shifted 30 feet, or 15 feet either side of the center of the dam. The loaded skips from the quarry brought to the dam by the overhead cable were picked up by the secondary cable and carried to any point desired along the line of the dam. Tools, materials, derricks, 35-H.P. hoisting-engines, and all other articles required

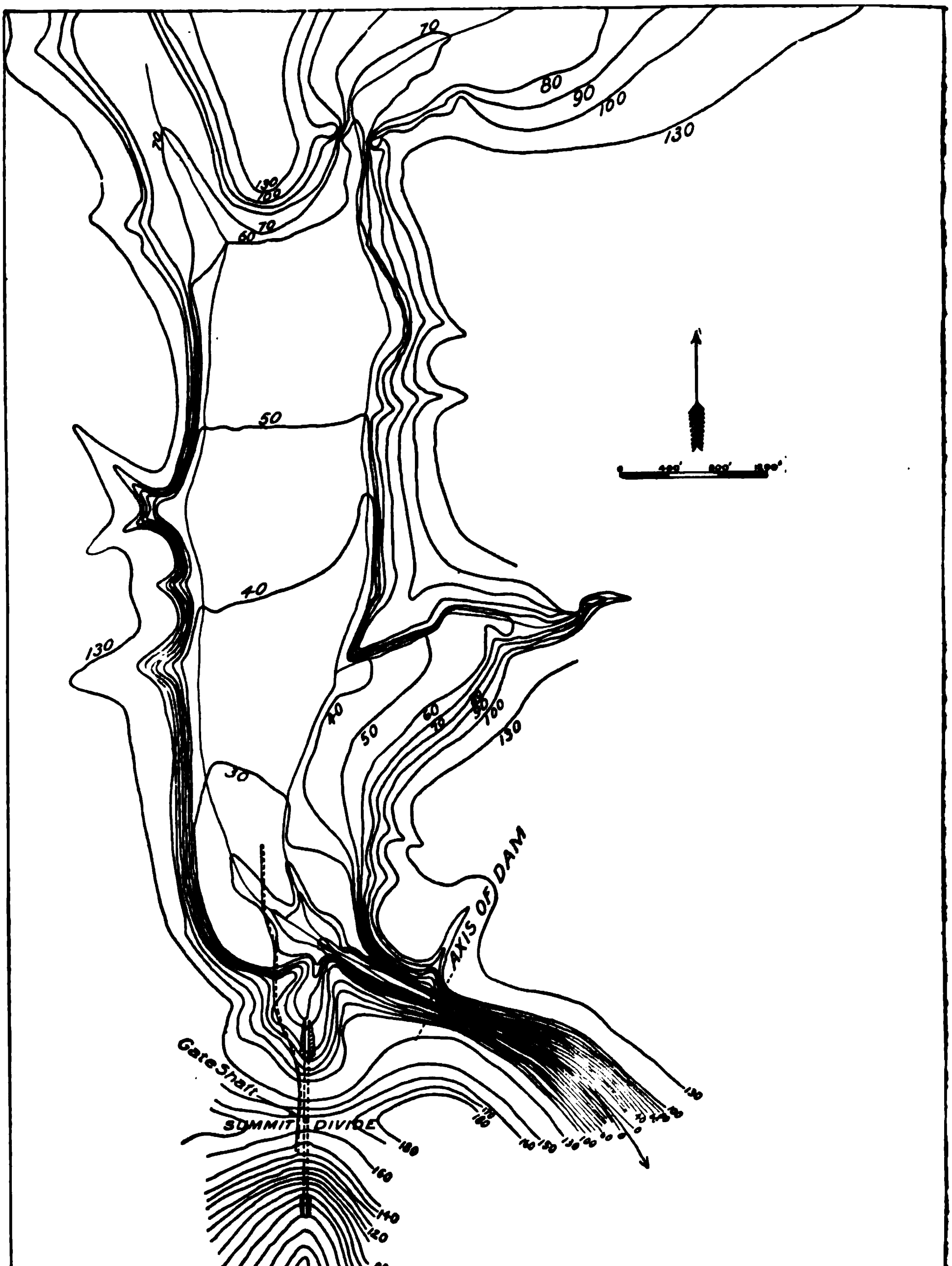


FIG. 14.—MAP OF LOWER OTAY RESERVOIR.

to be moved from one position to another were hauled rapidly and safely by means of these cableways, and not infrequently the employees preferred the aerial journey across the canyon by the cableway to the more laborious climb over the trails. Fig. 15 illustrates the general plan of the dam, with a cross-section of the site and details of the outlet tunnel.

*Quarry.*—All or the greater portion of the rock had been loosened in the quarry by very heavy blasts, the first of which was made by driving a tunnel 50 feet into the face of the cliff with lateral drifts, 18 and 28 feet long respectively. In the shorter drift, 4000 pounds of Judson powder (containing 5% nitro-glycerine) under a vertical depth of 70 feet, and in the larger, 8000 pounds under a depth of 85 feet, were exploded simultaneously, which resulted in loosening and throwing out about 50,000 to 75,000 cubic yards. A view of this blast taken at the moment of explosion is shown in Fig. 16. The second large blast was prepared by sinking a shaft 115 feet deep, 85 feet back from the nearly vertical face left by the first blast. At a depth of 50 feet two drifts were run laterally a distance of 25 feet each, and at the bottom of the shaft two more drifts, 30 and 35 feet long respectively, were extended into the rock toward the face and in the opposite direction, and the four holes thus prepared were loaded with 30,000 pounds of powder, of which the greater portion was located in the bottom drifts. This blast did greater execution than the first, and supplied sufficient rock to complete the dam. Minor blasting of the ordinary class was necessary throughout the work to break up the larger masses to sizes that could be handled by the cableway. The quarry being near the lower toe of the dam, the first large blast filled in the toe with large bowlders, some of which weighed upwards of 50 tons, and a subsequent freshet, pouring over and through these rocks, scoured out the sand beneath them so as to settle them well to bed-rock, which was a fortunate occurrence.

The watershed of Otay Creek above the reservoir is about 100 square miles in area, but as its average altitude is not over 1600 feet the precipitation is light and the run-off insufficient to fill the reservoir except in occasional years. In dry seasons there is no flow whatever. The catchment in four years prior to September, 1899, has not exceeded 5000 acre-feet. To make up for this shortage in supply and to fill the reservoir regularly the company is planning to divert water from Cottonwood Creek, a stream adjoining on the south which drains an extensive region of the highest mountains of the main range. This stream enters Mexican territory and returns again, emptying into the sea near the boundary-line, where it is known as the Tia Juana River. The conduit for diverting its flow will start at the second reservoir of the system, known as the "Barrett dam," at an elevation of 80 feet above the stream-bed, or about 1650 feet above sea-level, and be supported along the southerly slopes of Lyon's Peak to Dulzura Pass, where the divide will be crossed by a long tunnel, from which

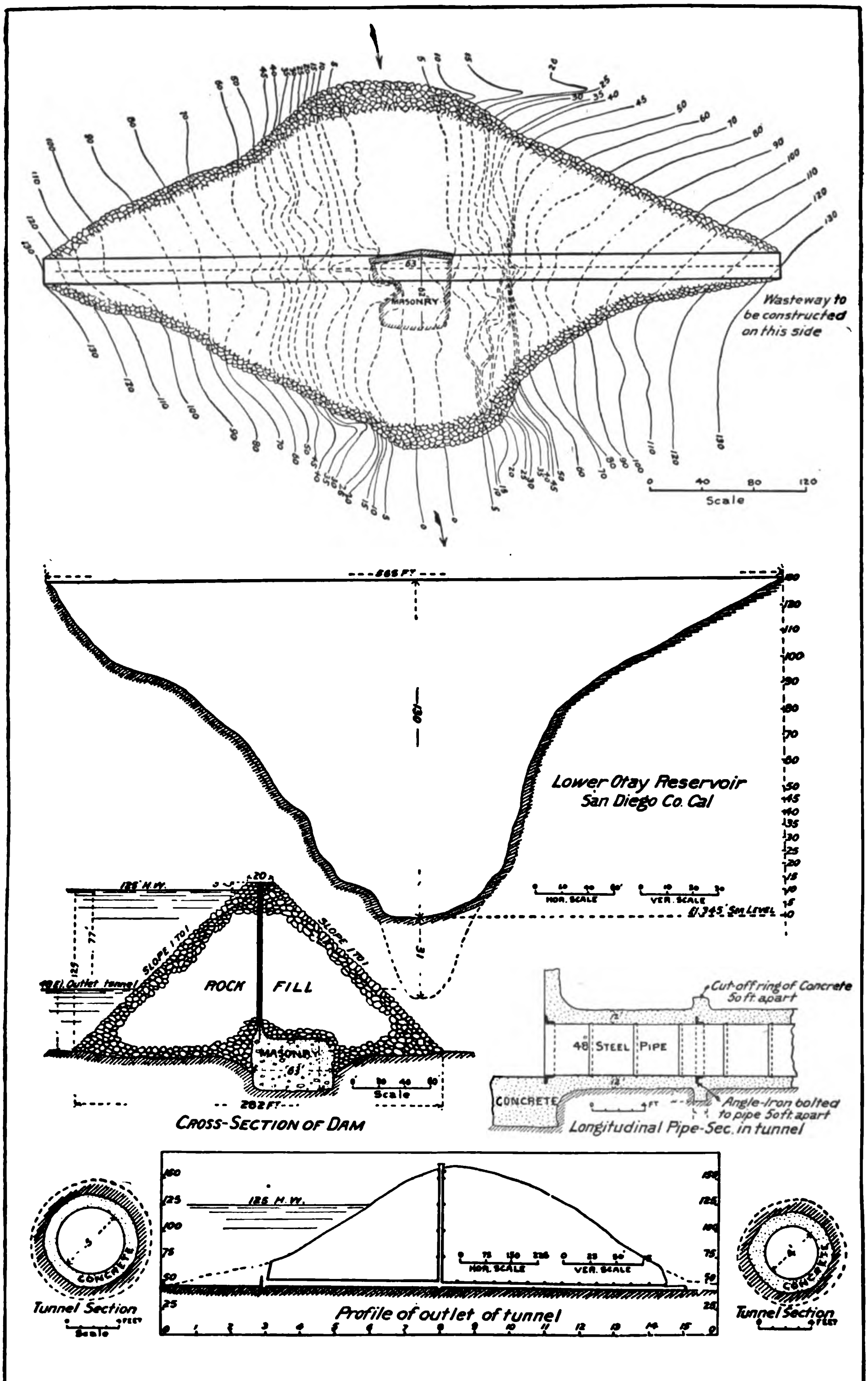


FIG. 15.—PLANS OF LOWER OTAY RESERVOIR.

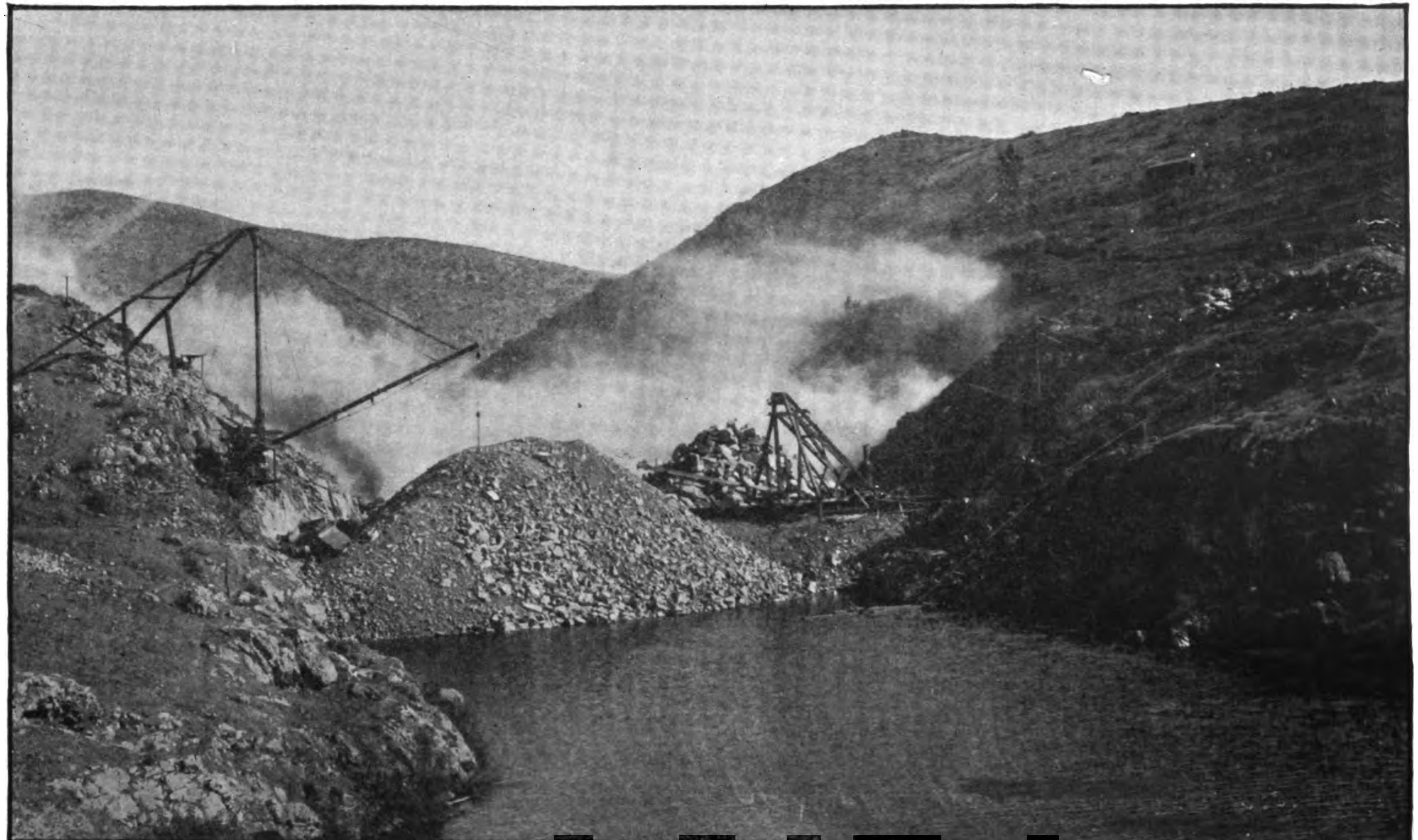

FIG. 16.—EXPLOSION OF GREAT BLAST AT LOWER OTAY ROCK FILL DAM.

the water will drop into the east fork of Otay Creek and thence to Otay reservoir. The conduit will be a trifle over 8 miles in length, and consist of a succession of cement-lined tunnels in granite. To regulate the flow of the stream and store additional water the company have under construction two dams of mammoth size—the Barrett and Morena, both of which have been projected as rock-fill dams.

*Outlet Tunnel.*—There are no pipes or outlets through or under the dam proper, and the only outlet provided is a circular tunnel through a narrow part of the enclosing ridge 1000 feet west of the dam. This tunnel is 1150 feet long, the bottom of which is at the 48-foot contour. Below the tunnel-level, therefore, as will be seen by reference to the table of reservoir capacities in the Appendix, there remains a volume of water of approximately 2000 acre-feet (652,400,000 gallons), covering nearly 160 acres of surface which can never be drawn off. The material encountered in this tunnel was a brown hard-pan, resembling marl, and cemented gravel, both bone-dry. The western limit of the porphyry dike is between the tunnel and the dam. For 500 feet from the inner heading the tunnel was lined with concrete to a clear circular diameter of 5 feet, the lining being 12 to 18 inches thick and plastered with cement mortar. At the end of this section a shaft, 104 feet in depth, reaches to the surface. Below this shaft a 48-inch riveted steel pipe is laid to the outside, and the entire annular space between the pipe and the walls of the tunnel is filled with concrete, with a minimum thickness of 12 inches. This pipe was put together in sections of 38 inches in length, stovepipe fashion, the insertion at each joint being 2 to 3 inches. The joints were driven as closely as possible, but owing to the sag of the pipe and the absence of careful ramming of the concrete at the bottom of the joint it was found on completion that there were cavities which rendered it impossible to calk the joints from the inside and make them water-tight. As it was desirable to utilize the full depth of the reservoir pressure on the conduit outside the tunnel, it was essential to stop the leakage in the pipe lining of the tunnel, and a plan has been devised by H. N. Savage, M. Am. Soc. C. E., consulting engineer of the company, to do this by means of threaded "patch-bolts," tapped into the joints at intervals of 3 inches, thus drawing the plates together. When this is done cement grout will be pumped into the cavities at one of the bolt-holes, an inside band will be inserted covering the heads of the patch-bolts, and the space filled with cement. It is expected that the device will prove successful. At the upper end of the tunnel a balanced valve will control the admission of water, and additional control will be supplied by a gate-valve in the pipe at the tunnel-outlet, and a gate-valve operated from the shaft at the junction of the large and small sections of the tunnel. The location of this tunnel-outlet through the hill saved a mile or more of pipe-line through the canyon from the dam, although the latter might have been cheaper. The main conduit from the reservoir to San Diego will consist of steel and wood-stave pipe, from which the intermediate lands will be supplied.

**The Barrett Dam.**—The middle one of the chain of three great reservoirs under construction by the Southern California Mountain Water Company is located about 40 miles southeast of San Diego, and about 6 miles north of the Mexican boundary, at an altitude of about 1600 feet. It occupies a singularly valuable strategic position, as it is the lowest feasible reservoir-site on the stream from which water can be conveyed by gravity conduits without passing through foreign territory. It is also at the lowest elevation from which water can be distributed to the most valuable mesa lands adjacent to the coast, and at the same time it is low enough on the stream to receive the run-off from the greatest area of mountain watershed available for any reservoir in southern California. This area is about 250 square miles. The precipitous and rocky character of this watershed insures a maximum average run-off and catchment in years of normal precipitation.

The dam- and reservoir-site were acquired by the San Miguel Water Company, a local organization, in 1889, and subsequently transferred to the Jamacha Irrigation District, organized under the Wright Law of California, for the consideration of $105,000 of the bonds of the district, the purchase including 560 acres of land and certain water-rights. The district has taken no steps to construct the dam and conduit by which alone the property would have value, other than to contract with the Southern California Mountain Water Company for its water-supply, and the latter is now engaged in constructing the dam. In 1897 the company erected a masonry dam, shown in Fig. 17, 72 feet in height from its base, which is 22 feet below the stream-bed, to its top 50 feet above. This structure rests on solid granite bed-rock throughout, and is 14 feet thick at bottom, 5 feet at top, and about 30 feet long on the crest. This was to be used simply as a pick-up weir to divert water into the Dulzura pass conduit. Subsequently it was decided to build a storage dam, similar in plan to that of the Lower Otay, to an extreme height of 175 feet, and a new location was chosen about 1000 feet further down stream, where rock could be more conveniently obtained for a rock-fill structure. Here a new masonry dam was built in 1898, reaching to bed-rock in the stream-bed and extending about 35 feet above, upon which to begin the sheet-steel core of the rock-fill The dimensions were as follows:

| | | |
|---|---|---|
| Length on top | 115 | feet. |
| Thickness at base | 30 | " |
| Thickness at top | 13 | " |

Its cubical contents are 3100 cubic yards, and there were consumed in its

FIG. 17.—BARRETT DAM.

construction 1777 barrels of cement. An outlet tunnel, 8 × 8 feet in size, 600 feet long, has been excavated in solid rock on the right bank, at a height of 80 feet above the stream, which is the beginning of the tunnel conduit to Dulzura Pass. Actual work upon the rock-fill portion of the dam has not yet begun, and it is possible that the plans may yet be reconsidered and a masonry dam substituted for the rock-fill, out of deference to the torrential character of the stream in seasons of exceptional rainfall, and the possible risk involved in a rock-fill on such a stream during construction and subsequently. The vast importance of this structure as the key to the entire system, not only for storage but for the diversion of water, doubtless emphasizes the necessity for unquestionable stability, and suggests the wisdom of relying upon masonry. It cannot be claimed for rock-fill dams that they are inherently superior to masonry or concrete structures of heavy gravity section, and they are only to be preferred as a substitute where natural conditions render them very much cheaper, and hence practicable for use in cases where the greater cost of masonry would be prohibitive.

*Watershed.*—The tributary watershed ranges in altitude from 1600 to 6000 feet, and probably averages 3600 feet. The mean precipitation on this shed may ordinarily be expected to be from 10 to 20 inches greater than that of San Diego, from the natural increase due to altitude, and in some years it may be 30 to 35 inches greater. The mean precipitation of San Diego for 40 years from 1850 to 1890 was 9.86 inches, ranging from 3.02 inches in 1863 to 27.59 inches in 1884. To fill the reservoir to the 175-foot contour will require 47.970 acre-feet (20,900,000,000 cubic feet) which would be supplied by an average run-off of 3.6 inches from the watershed. Under unfavorable conditions this depth of run-off would be expected from an annual rainfall of 24 inches, and may at times be the product of but 15 inches' precipitation, depending largely upon the distribution of the storms, and the frequency with which they succeed each other. In years like 1884 or 1895 the run-off may be as great as ten times the capacity of the reservoir, and the maximum spillway capacity to be provided may reach 40,000 second-feet.

**Morena Rock-fill Dam.**—The third great reservoir of the Southern California Mountain Water Company is located 10 miles east of the Barrett dam, on one of the two streams that unite just above Barrett, at an altitude of 3100 feet above sea-level. It is 50 miles from San Diego, and 7 miles north of the international boundary. The dam is a rock-fill structure, placed in a narrow canyon, cut through massive granite cliffs that tower hundreds of feet high, on the brink of a precipitous fall or cataract, where the stream takes a plunge of 1200 to 1300 feet in a mile of distance. This canyon is filled with enormous bowlders throughout, and at the site of the dam the narrow fissure eroded by the stream was found to be more than

100 feet deep below the stream-bed. Fig. 18 is a view taken of the dam-site looking up stream, and well illustrates the character of the rock-masses filling the gorge. The tree growing at the right of the picture is on the line of the masonry toe-wall. This wall was carried down to the bottom of the fissure, 112.5 feet below the general stream-bed at that point. This wall is at the upper toe of the rock-fill, and is 36 feet thick at the bottom, where the width between solid walls was but 4 feet for a height of 12 feet. The widest part of the fissure was 16 feet, and at the zero contour it was 80 feet wide. At this point the thickness of the masonry was made 20 feet. It was carried up 30 feet higher, where the thickness is 12 feet. The top of the wall is shown in the view of the partially finished dam (Fig. 19) just above the water-line. The upper toe of the rock-fill, which will be finished on a slope of 1½ to 1, will reach to the top of this toe-wall, and will be covered with 5 feet of Portland cement, uncoursed rubble masonry, over which it was intended to lay a sheet of asphalt concrete, 12 inches thick at base and 4 inches thick on top, extending into a groove moulded in the wall, 5 feet in depth. The plan for using asphalt concrete has been abandoned recently and some other material will be substituted. The rock-fill, as shown by this view, is about 80 feet high above the wall.

The canyon walls are of clean, hard granite, singularly free from fissures and seams. The width between them is but 80 feet at the stream-bed and 470 feet at the height of 160 feet above. The sides thus have a slope steeper than 1 to 1, or about 41° from the vertical. Had the planes of the side slopes continued beneath the surface the maximum depth to bed-rock would have been but 30 feet instead of 112.5 feet where it was found. The situation is a favorable one for any type of dam, except earth, and especially favorable for a masonry structure, although the freighting of cement to the site would have made that class of work more costly than at the Lower Otay. Work was begun in the summer of 1896, and by the fall of the following year the rock-fill had reached a height of 80 feet above the top of the toe-wall, when work was suspended. The ultimate height to which the dam is designed to be carried is 160 feet, to hold a maximum depth of 150 feet of water, and impound 46,733 acre-feet (20,360,000,000 cubic feet). The volume of rock in the structure, computed on slopes of 1 to 1 on the face, and 1½ to 1 on the back, will be approximately 400,000 cubic yards. If the face is given a slope of 1½ to 1, the volume will considerably exceed this amount. The thickness at base is over 800 feet, while the extreme height of rock-fill from the lower toe down the canyon will be in excess of 250 feet. Large blasts were employed in loosening the rock for the dam in a similar manner to the method used at the Otay dam, with the exception that the quarries were located on each side of the canyon above the top of the dam, in such position that much of the rock was thrown down in place thereby and did not subsequently require removal. Bowlders weighing

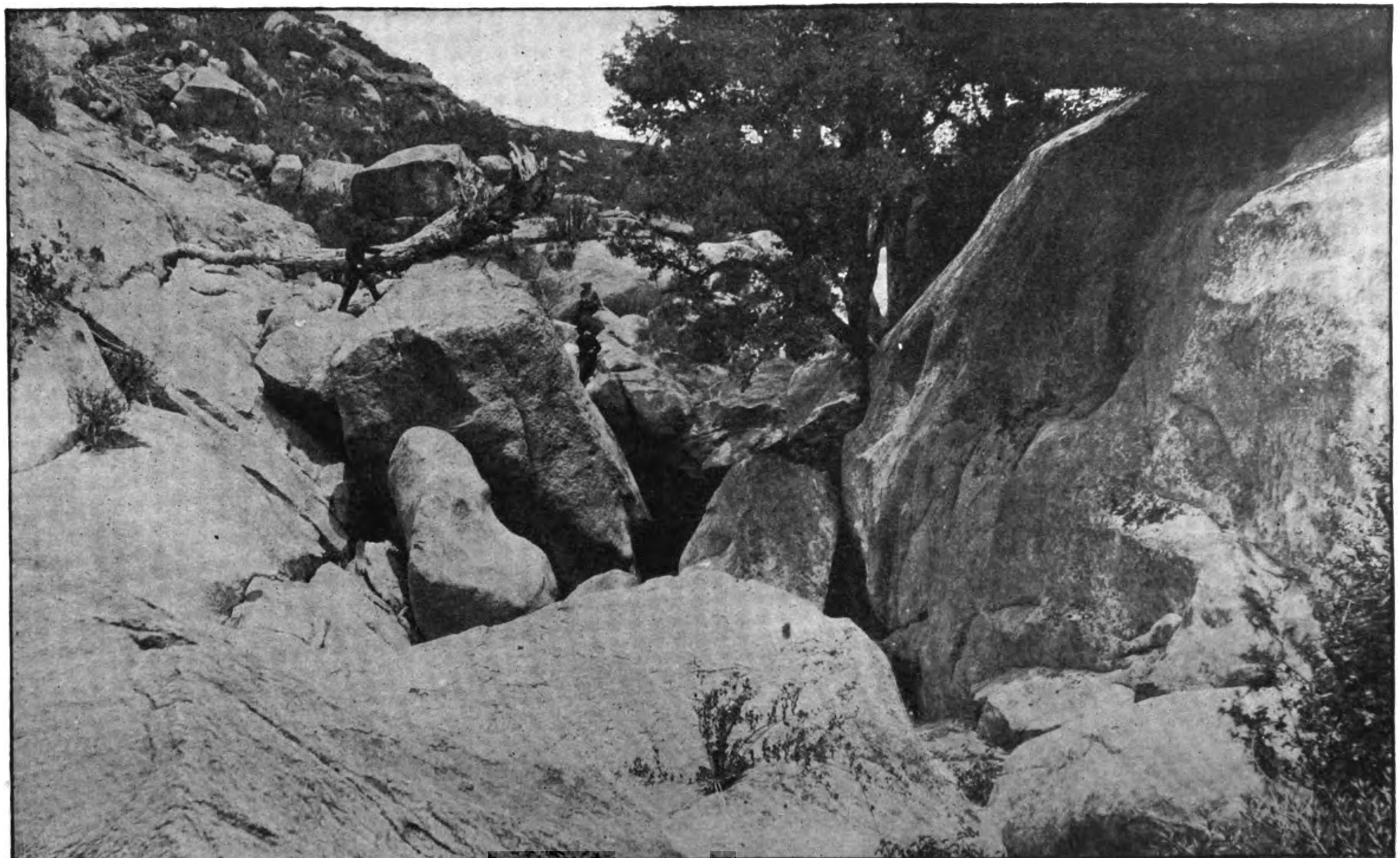

FIG. 18.—MORENA DAM-SITE, LOOKING EAST.

hundreds of tons were thus deposited in the bed of the canyon and on its slopes.

The first blast of 100,000 lbs. of powder, exploded December 26, 1896, was estimated to have moved 75,000 cubic yards. A second blast, fired five days later, with 80,000 lbs., did good execution, and on March 24, 1897, the explosion of 70,000 lbs. is reported to have loosened 100,000 tons.

The machinery assembled for the construction is said to have cost $175,000. Two lines of Lidgerwood cableway span the chasm at a height of 400 feet, operating from the quarries on either side. These cableways are attached to heavily ballasted cars, supported on three lines of railway-track on either side, with a range of movement of 100 feet each, parallel with the axis of the dam. Powerful derricks of the most improved types

FIG. 19.—MORENA ROCK FILL DAM IN PROCESS OF CONSTRUCTION. SHOWING TOP OF TOE-WALL ABOVE THE WATER-LINE.

have been placed in convenient position, and no less than twenty hoisting-engines have been assembled for the work.

*Outlet.*—The water is to be drawn from the reservoir through a tunnel, 600 feet long, cut in the granite on the south side at the 30-foot contour, the dimensions of which are 8 × 8 feet. This tunnel is to be controlled by a series of balanced valves to be placed at the reservoir end, while the water is to be discharged into the canyon and flow down the channel to the Barrett reservoir below.

*Watershed.*—The area of drainage intercepted by the dam is 130 square miles, or rather more than half of that tributary to the Barrett, of which it is a part, and ranging in altitude from 3200 to 6000 feet, averaging about 4000 feet. Both reservoirs cannot be expected to fill every year, although there are frequent seasons when the run-off will surpass the capacity of all three reservoirs in the system. By providing ample storage and holding over a large surplus every year, the maximum duty can be obtained from the tributary streams.

*Conditions of Construction.*—The dam is being built under a contract with the city of San Diego by which the company undertakes to deliver 1000 miner's inches continuous flow (12,960,000 gallons daily), at a point designated as the "Meter-house Site," about 11 miles southeast of the nearest limits of the city, for the sum of $727,000. This is to be accomplished by the conduit from the Barrett dam to Dulzura Pass, 9.5 miles in length, which is to have a large surplus capacity for conveying water to the Otay reservoir, and by a continuation of this conduit of smaller capacity a

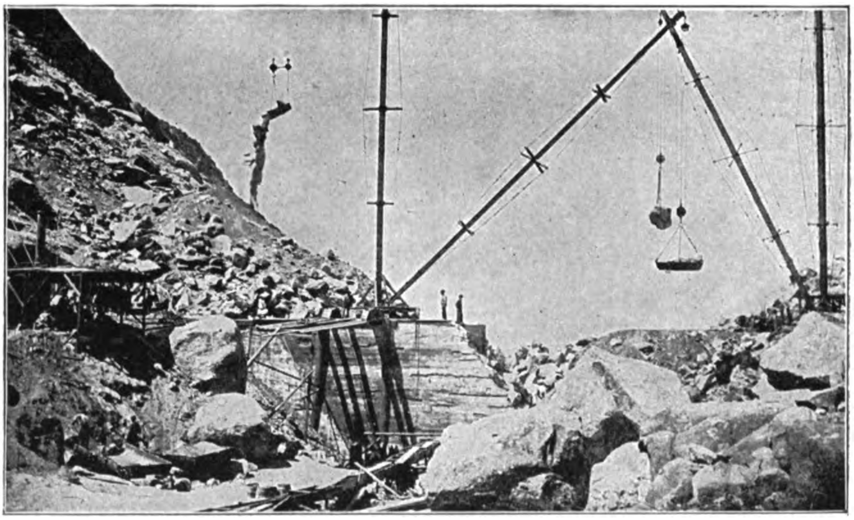

FIG. 20.—MORENA ROCK-FILL DAM, SHOWING A PORTION OF TOE-WALL UNDER CONSTRUCTION.

distance of 26 miles further, from the Dulzura Pass to the Meter-house Site.

Between the outlet level and the 120-foot contour the reservoir has a capacity sufficiently in excess of the agreed amount required to supply 1000 inches flow for one year to cover probable loss by evaporation, and under the contract so much of the reservoir up to the 120-foot contour is to be conveyed by deed to the city, while all the land above the 120-foot level is to be reserved by the company, together with the privilege of building the dam to a greater height, thus storing water for its own use and for sale to other parties on top of the city's reservoir. The addition of 30 feet will increase the capacity 200%, giving the company about 30,000 acre-feet of water. The watershed area above the dam as before stated is about 130 square miles, from which a run-off of 20% of 32 inches of rainfall would suffice to fill the reservoir.

Work upon the reservoir has been suspended pending the outcome of protracted litigation over the validity of the contract between the city council of San Diego and the water company, and the validity of the city bonds voted for the water-works.* Meantime it is understood that the Barrett dam is to be completed, and the conduit to Dulzura Pass and beyond, by which the company will be enabled to utilize its system for irrigation independently of the water-supply of San Diego.

The entire system is the most comprehensive storage enterprise yet projected in California for the utilization of water that normally flows to the sea unemployed and useless. Its completion will be an important factor in the development of a portion of the frostless area of southern California.

**The Upper Otay Dam.**—This structure, which is a part of the general system just described, is on the West Fork of Otay Creek, and is at such an elevation that the high-water line of the Lower Otay reservoir will touch the base of the dam of the Upper one. The dam-site is in a porphyry-rock

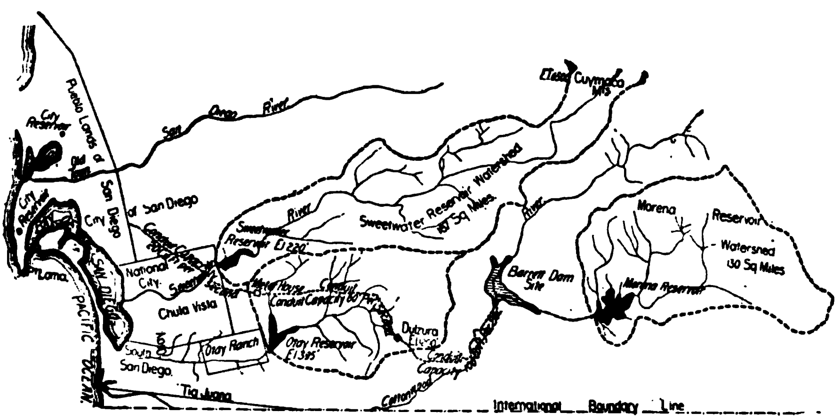


FIG. 21.—RESERVOIRS NEAR SAN DIEGO, CALIFORNIA.

gorge, where the width between walls at the stream-bed is but 20 feet. The supporting hills fall away quite rapidly, however, so that at the 60-foot contour the width is 216 feet, and at the 120-foot contour it is 1060 feet. The dam has been started as a masonry structure and carried to a height of 34 feet, but as the watershed directly tributary is but 8 square miles, and the capacity of the reservoir quite limited (15,342 acre-feet), as compared with the Lower Otay, its completion and ultilization as a storage-reservoir will be independent of its own local water-supply. The masonry wall already laid has a length at bottom of but 12 feet, and is but 75 feet long

* This contract has recently been declared void, the Supreme Court of California having decided that the election for the bonds voted by the City was illegal and invalid.

on its present crest. The height is to be materially increased in the near future if the plans of the company are not changed, and it may become a structure of considerable magnitude.

**Chatsworth Park Rock-fill Dam.**—A structure of more than common interest as an example of "how not to do it" was erected on Mormon Canyon, in the westerly part of San Fernando Valley, Los Angeles Co., California, near the station of Chatsworth Park, in the winter of 1895–96, for impounding water for irrigation and to serve as a diverting-dam for a conduit to carry the flood-water of the stream to a secondary reservoir of

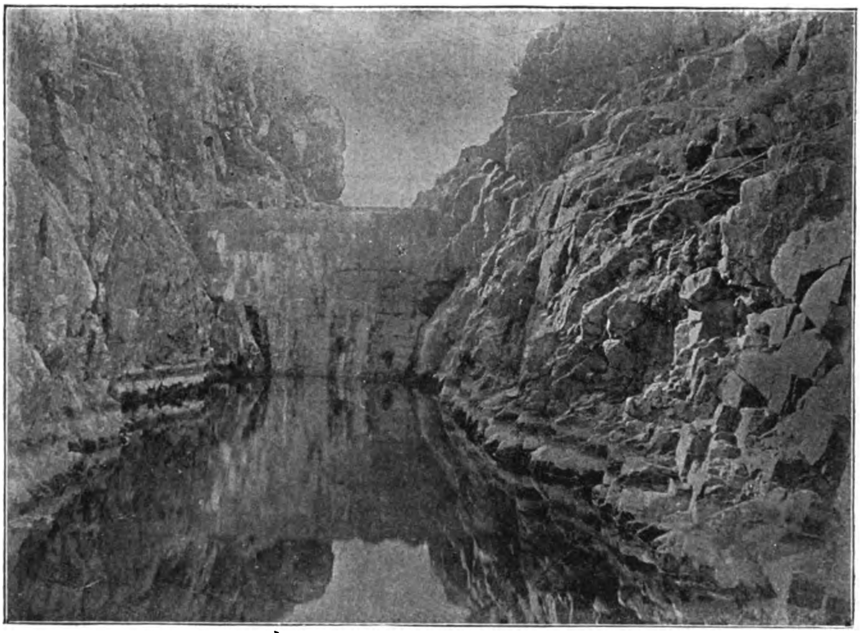

FIG. 22.—UPPER OTAY DAM, FOUNDATION MASONRY.

much larger capacity a short distance away to the south. Two failures of earth dams erected at the same site had already occurred prior to the building of the dam in question, both having been overtopped and carried away by reason of insufficient spillway capacity. The last one was swept out shortly before beginning work on the rock-fill, chiefly as the result of bad management. The spillway had been filled with sand-bags to make the reservoir hold a little more, and when the flood came there was no one at hand to remove them. When the attendant finally arrived the sluice-gate was stuck fast and could not be opened, and before any relief was afforded the water rose over the top of the dam and washed it away, although it was a well-built structure.

The rock-fill dam was built 41.33 feet high above the creek-bed, 10 feet wide on the top, with sides sloping at an angle of 60°, above and below alike, or 1 vertical to 0.57 horizontal, which gave a base width of 60 feet. The length on bottom is 100 feet, and at top 159 feet; cubical contents, 6.025 cubic yards; area of water-face 7700 square feet, covered with Portland-cement concrete from 8 inches thick at top to 16 inches at bottom. The rock used for the fill is a soft sandstone, quarried on the line of the dam at one end, 500 feet away, and 75 feet to 100 feet higher than the top of the dam. The quarry-face was 30 to 40 feet high. A light trestle was built on a sharp incline from the quarry to and across the dam, and a cable, passing over a drum or pulley at top and with a car attached to each end, was the means employed for transportation, the loaded cars fetching up the empty ones. The material was dumped in place promiscuously and without selection. Some of it disintegrated and crumbled into sand when blasted, hammered, or dropped from a few feet in height, and, as everything loosened in the quarry was put into the fill, the proportion of sand and earth is very large and the natural angle of repose of the mass is much flatter than that of rock alone, and flatter than the slopes proposed by the plans. The specifications required the slopes to be laid up two feet in thickness as a dry wall of uncoursed rubble, but this was done in such an indifferent manner that within two weeks after the contractor had moved off the work more than three-fourths of the lower face-wall fell or slid down, followed by some of the embankment behind it so as to leave the concrete facing unsupported and its under side exposed to view for several feet from the top of the dam. The dam was not of much value for water-tightness, as it leaked considerably with but 10 feet of water behind it. The work was done by contract, at a total cost of about $9000, part of which was payable in land. After the work was done the contractor took advantage of the failure of the company to comply with the California law requiring contracts to be recorded to make them valid, and brought suit to recover a greater amount than the contract price. He succeeded in getting a jury to give judgment for about 40% additional, while the owners have been obliged to reconstruct the dam. This was begun on the plan illustrated in Fig. 23, the lower slope being hand-laid to a thickness of 4 feet, and covered with a masonry slope-wall 6 feet thick, although the work is still incomplete. This is believed to be the first case on record of a dam falling down before the water-pressure had been applied to it.

The watershed area above the dam is about 15.5 square miles, from 1000 to 3800 feet in elevation, from which maximum floods of 700 to 800 second-feet may be expected—sufficient to fill the reservoir in three or four hours, as the capacity is not in excess of 200 acre-feet.

**The Castlewood Dam, Colorado.**—The Chatsworth Park dam, just described, bears some resemblance to the Castlewood dam erected on Cherry Creek, some 35 miles above Denver, Colorado (which city is at the mouth of the same stream), although the latter structure is a much more successful engineering work and of greater size and importance. The Castlewood dam was built in 1890 by the Denver Land and Water Company, for the impounding of water for the irrigation of some 16,000 acres of fertile mesa land lying between Cherry Creek and the South Platte River, and extending to the city limits of Denver.

The area of watershed above the dam is about 175 square miles, from which the run-off after severe cloud-bursts on the "divide" sometimes

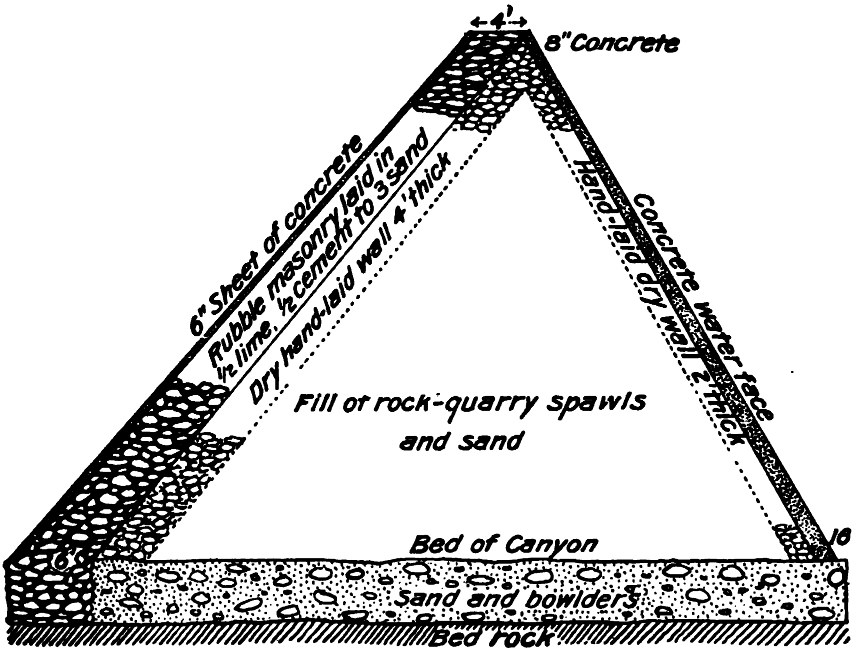


FIG. 23.—SKETCH OF RECONSTRUCTION OF CHATSWORTH PARK ROCK-FILL DAM.

reaches or exceeds 10,000 cubic feet per second for a short time. The reservoir covers about 200 acres, and has a capacity of 4,000,000,000 gallons, or about 12,280 acre-feet. The dam is a rock-fill with a masonry wall on the upper face, while the lower slope is covered in steps of 2 feet with large blocks of stone laid in cement mortar, the general slope being 1 to 1. The facing wall is of rough rubble masonry, 4 feet thick, standing on a slope or batter of 1 to 10. The two walls are joined at the top with a coping of large stones, forming the crest of the dam, 8 feet in width, 4 feet thick. The geological formation at the dam-site is peculiar. The floor of the reservoir basin is covered to a great depth with hard, blue clay, overlying which is a great sheet of sandstone and conglomerate rock or "pudding-stone" 100 feet or more in thickness. The dam was founded on the clay, and the facing-wall was carried down into it to a depth of 6 to

22 feet. The lower slope-wall was also founded on this clay at a depth of 10 feet from the surface. The general dimensions of the structure are: length at top, 600 feet; extreme height above floor of reservoir, 70 feet; height above foundation of face-wall, 92 feet; width on top, 8 feet. The main spillway is located in the center of the dam, and is 100 feet long by 4 feet deep. An auxiliary spillway, called a by-pass, is located at the west end of the dam, and is 40 feet in width. The total spillway capacity thus provided is about 4000 second-feet, while the outlet-pipes, eight in number, each 12 inches diameter, have a combined capacity of about 250 second-feet.

A "water-cushion" has been provided at the toe of the dam, to receive the impact of the waste water pouring over the structure and to prevent erosion of the toe. This is 25 feet wide, 200 feet long, and consists of a rock pavement, 3 to 6 feet deep, heavily grouted at the top with cement mortar.

The face-wall has been reinforced by an embankment of earth placed against it, and covered with stone riprap, 1 foot thick. This embankment reaches to within 30 feet of the top of the dam at the outlet-tower near the center, and rises to the full height at either extremity. The outlet-tower is a rectangular structure, built in the body of the dam, with a central opening of 6 × 7.5 feet reaching to the top. Into this the eight 12-inch outlet-pipes discharge at four successive levels, 6 feet apart from the base up, the gate-valves being placed inside the tower. From the base of the tower the water discharges into the creek channel through a 36-inch open pipe, made of concrete 4 feet thick, surrounding a cement pipe of standard dimensions. The water is picked up 1½ miles below the storage-dam by a low diverting-dam, 125 feet long, and conveyed through 40 miles of canals, with maximum capacity of 75 second-feet, to the lands irrigated and to an auxiliary reservoir, formed from a natural depression in the plain. This reservoir has a surface area of 60 acres and a capacity of 700 acre-feet, its maximum depth being 16 feet.

The construction of the Castlewood dam was attended by much opposition from the citizens of Denver, who were apprehensive of its safety and severely criticised the plan. Unsuccessful attempts were made to enjoin the construction, but it was finally permitted to be completed and has successfully withstood all floods to the present time. The facing-wall has shown no sign of settlement, but the main embankment settled a few inches, sufficiently to produce an unsightly crack in the center of the dam along the lower line of the face-wall. The coping-stones were subsequently relaid to true line again and no subsequent crack has developed. The canals and reservoirs have cost about $425,000. The dam was planned by A. M. Wells, C.E., of Denver, with Mr. Alfred P. Boller, M. Am. Soc. C. E., of New York, as consulting engineer. Fig. 24 (taken from *Engineer-*

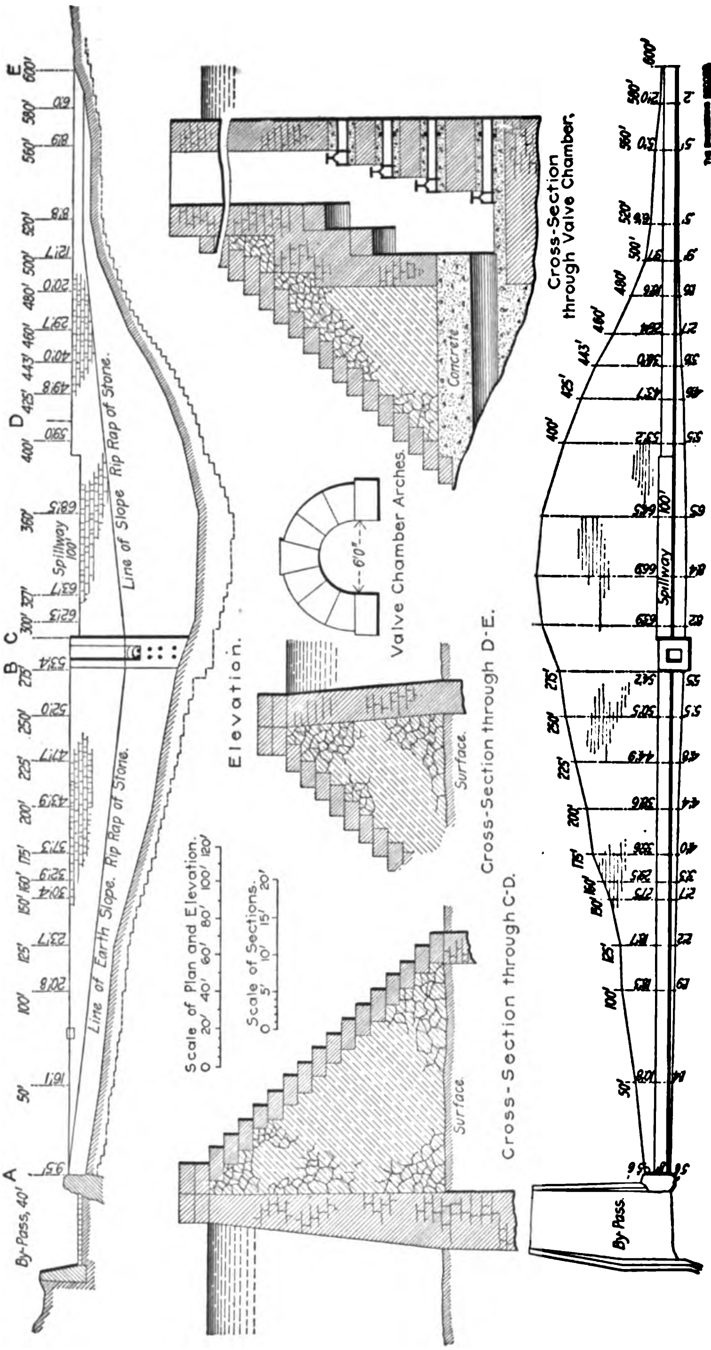


FIG. 24.—CASTLEWOOD DAM, COLORADO; PLAN, SECTIONS, AND ELEVATION.

Fig. 24a.—View of Castlewood Dam, Colo., during Construction, Looking North.

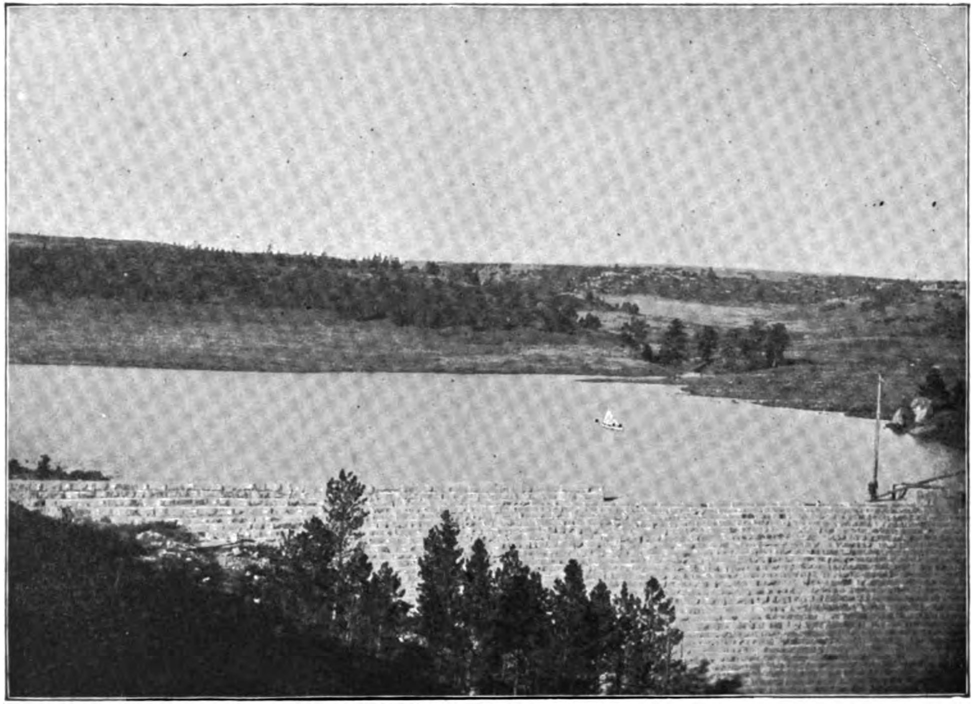

Fig. 24b.—View of Castlewood Dam and Reservoir, Colorado.

*ing Record*, Dec. 24, 1898, and reproduced by courtesy of that journal) illustrates the construction of the dam in plan, section, and elevation.

**Pecos Valley Rock-fill Dams, New Mexico.**—Two rock-fill dams with earth facings have been constructed across the Pecos River, in the Pecos Valley, New Mexico, which have boldly and successfully exemplified a distinct type of dam that is considered to be preferable to all other rock-fills where the proper conditions exist and suitable materials are obtainable. One of these dams is located 6 miles and the other 15 miles above the town of Eddy, N. M. They were built by the Pecos Irrigation and Improvement Company.

**Lake Avalon Dam.**—The lower dam, designated locally as the Lake Avalon dam, was built primarily as a means of raising the level of water of the river in order to divert it into a canal at a safe height above the reach of maximum floods, and at the same time to equalize the flow by providing

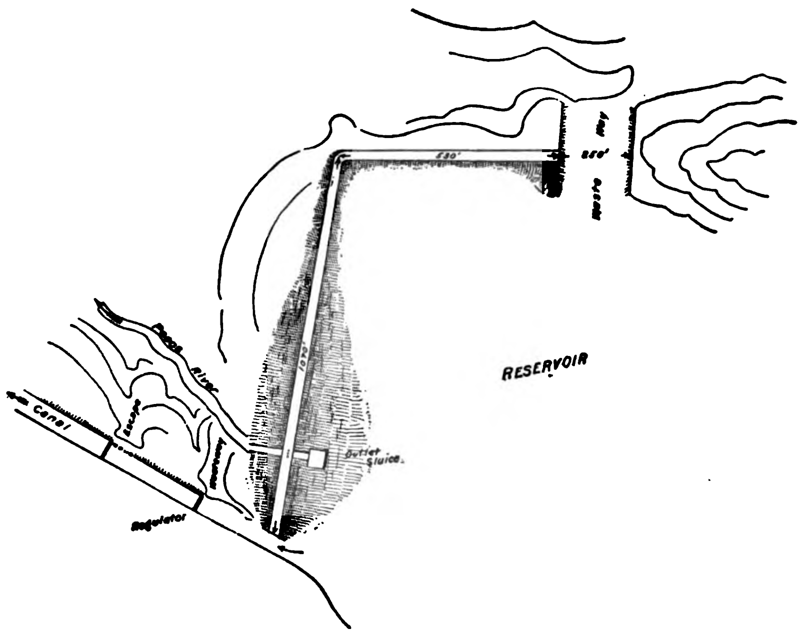


FIG. 25.—SKETCH-MAP OF DAM AT HEAD OF PECOS CANAL

a considerable volume of storage in the reservoir thus created. The present dimensions of the dam are as follows: length on crest, 1135 feet; maximum height, 48 feet; outer slope of rock-fill, $1\frac{1}{2}$ to 1; width of rock base, 106 feet; crown, 10 feet. The earth facing has also a crown width of 10 feet, making the total width 20 feet on top. The slope of the earth embankment that is built against the rock-fill is 3 to 1, which is covered with a revetment of loose stone 2 to 3 feet thick for wave protection. The rock-fill before the addition of the earth facing is illustrated by Fig. 26, a view taken during construction. Fig. 27 is a view of the finished dam, taken in 1892. The grade of the main canal leading out from the dam on the east side of the valley is 10 feet above the base of the dam, and is excavated in limestone to a maximum depth of 38 feet. Fig. 28 is a view of the main canal and headgates, taken from the lower side.

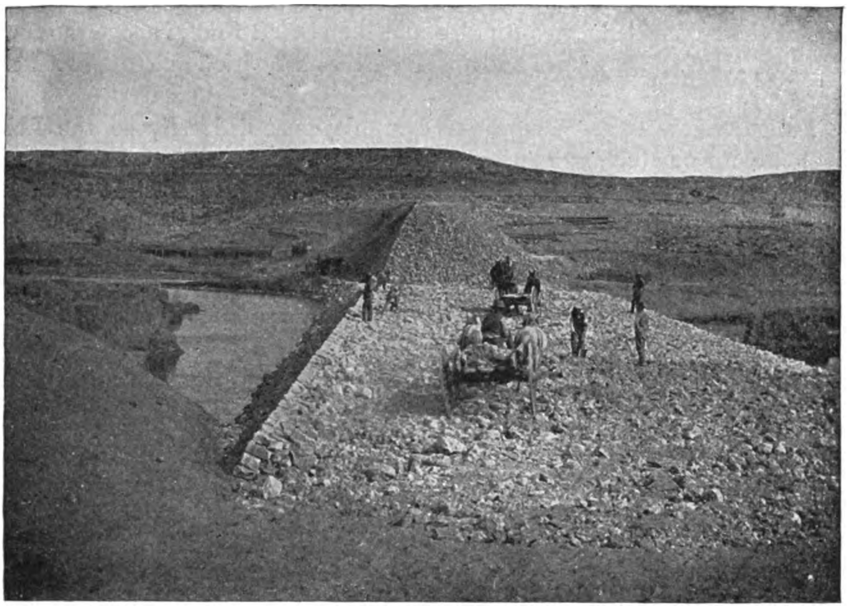

FIG. 26.—LAKE AVALON DAM. ROCK-FILL IN PROCESS OF CONSTRUCTION.

The dam was in service until August 3, 1893, when it was ruptured by a flood-wave that was in excess of the spillway capacity—the old story connected with dam failures. The water poured over its crest, and, as this style of dam is not calculated to withstand such an overflow, it speedily washed out a breach to the bed-rock over 300 feet in length. This was immediately repaired and built 5 feet higher, at a total cost of $86,000. The capacity of the open spillway at the west end of the dam was increased by widening it from 200 feet to a width of 240 feet, and by cutting it 3 feet deeper, making it begin to discharge while the water is 15 feet below the crest. A second spillway in rock was cut about half a mile to the west of spillway No. 1, having a length of 300 feet. In addition to these discharge-channels the main canal below the dam is so arranged that surplus water will begin to slop over its banks at a height of 13 feet above the bottom of the canal, over a length of about 200 feet. By opening the headgates and partially closing the secondary gates across the canal below, this slop-over can be given a large capacity of discharge. Ordinarily, however, the water-level in this section of canal is maintained to a depth of over 20 feet above the floor of the canal by a series of thirty-one gates placed on the side of the canal, parallel to it, and across the spillway. These gates are hinged at the sides, and are each 5 feet ½ inch wide by 7 feet 2 inches high. They can be opened in an emergency almost instantly by the stroke of a

FIG. 27.—LAKE AVALON DAM, PECOS RIVER, NEW MEXICO. SHOWING THE CREST OF COMPLETED DAM AND SPILLWAY DISCHARGING.

hammer upon a latch-releasing bar at each gate, when the pressure forces them to fly open like a door. The opening can be closed above the gates by flash-boards, permitting the closing and latching of the doors. (See Fig. 29, taken from *Engineering News*, Sept. 17, 1896.) The total capacity which the spillways now have is estimated at 33,000 second-feet, while the water-level is still below the top of the dam.

The original cost of the dam was about $90,000, and the reconstruction was therefore but little less than the first cost.

Mr. H. H. Cloud, formerly of the Colorado Midland Railroad, was the chief engineer of the dam, with Mr. E. S. Nettleton acting as consulting engineer, and Mr. Louis D. Blauvelt as principal assistant. Mr. Cloud ascribes the cause of the overtopping of the dam to the fact that the spillways were choked by the débris from bridges, together with the bodies of drowned cattle brought down by the river. Another account states that the gate-keeper and his assistants were in Eddy at the time, indulging in a drunken spree, and did not start for the dam until the only bridges across the river were washed away, and they could not cross. When they finally secured boats for crossing and reached the dam just before the disaster, they were unable to open the waste-gates because of a defect in construction, since remedied. It was believed that if the lateral waste-gates along the canal had been opened when the flood-wave first reached the dam, the relief thus afforded would have avoided the disaster. No loss of life was reported as a result of the flood, and but little property was damaged.

The reservoir capacity of Lake Avalon from the floor of the canal to the spillway-level is about 6300 acre-feet.

*Irrigation from Reservoir.*—The main canal, on the east side of the

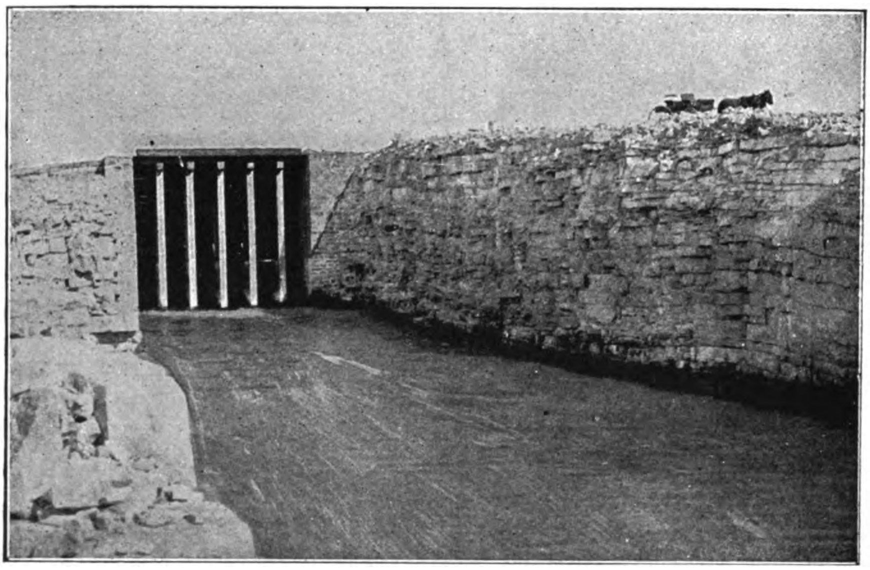

FIG. 28.—CANAL HEADGATES, LAKE AVALON DAM.

river, has a capacity of 1300 second-feet for 3.2 miles, to the junction of the Southern and East Side canals, the width on bottom being 15 feet, depth 7 feet, and grade 1.5 feet per mile. The Southern Canal from the junction down for 9 miles has a capacity of 680 feet. On this section the canal is carried across the river from the east side to the west, in a flume 468 feet long, 25 feet wide, 6 feet deep, supported on high trestle bents. The approaches consist of embankments, or "terre pleins," with maximum height of over 30 feet. The second section is 4.2 miles long with 460 second-feet capacity. The third section is 2 miles with 385 second-feet capacity, followed by 21.6 miles in which the maximum capacity is 215 second-feet—the bottom width being 14 feet and the depth 4 feet. The total length is 40 miles, although operated for but 31 miles.

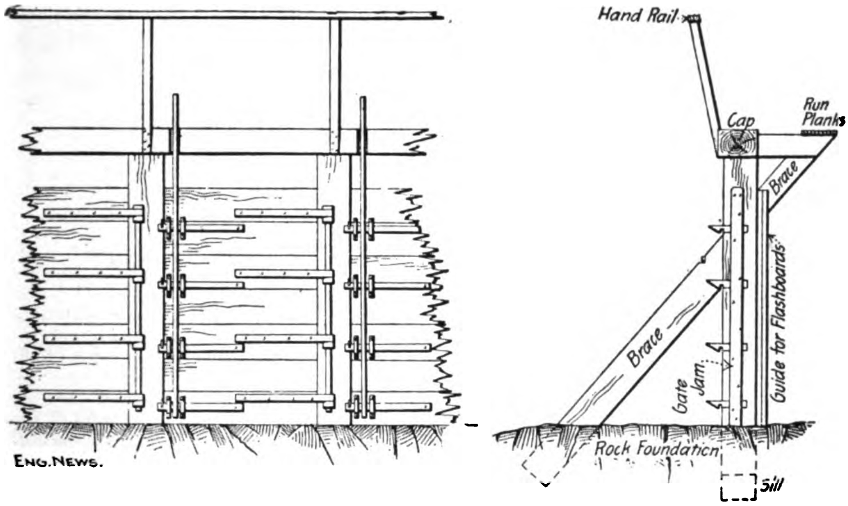


**Fig. 29.—Quick-opening Gates in Spillway of Lake Avalon Reservoir, Pecos Valley, N. M.**

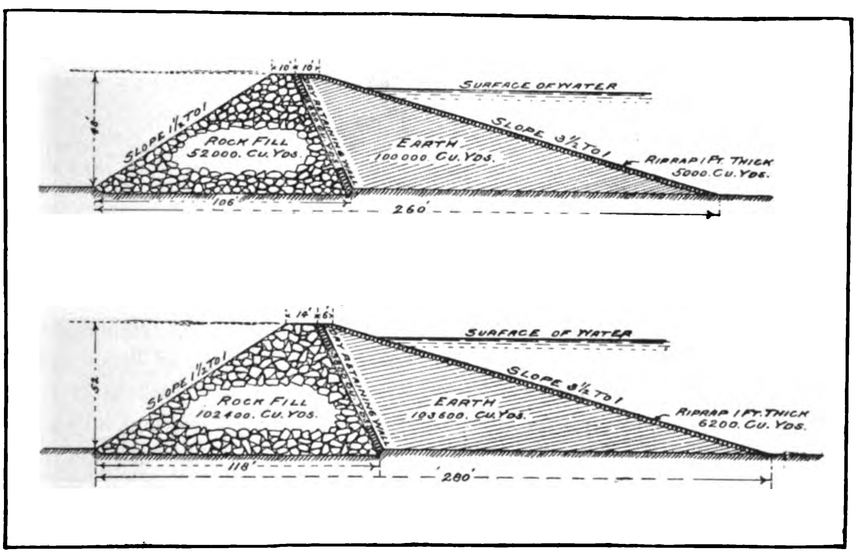


**Fig. 30.—Sections of Lake Avalon and Lake McMillan Rock-fill and Earth Dams, Pecos Valley, N. M.**

The East Side Canal is 19.6 miles long, with maximum capacity of 224 second-feet. The upper 4 miles only are used, and but 16 miles are available for service. The entire canal system has cost about $400,000 in all. The area irrigated from these canals in 1897 was as follows:

| | | |
|---|---|---|
| Southern Canal | 13,000 | acres. |
| East Side " | 2,500 | " |
| Total | 15,500 | " |

The area commanded by these two canals is 110,000 acres, of which 90,000 acres are under the main Southern Canal.

*Water-tightness of Lake Avalon Dam.*—The dam is apparently free from direct leakage through it, although water stands in a pool at the base

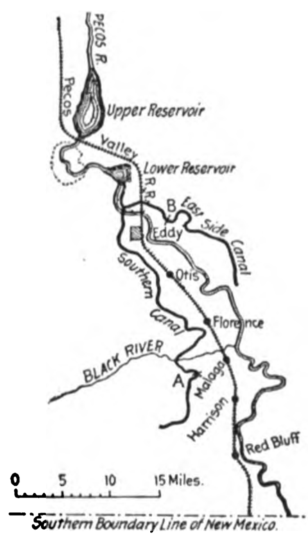


FIG. 31.—SKETCH-MAP OF PECOS VALLEY CANALS.

of the dam, which is believed to come from springs, issuing from the rock. From the dam down for several miles there are springs of large volume coming out on the river-banks, whose total flow at the stone dam at Eddy, as measured by the writer in October, 1897, was approximately 90 second-feet. Since the construction of the reservoir these springs are said to be increasing in number and volume. The largest one, flowing 5 to 6 second. feet, broke out in a new place in 1896, some 3 miles below the dam. Distinct swirls and miniature maelstroms have been observed on the surface of both reservoirs, from which it is surmised that water in considerable quantity is thus lost through the limestone formation, and that some of the springs are fed from this source, although many were in existence prior to

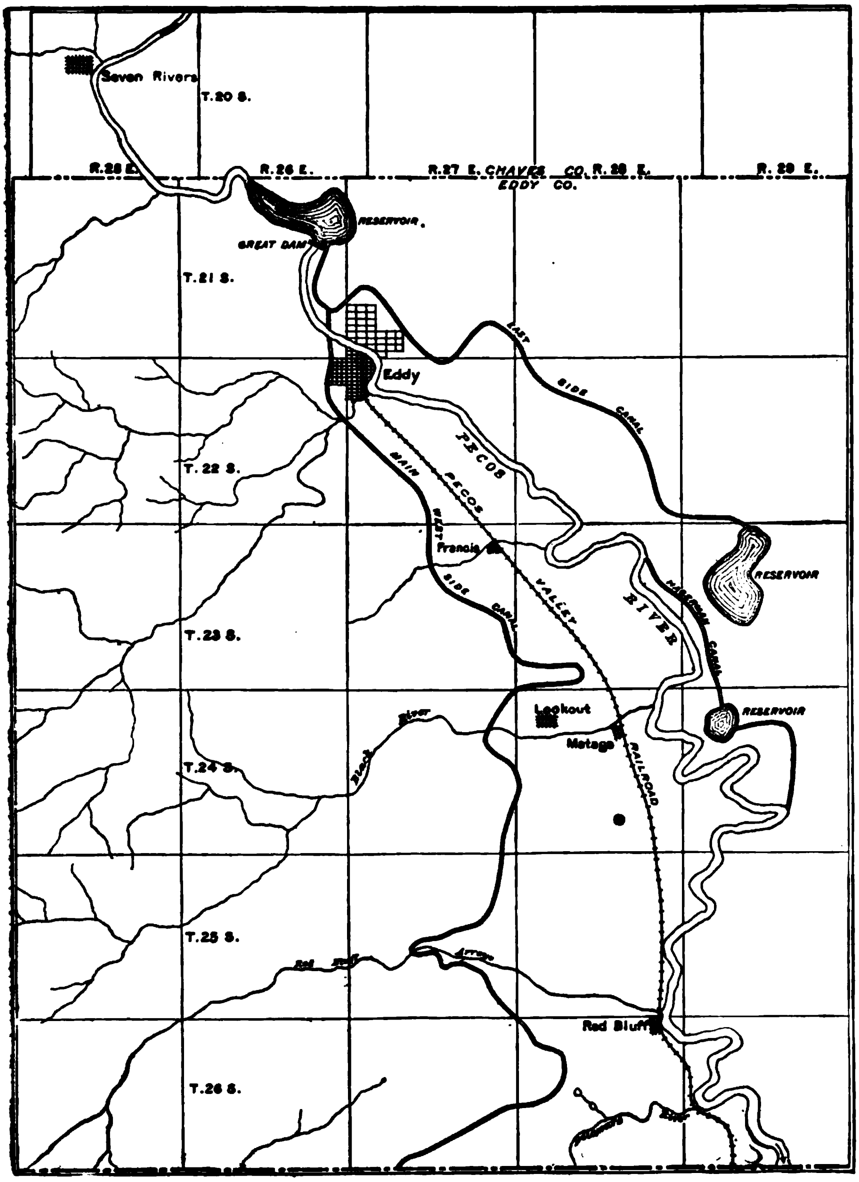


**Fig. 33. —Map of Pecos Valley, N. M., showing Location of Reservoirs and Canals.**

the building of the dams. This "leakage" does not in any manner affect the stability of the dams and is of interest chiefly because of the fact that reservoirs in limestone formation are generally to be expected to be subject to similar losses, and in this case the illustration is specially well marked and visible.

**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., $1\frac{1}{2}$ 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, 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, " ........... | ..... | 15.82 | 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. 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, some of whose possibilities are discussed in subsequent pages.

**Duty of Water in Pecos Valley.**—From all the evidence obtainable it is concluded that the average consumption of water in Pecos Valley the first year of irrigation is 4 to 5 acre-feet per acre, and the ultimate duty after the third or fourth year is about 2 acre-feet per acre, including all losses by percolation, leakage, and evaporation in the canals. Alfalfa requires about three-fourths of a foot at the first watering each year, and yields four crops, needing one good irrigation of half a foot in depth at each cutting. Sugar-beets, planted in June, have to be irrigated three or four times, besides the watering needed for preparing the ground. They take about one-third of a foot at each irrigation. Small grain, sown in October, is irrigated once before sowing and once in November or December. In March, when dry winds prevail, the surface has to be wetted every ten days. In all six or seven irrigations, consuming about 2 acre-feet per acre, are required. Orchards need three to six irrigations. The labor-cost of irrigation averages about 15 cents for each application, and the cost of water is $1.25 per acre for the entire season, regardless of the volume used.

**The Walnut Grove Rock-fill Dam, Arizona.**—Among 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

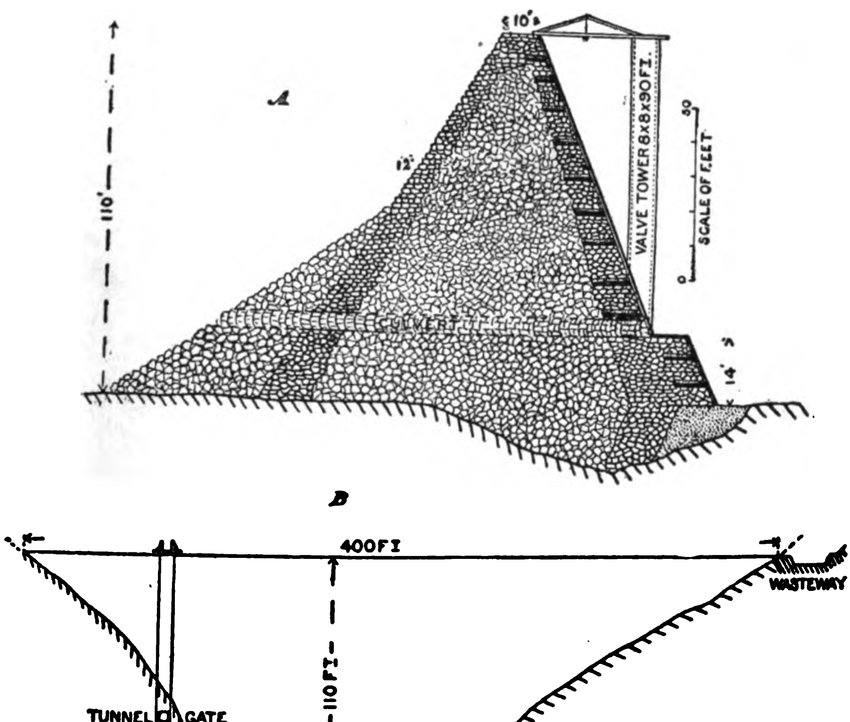


FIG. 33.—CROSS-SECTION AND ELEVATION OF WALNUT GROVE DAM, ARIZONA.

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

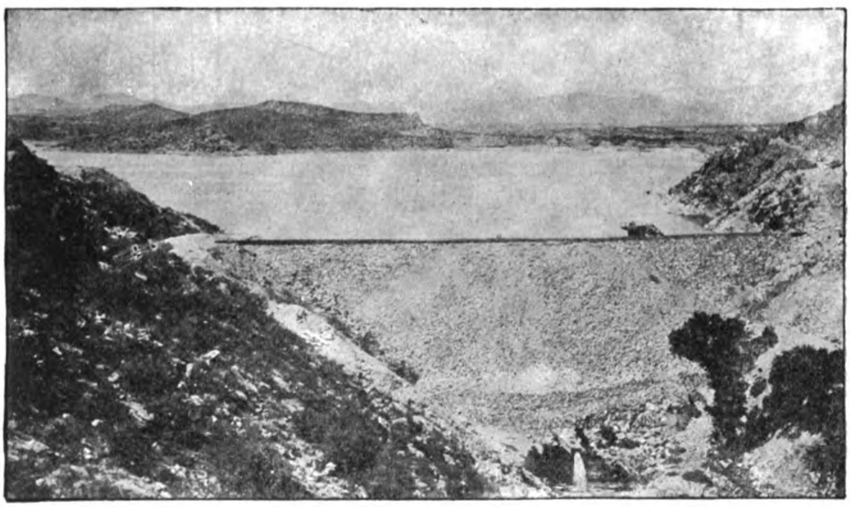

FIG. 34. VIEW OF WALNUT GROVE DAM, ARIZONA.

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 cars to pass the empty car. 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), who barely escaped with his life.

The original owners of the property have had in contemplation for some time past the reconstruction of the dam in a substantial manner, although plans for the new structure have not been made public.

**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 5700 acre-feet capacity, to be used for irrigation, supplementary to the supply of the Davis and Weber Counties Canal Company.

The dam is 68 feet high above the creek-bed, where the width of the canyon is but 50 feet. The length of the dam on top is 100 feet.

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 $\frac{3}{4}$ 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. 35. 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 remained with full head of water against it for several months without apparent leakage, except through crevices in the bed-rock, and it is believed the expense of repairs will be light. The total cost of the structure was $40,000.

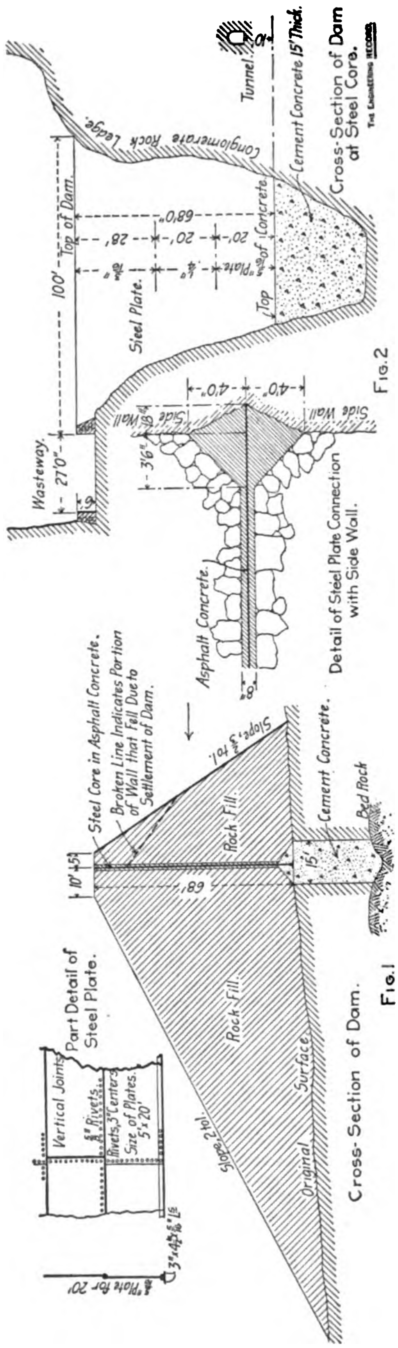


**FIG. 35.—EAST CANYON CREEK DAM, UTAH. ROCK-FILL WITH STEEL CORE**

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.

**Denver Water Company's Rock-fill Dam.**—The third American dam where steel plates are employed to give water-tightness to a rock-fill is in process of erection on the South Fork of the South Platte River, 48 miles above Denver, Colorado, by the Denver Union Water Company. It is the highest and most pretentious dam of its class that has ever been projected, and when completed it will be one of the highest dams in the world. Its estimated cost is $350,000. It is to be 210 feet high, 600 feet long at top, and have a base of 450 feet, up and down the canyon. The dam is being constructed as a rock-fill, loosely dumped from cars that run by gravity from the quarries out upon a bridge that spans the canyon above the top of the dam. The lower slope is $1\frac{1}{2}$ to 1, and the upper slope $\frac{1}{2}$ to 1, with a dry, hand-laid wall, 15 feet thick at bottom, 5 feet in thickness at top, on the water-face. Over the face of this wall on the slope is placed a web or skin of sheet-steel plates, 1130 in number, dipped in asphalt, and riveted to 6-inch T beams, placed 5 feet apart, and resting against the wall. The plates are flanged at the side of the canyon and bolted to the solid granite, with split bolts, driven 1 foot deep into the rock. The space between the plates and the face of the dry wall is filled with concrete, and the entire sheet is covered with a layer of concrete from the bottom up to a height of 126 feet, or 10 feet above the top of the upper outlet or spillway tunnel. The plates are $5' \times 10' \times \frac{3}{8}''$ thick for 75 feet in height; then for the second 75 feet the thickness is reduced to $\frac{5}{16}$ inch, and for the remaining 60 feet to $\frac{1}{4}$ inch in thickness, the size being uniform throughout. For the upper 80 feet the plates will be unprotected from the action of the elements, except by such paint as may be applied from time to time. The spillway tunnel being located below this level permits the inspection of the exposed plates at any time by drawing down the water of the reservoir. The gorge is an exceptionally narrow one, and the walls are of remarkably hard granite, of close texture, and comparatively free from seams or fissures. Indeed the site would be regarded as a particularly favorable one for a masonry dam, although its remoteness in the mountain fastnesses would render the cost of cement for masonry very high. At the extreme base, which is 18 feet below the outlet tunnel, the width between canyon walls is but 43 feet. The volume of rock required for the structure is estimated at 225,000 cubic yards, which is very small indeed for an embankment of such unusual height.

*Outlet.*—The main reservoir outlet is a tunnel starting 100 feet above the dam at the base, and piercing the spur of the mountain, forming one of the abutments of the dam. This tunnel is 7 feet wide, and 6 feet high for about half its length, to the junction with the inclined spillway tunnel, whence its size is increased to 8 feet wide and 9 feet high, the total length being 470 feet.

The spillway tunnel starts 110 feet above the lower tunnel and dips at an incline of 45° to its intersection with the lower tunnel. Its size is $7 \times 6$ feet. Both tunnels are controlled at the upper end by balanced valves, set over the tunnel-mouth at an incline of 30° from the horizontal. These valves are closed by gravity, and opened by hydraulic pressure conveyed to the cylinders at one end of the valves through lead-lined steel pipes, laid in trenches surrounded by concrete, from the valves to a reservoir located at suitable height on the adjacent mountainside. When submerged there will be no other connection with the surface, and no other means of moving the valves. The opening of a faucet will put on the pressure that will open the valves and release the water from the reservoir, and the entire operation will be out of sight and perfectly noiseless. The valve was made from drawings prepared by the chief engineer, Mr. Charles P. Allen, to whose courtesy the writer is indebted for the accompanying illustrations. Fig. 36 illustrates the construction of the valve, which consists of four

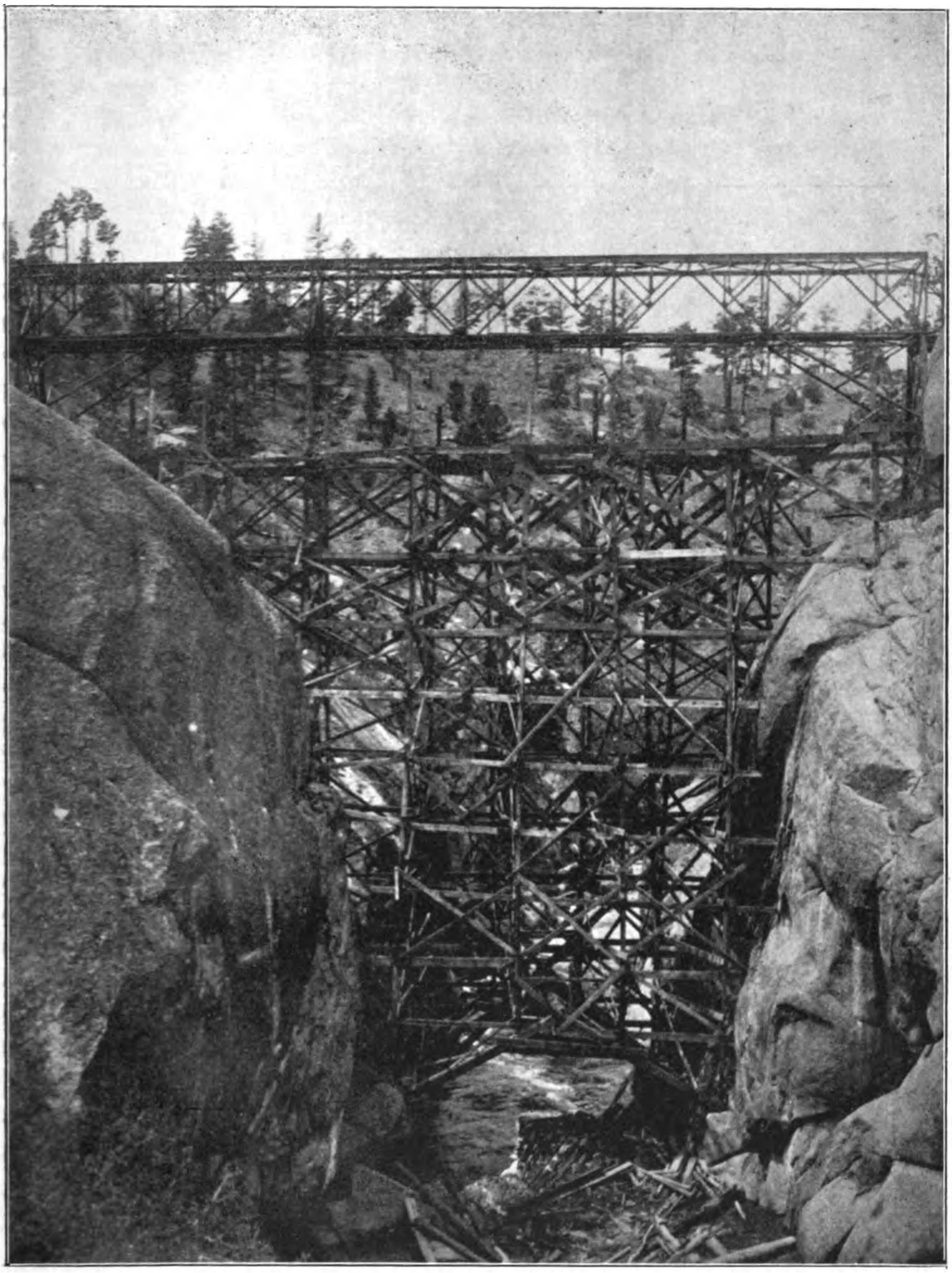

FIG. 37.—SOUTH PLATTE ROCK-FILL DAM. VIEW OF FALSE WORK AND BRIDGE OVER THE DAM-SITE.
The stone for the rock-filling is dumped from the top of this bridge to the canyon below.

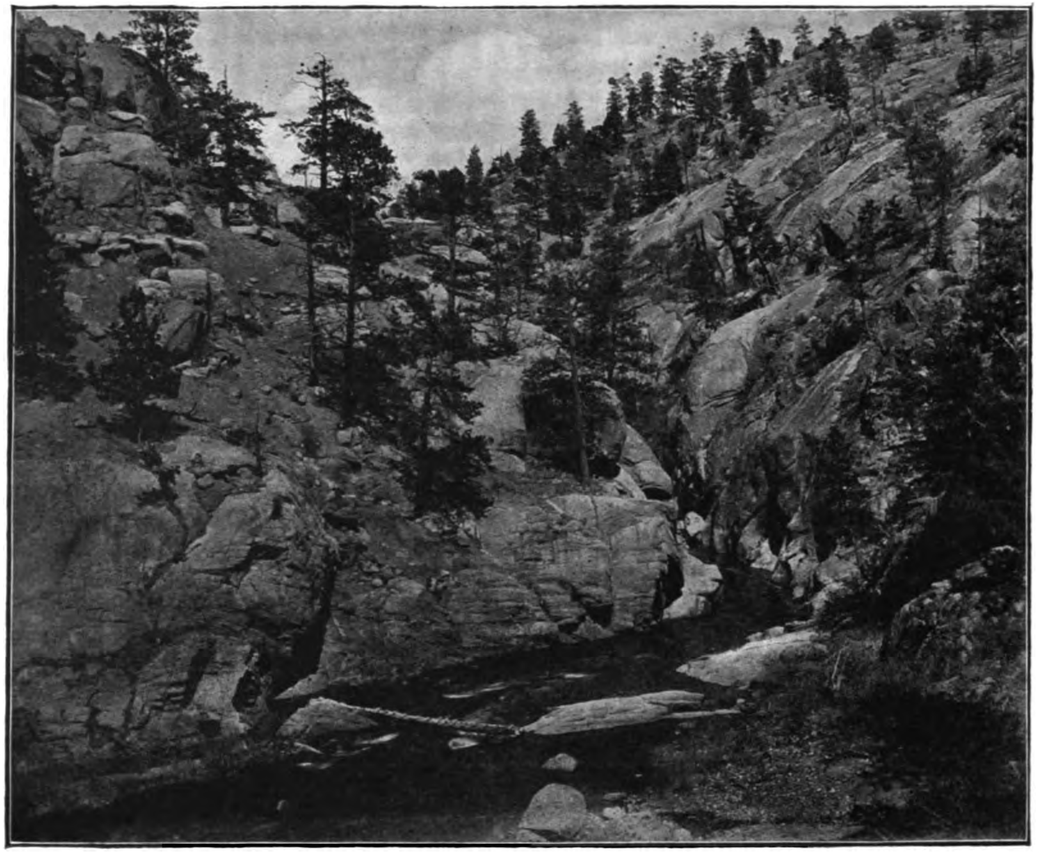

FIG. 37a.—SITE OF DAM, SOUTH PLATTE RESERVOIR-SITE—ABOVE.

[To face page 71.

and all the moving parts of the valves are accessible from the chambers in which they are placed, and from which the water is excluded by concrete walls separating the chamber from the tunnel proper.

The reservoir, when full, will cover 775 acres and extend up the canyon a distance of 7 miles. Its maximum capacity will be 67,210 acre-feet, or 21,900,000,000 gallons. A table of contents and areas at different levels will be found in the Appendix.

This site was examined, surveyed, and reported upon favorably in 1897 by Col. H. M. Chittenden, Corps of Engineers, U. S. A., under authority of the Congressional River and Harbor Act of June 3, 1896, directing an examination of at least one site each in the States of Wyoming and Colorado "for the storage and utilization of water, to prevent floods and overflows, erosion of river banks and breaks of levees, and to reinforce the flow of streams during drought and low-water seasons."

In his able and exhaustive report on this subject Col. Chittenden says: "This site is remarkable in affording an excellent place for a high masonry dam." He recommends a dam 200 feet high, on curved plan, with 300 feet radius, whose cubical contents would be 75,200 cubic yards. His estimate of cost was $540,000. The area of watershed above the dam is given at 1645.2 square miles, and the volume which could probably be stored annually at 43,620 acre-feet, or a mean of 60 second-feet. The average run-off for 1896, a low year, was estimated to be about 166 second-feet past the dam-site. The loss by evaporation he estimates at not exceeding 100,000,000 cubic feet annually.

The dam was expected to reach the height of 100 feet by May, 1900. Fig. 37 shows the false work for the erection of the bridge across the canyon, from which the rock is dumped. This bridge rests on trestle piers at the ends, which are long enough to permit the bridge to be moved up and down stream to facilitate the spreading of the rock-fill uniformly over its base. The outlines of the reservoir are shown on Fig. 38.

**The English Dam, California.**—Among the earlier constructions of the rock-fill type was one known as the English dam, situated on the headwaters of the Middle Fork of the Yuba River, in California, at an elevation of 6140 feet, which was destroyed June 17, 1883. The reservoir was formed by means of three timber crib-dams, and covered an area of 395 acres, impounding 650,000,000 feet of water. It was supplied by the run-off from a drainage area of 12.1 square miles, reaching to the summit of the Sierra Nevada. The middle dam, the largest of the three and the one which was subsequently destroyed, had a vertical height of 100 feet on the interior, and 131 feet on the exterior, above the deepest part of the foundation. Its thickness at base was 185 feet, length on top 331 feet, and bottom length about 50 feet. The original construction consisted of a crib made of tamarack logs, 79 feet high, 100 feet thick at base, with inner slope of 60° from

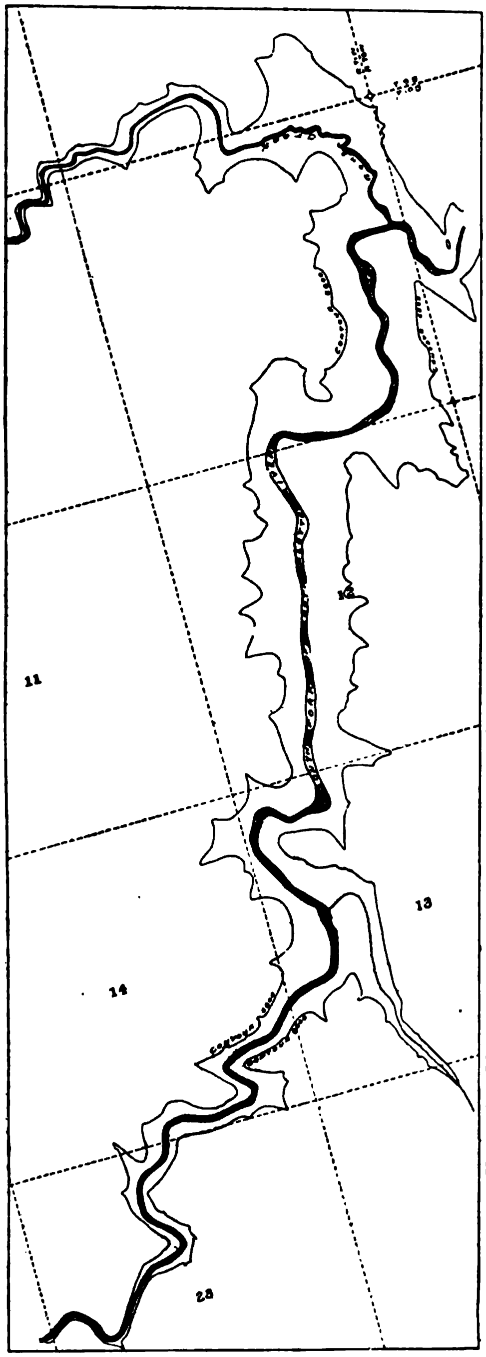


FIG. 38.—MAP OF RESERVOIR FORMED BY ROCK-FILL DAM ON SOUTH PLATTE RIVER, COLORADO.

the horizontal, the crib being filled with rock, and the whole structure faced with plank. It was built in 1856, and repaired in 1876–77, by tearing out the decayed portion of the old crib and replacing it with new timbers. At the same time an addition to the thickness and height was made by building a stone facing on the outside, laid up as a dry rubble wall, on a slope of 44°. This wall was carried up to a height of 14 feet above the top of the original dam, meeting a similar wall laid on the inner slope. The upper 7 feet was formed of a substantial timber cribwork. The addition to the dam cost $70,000, and the entire cost of the three structures was $155,000, or $10.40 per acre-foot of storage capacity. The high-water mark, or the spillway-level, was 14 inches below the top of the upper cribwork. From the time the repairs were completed until the destruction of the dam, about five years, no signs of weakness or leakage were manifest, and the water-level was raised annually to the high-water mark. On the evening before the break the water-level was 2½ inches below the spillway. The first intimation given of the break was at 5.30 A.M., when the watchman heard two violent explosions, and on reaching a point where he could see the dam he observed the water pouring through a wide breach in the upper cribwork. It was inferred that the break had been caused by dynamite. In a few moments the water cut an immense gap through the structure to its very foundation and the entire contents of the reservoir were emptied inside of an hour. The flood-wave caused a rise of 40 feet at a point 43 miles below. At Marysville, 85 miles below, the rise observed was but 2 feet 8 inches, and at Sacramento the extreme rise was but 8 inches. The damage done by the flood was estimated at about $4000 to some wheat-fields that were overflowed. The flood was 24 hours in reaching Sacramento, and the total time in passing that point was 26 hours. Had the break occurred in time of flood the opinion is expressed by A. J. Bowie, M.E., that it would not have been observed by a marked increase in the level of the larger streams of the Sacramento Valley—the Feather and Sacramento rivers.* While the composite character of this structure, and its age at the time of its failure, would lessen confidence in its stability, it is the only one of its type which has given way, and the circumstances seem to point to malice rather than inherent weakness as the possible cause of its failure.

The volume of water released by the breaking of the dam was about 600,000,000 cubic feet, which exceeded by nearly 20% the contents of the South Fork reservoir whose failure produced the frightful Johnstown, Penn., disaster in 1889, and that there was no loss of life resulting from it and very slight property damage is quite remarkable.

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* Transactions Technical Society of the Pacific Coast, vol. II. page 10.—A Paper on the Destruction of the English Dam.

**The Bowman Dam.**—The timber-crib rock-filled dams of the mining regions of California are well illustrated by the Bowman dam, located on the South Fork of Yuba River, and impounding the drainage from 19 square miles of the higher Sierras.

The dam was built in 1872 to the height of 72 feet in a manner similar to the original construction of the English dam, consisting of a timber crib of unhewn cedar and tamarack logs, notched and bolted together and filled with small stones. The slopes on each side were 1 on 1, and the face was made with a skin of pine planking, laid horizontally. In 1875 the dam was raised to the extreme height of 100 feet, by adding an embankment of stone to the lower slope, wide enough to carry the entire structure, including the crib-dam, to the desired height. The outer face of this embankment was made as a hand-laid dry rubble wall in which stone of large size were used. This wall is 15 to 18 feet thick at base, and 6 to 8 feet at the top, the stone weighing from ¾ ton to 4½ tons. Vertical ribs were bolted to the wall on the water-face, with ¾-inch rods, 5 feet long, and to these the plank were spiked. These were 9 inches thick, in three layers, for the bottom 25 feet, 6 inches thick for the next 35 feet in height, and 3 inches thick on the upper 36 feet. The outlet to the reservoir is arranged by three 18-inch wrought-iron riveted pipes, about 25 feet long each, extending from the inner face of the dam to a culvert, built in the dam from the lower side to the gates placed at the outlet end of these pipes. The combined discharging capacity of the pipes is 280 second-feet, when the reservoir is full. They discharge into a covered sluice or flume in the bottom of the culvert, 21 inches high, 7½ feet wide. The gates are approached by a walk above this flume. The culvert is 8 feet high, 7.5 feet wide at bottom, 5½ feet at top, made of dry rubble side walls, covered with heavy granite slabs, 18 inches thick, 6.5 feet long.

The dam is 425 feet long on top, and has a base thickness of 180 feet. Its contents are 55,000 cubic yards, and its cost was $151,521.44.

Like many of the earlier types of rock-fill dams it was built with an obtuse angle in the center, whose apex is pointed up-stream. This angle is 165°. Its purpose was evidently to give a fancied additional security, and was the nearest approach to the arched form which could conveniently be given to such a structure.

The reservoir covers an area of nearly 500 acres, when full, and has a maximum capacity of 918,000,000 cubic feet, or 21,070 acre-feet. Its cost was therefore an average of $7.19 per acre-foot of storage capacity.

The annual precipitation at the Bowman dam, as recorded for sixteen years prior to 1887, ranged from a minimum of 44 inches to a maximum of 120 inches, the mean being about 72 inches. The watershed is of a character to yield maximum run-off estimated at 75% of mean precipitation. Maximum floods from melting snows reach 5000 to 7000 cubic feet per

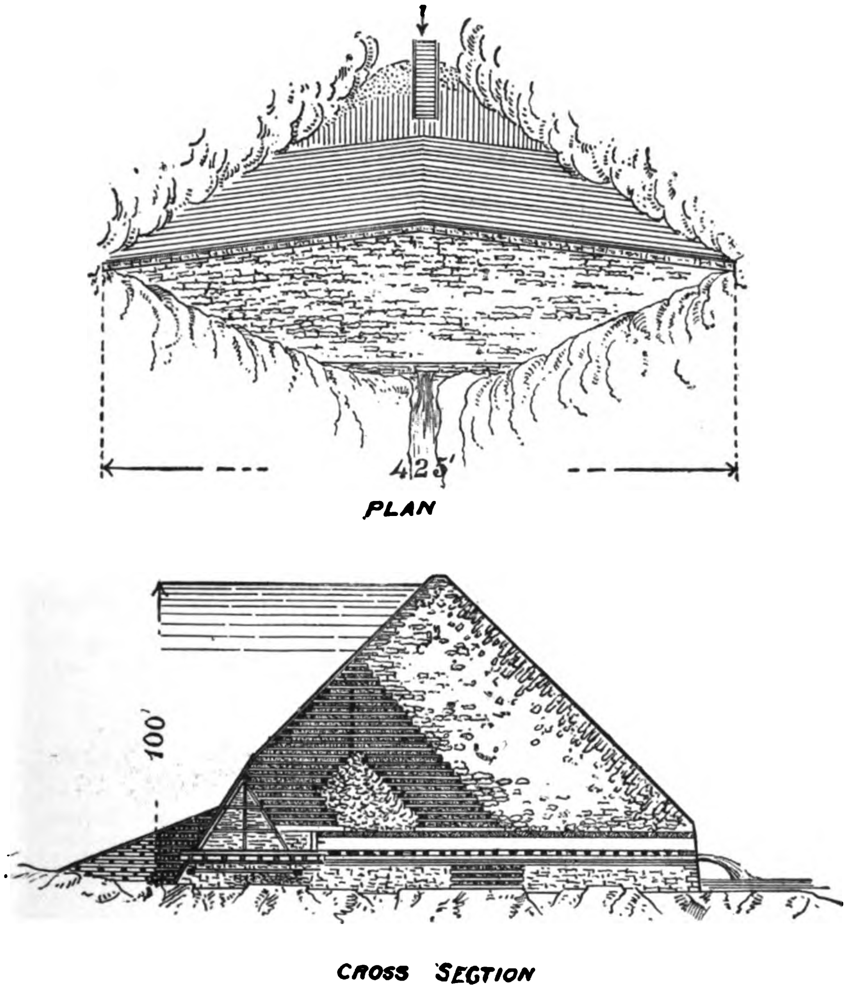


**Fig. 88a.—Plan and Cross-section of the Bowman Dam, an Early Type of the California Rock-fill Dam for Hydraulic Mining Storage.**

[*To face page 74.*

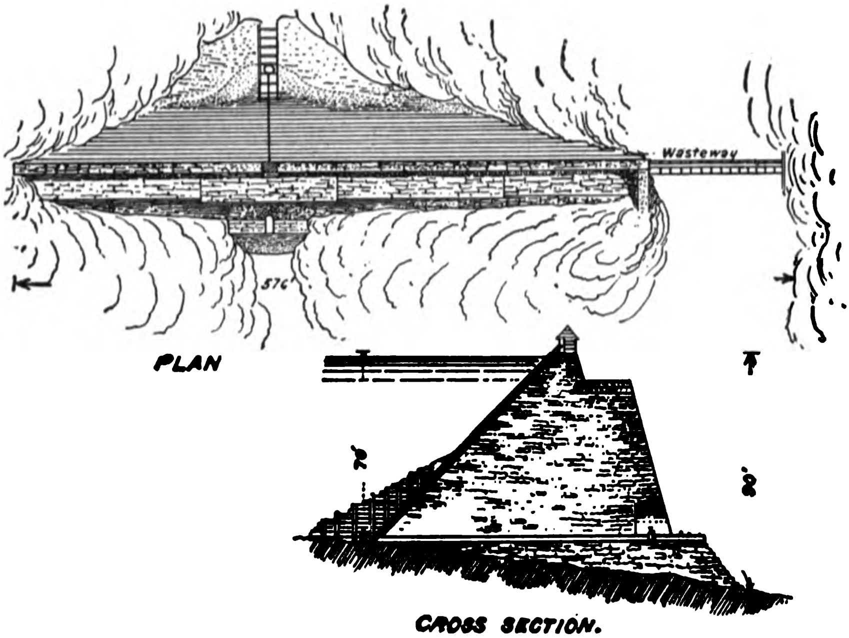


FIG. 88b.—PLAN AND CROSS-SECTION OF THE FORDYCE ROCK-FILL DAM, CALIFORNIA.

[To face page 75.

second. The minimum annual rainfall is sufficient to give ample run-off to fill the reservoir, while the maximum precipitation would yield sufficient to fill it four times in one year. The crest of the spillway is placed but 18 inches below the crest of the dam. The latter is made as a coping of hewn cedar, 18 inches wide on top, anchored by iron bolts into the wall. The structure is so well built that a few inches depth of water overflowing the crest of the dam would pass off without injury to the lower slope-wall. The reservoir is owned by the North Bloomfield Mining Company, and the water is used for hydraulic mining.

The same company have four smaller reservoirs of similar type, constructed at a total cost of $95,000. The following table gives the capacity of the principal mining-reservoirs of California, which have been the prototypes of rock-fill dam construction in the West, some of which have been more fully described in the foregoing pages. Many of them are located at the sites of natural lakes whose surfaces have been raised by the erection of dams at their outlets.

CAPACITY OF THE PRINCIPAL MINING-RESERVOIRS OF THE HYDRAULIC MINING DISTRICTS OF NORTHERN CALIFORNIA.

| Name. | Company. | Capacity of Reservoir. | Area. | Height of Dam. | Length of Dam. |
|---|---|---|---|---|---|
| | | Cubic Feet. | Acres. | Feet. | Feet. |
| Bowman........... | North Bloomfield Mining Co. | 900,000,000 | 500.0 | 100.0 | 425 |
| Shotgun Lake...... | Do. | 3,423,000 | 26.2 | 10.0 | .......... |
| Inland Lake........ | Do. | 23,028,000 | 48.8 | 12.8 | .......... |
| Middle Lake........ | Do. | 2,395,800 | ........ | ........ | .......... |
| Round Lake........ | Do. | 2,907,700 | 10.3 | 3.0 | .......... |
| Weaver Lake...... | Eureka Lake Mining Co. | 150,000,000 | 83.5 | 21.8 | .......... |
| Eureka Lake....... | Do. | 661,000 000 | 337.3 | 68.2 | .......... |
| Faucherie Lake .... | Do. | 58,800,000 | 90.0 | 21.0 | .......... |
| Jackson Lake....... | Do. | 15,000,000 | 20.0 | 5.0 | 250 |
| Smaller lakes...... | Do. | 50,000,000 | .......... | .......... | .......... |
| English dam....... | Milton Mining Co. | 650,000,000 | 395.0 | 131.0 | 331 |
| Fordyce dam....... | South Yuba Mining Co. | 1,075,525,000 | 1,200.0 | 75.0 | 650 |
| Meadow Lake...... | Do. | 107,950,000 | 262.0 | 28.0 | 500 |
| Sterling Lake...... | Do. | 53,975 000 | ......... | 30.0 | 300 |
| Omega ............ | .................... | 300,000,000 | .......... | .......... | .......... |
| California ......... | .................... | 1,071,000,000 | .......... | .......... | .......... |

## CHAPTER II.

### HYDRAULIC-FILL DAM-CONSTRUCTION.

THE forces employed in hydraulic mining for tearing down a bank of sand, by the use of a large volume of water issuing from a nozzle under pressure, gravel, and rock, and transporting the materials considerable distances on suitable grades while suspended in water and depositing them where desired, have been utilized in the evolution of a novel and interesting type of dam-construction, which in many localities can be applied successfully where the cost by other methods would be prohibitive. The conditions required for the successful employment of hydraulic-dam construction are:

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

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; and

3d. A suitable foundation, which is, of course, requisite in all dams.

The volume of water necessary for a "sluicing-head" should be from 5 to 10 cubic feet per second, although smaller heads may be used. Ten 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 percentage 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 2000 to 4000 cubic yards per 24 hours.

The most suitable material is an admixture of soil, sand, and gravel of all sizes. Small angular stones, not exceeding 100 lbs. weight, may be carried through the sluice-boxes with a sufficient amount of sand and soil 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.

**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 2½ 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 120 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 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. 39, in which are

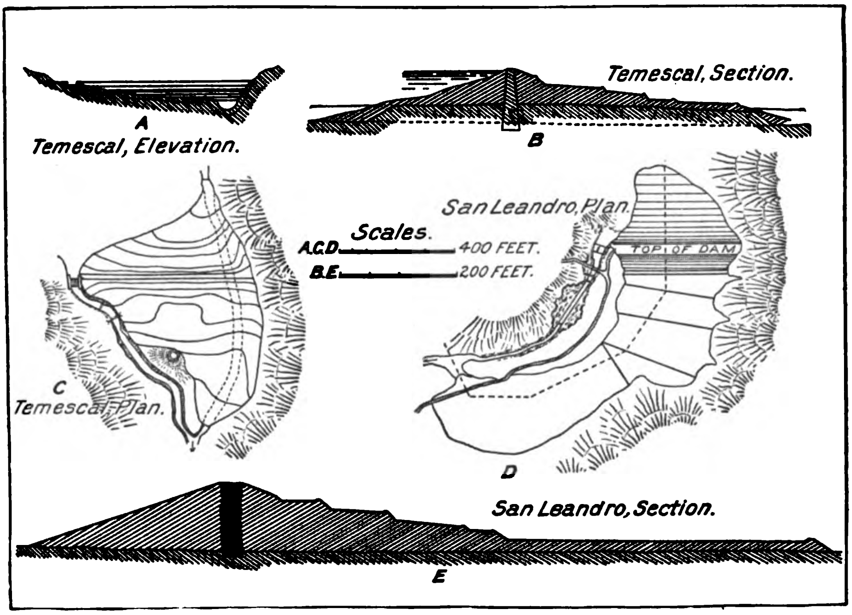


FIG. 39.—PLANS AND CROSS-SECTIONS OF SAN LEANDRO AND TEMESCAL DAMS.

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., was but 4¾ cents per cubic yard. The dam, Fig. 40, is 575 feet long on

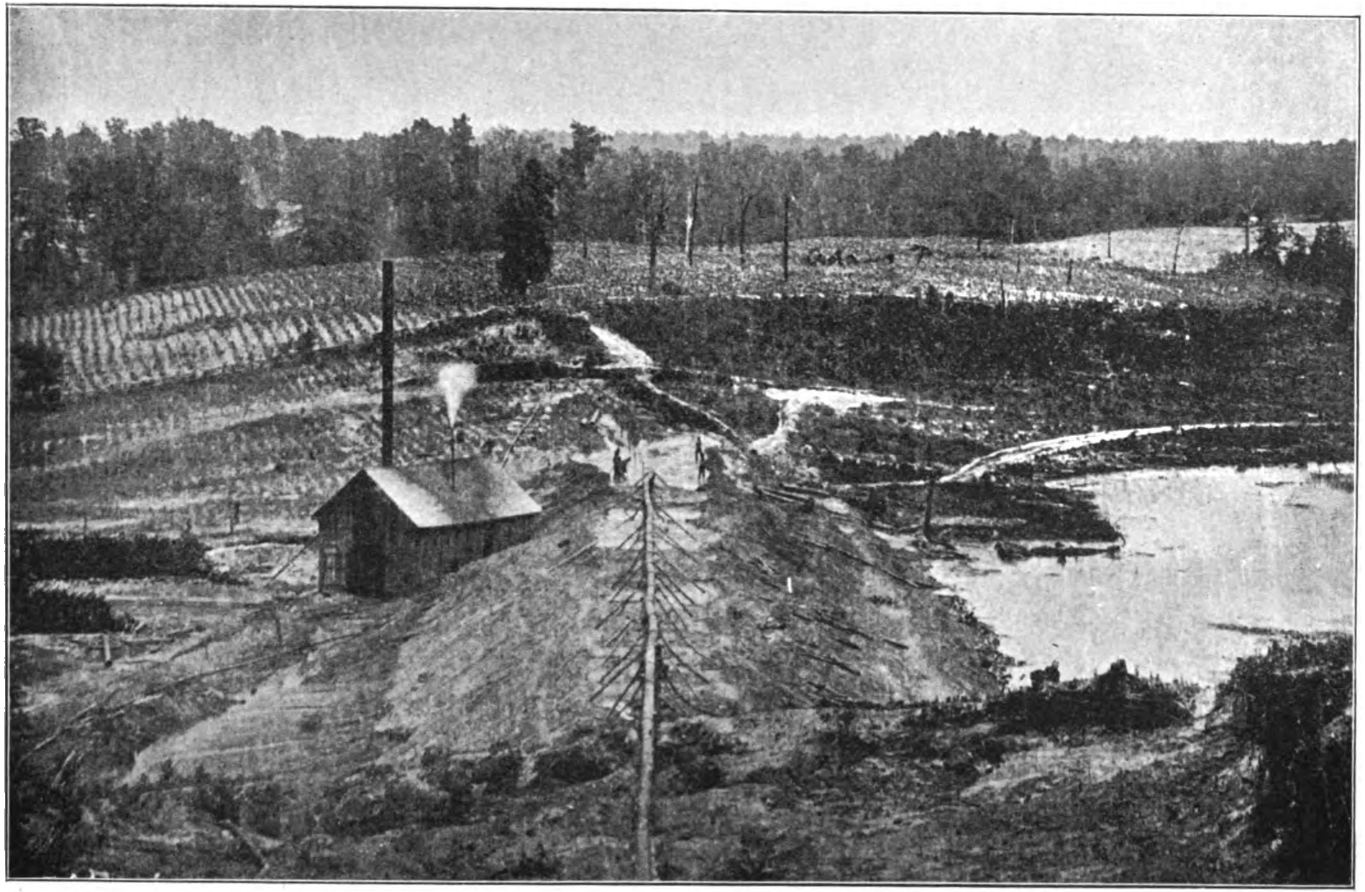

FIG. 40.—HYDRAULIC-FILL DAM AT TYLER, TEXAS, SHOWING DELIVERY-PIPE SUPPORTED ON A GRADE-LINE, CARRYING MATERIAL TO OPPOSITE SIDE, AND SPILL-WAY CUT MADE BY SLUICING THE EARTH INTO BASE OF DAM.

FIG. 41.—HYDRAULIC SLUICING FOR BUILDING DAM AT TYLER, TEXAS.
The small stream here shown did the entire work.

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 2½-inch fire-hose, with a nozzle of 1½ 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. 41). 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. 42). 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. 43 and 45) 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. 42.—Hydraulic-fill Dam, at Tyler, Texas, in Process of Construction. Water supplied by pump in building at right of picture.

FIG. 48.—VIEW OF FINISHED DAM AND WASTEWAY OF LA MESA RESERVOIR.

Fig. 48*a*.—La Mesa (Cal.) Dam in Course of Construction by the Hydraulic Process.
Showing method of loosening earth to get it in suspension before taking it into carrying conduit. The conduit was built in 20-foot sections, which could be and were frequently taken apart and moved as conditions required.

methods in a modified form to the erection of La Mesa dam. The situation and materials available were less favorable than at Tyler, and it was not possible to obtain water under pressure for disintegrating the soil. Hence it was necessary to resort to ground-sluicing alone.

The dam-site is in a narrow gorge cut through hard porphyry, whose walls are but 40 feet apart at the stream-bed, and stand nearly vertical on one side for 40 feet in height, from which elevation the ground slopes gently upward on both sides. The site had been regarded as particularly suitable for a masonry or rock-fill dam, as the foundations were of the best character and the materials at hand all that could be desired. With these advantages in view the first plans made were for a rock-fill with plank facing, of the following dimensions: height, 55 feet; length on top, 470 feet; thickness at base, 110 feet; at top, 12 feet; upper slope, ½ to 1; lower slope, 1 to 1; volume, 15,000 cubic yards. Bids were received on these plans, the lowest of which called for 99 cents per cubic yard for the rock-fill, and $2.08 for dry rubble wall. These prices are but 55% to 66% of the contract prices paid for the Escondido dam. The total cost under these bids would have been $20,260, exclusive of the plank facing and the outlet-gates and pipes. The hydraulic-fill dam proposed by Mr. Howells was given the preference by the company on a guarantee of a material reduction of cost below the bids for the rock-fill dam, and, although numerous difficulties were encountered, it was finally completed for about $17,000, including plant, excavations for foundations and spillway, outlet-gates, culvert and stand-pipes, paving of slopes, and all accessories, and furthermore it was built to a height of 66 feet, or 11 feet higher than the proposed rock-fill. It was made 20 feet wide on top, with a base width of 251.5 feet. All of the dam except a few feet on top, which had to be finished out with wagons, was put in place by flowing water. The surplus water from the flume was used at a time when little or no irrigation was going on, and at the same time the water was stored in the reservoir as it was being formed back of the dam.

The total volume of material handled was 38,000 cubic yards, some of which was transported an extreme distance of 2200 feet, and taken from an area of 11.5 acres, which was stripped to a mean depth of 2 feet. Had the material been as abundant and as accessible throughout the construction as it was up to the time one-fourth of the dam was in place, the entire structure could have been finished for 25% to 30% of its ultimate cost, but unfortunately it was found that below a depth of 2 feet from the surface the gravel and cobblestones of the mesa were cemented together so hard as to resist further washing, and this condition necessitated the employment of horses and scrapers to bring much of the material used to the sluiceways, at greatly increased cost. The results, considering all the unfavorable conditions, are an indication of what can be accomplished by this process where surrounding conditions are more auspicious. The surface soil and sand contained in the coarse gravel constituted less than one-third of the mass, and consequently the dam can properly be termed a rock-fill with an earth core. The deposit on the dam being always near the outer slopes, the larger stones were naturally dropped there, while the finer materials shaded off towards the center. The gravel is of all grades, from egg size to large cobbles, 8 to 10 inches in diameter. On the outer slopes the largest of these were laid up in a dry wall of uniform slope and surface.

In beginning the work a trench was excavated in bed-rock, as shown in Fig. 44, from 2 to 5 feet deep, 20 feet wide at center and tapering to 5 feet at the ends. At right angles to this trench in the bed of the gulch a culvert was built to reach entirely through the dam at its widest point. This culvert, whose details are shown in Fig. 45, consisted of a concrete conduit, 48 inches wide, 30 inches high, extending from the inner face of the dam outward 180 feet, to a point 72 feet from the lower toe, where it connects with two 24-inch cast-iron pipes, that form the outlet to the reservoir. One of these pipes connects with a wood-stave pipe supplying water to San Diego, and the other is used as a waste, or clean-out, pipe. Both are controlled by gate-valves at the toe of the dam. The walls of the concrete culvert are 12 inches in thickness, and four vertical stand-pipes connect with the culvert at intervals of 35 feet from the inside end. These stand-pipes consist of 24-inch vitrified pipes, surrounded with concrete, which pass upward through the body of the dam, and are now used as outlet-pipes to the reservoir at four different levels. During construction they performed the important function of conveying the water into the reservoir after it had dropped its load of gravel and sediment on to the surrounding embankment. They were built up a joint at a time in 2-foot sections, as the work progressed, and were finished off at the top with brass ring and flap-valve, the latter being controlled by rods reaching up the slope through the water to the surface. (See Fig. 43.) These flap-valves can only be opened when pressure is relieved by closing the gate-valves below.

The volume of water used in constructing the dam was from 300 to 400 miner's inches—6 to 8 second-feet, which was all that could be spared from the flume after supplying the domestic consumption in San Diego and along the line, and the little irrigation which is kept up, even in winter, when the rains do not come just right. From the end of the 37-mile flume, which terminates on the mesa 10 miles from San Diego, the water was siphoned across a deep ravine by a 36-inch wood-stave pipe, 3000 feet long, discharging into a ditch which carried the water 1.5 miles to the top of the ridge overlooking the dam-site on the south. From this main ditch at various points laterals were carried down the slope of the hill towards the dam on a grade of 6%, dividing the ground into irregular zones of 50 to 100 feet in width, by several hundred feet in length. In sluicing these divisions

FIG. 44.—LA MESA RESERVOIR. BEGINNING OF THE CONSTRUCTION OF HYDRAULIC FILL DAM.

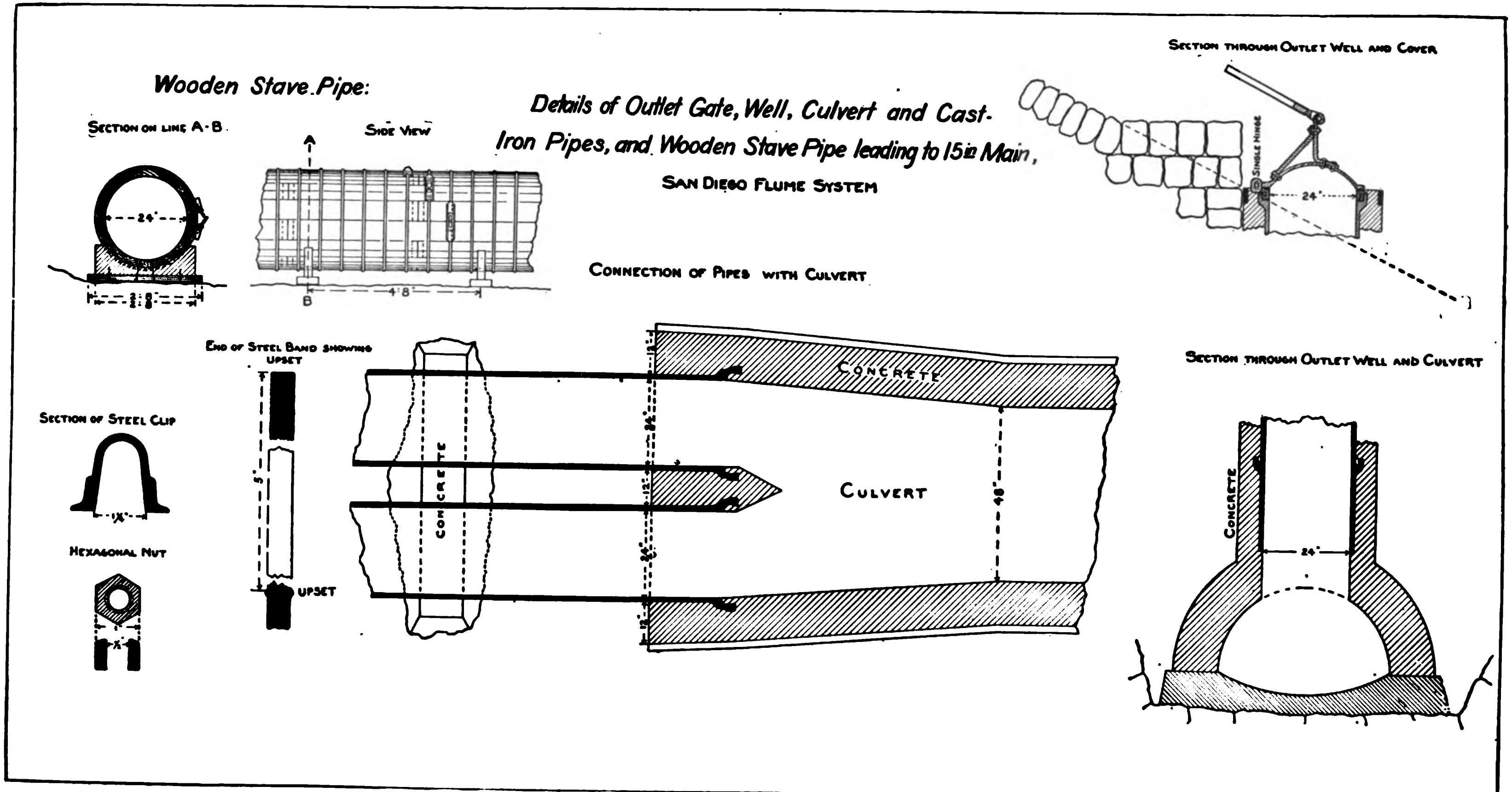


Fig. 45.—Details of Outlet-gate and Well-culvert of La Mesa Dam.

were stripped off clean to the cemented gravel bed-rock, beginning next to the head ditch and working downward toward the dam across the end of the strip. The fall from the upper-line ditch to the lower side of the zone was as great as the slope of the ground would admit,—the greater the fall the more rapidly the sluicing was done. The work accomplished was satisfactory as long as this slope was not flatter than about 25%, but as the hill from which the material was taken rounded off toward the top the velocity of the water in the cross-ditches became lessened, until it was insufficient to erode the material from its bed, and the process had to be assisted by the use of picks or plows, where the ground was not too soft for teams to get over it. This additional labor of loosening materially increased the cost. All of the material was obtained from one side of the dam, which was a further disadvantage.

As the stream secured its load of earth or gravel it was conveyed along the line of the lower ditch by 24-inch wood-stave pipes until deposited on the embankment. About 2000 feet of this piping was used in the work, the first cost of which was 90 cents per foot, exclusive of the lining of strips of tire-steel subsequently added to resist wear and tear. It was made in sections of 10 to 14 feet, loosely placed together and connected by strips of canvas wound around the ends of abutting joints and held in place by an ingenious tourniquet of tarred rope placed back of the last round band on the end of each section, the twist on one being made by a long nail, and on the other by an 8-inch piece of ½-inch gas-pipe, the nail slipping into the gas-pipe and so preventing both ropes from loosening or untwisting. During a portion of this work the pipes were supported to the desired grade-line on the dam by trestle-work. A wire cable was also used for this purpose, although the latter did not give satisfactory results. Fig. 46 illustrates both methods of suspending the pipes, and shows the dam when about 30 feet high. The necessity of frequently unjointing the pipe on the dam for distributing the material evenly over the line from side to side made the use of a canvas joint over that portion of the pipe inconvenient, and it was replaced by loose straps of iron bolted to the pipes on the sides, which kept them in line, and the water would shoot across the joint without material loss. These joints were easily taken apart when desired. The pipes were found to wear very rapidly, and were lined, first with strips of wood, and later with strap-iron or tire-steel. Cast-iron pipe or open flumes would be preferable for this sort of service.

The work on the dam began February 14, 1895, and during the first thirty working-days, of 24 hours each, 21,000 cubic yards, or 55% of the entire dam, were put in place—an average of 700 cubic yards per day, although at times more than double this amount was moved in 24 hours. The ratio of solid embankment to water used during this period was about 3.3%. The force of men employed varied from 27 to 45, working in eight-hour shifts.

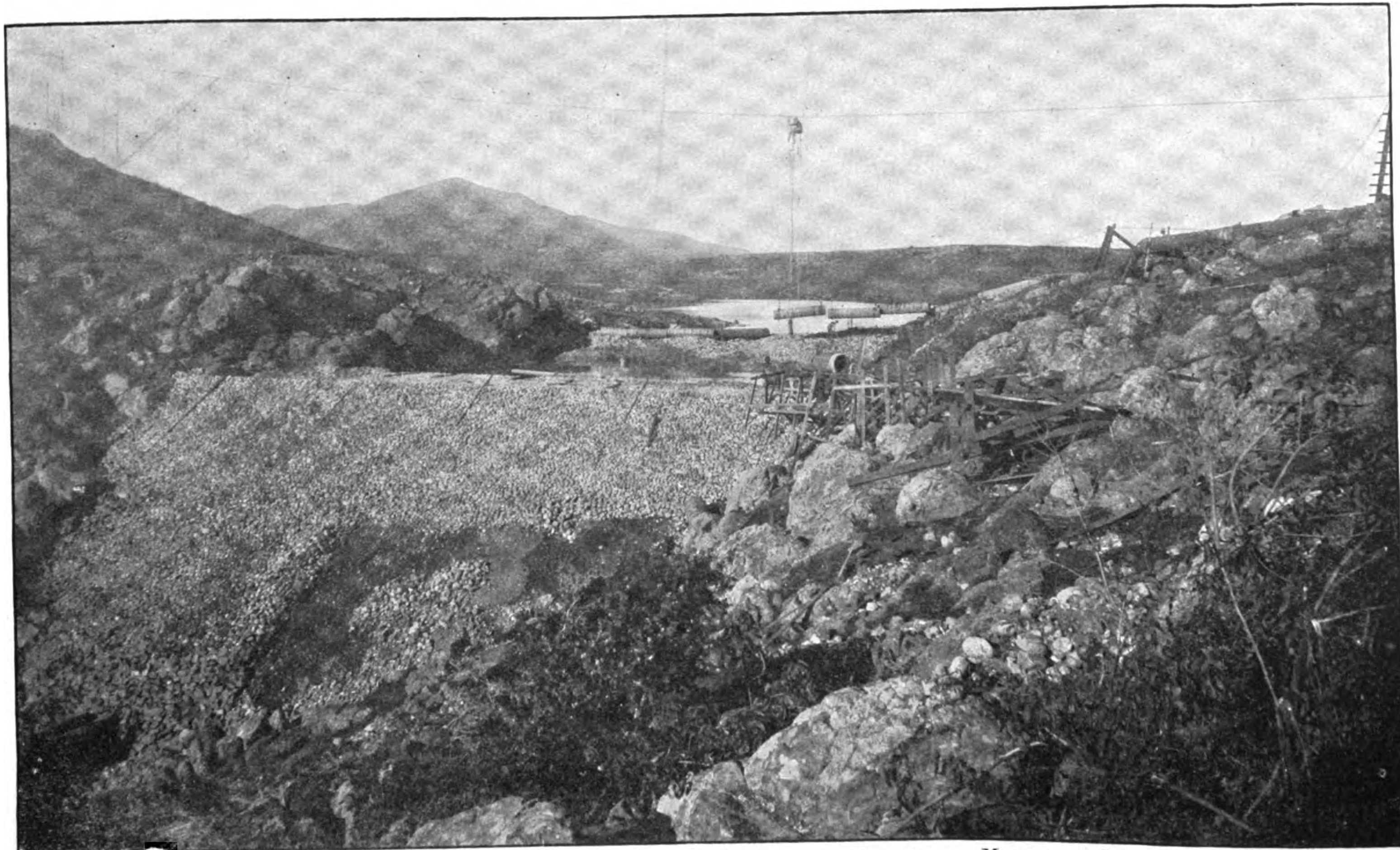

FIG. 46.—CONSTRUCTION OF HYDRAULIC DAM, LA MESA RESERVOIR, ILLUSTRATING THE METHOD OF SUSPENDING PIPES.

Two men were kept on the dump directing the stream of material and building up the outer edges of the slopes to the proper lines, while the others were chiefly engaged in ground-sluicing. With looser or deeper soil, or under conditions permitting the use of a jet of water under pressure, the cost of loosening, which in this case was the chief item of expense, would be reduced to a nominal amount.

It is apparent that an embankment built in this manner is compacted as thoroughly as it could be by any process of rolling and is not subject to further settlement. It is also manifest that the finer materials are by this process precipitated in the interior of the fill, next to the discharge-outlets for the water, and that the particles are in a general way graded in size from the outside toward the center. In this dam all of the stand-pipes are placed inside of the center line, as shown by the section of the dam (Fig. 47), and therefore more of the coarse and permeable bowlders and gravel are placed on the outer half of the embankment, where they afford

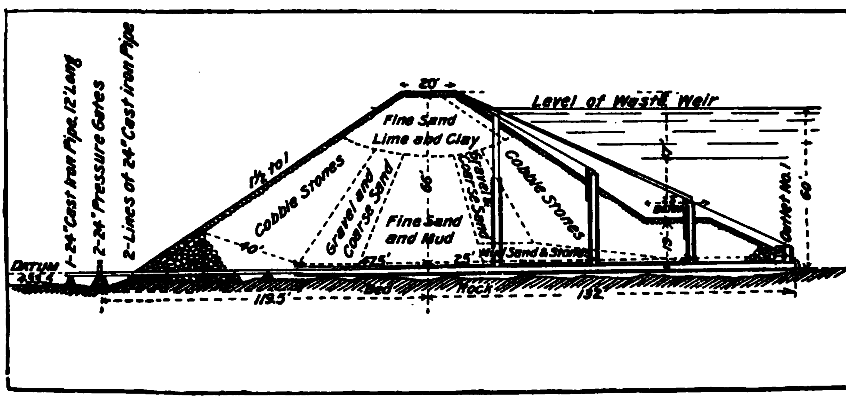


FIG. 47.—CROSS-SECTION OF LA MESA DAM.

ready drainage to the percolation that might find its way through the dam. (See Fig. 47.) Thus the failure of the structure through the ordinary process of supersaturation and the sloughing of the outer slopes is rendered highly improbable if not impossible. A dam built in this way is tested as it grows by the pond of water standing on top of it and the rising lake behind it, and if any weakness exists it is sure to be discovered and remedied by the operation of natural laws.

This dam is not entirely free from leakage, although as the water comes through quite clear it causes no anxiety and shows no tendency to increase. The leakage measures 100 gallons per minute when the water in the reservoir stands at the 54-foot level, and 23 gallons per minute when the water stands at 46 feet.

The reservoir-basin is large enough to impound 18,890 acre-feet if the dam be raised to the 140-foot contour. Such a dam, of safe dimensions, would contain 682,000 cubic yards, and its construction has been seriously considered, the material to be obtained by excavating the interior of the basin, conveying it to the dam by the hydraulic method and then hoisting it in place by mechanical means.

The elevation of the base of the dam is 433.5 feet above sea-level, and a 24-inch wood-stave pipe, 6500 feet long, banded to withstand 180 feet maximum pressure, connects it with a 15-inch steel main that is laid from the end of the main flume to San Diego. The location and elevation of the connection of these pipes has practically determined the 43-foot contour in

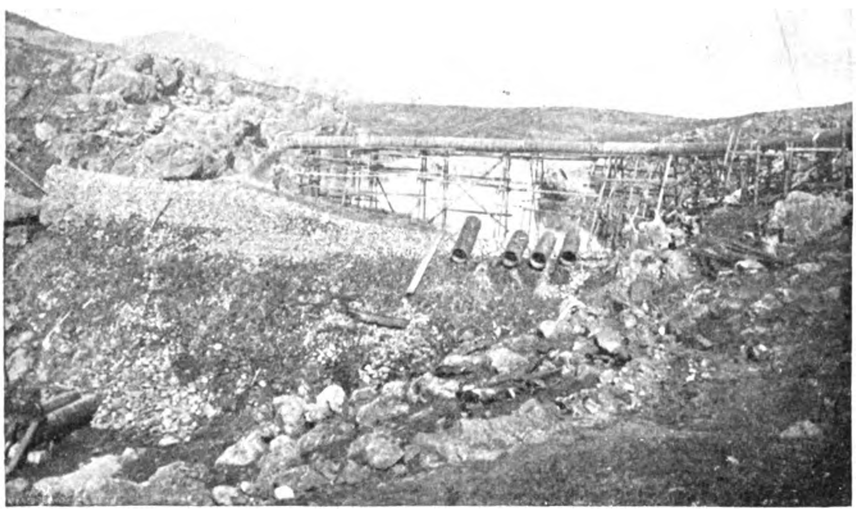

FIG. 48.—LA MESA HYDRAULIC-FILL DAM, SHOWING PIPE DISCHARGING MATERIAL ON THE DAM.

the reservoir as the lowest level to which the water will ordinarily be drawn when used for city service, unless a more direct connection be made. In times of scarcity the water below the 43-foot level has been pumped from the reservoir.

**Lake Christine Hydraulic-fill Dam, California.**—Some years ago the San Joaquin Electric Company erected a power-plant on the San Joaquin River, 34 miles north of Fresno, to utilize water brought from the North Fork of the San Joaquin to the power station. The power-drop at this place is 1410 feet, and the plant is remarkable as one of the first to make use of so high a drop, as well as for the long distance of the transmission of power, as the company deliver electricity to Hanford, a distance of 70 miles, as well


FIG 48a.—VIEW OF LAKE CHRISTINE DAM-SITE, SHOWING OUTLINES OF HYDRAULIC-FILL DAM.

[To face page 98.

FIG. 48*b*.—VIEW OF L KE CHRISTINE DAM-SITE, SAN JOAQUIN RIVER, NEAR FRESNO, CALIFORNIA, WHERE A HYDRAULIC-FILL DAM IS IN PROCESS OF CONSTRUCTION.

[*To face page* 99.

as to Fresno. The plant was designed and built by J. J. Seymour, C.E., president of the company, and by J. S. Eastward, chief engineer, under contracts with the General Electric Company. The plant was entirely successful until the recent drouth developed such an unprecedented shortage in the low-water supply as to diminish the possible power output below the demands upon it. To remedy this deficiency the company is engaged in the erection of a storage-dam for impounding the flood run-off of the North Fork. The dam has been planned and is being built by J. M. Howells, C.E., and is to be purely of the hydraulic-fill type. The general dimensions are as follows:

| | |
|---|---|
| Maximum height | 100 feet. |
| Length on top | 720 " |
| Slope on water-side | 2 : 1. |
| " " lower side | 1.5 : 1. |
| Width of canyon at base | 30 feet |
| Width 65 feet higher | 300 feet. |

Water for sluicing is brought to the dam-site a distance of 5 miles, by flumes and ditches. The volume used is 15 second-feet (750 miner's inches), which is delivered to the summit of a hill overlooking the dam and 200 feet above it. This hill, which is to furnish the materials for building the dam, has been surveyed and explored by borings to determine the quantity and quality of available earth for the purpose. The hill has an underlying base of granite, which has disintegrated very irregularly, leaving hard exposures at various points, while in places the depth to solid rock is very great. This disintegrated material is sandy in places, and in spots it has passed into the clayey stage, while fragments of granite still lie bedded intact, furnishing rock for the outer paving of the embankment. Hard bed-rock is exposed over nearly the entire area covered by the dam. It is of granite throughout, hardest near the level of the stream, where erosion has polished it smooth and glassy. Higher on the sides it is not so hard, but will make an excellent foundation. Advantage has been taken of a cut, blasted out from the solid rock, at a level 14 feet above the stream-bed, by an old mining company for a ditch grade, in which to place the outlet sluices. This cut is arched over with masonry for the entire width of the dam, and will serve to carry the flow of the stream during construction. Gates are set in this cut on the center line of the dam, to be closed when the dam is finished and storage begins. The gate-stems will extend up through a circular shaft, 22 inches in diameter, 3 inches thick, reaching to the top of the dam. This shaft is made of successive rings of cement pipe, 12 inches in height, which are added one at a time, as the dam rises. During construction this shaft will serve to draw off the surplus water from the pond formed on top of the embankment, after its load of material has been dropped on the rising dam.

A center core of double plank sheeting will be carried up through the dam from bottom to within 10 feet of the top, and throughout its entire length. This sheeting will be embedded in concrete at bed-rock. The concrete will be made of high grade, thoroughly rammed and water-tight on the upper side of the sheeting, but made open and porous on the lower side, with a 4-inch pipe molded in it close to bed-rock and running the entire length of the sheeting. This conduit is intended to drain the dam of any water which may pass through seams in the rock, underneath the dam, or leakage through the puddle-core in the center. The outlet to this drain is a 6-inch pipe of cement, laid from the lowest point in the drain to the outer toe of the dam.

The dam will be composed of a combination of rock, gravel, coarse and fine sand, and clay, the finer particles being graded by the varying velocities of the water and deposited in the center of the embankment, while the coarser materials, and fragments of granite, up to 12 inches in dimension, will be dropped on the outer faces and slopes. This method of filling will more perfectly fill all the voids in the dam than any other possible means. The materials will be transported from 600 to 2000 feet, and deposited on the dam by the agency of water alone. The fineness of the central mass, and its impervious character, are relied upon to remain constantly moist and free from air, and thus preserve the wooden sheeting from decay. To more thoroughly mix the materials of the puddle-core and break up a tendency to stratification, it is proposed to draw wagon-wheels, properly weighted, backward and forward, parallel with the central sheeting, during construction, by means of a wire cable and capstans.

The dam is estimated to cost but $25,000, including the entire cost of the flumes and conduits. Considering the remoteness of the site in the mountains, and the difficulty involved in transporting supplies, this cost, for so high a dam, is remarkably low, and the completion and test of the work will be looked forward to with unusual interest. The spillway of the dam will be through a natural gap, located 800 feet away from the dam. This spillway will be 100 feet wide at the 90-foot level, and 225 feet at the 100-foot level.

The reservoir will have a length of 3 miles, and an average width of about ½ mile. Its capacity will be approximately 360,000,000 cubic feet (8264 acre-feet), which is estimated to yield a flow during low-water period of three times the present requirements of the power-plant.

**Hydraulic Fills on the Canadian Pacific Railway.**—Further examples of the successful employment of hydraulic mining principles to the work of building embankments are to be found on the Pacific coast, but none more instructive than the extensive hydraulic fills made by the Canadian Pacific

Railway in British Columbia, where trestles of great height are being supplanted by earth and gravel embankments made by the agency of water alone. The methods employed differ materially from those described in the foregoing pages, but will doubtless find frequent application elsewhere in irrigation-dam construction.

At trestle No. 374, near North Bend, in Fraser River Canyon, 110 miles east of Vancouver, there was required to fill a chasm an embankment 231 feet in height, containing 148,000 cubic yards. When visited by the writer in November, 1896, the fill had reached a height of 167 feet and contained 70,000 cubic yards, all of which had been put in place by the hydraulic process. The plant used consisted of 1450 feet of double-riveted sheet-steel pipe, 15 inches in diameter, 1200 feet of sluice-boxes or flumes, about 3 feet wide and the same depth, one No. 3 double-jointed "Giant" monitor with 5-inch nozzle, and a large derrick fitted with a Pelton wheel connected with the winding-drum of the derrick and operated by diverting the jet of water, used in piping the bank, upon the wheel when loads were to be hoisted by the derrick. The gravel bank where the material was obtained was 1130 feet distant from the center of the track, and from this pit the pipe was laid to an adjacent stream, 1450 feet, in which length the fall available was 125 feet. The sluice-boxes were laid on a grade of 11% for the first 425 feet, increasing to 25% the rest of the way. They were chiefly supported on trestles. These boxes, constituting a continuous flume, were paved with wood blocks on the lighter part of the grade, and with pieces of old railway rails, laid close together lengthwise of the flume, where the grade was heaviest.

One of the most serious difficulties here encountered—and each locality develops its special problems—was the fact that about 50% of the materials in the gravel-pit was such as to be classed as cemented gravel; 20% consisted of bowlders, too large to pass through the flume and requiring to be hoisted out of the way and piled up by the derrick; while but 30% was loose gravel, of the character best adapted for the work. Notwithstanding these disadvantages the results accomplished are quite remarkable, as the entire cost of the work, including the plant, was but $5089, an average of 7.24 cents per cubic yard. The entire force employed consisted of eight men, disposed as follows: 1 piper at the monitor, 1 man at the head of the sluice-boxes and in the pit, 2 on the flume, "driving" the material along to prevent choking, 3 on the dump, distributing the material and making brush mattresses for the slopes, and 1 foreman, a carpenter, chiefly engaged on general repairs of flume and overseeing the work. The time occupied was as follows: sluicing, 95.3 days; removing bowlders from the pit, 50.4 days; repairing flume and plant, 13.5 days; total, 159.2 days of 10 hours of the entire force. The total number of yards moved, divided by the actual working-time when sluicing was in progress, gave an average of 738 cubic yards per day of 10 hours, or at the rate of 1771 cubic yards per 24 hours. The water used was approximately 11 cubic feet per second, or 550 miner's inches under 4-inch pressure (440 inches under 6-inch pressure), the duty performed being 3.22 yards per 24-hour inch under 4-inch pressure, or 4.02 cubic yards per inch under 6-inch pressure, which latter is the unit of measure most commonly used in the hydraulic mines.

Had the gravel-bank been free from large bowlders, the work could have been done in two-thirds of the time actually occupied, and had the pressure been greater and the gravel all loose instead of being partially cemented, requiring the use of explosives to loosen it, the duty of the water, on the high grades available for the flume, should have been increased more than threefold, as the ratio of solids carried was only about 5% of the volume of water used. An understanding of all these conditions suggests what might be accomplished by this method with a perfect combination of circumstances, viz., water under pressure of 400 to 500 feet head, loose materials in abundance for washing, freedom from rocks of large size, and heavy grades to the dump.

In building the embankment no provision was made for draining off the water down through the center, but it was allowed to pour over the slopes, which were protected from erosion by brush and tree-tops woven in alternating layers along the edges of the fill. Old track-ties and poles were also used with the brush. In addition to this protection it was necessary to exercise care to prevent the water from concentrating in channels or from reaching to the sides or flowing down the hill over the natural surface. By keeping the sides of the fill as nearly level as possible the water was spread in a thin sheet over the face-slopes and reached the bottom of the embankment without washing or doing injury. The slopes are remarkably true and uniform, and the embankment was packed very hard, particularly near the end of the sluice, where the gravel had dropped from a considerable height to the dump below.

The device employed for handling the bowlders in the pit by water-power was ingenious and effective, and was similar to those in common use in hydraulic mines, where water under pressure is turned at will upon a tangential water-wheel with peripheral buckets. This wheel, being attached to a winding-drum, the wire hoisting-rope leading from the derrick boom is rapidly wound up and the load handled at will. A friction-brake with long lever gave the operator perfect control of the load and enabled him to lower it as swiftly or as gently as desired. Sharp turns in the flume were made by vertical drops of 2 feet at the angle, and two turns of 90° each were thus successfully made.

Bowlders with one or two square feet of face would sometimes stop rolling, and if not quickly started would cause a jam and overflow, endangering the flume on the gravel hillside. Hence it was necessary to employ two "drivers" to patrol the portion of the flume where the grade was lightest, to keep all such stones in continuous motion. On the heavier grade, however, no such attention was necessary.

In the summer of 1894 the railway company made a similar fill of 66,000 cubic yards, at the crossing of a stream called Chapman Creek, the average cost of which was 7.5 cents per cubic yard, of which 3.2 cents was for plant. The actual work of sluicing was but 1.78 cents per cubic yard. In this case also, it was necessary to use explosives to loosen the gravel and prepare it for washing.

In 1897–98 the same company made a similar fill at the crossing of Mountain Creek, in the Selkirk Mountains, requiring 400,000 cubic yards. (See Fig. 50.) The total length was 10,086 feet over all, with extreme depth of 154 feet. The fill was carried up on a slope of 1½ to 1. Between Aug. 10 and Nov. 1, 1897, over 65,000 cubic yards were sluiced in place, at the following cost:

| | |
|---|---|
| Mattresses | $1370.79 |
| Sluicing labor | 1195.96 |
| Maintenance and repairs | 678.90 |
| Superintendence and tools | 385.05 |
| Total | $3630.70 |

This gives the average cost of the first 65,000 cubic yards at 5.59 cents per yard. Including a proportion of the plant, the average was less than 8 cents per cubic yard of embankment. The work was done in about 60 working days of 10 hours each, and the average was nearly 1100 cubic yards per day. The water was delivered to the nozzle of the monitor under a head of 160 feet, the diameter of nozzle being 5.5 inches. The volume was therefore 15.75 second-feet, or 787 miner's inches. The ratio of water to gravel was as 19 to 1 and the duty of the water was nearly 4.2 cubic yards per 24-hour inch under 6-inch pressure. The sluice-boxes had a grade of 8%. The water-supply was brought in a flume, 4 feet wide, 2 feet high, 2 miles long, built on a grade of 20 feet per mile. The entire plant, including roads, camp, stables, flume, pipe-line 1200 feet long, sluice-boxes 600 feet in length, etc., cost $10,038.40. Considerable expense was caused by snow and land-slides, which damaged the plant.

The trestles were filled beginning at the banks of the stream and working back each way. On the made bank thus formed masonry piers were constructed, and a steel bridge of five spans was built over the main stream between them.

The work has been planned and executed under direction of H. J. Cambie, Chief Engineer Pacific Division, Canadian Pacific Railway, and his Chief Assistant Engineer, Edmund Duchesnay, of Vancouver, B. C., by whose courtesy the data concerning the work have been supplied.

The class of work done on the Canadian Pacific Railway described in the foregoing pages is identical with that which is required in dam-construction with similar materials, and the processes employed will be recognized by engineers as distinctly applicable in a treatise on the subject of hydraulic dam-building, the only difference being that in railway fills no attention is paid to such a distribution of materials as will secure the water-tightness of the bank and free drainage of percolating waters on its exterior surface.

**Hydraulic Fills on the Northern Pacific Railway.**—The cheap and effective transportation of earth, gravel, rock, and sand and their deposit in embankment by water at a cost far below all other feasible methods, is the main principle involved, and this principle has been given further demonstration on a large scale on the Northern Pacific Railway, in the State of Washington, during the years 1895–96–97. No less than fifteen high and dangerous trestles on the Cascade Mountain division have been replaced by hydraulic-made embankments of earth, gravel, and loose rock, washed from the adjacent mountainsides. The total amount of material thus moved aggregates 606,750 cubic yards, the average cost of which was 6.39 cents per cubic yard; or 5.82 cents for labor and 0.57 cents for materials. The lowest cost of any of the fills was 3.38 cents per cubic yard, everything included.

The average cost of 377,000 cubic yards was 4.79 cents per yard, of which the detailed cost per cubic yard was as follows, figures which may be of special interest to those contemplating similar undertakings:

| | | |
|---|---|---|
| Sluicing and building side levees....... | 3.89 | cents per yard. |
| Hay used in side levees............... | 0.09 | " " " |
| Tools.............................. | 0.08 | " " " |
| Lumber and nails.................... | 0.22 | " " " |
| Labor building flumes................ | 0.44 | " " " |
| Engineering and superintendence...... | 0.11 | " " " |
| Total........................ | 4.79 | " " " |

This work was done in the midst of a dense forest, where the ground to be sluiced had to be cleared, and stumps and roots necessarily interfered with the loosening of the material. All of the 377,000 yards were carried and deposited by water brought to the pits by gravity. In one case, however, that of bridge 191, the water was supplied by pumping and 42,250 cubic yards were moved by water thus lifted at an average cost of 13.5 cents per cubic yard, the detail of which was as follows:

| | | |
|---|---|---|
| Sluicing and building levees.......... | 10.81 | cents per yard. |
| Hay used in side levees.............. | 0.21 | " " " |
| Tools............................. | 0.14 | " " " |
| Lumber and nails................... | 0.12 | " " " |
| Labor building flumes............... | 0.14 | " " " |
| Coal used in pumping............... | 1.87 | " " " |
| Engineering and superintendence..... | 0.20 | " " " |
| Total....................... | 13.50 | " " " |

FIG. 49.—HYDRAULIC SLUICING, CANADIAN PACIFIC RAILWAY. VIEW OF PIT, AND HYDRAULIC GIANT AT WORK

FIG. 50.—HYDRAULIC FILLS, PARTIALLY COMPLETED, AT MOUNTAIN CREEK, B. C., CANADIAN PACIFIC RAILWAY.

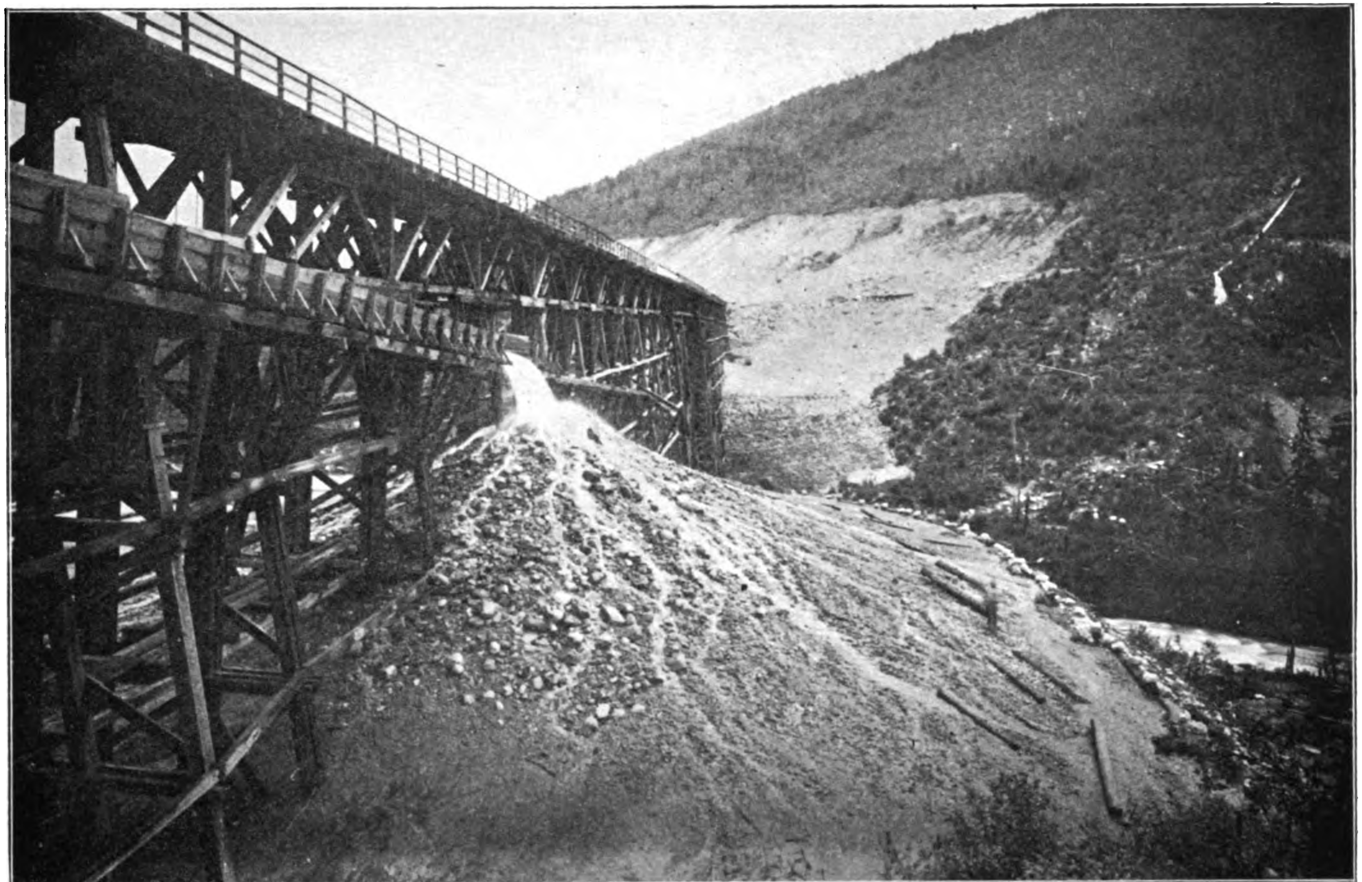

Fig. 51.—Hydraulic Filling of High Trestle at Mountain Creek, B. C., on Canadian Pacific Railway, near View of Dump.

The plan adopted on this work for disposal of the water after it had accomplished its duty was practically the same as that used at the La Mesa dam. A waste-box (or a number of them if the fill was a large one) was taken up through the body of the embankment, and built up a little at a time, as the filling increased in height. The top of the boxes was always kept lower than the side levees, so that the water could escape without overflowing the sides as in the case of the Canadian Pacific fills. Hay or straw was used for the side levees instead of brush or logs, which would

FIG. 52.—NORTHERN PACIFIC RAILWAY. BRIDGE 190.

have cost considerably more. In order to prevent the rapid wearing out of the bottom of the flumes a paving of square timbers was used, cut into 3-inch blocks, so that the end would be presented as wearing surface.

It was found that grades of 7% and preferably 8% were most advantageous for the sluicing-flumes to carry material containing considerable gravel and rock, to prevent frequent blocking of the flumes.

By courtesy of E. H. McHenry, Chief Engineer, and Charles S. Bihler, Division Engineer, Northern Pacific Railway, the writer has been furnished with the interesting photographs of the work (Figs. 52, 53, 54, and 55), which illustrate the process of hydraulic filling very clearly in all its phases, and demonstrate with what precision embankments can thus be formed.

The following general description of the work from the pen of Mr. Bihler is appended:

"The results have been very gratifying, both as to cost and character of the fills made. We are using, or trying to obtain, about 100 inches of water for each nozzle, as with a less quantity the rocky character of the material moved does not give good results. In some cases we have been able to obtain water at the bridge, without the necessity of building any considerable length of flumes. In other cases we had to construct several miles of flumes for the water-supply. These flumes are constructed in the

FIG. 53.—NORTHERN PACIFIC RAILWAY. BRIDGE 189, CASCADE MOUNTAINS.

most temporary manner, of inch-and-a-quarter lumber, 16 to 18 inches square. Where the locality would permit we have carried the dirt to the bridges to be filled a distance of over half a mile. The manner of building up the fill is very clearly shown in the photographs. We use hay for keeping up a levee on the outside, and wooden frames or baffle-boards which are easily moved, to deflect the main current from the levees. The waste-water is taken off through a waste-box which is taken up through the body of the fill and built up as the filling increases in height. By adjusting the height of the waste-gate a larger or smaller amount of fine material can be retained in the fill, as desired. In building up the fill naturally a separation of the materials takes place. The coarser material is deposited right under the end of the sluice-boxes, while the finer material is carried along toward the waste-boxes, the finest particles of each being deposited in the vicinity of the waste-gate in the shape of mud. For large embankments it is therefore necessary to have several waste-gates, so that coarse material may be deposited, from time to time, at those places, and the accumulation of too much of the fine material at any one point may be avoided.

"The plant required for the work is rather inexpensive. According to locality, one nozzle would require from 300 to 1000 feet of light sheet-iron

FIG 54.—NORTHERN PACIFIC RAILWAY, HYDRAULIC-FILL CONSTRUCTION. VIEW IN PIT SHOWING HYDRAULIC GIANT IN ACTION.

pipe, costing about 27.5 cents per foot, and a No. 2 Giant, costing $95. Outside of this nothing is required except picks, shovels, hoes, and axes.

"The character of the material that we have available is not very favorable. The pits are very rocky, and the banks overlying bed-rock which can be loosened by the water-jet are not deep. The cost given for sluicing and building levee includes all costs of clearing. From five to six men are required with each nozzle, to build the levee, move sluice-boxes, and do everything else connected with the work."

Following is a summary of the volume and cost of hydraulic filling as reported to date, on the Northern Pacific Railway:

| | | | Average Cost per Yard. |
|---|---|---|---|
| Bridge | 164 ................ | 18,300 cubic yards. | 8.21 cents. |
| " | 165 ................ | 6,200 " " | 16.58 " |
| " | 167 ................ | 24,500 " " | 14.00 " |
| " | 170 ................ | 30,800 " " | 8.75 " |
| " | 172 ................ | 4,300 " " | 10.55 " |
| " | 173 ................ | 9,700 " " | 6.23 " |
| " | 178 ................ | 2,100 " " | 13.25 " |
| " | 179 ................ | 19,800 " " | 9.31 " |
| " | 182 ................ | 53,600 " " | 3.80 " |
| " | 184 ................ | 96,650 " " | 4.34 " |
| " | 185 ................ | 800 " " | 30.24 " |
| " | 186 ................ | 51,600 " " | 7.02 " |
| " | 189 ................ | 158,100 " " | 5.19 " |
| " | 190 ................ | 128,800 " " | 6.11 " |
| " | 191 ................ | 42,250 " " | 13.50 " |

FIG. 55.—NORTHERN PACIFIC RAILWAY, BRIDGE 184. HYDRAULIC FILLING IN PROGRESS.

The distinctive advantage recognized in favor of hydraulic filling of trestles on railways is that it can be carried on without interruption to the traffic and without endangering the trestle, either by falling rocks or unequal settlement, and when it is completed no further settlement of the embankment can occur. The latter advantage applies with special force to dam-construction, and is one whose importance can scarcely be overestimated. Where the materials available consist of large and small stones, either angular or rounded with small gravel, sand, and silt, the ease with which these materials may be graded and assorted so as to permit the outer portion of the embankment to be built of the coarser rock where it will afford ready drainage, while the finer particles may be assembled in the center and inside where they will best resist percolation, constitutes a further advantage, which may well be considered as an efficient substitute for the ordinary puddle-wall of earth dams built in the usual manner.

### OTHER HYDRAULIC CONSTRUCTION.

**Seattle, Washington.**—Except in the manner of loosening the materials and putting them in motion, the methods of hydraulic construction of embankment described in the foregoing pages are quite similar to those employed in the reclamation work done by the Seattle and Lake Washington Waterway Co., at the city of Seattle, Washington.

This work, however, has a totally different object, namely, the opening of navigable tidal channels by dredging and the reclamation of valuable tide-lands adjacent to the business center of the city, by filling them with the fine black sand dredged from the channels. Two powerful suction-dredges were used, each with a capacity of removing 6000 to 7000 cubic yards of solids per 24 hours, which was pumped from the bottom of the channel through 18-inch pipes, a distance of 2000 to 4000 feet, and deposited to a depth of 18 or 20 feet over the area to be reclaimed. Some 36,000,000 cubic yards are to be handled in this way, and 1500 acres filled in solidly to a height of 2 feet above high tide. The actual cost of this class of work does not exceed two cents per cubic yard.

The mean velocity maintained in the delivery-pipes was 13.5 feet per second, and the discharge was 24 second-feet, so that when the work was at a maximum the percentage of solids carried by the water was 9%, although tests have shown as high as 20%. The bulkhead along the channels which hold the sand in place is made of brush mattresses, while the temporary cross-levees are effectively formed by the use of coarse hay, straw, or swamp-grass, precisely as used on the Northern Pacific fills.

**Tacoma, Washington.**—Hydraulic filling was done on a very large scale a few years since, at Tacoma, Washington, with salt water pumped from Puget Sound. The wharves in front of the city were located near the foot of a high bluff of glacial drift, and it was desired to fill a large area of lowland approaching the wharves, and substitute a portion of the wharves with an embankment of solid ground. To do this work the pumped water was piped against the bank, which was undermined, and the material carried to the place of deposit by the water. The cost of the work is represented to have been very low, not exceeding six cents per cubic yard, and the object sought was attained with entire success.

**Holyoke Dam, Massachusetts.**—The Holyoke dam, across the Connecticut River, was built as a timber-crib structure 1017 feet long and 30 feet high. In 1885 the dam was reconstructed and filled with a mass of puddle-gravel, washed in and puddled by hydraulic streams, under direction of Mr. Clemens Herschel, M. Am. Soc. C. E., of which he writes: * "No part of the work gave less anxiety and more satisfaction than this from the day it was started." Referring to similar work Mr. Herschel again writes: † "Pure gravel, just as it comes from the gravel-pit, will make a water-tight stop, when used between planks, or in any other position for which puddle is used, as far as my experience goes, better than clay or a clay mixture ever did."

**Georgia.**—In the course of an extended experience in hydraulic mining on the Etowah River, in Georgia, Col. Latham Anderson, M. Am. Soc. C. E., demonstrated that "Gravelly hydraulic tailings could be deposited within sharply defined limits and in any shape desired, limited only by the condition that the slopes should not be steeper than the natural repose of the material." (Private letter to the writer.)

**Utah Experiments.**—The experiments made by Prof. S. Fortier, of the Utah Agricultural College Experiment Station, on the mixture of various aggregates for use in construction of earthen dams, shows that gravel, sand, and clay will occupy less space and become more compact when poured into water, mixed therewith, and allowed to drain and settle, than by any process of tamping either moist or dry.‡

These miscellaneous citations sufficiently illustrate the principles and methods that may be successfully employed, in any locality where natural conditions are favorable for the construction of dams, safely, cheaply, and efficiently by the powerful and convenient aid of flowing water.

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* Trans. Am. Soc. Civil Eng., vol. xv. p. 568.

† *Ibid.*, vol. xxvi. p. 684.

‡ Earthen Dams, by Samuel Fortier; Bulletin Utah Agricultural College, No. 46, Nov. 1896.

## CHAPTER III.

### MASONRY DAMS.

The character of structure which appeals most effectively to the majority as worthy of confidence in its ability to withstand water-pressure and the action of the elements for ages is unquestionably the masonry dam, founded on solid rock and built up as a monolith between the natural rock buttresses of a gorge, with Portland-cement mortar. Such a structure invariably commands greater respect and confidence in the public mind than any other. It may not in certain cases actually be safer from overturning or better able to resist the strains and forces tending to rupture it than well-built dams of wood, earth, or loose rock, but it usually has the appearance of strength; and the moral effect of a dam of that character upon the public, as well as upon investors in securities dependent upon the stability of dams and the permanence of the water-supply retained by them in reservoirs, is one which cannot be disregarded.

That masonry dams are not built in every site is due to the fact that the foundations are not always suitable, and surrounding conditions oftentimes render their cost prohibitive.

Masonry dams are distinct from buildings, arched bridges, and other masonry structures in that the best class of masonry as ordinarily applied and used is not best adapted to dam-construction. Cut-stone masonry or ranged ashlar, while more expensive and of greater strength than, is not so suitable for masonry dams as, random rubble, laid regardless of beds or courses, homogeneous concrete, or a combination of large irregular masses of stone embedded in concrete — a rubble-concrete,—either of which is much cheaper. The strains in a dam are in various directions, whereas ranged ashlar, laid in horizontal courses, is best adapted to resist the forces acting perpendicular to those courses, and not those having the same horizontal direction. The dam should therefore be made as nearly homogeneous and monolithic as possible, and the stones used thoroughly interlocked in all directions, avoiding the horizontal courses of ordinary cut-stone masonry.

While masonry dams have been built antedating the Christian era, and some very notable ones were constructed in Spain for irrigation-storage more than three hundred years ago, it is only within the past fifty years that the correct theories of the strains to which such structures are subjected, and the proper proportions to be given them to secure stability under all conditions, have been reduced to some degree of mathematical certainty. The Spanish dams built in the sixteenth century were massive blocks of masonry, almost rectangular in form, containing a large surplus of material beyond actual requirement, but so unscientifically disposed as to produce maximum pressures dangerously near the point of crushing.

The French engineers who were required by the French Government to prepare plans for high masonry dams for the control of floods on torrential rivers in southern France about fifty years ago, were the first to advance new ideas and practical theories on the principles that should govern the design of these structures. M. Sazilly prepared a paper on the subject in 1853, and a few years later the matter was more fully elaborated by M. Delocre, on whose formula were drawn the plans for the great Furens dam, 183.7 feet high. In 1881 Prof. W. J. M. Rankine, the noted English engineer, was called upon to report on the best form of masonry dam to be built for the city of Bombay, India, and investigated the question in a thorough mathematical way, producing a form of profile which is recognized as one of the most logically correct in its conformity to all requisite conditions. He established as one of the governing principles that no tension strains should be permitted in any part of the masonry, and that therefore the lines of resultant pressure, with reservoir either full or empty, should fall within the inner third of the dam at all points. The acceptance of this principle carries with it as a necessary sequence that the maxima pressures will fall below safe limits, whereas if the dam be designed with regard to safe limits of pressure alone the structure may be so slender as to carry the lines of pressure far beyond the center third and thus set up dangerous tension in the masonry.

Other prominent English engineers who have investigated the subject are Mr. Guilford L. Molesworth and Mr. W. B. Coventry.

Mr. H. M. Wilson, Assistant Hydrographer, U. S. Geological Survey, in his "Manual of Irrigation Engineering," devotes a long chapter to an admirable discussion of masonry dams, while the most recent American treatise is the elaborate work entitled "The Design and Construction of Dams," by Edward Wegmann, C.E.; of which the fourth edition was issued in New York in 1899. Mr. Wegmann has rendered invaluable service to the profession in the investigation of the difficult problems involved in the design of masonry dams, and in simplifying the mathematical formulæ for computing the economical safe proportions of such structures.

The general principles to be considered in designing such a dam are briefly as follows:

(1) That it must not fail by overturning.

(2) That it must not slide on its foundation or on any horizontal joints.

(3) That it must not fail by the crushing of the masonry or the settlement of its foundation.

(4) That it must be equally safe from excessive pressure upon the masonry whether the reservoir be full or empty.

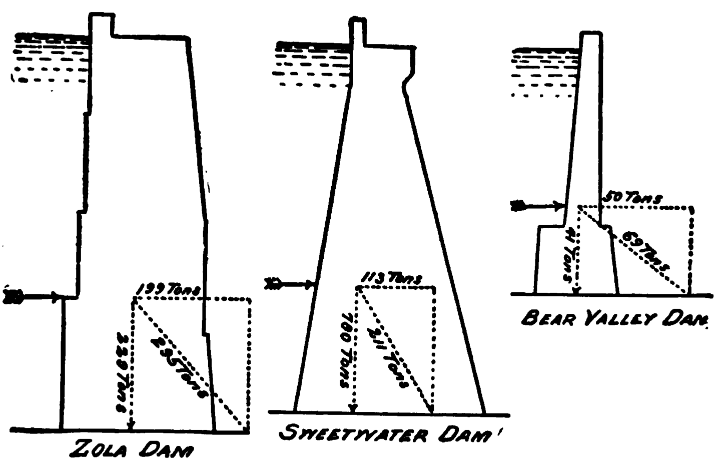
(5) That certain known safe limits of crushing of masonry of the class to be used shall not be exceeded.

Masonry dams may resist the thrust of water-pressure either by their weight alone or by being built in the form of an arch, which will transmit the pressures to the abutments. The first of these two classes of structure is called the gravity dam. The second is the arch dam, and it may be either of the gravity type in arched form, or it may depend upon its arched form alone. In either case the weight of the dam must be borne by the foundations, and these must be of the best quality of solid bed-rock. Everything of a friable nature should be removed, and the excavation so made as to leave the surface rough, to avoid the possibility of the dam sliding on its base. The maxima pressures permissible should not exceed 15 tons per square foot, and may require to be as low as 6 tons per square foot. For very high dams it is essential that they should diminish in thickness as the top is approached, else the masonry might be crushed and fail of its own weight. This consideration suggests the simple triangle as theoretically correct, with certain modifications. The thrust of the water tends to overthrow the dam by revolving it around its lower toe, and hence there is such a concentration of water-pressure and weight of masonry at that point as to necessitate a sufficient width of base to confine the resultant of these forces inside the outer toe-line of the wall, and avoid the crushing of the masonry by distribution of the strains over a greater area. If the hypothenuse of the right-angle triangle were presented to the water as the upper face of the dam, the forces acting perpendicular to that face would give the wall greater stability from overturning, if the structure were considered as a rigid body incapable of being crushed. On the contrary, if the vertical side of the triangle be presented to the water, the dam, while less liable to be overturned, is more capable of resisting fracture or crushing, the pressures are more evenly distributed over its base, and the foundations less likely to yield.

While the simple triangular form of dam, of such base-width that the lines of pressure with reservoir full or empty fall within the inner third, amply fulfills the requisite conditions to resist the quiet pressure of water, in practice it is necessary to give a certain definite width to the top of the dam to enable it to resist wave-action and ice-thrust. In dams 50 feet high or less this top width need not exceed 5 feet; for dams 100 feet high the width need not be more than 10 feet, and for a height of 200 feet a width of 20 feet is considered ample. Greater widths are given where the top of the dam is to be used as a roadway. The crest of the structure should also be raised a certain elevation above the highest water-level to provide for extreme floods. This superelevation will necessarily be governed by the size of the spillway provided and the area of watershed tributary, but ordinarily it should be limited to about 10 feet at the extreme.

High reservoir dams erected across large streams, where conditions do not easily permit of the construction of a spillway to carry the water around them and it is necessary to permit the passage of floods over their crest, are subjected to shocks due to the weight of water falling upon the toe of the dam, which cannot be computed accurately and for which no formulæ have been deduced. In cases of this kind it is customary to allow a substantial addition to the dimensions given by the theoretical profiles deduced from the formulæ for gravity dams under quiet pressure, and to provide a water-cushion at the toe of the dam by the erection of an auxiliary wall a little distance below. The lower face of the dam should also conform as closely as possible to the natural curves assumed by the falling water.

**Curved Dams.**—While there is an essential general agreement among engineers as to the theoretical profile best adapted for gravity dams, there is a wide difference of opinion as to the effect of the value of the arch in adding stability to the dam. That such structures can and do successfully transmit pressures laterally to the abutments is proven by the Bear Valley, the Zola, and the Sweetwater dams (Fig. 56), the three highest and most




(Scale, 1 Inch = 50 Feet)

FIG. 56.—COMPARISON OF PROFILES OF ZOLA, SWEETWATER, AND BEAR VALLEY DAMS.

noted types of arched dams in existence. The Bear Valley and Zola dams are so slender in profile as to be absolutely unstable were they built straight, while the Sweetwater dam, though more nearly approaching the gravity type, is of such proportions as to be theoretically unstable as a gravity dam, although it has successfully withstood the shocks of an enormous flood pouring over its crest for nearly two days.

M. Delocre has said that a curved dam will act as an arch if its thickness does not exceed one-third of the radius of its upper face, while another eminent French engineer, M. Pelletreau, considers that it will so act provided the thickness be not greater than one-half the radius. Mr. J. B. Krantz maintains that a radius as small as 65 feet is essential to permit a dam to act as an arch and transmit water-pressure to the sides. All engineers appear to agree that the mathematics of curved dams are extremely uncertain, and irreducible to a satisfactory demonstration. It is undoubtedly true that in a narrow gorge a considerable saving of masonry might be made by constructing the dam as an arch, with equal stability to one of gravity type built straight. M. Delocre is of the opinion that in no situation is it necessary for a curved dam to be of greater thickness at any point than the width of the valley at that height. The principle now generally adopted as safe is to make the structure strong enough to resist water-pressure by its weight, and curve the form as an additional safeguard.

The curving of all dams of whatever length or height regardless of whether they may act as an arch or otherwise for the purpose of enabling them to better resist the tendency to vertical cracks due to variations in temperature, especially in countries subject to climatic extremes, is coming to be recognized as of sufficient importance to lead to its general adoption. In this connection the following quotation is taken from the remarks of Prof. Forchheimer of the Aix la Chapelle Polytechnic School, Germany, in discussing a paper read by Mr. George Farren, before the Institution of Civil Engineers, in 1893, on "Impounding Reservoirs." * Referring to a dam 82 feet high, plastered and rendered over with two coats of asphalt, built by Prof. Intze in Remscheid, Westphalia, Prof. Forchheimer says:

"A backward and forward movement, amounting to $1\frac{1}{16}$ inches, occurred during the filling and emptying of the reservoir, and the movement due to temperature was almost as great as this. The latter was due less to the temperature of the air than to direct solar radiation. The crest of this dam was 460 feet long and was arched with a radius of 420 feet. One side was exposed to the sun longer than the other, and the more exposed part moved to and fro seven-eighths of an inch in the course of the year, while the other part moved only one-eighth of an inch, the crest expanding one nine-thousandth of its length, or five-eighths of an inch. In arched dams such movements do no harm, but in straight dams these phenomena are objectionable. As dams are usually built during the warmer seasons of the year, the masonry has a tendency to contract in the colder weather. In a curved dam this can take place by movement of the structure without cracking, but not in a straight dam. . . . If the temperature is lowered

* Proc. Inst. Civil Eng., vol. cxv. p. 156.

10° C. (18° F.) and it is not free to contract, tension amounting to between 140 and 280 pounds per square inch is set up, which is greater than the mortar will stand. . . . That a straight, or almost straight, wall incurs considerable danger of fracture is shown by practical experience. The dams of Habra, Grands-Cheurfas, and Sig, in Algiers, have broken, and in that of Hamiz a tear occurred during the first filling. The Habra dam broke in December, and the Grands-Cheurfas and Sig dams gave way in the month of February. The Beetaloo dam, in Australia, also developed a crack one-eighth of an inch wide in the middle of winter without any apparent cause. The Mouche dam, Haute Marne, a structure 1346 feet long and about 100 feet high, exhibits clearly the dangers attending straight dams. In the winter of 1890–91, when the temperature varied between – 10° C. and – 20° C. (14° to – 4° F.) and the water-surface was 10 feet 8 inches below the normal level, seven vertical cracks appeared in the dam, situated at uniform distances of about 160 feet apart. They were widest at the top, and died out about 37 feet below the normal water-level. Their aggregate breadth was 2¼ inches. The cracks gradually closed as the temperature rose, and by the end of February, 1891, four of them had completely vanished, while the others had perceptibly contracted."

It has been the observation of the writer that all curved dams are free from cracks, but that straight reservoir walls are quite certain to crack. The tendency of the water-pressure is to close any cracks that may appear where the dam is curved, and a curved dam is able to take up the movement due to temperature, without cracking, even though the pressure may not cause the arch to come in action. The inference is that every masonry dam should be built in the form of an arch, whatever its profile may be, for the avoidance of temperature cracks.

Mr. H. M. Wilson says: * "An additional advantage of the arched form of dam is that the pressure of the water on the back of the arch is perpendicular to the up-stream face, and is decomposed into two components, one perpendicular to the span of the arch and the other parallel to it. The first is resisted by the gravity and arch stability, and the second thrusts the up-stream face into compression, which has a tendency to close all vertical cracks and to consolidate the masonry transversely. An excellent manner in which to increase the efficiency of the arch action in a curved dam is that employed in the Sweetwater dam. This consists in reducing the radius of curvature from the center towards the abutments. The good effect of this is to widen the base or spring of the arch at the abutments, thus giving a broader bearing for the arch on the hillsides. The effect of this is seen in projections or rectangular offsets made on the down-stream face of the dam, the center sloping evenly, while the surface is broken by

* Manual of Irrigation Engineering, pp. 390, 391.

Fig. 57.—Old Mission Dam, near San Diego, Cal. The First Irrigation Dam built in the United States.

steps when it abuts against the hillside. . . . Though the cross-section of a curved dam may unquestionably be somewhat reduced, it would be unsafe to reduce it as much as has been done in the case of the Bear Valley and Zola dams, though these have withstood securely the pressures brought against them. It might with safety be reduced to the dimensions of the Sweetwater dam, thus saving largely in the amount of material employed."

## AMERICAN DAMS.

**Old Mission Dam, San Diego, Cal.**—The first masonry dam built in California of which there is any record was erected in 1770 by the Jesuit Mission Fathers. It was constructed across the San Diego River, 13 miles above its mouth, at the lower end of El Cajon Valley, where the stream cuts through a dike of porphyry. It was built for impounding and diverting water for irrigation and domestic use at the San Diego mission 4 miles below. It was 244 feet in length, 13 feet in thickness, and about 15 to 18 feet high. Fig. 57 is a recent photograph of the old dam in its present condition, half buried in trees and driftwood. The view is taken below the main outlet-sluice. The water was conveyed to the mission through an open masonry conduit, lined with semicircular tile or half-pipes. The cement used in the dam was made from limestone possessing hydraulic properties, quarried near the dam. The dam, though still in existence, has been disused for half a century past. It shows evidence of having been damaged by floods and repaired at various times. The manual labor of construction was done by Indians, of whom no less than 1600 neophytes were at one time supported at the mission. Considering the quality of the materials and labor available, and the torrential nature of the river, which it has resisted, as evidenced in the photograph by the driftwood piled up against it, the masonry is of excellent grade.

**El Molino Dam.**—A few years after the erection of the Old Mission dam of San Diego the Jesuit Fathers constructed a masonry wall of similar size about 10 miles east of Los Angeles, the purpose of which was to control and raise the level of a natural lake and impound it for use in irrigation at the Mission San Gabriel. The dam is located on what is now known as El Molino rancho, the name being derived from the fact that the priests here built a mill, whose massive walls are still intact, for grinding corn and wheat, the power for which was derived from water gathered from springs that issued from the hillside and fed the lake. The mill was a little above the level of the crest of the dam, and the water from the wheels flowed into the reservoir, where it was caught for use in the valley below. The dam was straight in plan, about 200 feet long, and 15 feet high at the center. The masonry is of superior character and is still in perfect state of preservation, although it has not been in service as a dam for many years past.

**The Sweetwater Dam.**—This structure is located in the Sweetwater River, 7 miles above the mouth of the stream and 12 miles southeast of the city of San Diego, California, and was built in 1887–88 by the San Diego Land and Town Company to impound water for the irrigation of lands bordering on the bay of San Diego and for the domestic supply of National City. The Sweetwater, like all the so-called rivers of San Diego County that empty into the Pacific Ocean, is a torrential stream, subject to violent floods in seasons of abundant rains, and dwindling to a diminutive brook within a few weeks or months after the rain ceases. During the summer and fall it ceases to flow, and on occasional years of low rainfall the run-off even in winter is practically nothing, so that it was essential to provide storage for at least two years' supply for the territory depending upon it. Prior to the beginning of work nothing was known of the probable run-off to be expected, further than that the watershed area of 186 square miles, having an extreme elevation of about 6000 feet, would probably receive a precipitation very greatly in excess of the recorded rainfall at San Diego, where the record has been maintained for nearly forty years, and that judging by this record the run-off from such a watershed should give an average supply adequate to the needs of the community to be provided, with a storage capacity of two years' supply in the reservoir. Subsequent experience has shown that the fluctuation in run-off has ranged from practically nothing for three consecutive years to 70,000 acre-feet in one year, or nearly four times the reservoir capacity, per annum. At the time the construction of the dam was begun in November, 1886, an active land "boom" was in progress in southern California, and the San Diego Land and Town Company, owning a large area of fertile lands, found them unsalable without water. It was essential, therefore, to obtain a certain portion of the supply quickly in order to market the lands. The dam was thus necessarily planned without the usual preliminary studies of its capacity for storage, or the volume of supply which would be required or could be made available.

As originally designed, the dam was to be a slender masonry or concrete structure, fashioned after the Bear Valley dam by the same engineer who built the latter, and was to be but 10 feet thick at base, 3 feet at top, and 50 feet high, backed on the water-face by an embankment of quicksand. When the wall had reached a height of 15 to 20 feet at the highest part, at an expenditure of $35,000, and its outline and design were fully realized by the management, the plan was disapproved and the writer was engaged to construct a more substantial work on the same site, utilizing the masonry already in place. The new plan was drawn to have an extreme height of 60 feet, and the new work enveloped the old. This structure is shown nearly complete in Fig. 58, and its profile is shown in dotted lines in the middle section on Fig. 59. It was built in steps onthe back with a view to

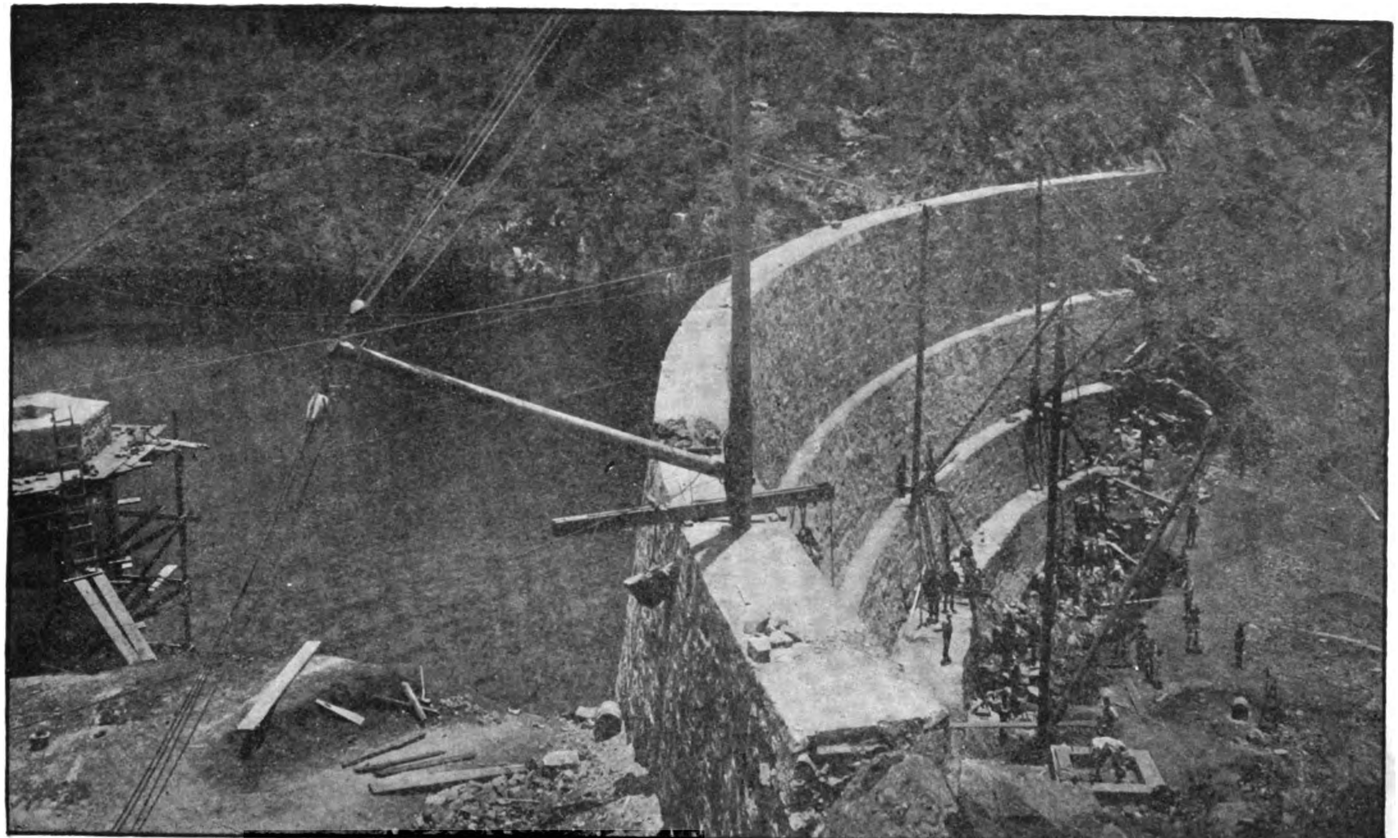


FIG. 58.—ORIGINAL SWEETWATER DAM AS COMPLETED TO THE SIXTY-FOOT CONTOUR.

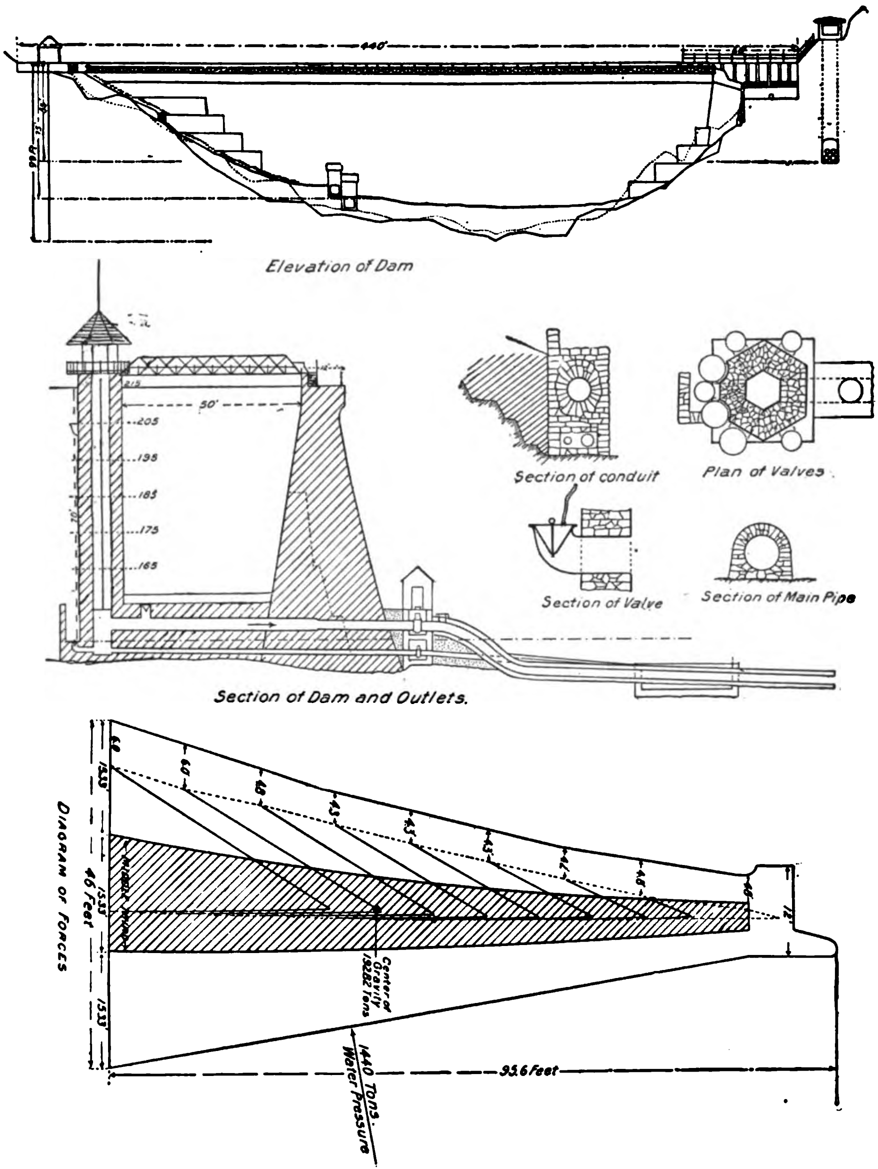



FIG. 59.—ELEVATION AND SECTIONS OF SWEETWATER DAM.

adding to its height, as was subsequently done. The dam had a maximum thickness of 35 feet at base, and was 5 feet thick at the top. It was fortified by an embankment of clay and gravel 50 feet wide, 10 to 15 feet high.

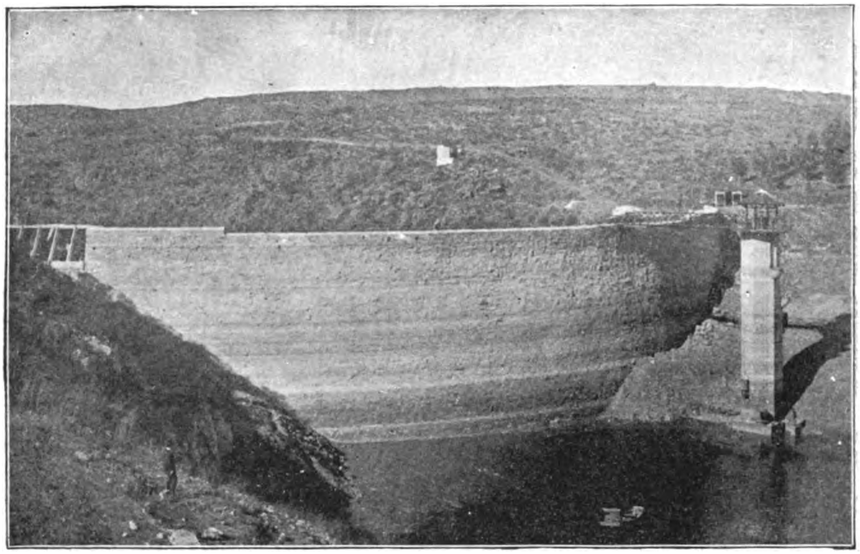


FIG. 60.—FACE OF SWEETWATER DAM IN 1899. AFTER TWO YEARS OF DROUTH.

placed against the upper side and well tamped in place. A portion of this embankment above the water-line is shown in Fig. 60, a view taken in the summer of 1899 when the reservoir was practically empty.

Shortly before the completion of the 60-foot dam authority was given for its extension to 90 feet in height, on the recommendation of the writer, whose surveys had revealed the fact that the reservoir capacity could be increased nearly fivefold by such addition of 30 feet to the height. Accordingly excavation was renewed at the lower side for an extension of the width of the base, and work proceeded on the final plan without interruption until the completion of the entire structure in April, 1888. The construction occupied sixteen months in all, including two months of waiting for cement. The profile adopted is shown in Fig. 59. As finished the dimensions were the following:

| | |
|---|---|
| Length on top | 380 feet. |
| " at base | 150 " |
| Thickness at base | 46 " |
| " " top | 12 " |
| Height on upper side exclusive of parapet | 90 " |
| Height on lower side | 98 " |
| Radius of arch | 222 " |

The up-stream face has a batter of 1 to 6 from base to within 6 feet of top; thence vertical. The lower slope has a batter of 1 in 3 for 28 feet, then 1 in 4 for 32 feet, and thence 1 in 6 to the coping.

Water is drawn from the reservoir through a tower of hexagonal form, placed 50 feet above the dam, near the center (see Fig. 61), and connected with the dam by a foot-bridge of iron (see Fig. 62).

It has seven inlet-valves which are placed at intervals of 10 feet in height from the top down. Two cast-iron outlet-pipes, 18 and 14 inches diameter respectively, lead from the tower to and through the dam. They lie in a trench cut in the bed-rock, and on top of them is built a masonry conduit from the tower to the dam, connecting with a third pipe, 36 inches diameter, of riveted wrought iron, ½ inch thick. All are carefully embedded in the masonry of the dam, and no leakage has ever taken place along them. Gate-valves control their flow below the dam. The tower valves are simple plates of cast iron fitting over elbows set in the masonry of the tower, and can only be moved when the lower gates are closed.

The stone used in construction was quarried from the cliffs on either side below the dam, within a distance of 800 feet, and was all hauled in wagons and stone-boats. Animal power was alone used for manipulating the derricks in the quarry and on the dam, as well as for mixing concrete. The stone was a blue and gray porphyry impregnated with iron, weighing 175 to 200 pounds per cubic foot. It quarried out with irregular cleavage, but generally presented one or two fairly good faces. The seams in the rock contained plastic red clay to such an extent that it was necessary to wash and scrub by hand every stone that went into the dam with good steel and fiber brushes. Imported English and German cement was used throughout the work, mixed with clean, sharp river sand in a revolving square box of wood, with a hollow shaft passing through two diagonally opposite corners, through which the water was introduced. The masonry weighed when tested 164 pounds per cubic foot.

The waste-weir is formed at the left bank as a part of the dam, and as first built consisted of seven bays, each 4 feet in clear width, closed with flash-boards, which could be opened to a depth of 5.7 feet below the crest of the dam. These bays were separated by masonry piers, each 2 feet in thickness. This wasteway and a 30-inch blow-off gate from the main pipe below had a combined capacity of 1800 second-feet, which was in excess of the maximum flood discharge as indicated by high-water marks, although a subsequent flood exceeded this capacity a little more than ten times.

The volume of masonry in the dam proper, including the parapet 3.5 feet high, 2 feet thick, was 19,269 cubic yards. The wasteway, inlet-tower, and other accessories required 1238 cubic yards additional, or a total of 20,507 cubic yards of masonry, in which were used 17,562 barrels of

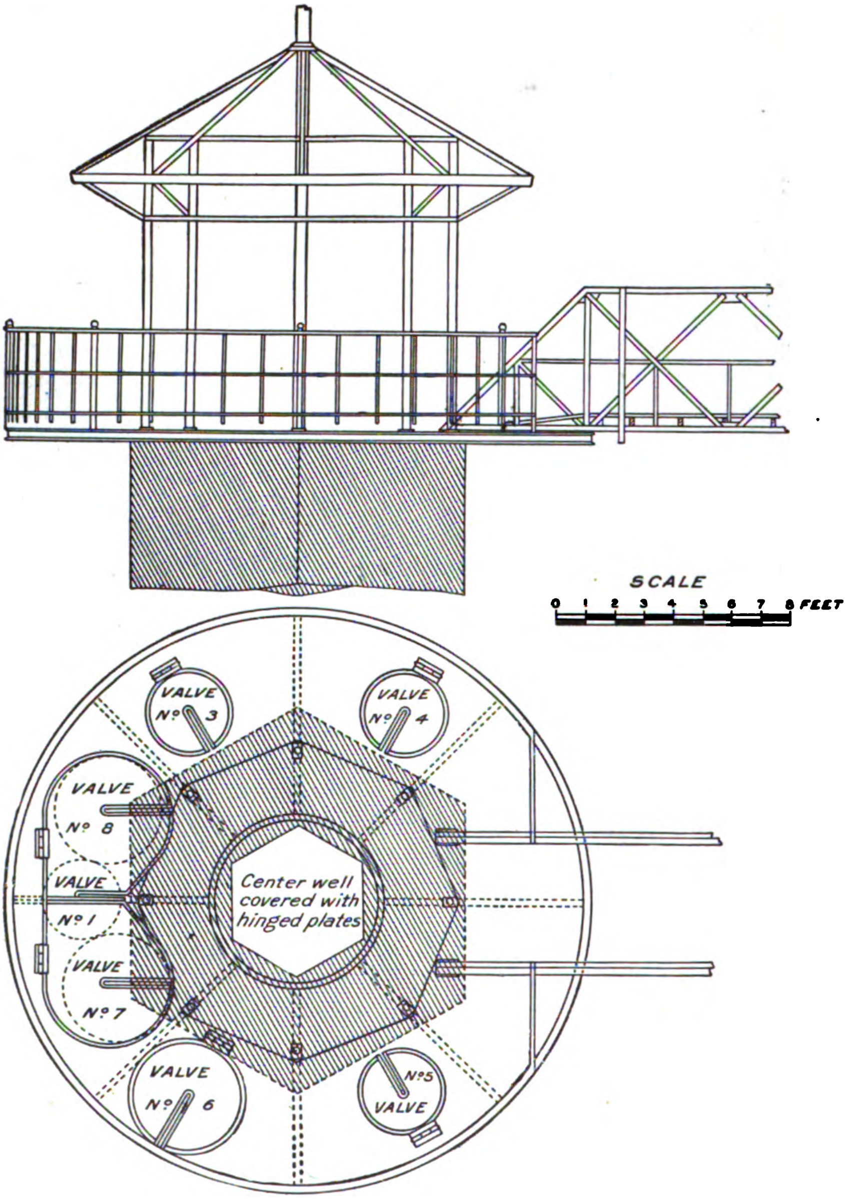



FIG. 61.—DETAILS OF TOWER OF SWEETWATER DAM.

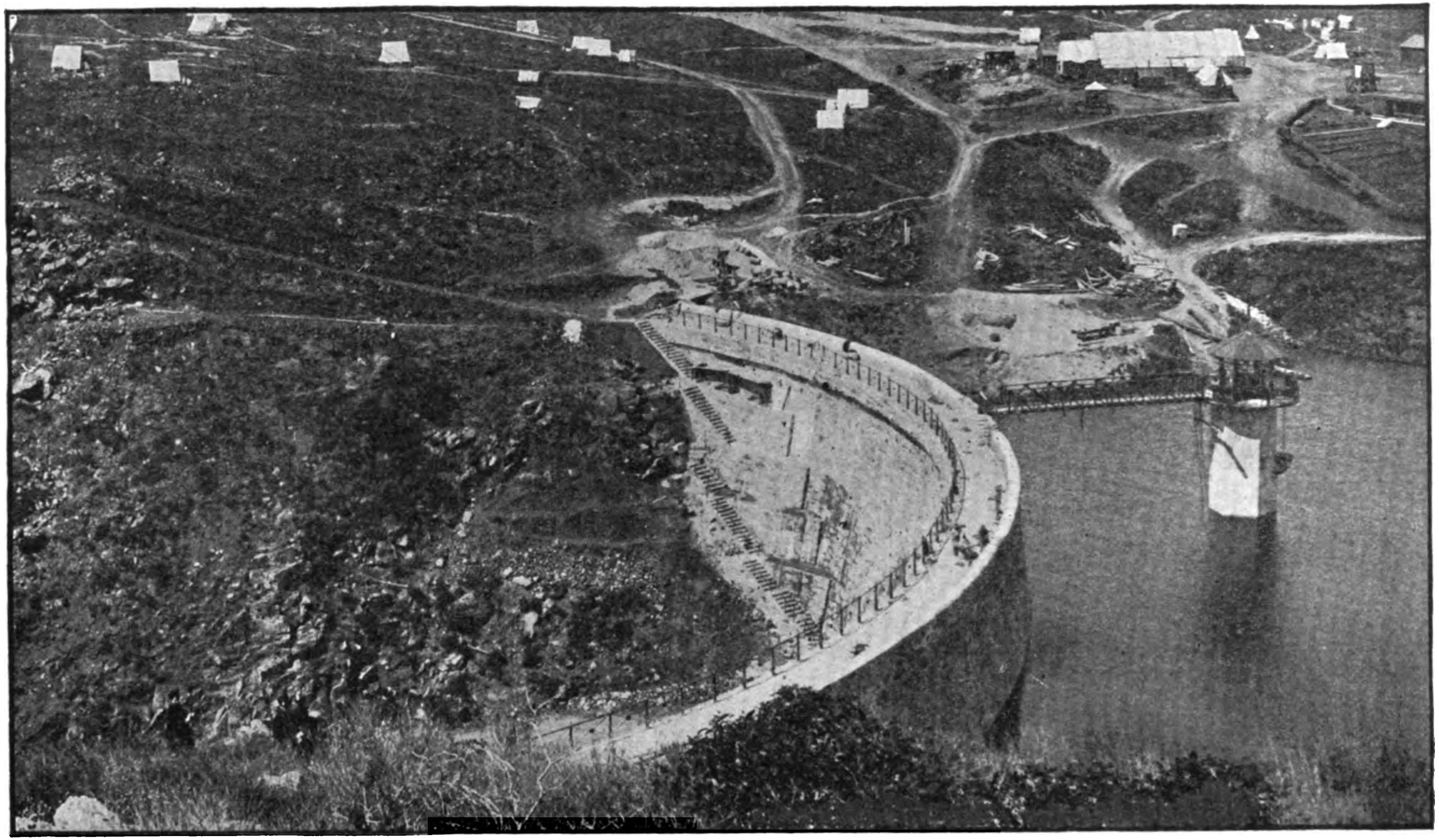


FIG. 62.—SWEETWATER DAM AS FINISHED, APRIL, 1888.

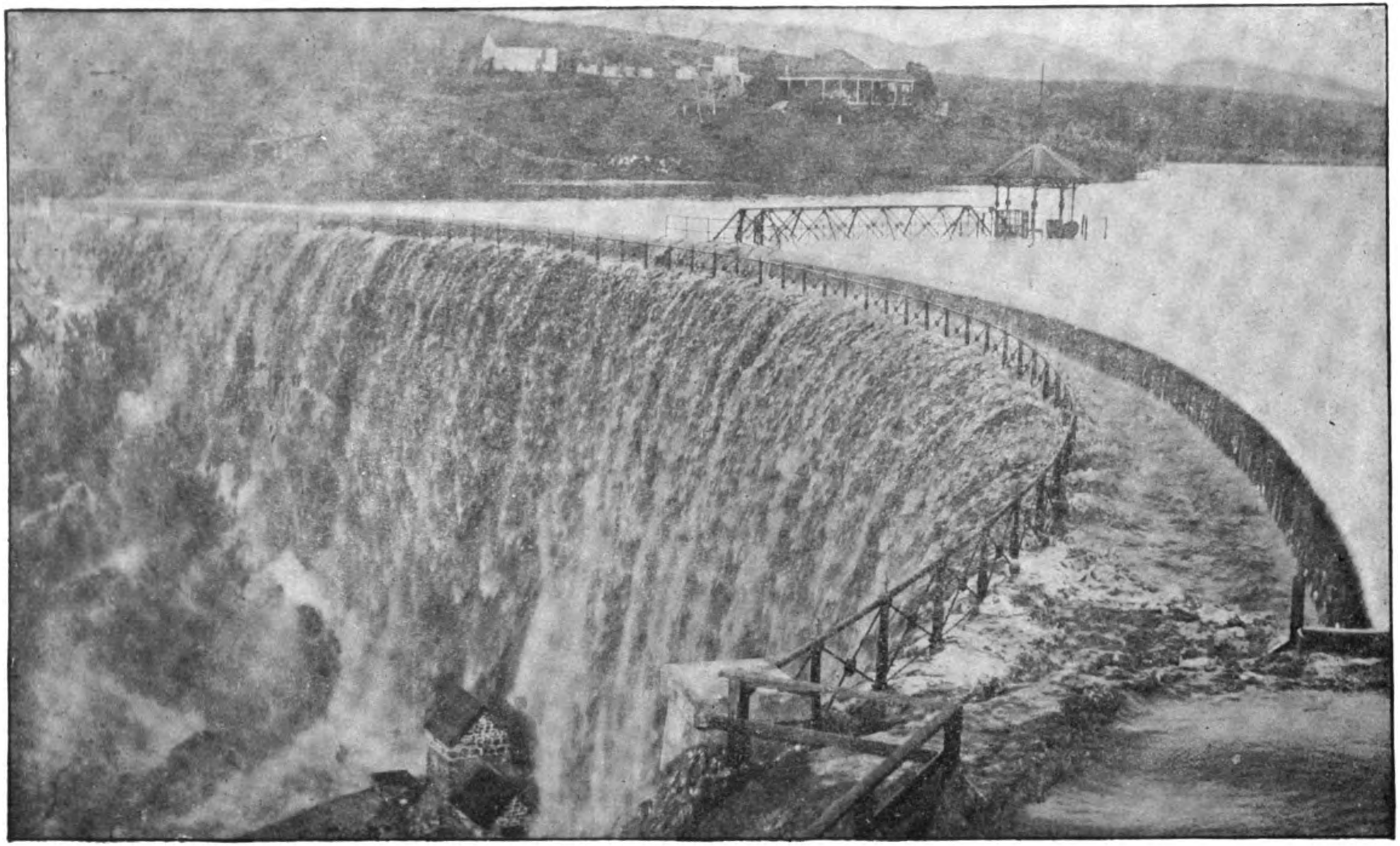


FIG. 63.—SWEETWATER DAM DURING THE GREAT FLOOD OF JANUARY 17, 1895.

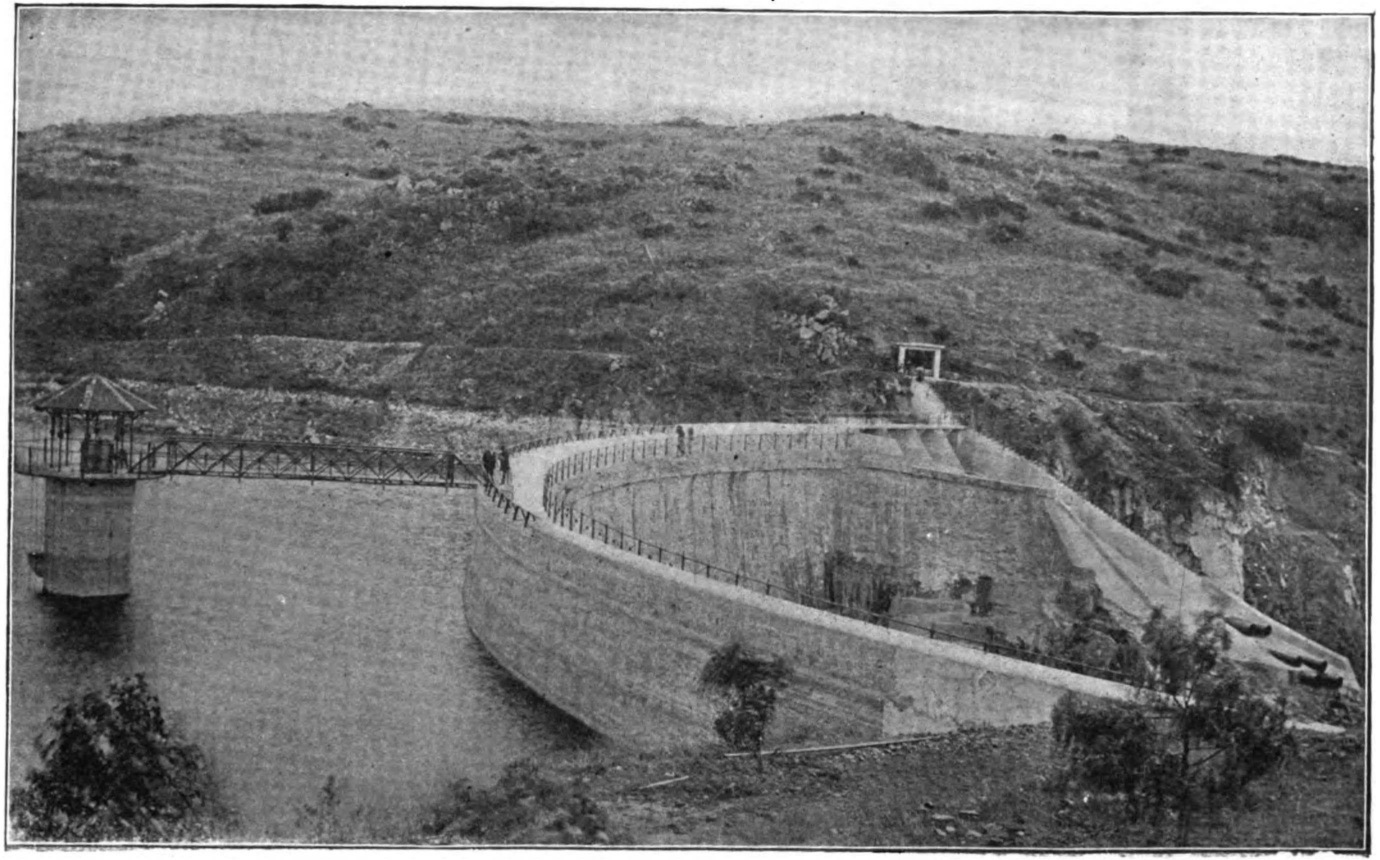


FIG. 63a.—SWEETWATER (CAL.) MASONRY DAM

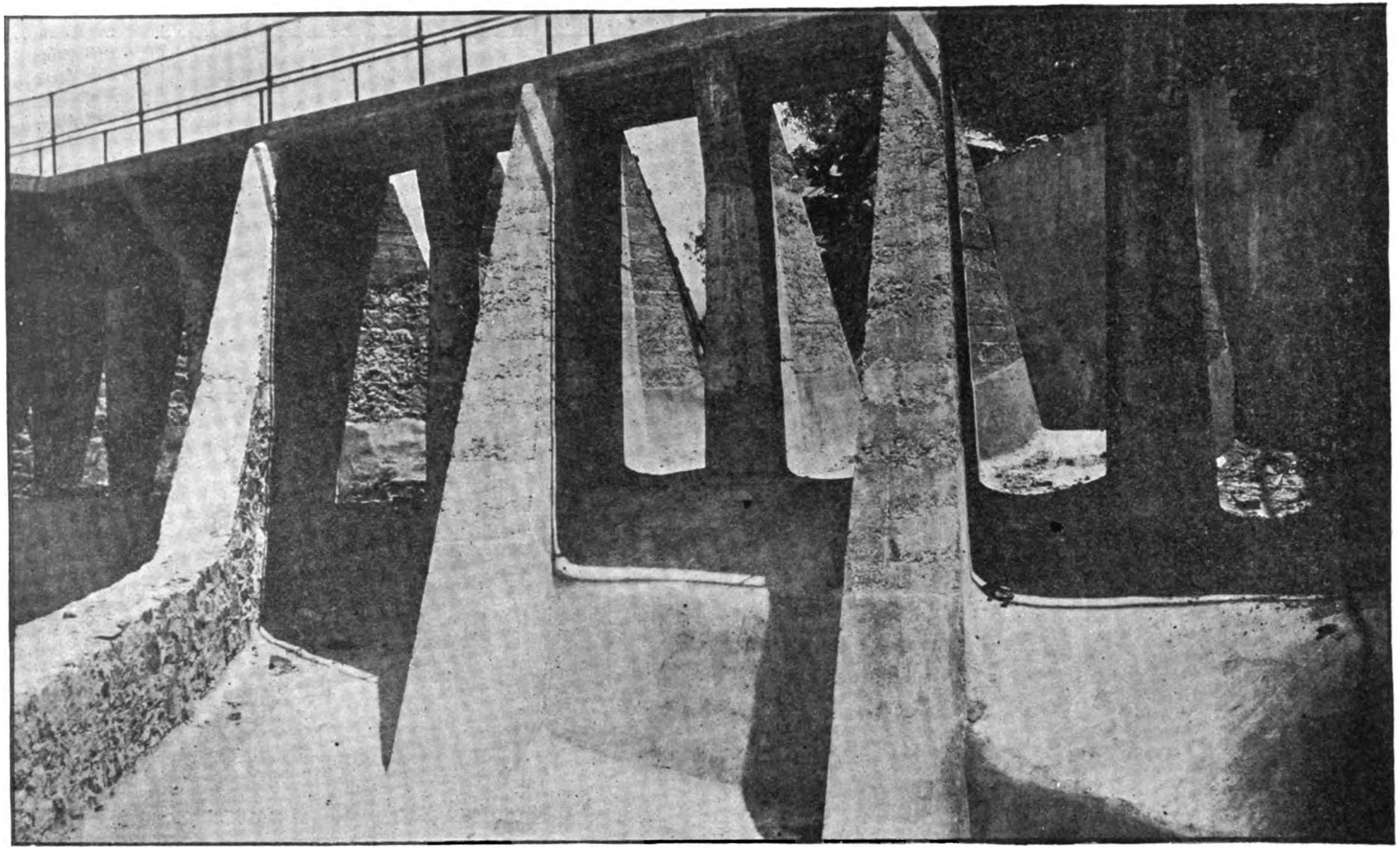


Fig. 64.—Spillway of Sweetwater Dam, seen from Below

cement, an average of 1.17 cubic yards per barrel. The total cost was $234,074.11, divided as follows:

| | |
|---|---|
| Plant | $6,236.76 |
| Materials | 87,431.70 |
| Labor | 140,405.65 |
| Total | $234,074.11 |

The reservoir capacity formed by the dam was 5,882,278,000 gallons or 18,053 acre-feet, of which 80% is within the upper 30 feet, and 40% in the last 10 feet. The area covered at high-water mark was 722 acres, of which 300 acres was cleared and grubbed at a cost of $10,808.46, or about $36 per acre. The average depth of the reservoir is 25 feet.

*Enlargement.*—On the 17th and 18th of January, 1895, the Sweetwater dam successfully withstood a test far more severe than is usually imposed on reservoir walls of such comparatively slender dimensions (thanks to the painstaking care exercised in its original construction), and beyond any previous calculation or expectation. On those dates the reservoir was filled to overflowing by a flood resulting from a rainfall of more than 6 inches in 24 hours, and for forty hours the dam was submerged to a maximum depth of 22 inches over the parapet wall, with the wasteway and blow-off gate wide open. This was 5.5 feet higher than the water had been expected to rise in extreme floods, as it had not been considered possible for the crest of the parapet to be reached.

A gap in the ridge to the south of the reservoir, the crest of which was about level with the parapet, carried off quite a large additional volume at the extreme of the flood. The maximum rate of discharge during the flood was carefully computed by Mr. H. N. Savage from weir measurement, and found to be 18,150 second-feet, a rate of discharge which was maintained for one hour.

This extraordinary freshet, which within a week produced a run-off of nearly three times the capacity of the reservoir, was gratifying in one respect, in that it demonstrated the ability of the dam to cope with such emergencies, as not a stone of the masonry was disturbed or moved from place, although so much damage was done to the pipes and surroundings of the dam as to necessitate a large expenditure in repairs. The water-supply was cut off from consumers for more than a month before a partial restoration could be made.

Advantage was taken of the opportunity afforded by the general repairs to make a material enlargement of the reservoir capacity by virtually raising the permanent high-water level to the point it had assumed during the flood, and at the same time preparing the dam for receiving a repetition of such an experience by enlarging the wasteway and fortifying the weak points developed by the flood.

The freshet caused a tremendous erosion of the bed-rock on either side of the dam, particularly in front of the spillway discharge, where the strata were inclined at about the proper angle to enable the water to strip off layer after layer with surprising rapidity. It was estimated that no less than 10,000 cubic yards of the solid rock on that side were torn away and washed down-stream, and some 2000 yards from the opposite wall of the canyon. The approach of a disused tunnel below the spillway, which was some 25 feet long, and about 30 feet of the tunnel itself, in solid rock, were cut off and the surrounding rock washed away. This tunnel had been opened some years before to draw down the reservoir, in compliance with the order of the United States Circuit Court, in the famous litigation over the condemnation of lands in the reservoir-basin, and terminated directly in front of the spillway channel. The bombardment of the stones rolled down the canyon during the flood upon the pipe-line resting on one side and covered with masonry, destroyed it for a considerable distance down-stream, as well as the railway track leading to the dam.

The repairs to the dam, and the general improvements designed, were completed in the summer following at a cost of $30,000, under the capable direction of H. N. Savage, chief engineer, the writer acting as consulting engineer during its progress. The alterations made were the following:

1. The parapet of the dam was raised 2 feet and strengthened, so as to permit of permanently holding the water in the reservoir as high as its crest, leaving 200 feet in the center as a weir, 2 feet deep. This weir was arranged with cast-iron frames carrying flashboards, to be removed in extreme floods, as shown in Fig. 66.

2. The spillway was extended in length by adding four more bays, each 5 feet wide, and carrying all the bays up to the level of the new crest of the dam, giving it a maximum depth of 11.2 feet and a discharging capacity of 5500 second-feet.

3. The unused tunnel, 8 by 12 feet in size, the bottom of which at the head is 50 feet below high-water mark, was adapted for use as an additional spillway discharge, by laying four pipes through it on a 4% grade, two of which are 36 inches and two 30 inches in diameter, all arranged with valve covers over elbows at their upper ends, where a shaft, reaching to the surface on the line of the dam, gives means of control (see Figs. 68, 69, and 70). Further control is had by gate-valves set in the pipes directly below the masonry bulkhead built across the tunnel at the shaft, all the pipes passing through this bulkhead. In the summer of 1899, when the reservoir was empty, the head of this tunnel was protected by a concrete portal with an inclined grillage of iron rails to keep out drift, as shown in Fig. 70.

4. The eroded rock slope below the wasteway after being made uniform was covered with a grillage of iron rails embedded in concrete, which has a

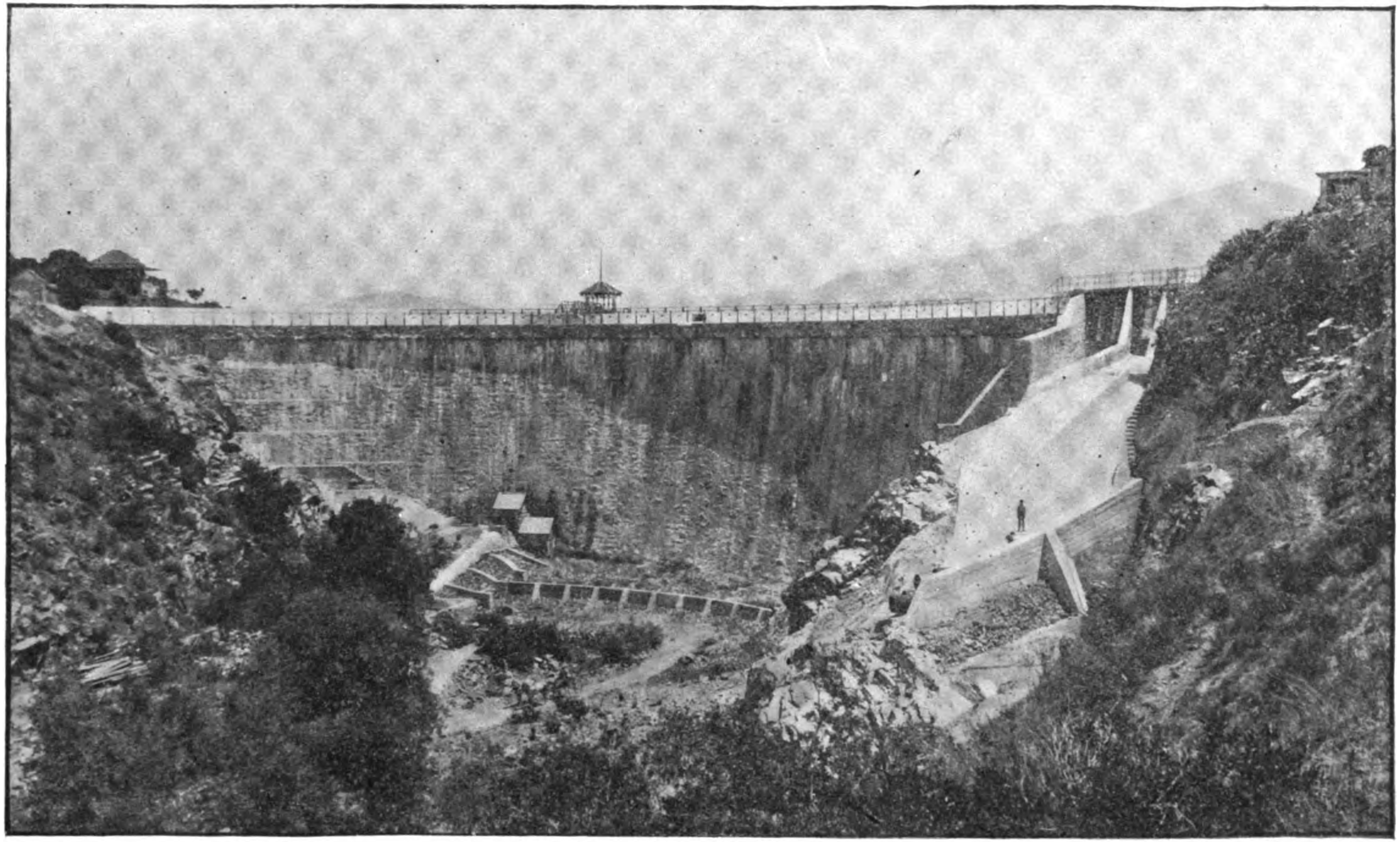


FIG. 65.—SWEETWATER DAM, SHOWING NEW APRON OF SPILLWAY AND PROTECTING SPUR-WALLS ON PIPE-LINE.

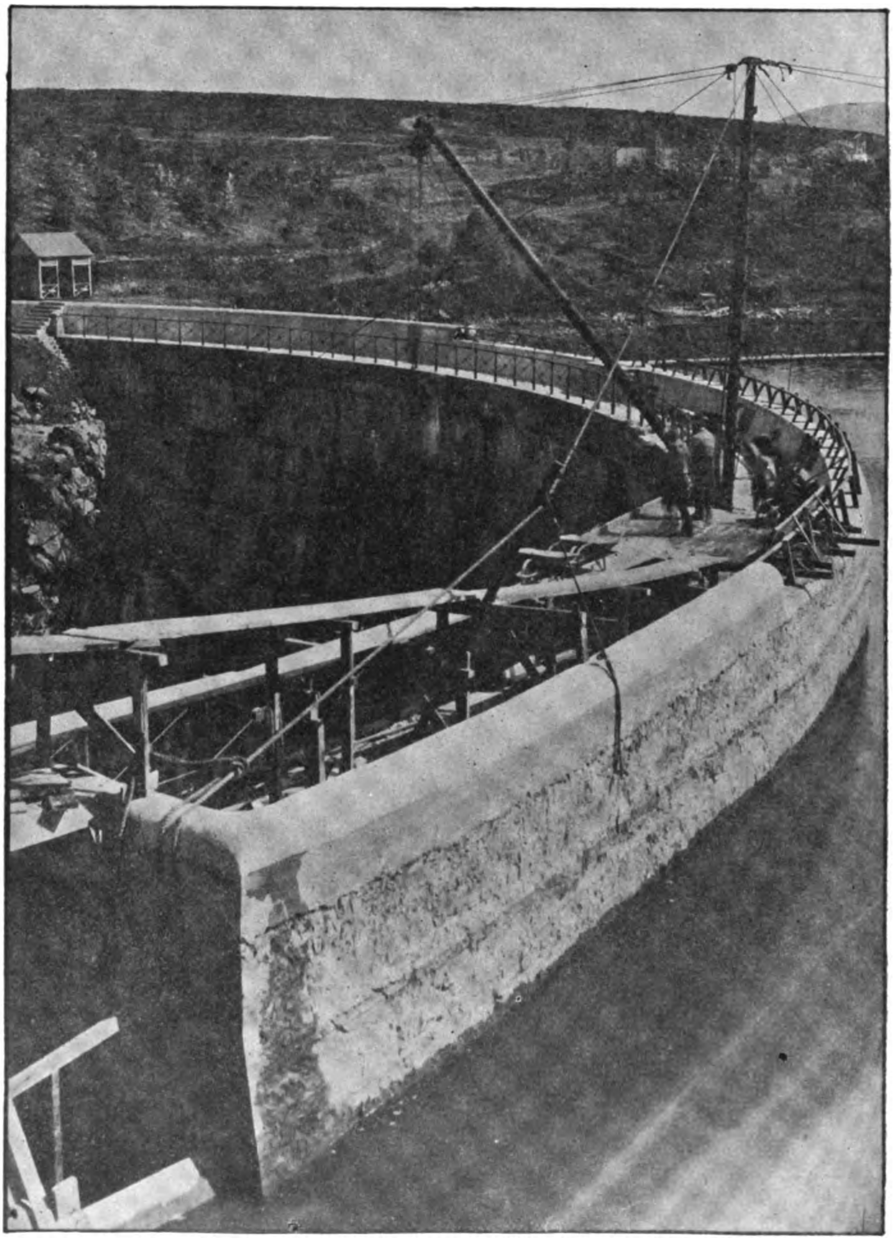


Fig. 66.—Repairing and increasing the Height of the Parapet of Sweetwater Dam.

thickness of 3 feet, and is designed to prevent all future erosion of the bed-rock (Figs. 65 and 69).

5. A concrete wall 15 feet high, 18 inches thick, with counterforts of

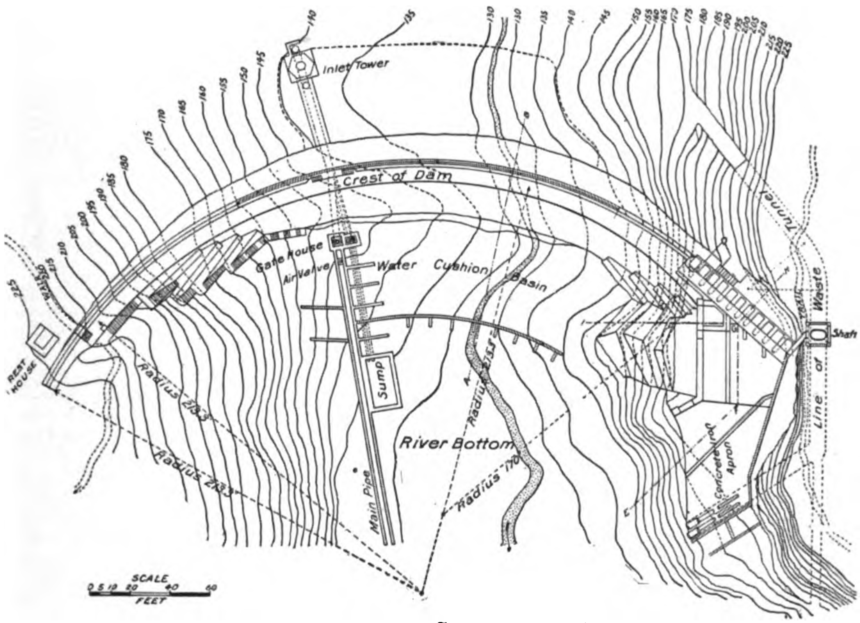



FIG. 67.—PLAN OF SWEETWATER DAM.

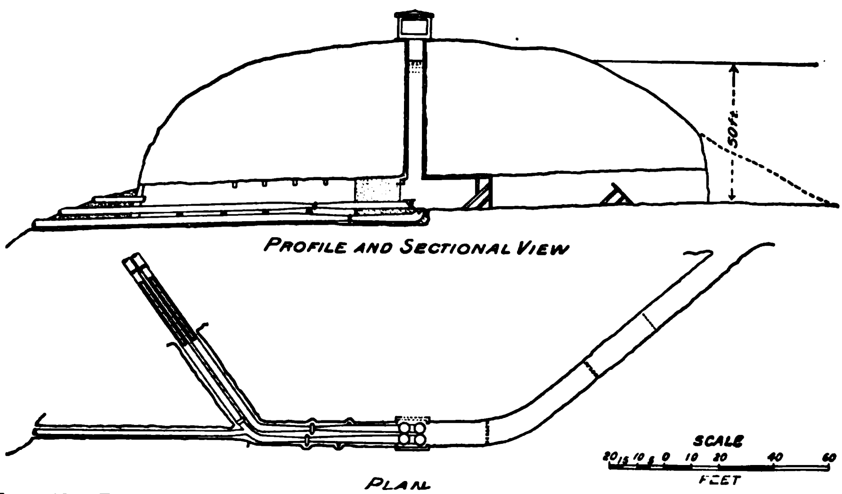



FIG. 68.—PROFILE AND SECTIONAL VIEW AND PLAN OF WASTEWAY TUNNEL, SWEETWATER DAM.

15 feet base, was built from bed-rock 50 feet below the dam on a curve concentric with it, to form a water-cushion or pool in case of a future overflow. This is shown in plan in Fig. 67.

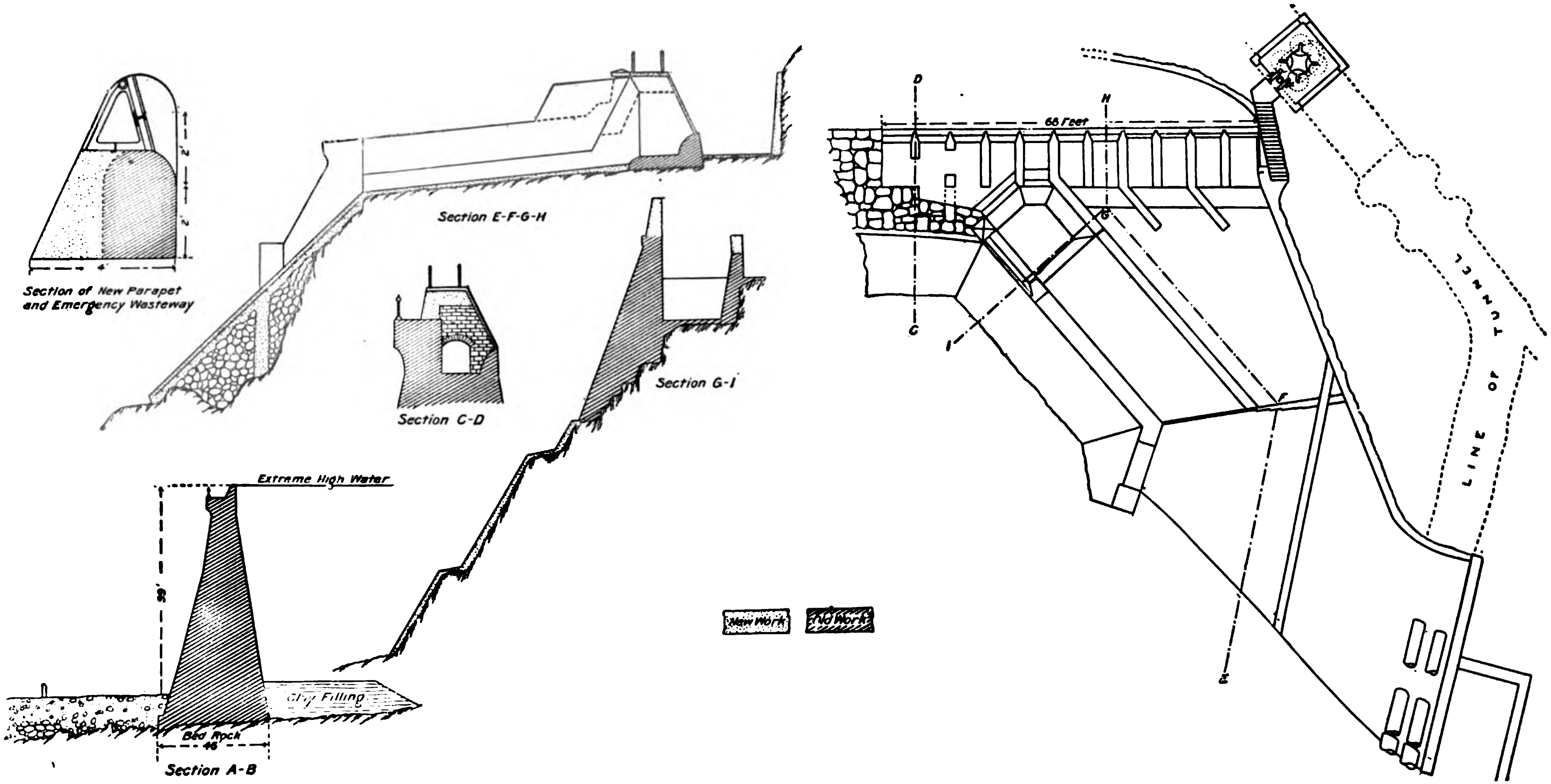



FIG. 69.—DETAILS OF SWEETWATER DAM.

6. The main supply-pipe was replaced through the canyon in a solid rock cut a portion of the way, and protected throughout the canyon by concrete collars and covering and spur walls, all with iron rods incorporated.

At the same time a new steel pipe-line, 24 inches in diameter, which was partly laid when the flood occurred, was completed to National City on

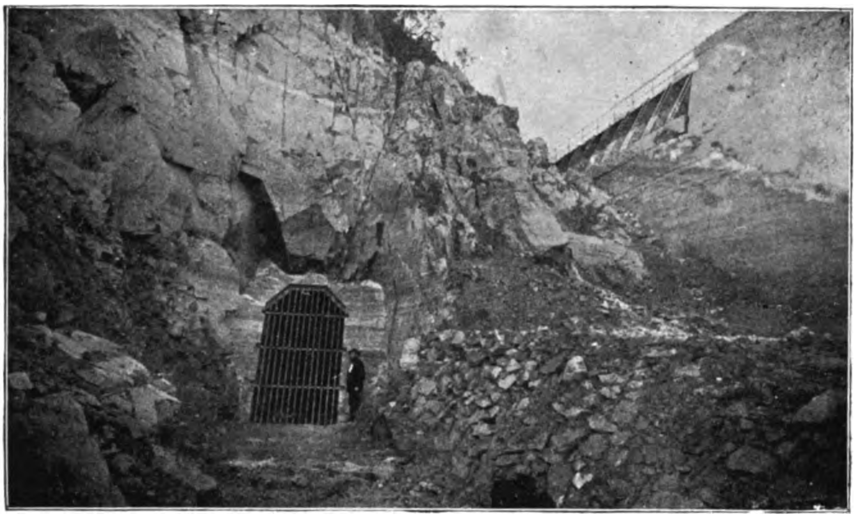


FIG. 70.—SWEETWATER DAM, SHOWING HEAD OF OUTLET TUNNEL AND SPILLWAY.

the north side of the valley, as a high-level conduit. This was connected with and took supply from one of the 30-inch-diameter pipes built in the tunnel, and connected with the original distribution system at National City, thus giving two independent conduits.

The effect of raising the parapet wall in the manner described has been to raise the height of the reservoir 5.5 feet and increase its capacity about 25%, or from 18,053 acre-feet to 22,566 acre-feet. The dam having shown its ability to withstand this increased pressure, it is now proposed to make this addition to the reservoir a permanent feature of the works.

Concrete was used in all the new work, as preferable to rubble masonry, because of the greater ease with which all the materials could be handled and because of the fact that the work could be performed by unskilled labor under intelligent foremen. The concrete was mixed with a rotary Ransome mixer, one of the best machines for the purpose yet devised. A steam hoisting-engine furnished all power required for rock-crushing, actuating the mixer, and hoisting the concrete to the top of the dam, where it was distributed by wheelbarrows. Old rails and scrap bar-iron of all sizes were embedded in the concrete wherever it would add desired reinforcement to the strength, as in the 6-inch floors of concrete forming the foot-bridge over the wasteway, spanning the 5-foot spaces between piers; in the roof of the gate-house over the shaft in the tunnel from which the heavy gates are suspended, and in the floor of the house; in the curved wall forming the auxiliary water-cushion dam, which is 10 to 15 feet high, and but 18 inches thick, and in the inclined apron of the wasteway. This construction is quite satisfactory, and shows no cracks anywhere. The rates of expansion and contraction of iron and concrete under changes of temperature are practically identical, and no separation of the two elements can occur by such changes.

There are no visible evidences of cracks in any of the masonry of the dam, nor any indications of a tendency towards crushing at the toe of the dam. This may be due to the fact that the stone is extremely hard and strong, and the mortar of prime quality. It may be further owing to the fact that arch action has resisted pressure from the top down to some neutral point where gravity alone suffices. There have never been any spouting leaks to indicate the transmission of an upward pressure upon the masonry of the slightest moment. The leakage through the wall was never of considerable amount, and has steadily diminished, so that when full the wall is practically dry over most of its outer face.

This leakage was reduced in amount in 1890 by carefully repointing the inside face as far down as the water was lowered in the reservoir, about 60 feet below the top, and applying successive washes of potash-soap and alum-water alternating.

Protracted litigation followed the building of the Sweetwater dam, over the attempted condemnation of a tract of about 300 acres of land at the upper end of the reservoir-basin, submerged by the impounded water. The land was comparatively valueless for agricultural purposes, but a jury gave an exorbitant judgment of its value on testimony erroneously admitted as to its special adaptability for reservoir purposes. This litigation lasted several years and was finally compromised, but the effect of it was quite disastrous to the progress of the country depending upon it for irrigation. During the progress of this litigation a tunnel, heretofore referred to, was opened around the south end of the dam, at the level of 25 feet above the lowest outlet, by means of which the flooding of the land could be avoided. In obedience to an order of the United States Circuit Court the reservoir, which had been filled, was ordered emptied, and an enormous volume of water was thus wasted at a time when it was greatly needed for irrigation.

Including the period of retarded growth during the progress of litigation the dam has been in service for thirteen irrigation seasons, during which time the impounded water has created values aggregating several millions of dollars, reckoning all improvements made in the district directly dependent upon it for water-supply. The area irrigated from it is now 4580 acres, chiefly planted to citrus fruits, of which the greater part is devoted to lemons. A population of 2500 to 3000 people is dependent upon the reservoir for domestic water. The distribution for irrigation as well as for domestic use is entirely by pressure-pipes, and the agricultural community is as well equipped for fire-pressure and general water-supply as the average American city. All water for irrigation, and practically all domestic water, is measured by standard water-meters. The pipe system has cost in the aggregate some $800,000.

**Run-off of Sweetwater River.**—The area of watershed above the Sweetwater dam is 186 square miles, ranging in elevation from 220 feet above sea-level, which is the elevation of the top of the dam, to about 5500 feet at the summit of the mountain-range in which it heads. The mean elevation of the basin is probably about 2200 feet. There is practically no diversion of the stream above the reservoir, and no utilization of its water other than that of the dam. Hence the catchment at the reservoir represents the entire run-off of the shed. A careful record of this run-off has been kept since the construction of the dam. Its extremely variable character is shown by the following table:

TABLE OF MEASURED RUN-OFF, SWEETWATER DRAINAGE-BASIN.

Area 186 square miles.

| Season. | Rainfall at Sweetwater Dam. Inches. | Run-off as measured at the Dam. Acre-feet. | Average Yearly Run-off in Second-feet per Square Mile. | Average Annual Run-off. Second-feet. |
|---|---|---|---|---|
| 1887–88 | | 7,048 | 0.0524 | 9.74 |
| 1888–89 | 13.53 | 25,253 | 0.1875 | 34.88 |
| 1889–90 | 16.52 | 20,532 | 0.1525 | 28.36 |
| 1890–91 | 12.65 | 21,565.5 | 0.1602 | 29.79 |
| 1891–92 | 9.88 | 6,198.3 | 0.0460 | 8.26 |
| 1892–93 | 11.62 | 16,260.7 | 0.1210 | 22.51 |
| 1893–94 | 6.20 | 1,338.4 | 0.0099 | 18.45 |
| 1894–95 | 16.19 | 73,412.1 | 0.5453 | 101.40 |
| 1895–96 | 7.29 | 1,320.9 | 0.0098 | 1.83 |
| 1896–97 | 10.97 | 6,891.6 | 0.0512 | 9.52 |
| 1897–98 | 7.05 | 4.3 | 0.00003 | 0.006 |
| 1898–99 | 5.05 | 245.5 | 0.0018 | 0.34 |
| 1899–1900 | ............... | 0.0 | 0.0000 | 0.00 |
| Total............ | ................ | 180,066.1 | | |
| Mean for 13 yrs.. | ................ | 13,851.2 | ............... | 20.89 |

Of the entire period of twelve years recorded the run-off has exceeded the capacity of the reservoir in but four seasons. The remaining eight seasons have been so far below the full reservoir-capacity in yield of stream-flow as to justify the recommendation made by the writer on the completion of the dam that a full reservoir should always be considered as a two-years' supply, and that no more than one-half its capacity should be used in any one season. The percentage of probable mean rainfall which this run-off represents is remarkably small, in view of the mountainous and precipitous character of a considerable part of the drainage-basin. The mean rainfall of 1894–95 was estimated at 27.14 inches, of which the run-off was but 26%. The following year, with an estimated mean rainfall of 16 inches the run-off was but six-tenths of 1%. This illustrates the great variation to which such streams are subject. When the rainfall in the lower two-thirds of the basin does not exceed 12 inches it is all absorbed in plant-growth and evaporation from the soil and does not feed the stream except when it comes in violent storms. Under such conditions the upper third of the basin supplies all the run-off, and if that portion does not receive more than 18 to 20 inches, the stream-flow is very small and of short duration. The record of catchment at the Cuyamaca reservoir, whose watershed is all on the mountain-top from 4800 to 6500 feet in elevation, adjoining the upper portion of the Sweetwater shed, clearly shows that the larger part of the run-off of all of these coast streams must ordinarily come from the higher mountains, and illustrates the value of elevation in any shed for purposes of yielding run-off for reservoirs.

The precipitation and catchment record kept at the Cuyamaca dam from 1888 to 1896 shows that the drainage-basin of 11 square miles gave an average yield of 491 acre-feet of water per square mile, while the mean of the Sweetwater during the same period was 100 acre-feet per square mile, or about one-fifth that of the Cuyamaca.

Since the great flood of January, 1895, the Sweetwater system to and including 1899 has not experienced a season of sufficient run-off to fill the reservoir, and has endured practically four years of continuous drouth, as the entire catchment in these four seasons was 8,034 acre-feet, or 36% of the reservoir capacity. As a result the reservoir was drained to the bottom early in 1899, and it became necessary for the company to develop and put in operation an entirely new and independent supply for the preservation of the orchards. Two independent gasoline-engine, centrifugal-pump pumping-plants were established in the bed of the reservoir about 1½ miles above the dam, by which water was drawn from 35 small wells put down in the shallow sand and gravel-bed; the water there stored in the subterranean voids was thus made to yield a constant flow of about 1 second-foot. This was conducted in a flume to the dam, and there admitted to the tower and the distributing system. The pumping was done with gasoline-engines, the lift being about 18 feet. In the valley below the dam three substantial pumping-stations were installed, with steam-pumps, drawing from a large number of wells, bored at intervals of 100 feet along the suction-pipe leading to the pump. In this manner the stored water in the sandy bed of the valley was made to produce 4 to 5 second-feet additional. The season was successfully passed owing to the energy with which the supply was developed, the orchards were kept alive and thrifty, and no great suffering was experienced, although it seemed inevitable at the beginning of the irrigation season of 1899 that the orchards would perish, or at least that there would be a total loss of fruit, if not of the trees. Pumping operations extended from May to November 23, 1899, during which time the total volume pumped was about 458,000,000 gallons, or 1402 acre-feet. The area irrigated was approximately 3800 acres. Deducting from this total the amount of water used for domestic service, the mean depth actually applied to the orchards averaged 3.$\frac{3}{8}$ inches. This small amount, supplemented by thorough cultivation, proved sufficient to save the orchards and keep them in healthy growth, which is an interesting demonstration of what can be done in an emergency.

The cost of the pumping-plants and wells so quickly inaugurated as a substitute for the reservoir was about $27,000. The cost of pumping was about 6½ cents per 1000 gallons, which was covered by an increase in rates, to which the community cheerfully acceded as an emergency. The season of 1899–1900 having failed to give any run-off to the reservoir, all the pumping-plants in the reservoir-basin and below the dam were reinstalled, and an auxiliary plant, consisting of 40 wells, 2 inches diameter, 50 feet deep, pumped by a 22-H.P. gasoline-engine and 6-inch centrifugal pump, was added to the main plant at Linwood Grove, while at Bonita the same number of wells were sunk, and pumped by two 6-inch centrifugal pumps, placed in tandem and actuated by gasoline-engines. In this way it is hoped to tide over the third year of drouth.

**Sedimentation of Sweetwater Reservoir.**—Prior to the construction of the dam some apprehension was felt as to the probability of the speedy filling of the reservoir with sand brought down by the stream, which had been thought to be so large in volume as to destroy the usefulness of the reservoir in a short time. The writer made some observations on the load of sediment carried by the stream in flood during the construction of the dam, which led him to conclude that the reservoir might be filled with water a thousand times before becoming entirely filled with sediment.*

Careful re-surveys of the reservoir made by Mr. H. N. Savage, chief engineer, since it became empty, demonstrate that the total filling has been about 900 acre-feet since the construction of the dam, or at the average rate of 75 acre-feet per annum. The total volume of water that has entered the reservoir in twelve years has been 180,066 acre-feet. The measured solids deposited from this water have therefore averaged a trifle more than one-half of 1%. The deposit has been almost directly as the depth, being greatest at the dam, where the depth of silt of almost impalpable fineness is 2½ to 3 feet. The addition made to the reservoir capacity after the flood of 1895 was 4.6 times the accumulated sediment of twelve years, or, in other words, sufficient to offset the filling of half a century.

* The Construction of the Sweetwater Dam. Trans. Am. Soc. Civil Eng., vol. xix. p. 214.

*Evaporation.*—The percentage of water lost in storage-reservoirs by evaporation is the most serious factor which the projectors of such enterprises have to anticipate. It is subject to wide variation due to differences in mean depth, exposure, temperature, winds, and relative humidity, but it is always in operation, and subjects the reservoir to a constant loss, so great that it must be considered in all calculations of reservoir duty, as, in extreme cases, it may amount to 50% per annum.

Careful measurements of evaporation in a floating pan at Sweetwater dam shows the annual loss to be about 54 inches in depth. It is about 2 inches during the month of January, and over 8 inches per month during July and August. This causes an annual loss of about 15% of the stored water, and as a reservoir must always be held back for dry years, so that practically a reservoirful is at least a two-years' supply, the loss is really 30% of the total supply, leaving but 70% of the reservoir capacity available for use, one-half of which only can be safely counted on each year. This reduces the available annual supply to about 8000 acre-feet.

At the Cuyamaca reservoir, on the adjacent watershed, the average loss reported during nine years prior to 1897 was 56¾ inches in depth per annum. This loss amounted to 25.5% of the total water caught and stored during that time, which is nearly double that of the Sweetwater. This difference is due to greater surface exposure per unit of volume stored. The Sweetwater reservoir has an exposure of 39.8 acres per 1000 acre-feet of capacity when full, while the Cuyamaca has an exposure of 84 acres per 1000. This is an illustration of the advantage of great average depth in reservoirs, and an argument in favor of high dams for effective conservation of water.

*Conduits.*—The main pipe leading from the dam is 36 inches in diameter for 1600 feet, thence 30 inches diameter for 28,200 feet to Chula Vista. It has a minimum capacity for delivery of 1260 miner's inches (25.2 second-feet) to an elevation of 90 feet above sea-level, which is high enough to cover the larger part of the settlement. This pipe was found to be inadequate to the demands upon it, because in practice the maximum rate of consumption is about double the mean rate, and for the further reason that the higher levels could not be supplied and at the same time permit the maximum discharge to the lower levels. To remedy this lack of efficiency a second conduit, 24 inches diameter, was built in 1895 on the north side of the valley of the Sweetwater. It is of riveted steel, 30,142 feet in length, and cost $65,000. It has a minimum capacity of 450 miner's inches (9 second-feet) and is used chiefly for high service. It connects at the dam with one of the 30-inch pipes laid through the tunnel. The distributing system of pipes, from 4 to 24 inches diameter, is over 65 miles in length, and has cost over half a million dollars.

**Hemet Dam, California.**—The most massive and imposing structure that has thus far been erected in western American for irrigation-storage is the dam erected in the San Jacinto Mountains, in Riverside County, California, at the outlet of Hemet Valley, the location of which with respect to the irrigated lands is shown in Fig. 71. The view in Fig. 72 is rather an imperfect representation of the appearance of the dam from below. Fig. 73 is an end view which shows the arched form of the dam.

The dam is built of granite rubble, laid in Portland-cement concrete, and was designed to be carried to the ultimate height of 160 feet above the stream-bed. Its present height is 122.5 feet above base, or 135.5 feet above

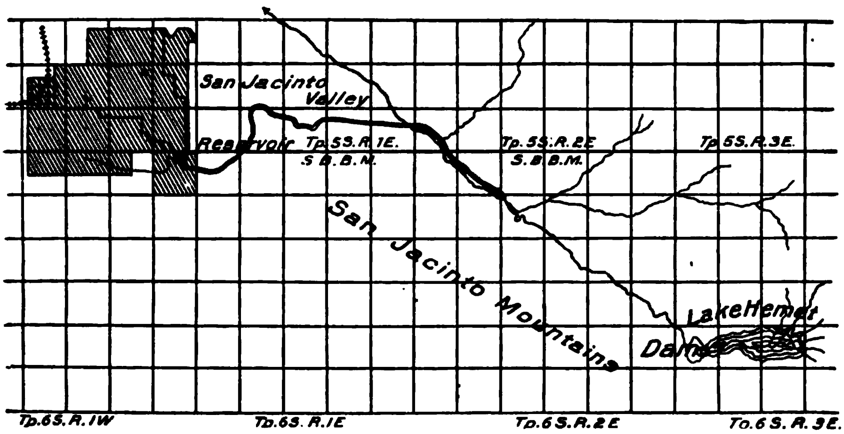



FIG. 71.—MAP SHOWING LOCATION OF LAKE HEMET, THE MAIN CONDUIT, AND IRRIGATED LANDS.

lowest foundations. It is 100 feet in thickness at base, and has a batter of 1 in 10 on the water-face, and 5 in 10 on back. Its present crest is 260 feet long, while the length on base is but 40 feet. The dam was built up with full profile to the height of 110 feet above base, at which point the thickness is 30 feet. Here an offset of 18 feet was made, and the remaining wall is 12 feet at base, and 10 feet thick at top. A spillway notch 1 foot deep, 50 feet long, was left in the center. Extreme floods may exceed the capacity of this spillway and pass over the entire length of the wall to the depth of several feet. This actually occurred in January, 1893, when the dam was 107 feet in height. The dam is arched up-stream with a radius of 225.4 feet on the line of its upper face at the 150-foot contour, although it has a gravity section, with the lines of pressure inside the center third, as shown on section in Fig. 75.

The site seemed to be more suitable for a masonry structure than any other type because the canyon is extremely narrow, the foundations excellent, and materials for construction abundant. After due consideration of all alternative possibilities the writer was directed to prepare plans suitable for the maximum height to which a dam could be built to advantage at this site, and in the summer of 1890 the plant was assembled and excavation begun. The stripping to bed-rock occupied several months, with the aid of a cableway for conveying the waste to a dump below the dam. In this operation a large hole was developed in the rock, 13 feet in depth, within the lines of the base of the dam. This hole was found to be filled with gravel, firmly cemented in place so tightly that it might safely have been built upon had its limits been known. After the hole was cleaned out a center trench was cut in the bed-rock up the sides, as a key or anchorage, to receive the masonry.

The cement and all tools had to be hauled up the mountain, a distance of 23 miles from the nearest railroad station, over a road whose maximum grade is 18%, making a total ascent of 3350 feet, and descending to the dam from the summit nearly 600 feet. The hauling was done at a cost of $1 to $1.50 per barrel, and occupied a considerable time in delivering a sufficient quantity to make a beginning, and it was the 5th of January, 1891, before the first stone was laid.

The total amount of cement used was about 20,000 barrels, which cost delivered about $5 per barrel.

Work was prosecuted without interruption until January 24, 1892, when severe weather and floods compelled a suspension of construction for four months, when the 45-foot level was reached.

On resumption of work the following spring it was pushed to the 107-foot contour, when the workmen were again driven off by a storm and freshet on January 9, 1893, when the reservoir was filled so rapidly that many of the buildings and tools were submerged before they could be removed. The work remained at this stage until the fall of 1895, when the dam was completed to its present height and all machinery and tools were brought down the mountain. At its present height the dam contains 31,105 cubic yards of masonry.

The concrete used to embed the blocks of stone was mixed in the proportion of 1 of cement, 3 of sand, and 6 of broken stone, crushed to pass through a 2½-inch ring. Mortar was only used in laying the facing-stones and pointing the joints on the exterior faces. Both concrete and mortar were mixed by a cubical iron mixer, one of a number that had done service on the San Mateo dam in northern California. The sand used was clean and sharp, and was constantly brought to the dam by the small living stream flowing from the mountains, the sand being rolled along its bed. It was accumulated in a little reservoir formed by a temporary log dam, and conveyed to the mixing-platform by an endless double-wire-rope carrier, fitted with triangular buckets, placed at intervals of 20 feet. By this means the sand was hoisted 125 feet and carried horizontally 400 feet to the mixing-platform, where it was stored in a bin. This device was very simple, inexpensive, and quite effective, and the sand was always washed clean. Fig.

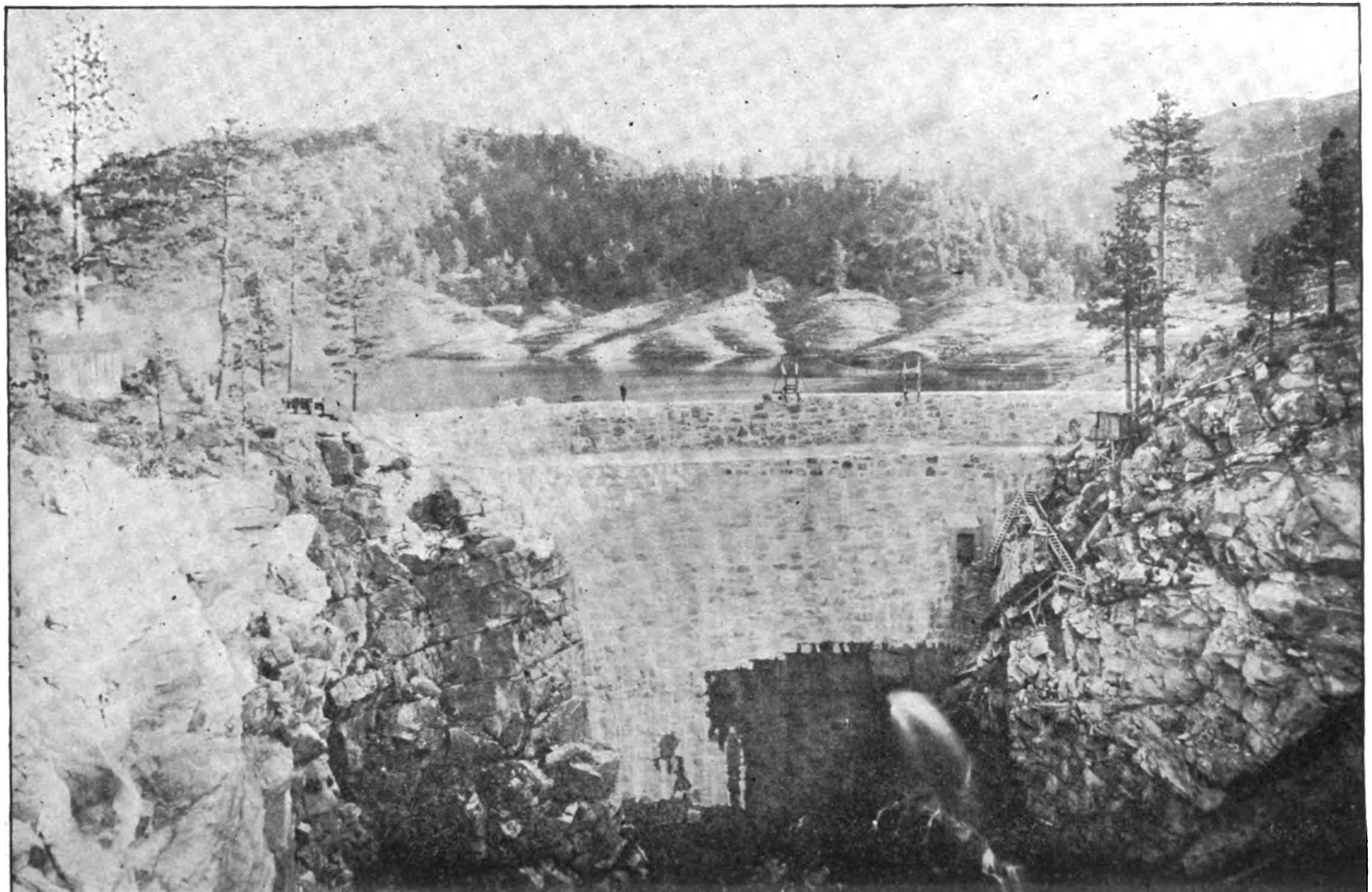


FIG. 72.—HEMET DAM, RIVERSIDE COUNTY, CALIFORNIA.

Fig. 73.—Hemet Dam as finished, showing the Spillway Ridge South of the Dam.

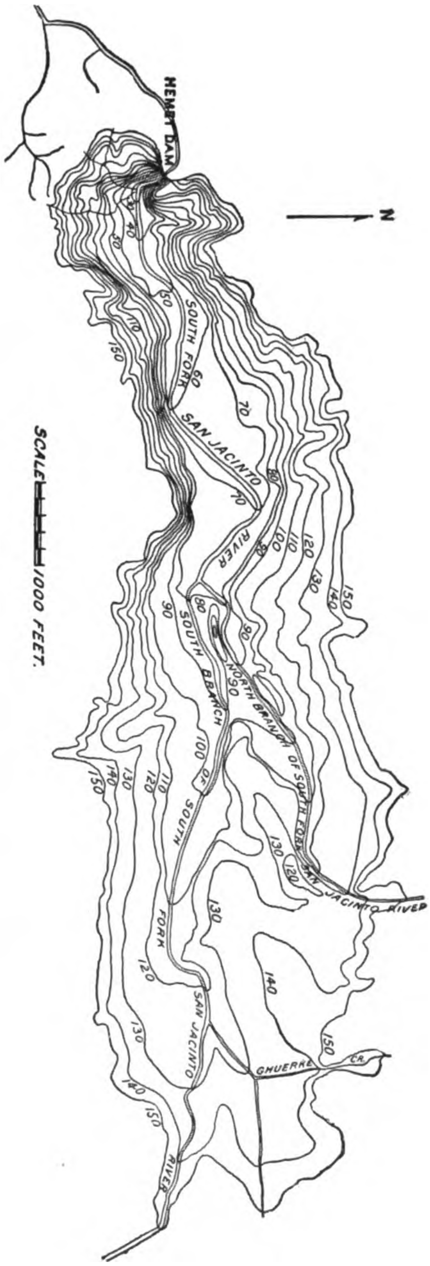



FIG. 74.—CONTOUR MAP OF THE LAKE HEMET RESERVOIR.

76 shows a view of the plant for crushing the stone and mixing the concrete. A portion of the sand-conveyor is also visible in the photograph, as well as one of the engines used on the cableways, and the cars for the

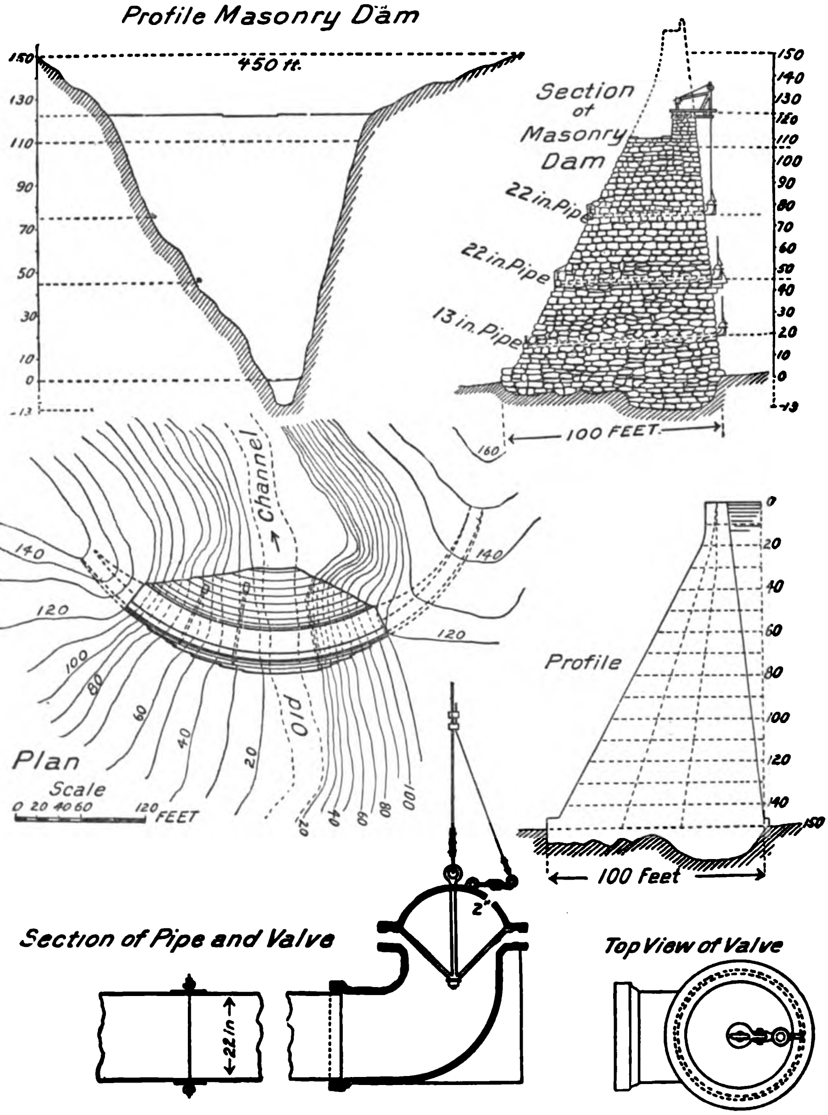



FIG. 75.—HEMET DAM, RIVERSIDE COUNTY, CALIFORNIA.

delivery of concrete to the dam. These latter ran along a tramway, laid on a trestle built from the mixing-platform along the face of the vertical cliff, some 300 feet, to the dam at the 80-foot level. When the dam reached this level an elevator was built to a higher line of trestle.

The stone was all quarried within 400 feet of the dam, on both sides of the canyon, both above and below the dam. It was hoisted and conveyed to the wall by two cableways, each about 800 feet long and 1½ inches in diameter. The cables crossed the dam nearly at right angles with the chord of the arch, but diverging from each other, and were anchored to convenient trees on either side of the gorge. Their position was seldom changed, except to lift them higher up into the tree-tops, and to erect "A" frames on top of the masonry to support the cables, when the wall had reached such a height as to require it. Loads of 10 tons could be hoisted

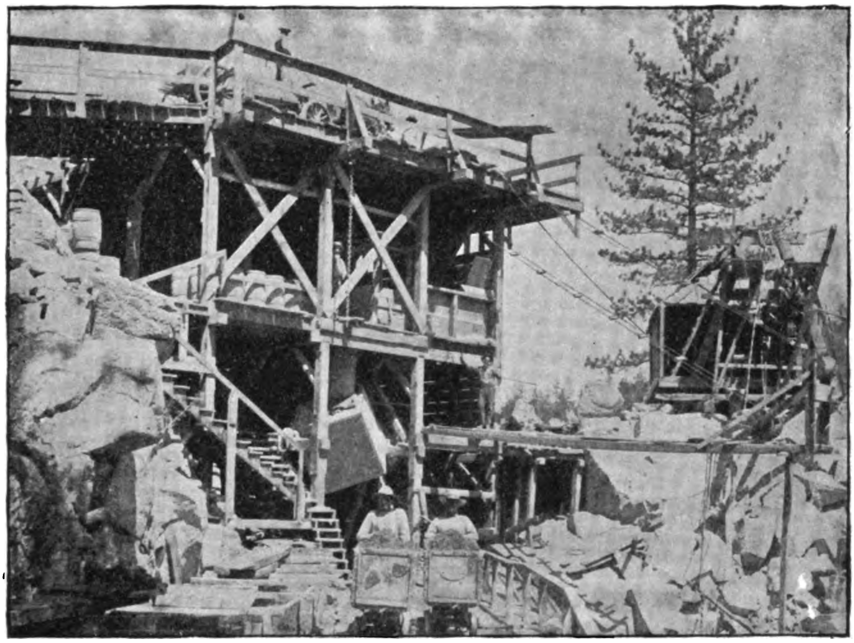


FIG. 76.—HEMET DAM CONSTRUCTION PLANT.

and handled with ease, and with the aid of two derricks, one at each end of the dam, the rock brought by the cables was placed where required. The loads were readily transferred from the cableway to the derricks while in the air. The trolley which traveled on the cableway, and the devices for sustaining the hoisting-line as the load moved back and forth, were devised on the ground and operated satisfactorily.

The derricks were actuated by water-power obtained from a 36-inch Pelton wheel located below the dam and propelled, under a head of 75 feet, by about 80 miner's inches of water, brought from the stream by a flume 1.5 miles long to the edge of the cliff at the mixing-platform, and thence in a 13-inch riveted steel pressure-pipe. The pipe passed through the line of the dam and was embedded in the masonry. Subsequently it was cut off at the upper face of the dam and was made available as the lowest outlet of the reservoir. Two other outlets were provided, consisting of 22-inch lap-welded steel pipes, placed at the 45-foot and 75-foot levels, near the left wall of the canyon. These pipes were provided with cast-iron elbows turning upward and flaring to 30 inches diameter, just inside the line of the dam. They are closed by semi-spherical cast-iron covers, which are raised and lowered by wire ropes passing over a pulley and windlass that are provided for each, and stand on an overhanging frame bolted to the top of the masonry. These covers are ordinarily removed and replaced by cylindrical fish-screens that stand on the top of the elbows, and the main control is had by gate-valves set on each pipe at the lower line of the dam. When these valves are open the water spouts freely into the air and falls in a spray upon the rock below. This water is collected in a pool a short distance from the dam, and passes over a weir for measurement, before beginning its 5-mile plunge down the canyon, to the final point of diversion into the main flume.

When construction began, the reservoir-site was well covered with pine forest, and, as it was desirable to clear the flowage tract, the trees were cut and sawed into lumber. Over one million feet B.M. of this lumber was used for buildings, flumes, and staging about the dam, and half a million more was hauled to the valley for flumes and trestles. Much of the firewood cut from the tree-tops was also hauled down the mountain by the returning cement teams. The main conduit is partly built of this mountain pine, and, although it is knotty and inferior lumber for general purposes, the flume made of it did good service for six or eight years before it was recently replaced with California redwood, which is much more durable. The conduit is 3.24 miles in length from the pick-up weir, just above the junction of South Fork and Strawberry Fork, to the mouth of the main canyon, where it connects with a 22-inch riveted iron pipe, 2 miles long. From the end of this pipe an open ditch, lined with masonry 8 to 10 inches thick, and plastered with cement mortar, conveys the water 5 miles to a 20-acre distributing-reservoir, located near the highest corner of the irrigated lands. This reservoir has a capacity of about 90 acre-feet, and from it the water is distributed by some 30 miles of pipe, flumes, and lined ditches. The slope of the land is 40 feet per mile from east to west, requiring small conduits for distribution. The main canyon flume was built of 1½-inch lumber, and is 38 inches wide, 18 inches deep, and has a grade of about 140 feet per mile. It was calked and battened, smeared with asphalt inside, and whitewashed on the exterior with lime. The ditch-lining consists of granite cobbles of 10 inches maximum diameter, laid in equal parts of lime and cement mortar. It is 2.75 feet wide on bottom, 7 feet at top, 2.75 feet deep, and has a capacity of 60 second-feet or 3000 inches.

The dam of the distributing-reservoir is of earth, 300 feet long, 14 feet high, and 8 feet wide on top. The reservoir is usually filled within a foot of the top of the dam. In construction a trench was excavated 9 feet deep under the center line, in the center of which a tight board fence was built, reaching to the top of the dam, to prevent the burrowing of ground-squirrels and gophers, a function which it effectually performs. The trench was refilled with puddled soil each side of the fence, and the puddle brought to the top of the dam. The area irrigated by the system in 1896 was 1092 acres, and is increasing each year as the tracts are sold to settlers.

This area was in 72 separate tracts, of which the average size is 10 to 20 acres. The rates charged for water are $2 per acre annually, with an additional charge during the nominal "non-irrigating season" (November 15 to April 15) of $1 per month for each tract for domestic service. In the town of Hemet, which is supplied by the same system, there were, in 1896, 55 taps, paying a uniform domestic rate of $1.50 per month. Water-power is used in the town to drive an electric dynamo for lighting the hotel and some of the buildings, the waste water flowing to a small reservoir.

The apportionment of water by the water-right contracts given with the deeds to the land is at the rate of "one-eighth of 1 miner's inch of perpetual flow from April 15 to November 15 of each year for each acre." This is equivalent to 46,224 cubic feet per acre per annum, or a mean depth of 12¾ inches over the land. The water-rate of $2 per acre would thus be equal to 4.3 cents per 1000 cubic feet, or 0.57 cent per 1000 gallons.

The altitude of Hemet Valley where the dam is located is approximately 4300 feet. The watershed area, as determined from the topographic map of the United States Geological Survey, is 69.5 square miles, the extreme elevation of which is about 9000 feet. This point is Tahquitz Peak, a spur of Mt. San Jacinto. The total drainage-area of the San Jacinto River above the mouth of the canyon is 141.8 square miles. The reservoir therefore receives the run-off from nearly one-half the entire drainage-basin of the river. The average yield of the shed has not been accurately determined, although it has been insufficient to fill the reservoir in any one season since 1895. The irrigation season of 1899 began with but 1000 acre-feet in the reservoir (gage 73 feet).

The present capacity of the reservoir is 10,500 acre-feet, but the addition of 27½ feet to the height of the dam will increase it 2½ times. The cost of the dam and irrigation-works has never been made public. The area of the tract depending upon the reservoir for irrigation is about 7000 acres, of which not more than half have been irrigated.

**The Bear Valley Dam, California.**—Probably the most widely known irrigation system in California is that of the Bear Valley Irrigation Company of Redlands, California, chiefly by reason of the remarkably slender proportions of the Bear Valley dam, which has been to the engineering

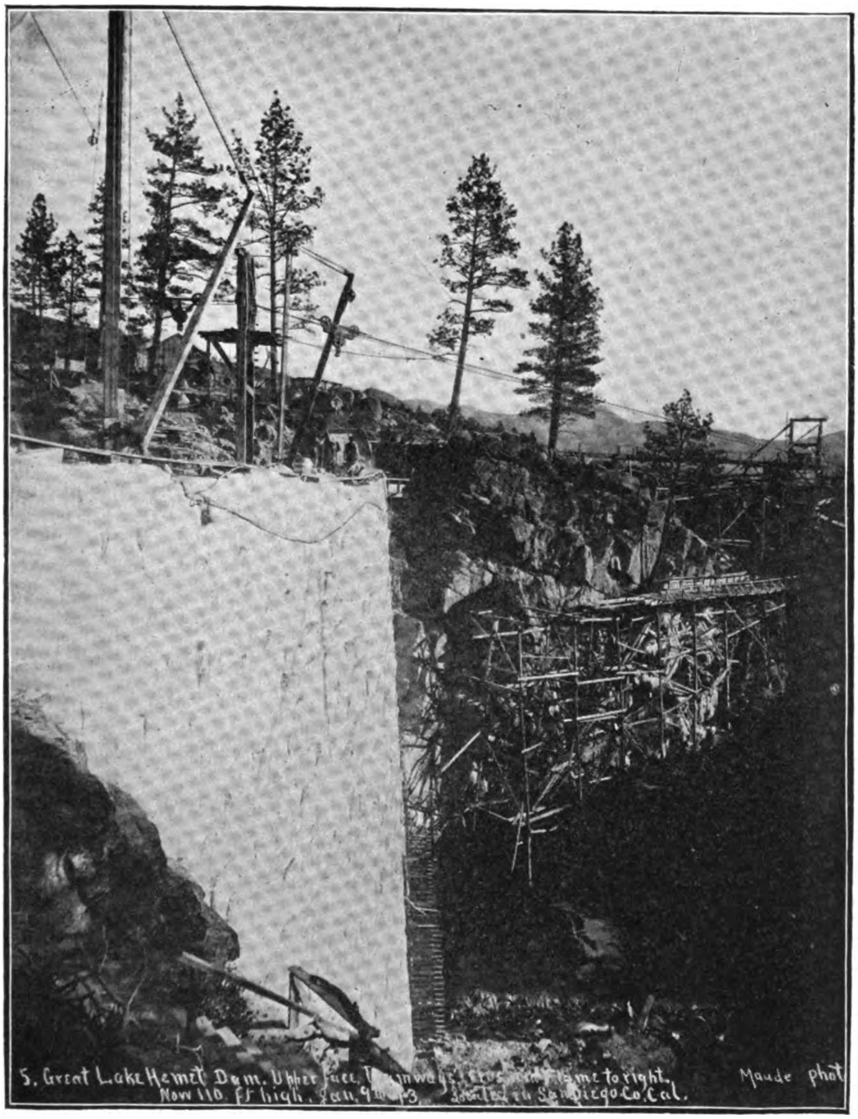



**Fig. 76a.—Lake Hemet (Cal.) Masonry Dam.**

yards of masonry, in which were used about 1600 barrels of cement. It is reported to have cost $75,000, or over $22 per cubic yard, of which the cement alone cost but $7.50 for each cubic yard of masonry laid. That the plant and labor could have cost so much as $14.50 per cubic yard, which is several times the ordinary cost of such work, must, if true, have been largely attributable to the lack of adequate machinery, as well as extravagant management. The masonry is a rough, uncut, granite ashlar, with a

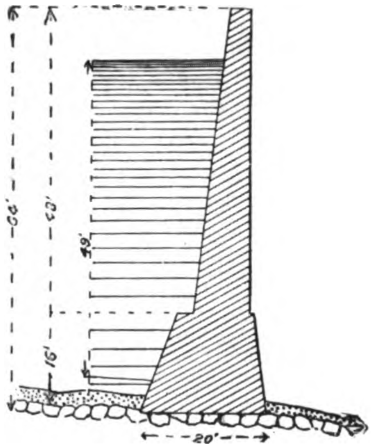



FIG. 77.—CROSS-SECTION OF BEAR VALLEY DAM.

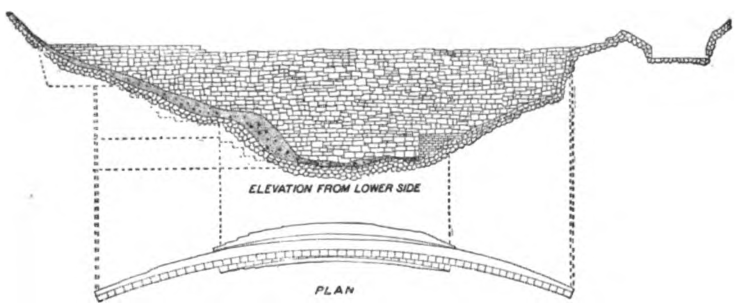



FIG. 78.—PLAN AND ELEVATION OF BEAR VALLEY DAM.

hearting of rough rubble, all laid in cement mortar and gravel. At the beginning an earth dam was erected, 2½ miles above, 6 feet in height, to retain the summer flow. As the masonry rose water was let down to the main dam, forming a pond which floated timber rafts on which stone was transported to the site, and from which construction was carried on. Hand-derricks were carried on these rafts.

The work was evidently done slowly and with great care, as it has leaked but little beyond the usual sweating, which has left its marks in an efflorescence or deposit of lime, brought out of the mortar by the moisture oozing through. This occurred during the first few years after completion and has almost entirely ceased. When inspected by the writer in August, 1896, the water stood within 10 feet of the top of the dam with little or no visible leakage below.

The south end of the dam abuts against a projecting ledge of granite, standing boldly out from the side of the canyon 100 feet or more beyond the general line of the side slopes, illustrated in the photograph, Fig. 79. Over the top of this ledge, as far from the dam as it could be placed, a spillway, 20 feet wide, was excavated to a depth of 8.5 feet below the level of the extreme top of the dam (Fig. 80).

The extreme capacity of this spillway does not exceed 1700 second-feet, which is dangerously small.

The great Sweetwater flood of 1895 gave a maximum discharge of nearly 100 second-feet per square mile of watershed. A freshet of proportional volume from the Bear Valley shed would give a discharge of about 5600 second-feet, or more than three times the spillway capacity. Occurring at a time when the reservoir were full, such a flood would overtop the dam by a depth of 2 to 3 feet. The result might be disastrous.

The spillway was for a time closed with sand-bags to hold the lake to a higher level, but this device was substituted by movable flashboards, arranged in four bays, separated by suitable framework.

The only outlet or means of control of the reservoir is an iron gate made to slide on brass bearings, and closing a rectangular opening, 20 by 24 inches, leading to a culvert cut in the bed-rock. The culvert trench was made 2 feet wide and 3 feet high, flat on bottom and arched over the top with concrete. The dam was built over it, and the culvert simply passed through or under the wall. The gate is operated by a screw-stem that passes up through a 6-inch pipe, standing vertically in the water next to the dam, and reaching up to a wooden platform at the coping-line. The gate-stem, hand-wheel, and mouth of outlet culvert are shown in the illustration. The maximum discharge capacity of the gate when wide open with full reservoir is about 167 second-feet, which is much more than is ever required to be drawn. The capacity with reservoir practically empty is over 80 second-feet.

The top of the dam is not finished to a true level line, as the coping-stones have been omitted over about one-half the length, and this portion is 2 to 3 feet lower than the finished crest. It requires considerable nerve to walk over the top of the dam, because it has no hand-rail or parapet and is so narrow that few visitors care to attempt the feat. Water has stood for a considerable time within a few inches of overflowing, although it has never actually passed over the top, as the spillway has thus far been capable of carrying the surplus flood-water. The maximum volume stored in the reservoir, thus far, has been somewhat in excess of 40,000 acre-feet, and

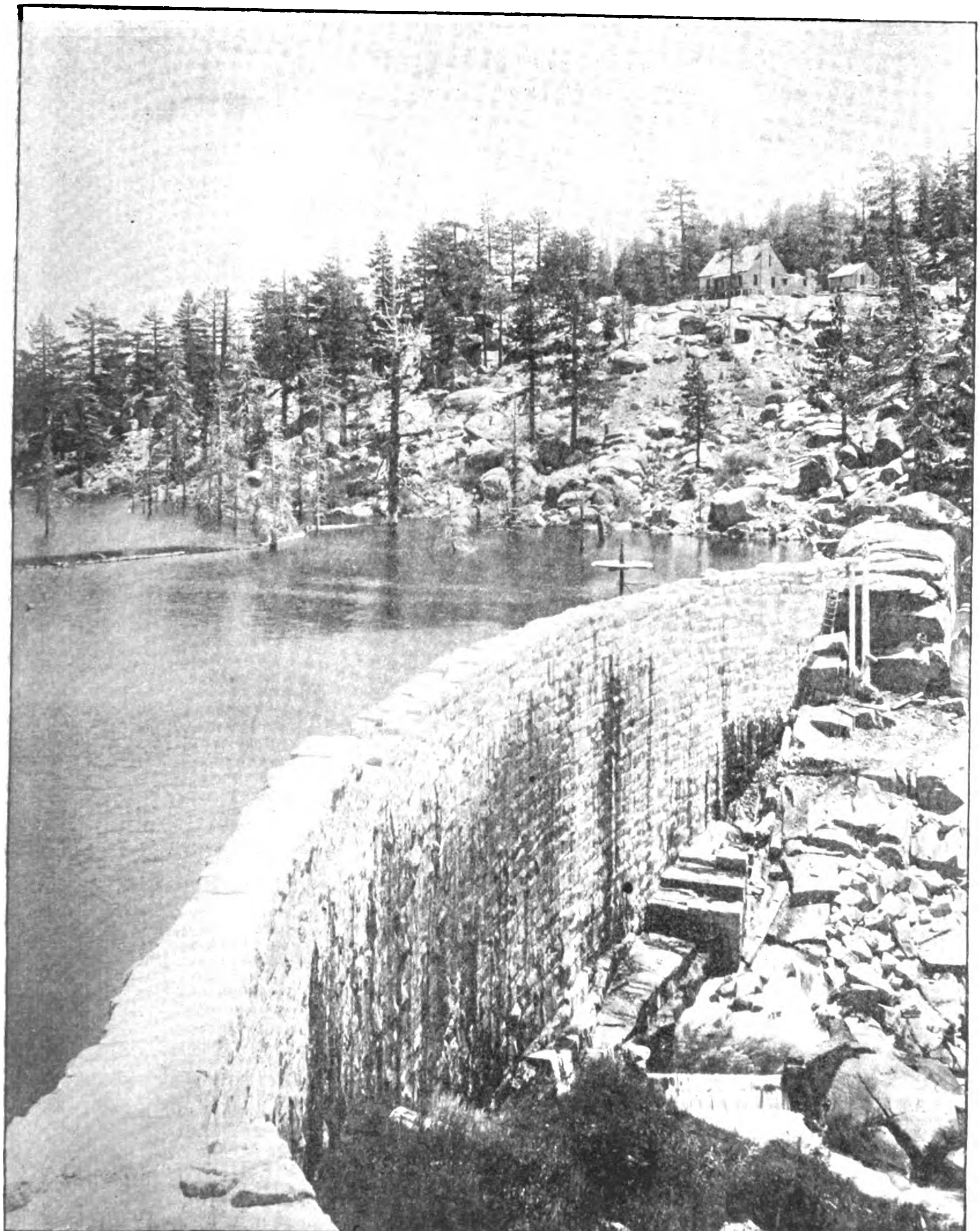


FIG. 79.—BEAR VALLEY DAM, LOOKING SOUTH, TOWARD SPILLWAY.

FIG. 80.—SPILLWAY OF BEAR VALLEY DAM, WITH FLASHBOARD GATES.

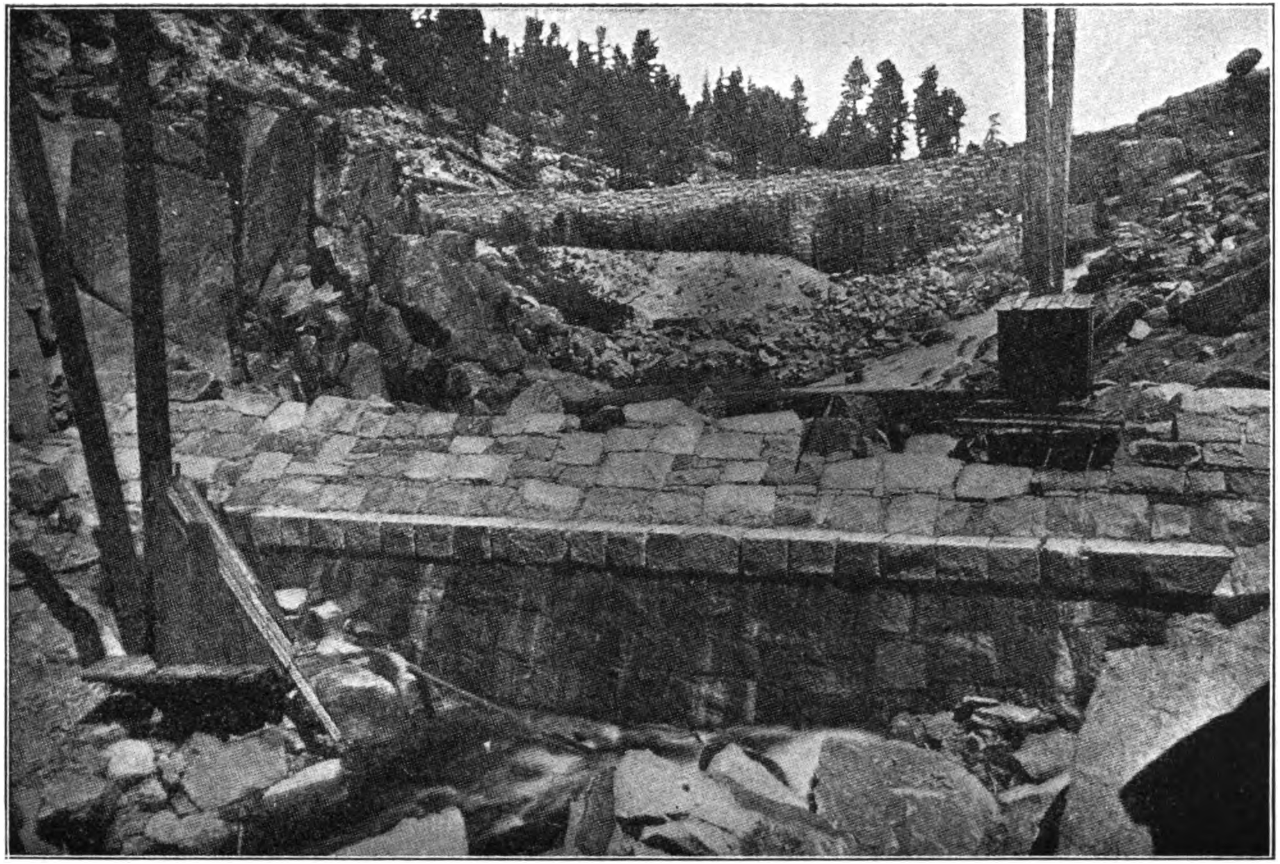


FIG 81.—BASE OF NEW ROCK-FILL DAM, BELOW THE BEAR VALLEY DAM (SHOWN IN BACKGROUND).

in seasons of excessive precipitation the run-off has exceeded the reservoir capacity.

In order to be able to impound the entire run-off from the watershed, or the greater portion of it, the company at one time contemplated the erection of a higher dam, to be built about 200 feet down-stream from the present dam, and impound water to the 75-foot contour of the reservoir, or 11 feet higher than the crest of the existing structure, at which level the capacity of the basin is 80,000 acre-feet, flooding a surface area of 3060 acres to a mean depth of 25.3 feet. It was regarded as impracticable to add another foot to the height of the present dam, and no engineer cared to risk the responsibility of excavating at the toe of the wall for such an addition to it as would enable it to be raised to the desired height; hence it was deemed best to go a safe distance below to avoid jarring or disturbing the fragile wall, and there begin an entirely independent structure. The new dam was designed as a rock-fill, and was to be 80 feet in height above the base of the present dam, but was never finished beyond the foundations, which were laid in a substantial manner in 1893 (Fig. 81). It is a matter of regret that the second dam was not completed, as its completion was recognized as affording a rare opportunity for studying the arch action upon the present masonry wall. At the time it was begun a committee was appointed by the American Society of Civil Engineers to examine and measure the movement in the masonry incident to the loading and unloading of the arch. This could be quickly accomplished by emptying and refilling the pond between the two dams. If taken at the right time, the effect of a flood pouring over the crest of the thin masonry wall could have been observed, and much useful knowledge obtained on the subject of the strains in arched dams of which so little is now known.

The watershed tributary to the Bear Valley reservoir, as determined from the best available maps, is approximately 56 square miles, the maximum elevation of which is about 7700 feet, or 1500 feet higher than the valley. On the north and east the shed borders on the desert, and the precipitation shades off to a considerably less amount than is recorded at the dam.

The record of rain and melted snow at the dam from 1883 to 1893, the season beginning in each year on September 1st, is as follows:

| | Inches. | | Inches. |
|---|---|---|---|
| 1883–84........ | 94.60 | 1888–89........ | 46.03 |
| 1884–85........ | 28.06 | 1890–91........ | 78.40 |
| 1885–86........ | 65.51 | 1891–92........ | 38.00 |
| 1886–87........ | 24.00 | 1892–93........ | 44.32 |
| 1887–88........ | 62.30 | 1894–95........ | 50.00 |
| | | Mean for 12 years........ | 53.70 |

The dry years which have occurred since 1895 must undoubtedly reduce this mean very considerably, although the record has not been made public. In 1891 the run-off from the watershed was computed by Wm. Ham. Hall from the records of catchment, as follows, beginning with the completion of the dam:

| Season. | Run-off. Acre-feet. | Season. | Run-off. Acre-feet. |
|---|---|---|---|
| 1883–84........ | 236,000 | 1887–88........ | 132,400 |
| 1884–85........ | 21,600 | 1888–89........ | 70,400 |
| 1885–86........ | 142,400 | 1889–90........ | 211,600 |
| 1886–87........ | 8,000 | 1890–91........ | 186,800 |
| | | Mean........ | 126,150 |

This estimate is so large as to be decidedly questionable. Mr. J. B. Lippincott, Hydrographer U. S. Geological Survey,* estimates, by comparison of observations in other parts of the State, that the probable maximum run-off of the shed is about 100,000 acre-feet, and the mean about 28,500. The minimum was doubtless reached in 1895–99. The irrigation season of 1899 began with but 1560 acre-feet in the reservoir, a small portion of which was held over from the previous year. This was entirely exhausted early in the season, and an attempt was made to maintain the supply by pumping from shallow wells in the bed of the reservoir, although with indifferent success. Four to six acre-feet per day were obtained for a time, but it was largely dissipated by evaporation in passing down the canyon.

The loss to be anticipated from this reservoir by evaporation is a subject of much interest. It is at an altitude of 6200 feet, and well sheltered from winds by surrounding mountains, favoring minimum loss. On the other hand the water is shallow and spread out over a large area. Observations made at the gate-house of the Arrowhead Reservoir Company in Little Bear Valley, in the same mountain-range, but at lower elevation (5160 feet above sea-level), indicate that the evaporation from water-surface is about 36 inches per annum in that locality, of which about 90% occurs in the eight months from March to November, inclusive. This rate of loss applied to Bear Valley reservoir when full would indicate a probable loss of over 20% per annum if no water were drawn out, or about 14% per annum if a uniform draft of 2500 acre-feet per month were made during the period from March to November, inclusive.

The general form of the reservoir is shown in Fig. 82.

**La Grange Dam, California.**—There is something quite unusual in a masonry dam 125 feet high which is erected for the sole purpose of diverting water from a stream for irrigation purposes, and this is the character of structure that was built on the Tuolumne River, 1½ miles above the town

* Nineteenth Annual Report for 1897, U. S. Geol. Sur., Part IV., p. 585.

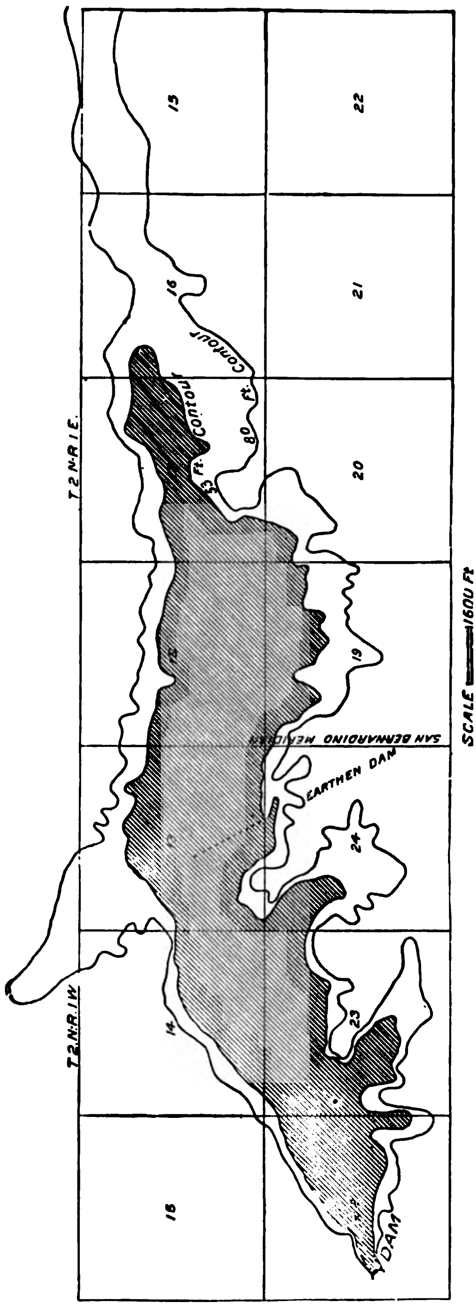



FIG. 82.—MAP OF BEAR VALLEY RESERVOIR.

of La Grange, California, in 1891–94, by the Turlock and Modesto irrigation districts jointly. The Tuolumne River, as it leaves the mountains, on its way across the San Joaquin Valley, is cut down so deeply below the general level of the plain as to require a high dam to raise the water sufficiently to get it out on the irrigable lands. The dam is located at the mouth of a narrow box canyon and is in no sense designed or used for storage. It is 125 feet high on the up-stream face, 129 feet on the down-stream side, 90 feet in thickness at bottom, 24 feet at crest, and but 310 feet long on top. The wall is built as the segment of a circle of 300 feet radius, the arch being opposed to the direction of the water-pressure, although its profile is of purely gravity type, in which the lines of pressure are well within the middle third. On the water-face the dam is vertical for 70 feet below the top, and thence to the foundation has a batter of 1 in 20. The edges of the crest are rounded off on a radius of 3 feet on upper side, and 17.5 feet on lower side, leaving 6 feet of the crest level. At 6 feet below the crest the dam is 24.13 feet thick; at 69 feet below it is 52 feet thick; at 89 feet it is 66.25 feet; and at 97 feet, the top of the foundation masonry, it is 84 feet thick. The extreme bottom width at the highest point of the dam is 90 feet. The lower face has a batter of ½ to 1, from 70 feet below the crest, where a compound curve of 63 and 23 feet radii commences, which carries the face to its intersection with the battered face of the foundation masonry about 3 feet above low water. From this point the foundation batter is 1 in 7, to the bottom, about 32 feet in the deepest place. These dimensions give practically an ogee form to the down-stream face, which permits the water to follow the masonry without leaving its face in its descent, provided the depth be not more than 4 to 5 feet, and gives it a horizontal direction at the bottom. The curvature of the dam and the fact that the canyon is but 80 feet wide at the base of the dam, or top of foundations, so concentrate the stream that some erosion may be anticipated at the base, although nothing serious in that line has been reported.

The dam contains 39,500 cubic yards of masonry and cost $550,009. It is built throughout of rough, uncoursed rubble masonry, laid in Portland-cement concrete, in practically the same manner as that described in the construction of the Hemet dam. The work was done by contract, at $10.39 per cubic yard, including the excavation for foundations, but not including cement, which was furnished by the districts. The cement cost $4.50 per barrel delivered, and 31,500 barrels were used in the work.

It is believed to be the highest overflow dam in the United States, if not in the world. The volume of water passing over it may in extreme floods amount to 100,000 second-feet. The maximum flood that has yet gone over the dam was about 46,000 second-feet in volume, the depth on crest being 12 feet.

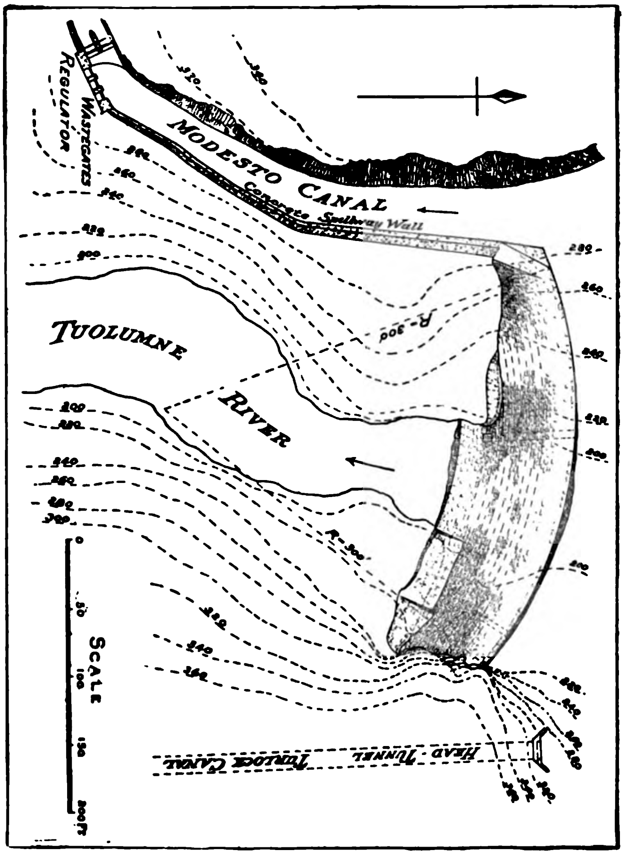



**Fig. 82a.—Plan of La Grange Dam, California.**

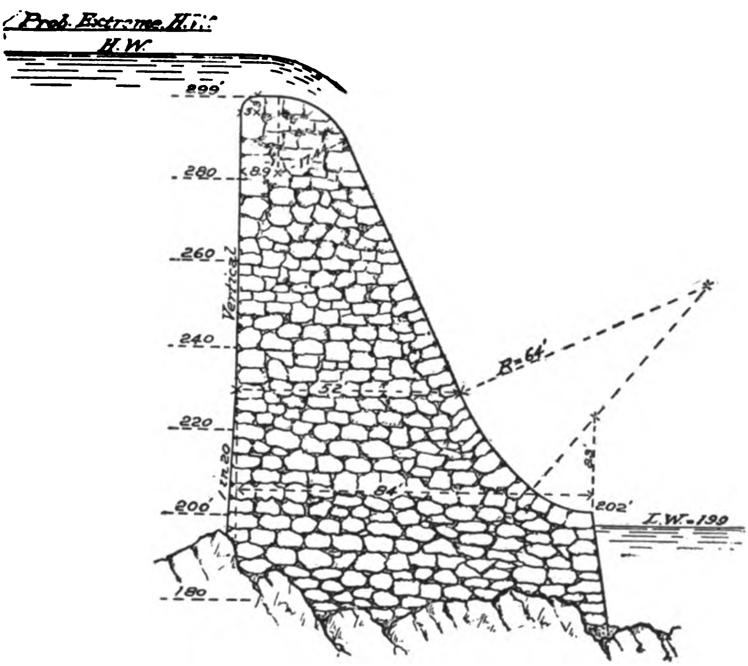



**Fig. 82b.—Profile of La Grange Dam, California.**

During construction the low-water discharge was carried past the work in a flume the first year, and subsequently through two culverts, one at low-water level, and a second 10 feet higher. These were 4 feet wide, 6 feet high.

The Modesto Canal takes water through an open cut from the dam, on the right bank, and has a capacity of 750 second-feet. The Turlock Canal reaches the reservoir above the dam by means of a tunnel 560 feet long, 12 feet wide, 11 feet high, with regulating-gate at the head.

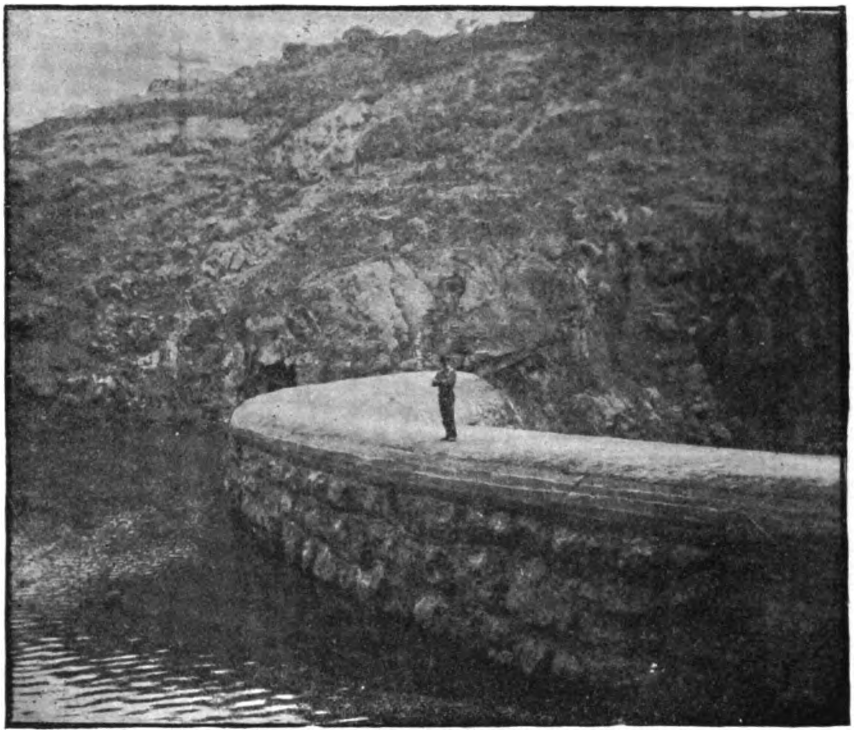


FIG. 88.—UPPER FACE OF LA GRANGE DAM.

In construction of the dam three lines of cableway were used, spanning the canyon, for hauling the materials.

The excessive cost of the work was doubtless due to the uncertainty as to the value of the bonds of the irrigation districts, which created a temerity among contractors, and there were few bidders. The contractor was obliged to buy the bonds at not less than 90% of their face value, and dispose of them at a figure from which he could obtain a profit on his work. Under ordinary conditions of prompt payments in cash the construction should have been done for one-half the actual cost.

The dam was designed by Luther Wagoner, C.E., who resigned shortly after work began, and construction was completed under charge of E. H. Barton, engineer for the Turlock district, and H. S. Crowe, representing the Modesto district.

The elevation of the crest of the dam is 299.3 feet above sea-level, and the canal grade is 8.3 feet lower.

The Turlock irrigation district embraces 176,210 acres, and the canal supplying it has a reported capacity of 1500 second-feet. The main canal is 18 miles long, feeding five laterals of an aggregate length of 80 miles.

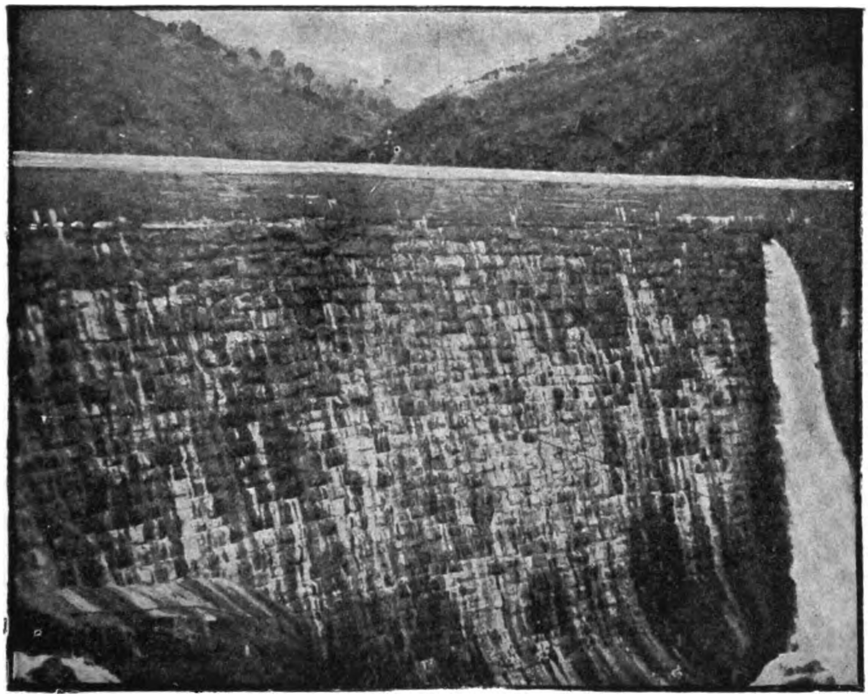


FIG. 84.—LOWER FACE OF LA GRANGE DAM.

The Modesto district covers 81,500 acres, with a main canal 22.75 miles long before reaching the district, having a capacity of 640 second-feet. The entire irrigation system when fully completed will be the largest and most comprehensive one in California, and the dam upon which its success depends has been wisely constructed of such dimensions as to be of unquestionable stability. Figs. 83 and 84 give two views of the structure.

**Folsom Dam, California.**—There are many features of the Folsom dam, on the American River, California, which give it special interest to engineers and all others who have seen it, one of which is that it was built by the State of California entirely with convict labor, incidentally to give employment to the inmates of one of the State prisons, but primarily to develop water-power for use in various industries about the prison and for transmission to other localities. A further purpose is served by the dam in the diversion of water from the American River out upon the plains of the Sacramento Valley for irrigation. The plan, profile, and section of the dam are shown in Fig. 90, and a photograph taken by a convict during construction is given in Fig. 91.

The dam is of the same general character as the La Grange dam, serving no purpose of storage, but designed solely for the diversion of the stream and so constructed as to permit flood-water to pass freely over its crest.

It is located at the top of a natural fall in the bed-rock of the stream, its height at the up-stream toe being 69.5 feet, while at the down-stream footing the height is 98 feet to the crest-line. The top thickness is 24 feet; base 87 feet. A movable shutter, 180 feet long, is placed in the center of the dam for raising the normal water-level at low stages. This shutter is placed in a depression, 6 feet in depth, below the general level of the dam, and is lowered during floods to allow the passage of extreme freshets over the dam. At low water the shutter is raised to a nearly vertical position by means of hydraulic jacks, as shown in Fig. 92, which are operated from the prison power-house. The entire crest length of the dam is 650 feet, including the curved approach to the canal head-gates.

The main dam is straight in plan. The construction of the dam was begun in 1886 and completed in 1891. It contains 48,590 cubic yards of masonry in the dam proper, while the retaining-wall of the canal has 27,000 cubic yards and the power-house 13,700 cubic yards of granite masonry, all laid in Portland-cement mortar. The dam is a very massive and substantial piece of masonry, composed of rough granite ashlar in large blocks of 10 tons or more in weight. The quarry, which determined the location of the State prison, affords an unlimited quantity of excellent granite which has a fine cleavage and is readily quarried into blocks of any desired size. The excavation of the canal along the granite cliff gave all the material needed for the dam. The stone was delivered to the dam by a cableway of unusual construction, in that two cables were used side by side like a suspended railway-track, and the trolley was a four-wheeled carriage from which the loads were hoisted and suspended. There are many disadvantages to this form of cableway, and no special features to recommend it as preferable to the single cable. The latter admits of dragging rocks from either side of the line of the cable for a considerable distance, an operation which would tend to derail the trolley of a double cableway.

The canal taken from the left side of the dam passes through the prison grounds and thence to the town of Folsom, one and one-half miles below, where the main power-drop of 85 feet is utilized for generation of power, which is transmitted electrically to Sacramento, 22 miles distant.

FIG. 85.—LA GRANGE DAM, CALIFORNIA, DURING CONSTRUCTION—FINISHING THE CREST.

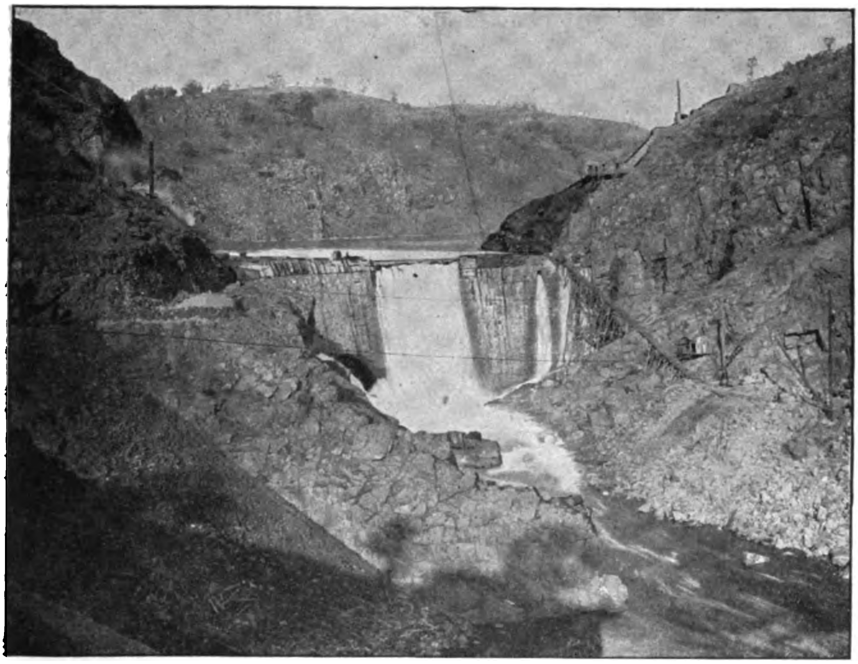


FIG. 86.—LA GRANGE DAM, CALIFORNIA.

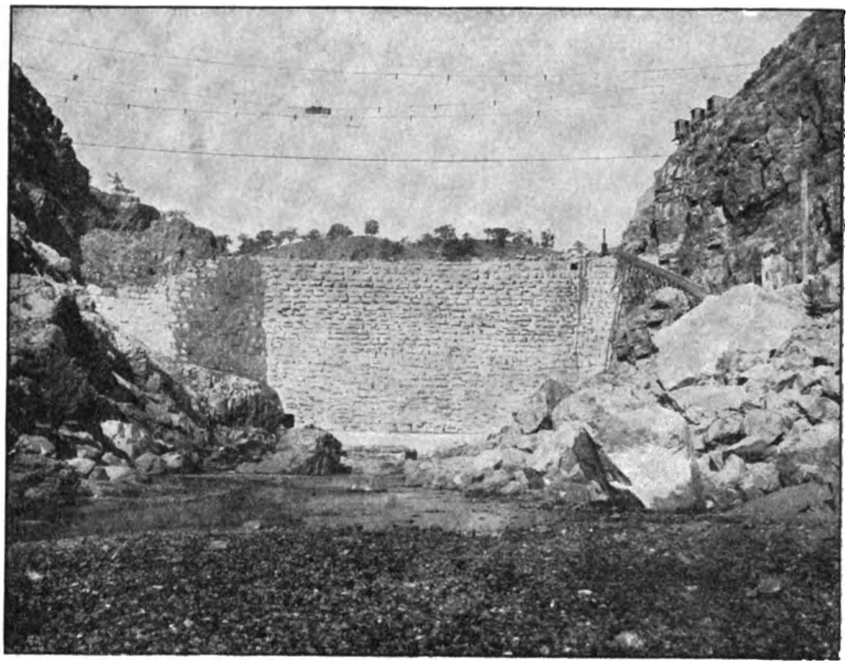


FIG. 87.—LA GRANGE DAM, CALIFORNIA.

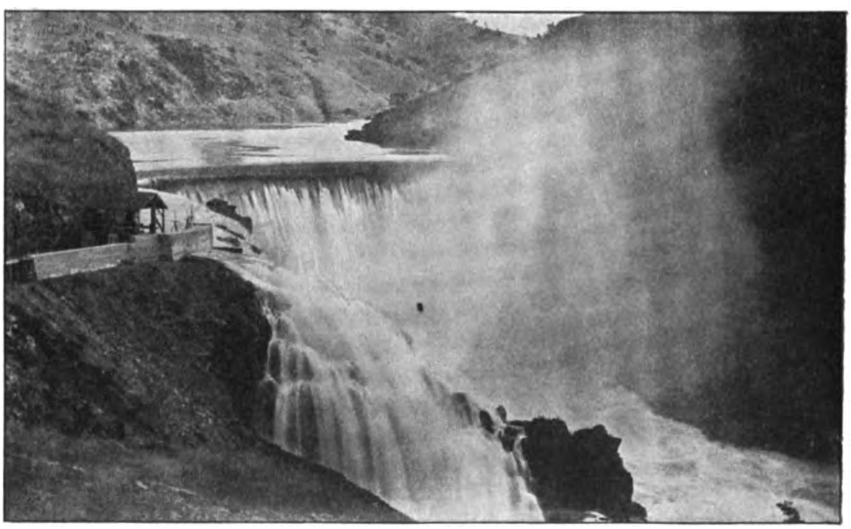


FIG. 88.—LA GRANGE DAM, CALIFORNIA, DURING FLOOD.

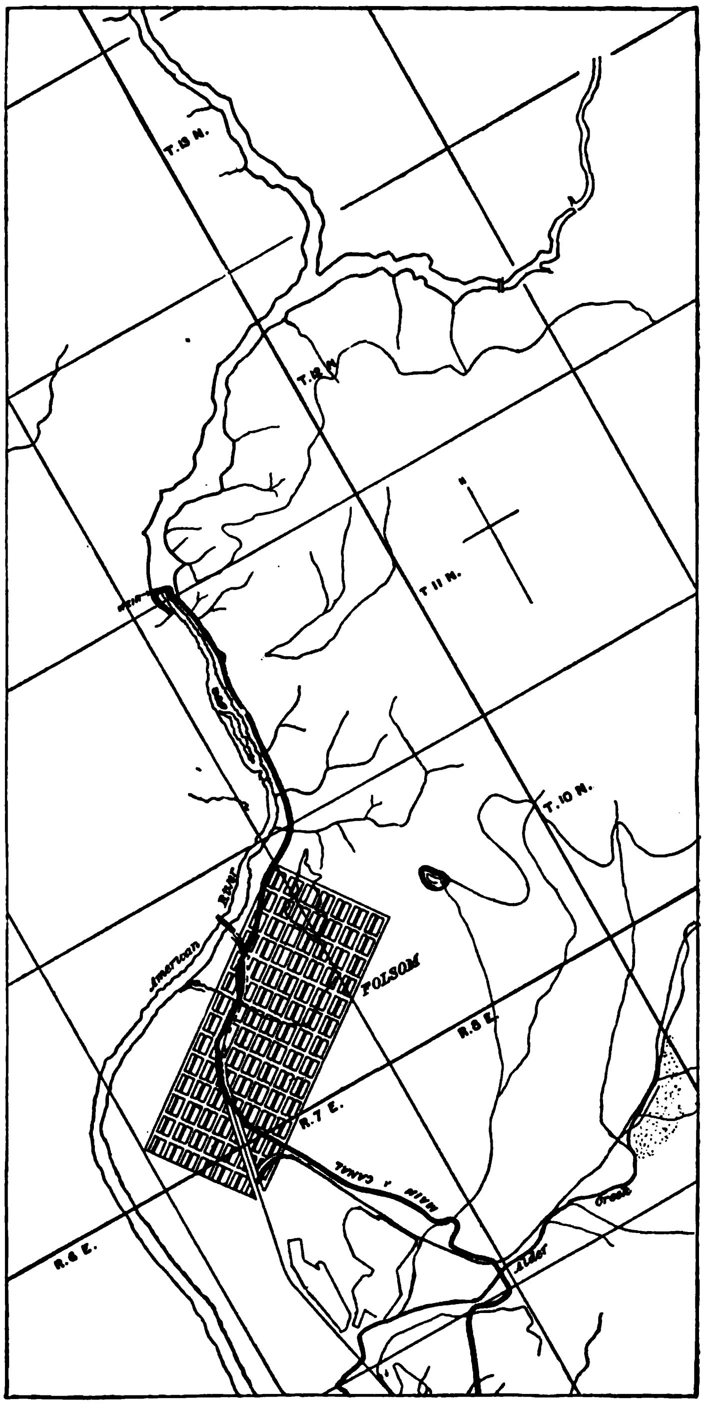



**Fig. 89.—Map showing Location of Folsom Dam and the Main Canal.**

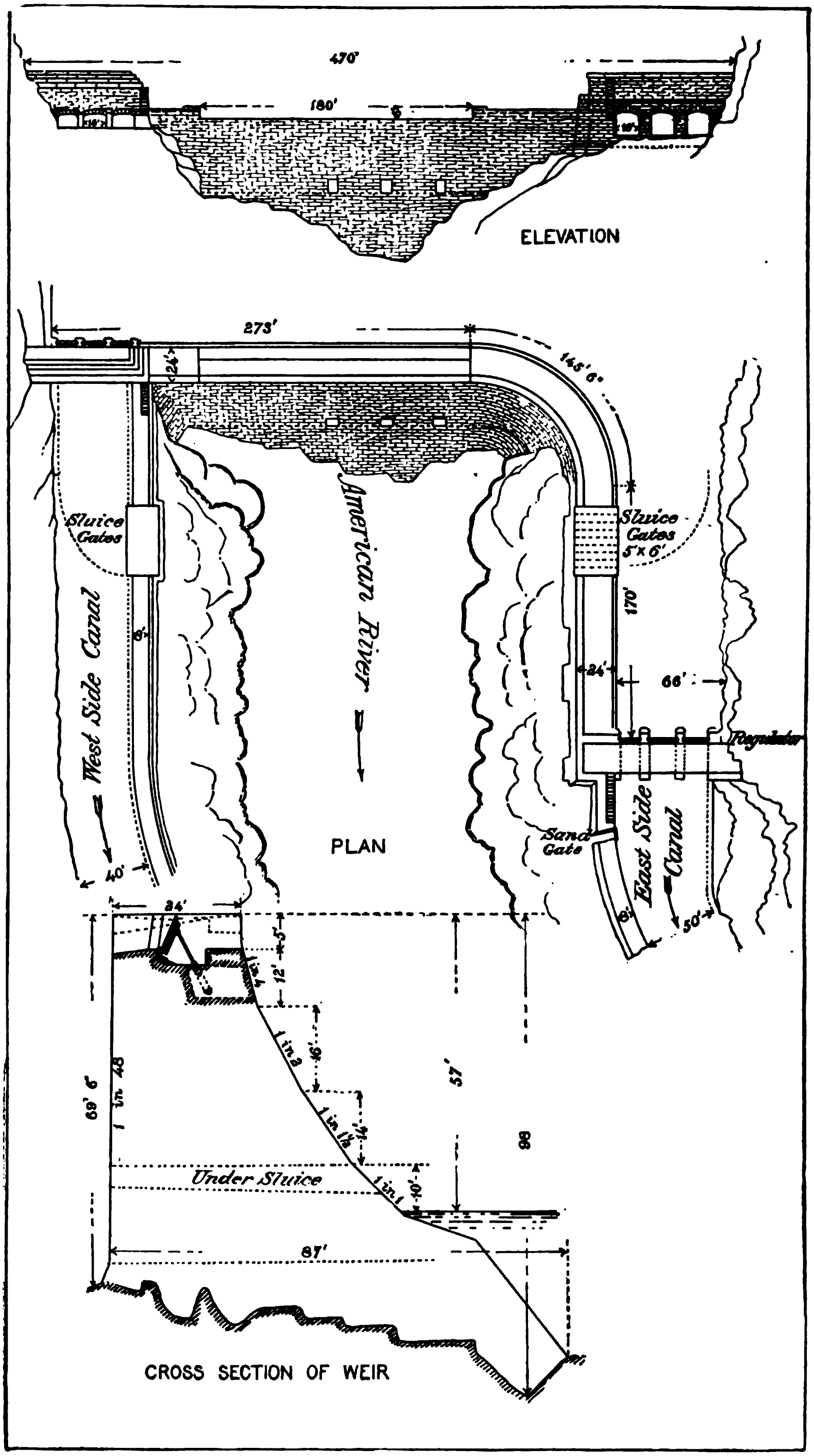



**Fig. 90.—Plan, Cross-section, and Elevation of Weir and Headworks of Folsom Canal.**

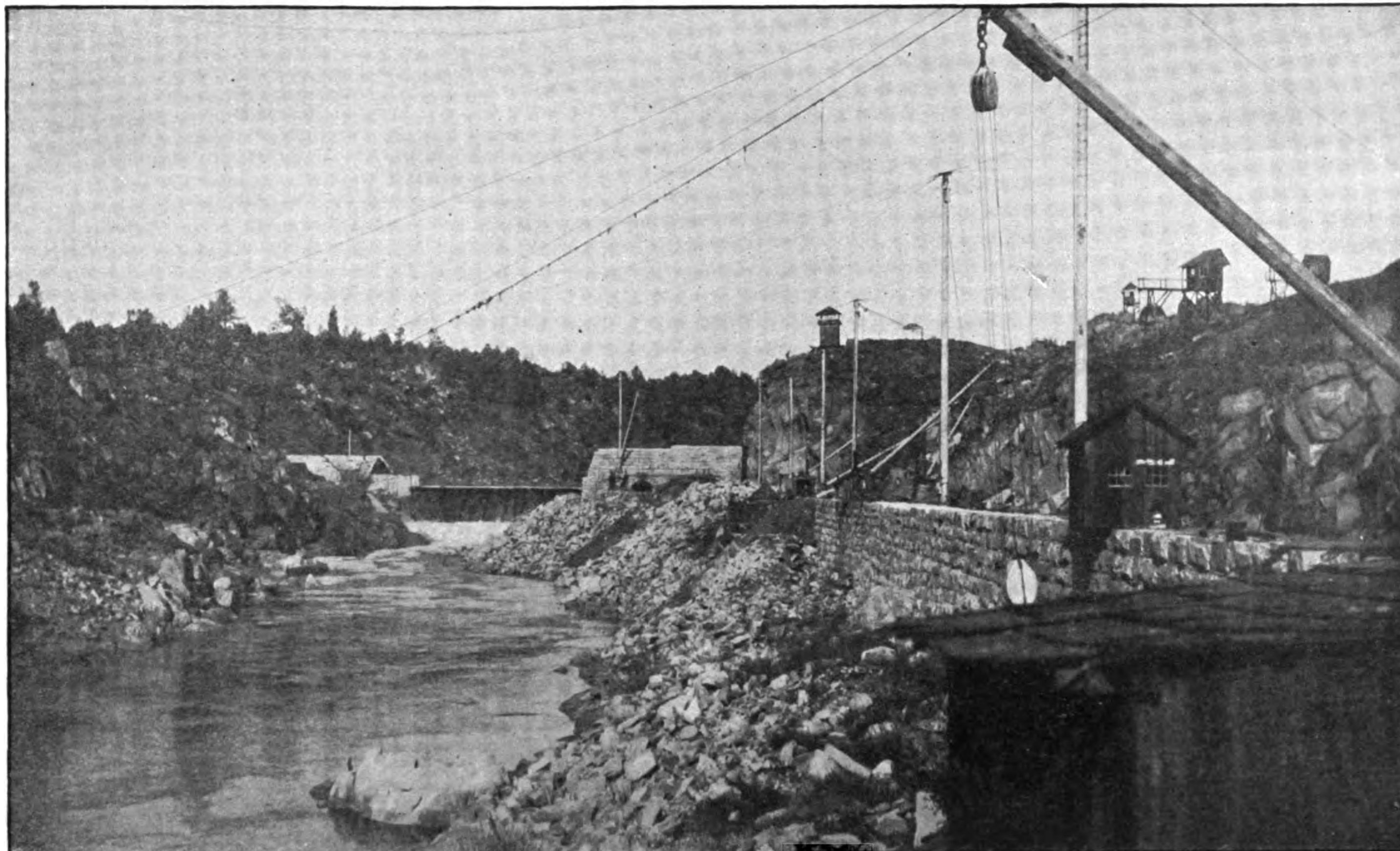


FIG. 91.—AMERICAN RIVER DAM AT FOLSOM.

In passing the prison power-house a drop of 7.5 feet is utilized by six 87-inch Leffel turbines of the double improved type, and about 800 H.P. are developed at the maximum. The canal is 8 feet in depth throughout, the width below the prison power-house being 30 feet on bottom, 40 feet on top. Above the power-house the width is 10 feet greater. The grade is 1:2000, and the capacity of the canal about 1000 second-feet.

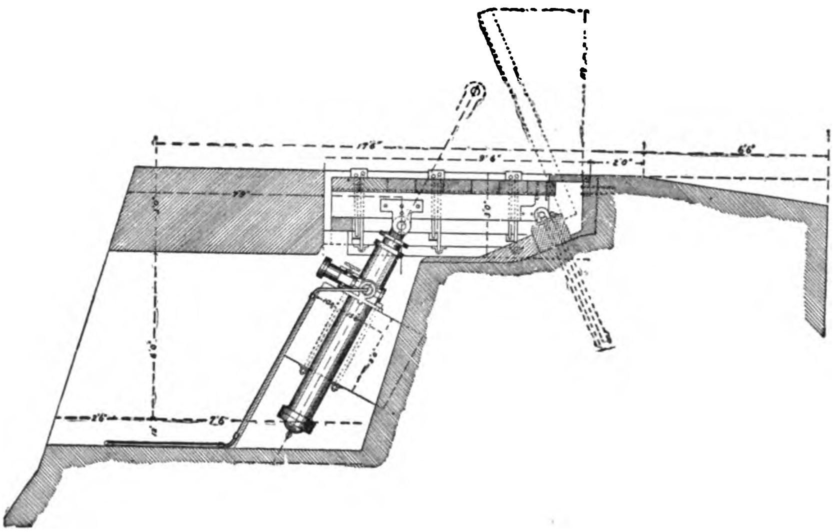


FIG. 92.—HYDRAULIC JACKS FOR RAISING SHUTTER ON FOLSOM DAM.

**The San Mateo Dam, California.**—Doubtless the most enormous mass of masonry of any sort in the West, if not in the entire United States, is the great concrete dam erected on San Mateo Creek, 6 miles above the village of San Mateo, California, by the Spring Valley Water-works of San Francisco, to impound water for the supply of that city. The dam ranks among the highest and most costly of the world, and was erected in 1887 and 1888.

It was projected to reach to a height of 170 feet, at which the top width was to be 25 feet and base width 176 feet, but construction was suspended at the height of 146 feet, or 34 feet below the ultimate height. When finished the top length will be 680 feet. It has a uniform batter of 4 to 1 on the up-stream face, while the lower slope, beginning with a batter of 2½ on 1 near the top, curves with a radius of 258 feet to near the bottom, where the batter is 1 to 1. The dam is arched up-stream with a radius of 637 feet.

It is built throughout with concrete, made of broken stone, beach sand, and Portland cement. This material was chosen because of the difficulty of securing rock in the vicinity suitable for rubble masonry. The stone was quarried in the immediate vicinity, and occurred in small irregular nodules, frequently so coated with clay and serpentine as to require it to be thoroughly washed before it was fit for use. After crushing, it was passed through revolving cylindrical tumblers, where a constant stream of water was maintained to carry off the mud and tailings, which passed off through a flume and dropped to the stream-channel, where the deposit from these washings covered several acres to a considerable depth. The proportion of waste was large. The sand used in the concrete was obtained from the sand-dunes of North Beach, San Francisco, where it was loaded on cars, hauled one mile, and dumped into barges, then towed 25 miles up the bay to a landing opposite San Mateo, and thence hauled 6 miles by wagon to the dam. All the materials were thus unusually expensive.

The concrete was mixed in a battery of 6 cubical iron mixing-machines revolved by steam-power. It was delivered to the work by a double-track tramway on a high trestle carried part way across the canyon at the level of the top of the dam on the lower side, as shown in Fig. 94. The cars on this tramway were pushed by hand and dumped into hoppers let into the floor between the rails, leading to vertical pipes, 16 inches in diameter, which extended down to platforms that were placed from time to time at a level with the top of the work as as it progressed. The concrete dropped down these pipes, striking on steel plates, from which it was shoveled into wheelbarrows and trundled to the place of use. The height of this drop was sometimes as great as 120 feet, but no injury resulted to the concrete, or to the men shoveling it as it fell. The concrete was mixed in the proportions of 1 part cement to 2 parts sand, 6½ parts broken stone, and ⅞ part water by measure. It was moulded in cyclopean blocks of 200 to 300 cubic yards each, with numerous offsets ingeniously dovetailing the blocks together, and every possible precaution was taken in the joining of the successive portions to secure an absolute bond. The surfaces of the blocks after the forms were removed were roughened with picks, swept and washed clean, and grouted with pure cement before concrete was placed against them. The result has been very satisfactory; the dam is almost absolutely water-tight, although some moisture does find its way through and appears in spots on the lower face. No settlement or expansion cracks are visible, and the work has the appearance of being absolutely homogeneous. Figs. 96 and 97 show the general method of forming the blocks and preparing them to receive fresh concrete, and Fig. 98 is a general view of the dam taken at the time of the visit of the American Society of Civil Engineers in Annual Convention, July, 1896. Plans and sections of this dam are shown in Fig. 99. At the 170-foot level the reservoir will have a capacity of 29,000,000,000 gallons, or 89,000 acre-feet. The present capacity is approximately 20,000,000,000 gallons.

The entire volume of the dam is approximately 139,000 cubic yards.

When the dam is extended to its ultimate height it will be necessary to

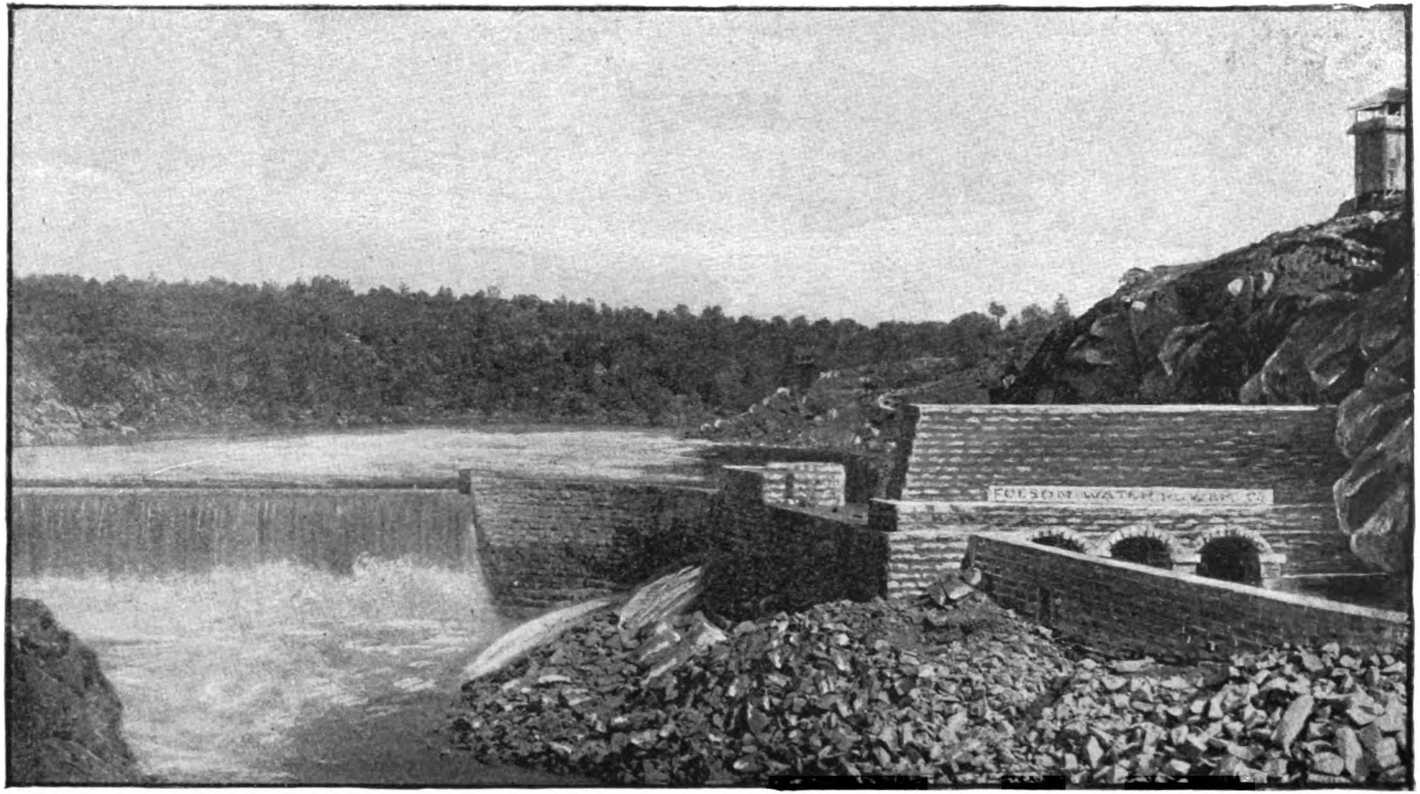



FIG. 93 — VIEW OF MASONRY DAM ON AMERICAN RIVER, CALIFORNIA, AT THE FOLSOM STATE PRISON, SHOWING CANAL HEAD-GATES. Dam built by prison labor.

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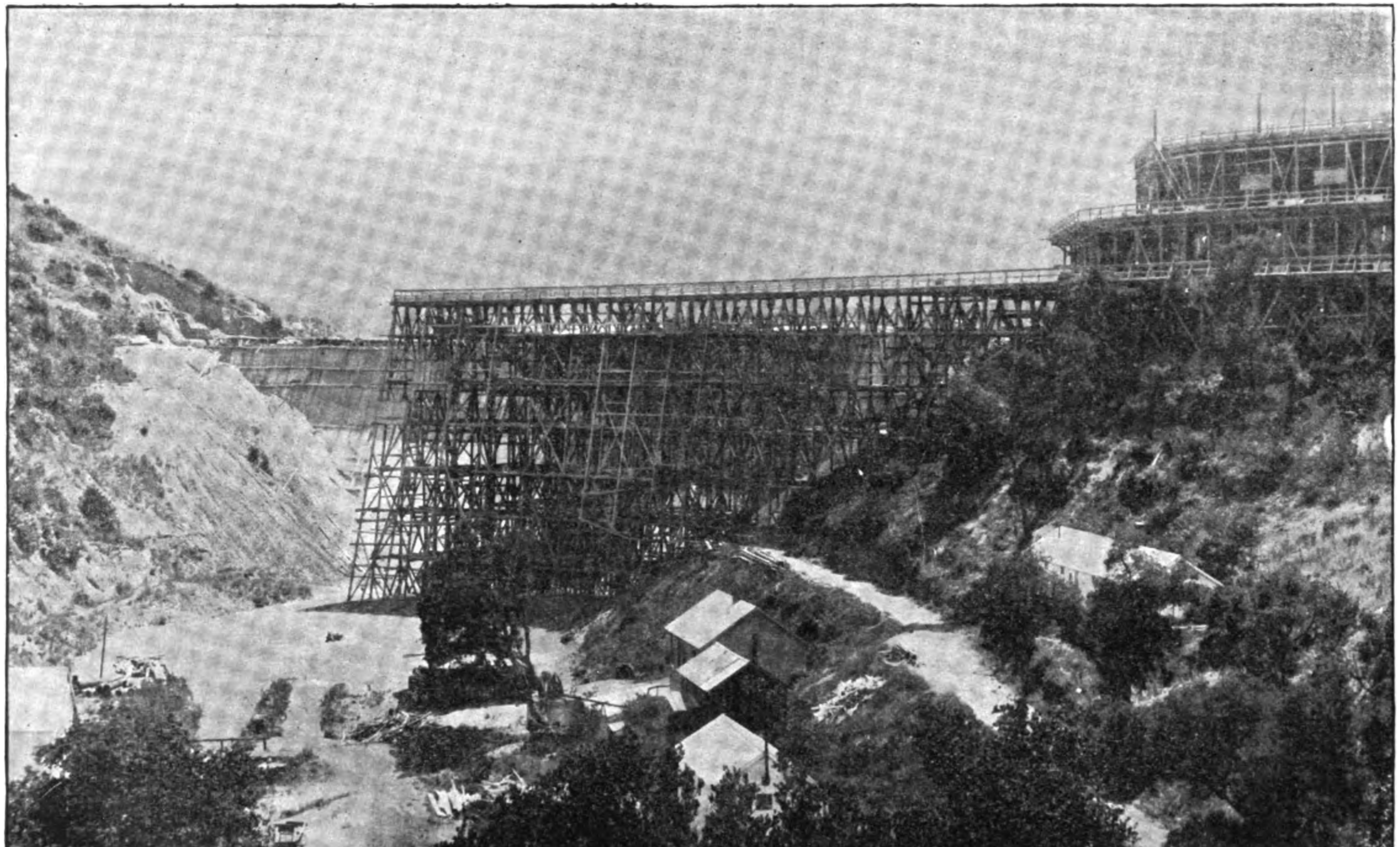


Fig. 94.—Plant for Mixing and Handling Concrete at San Mateo Dam.

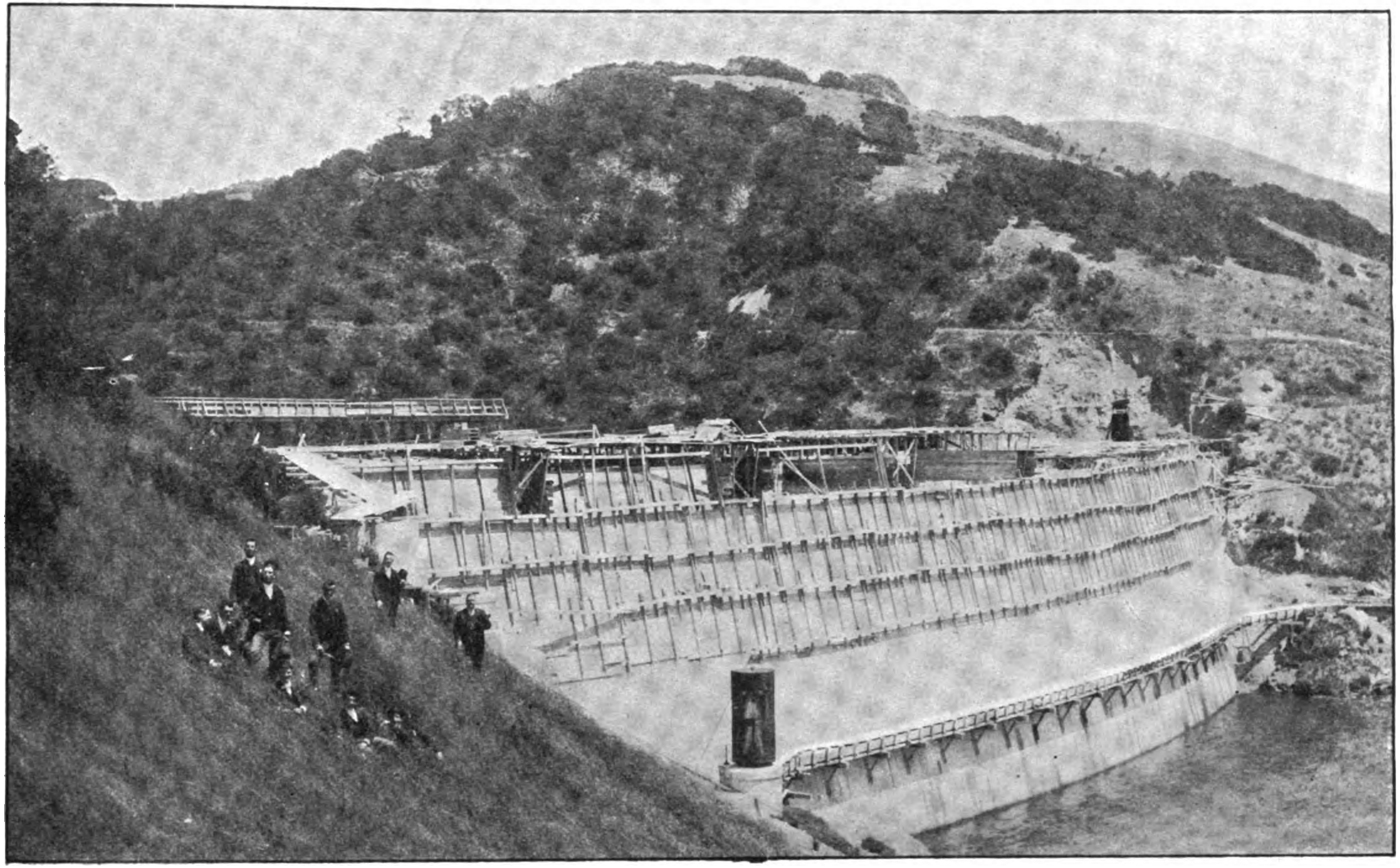


FIG. 95.—CONSTRUCTION OF INTAKE OF SAN MATEO DAM.

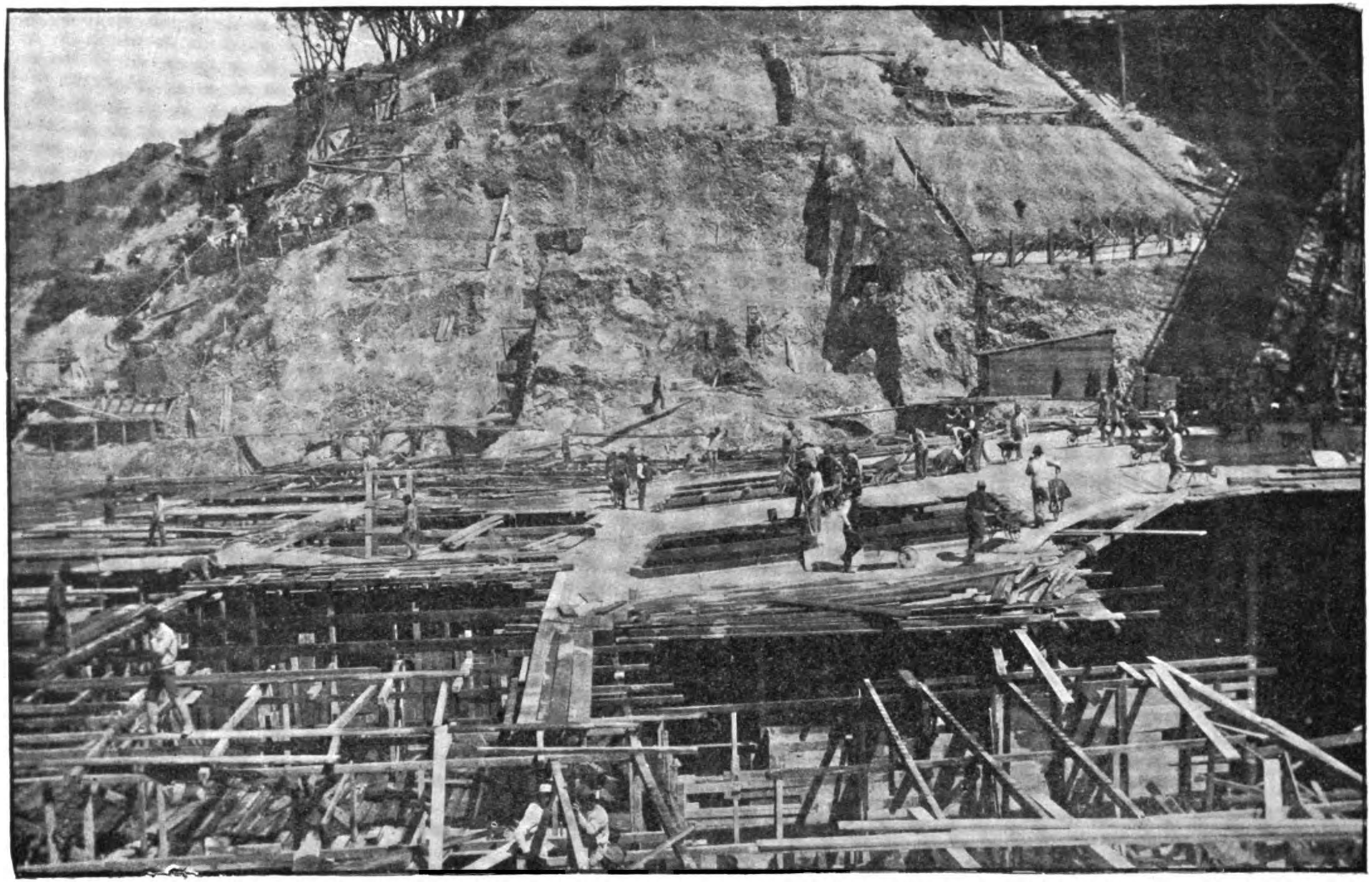


Fig. 96.—Moulds for Concrete Blocks, San Mateo Dam.

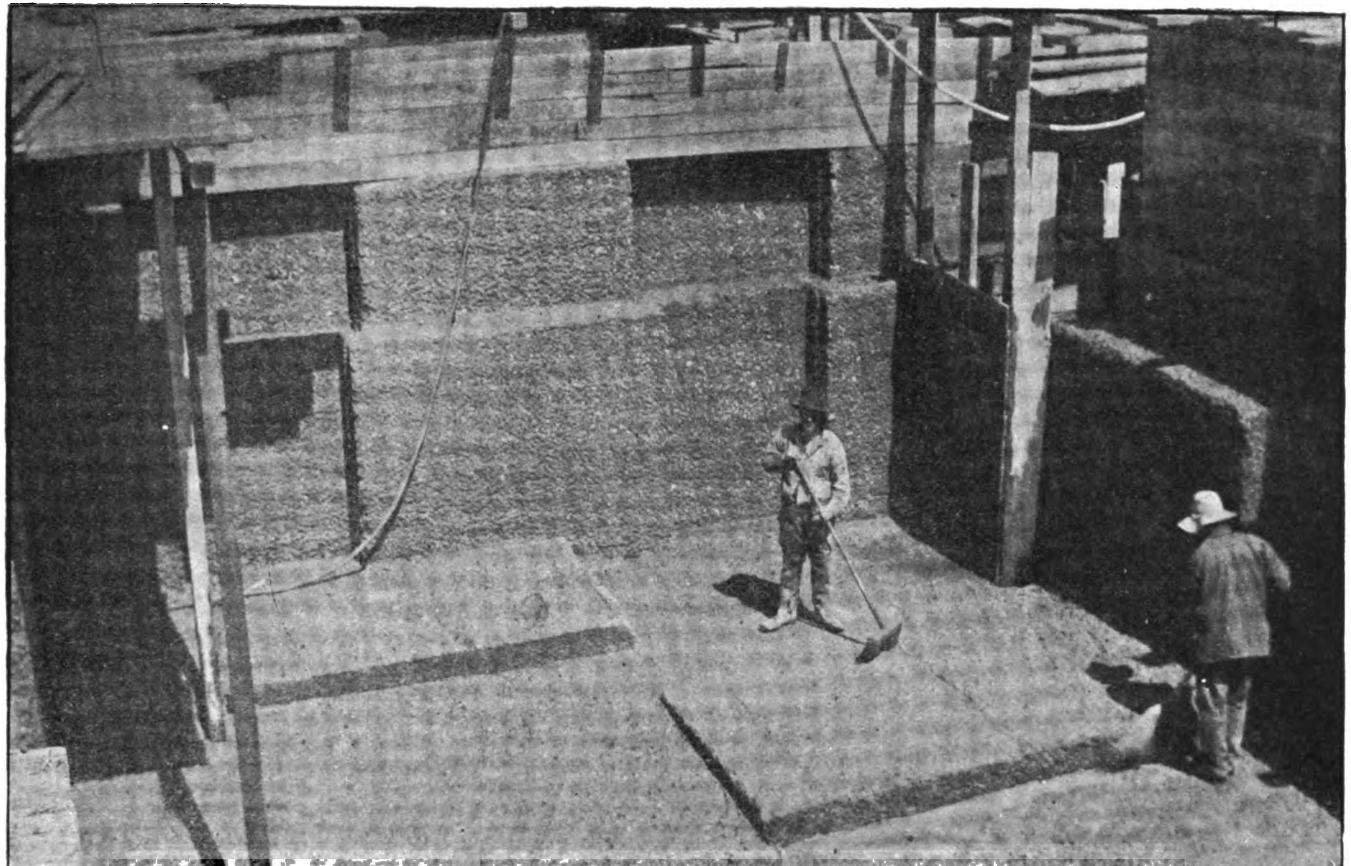


FIG. 97.—ROUGHENING SURFACE OF CONCRETE BLOCKS TO RECEIVE FRESH CEMENT, AT SAN MATEO DAM.

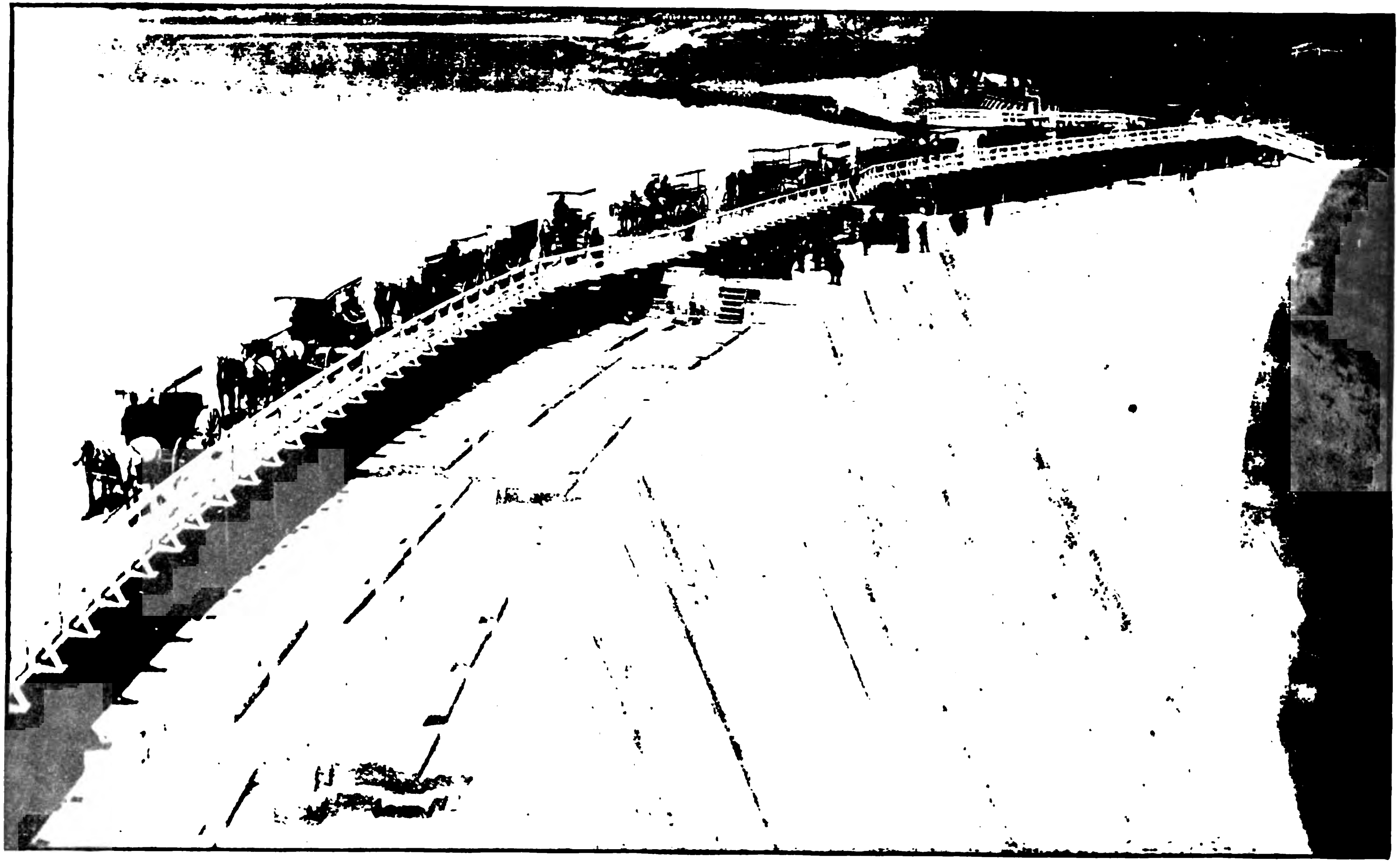


FIG. 93.—SAN MATEO DAM BEING INSPECTED BY AMERICAN SOCIETY OF CIVIL ENGINEERS IN JULY, 1896.

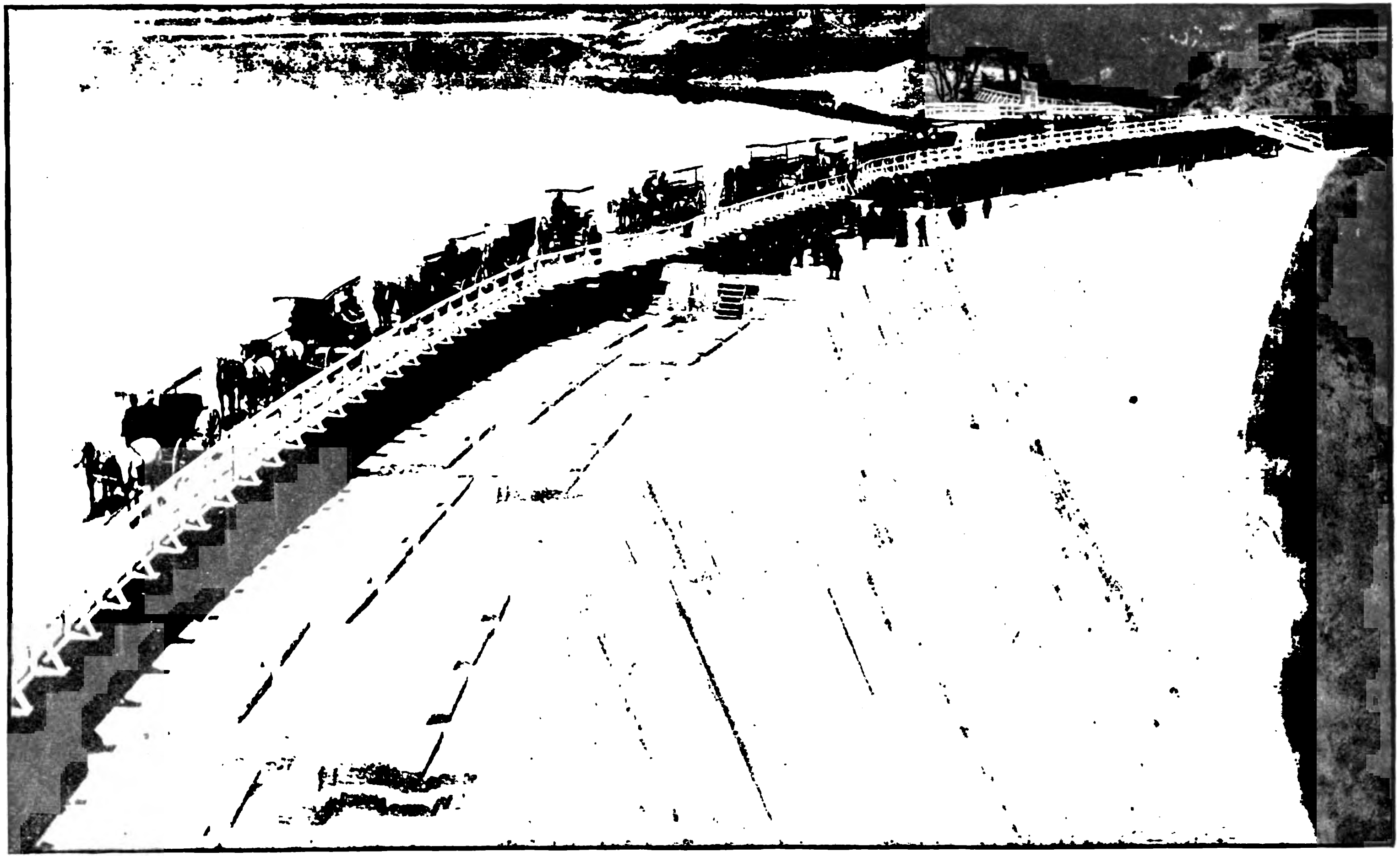


FIG. 93.—SAN MATEO DAM BEING INSPECTED BY AMERICAN SOCIETY OF CIVIL ENGINEERS IN JULY, 1896.

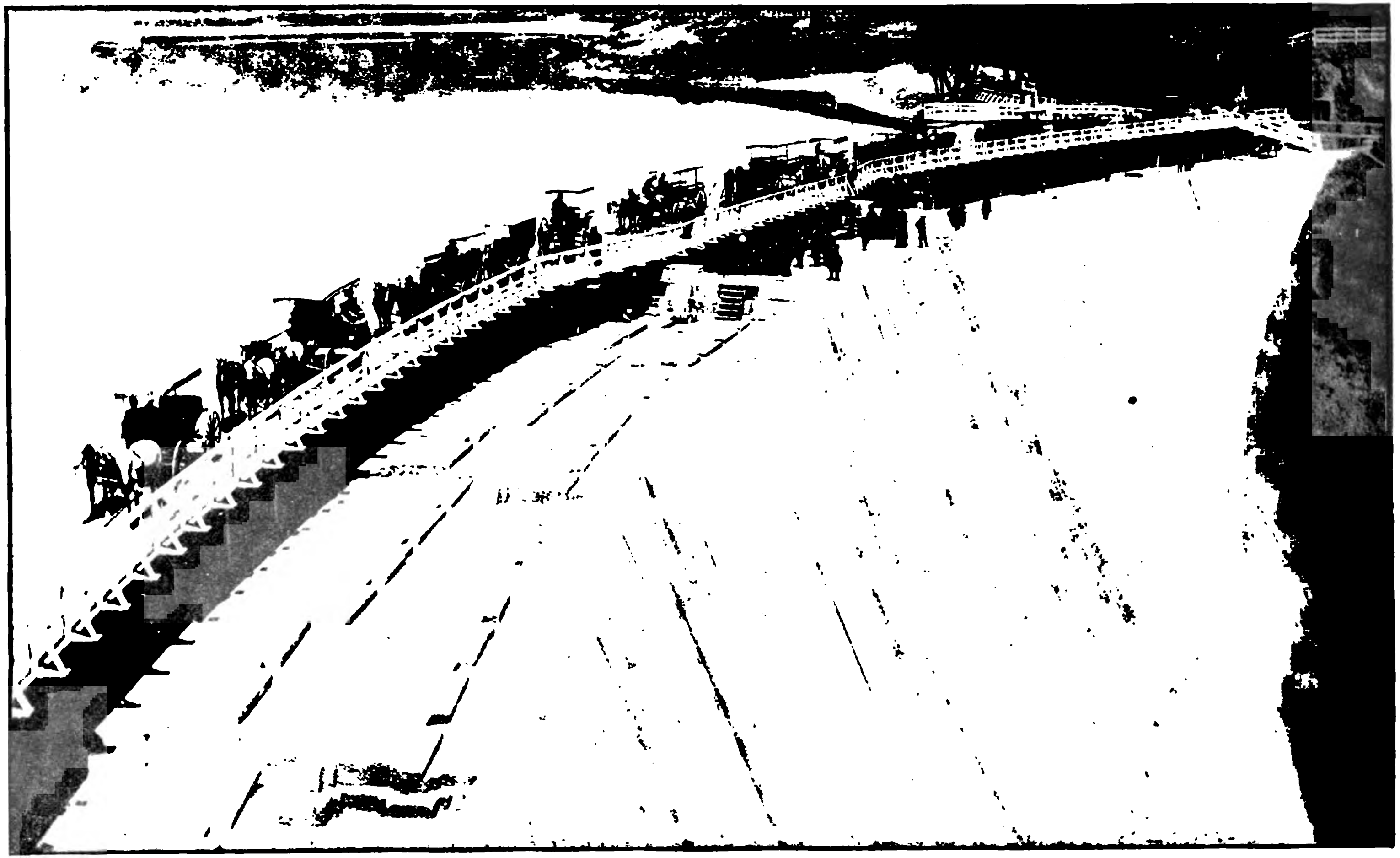


FIG. 93.—SAN MATEO DAM BEING INSPECTED BY AMERICAN SOCIETY OF CIVIL ENGINEERS IN JULY, 1896.

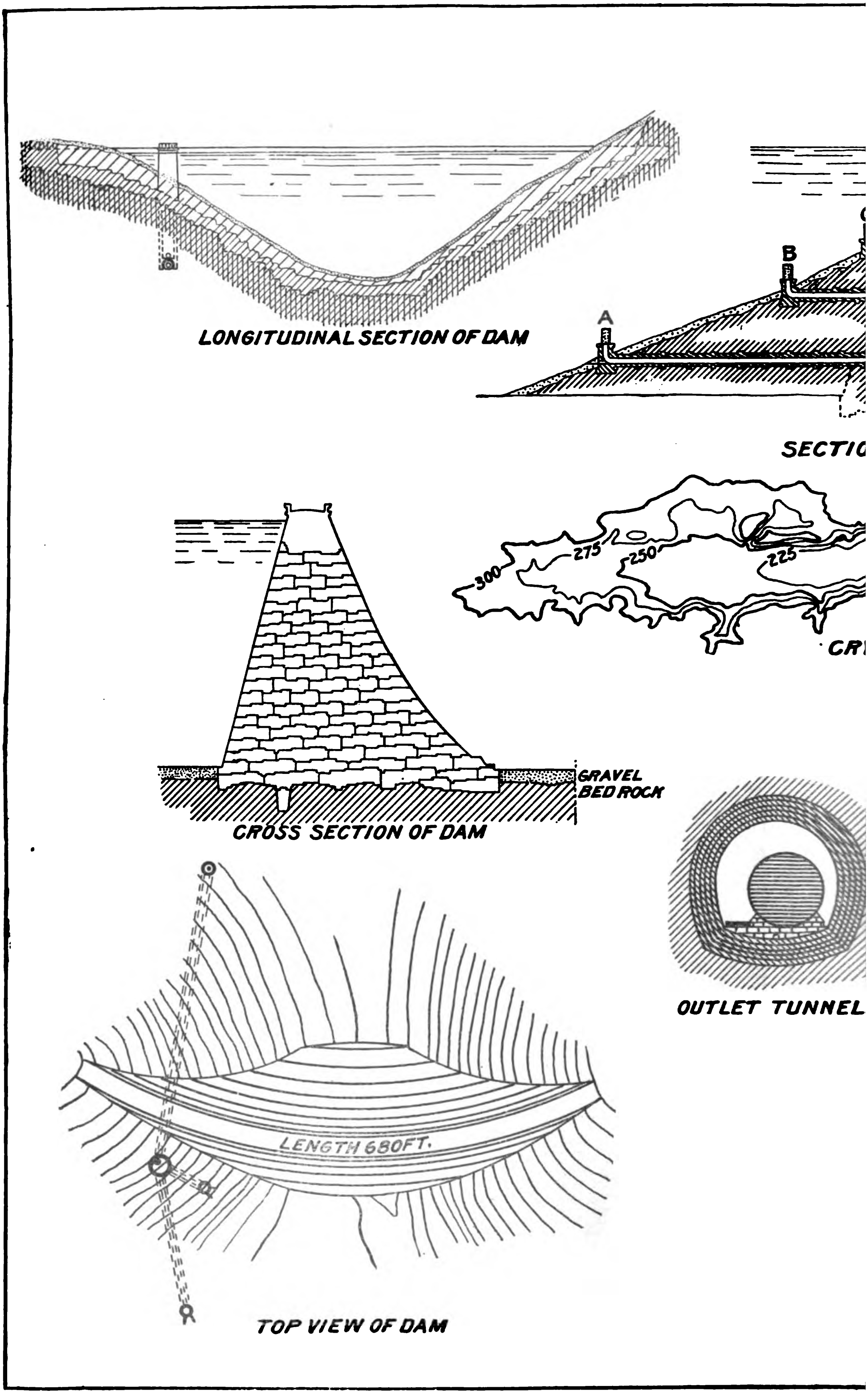
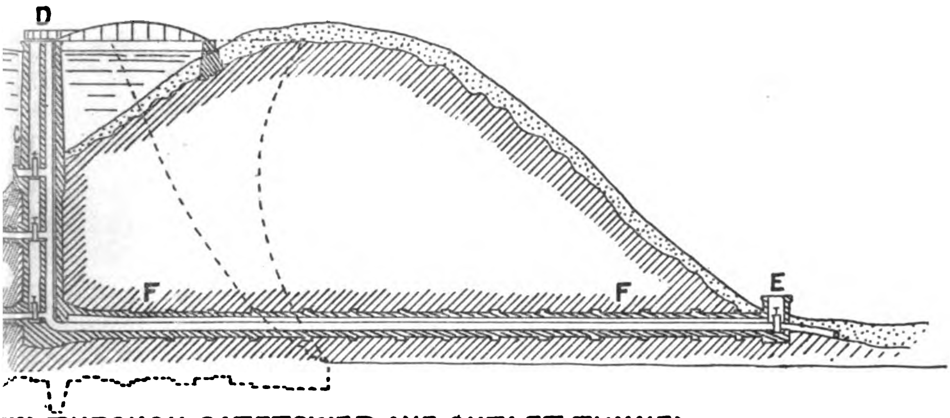
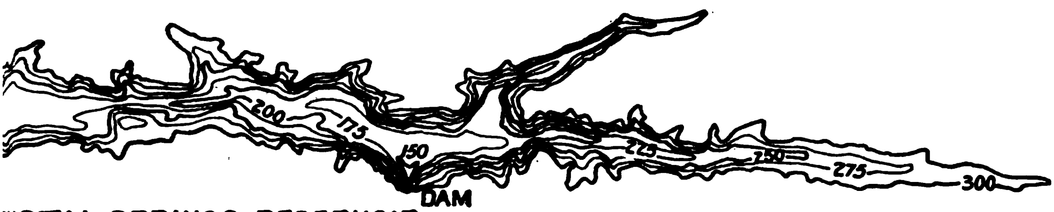



FIG. 99.—PLANS AND SECTIONS OF SAN M...




ION THROUGH GATETOWER AND OUTLET TUNNEL




YSTAL SPRINGS RESERVOIR

PLAN SHOWING LAYER OF CONCRETE BLOCKS

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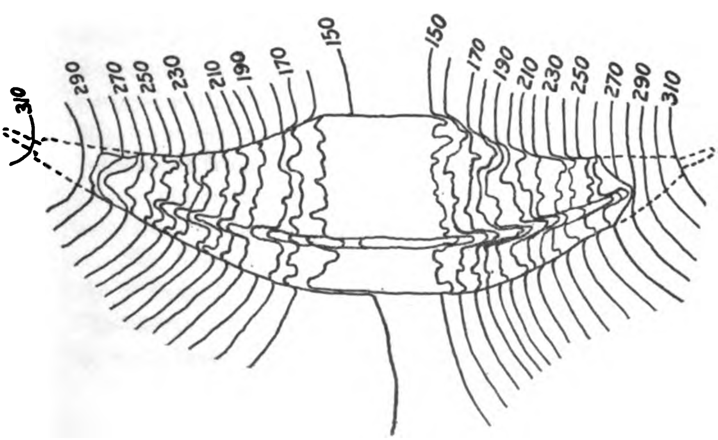


ROCK EXCAVATION FOR FOUNDATION OF DAM

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close a gap in the ridge a short distance north with a wall about 25 feet high. The outlet to the dam is a tunnel 390 feet long, driven through the hill on the north side of the channel, through which a 54-inch riveted iron pipe is laid. The tunnel is $7\frac{1}{2}$ feet wide inside the lining, and of the same height, and is lined with four courses of brick, 21 inches thick.

The tunnel is intersected by a brick-lined shaft, 14 feet clear diameter, placed just inside the dam in the reservoir. Inside this shaft is a stand-pipe connecting with the main outlet-pipe. Three branch tunnels, carrying large pipes, open out from the reservoir to this stand-pipe, each pipe being controlled by gate-valves that are placed in the main shaft. This is an admirable form of outlet, as all the pipes from the shaft are accessible to inspection and repair. The ends of the tunnels under water have plain cover-valves over elbows, and are provided with fish-screens that are put into position from floating barges. A main pipe, 44 inches in diameter, leads from the dam to San Francisco. The present crest of the dam is 281 feet above tide-level.

When the reservoir is filled it submerges the old Crystal Springs reservoir and dam, the latter being an earth structure which did service for many years until superseded by the new dam. A smaller reservoir, that formerly supplied the town of San Mateo, was also obliterated from view, and the water at highest level will extend up the valley of the north arm of the creek nearly to the toe of the San Andreas dam.

The old Crystal Springs reservoir had a tributary watershed of 14 square miles, which yielded a mean annual run-off of 319 acre-feet per square mile during the eight years from 1878 to 1886. The mean rainfall during that period was 34.95 inches. This run-off is equivalent to a mean of 14.4% of the mean rainfall, the maximum having been 34% and the minimum 0.5%.

The Pilarcitos and San Andreas watersheds, whose catchment is retained by earthen dams, receive a much higher precipitation, especially the former, which is more directly exposed to the saturated wind-currents from the ocean. The average precipitation over all the Spring Valley Water Co.'s sheds, during the seven years from 1868 to 1875, was 43.5 inches, from which the mean run-off was 35.5%, including loss by evaporation. These watersheds are partially wooded, undulating pasture-lands, uncultivated, covered with deep soil, and clothed with native grasses that spring up annually from seed and have little permanent sod. The results of the measured catchment from these areas indicates that, in general terms, on watersheds of this character from 20 to 35 inches of rainfall are annually taken into the soil and absorbed in plant-growth and evaporation.

*The Newell Curve of Run-off.*—On Fig. 100 is shown a diagram, called the "Newell Curve," from its originator, Mr. F. H. Newell, C.E., Chief Hydrographer, U. S. Geological Survey, which expresses the general relation between mean annual rainfall and mean run-off, as determined from the

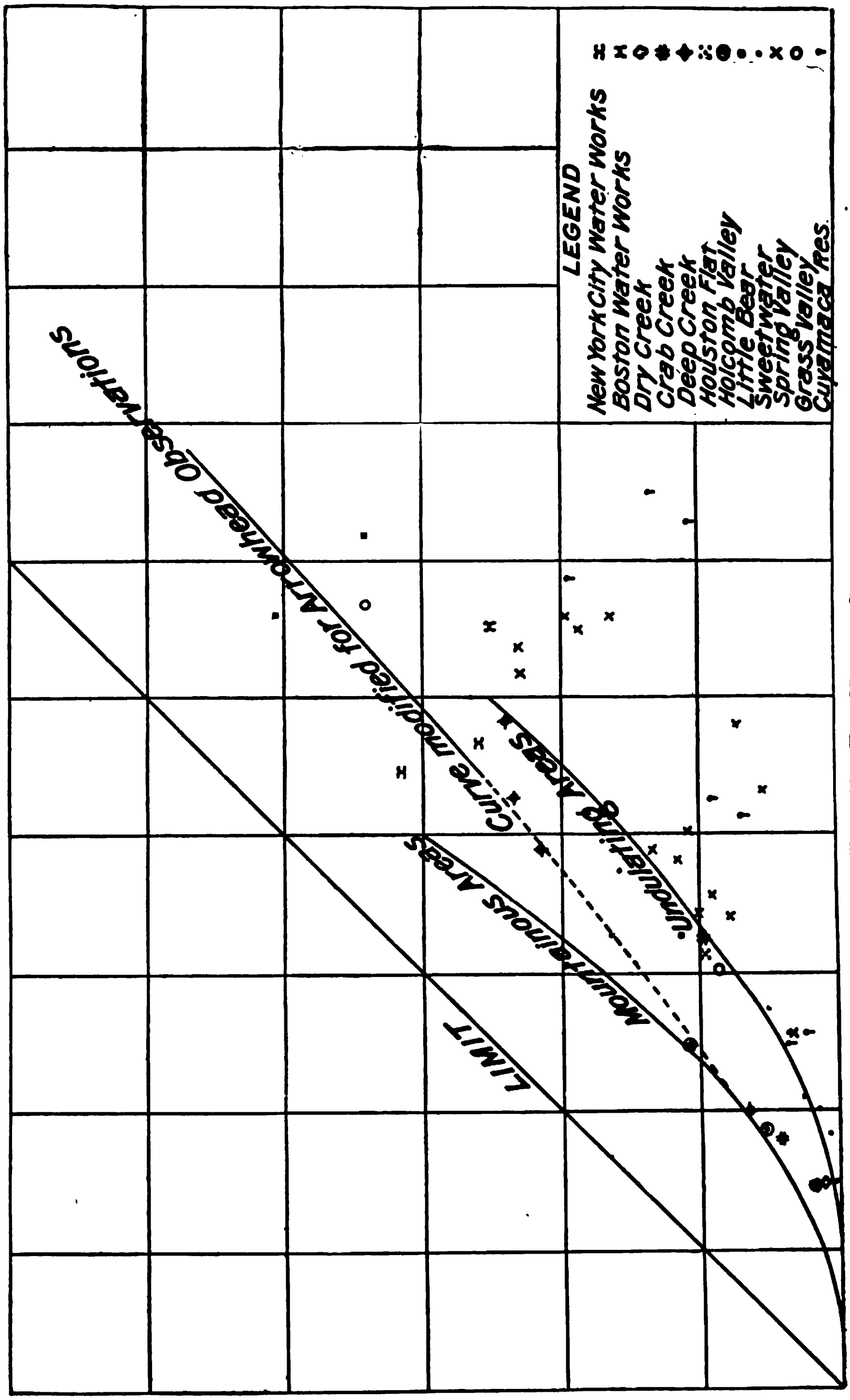



FIG. 100.—THE NEWELL CURVE.

measurements of a large number of streams, compared with the best available data as to the probable mean precipitation on the watersheds of those streams. This is a convenient diagram for general deductions, as it shows at a glance the increasing percentage of run-off to be expected from heavy rains, and the very small amount to be derived from low rainfall. Upon this diagram the author has platted a number of actual measurements of run-off on certain California watersheds and some others, which are mostly indicative of lower percentage of run-off than the lines of the curve. The difficulty in applying such a diagram to estimates of probable run-off is in determining the mean rainfall applicable to any given shed, and in the variability of run-off in different seasons, due to the uneven manner in which storms appear. Rains gently and evenly distributed will give a much smaller stream-flow than the same amount would yield if it came in a succession of violent storms, quickly following one another.

**Pacoima Submerged Dam, California.**—One of the most novel and interesting masonry dams erected for impounding water in California, where so many novelties and experimental works have been carried out, is a slender little reservoir wall built across Pacoima Creek, in the San Fernando Valley, 20 miles north of Los Angeles, for the purpose of forming an underground reservoir, whose storage capacity consists solely of the voids in the gravel-bed filling the valley of the stream.

The creek drains a watershed whose area is 30.5 square miles above the point where it issues from the mountains. Here it flows over exposed bed-rock, and the normal summer flow, which diminishes gradually from about 100 to less than 10 miner's inches, is entirely diverted by a pipe-line and used below for irrigation. The dam in question is located 2½ miles further down, where the channel of the stream is contracted to a width of 550 feet by a ledge of sandstone which crosses it at about right angles. Between the dam and the mouth of the canyon is a continuous bed of gravel, in places half a mile wide, which, though lying on a heavy grade, constitutes the storage-reservoir. The dam was constructed by excavating a straight trench (shown in Fig. 101), 6 feet wide, from side to side of the channel, down to and into the sandstone bed-rock. In the center of the trench a wall of rubble masonry was laid, 3 feet wide at base, 2 feet at surface, using the cobbles excavated from the trench, and a mortar of Portland cement and sand. The mistake was made of not filling the entire width of the trench with concrete, thoroughly rammed between the side walls, which would probably have insured satisfactory water-tightness. As it was, the space each side of the wall was refilled with gravel, and the wall was not thick enough or sufficiently well pointed to be entirely water-tight. The general height of the wall is 40 feet, the maximum being 52 feet. Plan, profile, and section of the dam are shown in Fig. 103. Two gathering-wells are provided in the line of the wall, each 4 feet inside diameter, reaching from bottom to top.

Three lines of drain-pipes, 8 and 10 inches diameter and made of asphalt concrete, laid with open joints, are placed inside the dam leading to the wells, the function of which is to gather the water and feed it to the wells. Outlet-pipes 14 inches diameter, one from each well, lead to either side of the valley. These are placed 13 feet below the top of dam and connect with a main leading to the pipe distributing system supplying the irrigated lands. When the reservoir is drained down to the level of these outlets further draft is made by pumping, which is required for about 100 days during late summer and fall.

The cost of the dam is given at $50,000, and the volume of masonry was about 2000 cubic yards. It is a piece of amateur work, built without engineering advice, but it serves a useful purpose, though not at all commensurate to its cost. It is, however, a type of dam that may be applicable to other localities more naturally favorable than this.

The dimensions and capacity of this novel reservoir cannot be clearly determined, but its surface area is approximately 300 acres, its mean depth probably 15 to 20 feet, and its capacity equivalent to the volume of voids in the gravel, or 1300 to 1500 acre-feet.

**Agua Fria Dam, Arizona.**—One of the tributaries of the Gila River, which joins it from the north, below the city of Phœnix, is the Agua Fria River, heading in the mountains near Prescott, and draining some 1400 square miles of mountainous territory. The Agua Fria Land and Water Company have erected a masonry diverting-weir across the stream, at a point 1½ to 2 miles above the northerly line of Gila Valley, and have projected a storage-dam 1¼ miles higher up the stream, at a point called the Frog Tanks, to impound the flood-water for irrigation of the plains, beginning some twenty miles west of Phœnix.

The dam is projected to the height of 120 feet above the bed of the stream. The width of the canyon is here 298 feet at the level of the sand, but at top the dam will be 1160 feet long. Sections of the two dam-sites and profiles of the dams are shown in Fig. 105. Soundings have been made over the greater portion of the channel width, and what is presumed to be bed-rock has been found at depths of 9 to 15 feet, but for a space of 50 feet no bottom was found with 24-foot sounding-rods. As the greatest depth to bed-rock at the diverting-dam below was but 40 feet, this depth has been assumed for the maximum of the unexplored 50 feet at the upper site, thus making the extreme height of the dam 160 feet. The reservoir to be closed by this dam will be 5 miles in length, flooding an area of 3200 acres and impounding 108,000 acre-feet. With a dam of gravity profile, with base of 124 feet and crest 8 feet wide, the volume of masonry required is computed at 128,650 cubic yards.

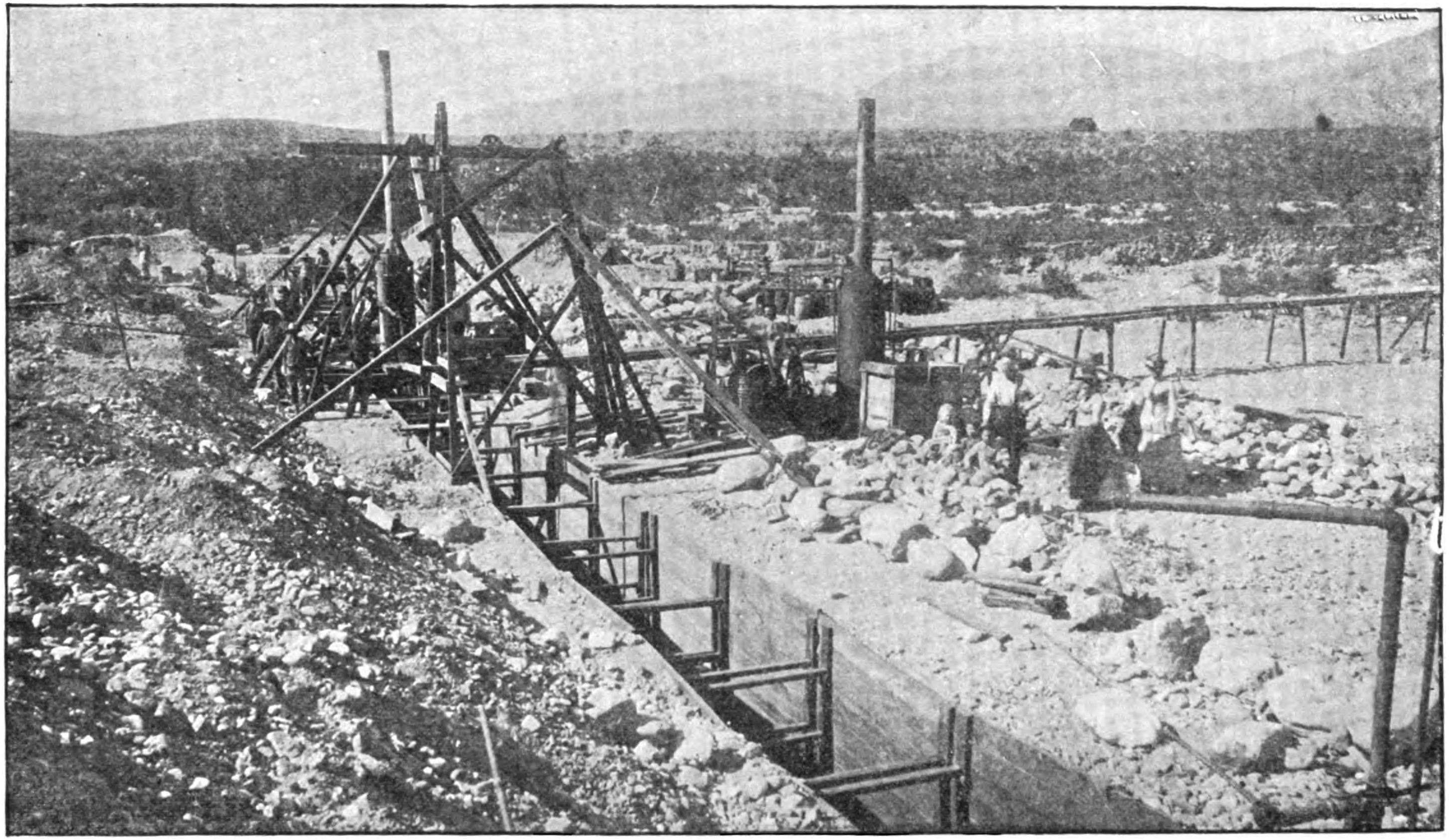


FIG 101.—EXCAVATION OF TRENCH FOR PACOIMA SUBTERRANEAN DAM.

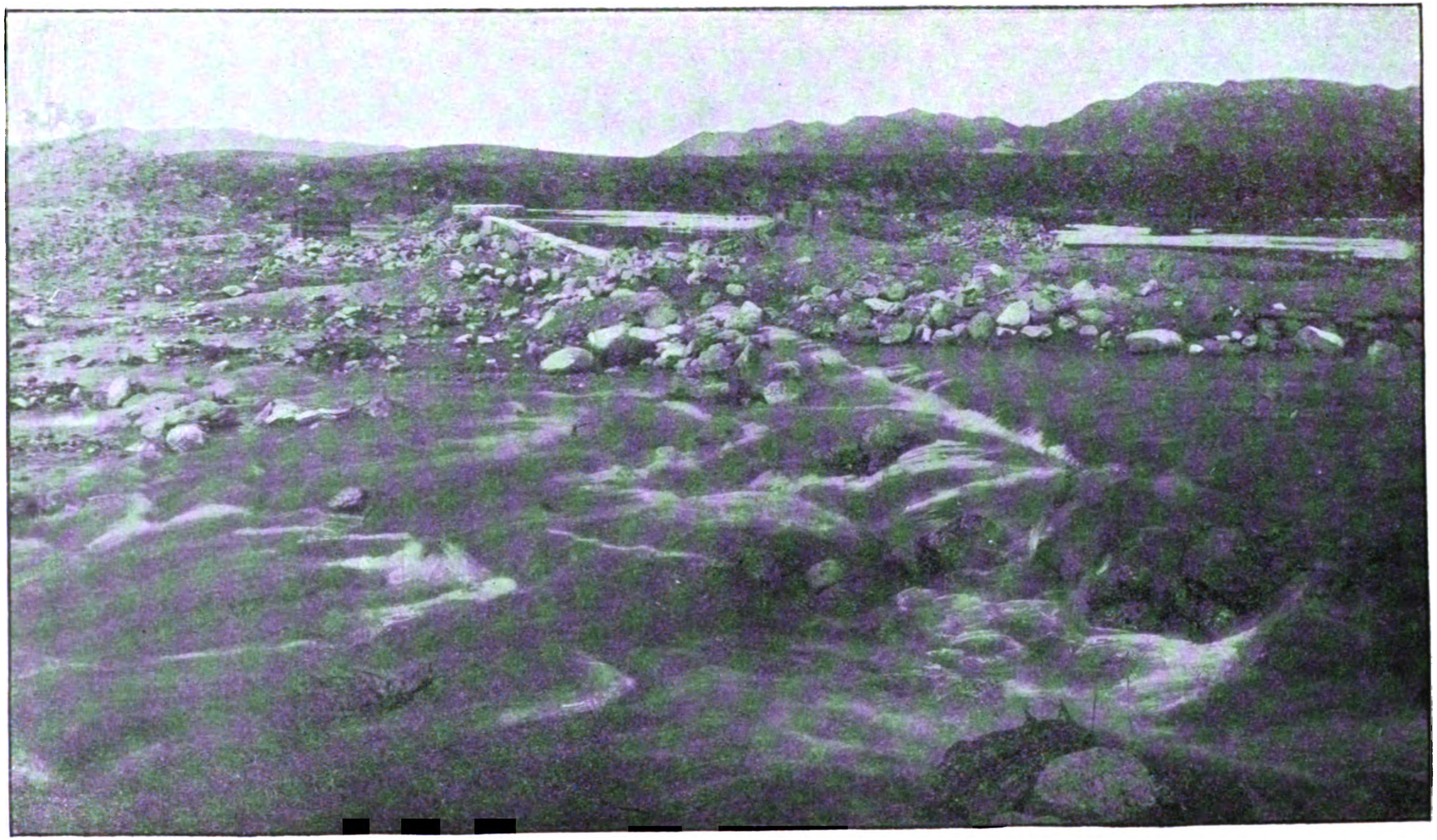


FIG. 102.—VIEW OF FLOOD PASSING OVER PACOIMA SUBTERRANEAN DAM.

The enterprise, when completed, is expected to furnish water for irrigating 50,000 acres of superb valley land that is now an absolute desert. A main canal has been projected, 25 miles in length, with a capacity of 400 second-feet, and some 4 miles of the heaviest work was completed

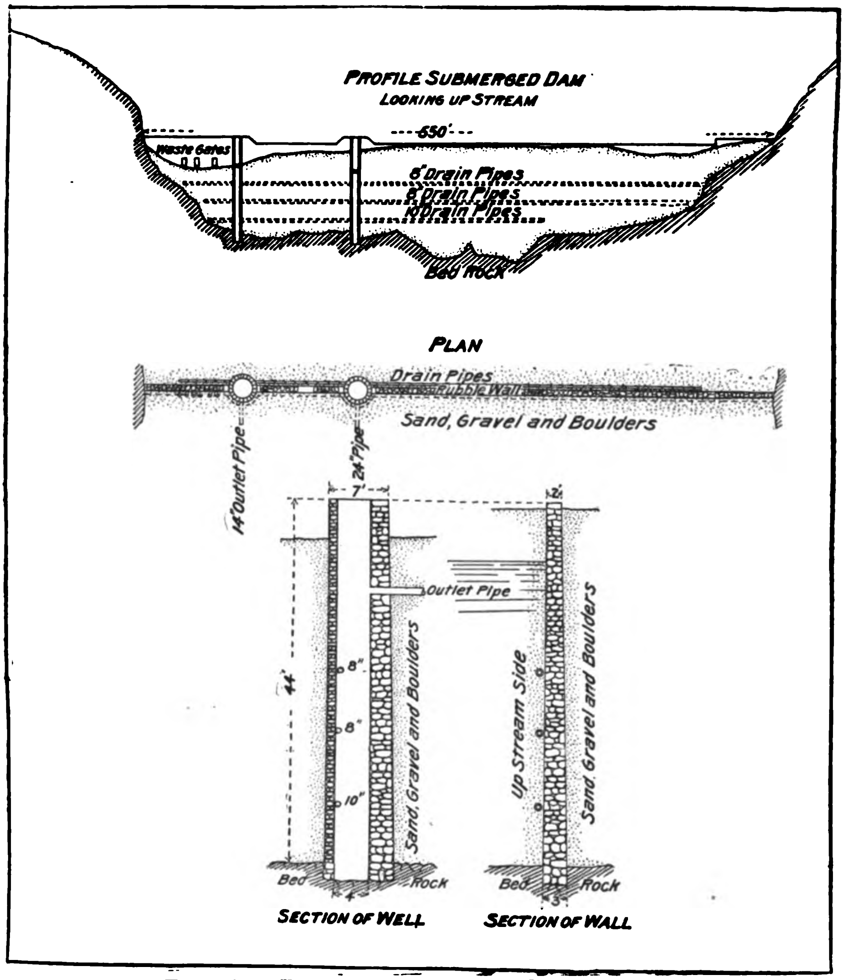



FIG. 103.—PLAN AND PROFILE OF PACOIMA DAM.

from the dam down the left bank, to the point where the canal is intended to cross the river by a 700-foot flume. This canal is 18 feet on bottom and is to carry 8 feet depth of water, on a grade of 2.11 feet per mile. The diversion-dam, upon which about $100,000 had been expended at the time work was suspended in the fall of 1895, will have a top length of 640 feet, a maximum height of 80 feet, a top width of 10 feet, and a base of 65 feet.

When finished it will contain 17,200 cubic yards of masonry, and will have cost in the neighborhood of $150,000.

The only apparent purpose of this dam was to save the construction of a conduit, 1¼ miles in length, in the canyon between the storage-dam proper and the diverting-weir. The storage-dam must be built before the scheme is of any value, or before there is any water available for irrigation.

The reasons which led to this error in judgment were, first, a misapprehension as to the depth to bed-rock at the lower site. In fact, the dam was begun without a sufficient knowledge of what a great undertaking it was to be, and so much money had been expended before it was known or suspected that the extreme depth finally reached was to be so great that it was then

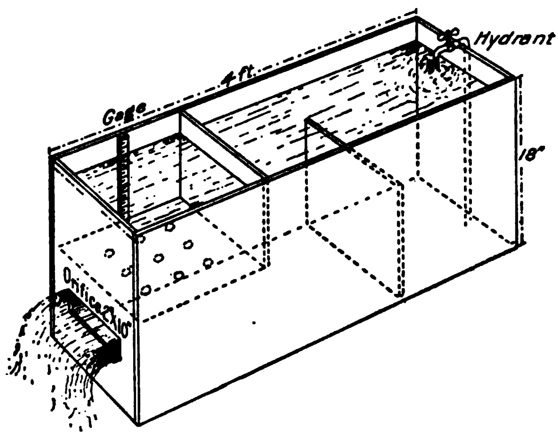



FIG. 104.—MEASURING-BOX USED BY MACLAY RANCHO WATER COMPANY.

too late to abandon the work. The second reason was the confident expectation that the volume of underflow that would be brought to the surface of the dam would reach from "500 to 1000 miner's inches," which, if realized, would have enabled the projectors to use the canal at once in the reclamation of the desert land entered under the United States Desert Land Act before the main reservoir could be made available. This "underflow" development was, however, a sore disappointment, as the flow when finally secured amounted to less than fifteen miner's inches, about what had been predicted by the writer when consulted on the subject a year or more before.

The cross-sectional area of the two channels in which the underflow was passing beneath the surface is approximately as follows:

| | |
|---|---|
| East Channel | 504 square feet. |
| West " | 2635 " " |
| Total | 3139 " " |

If the voids in the coarse sand with which these channels are filled could be assumed to be 28% of the entire area, which they are approximately, the

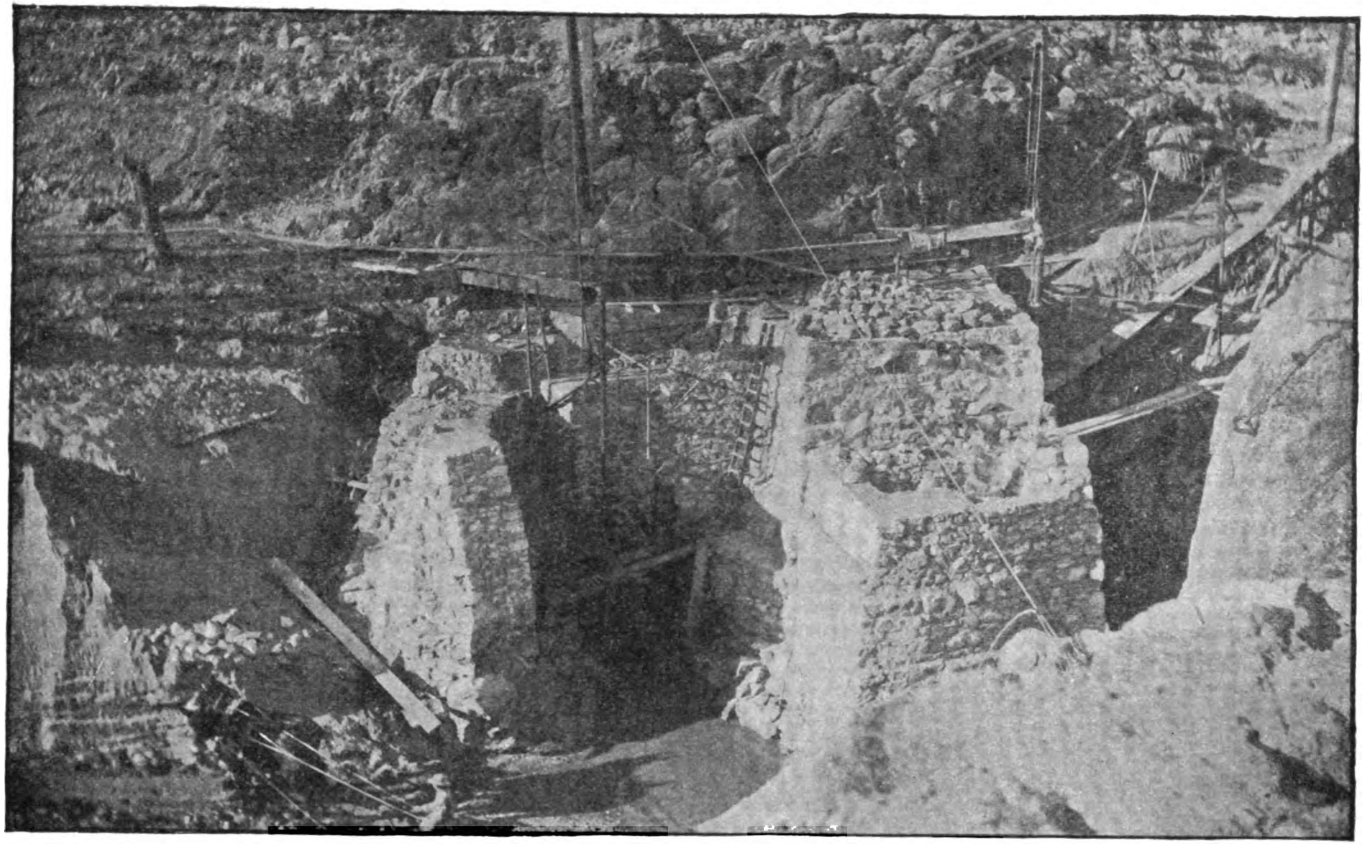
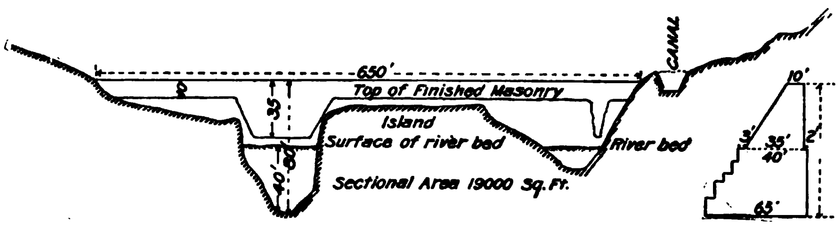


FIG. 106.—FOUNDATIONS OF WEST CHANNEL OF AGUA FRIA DIVERTING-DAM.

rate of flow established by the discharge of 15 inches (0.3 second-foot) would be precisely one mile per annum, a velocity which coincides with the observations of several authorities on the rate of flow through sand of that character. It may be noted in this connection that the volume of underflow in sandy rivers is generally vastly smaller than the popular conception of it, and for this reason submerged dams for raising this underflow are usually commercial failures, except where the material of the stream-bed is a coarse gravel, with little or no fine sand intermingled.



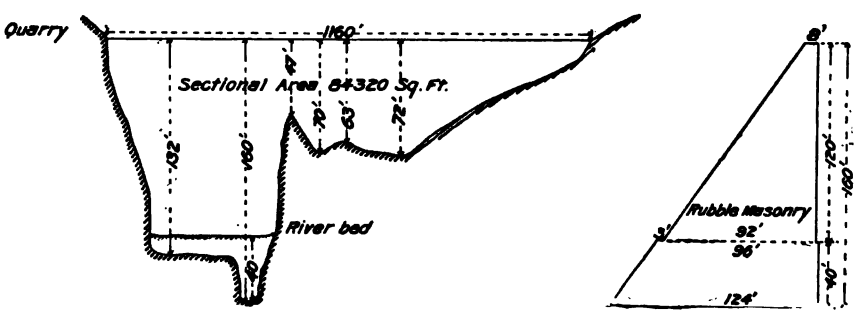




FIG. 105.—CROSS SECTIONS OF AGUA FRIA DIVERTING-DAM AND STORAGE-RESERVOIR DAM, ARIZONA.

The masonry used in the diverting-dam is a rough rubble, faced with coursed ashlar, mostly laid in a mortar of hydraulic lime of good quality, burned about 20 miles from the dam. (See Figs. 106 and 107.) For a portion of the work a small amount of Portland cement, made in Colton, California, was used. The rock was handled by a Lidgerwood cableway, with a span of 700 feet. The excavation of foundations, amounting to about 12,000 cubic yards, was accomplished by teams and scrapers, the water being handled by centrifugal pumps.

In October, 1895, a flood came which poured over the fresh masonry for several hours to the depth of 8 feet, and finally carried away a section 100 feet long, 12 feet deep, near the west end. The partial failure of the wall is accounted for by the fact that in laying the masonry each course was leveled off smoothly with mortar, in the fashion to which brick-masons are addicted in laying up house-walls. There was thus little bond between the courses, which is so essential in dam-work. A view of the dam, taken from the canal bank, is shown in Fig. 107, reproduced by permission from a paper entitled "Irrigation near Phœnix, Arizona," by Arthur P. Davis, C.E., Hydrographer, U. S. Geological Survey, being No. 2 of the series of "Water-supply and Irrigation Papers," from which some of the data for the foregoing description are derived.

In addition to the Frog Tanks reservoir-site the company have a second location, 8 miles higher up the river, where the gorge is but 262 feet wide at the river-bed, in solid rock, and but 500 feet wide at a height of 200 feet. This basin is said to have a capacity of 150,000 acre-feet, with a dam 150 feet high. The watershed, which drains the east slopes of the Bradshaw Mountains, reaches summit elevations of 6000 to 8000 feet. A reasonable estimate of rainfall and run-off from this shed is a precipitation of 16 inches and an annual run-off of 15%, which would yield 142,300 acre-feet.

**Storage-reservoirs for Water-Supply Along the Line of the Santa Fé Pacific Railway in Arizona.**—The northern portion of Arizona, traversed by the Santa Fé Pacific Railway, is an elevated plateau draining into the Colorado Canyon on the north, the Colorado River on the west, and the Verde, Salt, and Gila rivers on the south. This region has a maximum elevation of over 7000 feet along the railway and receives a greater precipitation than the lower altitudes in the southern part of the territory, but it is largely capped with volcanic lava and indurated ash, through which the water from rain and melted snow rapidly sinks and disappears. Living springs and streams are therefore infrequent, and the water-supply for railway purposes is so unevenly distributed as to necessitate the impounding of flood-waters in artificial reservoirs. This necessity is chiefly due to the general absence, in the valleys of that region, of beds of coarse sand and gravel, which constitute nature's storage-basins. The railway company, to avoid hauling water from point to point over this section of the road, has constructed several substantial dams for storage purposes at convenient points near the line of the railway, all of an interesting character in their construction from an engineering standpoint, although unimportant in the volume of water stored compared with works located in more favorable localities. These reservoirs are the following:

| Locality. | Volume Stored. | | Height of Dam. Feet. | Character of Dam. | Elevation above Sea-level. |
|---|---|---|---|---|---|
| | Cubic Feet. | Acre-ft. | | | |
| Kingman | ........... | ........ | 16 | Masonry, submerged | |
| Seligman | 30,651,000 | 703 | 68 | Masonry | 5284 |
| Ash Fork | 4,950,000 | 113.6 | 46 | Steel | 5445 |
| Williams | 14,700,000 | 338 | 46 | Masonry | 7000 |
| Walnut Canyon | 20,798,000 | 488 | 70.4 | Masonry | 6282 |

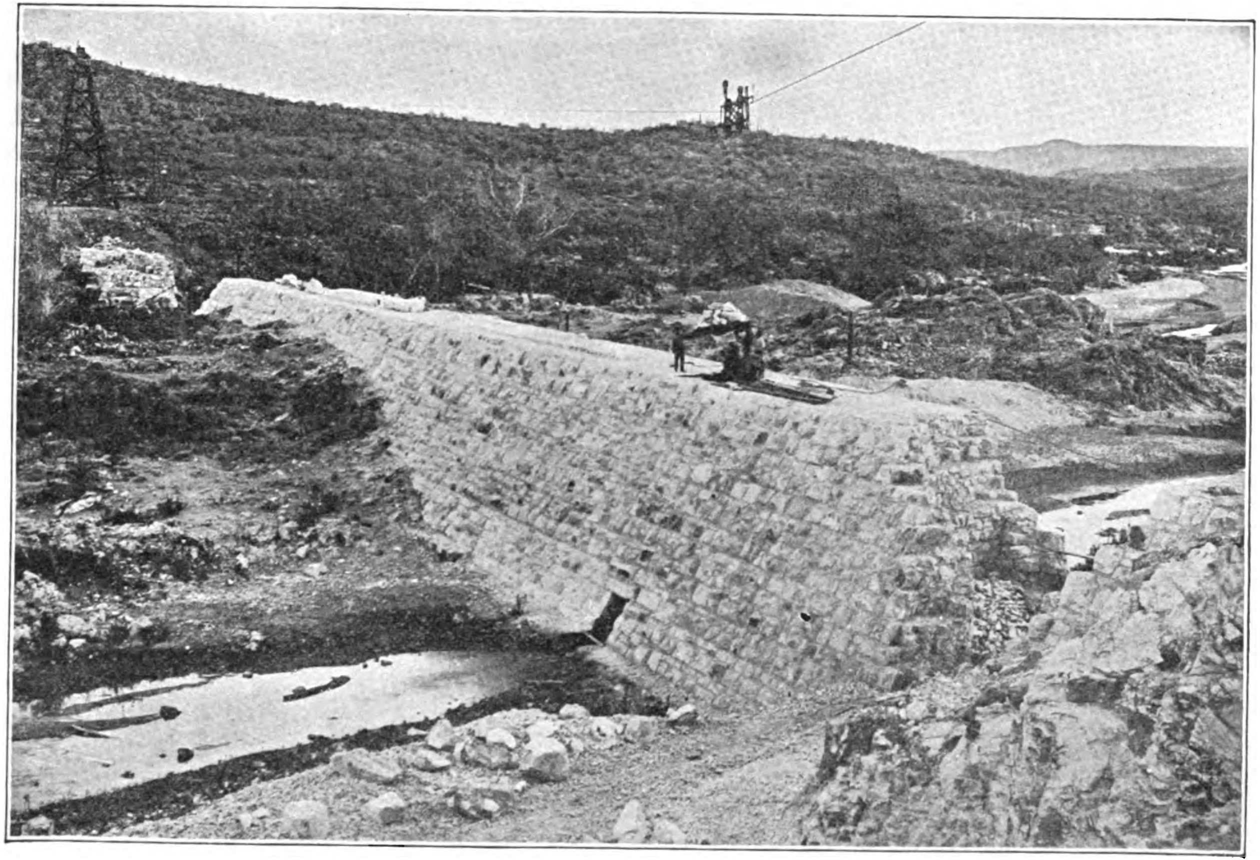


FIG. 107.—DIVERTING DAM ON THE AGUA FRIA.

**The Kingman Submerged Dam.**—About one mile west of Kingman the railway company have a well sunk in the gravelly bed of Railroad Canyon, from which they pump water for filling their tank at Kingman to supply the town, as well as the locomotives of the railway. To increase this supply and to furnish water by gravity to another tank 4 miles below, a masonry dam was built on bed-rock to intercept the underflow of the stream and store water in the gravel bed above the dam. The dam consisted of a slender masonry wall, 2 feet thick at top, 6 feet thick at base, and 16 feet high, crossing the canyon from side to side and reaching up nearly to the surface of the stream-bed. A trench was excavated in a straight line, the dam was built, and the gravel restored to its natural position, so that floods pass over its top unobstructed. The dam is thus entirely concealed from view. At the northerly end of the dam it was

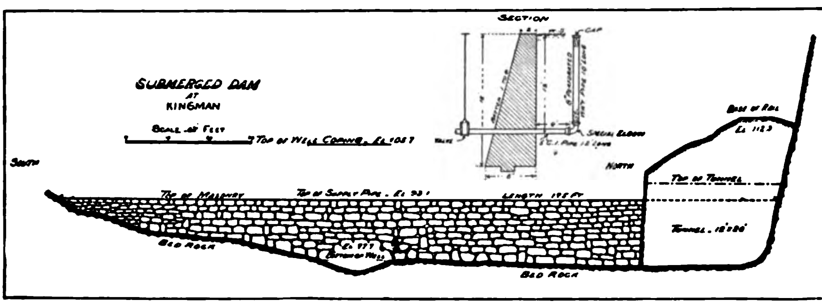



FIG. 108.—SUBMERGED STORAGE- AND DIVERTING-DAM, NEAR KINGMAN, ARIZONA.

necessary to tunnel some distance under the railway in gravelly formation in order to carry the masonry to the bed-rock wall of the canyon on that side. This tunnel was made 12 feet wide, 20 feet high, and about 30 feet long, the top of the tunnel being 16 feet below the rails. A 6-inch cast-iron outlet-pipe is built through the dam 12 feet below the top, at one side. Four feet above the dam an elbow is placed, upturned vertically, and an 8-inch wrought-iron stand-pipe 10 feet long is inserted in the elbow. This stand-pipe is perforated with ⅜-inch holes, placed ½ inch apart, for straining the water, the top being capped. The gravel reservoir is kept filled to the top of the dam by the natural underflow, and thus the town well is supplied and the lower tank automatically filled by gravity, the discharge being controlled by a float. No shortage of water has been experienced since the dam was built in 1897. The dam is 173 feet long on top, and contains 320 cubic yards of masonry. (See Fig. 108.)

**The Seligman Dam.**—This structure was begun June 25, 1897, and completed Feb. 28, 1898. It is the largest and most expensive of all the structures of its class built by the railroad company. It is located three miles southeast of the town of Seligman, an important division terminal the crest for a distance of 340 feet, and curved in the form of the segment of a vertical parabola for the overflow, which is the true form taken by falling water pouring over a weir. The maximum capacity of this spillway is 3400 second-feet, and as the watershed tributary to the dam is but 18 square miles, the capacity provided is doubtless greatly in excess of what will ever be required.

The outlets to the reservoir consist of two 8-inch cast-iron pipes, placed 6 feet apart between centers, 54 feet below the crest of dam, on the north side of the ravine, and one of similar size on the south side, used as a waste. These pipes are connected with vertical stand-pipes, inside the reservoir, standing 10 feet high and 6 feet from the face of the dam. They are of wrought iron, capped at top and perforated with ⅜-inch holes, bored ⅛ inch from center to center. They form the intake and serve to strain the water, and keep out trash from the pipes. Gate-valves are

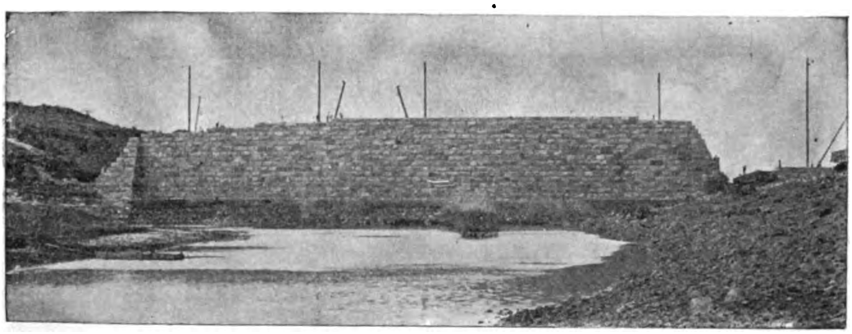


FIG. 110 — SELIGMAN DAM, ARIZONA. VIEW OF UPPER FACE DURING CONSTRUCTION.

placed in each pipe at the outside toe of the dam, and the pipes are reduced below the valves to 6 inches in diameter, where one of them is connected with the main pipe line leading to Seligman. The reservoir is 3000 feet long, and covers an area of 25¼ acres. Its maximum capacity is 30,651,000 cubic feet, or 703 acre-feet, of which one-third is in the upper ten feet. The average loss by evaporation from January to June inclusive was found to be 0.03 foot per day, or an annual rate of 10.95 feet. This loss, applied to the mean surface exposed, would amount to 15% per cent of the entire volume in 809 days, assuming an average daily consumption of 16,000 cubic feet during that time. A full reservoir is therefore expected to supply 120,000 gallons daily for 2¼ years, after deducting evaporation. The catchment is somewhat unreliable, and the reservoir did not receive any water for the first two years after it was built. Fig. 111 illustrates the section of the canyon and the profile of the dam. The fine appearance which the immense mass of masonry presents inspires regret that it should be hidden from public view from passing trains, although it is easily accessible to those who care to step off at Seligman and inspect it.

**The Ash Fork Steel Dam.**—This structure is the first one of its class that has ever been erected, and has so many novel features of an experimental character that it is specially interesting and instructive to the engineering profession. It was designed by F. H. Bainbridge, C.E., of Chicago, and was erected in 1897 on Johnson Canyon, at a point 4.3 miles east of Ash Fork, the junction of the Santa Fé Pacific with the Santa Fé, Prescott and Phœnix Railroad. The dam is one mile south of the track of the former road. The steel portion of the dam is 184 feet long, 46 feet maximum height for 60 feet in center. This steel structure connects with masonry walls at each end, which complete the dam across the gorge to a total length of 300 feet on top. The steel structure consists of a series of twenty-four triangular bents or frames, standing vertically on the lower side, with a batter of 1 to 1 on the upper. These frames are composed of heavy I beams,

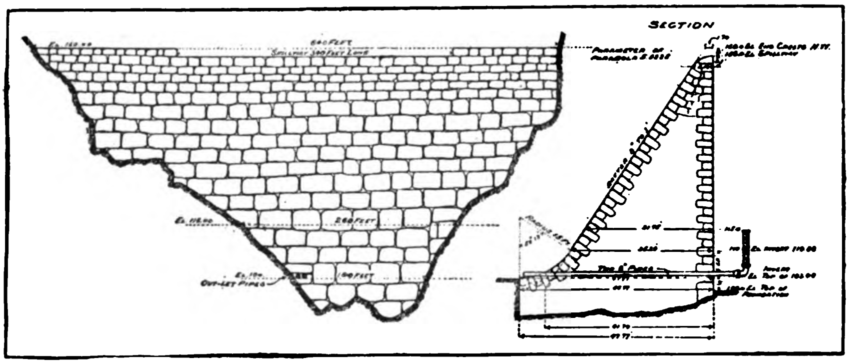



FIG. 111.—SECTION AND PROFILE OF SELIGMAN DAM, ARIZONA.

with diagonal struts and braces, resting on concrete foundations, and placed 8 feet apart, center to center, all well anchored into the bed-rock on the concrete base, and braced laterally in pairs. The dimensions of the bents vary with their height. The end bents are 12 to 21 feet in height, nine in number; four of the bents are 33 feet high, and the remainder from 33 feet to 41 feet 10 inches high. The batter-posts, to which the face-plates are riveted, are of 20-inch I beams, the longest being 66.5 feet. The face of the dam is composed of curved plates of steel, $\frac{5}{8}$ inch thick, 8′ 10$\frac{5}{8}$″ wide, and 8 feet long, the concave side being placed towards the water. They thus present the appearance of a series of troughs or channels between the supports. The bent plates do not extend into the concrete at the base, but the bottom course consists of flat plates, and the course next to the bottom is dished in the form of a segment of a sphere, making the transition between the curved and straight form. The edges of the plates are beveled for calking, and riveted together with soft iron rivets. The joint between the steel and masonry structures at the ends is formed by embedding flat plates into the concrete, the face of which has the same slope as the face of the steelwork. The abutments project 8 inches beyond the line of the face-plates. The masonry-work consists of 342.6 cubic yards of rubble and 1087 cubic yards of concrete, and there was used in the work a total of 1751 barrels of Portland cement. The work was begun October 7, 1897, and completed March 5, 1898, under the supervision of R. B. Burns, Chief Engineer, Santa Fé Pacific Railway, Mr. W. D. Nicholson, Assistant Engineer, being directly in charge.

The dam is designed to carry flood-water over the top of the steel structure. The steel plates are carried over the top of the frame, forming a rounded apron to carry the overfall beyond the line of posts. This apron, connecting with the curved inner plates, forms a series of trough-like channels between posts, 1.3 feet deep at center. The abutment wall at the east end of the dam is 2 feet higher than the bottom of the spillway channels, and that at the west end is nearly 8 feet higher. The rock at the dam-site is volcanic in origin, very hard on the surface where exposed, but containing occasional pockets of ashes or cinders, and badly broken by seams. The rock excavated for foundations was used for concrete and rubble masonry. The concrete was mixed in the proportion of 1 of Portland cement to 3 of sand and 5 of broken stone. The outlets consist of two 6-inch cast-iron pipes placed 6 feet apart, with perforated stand-pipes, 10 feet high, inside the reservoir, similar to those at the Seligman dam. The pipes are embedded in the concrete 28 feet below the top of the dam, and reduced to 4″ diameter at a point 16 feet below the gates that are placed at the toe of the masonry. The fall in the pipe-line, 4.3 miles long, is 200 feet from base of dam to the top of the water-tank at Ash Fork.

The reservoir has a capacity of 37,023,000 gallons, or 4,950,000 cubic feet, and receives the drainage from 26 square miles of watershed. The average consumption is estimated at 90,000 gallons per day, or three-fourths that of Seligman. The loss by evaporation is expected to be 40% to 50% of the total supply, but, inasmuch as it will receive water from summer rains as well as from melting snows, it is anticipated that the supply will be maintained equal to the ordinary demand.

It cannot be said that this experimental steel dam, the first of its class that has been erected, is entirely successful, and it is doubtful if the company, with the experience already had in two years of service, would care to repeat it or recommend that class of construction in lieu of something more substantial and permanent. It has been found difficult, and in fact impossible, to make a tight joint between the steel and masonry work. The structure leaks quite badly at both ends. The water also follows down the face-plates on the up-stream side and comes out on the down-stream side, notwithstanding that concrete has been rammed in on both sides of the plates for a distance of 5 feet.

The total weight of steel in the structure is 478,704 lbs., which was framed and erected by the Wisconsin Bridge and Iron Company at a cost of $55.78 per ton of 2000 lbs. The detailed cost of the entire dam is given as follows:

MATERIAL.

| | |
|---|---|
| Lumber, etc., in buildings | $659.94 |
| Explosives and tools used in excavating | 937.20 |
| Corrugated iron and nails in facing | 181.02 |
| Rubble stone | 155.25 |
| Paint and oil for painting dam | 213.49 |
| Cement, 1926 barrels | 5,774.92 |
| Steel in dam, erected | 13,351.05 |
| Fencing for reservoir | 409.26 |
| Total material | $21,682.13 |

LABOR.

| | |
|---|---|
| Spur-track | $15.00 |
| Building camp | 272.75 |
| Hauling material | 3,378.10 |
| Excavating and laying masonry | 15,440.36 |
| Engineering and superintendence | 3,102.83 |
| Plans and tests of metal | 233.63 |
| Freight on metal | 1,651.30 |
| Total labor | 24,093.97 |
| Total cost of dam complete | $45,776.10 |
| The pipe-line to Ash Fork cost | 15,978.70 |

Figs. 112 and 113 give an excellent general idea of the construction. Fig. 114 shows a portion of the reservoir, and represents clearly the igneous rock formation of the canyon in which it is located.

**The Williams Dam.**—The first of the series of dams for storage erected by the railway company was constructed near the town of Williams in 1894. It has an extreme height of 46 feet, is 385 feet long on the crest, 50 feet long at the base, where its thickness is 32 feet. The thickness at top is 4 feet. It is arched up-stream with a radius of 573 feet from the line of the vertical water-face. The dam contains 5226 yards of masonry, and consumed 3640 barrels of cement in construction. Its cost was $52,838. The dam has been a serviceable structure. The capacity of the reservoir is 110,000,000 gallons. The watershed area is not definitely known, but is small.

**The Walnut Canyon Dam.**—Walnut Canyon is a tributary of the Little Colorado River, which heads in Mormon Mt. a little south and east of Flagstaff. The watershed area above the dam is 126 square miles, which

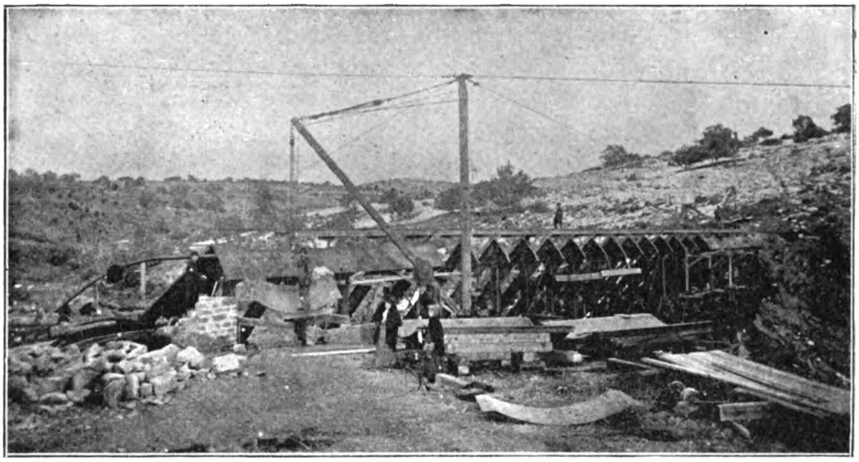


FIG. 112.—ASH FORK, ARIZONA, STEEL DAM, VIEW OF STEEL CONSTRUCTION FROM LOWER SIDE.

ordinarily affords a much greater run-off than the storage capacity of the reservoir. The geological formation of the canyon walls at the dam-site is sandstone in heavy layers or strata in nearly level beds. The bottom of the

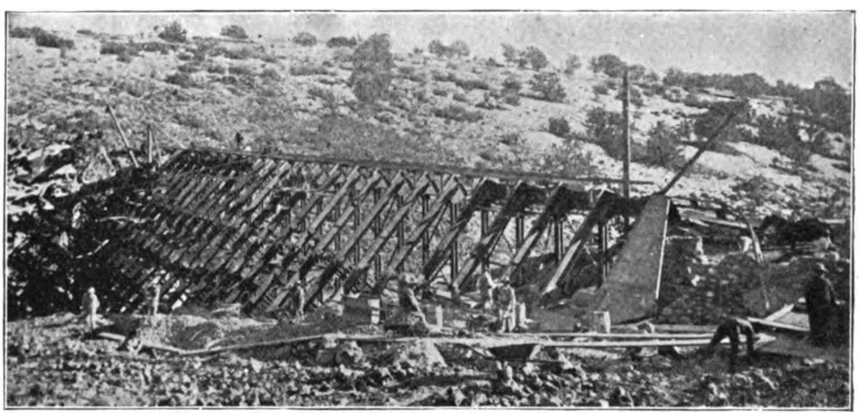


FIG. 113.—ASH FORK, STEEL DAM, SHOWING FRAME READY TO RECEIVE PLATES.

canyon was so filled with débris of earth and stone that it was necessary to excavate 28 feet below the surface to reach bed-rock, on which the dam was erected. The width at this point was but 30 feet, at the surface of stream-bed 120 feet, and at the top of the dam 268 feet. The extreme height of

The reservoir was filled for the first time on the 8th of March, 1898, and if it had been water-tight should have supplied an estimated consumption of 60,000 gallons daily for more than two years, allowing for a daily evapora-

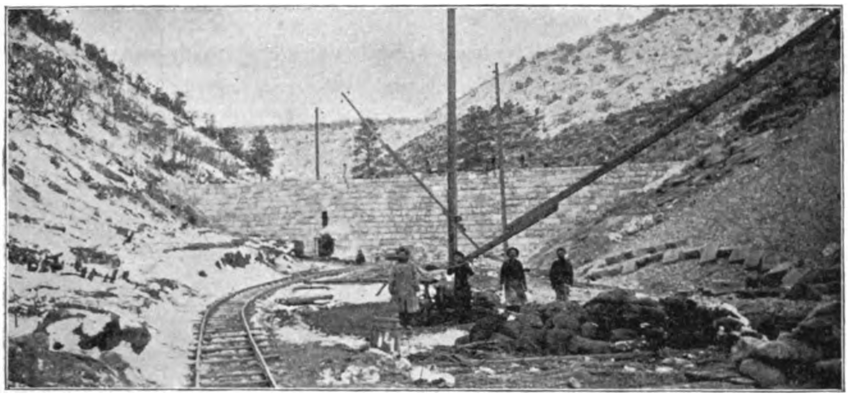


FIG. 115.—WALNUT CANYON DAM, ARIZONA.

tion loss of 0.03 foot. The water, however, disappeared very rapidly, and by September 20th was all gone, having lasted but 196 days instead of the estimated 356 days. The draft for consumption on the road was not greater

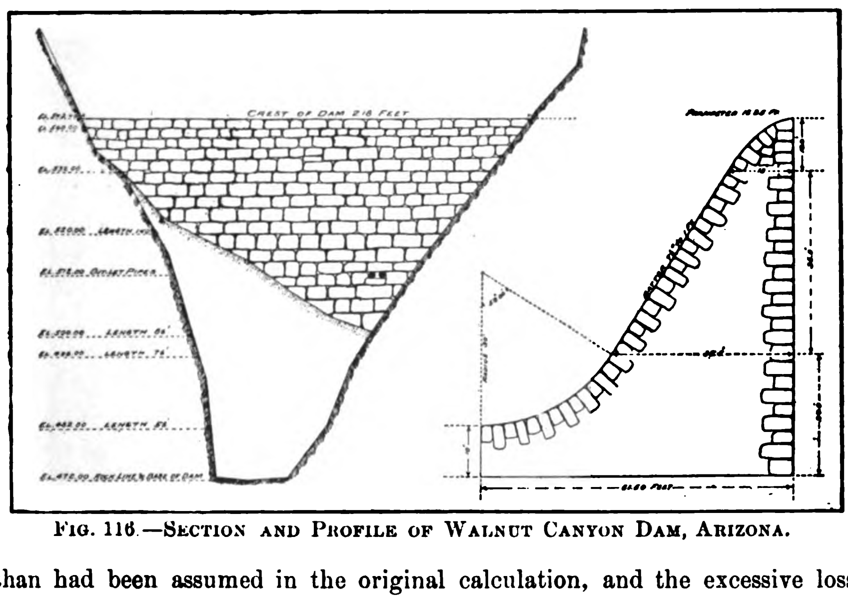



FIG. 116.—SECTION AND PROFILE OF WALNUT CANYON DAM, ARIZONA.

than had been assumed in the original calculation, and the excessive loss could only be accounted for by percolation through the sandstone or through the seams separating the underlying limestone from the sandstone. It is hoped that the reservoir will ultimately puddle itself and become tight, and efforts are being made to assist the process by plowing and loosening clay soil at points above. It is unfortunate that the usefulness of such a fine structure should be curtailed by this unexpected leakage in the walls of the reservoir, but it is possible that the loss of water may gradually lessen and finally cease. This experience illustrates, however, one of the vicissitudes attending the impounding of water. Under the most favorable conditions the annual loss by evaporation on this reservoir would be nearly 35% of the volume of storage capacity. No run-off was caught during the summer of 1899, and in the latter part of August it was still dry. The entire series of reservoir dams have been constructed under the supervision of Mr. R. B.


FIG. 117.—LYNX CREEK DAM, ARIZONA, AFTER RUPTURE BY FLOOD. VIEW FROM BELOW.

Burns, Chief Engineer, Santa Fé Pacific Railway, to whom the writer is indebted for the data concerning the works and the views which illustrate them.

**Lynx Creek Dam, Arizona.**—This structure was located 12 miles east of Prescott, Arizona, and was designed to impound water for hydraulic mining on Lynx Creek, some 4 miles below. It was intended for an ultimate height of 50 feet, and was started with a base of 28 feet. When it had reached a height of 28 feet on the up-stream side, the lower edge of the crest being 2 feet higher, it was roughly squared off with the intention of adding the remaining portion at a later date, when a sudden flood overtopped the dam and ruptured it, taking out about 35 feet of the masonry down to the bed-rock. The break is shown by the view, Fig. 117, looking up-stream. It occurred in 1891, and the dam has never been rebuilt. The dimensions of the dam were ample to withstand any overflow to be expected from the floods draining the tributary watershed of 30 square miles of territory, from 5500 to 7500 feet in elevation, had the masonry been of reasonably good quality. The failure, therefore, was clearly due to poor workmanship and unsuitable materials. The dam was 150 feet long on crest, and was built with a central angle of about 165° opposed to the direction of the current, the up-stream face being vertical. The wall consisted of a thin facing of hand-laid masonry, not over one foot thick, the core being filled with a weak concrete of fine gravel, stone, spawls, and sand. The section of the dam as constructed is clearly seen from the photograph (Fig. 118). Considerable

FIG. 118.—LYNX CREEK DAM, ARIZONA. SECTION SHOWING FACING WALLS AND CONCRETE HEARTING.

lime was used with the cement, which was of poor quality, and the concrete, though ten years old, possesses so little cohesion that it may be crumbled with a light touch. The cement used averaged but 1 barrel to 6 cubic yards of masonry. The failure of the dam, under all the circumstances, might have been anticipated. It is referred to here merely as an example to illustrate the natural consequences that must follow any carelessness or lack of attention to proper selection of materials and skill of construction in masonry or concrete dams that must withstand the erosive action of floods as well as normal water-pressure.

**Concrete Dams of Portland, Oregon.**—Among recent constructions of concrete masonry three dams designed and erected by the writer for the water-works of Portland, Oregon, in 1894, may be classed as worthy of note. They were built for the purpose of forming distributing reservoirs, and were located across natural ravines, or embayments in the hills, the reservoir space being largely augmented by excavation, and the slopes covered with a lining of concrete. One of these dams, shown in Fig. 119, closes reservoir No. 1 on the side of Mount Tabor, and is 35 feet high, 300 feet long, with a base of 18 feet and top width of 6 feet. The reservoir capacity is 12,000,000 gallons. Behind the dam the material excavated from the reservoir was placed, forming a heavy embankment whose top width is 100 feet. This is such an immovable barrier that the chief function of the concrete wall is to act as a retaining-wall for the inner slope of the earth-fill, and to form a part of the reservoir lining. The reservoir receives the water delivered by a steel-pipe line 24 miles long, amounting at maximum capacity to 22,400,000 gallons daily, and distributes it to three other reservoirs, one of which is but 2000 feet distant, shown in the photograph Fig. 121, and the other two are five miles away, across the Willamette River, and designated as reservoirs 3 and 4 (Fig. 120). Reservoir No. 3, high service, has a dam 200 feet long which is arched up-stream with a radius of 300 feet. Its height is 60 feet, base 40 feet, top width 15.5 feet, carrying on its crest a driveway of the City Park, in which it is located. This is the only dam of the three which is curved, and the only one which does not exhibit some slight expansion-cracks. The dam forming reservoir No. 4, low service, is 50 feet high, 350 feet long, and 40 feet wide at base. The faces of these two dams, both of which are in the City Park, are moulded and chiseled to resemble stone, and considerable ornamentation has been done on the parapets and about the gate-houses, as shown in Fig. 120, to which the concrete and iron construction lends itself to good advantage. It is needless to add that the dams of the dimensions given are of safe gravity profile, with ample factors of safety.

**Basin Creek Dam, Montana.**—This dam was built in 1893–95 to impound water for a portion of the domestic supply of the city of Butte, Montana, and is located 13 miles south of the city, on Basin Creek. It was designed by Chester B. Davis, M. Am. Soc. C. E., and constructed under direction of Eugene Carroll, C.E., Chief Engineer. The construction was described in *Engineering News*, December 17, 1892, Aug. 7, 1893, and Sept. 5, 1895, in communications prepared by these engineers, from which the following data have been taken. The dam is constructed of large stone, with spaces thoroughly filled with concrete, made of crushed granite 3 parts, sand 3 parts, and Yankton Portland cement 1 part. It was designed for an ultimate height of 120 feet above the lowest foundation, assumed to be at elevation 5780 feet above sea-level, or 30 feet below stream-bed, and was curved up-stream with a radius of 350 feet from its water-face. The thickness at base was to be 83 feet, and at top 10 feet; up-stream face vertical. At full height it would impound about 1,000,000,000 gallons (3069 acre-feet), covering an area of 130 acres to a mean depth of 23.6 feet. The dam was not completed higher than to the 5860-foot contour, or 40 feet below the projected crest, although its actual maximum height is 88 feet, of which 28 feet is below the stream-bed level, and it now can impound

Fig. 119.—Inner Face of Concrete Dam at Portland, Oregon.

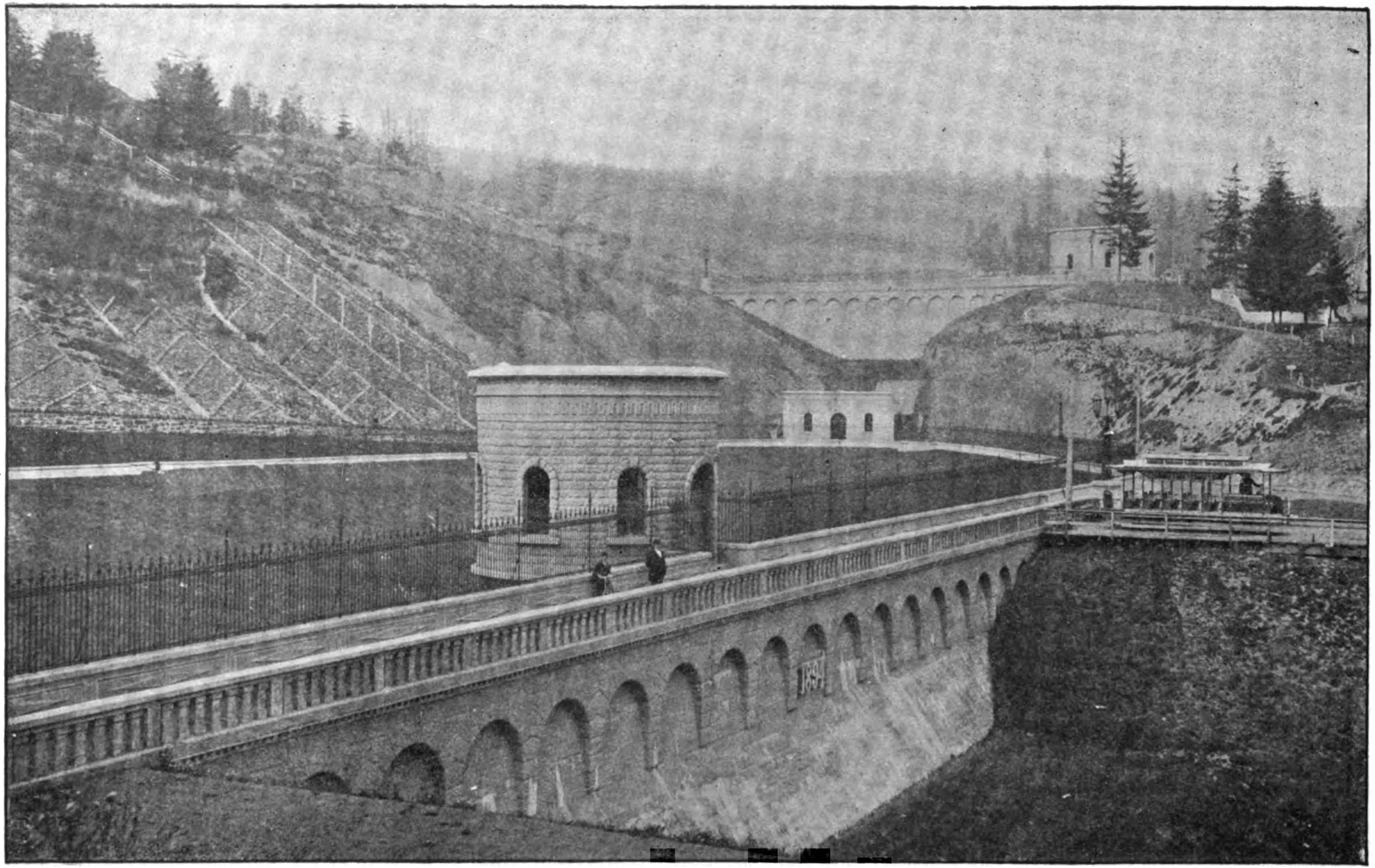


Fig. 120. - Exterior View of Reservoir Dams at Portland, Oregon.

200,000,000 gallons. The contents of the dam are 11,500 cubic yards of masonry. Its top length is 259 feet. Three 20-inch pipes are laid through the dam at its center, at the creek-bed level, two of which are used for blow-off. These pipes are controlled by plain cover-valves, resting on upturned elbows inside the dam, and raised by a windlass from the top. Gate-valves on the pipes below the dam give secondary control.

The materials of construction were hauled by a Lidgerwood cableway, with a clear span of 892 feet, the main cable being 2¼ inches diameter, sus-

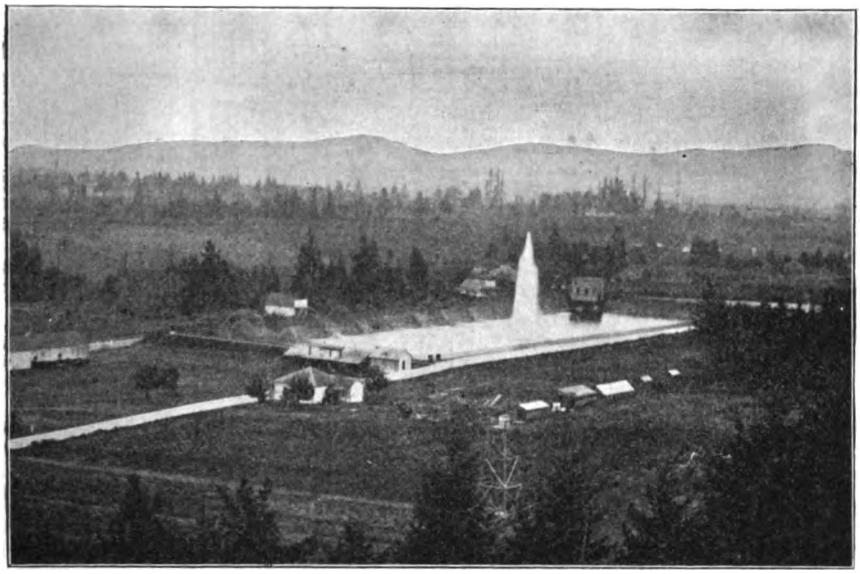
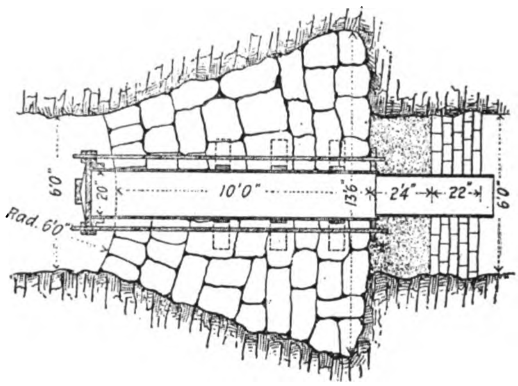


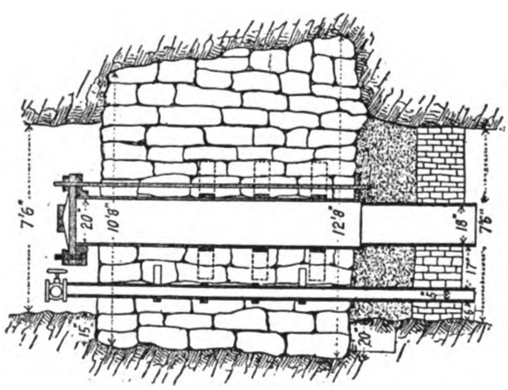
FIG. 121.—RESERVOIR No. 2, PORTLAND, OREGON, SHOWING AERATING FOUNTAIN 125 FEET HIGH.

pended 60 feet higher than the 120-foot crest-line. This cableway crossed over the quarry, and was stretched on the chord of the inner face of the dam. The loads were swung either side of this line by using a single horse pulling from a rope attached to the load and leading back over a sheave to a snubbing-post. The limited space made the use of derricks for this purpose inconvenient. For a distance of 9 miles from the dam the main conduit to the city consists of a wooden-stave pipe, 24 inches in diameter, built by the Excelsior Wood-stave Pipe Co. of San Francisco, of which Mr. D. C. Henny is manager and engineer.

**A Dam under 640-foot Head.**—A curiosity in the line of masonry dams is the one built in the Curry mine, at Norway, Michigan, to close a drift 6 feet wide, 7½ feet high, and thereby cut off a troublesome stream of water. It was built of sandstone, arched against the direction of the pressure, with a thickness of 10 feet, and laid in Hilton-cement mortar, in the proportion of 1 to 2 of sand. The dam (Fig. 122) is nearly 800 feet below the surface, and when the water fills behind it is subjected to a pressure of 277 lbs. to the square inch, equal to a static head of 640 feet, or a total pressure against the dam of over 800 tons. The dam was designed and built by Wm. Kelly, M. Am. Inst. M. E., and doubtless affords the most extraordi-




Plan.




Longitudinal Section.

FIG. 122.—MASONRY DAM UNDER 640-FOOT HEAD, THE GREATEST RECORDED WATER-PRESSURE ON MASONRY.

nary precedent on record of masonry under such extremely high pressure. It was made practically water-tight by building a brick wall, 22 inches thick, 26 inches above the face of the dam, filling the intermediate space with concrete, and placing a quantity of horse-manure against the brick-work, which was held in position by a plank partition or bulkhead. When finally tested the leakage was but 7 gallons per minute. The dam cost $484.27. (See *Engineering News*, Dec. 16, 1897.)

**New Croton Dam, New York.**—The great dam in process of erection for increasing the water-supply of New York City will, when completed, be the highest as well as the most costly dam in America. It will consist of a central masonry dam 730 feet long, 290 feet maximum height; a masonry overflow-weir about 1000 feet long, extending up-stream from the north end of the masonry dam; and an earthen dam with a masonry core-wall, about 440 feet long, continuing the masonry dam to the south side of the valley. The three sections of the dam, including the weir and core-wall, will thus form a continuous masonry wall across the valley, which will be about 1300 feet long on top. The masonry dam proper will have a base width of 185 feet and crest width of 18 feet, exclusive of the parapets protecting the roadway. The extreme height of the dam above the original stream-bed is to be 163 feet. The crest is to be 14 feet higher than the lip of the overflow-weir, and the top of the earth dam is to be 10 feet higher than the masonry. The contract for construction of the dam was let to Jas. S. Coleman, Aug. 31, 1892, for $4,152,573, of which $2,876,000 had been expended for work done to January 1, 1899. The ultimate cost will largely exceed the contract price, on account of a great increase of depth beyond the original expectations. The stone is handled by three lines of cableway with spans of 1200 feet between supports, and by 30 steam-derricks located on the dam. It is quarried 1½ miles distant and brought to the work by a narrow-gauge railway, on which 7 locomotives and 83 flat-cars are employed. Thirteen derricks with independent steam hoisting-engines are used in the quarry. The volume of water pumped from the excavations to and into the bed-rock has not exceeded 5,000,000 gallons daily. This volume, compared with the approximate area of the cross-section of the valley from bed-rock up to the level of the river-bed, indicates a maximum movement of the subterranean water down the valley at the rate of about 2½ miles per annum, assuming that none of the water pumped was returning to the pit from the lower side. The watershed area above the dam is 360.4 square miles. The reservoir when full will submerge an area of 3360 acres. The plans for the dam were designed by Alphonse Fteley, Chief Engineer of the Aqueduct Commission. Construction is under the immediate charge of Charles S. Gowen, Division Engineer, and B. S. Value, Assistant Engineer.

The original estimate of the volume of masonry of all kinds required in the dam was about 579,000 cubic yards, of which the greater portion, or 470,000 yards, was to be rough rubble laid in American (natural) cement mortar, the remainder to be laid with artificial Portland cement.

**The Titicus Dam, New York.**—This structure is a part of the system of storage for the supply of New York City, and was built in 1890 to 1895, at a cost of $933,065. It resembles the New Croton Dam in general design, in that it is a combination of masonry and earth, the higher portion in the center of the valley consisting of masonry, flanked on either side by earthen embankments, provided with a central core-wall of masonry. The main masonry dam is 135 feet high above foundation, 109 feet high above original surface, 75.2 feet thick at the level of the stream-bed, 20.7 feet thick at top, and 534 feet long. The earthen dams are 732 and 253 feet long, respectively, the total length of dam being 1519 feet. A waste-weir, 200 feet long, built in steps on the lower side, is carried over a portion of the main masonry dam. The masonry consists of rough rubble, faced on either side with cut stone, laid in regular courses. The earthen dam is 9 feet higher than the crest of the spillway. It is 30 feet wide on top, with slopes of 2½ to 1. The core-wall is of rubble masonry, 5 feet on top and 17 feet thick at a depth of 98 feet. It reaches to a maximum height of 124 feet above base. The greatest depth of water is 105 feet. The dam was planned by A. Fteley, Chief Engineer, and construction was originally in charge of Charles S. Gowen, who was subsequently succeeded by Alfred Craven as Division Engineer, and M. R. Ridgway, Assistant Engineer.

**The Sodom Dam, New York.**—This is a purely masonry structure, built across the east branch of the Croton River in 1888–93, by the Aqueduct Commission of New York, and, in connection with the Bog Brook dams 1 and 2, forms what is known as "Double Reservoir I." The reservoirs were connected by a tunnel, 1788 feet long, by which the surplus water from the Sodom dam is made to supply the other reservoir, whose watershed was but 3.5 square miles, while that tributary to the Sodom reservoir was 73.4 square miles. The tunnel thus equalizes the supply from the two watersheds. The combined storage capacity of the two reservoirs is about 9,500,000,000 gallons. The Sodom dam is 500 feet long on top, 98 feet high above foundation, 78 feet above stream-bed, and the masonry has a bottom thickness of 53 feet, and is 12 feet wide at top. It contains 35,887 cubic yards of rubble masonry, chiefly laid in Portland-cement mortar, mixed 2 to 1 and 3 to 1. A continuation of the masonry dam is carried along the crest of the ridge, nearly at right angles to the wall, in the form of an earthen embankment, 9 feet high, 600 feet long. In extension of this bank is a masonry overflow, 8 feet high, 500 feet long.

The cost of the dam was $366,490. It was planned by Chief Engineer Fteley, and constructed by Geo. B. Burbank, Division Engineer, and Walter McCulloh, Assistant, later Division Engineer. An interesting account of the dam is to be found in a paper prepared for the American Society of Civil Engineers in March, 1893, by Mr. McCulloh, from which it appears to be one of the few masonry dams that were quite water-tight from the first filling of the reservoir, although "sweating" appears at several points on the lower face. The dam was built by the aid of a 2-inch cableway, stretched along its axis, with a span of 667 feet between towers. The Sodom reservoir covers an area of 574.9 acres and impounds 4,883,000,000 gallons. The Bog Brook reservoir, with which it is connected, floods a surface area of 410.4 acres. The Bog Brook dams are of earth with masonry core. Dam

No. 1 is 60 feet high and holds 54 feet maximum depth of water. It is 25 feet wide on top. The core-wall is 10 feet thick at base, 6 feet at top. Dam No. 2 is 25 feet high. The cost of the two dams was $510,430.

**The Boyd's Corner Dam, New York.**—In 1866 the Croton Aqueduct Board of New York began a masonry dam near Boyd's Corners, on the west branch of Croton River, which was completed in 1872. The dam contains 27,000 cubic yards of masonry, of which 21,000 yards are concrete hearting and 6000 yards are cut-stone facings. The dam has a maximum height of 78 feet, is 670 feet long on top, 200 feet long at level of stream-bed, 53.6 feet thick at base, 8.6 feet at top. The base is laid with a batter of ½ to 1 on each side to the original stream-level, 60 feet below the crest, where an offset of 1.5 feet was made on each side, and the dam was then carried up vertically on the water-face, and given a batter of 0.4 to 1 on the lower side. The reservoir covers 279 acres and impounds 2,722,700,000 gallons of water.

**The Indian River Dam, New York.**—This important structure was erected in 1898 for increasing the size of Indian Lake and thus store water to supply the Champlain Canal, to add to the water-power, and to improve the navigation of Hudson River. It is located in Hamilton County in the northern part of New York State, on a tributary of the Hudson, at an elevation of 1655 feet at the high-water line. The dam is a combination masonry and earth structure, straight in plan, the masonry portion being 47 feet in extreme height, having a base width of 33 feet, a thickness on crest of 7 feet, and a total length of 207 feet. The earth embankment is a continuation of the masonry, 200 feet long, 15 feet wide on top, with inner slopes of 2½ to 1, paved with 12 inches of stone riprap. The outer slope is 2 to 1. Through the center is a core-wall of masonry, 4 feet thick at base, 2 feet at top, reaching to within 2 feet of the crest of the embankment. The end of the embankment next the dam is supported on the down-stream side by a masonry spur-wall at right angles to the dam. The embankment rests on hard-pan, into which the core-wall is carried down uniformly 4 feet thick to depths of 8 to 20 feet, filling the trench cut for it.

On the opposite or west end of the dam a spillway was excavated in granite, having an effective length of 106.5 feet and a depth of 6 feet, to the bottom of the floor-stringers of the foot-bridge which spans it and which rests on five masonry piers. The capacity of discharge is estimated at 5000 second-feet. The coping is made of large, selected stones firmly doweled to the masonry. A logway, 15 feet wide, whose crest is 17 feet below the top of the dam, is provided through the masonry. It is closed with 45 wooden needles, 4″ × 8″, 20 feet long, which are handled by block and tackle. The outlets to the reservoir consist of two 50-inch steel pipes, controlled by Eddy flume-gates, and having a discharging capacity of 1500 second-feet with full reservoir. The gates are inside of a tower, on the exterior of which are auxiliary sluice-gates of wood, raised by screws. A 6-inch by-pass pipe enters the tower from the reservoir, by which the tower is filled and the pressure relieved from the wooden gates, so that they can be readily raised.

The total actual cost of the work, including $13,000 for clearing, was $83,555, the contract price being $92,000. Under the most favorable conditions the cost per cubic yard for the masonry was as follows:

| | |
|---|---|
| Cement | $2.00 |
| Sand | .15 |
| Quarrying stone | .35 |
| Labor of laying masonry | .53 |
| Labor of pointing masonry | .15 |
| Labor of mixing mortar, concrete, and crushing | .20 |
| General expenses, superintendence, etc. | .27 |
| Total | $3.65 |

The cement used was made at Glenn's Falls, N. Y., of the "Ironclad" brand of artificial Portland.

The reservoir formed by the dam has a storage capacity of 4,468,000,000 cubic feet, or 102,548 acre-feet, and floods an area of 5035 acres. The original lake covered 1000 acres, and the new dam raised the mean surface of the lake 33 to 34 feet. The tributary drainage-area above the dam is 146 square miles, the run-off from which can be safely estimated to fill the reservoir every year.

The dam was built for the Forest Preserve Board of New York State by the Indian River Company. It was planned by Geo. W. Rafter, M. Am. Soc. C. E., and constructed under his supervision by Wallace Greenalch, Jun. Am. Soc. C. E., as Assistant Engineer.

For further details of this interesting work the reader is referred to *Engineering News* of May 18, 1899, containing descriptive illustrated papers on the subject by Messrs. Rafter and Greenalch.

**Cornell University Dam, New York.**—In 1897 an overflow masonry dam was built across Fall Creek near Ithaca, N. Y., as a portion of the hydraulic laboratory plant of Cornell University. It is curved in plan on a radius of 166.5 feet, and is 153 feet long on top, with a maximum height of 30 feet, and a gravity section, vertical up-stream, and stepped on the lower face. It is located at the head of Triphammer Falls, in a picturesque gorge, cut deeply into the shale formation of that region, where the total fall is about 400 feet in a mile. The stream drains a watershed of 117 square miles, on which the mean precipitation from 1880 to 1897 was 35.22 inches. The mean flow is about 175 second-feet, ranging from a minimum of 12 to a maximum of 4800 second-feet. In times of flood the water discharges over the crest of the dam and over a natural spillway ledge at one end of the dam, a total width of 267.5 feet, made up of 134.5 feet on the dam and 133 feet on the natural spillway.

The dam is of gravity section, and made of concrete, composed of four parts of hard, clean, argillaceous shale, two parts of sand, and one part of "Improved cement." The "Improved cement" is a mixture of Rosendale and artificial Portland in the proportion of weight of 3 to 1, ground together in the clinker state, and costing one-half the cost of pure Portland cement.

One of the interesting and unusual features of the construction of this dam was the provision made for concentrating the contraction due to temperature changes in the concrete to a central point of weakness. This was done by leaving a 5-ft. circular opening through the dam during construction, connecting with which was an open well extending up through the heart of the dam to its crest. At this point the section was thus reduced to 60% of the normal, and shortly after completion the wall cracked for one-half its height down through the well. During unusually cold weather, when the crack was widest, the opening through the dam and the well were filled with concrete, and the contraction-crack was thus effectually closed.

The dam and other works connected with the entire plant designated as the hydraulic laboratory were designed by Prof. E. A. Fuertes, M. Am. Soc. C. E., Director of the College of Civil Engineering. Construction was in charge of Mr. Elon H. Hooker, Resident Engineer. Mr. Ira A. Shaler, M. Am. Soc. C. E., was contractor for the work. A full description of the laboratory is given in *Engineering News*, March 2, 1899.

**The Bridgeport Dam, Connecticut.**—The town of Bridgeport, Conn., having a population in 1890 of 48,890, is supplied by a number of storage-reservoirs, one of which is formed by a masonry dam across Mill River, built in 1886. Its general dimensions are as follows:

| | | |
|---|---|---|
| Maximum height | 42.5 | feet. |
| Bottom thickness | 32.0 | " |
| Top thickness | 8.0 | " |
| Length at crest | 640 | " |
| Length at base | 50 | " |

The structure is composed of rubble masonry built of gneiss rock laid in a mortar of Rosendale cement and sand in the proportion of 1 to 2. The lower face of the dam is built in steps. The outlet from the gate-chamber is a 30-inch cast-iron pipe, controlled by a gate-valve in the chamber. The latter structure is built against the dam, is 10 × 15 feet inside, in two compartments, between which a fish-screen is placed. Three 30-inch openings, at different levels, controlled by gates, lead from the reservoir to the outer compartment. The spillway, at one end of the dam, is 80 feet long, 5 feet deep. The reservoir covers 60 acres and has a capacity of 240,000,000 gallons (737 acre-feet). The dam has leaked so much as to require an earth backing.*

* "The Design and Construction of Dams," by Edward Wegmann, p. 85.

**The Wigwam Dam, Connecticut.**—The city of Waterbury, Conn. (pop. 28,646 in 1890), constructed a masonry dam in 1893–94 to store water in a reservoir located on West Mountain Brook and receiving the drainage from 18 square miles of watershed. The dam was designed and built by Robt. A Cairns, City Engineer. It was planned for an ultimate height of 90 feet, at which its full length on top will be 600 feet, and it was completed with full section to within 15 feet of the ultimate crest, and there stopped, as the storage at that level was sufficient for present needs. The base thickness is 62.08 feet, and it is 12 feet thick on the crest. The cubic contents of the completed portion are 14,887 cubic yards, of which 5754 yards are laid in Rosendale cement, and the remainder in American Portland cement mortar. The cost has been $150,000. The present capacity of reservoir is 335,000,000 gallons (1028 acre-feet), which will be increased to 714,000,000 gallons when the dam is completed. A temporary wasteway, 82 feet long, 2 feet deep, has been made at one end of the dam, which is of insufficient capacity. The completed dam will have a wasteway 100 feet long over a rocky ridge some distance away, and another 78 feet long at the dam. An earth embankment is required to close a gap in the reservoir, as an auxiliary to the masonry dam. This will be 35 feet high when finished, but is built only to a height of 20 feet.

**The Austin Dam, Texas.**—The city of Austin, Texas, the capital of the State, with a population of about 25,000 inhabitants, has erected one of the most notable masonry dams of the United States, across the Colorado River, 2½ miles above the city, for power-development purposes. The dam, Fig. 123, was built in 1891–92. It was designed by Mr. Jos. P. Frizell, M. Am. Soc. C. E. of Boston, and about two-thirds completed by him. He was succeeded by Mr. J. T. Fanning. The dam proper is 1091 feet long between bulkheads and 68 feet high. It is vertical on the up-stream face, while the down-stream face is inclined at a batter of 3 in 8, terminating in a vertical curve of 31 feet radius, while the crest is rounded on a radius of 20 feet on lower side, forming an ogee curve that has the general shape of the trajectory of falling water.

Mr. Frizell's original design contemplated a flat top for the purpose of facilitating the erection on the crest of a series of movable flashboards, or some other form of falling dam, that could be lowered in flood-time, but would permit of increased storage during low seasons, and the development of a more uniform volume of power at low and high water.

The power is used for pumping water for city supply, for electric lighting, propulsion of street cars, and general manufacturing. Its volume is estimated at 14,636 horse-power for 60 working hours weekly.

The dam is straight in plan, and contains about 88,000 cubic yards of masonry, of which 70,000 yards are of rough rubble, made of the limestone quarried near the site, and 18,000 yards are of cut-stone range-work, in

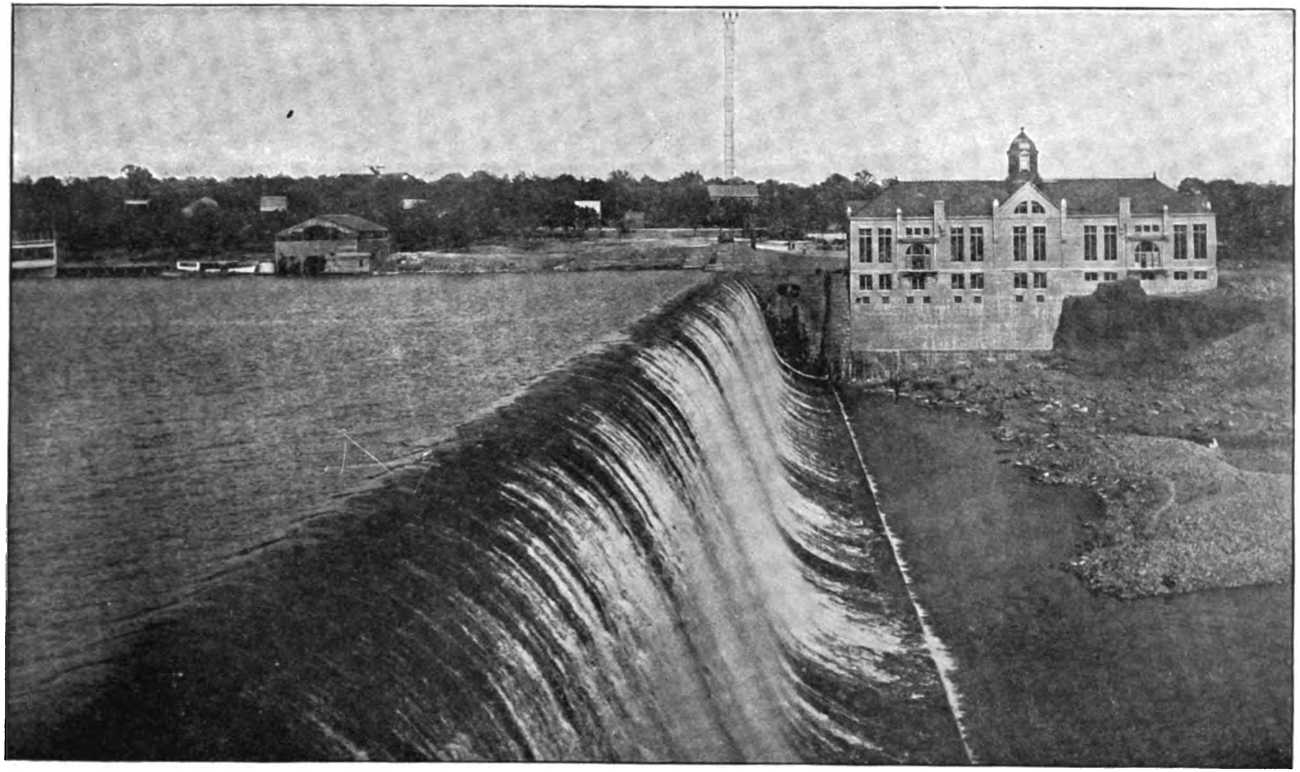


FIG. 123.—AUSTIN DAM AND POWER-HOUSE, TEXAS.

which Burnett County blue granite was used, brought a distance of 80 miles. The entire work was done by contract, at a cost of $11 to $15 per yard for the cut-stone masonry, and $3.60 to $4.10 per yard for the rubble, the larger sum being for work in which Portland cement was required. The cost of the dam and head-gate masonry was $608,000, and the entire expenditure, including dam, power-house, reservoir and distributing system, lighting-plant, etc., was $1,400,000, for which amount the city voted its bonds May 5, 1890.

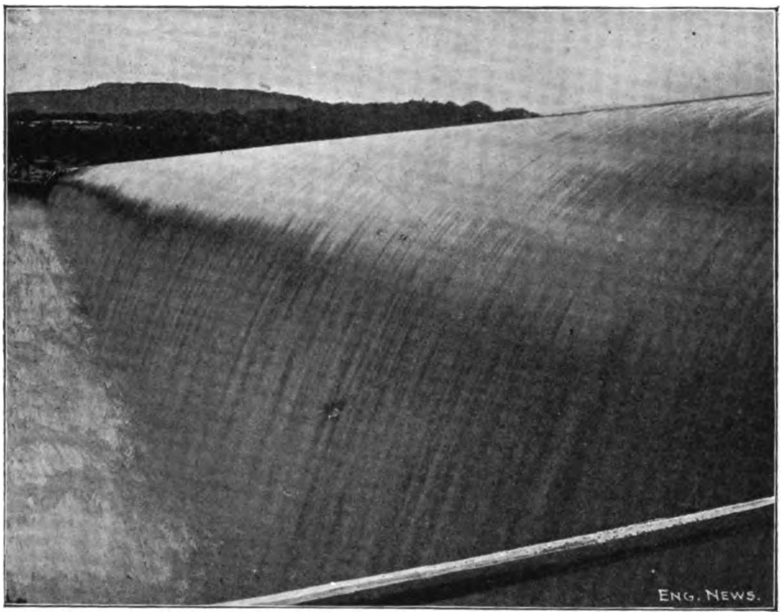



FIG. 123a.—AUSTIN DAM DURING FLOOD OF APRIL 7, 1900, AND IMMEDIATELY BEFORE THE BREAK.

The dam is founded on limestone rock throughout, the river here flowing through a gorge with cliffs rising from 70 to 125 feet in height above the river. Lidgerwood cableways were employed in placing the stone and for hauling all materials.

The Colorado River at Austin drains an area of 40,000 square miles, from which the discharge has a range of from 200 to 250,000 second-feet.

The reservoir formed by the dam is very long and narrow, extending back 19 to 23 miles up the river and having an average width of but 800 feet. Its surface area is 1836 acres, and the capacity at the time the dam was finished was 53,490 acre-feet, the mean depth being 29.1 feet, or 42.5%

of the maximum. The dam was completed in May, 1893, and the water first overflowed the crest of the dam on the 16th of that month.

Four years subsequently, in May, 1897, Prof. Thomas U. Taylor, of the University of Texas at Austin, made accurate soundings of the lake to determine the volume of silt which had accumulated in four years, and ascertained that the deposit amounted to 968,000,000 cubic feet (22,227 acre-feet), or 41.54% of the original capacity. The greatest depth of fill was at the dam, 23 feet; three miles above it was 16.5 feet deep at the maximum; seven miles above, 20 feet; 9.3 miles above, 21.3 feet; 14.6 miles above, 15.3 feet; 15.9 miles above, 6.6 feet. To this point the filling was composed of mud. Above this distance the deposit was mostly sand. Considering the total volume of water which must have passed through the reservoir during the four years, the percentage of silt deposited seems very small, and the result is not such as to discourage the construction of reservoirs on streams where the ratio between run-off and storage capacity is less disproportionate. There are no definite data available of the total discharge of the river, but assuming it to have been about 50 acre-feet annually per square mile of watershed, which is a reasonable assumption for streams of that class (the run-off of New York and New England streams is from 700 to 2000 acre-feet per square mile, while that of the Rio Grande and Gila rivers is 25 to 35 acre-feet per square mile), the total volume of water discharged in the four years must have been approximately 8,000,000 acre-feet, or about 160 times the reservoir capacity. The relation of the silt deposited to total run-off would be in the ratio of about one-fourth of one per cent of this volume, or 2770 cubic feet per million. The river Po,* as determined by M. Tadini, carried as the mean of four months 3333 cubic feet per million; the river Ganges, 980 as the mean of 12 months, and in flood 12,300; the Mississippi, 291 to 1893; the river Indus, in flood 2100. A stream of the size and character of the Colorado River of Texas, to be utilized for irrigation should have a reservoir of one to two million acre-feet capacity, to be in proper proportion to the volume of run-off and amount of silt carried, and maintain a sufficiently long period of usefulness to be profitable. Such a reservoir would probably not be filled with silt short of 400 to 500 years.

*Failure of the Austin Dam.*—On the 7th of April, 1900, a severe flood in the Colorado River and its tributaries, unprecedented since the erection of the dam, resulted in the failure of this fine structure, with considerable loss of life. About 500 feet of the masonry was first pushed bodily downstream, about 60 feet, apparently sliding on its base, and after a few hours was entirely broken up and washed away, with the exception of a small section, which still stands upright in the position where it was first de-

* See Humphrey and Abbott's report on Mississippi Delta Survey, 1876.

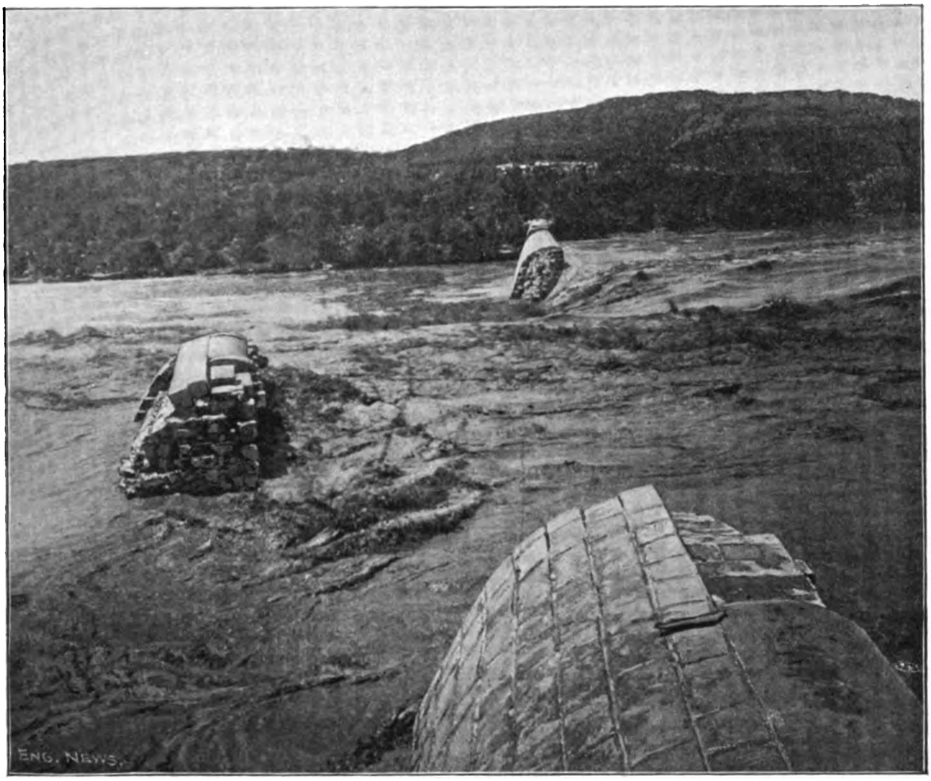



FIG. 123b.—AUSTIN DAM, TEXAS. VIEW TAKEN DURING FLOOD, A FEW MINUTES AFTER THE BREAK

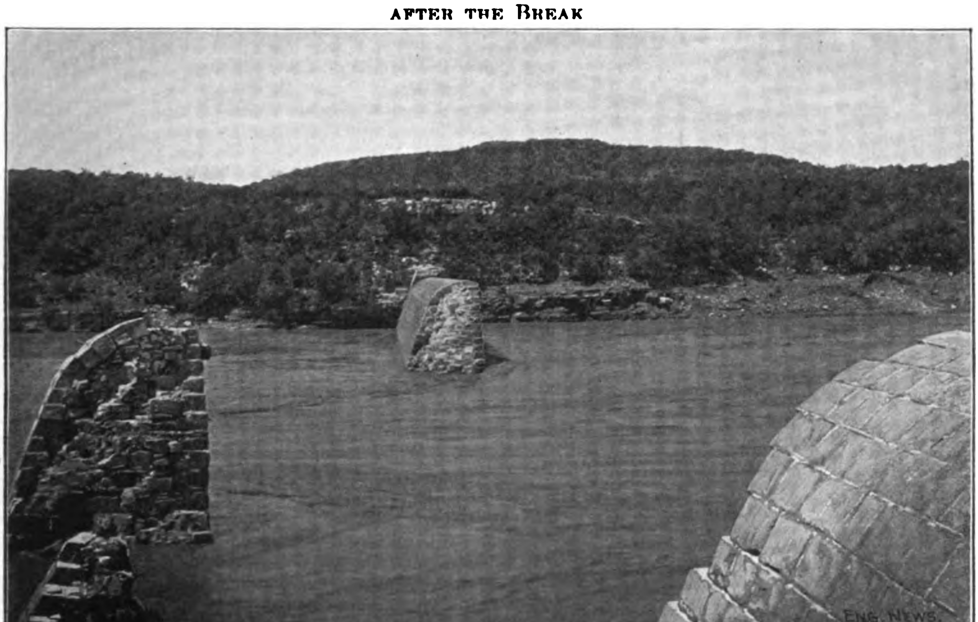



FIG. 123c.—AUSTIN DAM, TEXAS, AFTER SUBSIDENCE OF FLOOD OF APRIL 7, 1900.
Showing section of masonry moved bodily down-stream.

posited. Measured along the crest, the break left about 500 feet of the dam at the west end and 83 feet at the east end still unaffected. About two-thirds of the wall of the power-house below the dam next the river was also destroyed by the flood. The entire property loss must have exceeded $500,000. At the time of the break the lake-level had reached a height of 11.07 feet above the crest. The flood was the result of extraordinary rains throughout a very extensive watershed area. In fifteen hours the rainfall at Austin and vicinity was 5 inches, falling on ground already well soaked by previous rains. The maximum flood prior to the catastrophe occurred June 7, 1899, when the water rose to 9.8 feet above the crest of the dam, without injury to the structure. The dam will probably be rebuilt upon safer plans, and precautions taken to anchor it into bed-rock a sufficient depth to prevent it from sliding on its foundations.

The appearance of the dam immediately before the break is shown in Fig. 123*a*. Figs. 123*b* and 123*c* graphically present the break and the bodily movement of a section of the dam down-stream intact, better than any detailed description. The author is indebted to *Engineering News* for these three cuts.

**Mexican Dams.**—By courtesy of *Modern Mexico*, of St. Louis, Mo., the accompanying views of two notable masonry dams at Guanajuato, Mexico, are incorporated in this work, as types of reservoir construction in our neighboring republic. Fig. 124 shows the upper dam, from which water is supplied to the higher portion of the city, through a stand-pipe that is shown in the view of the lower dam, or the "Presa de la Olla," Fig. 125 (frotispiece).

The upper dam is evidently a massive, ornate structure that would do credit to any country of the world, as far as exterior appearances can lead one tö judge, although the precise dimensions are unfortunately lacking. Estimating from the proportions of the figures in the foreground, the height of the dam must be at least 80 feet.

The view of the lower dam was taken on St. John's Day, the 24th of June, which is celebrated annually by a function called the "Fiesta de la Presa," or the feast-day of the dam.

Sharply at 12 o'clock, noon, of that day, the people congregate to witness the opening of the gates, bringing refreshments and musical instruments for a picnic, and thus commences a fortnight of gayety, gambling, bull-fights, cock-fights, theater, and dancing. The object of letting out the water is to clear the reservoir preparatory to the advent of the rainy season, which usually begins about that day.

The water thus released washes out the river-bed below, which is the main drainage of the city.

## Foreign Dams.

The following descriptions of the principal masonry dams of the world outside of the United States have been condensed from the valuable work on "The Design and Construction of Dams," by Edward Wegmann, M. Am. Soc. C. E., published in 1899.

**The Almanza Dam, Spain.**—The oldest existing masonry dam was erected in the Spanish province of Albacete prior to 1586. It is built of rubble masonry, faced with cut stone, and is 67.8 feet high, 33.7 feet thick at base, and of the same thickness for 23.5 feet of its height, the upper side being vertical, and the lower face stepped. The crest is 9.84 feet thick. The lower 48 feet is built on curved plan with radius of 86 feet. The upper portion is irregular. The maximum pressure upon the masonry is 14.33 tons per square foot.

**The Alicante Dam, Spain.**—This structure, erected in a narrow gorge on the river Monegre, in 1579 to 1594, is the highest dam in Spain, and is used for irrigation of the plains of Alicante. The height is 134.5 feet, the base width being 110.5 feet, and the crest 65.6 feet. The gorge is remarkably narrow, being but 30 feet at bottom and 190 feet at the top of the dam. The dam is curved in plan, with a radius of 351.37 feet on the up-stream face at crest, which has a batter of 3 to 41. The dam is built of rubble masonry, faced with cut stone. It is supposed to have been designed by Herreras, the famous architect of the Escurial palace.

The reservoir formed by the dam is small for so large a structure, having a length of but 5900 feet and a capacity of 975,000,000 gallons (2982 acre-feet).

The stream carries such a large volume of silt that it is necessary to scour out the sediment by a device called a scouring-gallery. The scouring is done every four years. The gallery is a culvert through the center of the dam at the bottom, 5.9 feet wide, 8.86 feet high at the upper end, and enlarged below. The mouth is closed by a timber bulkhead, which is cut out from below when the scouring is to be done. The sediment forms to a great depth above the mouth of the culvert, and has to be started to move by punching a hole through it with a heavy iron bar. The total cost of scouring the reservoir amounts to $50. The sediment which is not swept out by the velocity of the current is shoveled into the stream by workmen.

**The Elche Dam, Spain.**—This structure has a maximum height of 76.1 feet and a base of 39.4 feet, and is formed in three parts, closing converging valleys. The principal wall is 230 feet long and built of rubble faced with cut stone. It is curved in plan, up-stream, with a radius of 205.38 feet. It is provided with a scourging-sluice similar to that at the Alicante dam, but so designed as to be safer for the workmen who remove the timbers

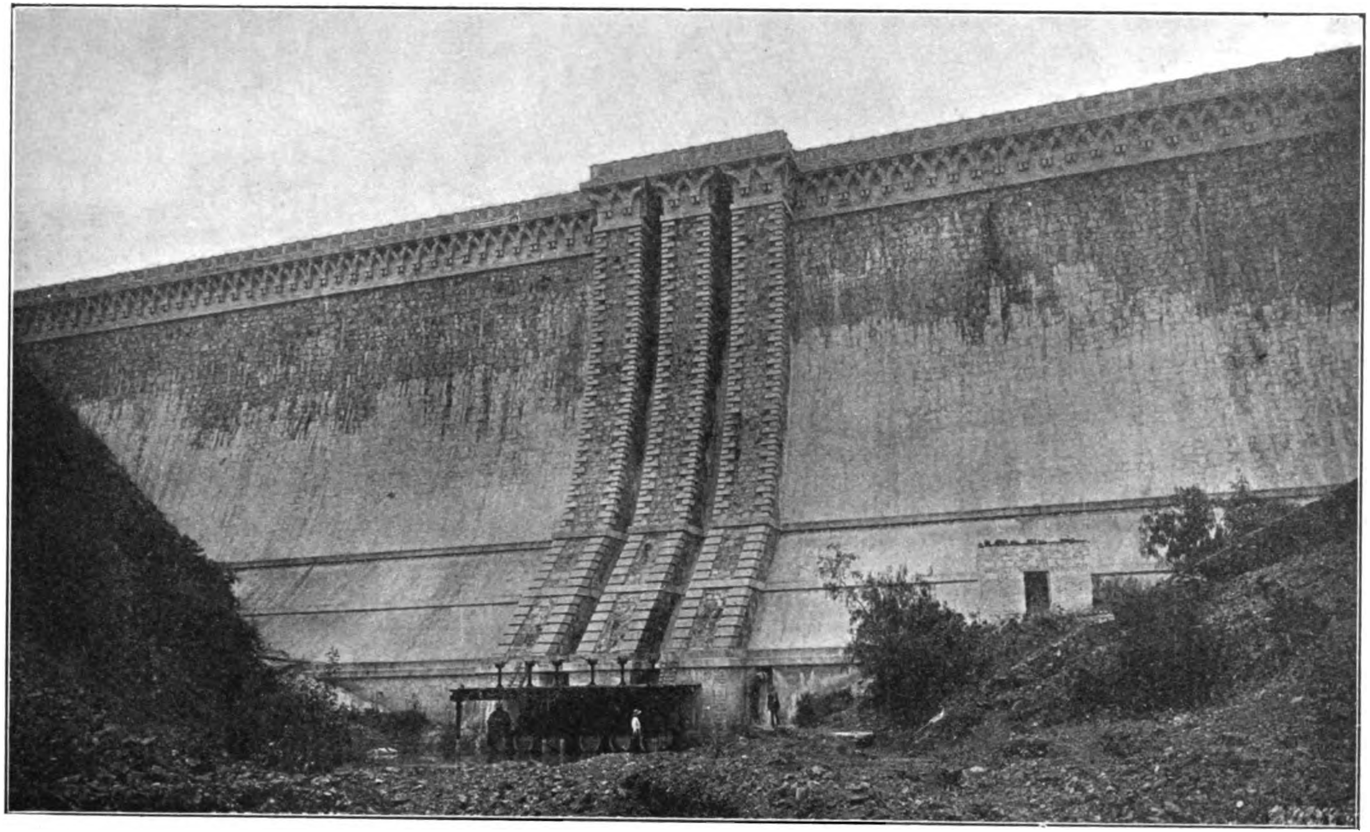


Fig. 124.—Upper Dam at Guanajuato, Mexico.

forming the bulkhead at the mouth of the sluice. The dam is located near the town of Elche, on the Rio Vinolapo.

**The Puentes Dam, Spain.**—This structure is noted because it was of unusual height and massiveness, and yet failed by reason of its having been founded on piles driven into a bed of alluvial soil and sand instead of bed-rock. It was erected in 1785 to 1791, on the Guadalantin River, at the junction of three tributary streams, and stood successfully for eleven years, during which time the depth of water never exceeded 82 feet, but in 1802 a flood occurred which accumulated a depth of 154 feet in the reservoir, and produced sufficient pressure to force water through the earth foundation. The reservoir was emptied in an hour, the pipe foundation was washed out, and a breach in the masonry, 56 feet wide, 108 feet high, was created, destroying the dam and leaving a bridge arching over the cavity. The extreme height of the dam was 164 feet, and its crest length was 925 feet; its thickness at base was 145.3 feet, and at top 35.72 feet. The extreme pressure on the masonry was computed by M. Aymard at 8.12 tons per square foot. It was built of rubble masonry, with cut-stone facings, and was polygonal in plan, with convexity up-stream. Water was taken from it through two culverts, one near the base, and the other 100 feet from the top. These were 5.4 feet wide, 6.4 feet high, and connected with masonry wells having small inlet-openings from the reservoir. A scouring-sluice, 22 feet wide, 24.7 feet high, was also provided through the dam, divided by a pier into two openings at its mouth to shorten the span of the timbers that closed it. At the time of the break the mud deposited in the reservoir was 44 feet deep.

The disaster caused the loss of 608 lives and the destruction of 809 houses. The property loss was estimated at $1,045,000.

The dam is reported to have been recently restored, and was doubtless extended to bed-rock for its foundation.

**Val de Infierno Dam, Spain.**—This dam is 116.5 feet high, and founded on rock. It has an enormous section, the base width being 137 feet. Even within 15 feet of the top the thickness of the wall is over 97 feet. It was built for irrigation in 1785 to 1791, and is located on one of the branches of the Guadalantin River, above the Puentes dam. It is not now in service, and the reservoir has entirely filled with sediment. The scouring of the silt from the reservoir injured the property below, which led to the abandonment of the structure.

The scouring-sluice of the dam is 14.8 feet high, 9 to 12.3 feet wide.

**The Nijar Dam, Spain.**—This dam has a maximum height of 101.5 feet above the bed of the stream, and consists of a massive base of masonry, 144 feet thick, 70 feet high. On this the dam proper rests, having a base thickness of 67.6 feet. The upper face is vertical, and the down-stream face is built in high steps. The scouring-sluice, which is an appendage of all Spanish dams, is 3.3 feet wide by 7.2 feet high, closed at its upper end by a gate operated by a long rod extending to the top of the dam. The reservoir capacity formed by the dam is 12,570 acre-feet.

**The Lozoya Dam, Spain.**—The object of this structure, which was built about 1850 across the Rio Lozoya, was not to store water, but simply as a diversion-weir to supply a canal leading to the city of Madrid. Its height is 105 feet, top length 237.8 feet, and it consists of a wall of cut stone, straight in plan, having a thickness of 128 feet at base, backed up partially by a sloping bank of gravel. The canal is taken through a tunnel in the rock on the right bank, 22.4 feet below the top. A second tunnel, used as a scouring-sluice, is placed 7.5 feet lower than the canal, below which the reservoir is allowed to fill with sediment. A waste-weir is cut in the rock, on the left bank, 11 feet deep, 27.6 feet wide.

**The Villar Dam, Spain.**—In 1870–78 the Spanish Government constructed a second dam on the Rio Lozoya, to supplement the supply to Madrid by storage. The dam is 170 feet high, 547 feet long on top, 154.6 feet thick at base, 14.75 feet thick at the crest, which is 8.25 feet above the spillway level. The dam is modern in design, and has a gravity profile with large factor of safety. It is also curved in plan, on a radius of 440 feet. It is constructed of rubble masonry throughout, with the exception of cut-stone copings. Its cost was about $390,000. The capacity of the reservoir formed by it is 13,050 acre-feet. Two scouring-sluices are built through the dam and closed by gates that are operated by hydraulic power from a central tower.

**The Hijar Dams, Spain.**—Water is stored for irrigation on the Martin River, above the city of Hijar, Spain, by means of two masonry dams built in 1880. The general dimensions of each of these dams are about alike, the height being 141 feet, length 236 feet on top, thickness at base 147 feet, and at crest 16.4 feet. The water-face is vertical for 82 feet from the top, continuing with a vertical curve to the base. The outer face is in a series of steps below a point 29.5 feet from the top, each step being 6.5 feet high, 4.9 feet wide. Both dams are arched up-stream with a radius of 210 feet.

One of the reservoirs has a capacity of 8913 acre-feet, and a watershed of 17 square miles; the other impounds 4864 acre-feet, and receives the drainage from 92 square miles.

**The Gros-Bois Dam, France.**—This structure has been severely criticised because of the fact that it would be more stable to resist water-pressure applied from the lower side than the upper, and for the reason that it has an excess of masonry over what would be required if it were distributed in proper form; and yet it has but a small factor of safety, as was proven by the fact that it slid down-stream on its base about 2 inches, and was only relieved of strains that produced cracks and leaks by the addition of nine counterforts, 13 to 37 feet thick, projecting 26 feet from the base. The dam was originally built vertical on the down-stream face, and stepped on the waterside. Its height above bed is 73.2 feet, extreme height 92.9 feet; top length 1804.6 feet; thickness at base 45.9 feet, at top 21.32 feet. It is founded on argillaceous rock, rather soft. The dam was built in 1830–38, on the Brenne River, for feeding the navigable canal of Bourgogne.

**The Chazilly Dam** was constructed after the general type of the Gros-Bois dam, and on the same profile. It is on the Sabine River, near the city of Chazilly, and is 1758.6 feet long, 73.8 feet high, 53 feet thick at base, 13.4 feet at crest.

**The Zola Dam,** designed by the father of the noted novelist, is one of the few dams depending solely upon their arched form for their stability. It is 119.7 feet high, 48.8 feet thick at base, 19 feet thick at top, and 205 feet long on the crest, which is surmounted by a parapet 4 feet high. The gorge has a width of but 23 feet at the base of the dam. The radius of the arch is 158 feet at the crown. The water-face has three steps or offsets from the vertical and the profile is quite erratic and irregular. It forms a reservoir for supplying the city of Aix with water, and was built about the year 1843. It is made of rubble masonry, founded on rock.

**The Furens Dam.**—Among many engineers this famous dam is recognized as a model of correct form, profile, and dimensions, whose outlines conform closely to what are accepted as certainly safe and well-balanced proportions throughout, even though the volume of material may be slightly excessive. It was built by the French Government in 1862 to 1866 for the purpose of controlling the floods of the Furens River and protecting the town of St. Etienne from inundations.

The dam is 183.7 feet in extreme height on the down-stream side, 170.6 feet in height on the up-stream side, and carrying a maximum depth of 164 feet of water. Its base thickness is 165.8 feet, and it is 16.4 feet thick at a depth of 21 feet below the top. The crest is 12.4 feet wide, and is used as a carriage-road; the top length is 326 feet. The dam was four years in building, construction being limited to six months each season, owing to the altitude and to the severity of the winter weather. Each year, while building, the water was allowed to flow over the top of the finished masonry, and when completed no leakage was visible further than a few damp spots on the lower side with full reservoir.

The dam contains 52,300 cubic yards of masonry, and cost $318,000, of which the city of St. Etienne paid $190,000 for the privilege of the storage for its domestic supply. The rock used was mica-schist. Notwithstanding its safe gravity profile the dam was curved up-stream, with a radius of 828 feet for architectural effect. The volume of water stored by this great dam, the highest in existence, is comparatively insignificant, being but 1297 acre-feet (422,625,000 gallons). M. Graeff, Chief Engineer of the Department of the Loire, and M. Delocre designed the dam, and M. Montgolfier was engineer in charge of construction.

**The Ternay Dam.**—Located on the river Ternay, in the province of Ardèche, southern France, this dam was erected in 1865 to 1868, for controlling floods and supplying the neighboring town of Annonay. It is constructed of granite rubble masonry, and is founded on bed-rock of granite. The proportion of mortar in the work was 40%. In plan it is curved with a radius of 1312 feet, while the profile is a gravity type, resembling that of the Furens dam. The extreme height is 119 feet, and bottom thickness 89.2 feet. The up-stream face is vertical for 58.5 feet, and battered below that point. The lower face is chiefly formed in a vertical curve of 147.6 feet radius, reaching from the water-level to within 30.5 feet of the bottom, the slope to the base being tangent to the curve. The center of the circular curve is 7.5 feet above the crown of the dam.

The dam was designed and built by M. Bouvier, Engineer des Ponts et Chaussées, under the general direction of J. B. Krantz, Chief Engineer. The profile of the dam, however, is considerably lighter than the type recommended by M. Krantz in his "Study on Reservoir Walls," which form resulted from his adherence to a limiting pressure of 6 kilograms per square centimeter (85 lbs. per square inch) upon any portion of the masonry, whereas the maximum pressures in the Ternay dam are estimated to be 9 kilos per square centimeter. M. Krantz comments, however, on the Ternay dam as follows: "The reservoir wall of Ternay, which was remarkably planned and built by M. Bouvier, has, in my opinion, scarcely a defect."

The capacity of the reservoir back of the dam is 686,766,000 gallons (2107 acre-feet). The total cost of the dam was $204,372.

**The Vingeanne Dam, France.**—This structure resembles the Ternay in height and general form, being 113.8 feet high, 18.1 feet thick at base, 11.5 feet on top. It is located near the town of Baissey, and was built in 1885.

**The Ban Dam, France.**—Next to the Furens dam in height the reservoir wall constructed in 1867 to 1870, near the city of St. Chamond, was built upon the same general principles, except that a greater maximum pressure was permitted upon the masonry, the computed extreme being 8.18 tons per square foot. Its extreme height is 157 feet, length 512 feet, base thickness 127 feet, top width 16.4 feet. The wall is battered or curved on both sides, there being no vertical faces. In plan it is curved convex up-stream. It is composed of rubble masonry founded on rock. It is used for the supply of the city of St. Chamond, and its cost was $190,000.

**The Verdon Dam, France.**—This structure is not of great height, being but 59 feet, but its construction presented great difficulties, owing to the volume of water carried by the Verdon River, and the narrow canyon in which it was placed. The low-water flow is 350 second-feet, while in floods the discharge reaches over 4200 second-feet. The dam had to be founded on rock, after excavating 20 feet through gravel and bowlders; and as the canyon is but 130 feet wide at the top of the dam and considerably less at the water-level, there was little room to do the work and take off the constant flow.

The dam is used for diverting water to a canal, supplying the city of Aix and other places in the vicinity. The dam proper is curved up-stream with a radius of 108.8 feet, resting on a rectangular base of concrete. The masonry consists of rubble with cut-stone facings. The general dimensions are:

| | |
|---|---|
| Length on top | 131.3 feet. |
| Thickness of base | 32.5 " |
| Thickness of crest | 14.2 " |
| Height above river-bed | 40.2 " |
| Height above foundations | 59.0 " |

The concrete foundation has a thickness of 48 feet. This is protected from the falling water by an embankment of large blocks of loose stone. The maximum depth of overflow was estimated at 16.4 feet.

**The Pas Du Riot Dam, France.**—Subsequent to the construction of the Furens dam, a second storage-reservoir for the further supply of the city of St. Etienne was built in 1872 to 1878 to the height of 113.2 feet, curved in plan, and similar in profile to its greater neighbor. The reservoir formed by it has a capacity of 343,380,000 gallons (1054 acre-feet). The cost of the dam was $256,000.

**The Cotatay Dam, France.**—In 1885 a dam was built on the Cotatay brook near the city of St. Etienne to supply the city of Chambon-Fengerolles. This also is of the Furens type, curved in plan, and of the same height as the Pas Du Riot dam—113.2 feet.

**The Pont Dam, France.**—This structure, of granite rubble, founded on rock, has a maximum length of 495 feet and an extreme height of 85 feet. It is curved in plan, with a radius of 1312.4 feet. The base thickness is 62 feet, and crest 16.4 feet. The water-face batters 4.2 feet in its total height.

On the lower face, from the top down for 62.3 feet, is a vertical curve, whose radius is 98.4 feet. The remaining height has a batter tangent to this curve. Nearly 20 feet of the base of the dam is below the river-bed. Seven counterforts or buttresses, 16 feet long, 3 feet thick, help sustain the dam. The dam was built in 1883 on the Armançon River, 2½ miles from the city of Semur.

**The Chartrain Dam, France.**—The profile of this modern structure, built in 1888–92, is one of the most graceful and scientific in design of all of the French dams of recent construction. It has a maximum height above lowest foundations of about 180 feet, and a base width on top of foundations of 135 feet, the foundations extending above and below the toes of the wall to a total width of 156 feet.

The dam is located on the river Tache, and was built to store water for the supply of the city of Roanne. The reservoir, however, is quite small for so high and costly a dam, covering but 54.36 acres in area and impounding 3647 acre-feet to a mean depth of 67 feet, or 41% of the maximum depth.

The cost of the dam was $420,000, or $115.10 per acre-foot of storage capacity.

**The Bousey Dam, France.**—The failure of this structure April 27, 1895, with the loss of one hundred and fifty lives and the destruction of much property, has particularly emphasized the value of several features of masonry dams which may be regarded as essential in the design of all such works:

1st. That they be founded on impermeable bed-rock, and the possibility of upward pressure from water passing through fissures be avoided.

2d. That they shall have a profile of such dimensions as to permit of no tension in the masonry.

3d. That the masonry shall be practically impervious to water.

4th. That it be curved in plan to avoid temperature cracks and movements as the result of expansion and contraction of the masonry.

The Bousey was lacking in all of these essential features, and its failure was not surprising in the light of all the facts that have been published regarding it.

It was built in 1878 to 1881, near Epinal, France, across the small stream of Avière to form a storage-reservoir of 1,875,000,000 gallons for supplying the summit level of the Eastern Canal, which here crosses the Vosges Mountains in connecting the rivers Moselle and Saône, this canal being a connecting link in interior navigation between the Mediterranean and the North Sea. The reservoir was fed by an aqueduct from the Moselle River. The reservoir covered an area of 247 acres. The general dimensions of the dam are as follows:

| | | |
|---|---|---|
| Length on top | 1700 | feet. |
| Height above river-bed | 49 | " |
| Height above foundations | 72 | " |
| Width on top | 13 | " |
| Width 36 feet below water-level | 18 | " |

The wall was vertical on the water-face from top to bottom.

The masonry was founded on red sandstone, which in places was fissured and quite permeable, with springs which gave trouble in constructing the foundations. The foundation was not excavated to solid, impermeable rock under the entire dam, but an attempt was made to remedy this deficiency by building what was called a "guard-wall," 6.5 feet thick on the upper side of the dam, extending down below the foundations through the imperfect rock for the purpose of cutting off leakage underneath. This was carried up to the river-bed and lapped against the main wall. The dam was completed in 1880, and the following year water was admitted. When it had reached about one-third the height, 33 feet below the top, enormous leakage, amounting it is said to 2 cubic feet per second, appeared on the lower side of the dam, partly due to two vertical fissures or expansion-cracks in the wall. March 14, 1884, when the water had risen to within 10.4 feet of the top, the pressure was sufficient to bulge the wall forward for 444 feet, forming a curve convex down-stream, the extreme movement being from 1 to 3 feet according to different authorities. Four additional fissures then appeared, and the leakage increased to about 8,000,000 gallons per day. These cracks opened in winter and closed in summer. The water was kept behind the dam and the following year allowed to rise to within 2 feet of the top, after which it was drawn off, when it was discovered that for 97 feet the dam had been shoved forward, separating from the guard-wall, and numerous cracks were found on the inner face. Extensive repairs were then undertaken. The joint between the main wall and the guard-wall was covered with masonry and surrounded by a bank of puddle, 10 feet thick, while a heavy, inclined buttress-wall was built at the lower toe, deep into the bed-rock, and toothed into the masonry of the dam to prevent the tendency to slide on its base. This abutment was nearly 20 feet in height, and its base was 84.3 feet below the top of the dam, making the total thickness of base 71.6 feet. Notwithstanding all this work the dam was fatally weak at a point near the river-bed level, where the line of resistance falls considerably outside the middle third, and the final break occurred at a point about 33 feet below the top, where the fracture was almost horizontal longitudinally, and 594 feet of the central part of the dam was overturned. The break was level transversely for about 12 feet and then dipped toward the outer face. The repairs finished in 1889 were presumed to have made the dam safe, and the break did not occur for six years afterwards, during which time the action of temperature-changes is presumed to have produced the weakness resulting in the final catastrophe. An interesting account of the failure of the dam was published in *Engineering News*, May 16 and 23, 1895. The lesson taught by it will be serviceable to engineers the world over.

**The Mouche Dam, France.**—The purpose of this structure, completed in 1890, is similar to that of the Bousey dam—to form a storage-reservoir for feeding a navigable canal. It is located on the Mouche River, near the village of St. Ciergues, and forms a reservoir of 241.8 acres, having a mean depth of 29 feet and impounding 7010 acre-feet. The general dimensions are as follows:

| | | |
|---|---|---|
| Length on top.............................. | 1346 | feet. |
| Maximum height, lowest foundation to parapet. | 114.5 | " |
| Height, base to water-line.................... | 94.5 | " |
| Width of base............................. | 66.7 | " |
| Width of top.............................. | 11.6 | " |

The up-stream face has a batter of 1 foot in 50, while the down-stream batter is nearly 1 to 1.

The dam is straight in plan and carries a roadway over the top, nearly 25 feet wide, supported by arches resting on abutment-piers that give the required extra width. There are forty of these arches, each with a span of 26.2 feet.

The masonry was found experimentally to weigh 134.2 lbs. per cubic foot, and the computations of the profile were made on that basis, preserving the lines of pressure, reservoir full and empty, well within the center third.

The excavations for foundation were required to be so deep to reach bed-rock that 56% of the masonry is laid below the surface, the maximum depth of excavation being about 40 feet. The water-face of the dam was given three coats of hot pitch, and subsequently whitewashed.

**The Gileppe Dam, Belgium.**—No masonry structure of modern times has so great a section as this, and few if any contain such an enormous mass of masonry, the total volume of which is 325,000 cubic yards, all of which was put in place in six years, from 1870 to 1875 inclusive. The dam is most imposing in appearance, but it has a vast excess of masonry beyond safe requirements, the effect of which is to place additional stress upon the foundation masonry without increasing the stability. The principal dimensions are as follows:

| | | |
|---|---|---|
| Maximum height............................ | 154 | feet. |
| Length on top.............................. | 771 | " |
| Breadth on top............................. | 49 | " |
| Breadth at base............................ | 216.5 | " |

The dam is curved up-stream on a radius of 1640 feet. It was designed by M. Bidaut, Chief Engineer, who occupied nine years in the preliminary studies before plans were submitted to the Belgian Government, by whom it was erected to regulate the flow of the Gileppe River and provide a pure-water supply for the cloth manufactories at the city of Verviers.

The reservoir formed by the dam covers an area of 198 acres and impounds 3,170,000,000 gallons, or 9730 acre-feet. The mean depth is 49 feet, or just one-third the maximum depth. The capacity of the reservoir is about one-half the average annual run-off from 15.4 square miles of watershed.

The masonry is rough rubble throughout, of sandstone quarried on the spot. The dam is surmounted by a cyclopean statue of a lion sitting on a pedestal. An ample carriageway is provided across the dam.

Considering the great thickness of the wall and the care taken in its construction, it was a great disappointment to find on filling the reservoir that it leaked quite considerably. This leakage gradually diminished and is of no importance as affecting the stability of the dam.

The entire cost of the dam was $874,000, or $89.83 per acre-foot of storage capacity.

**The Remscheid Dam, Germany.**—This structure is one of the best existing types of reservoir-walls as they are designed and built by modern German engineers, and possesses more than ordinary interest. It is 82 feet high, 49.2 feet thick at base, 13.1 feet thick at crown, and is curved in plan, with a radius of 410 feet. The total contents of the dam are 22,886 cubic yards, and its cost is given at $91,154, an average of $3.98 per cubic yard. The reservoir formed by it has a capacity of 35,310,500 cubic feet, of 811 acre-feet; while its average cost was $112.45 per acre-foot of storage capacity.

The dam is built across the Eschbach valley, and is designed to supply the city of Remscheid, and manufacturers in the valley below. It was begun in May, 1889, and water turned on November, 1892. It is composed of rubble masonry, the stone, a hard slate, being laid in trass mortar. Trass is a rock of volcanic origin, from which hydraulic lime is made resembling pozzuolana, used so extensively in Italy. The mortar consists of one part lime, one and one-half parts trass, and one part sand, and was preferred by the engineer to Portland cement, because it sets more slowly and tests showed it to be superior in point of elasticity. The dam has shown no settlement, no cracks, and no leaks. The courses of masonry were laid so as to be as nearly perpendicular as possible to the varying direction of the resultant pressures at all points. The water-face of the dam was plastered with cement mortar, over which two coats of asphalt were placed, the asphalt extending 20 inches over the bed-rock. Then a brick wall, 1½ to 2½ bricks thick, was carried up outside, tight against the asphalt.

The dam was designed and built by Prof. O. Intze, and described in a paper published in the *Journal of the Society of German Engineers,* from which the facts above given are gleaned.

**The Einsiedel Dam, Germany.**—This dam was completed in 1894, and forms a reservoir for supplying the city of Chemnitz. It is composed of rubble masonry, the total volume of which was 31,600 cubic yards. Its maximum height above foundation is 92 feet, of which 65 feet is above the natural surface. The length over top is 590 feet, top thickness 13 feet, base 65.5 feet. It is curved to a radius of 1310 feet. The storage capacity of the reservoir is 95,000,000 gallons (291 acre-feet).

**The Gorzente Dam, Italy.**—The city of Genoa derives a water-supply from a reservoir formed by a masonry dam, built in 1882, on the Gorzente River. The reservoir capacity is 748,800,000 gallons (2298 acre-feet), covering 64 acres. The dam has a maximum height of 121.4 feet, and is 492 feet long on top, 23 feet thick at top, 99.6 feet thick at base. The masonry is a rubble composed of serpentine rock and mortar of Casale lime and serpentine sand.

**Cagliari Dam, Italy.**—This structure is located on the island of Sardinia, 13 miles from the city of Cagliari, on the Corrungius River. It was built in 1866, and is 70.5 feet high, 52.5 feet thick at base, 16.4 feet at top, and 344.5 feet long on top. It is built of rubble masonry composed of granite and a hydraulic lime mortar, mixed with clean, well-washed, granitic sand.

**The Vyrnwy Dam, Wales.**—Since July 14, 1892, the city of Liverpool, England, has been chiefly supplied by water from a large storage-reservoir in the mountains of Wales, 77 miles distant, formed by a monumental dam of masonry erected across the Vyrnwy valley, in 1882 to 1889. The dam has a top length of 1172 feet, is straight in plan, and has a maximum height of 161 feet from foundation to parapet. It is used as an overflow-weir over its entire length, and its profile was designed to offer additional resistance over that presented by water-pressure alone. An elevated roadway is carried across the dam on piers and arches, above the level of flood-water, which adds greatly to the architectural effect and ornamentation of the imposing mass of masonry. The great wall is composed of cut stone. The base width of the dam is 117.75 feet. The back-water level below the dam is 45 feet above its base.

The total volume of masonry in the dam is 260,000 cubic yards, which was laid with such extraordinary care that its average cost was nearly $10 per cubic yard, in a country where materials and labor are of the cheapest.

The base of the dam is founded on a hard slate rock, and one end of the masonry is built into the solid wall of bed-rock on the side of the valley. At the other end, however, the rock was so deeply overlaid with a deposit of bowlder clay that the masonry was connected with this material by a puddle-wall of clay recessed into the masonry.

The general dimensions of the dam are as follows:

| | |
|---|---|
| Total length on top | 1172 feet. |
| Maximum height on top of roadway parapet | 161 " |
| Height, river-bed to parapet | 101 " |
| Height, river-bed to overflow-level | 84 " |
| Greatest width of base | 120 " |
| Batter of water-face | 1 to 7.27 " |

The cost of the dam is given as follows:

| | |
|---|---|
| Borings and preliminary work | $34,600 |
| Excavating 220,820 cu. yds. and backfilling 79,501 cu. yds | 287,600 |
| Puddle-wall, including excavation | 16,800 |
| Masonry and brickwork | 2,532,000 |
| Regulating and gauging plant | 46,000 |
| Basin and other work below dam | 40,000 |
| Total for dam proper | $2,957,000 |

In addition to this the removal of a village in the basin, the building of roads around the lake, culverts, fencing, planting, dressing slopes, and erection of superintendent's house cost $377,000, or a total of $3,334,000.

The reservoir formed by the dam covers a surface area of 1121 acres, and impounds 12,131,000,000 Imperial gallons, or 44,690 acre-feet. This gives a mean depth of 39.87 feet, or 47.5% of the maximum. The watershed area is 29 square miles, upon which the minimum recorded rainfall is 49.63 inches, and the maximum 118.51 inches.

The average cost of the dam per acre-foot of storage capacity formed by it was $74.61.

The dam was planned and constructed by Geo. F. Deacon, Chief Engineer, Liverpool Water-works. Messrs. Thos. Hawkesley and J. F. Bateman were consulting engineers.

Tests made by Kirkaldy of large blocks of the concrete and masonry taken from the dam showed a compressive strength of 300 tons per square foot, while the maximum strains to be borne by it are but 9 tons per square foot, an excess of strength which has been considerably criticised.

**The Habra Dam, Algiers.**—The French Government has built, or encouraged the construction by private parties of, a number of notable storage-reservoirs for irrigation in Algiers, of which the largest was that formed on the Habra River, by a masonry dam, whose disastrous failure has made it well known among the engineering profession, and added to the many lessons which such failures carry with them. The dam was begun in November, 1865, completed in May, 1873, and after eight years of service was ruptured in December, 1881, causing the loss of 209 lives and the destruction of several villages.

The main dam was straight in plan and 1066 feet long on top, flanked by an overflow wall, 410 feet long, making an angle of 35° with the direction of the dam, the top of which was 5.2 feet below the crest of the dam proper.

The maximum height of the dam was 117 feet from foundation to the water-line, above which a parapet extended 8 feet higher. The dam was 14 feet thick at top, 88.4 at base, battered on both sides and of ample dimensions to withstand the water-pressure, provided the masonry had been properly constructed and of first-class material. When completed and first filled the dam leaked like a gigantic filter, but the leakage practically ceased in course of time.

The reservoir formed by the dam had a capacity of thirty million cubic meters, or 24,330 acre-feet. The watershed of the Habra River is very extensive, covering 3859 square miles above the dam, from which the annual discharge, however, was only about 3½ times the capacity of the reservoir, owing to the slight rainfall of that region. The summer flow was about 18 second-feet, and the normal winter flow was about 100 second-feet, while extreme floods reached 25,000 second-feet in volume. The flood which caused the rupture of the dam came from a rainfall of 6½ inches in one short storm, during which the run-off in one night was computed at 3,500,000,000 cubic feet, or more than three times the reservoir capacity. This resulted in a general overflow of the crest of the wall, as the spillway was of insufficient capacity, and produced such excessive pressure upon the outer face of the masonry as to exceed its normal strength. Over 300 feet of the wall was torn out to the very foundation.

In a paper on the subject written the following year by the eminent Italian engineer, G. Crugnola, he attributes the failure to inferiority in the quality of the masonry. The sand was not of good quality, and in the center of the dam a red earth, containing 22 to 24 per cent of clay, was used instead of sand. Furthermore, the mortar was made of hydraulic lime burned from calcareous rock found on the banks of the river, which, though hydraulic, was not very good. The inference drawn by M. Crugnola is that the hydraulic lime contained a quantity of quicklime, which expanded in time, causing porosity if not actual cavities in the interior of the masonry. The stone, as well as the mortar, was extremely porous, consisting chiefly of calcareous Tertiary grit, which was of variable hardness, some having a decided schistose structure.

One must conclude from all the facts that had the spillway been sufficient in capacity to avoid the submersion of the dam, and had the face of the wall been made absolutely water-tight by such precautionary measures as were employed on the Remscheid dam, the failure would not have occurred. The curvature of a wall of the great length of the Habra would doubtless have avoided temperature cracks, which, as has been pointed out by Prof. Forchheimer (page 122), may have been a leading source of weakness. The failure occurred during the coldest weather, when such cracks appear in masonry walls.

**The Hamiz Dam, Algiers.**—Next in importance to the Habra dam, and somewhat higher, is the Hamiz dam, erected in 1885 on the Hamiz River. This wall is also straight in plan, but only 532 feet in length on top, 131 feet long at base. The extreme height above foundation is 134.5 feet, and above river-bed 91.2 feet, and at top 16.4 feet. Both faces are curved in outline.

The dam impounds 10,500 acre-feet of water, gathered from a shed of 54 square miles.

**The Gran Cheurfas Dam, Algiers.**—This structure is quite similar in dimensions to the Hamiz dam, and was built in 1882–84, on the Mekerra River, 9 miles from St. Dionigi. Its foundation extends 32.8 feet below the river-bed, and has a thickness of 134.5 feet at base and 78.7 feet at top. On this foundation the dam proper rests, with an offset of 3¼ feet on each side, making its thickness at bottom 72 feet, while at top the wall is 13 feet thick. Both faces are curved in parabolic form, presenting a graceful profile. The maximum pressures on the masonry are 6.1 tons per square foot.

The dam failed in part when first filled, and a breach of 130 feet was made in the wall, but it was immediately repaired. The failure occurred in winter. The dam is straight in plan.

The reservoir capacity behind the dam is about 13,000 acre-feet.

**The Tlelat Dam, Algiers.**—This masonry wall is 69 feet high, 325 feet long, 40 feet thick at bottom, 13 feet thick at top, and impounds 445 acre-feet, derived from a water-shed of 51 square miles. The dam was erected in 1869 on the Tlelat River to supply the town of Sante Barbe, 7½ miles below, and also for irrigation. The wall is vertical on the water-face, while the lower side has a vertical curve, the center of radius being 11.8 feet above the top of the dam.

**The Djidionia Dam, Algiers,** is 83.7 feet in extreme height, of which 28 feet is foundation below the river-bed level. The face is vertical, and the dam is straight in plan. The foundation is broader on top than the bottom of the dam, and will permit of an increased height in the structure by adding to the lower side from the foundation up. This has been decided upon, and 26 feet additional in height will be built. The reservoir will then have a capacity of about 4000 acre-feet. The dam was built in

1873–75, on the Djidionia River, to supply the towns of St. Aimé and Amadema with water. The masonry of this dam is slightly in tension on the water-face when the reservoir is filled, amounting to about 15 lbs. per square inch, but no injurious effect upon the masonry is apparent from this small tensile strain.

**The Tansa Dam, India.***—This great dam, forming a reservoir for the supply of Bombay, was begun in 1886, and completed in April, 1891. The work was done by contract and cost $988,000. It is straight in plan, the alignment consisting of two tangents, and it has a total length of 8800 feet, the maximum height being 118 feet. For a length of 1650 feet the dam is depressed 3 feet, to serve as a waste-weir. The thickness of the masonry at the base is 96.5 feet, and the entire section is made of sufficient dimensions for an ultimate height of 135 feet, to which it may be raised in future, when its length will be 9350 feet on top.

The dam was built with native labor, and consists of uncoursed rubble masonry throughout, all the stones being small enough to be carried by two men. The stone is a hard trap-rock, quarried on the spot. The cement was burned at the site of the dam from nodules of hydraulic limestone, called kunkur, which are found throughout India, and occur in clay deposits, although in this case it had to be brought long distances by rail and carts. Most Indian masonry is made with kunkur hydraulic lime. The nodules require to be exposed to the sun, dried and washed before being burned. They are usually of one or two pounds weight, although sometimes found in blocks of 100 lbs. or more.

From 9000 to 12,000 men were employed on this dam during the working season of each year, from May to October, but during the monsoons all work was suspended.

The volume of masonry in the work is 408,520 cubic yards. It is reported to be entirely water-tight. The excavation was carried to a considerable depth in places, and necessitated the removal of 251,127 cubic yards for the foundations.

The reservoir covers an area of 5120 acres and impounds 62,670 acre-feet above the level of the outlets, which are placed 25 feet below the crest of the spillway, or 89 feet above the river-bed. The loss by evaporation reduces the available supply to 15,870 acre-feet, although of course many times this quantity could be drawn from the lake if the outlets were near the bottom. The watershed area is 52.5 square miles, on which the precipitation is from 150 to 200 inches annually, and the estimated annual run-off is 267,000 acre-feet.

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* See Proceedings Institution of Civil Engineers, vol. cxv. Paper by W. J. C. Clerke, M.I.C.E., on "The Tansa Works for the Water-supply of Bombay"; also, "Irrigation in India," by Herbert M. Wilson, 12th Annual Report U. S. Geological Survey.

The dam was planned and built by W. J. C. Clerke, Chief Engineer.

**The Poona or Lake Fife Dam, India.***—This was one of the first masonry dams built in India by the British Government for irrigation storage, and was begun in 1868. It is made of uncoursed rubble masonry, founded on solid bed-rock, and is straight in plan, having a top length of 5136 feet (nearly a mile), of which 1453 feet is utilized as a wasteway. Its maximum height above foundation is 108 feet, and above the river-level 98 feet.

The design of the dam is extremely amateurish. The up-stream batter is 1 in 20, and the down-stream slope 1 in 2, unchanged from top to bottom, the top width being 14 feet, and the base 61 feet. The alignment of the dam is in several tangents with different top width for each, according to its height, the points of junction being backed up by heavy buttresses of masonry. When completed the dam showed signs of weakness and was strengthened by an embankment of earth, 60 feet wide on top, 30 feet high, piled up against the lower side.

The water is drawn from the reservoir 59 feet above the river-bed, and there is therefore available but 29 feet of the total depth of the reservoir. The amount available above this level is 75,500 acre-feet. The lake is 14 miles long and covers an area of 3681 acres.

The dam is located 10 miles west of the town of Poona, on the Mutha River. Its cost was $630,000, and it contains 360,000 cubic yards of masonry.

The canal on the right bank is 23 feet wide, 8 feet deep, and 99.5 miles long, drawing 412 second-feet from the reservoir and distributing it over 147,000 acres of land to be irrigated. At the town of Poona a drop of 2.8 feet is utilized for power by an undershot wheel, to pump water to supply the town. The left-bank canal is 14.5 miles long and carries 38 second-feet. The sluices from the reservoir are each 2 feet square, closed by iron gates operated by capstan and screw from the top of the dam. Ten of these supply the larger canal, and three discharge into the smaller one. Eight additional circular sluices, 30 inches in diameter, supply water to natives for mill-power and discharge into the larger canal.

**The Bhatgur Dam, India.**†—There are no masonry structures in the United States or Europe which surpass in size those of India which have been constructed for irrigation purposes by the British Government, in the attempt to render the great population of that country self-supporting

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* "Irrigation in India," by H. M. Wilson, in 12th Annual Report U. S. Geological Survey.

† *Ibid.*

and check the frightful famines by which it has been periodically devastated.

The Bhatgur dam, constructed on the Yelwand River, about 40 miles south of Poona, is one of the most notable of these great structures. Its length on top is 4067 feet, its extreme height above foundations is 127 feet, and it forms a reservoir 15 miles in length, having a capacity of 126,500 acre-feet. The extreme bottom width of the dam is 74 feet, and the crest is 12 feet wide, forming a roadway. The alignment of the dam curves in an irregular way across the valley, so as to follow the outcrop of bed-rock on which it is founded. The section of the dam was designed after a formula similar to that deduced by M. Bouvier, and all the calculations were worked out by Mr. A. Hill, M.I.C.E., who was afterwards assistant on the construction of the Tansa dam. The curve adopted for the lower face was a catenary, but the wall was actually built in a series of batters.

The three primary conditions of the design were:

1st. The intensity of the vertical pressure was nowhere to exceed 120 lbs. per square inch (8.64 tons per square foot);

2d. The resultant pressures were to fall within the middle third of the section; and

3d. The average weight of the masonry was assumed at 160 lbs. per cubic foot. The use of concrete was only permitted where the pressure was calculated not to exceed 60 lbs. per square inch, which gave a factor of safety of between 6 and 7.

The dam was designed and built by J. E. Whiting, M.I.C.E.

Waste-weirs at each end of the dam have a total length of 810 feet, and can carry 8 feet depth of water. The roadway is carried over these weirs on a series of 10-foot arches. Additional flood-discharge is given by twenty under-sluices, $4 \times 8$ feet in size (of which fifteen are located 60 feet below the crest), having a total capacity of 20,000 second-feet. These sluices are lined with cut stone, and closed by iron gates, operated from the top of the dam. The overflow wasteway is closed by a novel series of automatic gates that open in flood and rise up into position as the flood recedes, permitting the full storage of the additional 8 feet depth to be utilized. The gates are nicely balanced by counterweights that occupy pockets in the masonry. As the water rises to the top of the gate it fills these pockets, reducing the weight of the counterpoises, and the gate, being then heavier, will descend below the crest of the weir. When the level of the flood is reduced so that it no longer enters the pockets, the latter are emptied by small holes in the bottom, and the counterpoises overcome the weight of the gates, lifting them into place again.

The reservoir is used to supply the Nira Canal, which heads 19 miles below. This canal is 129 miles long, 23 feet wide, 7.5 feet deep, and carries

470 second-feet, supplying 300 square miles of land. The water is diverted to it by a masonry diverting-dam, known as the Vir weir, which is of itself an important structure, being 2340 feet long, 43.5 feet high, constructed of concrete faced with rubble masonry. Its top width is 9 feet. Maximum floods of 158,000 second-feet pass over its crest to a depth of 8 feet, coming from a watershed of 700 square miles. A secondary dam, forming a water-cushion, is located 2800 feet down-stream. This is 615 feet long, 24 feet high, built of masonry founded on bed-rock, and carries a roadway over its crest. During maximum floods the water is 32 feet deep in the cushion, when the water is 8 feet deep over the main dam.

The works were finished in 1890–91.

**The Betwa Dam, India.***—This masonry structure forms a diversion-weir for turning the water of the Betwa River into a large irrigation-canal, and also serves for storage to the extent of 36,800 acre-feet, which is the capacity of the reservoir above the canal flow, although not all available.

The total length of the dam is 3296 feet, and its maximum height is 50 feet. It has an extremely heavy profile, being 15 feet thick at top and 61.5 feet at base. At its highest part the down-stream face is vertical, and a large block of masonry 15 feet thick reinforces the dam at its lower toe. It consists of rubble masonry laid in native hydraulic lime, with a coping of ashlar, 18 inches thick, laid in Portland-cement mortar.

In plan the dam is divided into three sections, of different lengths, by two islands, and is irregular in alignment.

The canal floor is placed 21.5 feet below the crest of the dam. A masonry subsidiary weir, 12 feet wide on top, 18 feet high, to form a water-cushion for the overflow of the dam, was built 1400 feet below, across the main channel, and a second subsidiary weir, 200 feet below the main weir, was made, to check the right-bank channel at the same level. The main dam and subsidiary weirs cost $160,000, not including the regulating and flushing sluices, which cost $10,000. The main canal is 19 miles long, and with its branches supplies 150,000 acres.

**The Periyar Dam, India.**—None of the modern structures for irrigation storage in India have presented greater difficulties than the great dam erected across the Periyar River, which was begun in 1888 and completed in 1897. The project, of which the dam was the basis, includes the construction of a wall to close the valley of the Periyar River to store 300,000 acre-feet of water; of the construction of a tunnel 6650 feet long, through the mountain-range dividing the valley of the Periyar from that of the Vigay River, for the purpose of drawing off the water of the reservoir, with the necessary sluices and subsidiary works for controlling the water on its way down a tributary of the Vigay; and finally the necessary works

* See "Irrigation in India," by H. M. Wilson, in 12th Annual Report, U. S. Geological Survey.

for the diversion, regulation, and distribution of the water for the irrigation of 140,000 acres in the Vigay valley, of which area the water-supply of the Vigay was only sufficient for irrigating 20,000 acres.

The dam is 155 feet high above the river-bed, with a parapet 5 feet higher, the foundations reaching to a depth of 173 feet below the crest. It is 12 feet thick at top and 114.7 feet at base, and is constructed throughout of concrete composed of 25 parts of hydraulic lime, 30 of sand, and 100 of broken stone. The water-face is plastered with equal parts of hydraulic lime and sand. The length of the dam on top is 1231 feet. Its cubic contents are about 185,000 cubic yards of masonry.

A wasteway has been excavated on each side of the dam, one of which is 420 feet long, and the other 500 feet long. The latter is partially formed by a masonry wall 403 feet long, filling a saddle-gap. The crests of these wasteways are 16 feet below the top of the parapet. The rock is a hard syenite. The maximum floods of the river reach 120,000 second-feet at times. The drainage-area above the dam is 300 square miles, on which the rainfall is from 69 to 200 inches, averaging 125 inches per annum.

The river is one that is subject to violent and sudden floods, in an uninhabited tract of country, far even from a village, some 85 miles from the nearest railway, where there were no roads or even paths, in the midst of a range of hills covered with dense forests and jungles tenanted by wild beasts, where malaria of a malignant type is prevalent, where the commonest necessaries of life were unobtainable, and where the incessant rain for half the year prevented the importation of labor and rendered all work in the river-channel impossible for six months out of every twelve. During the first two years of construction watchmen with drums and blazing fires had to guard every camp at night against the curiosity of wild elephants that constantly visited the works, uprooting milestones, treading down embankments, breaking up fresh masonry, playing with cement-barrels, chewing bags of cement and blacksmith's bellows, kneeling on iron buckets, and doing everything that mischief could suggest and power perform.

The limestone for making the hydraulic lime was brought a distance of 16 miles, surmounting an elevation of 1300 feet by an endless wire rope, 3 miles long, to which the stone was brought by wagon-road. From the lower end of the ropeway the stone was carried on a short tramway to canal-boats plying on the river as far down as the dam, the stream having been made navigable for this purpose.

The sand used was dredged from the river-bed.

This brief summary of the unusual conditions under which the dam was built, gleaned from a paper written by Mr. A. T. Mackenzie, A.M.I.C.E., gives a general idea of the extraordinary difficulties which had to be overcome in constructing this great work, which is certainly one of the most notable of the many monuments to English engineering in India.

The total cost of all the works connected with the project amounted to about $3,220,000. The estimated net revenues were $260,000 annually.

The dam was designed and constructed by Col. Pennycuick, Chief Engineer. It is so designed (by M. Bouvier's formulæ) that the greatest pressure on front and back shall not exceed 9 tons per square foot, and the lines of pressure are kept within the middle third. Most modern dams of any magnitude have been built of uncoursed rubble masonry. Col. Pennycuick justifies the use of concrete in the Periyar dam in the following language, as quoted by Mr. Wilson: "Concrete is nothing more than uncoursed rubble masonry reduced to its simplest form, and as regards resistance to crushing or to percolation the value of the two materials is identical, unless it be considered as a point in favor of concrete that it must be solid, while rubble may, if the supervision be defective, contain void spaces not filled with mortar. The selection depends entirely upon their relative cost, the quantities of materials in both being practically identical."

In this opinion of the value of concrete he is less conservative than the engineers of the Tansa dam, who limited the use of concrete to the upper portion of the dam, where the limit of pressure did not exceed 60 lbs. per square inch.

While the full reservoir capacity is 305,300 acre-feet, the level of the outlet-tunnel is such that but 156,400 acre-feet can be utilized, although this may be supplied several times annually.

**The Beetaloo Dam, South Australia.**—Like the Periyar dam in India and the San Mateo dam in California, this structure is composed entirely of concrete, of which about 60,000 cubic yards were used.

The dam was built in 1888–90, to form a reservoir of 2945 acre-feet capacity for irrigation and domestic water-supply.

The dam is 580 feet long on top, curved in plan, with a radius of 1414 feet, and designed after Prof. Rankine's logarithmic profile type. The maximum height is 110 feet, the base width being the same as the height. The thickness at top is 14 feet. The spillway is 200 feet long, 5 feet deep. The cost was $573,300.

Water is distributed entirely by pipes under pressure, some 255 miles of pipe from 2 to 18 inches diameter being required.

The dam was designed and built by Mr. J. C. B. Moncrieff, M.I.C.E., Chief Engineer.

**The Geelong Dam, Australia.**—This structure is also constructed wholly of concrete, made of broken sandstone and Portland cement, in the proportion of 1 of cement to 7½ of aggregates.

The dam is 60 feet high, 39 feet thick at base, and 2.5 feet on crest. It is curved in plan on a radius of 300 feet from the water-face at crest. The coping is formed of heavy bluestone of large size, cut and set in cement. The work was carried up evenly in courses a few inches thick, and thoroughly rammed. The surface of the finished concrete was wetted and coated with cement grout before adding a fresh layer to it.

The dam forms a reservoir for the supply of the city of Victoria. Water is drawn from it by two 24-inch pipes passing through the masonry, one of which is used for scouring purposes. The dam leaked slightly at the outset, but this leakage quickly disappeared.

**The Tytam Dam, China.**—This modern English structure was built to store water for the supply of Hong Kong. It is about 95 feet high, and is intended to go 20 feet higher. The present crest width is 21 feet, base about 65 feet. The water-face of the wall is almost vertical, the outer face being stepped in 10 feet vertical courses. The water-face is laid up in granite ashlar, the remainder being concrete, with stones of 2 to 6 cubic feet embedded. About 40% of the entire wall is composed of stone, and 60% of concrete. The screenings of crushed granite were used as sand, together with some river sand, which was scarce, and used without washing, as it was believed the rock dust and fine particles of soil would conduce to water-tightness. The strength of the mortar was less of a consideration than the securing of a water-tight wall.

**The Assuan Dam, Egypt.**—A dam is under construction at the present time across the Upper Nile, in Egypt, by English capitalists and English engineers, which in many respects is equal to the boldest and most extensive storage works constructed in India. The dam is intended to form a reservoir in the Nile valley, whose storage capacity is about 1,031,500 acre-feet, for the irrigation of a tract of 2500 square miles of land, located some 350 miles down the valley of the Nile below the dam. Water released from the reservoir travels down the Nile a distance of 330 miles to a point called Assiout, where a diverting-dam is being constructed to raise the water to the level of the canal.

The Assuan dam is to be about 6400 feet long, founded on granite rock throughout, and having a maximum height of 90 feet above foundations. The thickness of masonry at base will be about 80.4 feet, and the top width 23 feet, the crest being 9.84 feet above the estimated level of high water in the reservoir, and carrying a roadway. It is built of granite, uncoursed rubble, the stone being quarried from adjoining ledges of red syenite The wall will have one hundred and forty culverts or undersluices passing through it, each 23 feet high and 6.56 feet wide, and forty upper sluices, having one-half the area of the lower culverts. These are to be employed for the passage of extraordinary floods and the scouring of silt from the reservoir. All of the upper sluices and twenty of the lower ones will be lined with cast iron, and the remainder with cut-stone ashlar. The piers between sluices are 16.4 feet wide, with an abutment-pier at every tenth sluice, 39.37 feet wide.

The maximum floods of the Nile are estimated to discharge 490,000 second-feet, and a mean maximum of about 350,000 second-feet.

The sluices will all be opened during floods. The under-sluices will be regulated by Stoney's self-balanced gates. A navigation-canal will be taken around the west end of the dam, 5250 feet long, having four locks, with a total descent of 68.9 feet. This canal will be excavated partly in rock and partly formed by an embankment. It will be 49.2 feet wide on bottom. The dam and locks are estimated to cost $6,125,000, and are being built by English contractors, who agree to complete the work by July 1, 1903.

The dam was designed by Mr. W. Willcocks, M.I.C.E., in the service of the Egyptian Government.

**The Assiout Dam, Upper Egypt.***—In connection with the utilization of water stored in the great Assuan reservoir a diverting-weir is being erected across the Nile, below the head of the Ibrahimia Canal, which is estimated to cost $2,245,000, including the navigation-canal and locks.

This dam is also of masonry, and will have a total length of 3930 feet, and a maximum height of 48 feet. The dam will have one hundred and twenty sluices, each 16.4 feet wide, with piers 6.56 feet wide between them. The navigation-lock will be 262 feet long, 52.5 feet wide, capable of passing the largest steamers that ply on the Nile. It is located about 200 miles above Cairo. The head-works of the Ibrahimia Canal will cost $380,000.

The loss of water from evaporation and seepage in the Assuan reservoir, and in traversing the distance of 330 miles to Assiout, is estimated at about 21.5%, leaving 736,800 acre-feet as the net amount available for irrigation.

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* See *Engineering Record*, Dec. 30, 1899.

## CHAPTER IV.

### EARTHEN DAMS.

THE earliest constructions for water-storage of which there is historical record have been earthen dams erected to impound the water for irrigation. India and Ceylon afford examples of the industry of their inhabitants in the creation of storage-reservoirs in the earliest ages of civilization, which for number and size are almost inconceivable. Excepting the exaggerated dimensions of Lake Moeris in central Egypt, and the mysterious basin of "Al Aram," the bursting of whose embankment devastated the Arabian city of Mareb, no similar constructions formed by any race, whether ancient or modern, exceed in colossal magnitude the stupendous tanks of Ceylon. The reservoir of Koh-rud at Ispahan, Persia, the artificial lake of Ajmeer, or the tank of Hyder in Mysore, cannot be compared in extent or grandeur with the great Ceylonese tanks of Kalaweva or Padavil-colon. The first Ceylon tank of which there is historical record was built by King Pandu-waasa in the year 504 B.C. The tank of Kalaweva was constructed A.D. 459, and was not less than 40 miles in circumference. The dam or embankment of earth which formed it was more than 12 miles in length, and the spillway of stone is described by the historian Tennent as "one of the most stupendous monuments of misapplied human labor on the island." The same author describes the tank of Padavil as follows:

"The tank itself is the basin of a broad and shallow valley, formed by two lines of low hills, which gradually sink into the plain as they approach the sea. The extreme breadth of the enclosed space may be 12 or 14 miles, narrowing to 11 at the spot where the retaining bund has been constructed across the valley. . . . The dam is a prodigious work, 11 miles in length, 30 feet broad at the top, and about 200 feet at the base, upwards of 70 feet high, and faced throughout its whole extent by layers of squared stone. . . . The existing sluice is remarkable for the ingenuity and excellence of its workmanship. It is built of hewn stones varying from 6 to 12 feet in length, and still exhibiting a sharp edge and every mark of the chisel. These rise into a ponderous wall immediately above the vents which regulated the escape of the water; and each layer of the work is kept in its place by the frequent insertion, endwise, of long plinths of stone, whose extremities project beyond the surface, with a flange to key the several courses and prevent them from being forced out of their places. The ends of the retaining-stones are carved with elephants' heads and other devices, like the extremities of Gothic corbels; and numbers of similarly sculptured blocks are lying about in every direction. . . . On top of the great embankment itself, and close by the breach, there stands a tall sculptured stone with two engraved compartments, the possible record of its history, but the characters were in some language no longer understood by the people. The command of labor must have been extraordinary at the time when such a construction was successfully carried out, and the population enormous to whose use it was adapted. The number of cubic yards in the bund is upwards of 17,000,000, and at the ordinary value of labor in this country [England] it must have cost £1,300,000, without including the stone facing on the inner side of the bank. The same sum of money that would be absorbed in making the embankment of Padavil would be sufficient to form an English railway 120 miles long, and its completion would occupy 10,000 men for more than five years. Be it remembered, too, that in addition to 30 of these immense reservoirs in Ceylon, there are from 500 to 700 smaller tanks in ruins, but many still in serviceable order, and all susceptible of effectual restoration. . . . None of the great reservoirs of Ceylon have attracted so much attention as the stupendous work of the Giants' Tank (Kattucarré). The retaining-bund of the reservoir, which is 300 feet broad at the base, can be traced for more than 15 miles, and, as the country is level, the area which its waters were intended to cover would have been nearly equal to that of Lake Geneva, Switzerland (223 square miles). At the present day the bed of the tank is the site of ten populous villages, and of eight which are now deserted."

It was but recently discovered that the reason why the great reservoir was never utilized after having been built at such enormous expense, was an error in the original levels by which the canal from the Malwatte River, that was intended to feed the reservoir, ran up-hill.

Capt. R. Baird Smith, in his work on "Irrigation in the Madras Provinces," says:

"The extent to which tank irrigation has been developed in the Madras Presidency is extraordinary. An imperfect record of the number of tanks in fourteen districts shows them to amount to no less than 43,000 in repair and 10,000 out of repair, or 53,000 in all. It would be a moderate estimate to fix the length of embankment for each at half a mile, and the number of masonry works in sluices, waste-weirs, etc., would probably not be overrated at an average of six. These data, only assumed to give some definite idea of the system, would give close upon 30,000 miles of embankments (sufficient to put a girdle round the globe not less than 6 feet thick) and 300,000 separate masonry works. The whole of this gigantic ma-

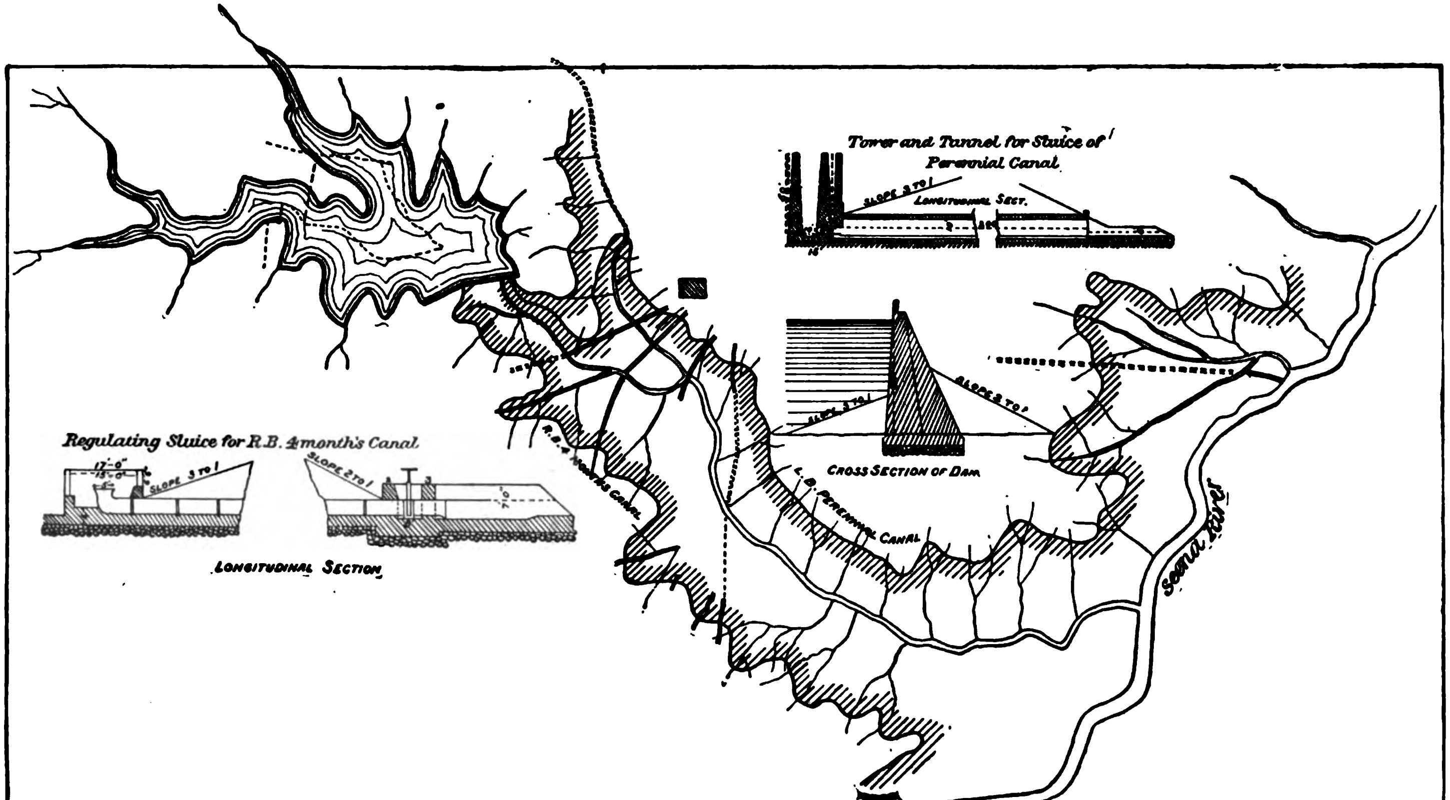


FIG. 126.—THE EKRUK TANK, BOMBAY. PLAN AND DETAILS.

chinery is of purely native origin, not one new tank having been made by the English. The revenue from existing works is roughly estimated at £1,500,000 sterling per annum, and the capital sunk at £15,000,000."

The same author described the Ponairy tank of Trichinopoly, now out of repair, as having an embankment 30 miles in length, and an area of 60 or 80 square miles. The Veeranum tank is very ancient, though still in service and yielding a revenue of $57,500 per annum. It has an embankment 12 miles long, and covers 35 square miles of area.

The Chumbrumbaukum tank has an embankment 19,200 feet in length, and forms a reservoir of 5730 acres, with a capacity of 63,780 acre-feet. The dam is 16 to 28 feet high. The water from the reservoir yielded an annual revenue to the government of $25,000 in 1853.

The Cauverypauk tank, in use from four hundred to five hundred years, has an embankment 3¾ miles long, revetted with a stone wall 6 feet thick at bottom, 3 feet at top, and 22 feet high, rising to within 5 or 6 feet of the top of the bank, which is uniformly 9 feet high above high-water mark. The embankment is nowhere less than 12 feet wide on top, with a front slope of 2½ to 1, and a rear slope of 1½ to 1. The whole outer surface is carefully turfed and planted with grass. Water is distributed from nine masonry sluices.

Mr. H. M. Wilson, in his work on "Irrigation in India," describes the abandoned tank of Mudduk Masur as having been built over four hundred years ago, when its capacity must have been 870,000 acre-feet of water. The restraining-dams were three in number; the main central dam, which is 91 to 108 feet high, and having a base of 945 to 1100 feet, is still intact, and the whole reservoir is capable of easy restoration. The lack of a spillway caused the destruction of the tank by the overtopping of one of the minor embankments. Mr. Wilson states that in the Mysore district of southern India there are 37,000 tanks, aside from the 53,000 enumerated in the Madras Presidency by Capt. R. Baird Smith. In the Mairwara District 2065 tanks have been built under English rule since the date of Capt. Smith's work, before quoted—1854.

Of the modern earthen dams built by English engineers in the employ of the Indian Government, two of the most interesting were recently constructed in the Bombay Presidency, the Ekruk tank near Sholapur, and the Ashti tank, on the Ashti River. The Ekruk tank (Fig. 126) impounds 76,130 acre-feet, and has a dam whose maximum height is 72 feet. The total length is 7200 feet, which included 2730 feet of masonry, of which 1400 feet is at the northern end and 1330 feet at the southern end. The cost of the dam was $666,000. The loss of water by evaporation during eight months is 7 feet in depth and amounts to 12,500 acre-feet, or 16% of the entire capacity.

The Ashti tank (Fig. 127) is formed by an earth dam 12,709 feet long,

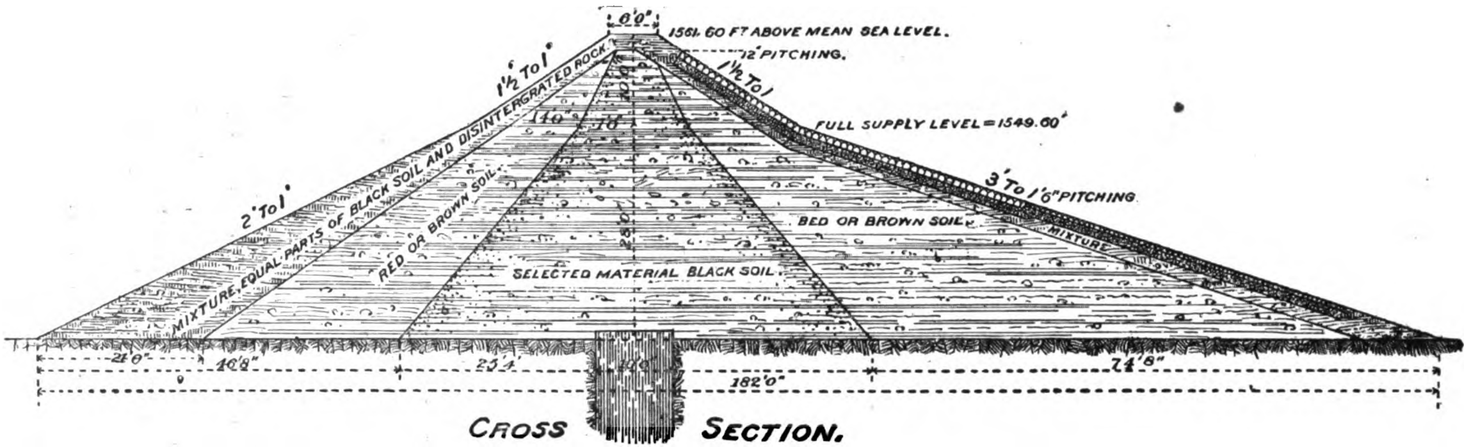


**Fig. 127**.—Cross-section of the Ashti Dam, India.

58 feet in maximum height, having slopes of 3 : 1 inside and 2 : 1 outside. The crest of the dam is 12 feet above high-water mark, and has a width of 6 feet. The interior slope is paved with stone. The storage capacity of the reservoir is 32,660 acre-feet, of which 9200 acre-feet, or 28%, is lost by evaporation. The reservoir has a surface area of 2677 acres. The following description of the construction of the dam is condensed from Mr. H. M. Wilson's "Irrigation in India":

The site of the dam was cleared of vegetation and top soil, so that the entire structure rests upon a sound and firm foundation. There is no puddle-wall proper, but a puddle-trench, 10 feet wide, was excavated down to a compact, impervious bed, the entire length of the dam, and was filled to one foot above the natural ground surface. This filling was composed of two parts sand and three parts black soil. The central third of the dam is built up of selected material of black soil, extending, as shown in the accompanying section, in a triangular section, 60 feet wide at the base, to the crest of the dam. Outside of this central section are two triangular sections of brown soil, faced with 1 to 15 feet of puddle of sand and black soil. On the inside a stone paving 6 inches thick is laid over the slope to resist wave-action. Across the river-bed a trench 5 feet wide was excavated along the entire length of the dam and extending 100 feet into the banks. On each side this trench was filled with concrete and connected with the puddle-trench. The puddle-trench was curved around the concrete wall and continued across the river at a distance of 20 feet from the concrete wall on the up-stream side. This work having been finished in dry weather, the sand of the river-bed was sluiced out of the way by confining the stream and directing it into narrow channels by loose rock spur-walls and piers.

The cross-section of the Ashti dam is considered amply strong, yet a more liberal section is believed to be advisable, especially in the matter of top width.

The wasteway of the Ashti reservoir consists of a channel 800 feet wide, cut through the ridge rock, the crest of which is level for 600 feet in length; thence the stream falls with a slope of 1% into a side channel. Its discharging capacity is 48,000 second-feet, causing the water to rise 7 feet above its sill, or to within 5 feet of the top of the dam.

In 1883 a serious slip occurred in the Ashti dam, causing a total settlement of 16 feet at the crest of the embankment, and causing the ground at the top of the dam to bulge upwards. The cause of this slip was attributed to the fact that for a considerable portion of the length of the dam it is founded on a clay soil containing nodules of impure lime and alkali, which render it semi-fluid when soaked with water. The slip occurred during or after excessive rains. It was corrected by digging drainage-trenches at the rear toe, which were filled with bowlders and broken stone, and by the addition of heavy berms or counterforts of earth, for 700 or 800 feet of its length, to weight the toe.

Similar slips occurred in the Ekruk dam, due to similar causes. These occurrences point to the value of thorough drainage to the outer toe of all earthen dams, and the desirability of the adoption of that form of combination of rock-fill and earth used so successfully in the Pecos dams, wherever rock can be obtained for the outer portion of such embankments.

**Vallejo Dam, California.**—Wherever earthen dams are constructed partially upon exposed bed-rock foundations, it is essential to provide free drainage to the water which seeks to follow along the bed-rock. An interesting application of this principle was made in the construction of a dam erected a few years since for the water-supply of Vallejo, California. The dam was built for storage purposes and formed a reservoir of 160 acres, 3 miles from the city. The bed-rock was exposed in the channel, and formed a low fall about the center line of the dam. Just above this fall a concrete wall was built upon the bed-rock some 6 feet high, with a drainage-pipe extending out to the lower toe of the embankment. A quantity of broken stone was placed above this wall, which formed a collecting-basin for any seepage that might pass through the embankment or that might creep along bed-rock, and the dam was then built over the wall in the ordinary way. This provision effectually prevents the saturation of the outer slope and keeps the dam well drained. The dam was planned and built by Hubert Vischer, C.E., with Mr. C. E. Grunsky acting as Consulting Engineer.

Earthen dams are usually constructed in one of the following ways:

(1) A homogeneous embankment of earth, in which all of the material is alike throughout;

(2) An embankment in which there is a central core of puddle consisting either of specially selected natural materials found on the site, or of a concrete of clay, sand, and gravel, mixed together in a pug-mill and rammed or rolled into position;

(3) An embankment in which the central core is a wall of masonry or concrete;

(4) An embankment having puddle or selected material placed upon its water-face;

(5) An embankment of earth resting against an embankment of loose rock;

(6) An embankment of earth, sand, and gravel, sluiced into position by flowing water—a form of construction described in the chapter on Hydraulic-fill Dams. Earthen dams have also been built with a facing of plank, made water-tight by preparations of asphaltum or tar. The choice of these various available plans is dependent upon local conditions at the site of the dam to be built, the materials available, and the predilection or education of the engineer planning the structure.

European engineers, judging from their works, lean toward the central puddle-core, and the greater number of the earth dams of the British Empire are constructed on this plan. American engineers appear to prefer the masonry core-wall, or the puddle facing on the inner slope of the embankment to the central puddle-core, as a means of cutting off percolation through the dam and thus securing water-tightness.

The natural slope of dry earth placed in embankment is about 1½ to 1, but in practice it is customary to increase this to 2 to 1 on the exterior, and to 3 to 1 on the interior slopes. The necessary height of the embankment above the high-water mark depends to some extent upon the length and size of the reservoir, and the "reach" of the waves generated by winds, as well as upon the width of the spillway and the height to which water must rise in the reservoir during maximum floods to find full discharge through the spillway. Ample spillway capacity is of primary importance to the security of any earthen dam, unless it be one whose reservoir is filled by a canal or other controllable conduit from an adjacent stream. A lack of sufficient spillway is the cause of the greater number of the failures of earthen dams that have occurred, of which the most memorable case was that of the Johnstown dam, whose rupture caused the loss of two thousand lives and the destruction of many millions of dollars' worth of property. Had the spillway been of ample dimensions, this dam would have resisted any pressure that could have been brought to bear upon it and the disaster would, in all probability, never have occurred.

A common source of failure is in the doubtful practice of building the outlet-pipes through the body of the dam. These should either be laid in a tunnel at one side, or in a deep trench cut into the bed-rock or the solid impervious base of the dam, and the pipes surrounded by concrete, filling the entire trench.

In building earth dams of any type it is essential that the earth should be moist in order to pack solidly, and if not naturally moist it must be sprinkled slightly until it acquires the proper consistency. An excess of moisture is detrimental. It should be placed in thin layers, and thoroughly rolled or tamped, and the surface of each layer should be roughened by harrowing or plowing before the next layer is applied. Droves of cattle, sheep, or goats are often used with success as tamping-machines for earth embankments. They are led or driven across the fresh made ground, and the innumerable blows of their sharp hoofs pack the soil very thoroughly.

**The Cuyamaca Dam.**—One of the first earthen dams built in California for irrigation storage was the Cuyamaca reservoir-dam, erected in 1886 by the San Diego Flume Company. It is located in a summit valley between two of the Cuyamaca peaks, some 50 miles east of San Diego, at an elevation of 4800 feet. The dam is 635 feet long on top, 41.5 feet high, with inner slope of 2 : 1, and outer slope of 1.5 : 1. The crest of the dam is 6.5 feet above the floor of the spillways, one of which is 90 feet and the other 41 feet in width.

Before work was begun on the dam the site was covered with loose rock, and it was supposed that bed-rock was near the surface. Hence the original plan was to build a masonry dam. Excavations were started for that purpose, and considerable cement was brought to the ground to construct the foundations of masonry. It was soon found, however, that the loose rock was merely a surface layer on top of a bed of clay, and the plan was changed to a dam of earth throughout.

The discharge-sluice of the dam was built through the center of the structure, and consisted of a masonry culvert 3½ feet wide, 4½ feet high, 120 feet long, resting on a bed of concrete 18 inches thick, laid in a trench of that depth cut in the clay. This culvert has a fall of 3½ feet in length. At its upper end is a circular brick tower, 5 feet in diameter inside, with an opening at the bottom 3 feet wide, 4½ feet high, that is closed by a ponderous wooden gate, so large and heavy as to be almost immovable. A second gate, 16 feet higher, of similar size and construction, is provided to close another opening into the tower. These

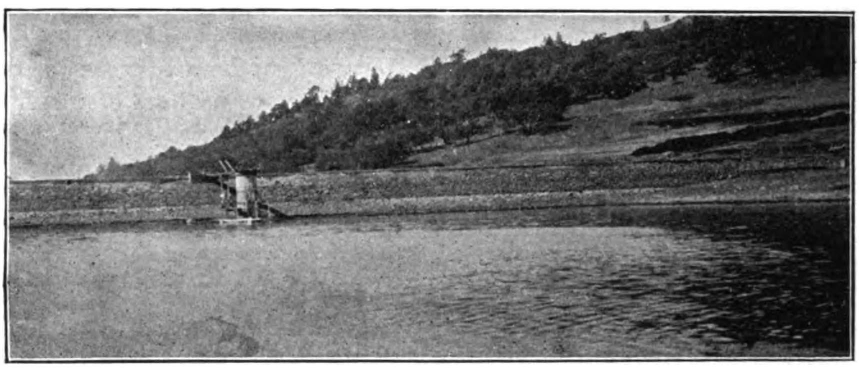

FIG. 128.—VIEW OF CUYAMACA DAM AND OUTLET-TOWER.

gates slide vertically in wooden grooves. An iron gate inside the tower closes the head of the culvert.

The bond between the earthwork and the culvert was imperfect, and considerable leakage ensued after the reservoir first filled, but this was afterwards remedied.

Fig. 128 is a view of the dam from the side of the reservoir, showing the tower.

The dam is reported to have cost $51,000 as originally constructed to the height of 35 feet. In 1894 an addition of 6.5 feet was made to the height of the dam, at a cost of $3400. This addition increased the capacity

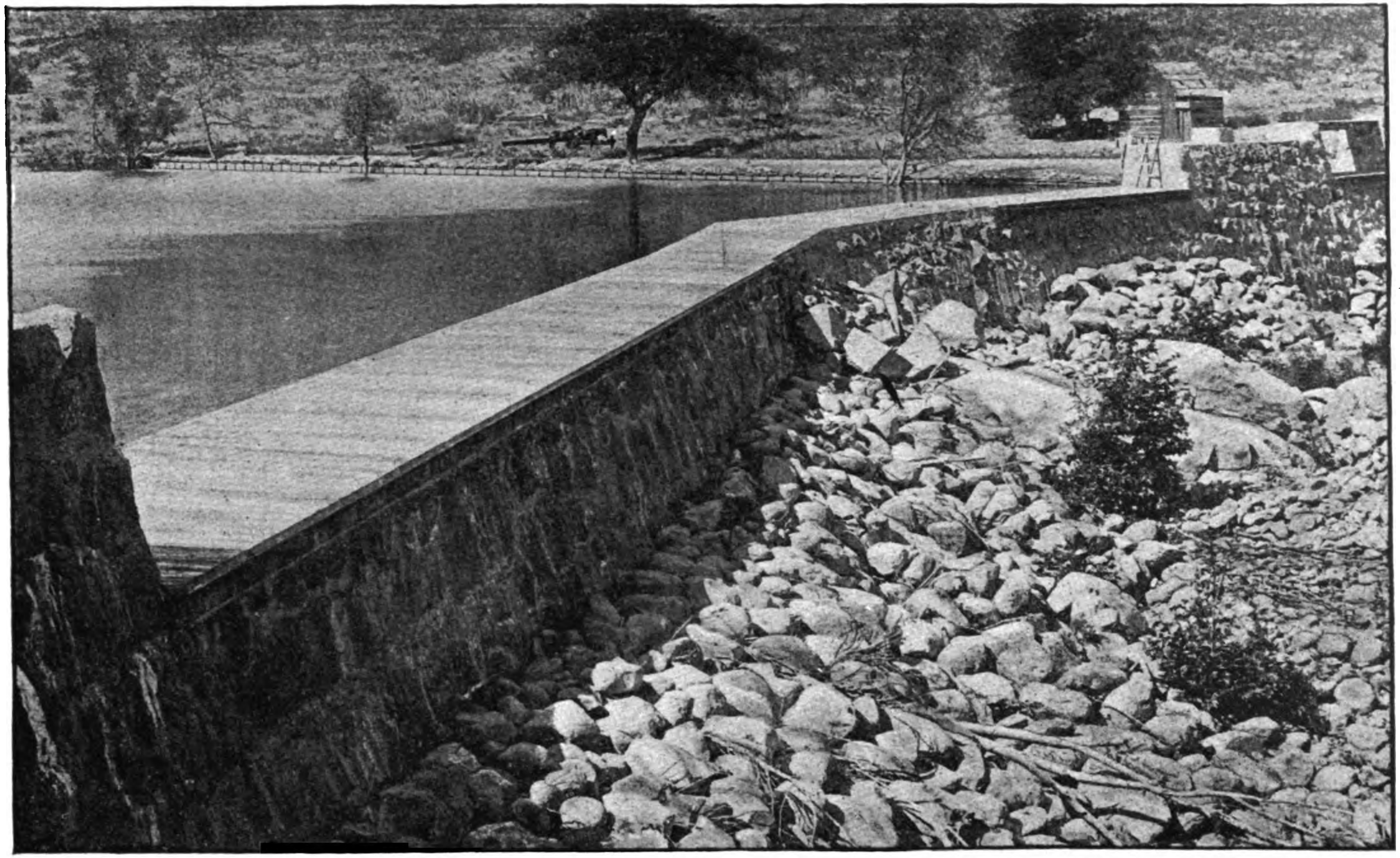

FIG. 129 —MASONRY DIVERTING-DAM OF THE SAN DIEGO FLUME CO., CALIFORNIA.

of the reservoir to 11,410 acre-feet, covering an area of 959 acres to a mean depth of nearly 12 feet. The watershed tributary to the reservoir is about 11 square miles. The following table, prepared by Mr. F. S. Hyde, C.E., from the records of the company in 1896, gives the volume of catchment and use during the first nine years after the completion of the dam:

TABLE OF RAINFALL, RUN-OFF, EVAPORATION AND AVERAGE DRAFT FROM THE CUYAMACA RESERVOIR, SAN DIEGO COUNTY, CALIFORNIA.

| Calendar Year. | Rain and Melted Snow. Inches. | Run-off in Acre-feet. | Percentage of Run-off to Precipitation. Per cent. | Run-off per Square Mile. Second-feet. | Evaporation. | | | Average Draft from Reservoir for Irrigation and City Supply. Acre-feet. |
|---|---|---|---|---|---|---|---|---|
| | | | | | Total. Ft. | In. | Average per Day. Inches. | |
| 1888 | 24.05 | 3,076 | 21.75 | 0.385 | 3 | 9.50 | 0.316 | |
| 1889 | 52.83 | 5,568 | 17.91 | 0.697 | 4 | 5.00 | 0.250 | 2,858 |
| 1890 | 62.91 | 6,214 | 16.79 | 0.768 | 3 | 9.25 | 0.208 | 2,881 |
| 1891 | 64.96 | 7,735 | 20.24 | 0.969 | 3 | 8.75 | 0.203 | 3,084 |
| 1892 | 42.56 | 5,163 | 20.62 | 0.647 | 3 | 6.75 | 0.241 | 4,821 |
| 1893 | 41.51 | 4,098 | 16.78 | 0.512 | 5 | 3.25 | 0.308 | 5,965 |
| 1894 | 24.90 | 2,035 | 13.89 | 0.255 | 7 | 1.00 | 0.341 | 2,939 |
| 1895 | 58.52 | 11,464 | 33.31 | 1.436 | 5 | 3.75 | 0.317 | 6,237 |
| 1896 | 26.44 | 1,158 | 7.45 | 0.145 | 5 | 7.50 | 0.284 | 5,777 |
| Means .. | 44.29 | 5,397 | 19.83 | 0.676 | 4 | 8.75 | .......... | 4,331 |

Subsequent years of drouth have resulted in emptying the reservoir entirely. The rainy seasons of 1897–98, 1898–99, and 1899–1900 have furnished practically no water for storage.

Referring to the above table of rainfall and run-off, it should be explained that as the rain-gauge on which the precipitation was recorded is located at the dam between two high, wooded peaks, which act as condensers of the moisture-laden clouds, the record shows a greater amount than the average of the watershed, which a few miles east of the dam borders on the desert, where the rainfall is known to be much less. This is borne out by comparing the measured run-off with the "Newell Curve" of run-off, which would indicate that if the recorded precipitation were a mean of the entire area, the yield should be two to three times as great as it actually was. This Cuyamaca rainfall record is misleading as a criterion of mountain precipitation in this region. The water actually flowing in different seasons from a known area, as shown by the table, is more reliable as a guide for estimates of the yield to be expected from adjacent sheds than any single rainfall record, or any possible collection of rainfall statistics without such empirical knowledge of actual yield in stream-flow produced by any given rainfall.

During the period covered by the table the mean annual draft from the reservoir was 4331 acre-feet, while the mean annual run-off was 5397 acre-feet. The difference between these figures, or 1066 acre-feet, represents the mean annual evaporation, or 19.75 per cent of total catchment.

After flowing down Bowlder Creek and the San Diego River 12½ miles, dropping 4000 feet vertically in that distance, the water released at the dam is picked up and diverted to the flume by means of a masonry weir extending across the San Diego River. This diverting-dam is 340 feet long on top, 35 feet high, 22 feet thick at base, 5 feet at the crest. To cut off leakage under the dam a subwall was built on the up-stream side in the main channel, lapping onto the base of the dam and extending down 15 feet deeper. This wall is 5 feet thick at bottom. The original wall had been founded on disintegrated granite. The subwall was built in a trench that cut deeper into the soft granite, but was not entirely effectual in stopping the leakage. (Figs. 129 and 130.)

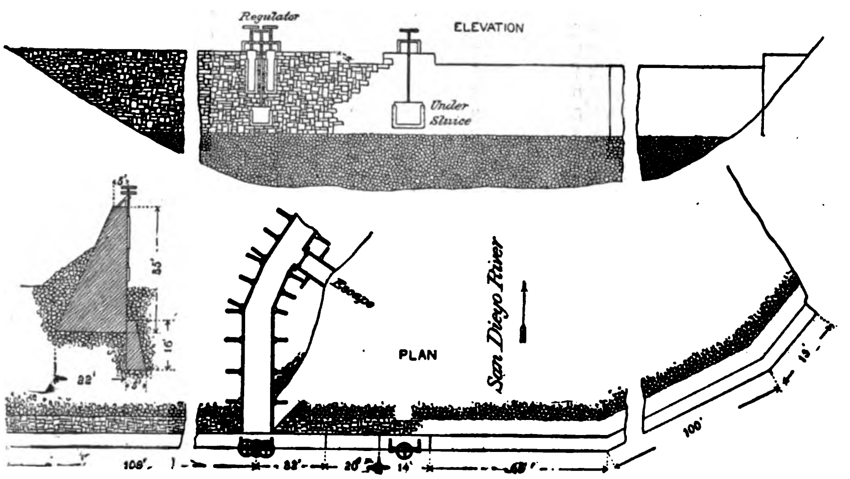


**Fig. 130.—Plan and Elevation of Diverting-dam of San Diego Flume Co., California.**

The main flume is 34.85 miles in length, 6 feet wide in the clear, with single sideboards 16 inches high, though the frame-posts are 4 feet high and will admit of additional sideboards to give a total depth of 4 feet. If completed as originally designed, the flume would have a capacity of 5000 miner's inches under 4-inch pressure. Its present maximum capacity is not over 900 inches. The flume is supported at places on high trestles, one of which is shown in Fig. 131, and there are a number of long and costly tunnels on the route. The grade of the flume is 4.75 feet per mile. It commands all the irrigable lands of El Cajon Valley, Spring Valley, and the San Diego mesa, and supplies water to about 5700 acres, mostly cultivated in orchards of citrus fruits. The city of San Diego has also received

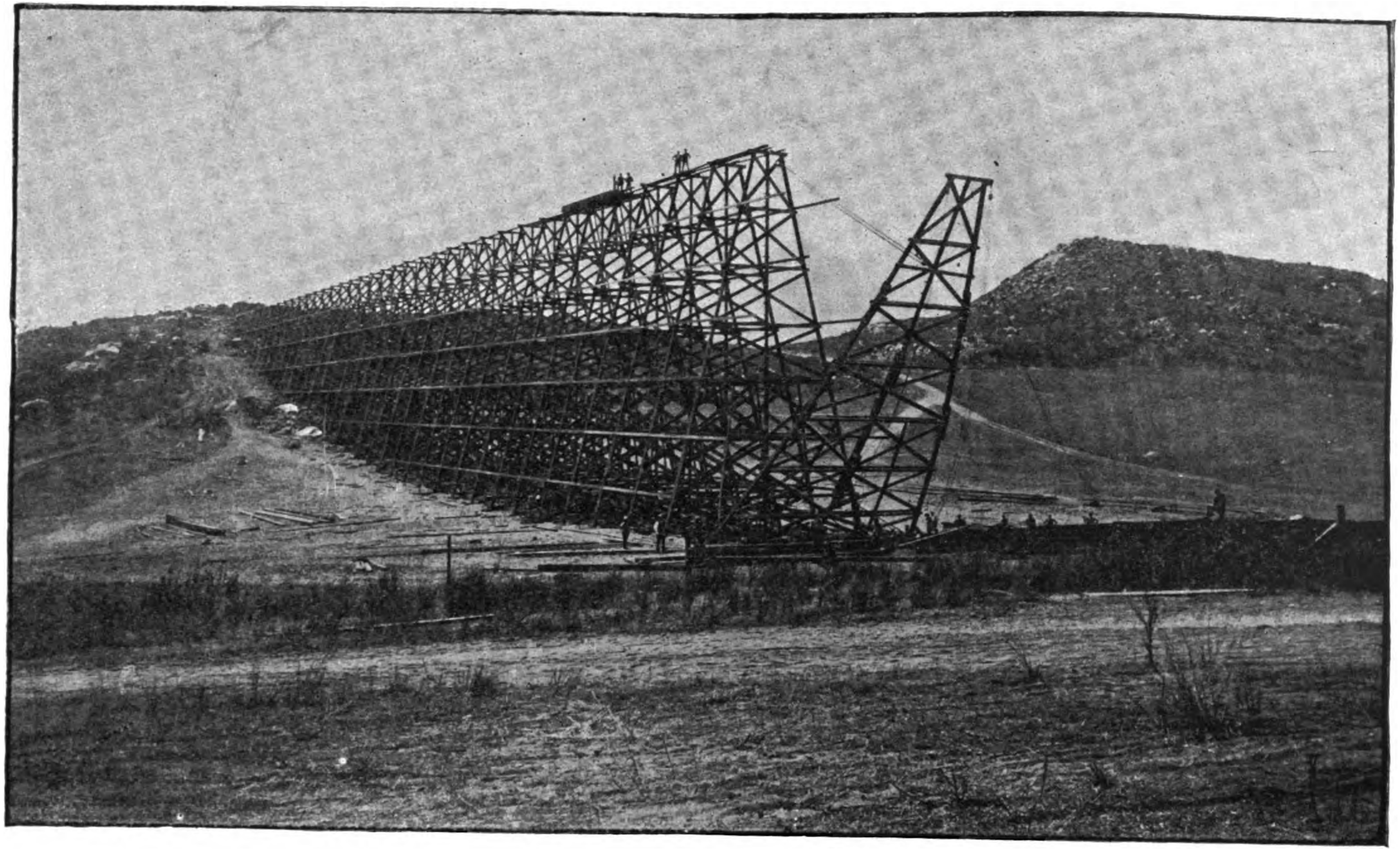

FIG 131.—SAMPLE OF HIGH-TRESTLE CONSTRUCTION ON SAN DIEGO FLUME, CALIFORNIA.

its domestic supply from this source during the greater portion of the time since its completion, through a 15-inch steel-pipe line laid over the mesa, from the end of the flume to the city, about 10 miles.

In the summer of 1897–98 the reservoir was quickly exhausted, and it became necessary to install an independent system of supply for the orchards and the city of San Diego. For the orchard supply this was accomplished by sinking a series of bored wells in the gravel bed of the San Diego River, above El Cajon Valley, where the flume leaves the immediate valley of the river. Pumping-stations were erected, and the wells, which were placed at intervals of 50 feet along a horizontal suction-pipe 1000 to 1300 feet in length, were drawn upon in series simultaneously, the water being forced up to the flume with a lift of 300 feet. About 3 second-feet (150 inches) were thus obtained, and though the supply was meager it was sufficient to maintain the life of the trees and keep them in bearing with good cultivation. The city was supplied in a similar manner by wells sunk in the river-bed in Mission Valley, from 2 to 4 miles above the main pumping-plant. The water was lifted to the surface at several points and conveyed to the pump-station by small flumes. Over 3,000,000 gallons daily were thus obtained. These plants have had to be maintained and increased in capacity up to the present writing (April, 1900), with a prospect of continuance until the next rainy season. The inhabitants of southern California have reason to congratulate themselves that Nature has provided underground storage-reservoirs capable of being drawn upon so liberally that they are able to endure such an unprecedented period of drouth as they are now experiencing. To obtain the supply, however, by wells and pumps is generally far more costly than water stored in surface reservoirs.

**The Merced Reservoir Dam, California.**—The highest and longest earthen dam closing a reservoir chiefly devoted to irrigation in California is that which forms the so-called "Yosemite Reservoir," 6 miles northeast of the town of Merced. This dam was constructed in 1883–84 by the Crocker-Hoffman Land Company as a part of its general system of irrigation, by which some 150,000 acres are commanded for irrigation. It has a maximum height of 50 feet, and is built entirely of earth composed of a sandy clay with inner slopes of 3 : 1 and outer slopes of 2 : 1. From the top down for 15 feet the interior is paved with loose rock, 12 inches thick, for wave-protection. The entire length of the dam is 2200 feet, of which 1400 feet is less than 10 feet high. It was built up as a homogeneous bank of earth, without a puddle-wall, or without adding to the natural moisture of the soil. The earth was simply put in place with scraper-teams, the material being deposited with care in thin layers. The top width is 20 feet, base 290 feet. The dam rests on a very firm foundation of cemented gravel, into which a wide, deep puddle-trench was cut and carefully re-

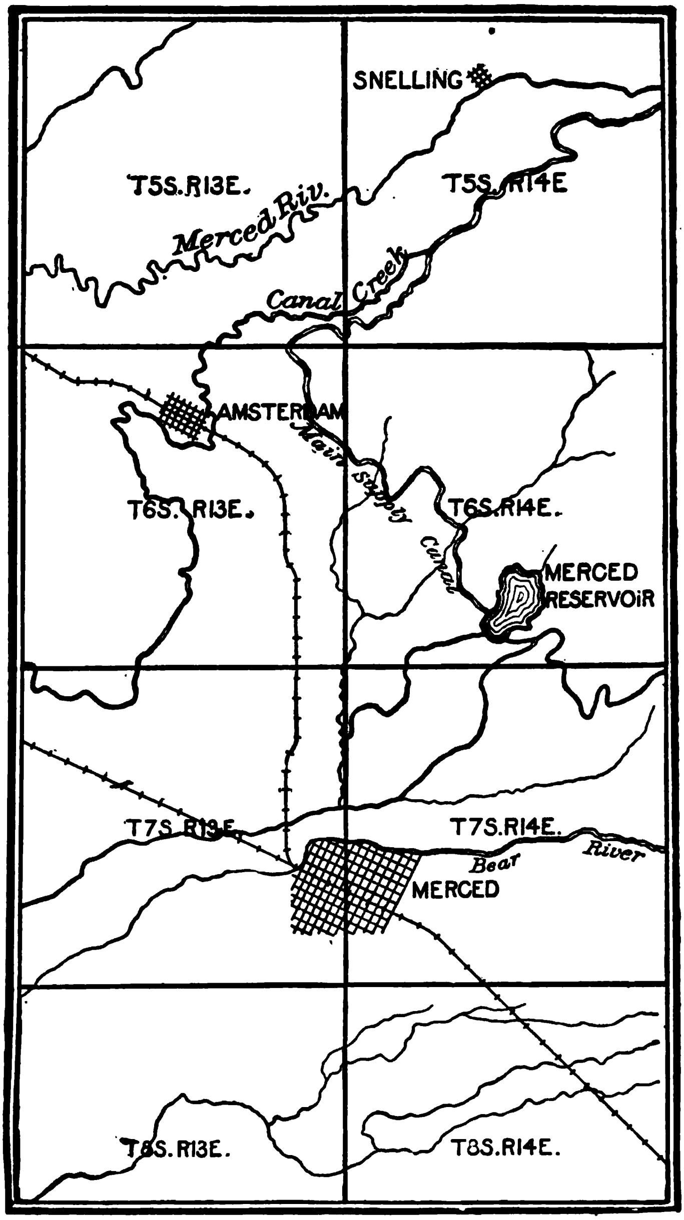


FIG. 181*a*.—MAP SHOWING LOCATION OF MERCED RESERVOIR, CALIFORNIA.

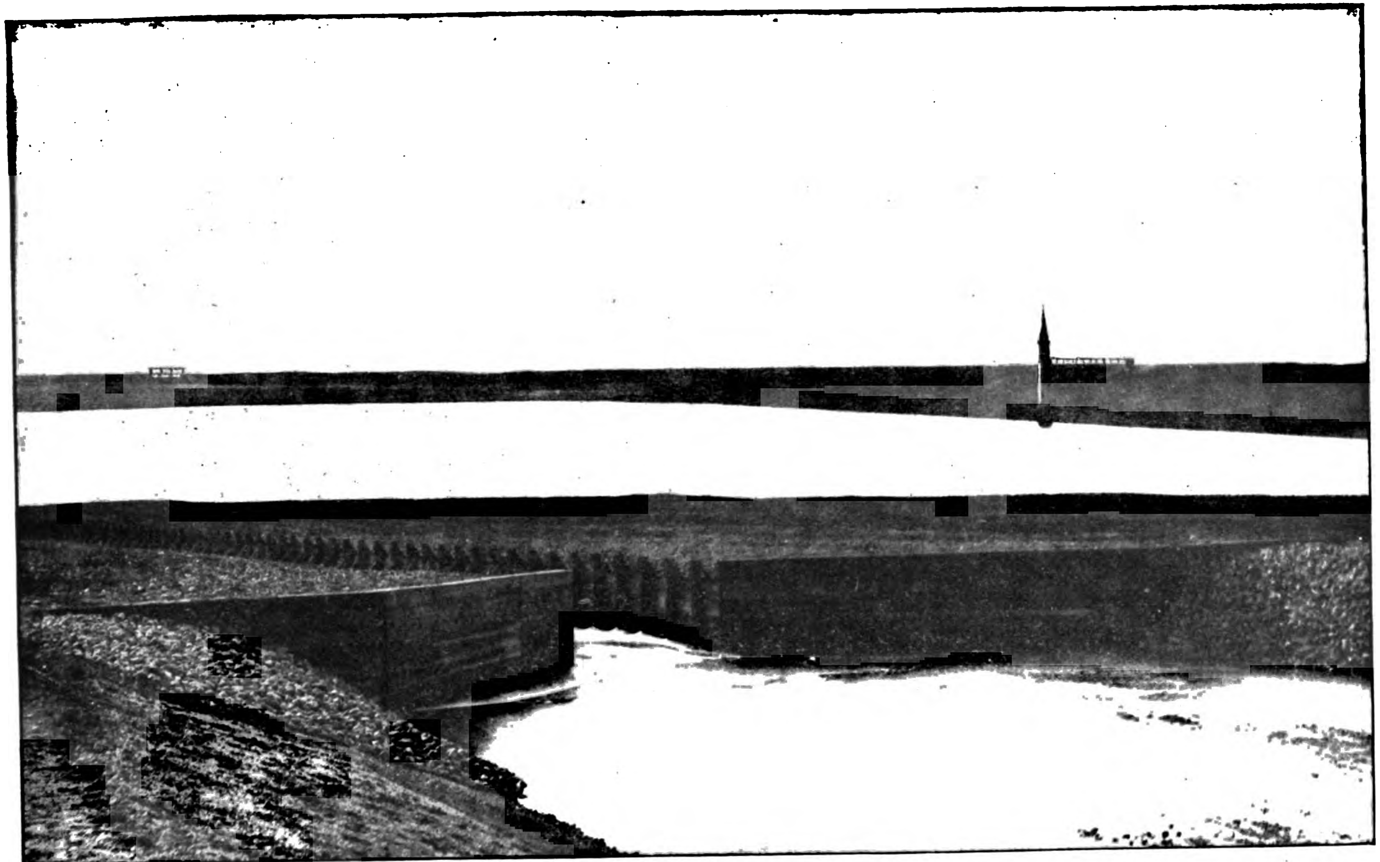

FIG. 132.—VIEW OF YOSEMITE RESERVOIR, MERCED, CAL., SHOWING FEEDER CANAL AND OUTLET-TOWER.

filled. Much of the material used in the dam had to be loosened by blasting.

The reservoir-outlet consists of a masonry conduit, made of brick laid in cement mortar, placed in a trench cut in the cemented gravel. This conduit carries the main, cast-iron, delivery-pipe, 24 inches in diameter, and a blow-off sluice-pipe. The conduit is 4 feet in diameter in the clear, the brickwork being 12 inches in thickness.

The reservoir, dam, and outlet-tower are shown in Fig. 132.

The reservoir covers 600 acres and has a capacity when full of 15,000 acre-feet, of which about 20% is annually lost by evaporation. It is fed by a canal 27 miles in length, leading from a diversion-weir placed in the Merced River a short distance above the town of Snelling. For the first 8 miles the canal has a maximum capacity of 1500 second-feet, which is the largest canal in California. The total cost of the canal system, with its laterals, and the reservoir was about $1,500,000.

The watershed area of the Merced River above the head of the canal is 1076 square miles, in which is included the famous Yosemite Valley. The mean annual flow of this stream as determined by the California State Engineering Department for the six years from 1878 to 1884 was about 1600 second-feet, the maximum being 6510 second-feet in the month of June, and the minimum 65 second-feet in the months of November and December. During the three months of May, June, and July, when the greatest amount of irrigation is required, the mean discharge of the river in the period named was about 4000 second-feet.

**Buena Vista Lake Reservoir, California.**—The large storage-tank formed of Buena Vista Lake, in the southern end of the San Joaquin Valley, is the largest irrigation-reservoir in the State, covering an area of 25,000 acres to a mean depth of nearly 7 feet. The volume of water which it is capable of impounding above the level of the outlet-canal is 170,000 acre-feet, and in its general characteristics it more nearly resembles the great tanks of India than any reservoir in this country.

The reservoir is formed by a straight dike, or dam, 5.5 miles in length, following a township line from the foot-hills at the base of the mountains, due north. The maximum height of the dam is 15 feet, tapering out to nothing at either end. Its top width is 12 feet, and the slopes are 4 : 1 inside, 3 : 1 outside, the crest being 4 feet higher than the high-water level of the reservoir when full. The erosion of this bank due to wave-action rendered it necessary to riprap the face with stone over a long section from the south end northward, where there were no tules growing to serve as a breakwater to lessen the effect of wave-action, as was the case at the north end. To procure the material for this riprap a narrow-gauge railroad was built for some ten miles from a quarry at the base of the mountains. The cost of this work was more expensive than the construction of the embankment and brought the entire cost of the dam and outlets up to about $150,000. The dam divides the reservoir from what was formerly known as Kern Lake, before its bed was drained and cultivated.

The reservoir now receives all the surplus water of Kern River and the waste at the tail end of all of the Kern Island canals below Bakersfield. The water thus stored is only available for use on a belt of arable land that was formerly a swamp, extending from Buena Vista Lake to Tulare Lake. This land before reclamation was periodically overflowed when the water of the river was not so extensively absorbed in irrigation in the delta and upon the adjacent plains as it has been in recent years. Since its reclamation it requires to be irrigated, and the reservoired water is devoted to that purpose.

The reservoir was first filled in 1890, and has been in service ever since. Its creation was the result of the compromise of the most extensive and costly litigation over water-rights that has ever arisen in California. The title of the action was that of Lux *vs.* Haggin. It will go down in history as the case in which the Supreme Court of California, by a majority of one, first established the English common-law doctrine of riparian rights as applicable to the streams of the State. It is believed that this doctrine, though greatly modified by subsequent decisions, has been a serious drawback to irrigation development in California.

The surface of the reservoir is so large as compared with the volume stored that the annual loss by evaporation is estimated at 120,000 acre-feet, or 70% of the total capacity. This is an enormous waste of water, which might be saved to a considerable extent by the construction of storage-reservoirs in the mountains, where the ratio between surface area and volume would be very much less, and the rate of evaporation smaller. The reservoir is generally filled from about May 1st to July 20th, during the melting of the snows, after which time to September 1st the inflow is about sufficient, ordinarily, to offset evaporation. Thus during the five hottest months, when nearly 70% of the total evaporation of the year takes place, the loss is supplied by the river, and by the return waters of irrigation. Therefore, in those seasons when the run-off is sufficient to supply the demand of the canals and yield a surplus great enough to fill the reservoir by September 1st, in addition to evaporation, the net amount available for use from the reservoir would approximate 125,000 to 135,000 acre-feet. Measurements of the river taken daily from 1879 to 1884, and from 1894 to 1897,—ten years in all,—show a minimum yearly discharge of 364,000 acre-feet, a maximum of 1,760,000 acre-feet, and a mean of 789,000 acre-feet of water discharging into the valley at the mouth of the canyon.

**The Pilarcitos and San Andrés Dams, California.**—The water-supply of San Francisco is largely derived from the storage of storm-waters on the peninsula south of the city. The San Mateo dam, of concrete, described in a previous chapter, supplanted one of the original earthen dams, that known as the Upper Crystal Springs; but there are two other notable structures still in service, called the Pilarcitos and the San Andrés dams.

The Pilarcitos dam is 640 feet long on top, 95 feet in height above the original surface of the ground, and has a top width of 24 feet. The slopes are 2 : 1 each side. A puddle-wall, 24 feet thick, extends down 40 feet below the surface, into a trench cut in bed-rock. The reservoir formed by the dam has a capacity of 1,180,000,000 gallons (3622 acre-feet), and gathers the run-off from a watershed of 2510 acres. The elevation of the lake is 696 feet above sea-level.

The San Andrés dam has a top length of 850 feet, a maximum height of 93 feet above the original surface, and a top width of 24 feet. The inside slope is 3.5:1, while the outer slope is 3:1. The central puddle-wall reaches to bed-rock through 46 feet of earth and gravel. The dam was originally built to a height of 77 feet, but in 1875 it was raised 16 feet by the addition of the new material upon the outer slope. The base of the new section was 135 feet. As the inner slope was projected to the new crest of the dam it became necessary to make a horizontal offset in the puddle-wall in order to keep it within the center of the new section.

The San Andrés reservoir has a capacity of 6,500,000,000 gallons (19,950 acre-feet), and intercepts the drainage from 2695 acres of watershed immediately tributary. It is also fed by a flume, 17.42 miles in length, leading from Lock's Creek. This flume gathers the water from 1800 acres of the Lock's Creek shed, all above 505 feet elevation. Other feeders to the reservoir gather the water from Pilarcitos Creek below the Pilarcitos dam, and from a branch of San Mateo Creek.

**Cache la Poudre Reservoir Dam, Colorado.**—The Union Colony of Greeley, in northern Colorado, is supplied with water for irrigation by the Cache la Poudre Canal, an important adjunct of which is a storage-reservoir of 5654 acre-feet capacity, formed by an earthen dam, 38 feet in height. For a long time after the construction of the canal it was thought unnecessary to supplement its river-supply by a reservoir. Later experience showed that the low-water period came on in many years before the potato-crop was made, and a reservoir-site was sought to store water to carry the farmers over this critical period. The site selected was one which could be filled by a supply-canal, 8 miles long, discharging into the main canal 2 miles below its head.

The dam was made by scraper-teams, of the soil at the site, and is homogeneous in character, without puddle. It was originally made with a uniform inner slope of more than 3 to 1, but the action of waves has made it quite irregular. The embankment settled 4 to 5 feet the first year after the water was turned in, and becomes quite soft throughout whenever the reservoir is filled, but this is yearly becoming less. The rock for rip-rapping the face of the dam was brought by rail to the nearest point, and hauled by wagon two miles, costing $1.10 per ton laid down. The dam cost $81,623 for construction, in addition to $28,643 paid for real estate and rights of way—a total of $110,266. The year after it was completed and filled, the reservoir proved its value by saving the crop of potatoes valued at $331,366, of which one-half is credited to the reservoir.

The feeder-canal has a capacity of 150 second-feet, while the outlet-canal will carry 200 second-feet.

The outlet-conduit is founded on tough clay, and has a floor of wide flagstones laid on concrete. The conduit is 5 feet wide, and 5 feet high in center, the side walls being 2½ feet high, and a semicircular arch forming the roof. Two collar-walls extend into the embankment to cut off leakage. The gates are the invention of Gordon Land, a well-known hydraulic engineer of Denver, and are known as "railroad gates." They are two in number and travel on a double track, set at an inclination of 20° from the vertical, the gates being provided with wheels. They go down to their seats by gravity, and are raised by wire ropes passing over a windlass at the top of the embankment.

**Colorado State Dams.**—In 1892 the State of Colorado by legislative enactment inaugurated a system of storage-reservoirs for irrigation, under which five dams were erected in different parts of the State by money appropriated for the purpose by the State legislature. This is a policy which has not been attempted by any other of the States of the Union, so far as the writer is aware, and in this case it does not appear to have been successful or to meet with popular favor. The dams are under the control of the State Engineer, and water from them is sold to the irrigators.

The selection of the sites and the expenditure of the money appear to have been controlled by politics rather than by good engineering. The experiment cost the State $102,544.88 in all, and the total storage provided was but 2574 acre-feet in the aggregate. An account of these works, gleaned from the State Engineer's reports, is of interest, and is condensed as follows:

*The Monument Creek Dam.*—This earthen dam is located on Monument Creek, some 15 miles north of Colorado Springs, at an elevation of 7000 feet above sea-level. Its dimensions are the following:

| | |
|---|---|
| Maximum height | 40 feet |
| Width on top | 20 " |
| Length on top | 855 " |
| Inner slope | 3:1 |
| Outer slope | 2:1 |

The water-line is 7 feet below the crest of the dam. The inner face of the dam is covered with a clay puddle-wall laid on the slope, with a horizontal thickness of 50 feet at the base and 10 feet at top. This puddle is carried down to bed-rock in a trench 14 feet deep, at the inner toe of the dam, the minimum width of the trench being 5 feet. Over the puddle-wall is laid a riprap wall of stone, placed with care by hand. The outer half of the dam is composed of coarse gravel, rock, and earth. These general principles must be regarded as unexceptionable in earth-dam construction.

The reservoir-outlet is formed by two 16-inch cast-iron pipes, laid in a trench excavated underneath the dam, with concrete collars, 12 inches wide and the same thickness, at each of the joints. Between these collars the trench was filled with puddled clay. Just above the inner line of the crest of the dam a gate-tower is carried up through the embankment from the level of the outlet-pipes. At the bottom of this tower two 16-inch stop-valves are placed in the outlet-pipes, their stems reaching to the top of the dam inside the tower. The tower is circular in form, 4½ feet inside diameter for the lower 8 feet, and 3 feet diameter for the remaining height. It is built of sandstone, 18 inches thick, laid in cement. The entire tower is encased in puddled clay.

The spillways provided each side the dam have a total width of 200 feet, although 50 feet width was regarded as probably ample to carry the maximum floods from the 22 square miles of drainage-area.

The dam was planned and built under the supervision of J. P. Maxwell, State Engineer. The work was done by contract for $25,000, exclusive of engineering, but when finally completed in 1894 its entire cost had reached $33,121.53. The award of the contract was made subject to the proviso that El Paso County, in which it is located, should furnish, without cost to the State, a clear title to the land required, which was done.

It was estimated that the reservoir could be filled three or four times every year, but it is found to fill once and sometimes twice in a year.

The reservoir covers 62 acres to a mean depth of 13.8 feet, or 42% of the maximum depth. It impounds 885 acre-feet.

*The Apishapa State Dam* is located in the Metote Canyon in Las Animas County, and was completed in 1892. The dam is of earth, and forms a reservoir of 459 acre-feet capacity. Its cost was $14,771.80. It is filled by a ditch, 2 miles long, leading from Trujillo Creek, which has 30 square miles of watershed, the water from which is fully appropriated and used by prior locators.

*The Hardscrabble State Dam* is an earthen structure, completed by the State in 1894, at a cost of $9997.31. It impounds but 102 acre-feet of water, and is filled by a ditch from Hardscrabble Creek, in Custer County.

*The Boss Lake State Dam* is located in Chaffee County, on the headwaters of the South Arkansas River. It was finished in 1894, at a cost of $14,654.24, and forms a reservoir with a capacity of 205 acre-feet. It is made of earth, and was reported to be unsafe in construction and was never filled. The tributary watershed is 4 square miles.

*The Saguache State Dam* is located near the town of Saguache, and is an earthen dam which cost $30,000. The reservoir capacity behind it is 954 acre-feet. It is filled by a ditch from the Saguache River, but as the normal flow of the stream is fully appropriated, only the winter and spring floods are available.

# CHAPTER V.

## NATURAL RESERVOIRS.

On the great plains east of the Rocky Mountains there are thousands of natural basins which have no outlets and which gather the storm-water run-off from a few hundred acres of surrounding territory, and hold it in shallow ponds until it is lost by evaporation. Many of these depressions have been utilized as storage-reservoirs by carrying water to them from adjacent streams, and by providing them with outlets, either by tunnels or cuts; and many more have been selected for future utilization. They are often at the proper elevation to command large areas of arable land, and can usually be converted into safe storage-reservoirs at small expense. Such natural basins appear to be invariably water-tight, and in every way suitable to the purpose, except in occasional instances where they contain deep beds of alkali.

**The Alpine Reservoir, California.**—The project of the South Antelope Valley Irrigation Company, completed in May, 1896, and put in service the following year, is dependent upon a reservoir, formed in a natural basin, which has unusual features and is of special interest, not only as the first reservoir of any magnitude completed on the borders of the Mojave Desert in southern California, but because it lies directly in the line of what is known as "the great earthquake crack" of this region, which is marked by a series of similar basins behind a distinct ridge that appears to have been the result of the great seismic disturbance.

This remarkable line of fracture can be traced for nearly 200 miles through San Bernardino, Los Angeles, Kern, and San Luis Obispo counties, and deviates but slightly here and there from a direct course of about N. 60° W. There appears to have been a distinct "fault" along the line, the portion lying south of the line having sunken, and that to the north of it being raised in a well-defined ridge. In many places along the great crack ponds and springs make their appearance, and water can be had in wells at little depth anywhere on the south side of the ridge before mentioned. A tough, plastic, blue clay distinguishes the line of the break in this portion of its course, at least, and where the line crosses Little

Rock Creek the blue clay has formed a submerged dam, which has forced the underflow to rise near the surface and created a "cienega" immediately above it. After crossing the line the water of the creek drops quickly away into the deep gravel and sand of the wash. The same effect is noticeable at other streams, and the earthquake crack has been suggested as the probable cause of the very distinct rim marking the lower margin of the San Bernardino Valley artesian basin and confining its waters within well-defined limits, as this rim is nearly on a prolongation of the line that is traceable on the north side of the mountains,—the break having possibly crossed the mountains through the Cajon Pass on the line of Swartout Canyon.

One of the largest depressions on the earthquake line is the basin near Alpine or Harold station on the Southern Pacific Railroad, which has always held a small amount of water, supplied by the rainfall over the small catchment of 6 or 8 square miles above it, but which is now transformed into a reservoir fed by a canal, 8.6 miles long, from Little Rock Creek. The railway passes through one side of the basin and crosses the outer rim near the outlet-tunnel. A low levee or dike, about 4000 feet long, will have to be built alongside the track to enable the reservoir to be filled to its maximum depth of 34 feet, for which it has been planned. At this level it will cover 263 acres of surface and impound 5500 acre-feet of water. The basin will carry 15 feet of water without submerging the track, and for present purposes a dike lower than that which is planned for a full use of the basin has been built to permit the storage of 21 feet depth of water. A corner of the basin is shown in Fig. 135 as it appeared before beginning work. The view is taken looking east across the railroad-tracks toward the mountain source of supply.

The feeder-canal from Little Rock Creek consists of 2 miles of flume and chute and 6½ miles of earth canal, including two ponds used as sand-settling basins, 1600 and 1400 feet long. The location of the conduit, after getting out of the canyon of the creek, is directly on the earthquake line for the greater part of the way, the straightness of the line being noticeable on the map, Fig. 134. The canal heads at an elevation of 3130 feet above sea-level, and it has a total fall to the surface of the reservoir of 317 feet, of which the canal grade required but 70 feet. The superfluous fall was taken up by a series of inclines or chutes, down which the water flows with great velocity. They are seven in number and have a total length of 4600 feet.

The canal has a maximum capacity of 250 to 300 second-feet. Under normal conditions it is expected that the reservoir can be filled twice or more each season, and by irrigating freely in winter and early spring the duty of the reservoir and canal system may be increased to accomplish the irrigation of as great an area as though the reservoir were of double the

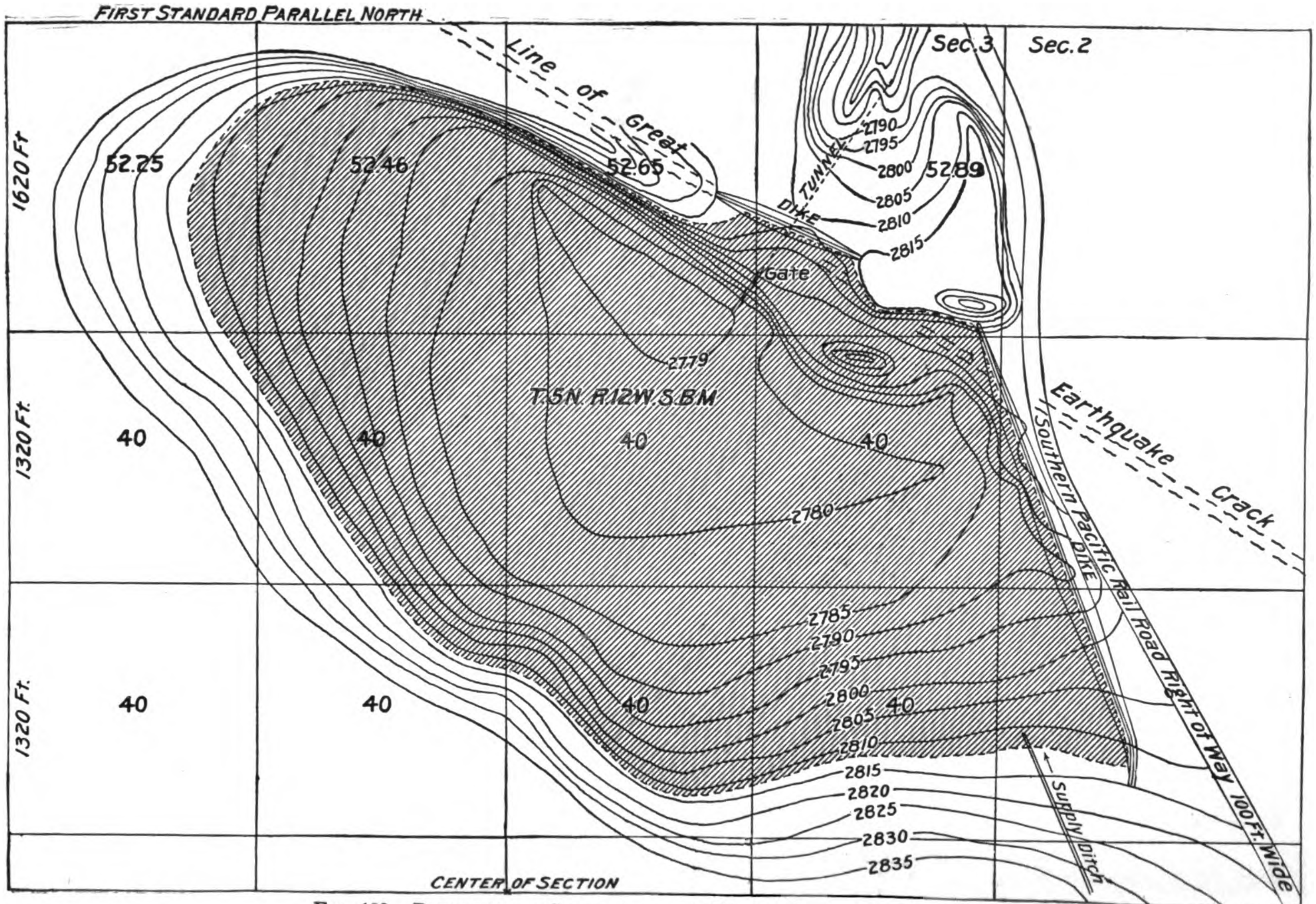


Fig. 188.—Reservoir of South Antelope Valley Irrigation Company.

capacity. The tract which the company hopes to supply from this source covers about 10,000 acres, a part of which is being planted in olives.

The watershed of Little Rock Creek, as shown by the best maps to be had, does not exceed 61 square miles, but as it heads in one of the highest peaks of the Sierra Madre and drains the north slopes of the mountain, the run-off to be expected from it may ordinarily reach 400 acre-feet per

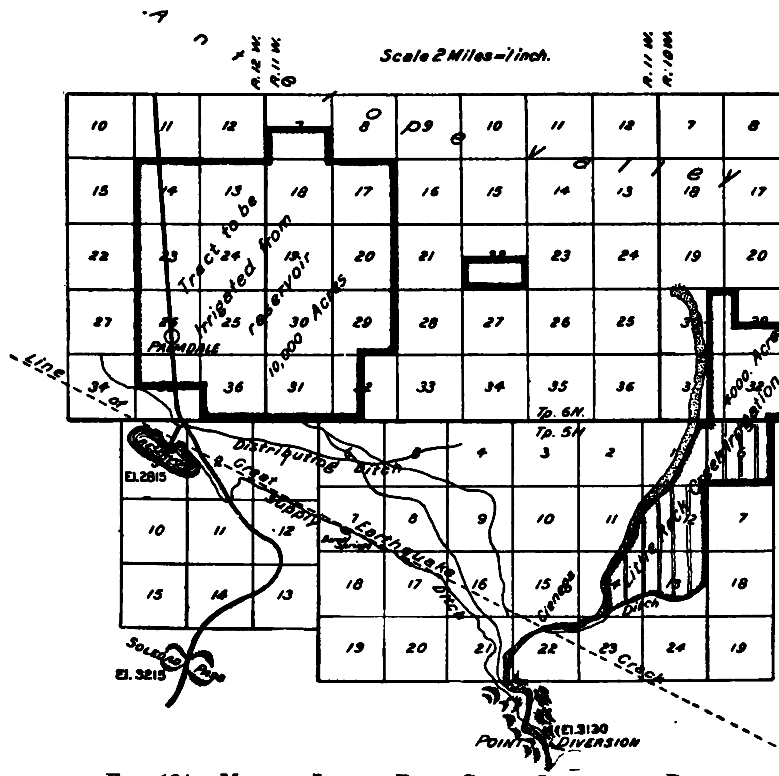


**Fig. 134.—Map of Little Rock Creek Irrigation District.**

square mile. The normal flow of the stream, which reaches a minimum of 2 second-feet, is diverted at the before-mentioned earthquake cienega by a ditch supplying the Little Rock Irrigation District, the outlines of which are shown on the sketch-map (Fig. 134). Consequently the South Antelope Valley Company must depend entirely upon the surplus flood-water after the district is supplied.

Incidentally it will be of interest in this connection to mention that a careful measurement of the underflow in the gravel bed of the stream overlying the blue clay of the earthquake crack, made by Mr. J. B. Lippincott in June, 1896, resulted in the conclusion that the rate of flow of the percolating water passing through the sand and gravel of the

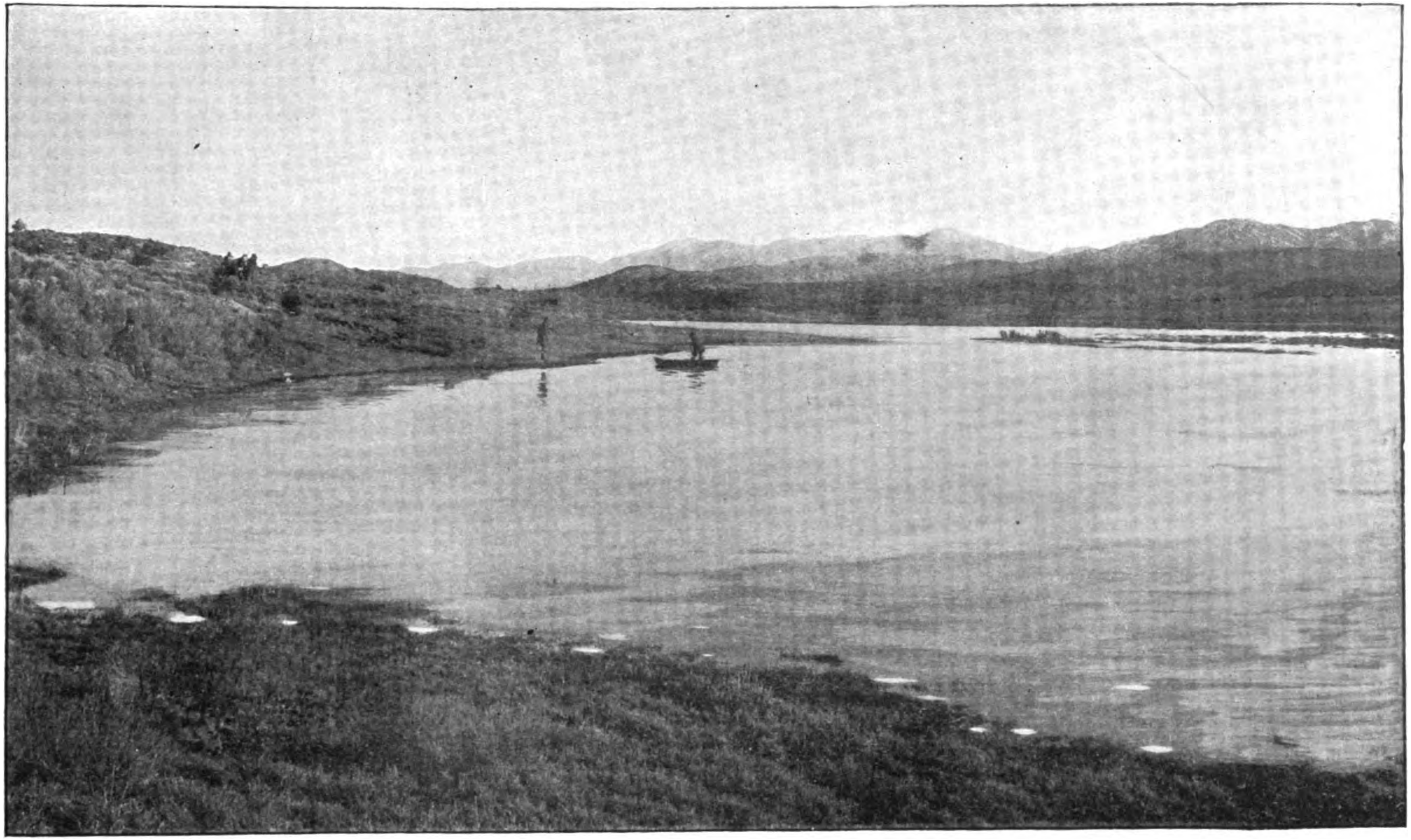

FIG. 185.—VIEW OF A CORNER OF THE BASIN OF ALPINE RESERVOIR BEFORE WORK WAS BEGUN.

channel was 2.16 feet per hour, or 3.53 miles per annum, which is extremely slow, but much greater than that noted at the Agua Fria River, Arizona (p. 210), doubtless because of the greater coarseness of the gravel at Little Rock.

The outlet to the Alpine reservoir (Figs. 135, 136) is made by a tunnel 750 feet long, in which a 36-inch riveted steel pipe is laid for irrigation supply alone, and a 10-inch pipe of the same character is placed above the former for domestic purposes only, both being surrounded with concrete, filling the 8-inch space concentric with the pipes to the walls of the tunnel. The pipes extend only 200 feet from the interior to a gate-shaft, and thence the main pipe discharges into a flume placed inside the tunnel-timbers. This flume is 2 feet deep, 3 feet 8 inches wide, and delivers the water to the distributing-ditches running east and west from the mouth of the tunnel on suitable grade-lines. A wooden platform on a trestle built over the inner end of the tunnel serves as a place from which to operate the 36-inch gate-valve at the head of the pipe and three 10-inch valves on a stand-pipe at different levels controlling the domestic supply, which is taken under pressure to the town of West Palmdale. The works were planned and built by Burt Cole, a civil engineer residing in the district. The cost of the system was about $100,000.

**Twin Lakes Reservoir, Colorado.**—One of the reservoir-sites surveyed by the government in 1892 was the Twin Lakes site, on a fork of the Arkansas River (Fig. 137). These lakes cover an area, at normal stage of water, of about 1900 acres, and have a depth of more than 80 feet. They are at an altitude of 9194 feet, and receive the drainage from 387 square miles of watershed, including within this area some of the highest mountains of Colorado. The annual run-off from this area is from 40,000 to 100,000 acre-feet.

The plan proposed by the government engineers for utilizing these two lakes and converting them into one large reservoir was to erect an earth dam, with a maximum height of 73 feet, across the valley below the lakes, and thus increase their surface area to 3475 acres. This would give a reservoir capacity above the normal lake surface of 103,500 acre-feet. To fill the reservoir it was designed to supplement the run-off of the streams directly tributary by diverting water from the main Arkansas River, by a canal leaving the river a short distance below Leadville.

Some years after this survey was made a private corporation, called the Twin Lakes Reservoir Company, was organized by Buffalo capitalists to carry out the work on a modified plan. This company acquired sufficient land around the margins of the lakes to control them, and began work in the summer of 1898. The plan adopted by them contemplated works that would enable them to draw off the lakes to 16 feet below their normal level, and in addition build a low dam that would store 9 feet in depth above that level,—thus commanding a total depth of 25 feet and a total volume of 48,000 acre-feet. Of this volume, two-thirds, or 32,000 acre-feet, is below the normal lake-level. In pursuance of this plan they excavated a canal at one side of the outlet-stream, 2000 feet long, from the edge of the lower lake to the point of its intersection with Lake Creek. This canal is 40 feet wide on bottom, and has a maximum depth of 37 feet. The excavation was in sand, bowlders, and silt, or "glacial flour," and was chiefly made with a steam-shovel. At the point where the excavation was

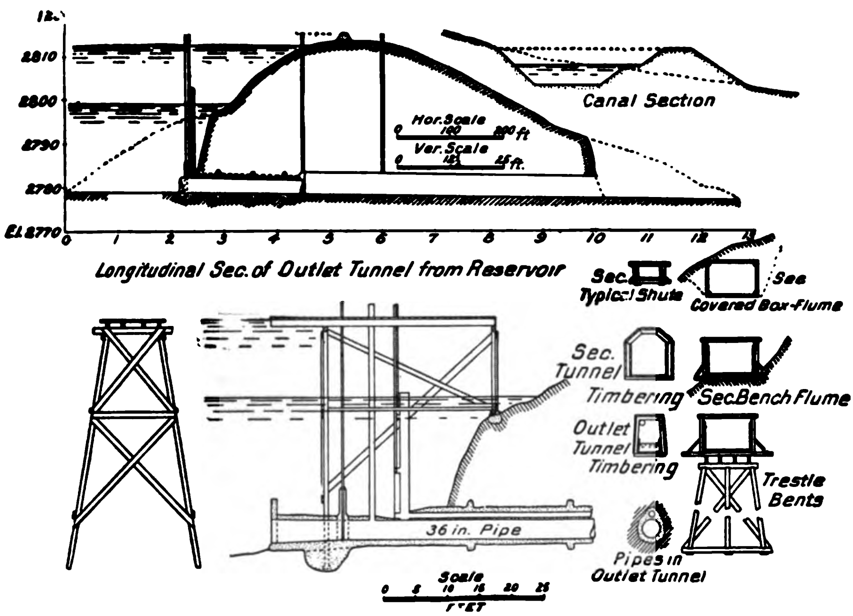


FIG. 136.—DETAILS OF TUNNEL-OUTLET OF THE ALPINE RESERVOIR.

deepest, some 200 feet from the lake margin, they prepared to erect head-gates of iron, on a heavy base of concrete, with abutment-walls of cut stone laid in cement mortar. The structure was to have been 32 feet in height. The gates were twelve in number, each 2 feet 8½ inches wide, 5 feet high, made of ½-inch boiler-plate, and carrying iron flashboards, loosely resting one above another, on top of the gate, and reaching up to above high-water mark. The gates were to slide vertically between 12-inch I beams. These beams were to be embedded in the concrete floor. The foundations for this floor were made by driving piles, upon which the abutment-walls and center pier rest. (Fig. 138.)

The concrete base of the gate structure was planned and built 72 feet long, with a width of 69 feet to the outer lines of the abutment-walls. It was made 5 feet in thickness, with double grillage of T rails, encased in the concrete. Three lines of apron or curtain walls extended down 5 feet below the bottom of the concrete, across the line of the canal.

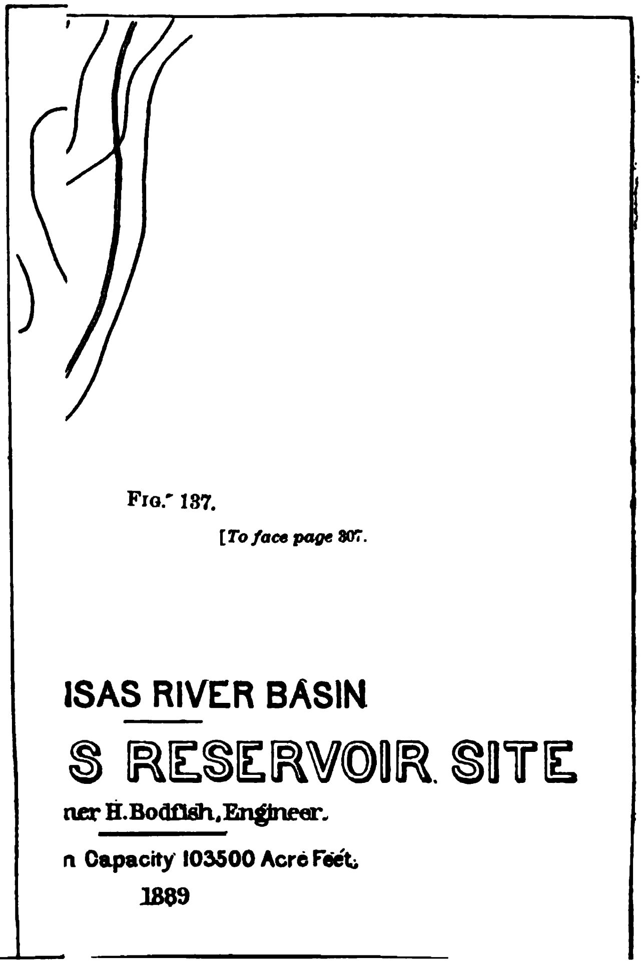


FIG. 137.

[To face page 307.

In the spring of 1899 this structure was partially completed, the floor was finished, and one of the abutment-walls was built 12 feet high, when work was stopped by threats of injunction made by officials of the Denver and Rio Grande and the Colorado Midland railways, whose tracks through the canyon of the river below would have been endangered by any failure of the proposed reservoir. At this juncture Mr. O. O. McReynolds was appointed Chief Engineer, and the writer was employed as Consulting Engineer to prepare plans to make the work secure and allay apprehensions of its safety. The modifications which were made in the plan are shown in Fig. 137, and the work has since been completed in compliance with the new design. The changes were made in such manner as to adapt them to the part already completed and to utilize materials already on the ground. These were the following: A series of four culverts were built on top of the completed floor, extending from the line of gates to the lower edge of the concrete platform, a distance of 47 feet. These culverts are each 7 feet 11 inches wide and 7 feet high, with a semicircular arch over them. They are built of concrete, the thickness of the arch being 2 feet. On top of these culverts a masonry dam is built across the canal, reaching to a height of 30 feet above the floor of the structure. This wall is of sandstone ashlar, laid in large blocks with Portland-cement mortar. Its base width is 15 feet, top 4 feet; down-stream batter 5 : 12. Extending well into the banks on each side, in line with the dam, is a concrete wall, 2 feet thick, designed to cut off seepage through the earth filling on the sides that would tend to pass around the dam. Against the masonry dam on the lower side is an embankment of earth over the top of the culverts, forming a driveway over the canal, 22 feet wide on top. The outer slope terminates against a low wall forming a façade for the culvert-portals. The slope is paved with stone. For 50 feet above and 75 feet below the concrete platform the canal is paved with concrete on the bottom, and the sides protected from erosion by substantial walls of concrete above the dry rubble below the headworks. The gates built for the original design were used, but the hoisting-device was improved, and a substantial gate-house built over the gates.

*Spillway.*—A space is left between the gates and the masonry which will admit of a maximum discharge of 600 second-feet over the top of the flashboards, without raising the gates. Whenever any water thus passes over the top of the flashboards it can escape freely through the culverts and down the canal. This provision for sudden floods in the possible absence of attendants to open the gates is considered an ample spillway allowance. The culverts have a combined capacity of over 2000 second-feet.

*Fishway.*—To provide for a free passage of migratory fish over the dam, in compliance with the State law, it is proposed to erect a fish-ladder

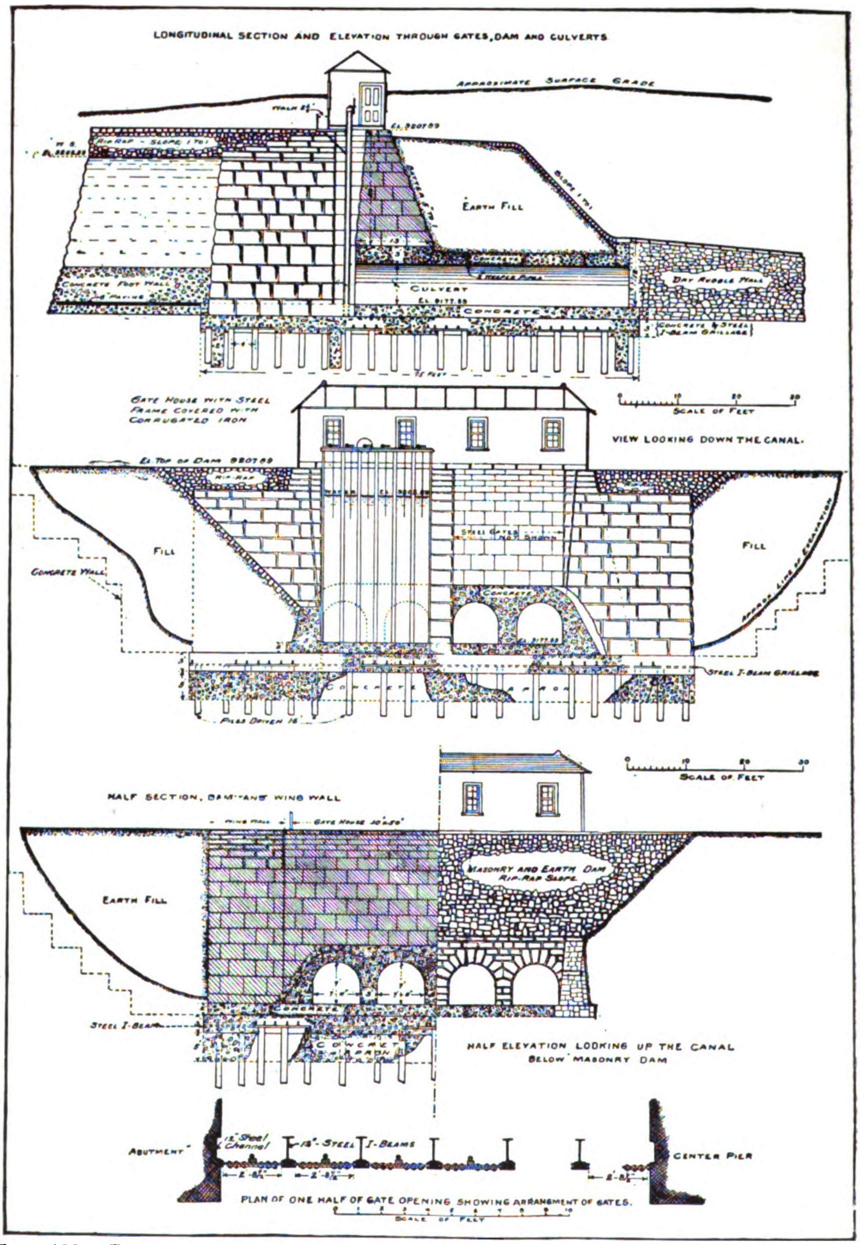


FIG. 138.—DETAILS OF OUTLETS FOR TWIN LAKES, COLO. DESIGNED FOR THE TWIN LAKES RESERVOIR CO. BY J. D. SCHUYLER, CONS. ENGR., AND BUILT BY O. O. MCREYNOLDS, CHIEF ENGINEER.

of approved design, supplying it with water piped from a neighboring stream. The lakes abound in trout.

The entire cost of the improvements, including the purchase of valuable villa sites on the lake margins, will be about $200,000. The works were finished during the current year (1900).

"*Glacial Flour.*"—An interesting feature of these improvements is the peculiar character of the material through which the canal has been excavated and upon which the head-works have been built. The lakes are located between two great lateral moraines, hundreds of feet in height, while the barrier across the valley, forming the natural dam inclosing the lower lake, is a terminal moraine deposit, consisting largely of rock dust, or almost pure silica ground to an impalpable powder, known to geologists as "glacial flour." This material is so fine in texture as to resist percolation through any considerable mass of it, and hence it becomes practically impervious as an embankment of ordinary dimensions. It is neither quicksand nor clay, and has none of the characteristics of these elements.

The natural channel through which the lakes overflow into the Arkansas River will be closed by an embankment of this glacial flour, well riprapped with stone on both sides.

**Larimer and Weld Reservoir.**—One of the natural basins, located 1½ miles north of Fort Collins, Colorado, has been made to hold an important auxiliary supply to the Larimer and Weld canal, feeding into the latter 2 miles below the head of the canal. When filled to the rim it holds a maximum depth of 25 feet, and has a storage capacity of 7700 acre-feet at that level. This capacity was increased in 1895 to 11,550 acre-feet by constructing a low levee or bank about 2000 feet long at the lowest part of the rim of the basin. This added 5 feet to the depth of water in the lake.

The cost of the improvements was $21,796, but land and water rights, attorneys and court fees, and miscellaneous expenses swelled the entire cost to $64,782. On the same canal system are two other natural basins, utilized as reservoirs, the larger of which, called the Windsor reservoir, is 25 miles below the head of the canal. It carries a maximum depth of 28 feet of water, and cost $52,000, of which $25,000 was for the land and attorneys' fees. To increase the depth to 40 feet, an embankment is to be built which is estimated to cost $23,000 additional. The reservoir will then have a capacity of 23,000 acre-feet.

The Larrimer County Canal utilizes six of these basins on the plains, as storage-reservoirs, which have a combined capacity of 10,560 acre-feet.

All of these basins above described derive their water-supply from the Cache la Poudre River.

**Marston Lake.**—One of the largest of these natural basins, situated at an elevation to command the city of Denver, has been utilized by the Denver Union Water Company as a storage-reservoir of 5,000,000,000 gallons capacity. It is fed by a canal from Bear Creek, and is provided with two outlet-tunnels which connect with the main conduits leading to the city of Denver, 10 miles distant.

**Loveland Reservoir-site.**—One of the largest of the natural-basin reservoirs that has been projected for use in Colorado is located 3 miles northeast of Loveland, Colorado, at Boyd Lakes. These are two basins adjacent, each containing small lakes, on the high ground between the Cache la Poudre and Big Thompson rivers. The basin will require no dam, and when filled will have a maximum depth of 44 feet, and a surface area of 1920 acres, the capacity of which will be 45,740 acre-feet.

The method proposed for its conversion into a reservoir is to make an open cut, 10 feet wide at the bottom, on a grade of 1.5 feet per mile. At the deepest point in the cut a masonry wall is proposed to be built across the cut, with six 3-foot, cast-iron pipes passing through the wall. The reservoir would be fed by two canals from the rivers on each side of it. The entire cost of the improvement is estimated by Capt. H. M. Chittenden * at $262,106.34, or $5.73 per acre-foot of storage capacity.

**The Laramie Natural Reservoir-site, Wyoming.**—Capt. Chittenden's able report † on reservoir-sites in Wyoming and Colorado describes a natural basin that could be made available for storing the surplus water of the Laramie and Little Laramie rivers, which is one of colossal magnitude. Its maximum depth is 170 feet, covering an area of 13,651 acres, and having a capacity of 937,038 acre-feet. This is greatly in excess of the supply available from the two streams mentioned, which is estimated at 70,000 acre-feet annually, although this could be increased by gathering the supply from more distant sources.

When filled to the 100-foot level, the annual loss by evaporation would be 24,000 acre-feet, leaving a supply of 46,000 acre-feet for irrigation. The estimated cost of the canals, reservoir-outlets, rights of way, etc., for utilizing the basin on the basis of storing only the waters of the two Laramie rivers, was $416,254, or $9.05 per acre-foot of average supply.

**Lake De Smet Reservoir-site, Wyoming.**—Among the reservoir-sites examined and reported upon by Capt. Chittenden, in the report quoted above, was a natural depression without outlet, called Lake De Smet. This basin is 3 miles long, 1 mile wide, and covers an area of 1965 acres. The improvement of this basin which he recommended was to construct

* Report of Capt. Hiram M. Chittenden, Corps of Engineers, U. S. A., upon examination of Reservoir-sites in Wyoming and Colorado, under the provisions of Act of Congress of June 3, 1896. House Document No. 141, 55th Congress, 2d Session.

† *Ibid.*

a feeder-canal, 3¼ miles long, with a capacity of 727 second-feet, and construct two outlets, one at each end of the basin, discharging into Box Elder Creek on one side and into Piney Creek on the other, each to have a capacity of 425 second-feet. This would convert the basin into a reservoir by the addition of 30 feet in depth, bringing the level of the lake up to the rim of the basin, increasing its surface area to 2400 acres, and affording an available storage of 67,627 acre-feet of water. The entire cost of the improvement was estimated at $113,360, or $1.67 per acre-foot of storage capacity.

Such natural basins as those described in the foregoing pages, which can be filled by controllable canals, present advantages as storage-reservoirs which are certainly ideal. The great thickness of the natural ridges which surround them renders them absolutely safe against bursting, provided their outlets are properly designed and well constructed; they are generally quite free from loss by percolation, and the volume of silt deposited in them is in direct ratio to their capacity, as no more silt-laden water need be put into them than is drawn out of them for use, in addition to evaporation, whereas a reservoir located in the channel of a river may often have to receive the silt from a volume of water many times the reservoir capacity. The only disadvantage they possess is that the surface area exposed may be greater per unit of volume stored than in deep reservoirs formed by high dams, and consequently the ratio of loss by evaporation may be somewhat greater.

This disadvantage is, however, amply offset by the many superior features they possess when compared with the average stream-bed reservoir.

**Natural Reservoirs of the Arkansas Valley, Colo.**—The most extensive enterprise for the storage of flood waters for irrigation in natural-basin reservoirs yet undertaken in the West was recently completed by The Great Plains Water Company in the Arkansas Valley in Eastern Colorado, and the reservoirs were partially filled and used for the first time during the irrigation season of 1900. The reservoirs are five in number, lying in a group closely adjacent to each other, and have the following capacities:

| * Name of Reservoir. | Area. Acres. | Total Capacity. Acre-feet. | Volume below Outlet Level and Unavailable Acre-feet. | Volume Available for Use. Acre-feet. |
|---|---|---|---|---|
| Nee Sopah | 3,600 | 34,372 | 10,908 | 23,464 |
| Nee Gronda | 3,490 | 97,069 | 39,860 | 57,209 |
| Nee Noshe | 3,770 | 82,121 | 21,485 | 60,636 |
| Nee Skah | 1,930 | 32,985 | 9,939 | 23,046 |
| King | 1,331 | 18,279 | .......... | 18,279 |
| Totals | 14,121 | 264,826 | 82,192 | 182,635 |

* The names of the reservoirs are from the Osage Indian language, and have the following interpretations: Nee Sopah, Black-water; Nee Gronda, Big-water; Nee Noshe, Standing-water; Nee Skah, White-water.

The reservoirs are located 12 to 18 miles north of the town of Lamar, and are fed by a canal from the Arkansas River, which heads near La Junta, Colo., and has a maximum capacity of 2096 second-feet. The company has built various other canals, as shown by the following table:

| Name of Canal. | Length in Miles. | Capacity in Sec-ft. |
|---|---|---|
| Fort Lyon | 113.00 | 2096 |
| Kicking Bird | 36.50 | 1000 |
| Satanta | 12.50 | 300 |
| Comanche | 16.78 | 400 |
| Pawnee | 6.34 | 200 |
| Amity | 110.00 | 870 |
| Buffalo | 16.10 | 192 |

The company has invested about $2,250,000 in its irrigation works and lands, the area of its holdings being about 100,000 acres. The manager of the company is Mr. W. H. Wiley, of New York, now residing at Holly, Colo.

The three reservoirs described in the foregoing table are so connected that they can be drawn upon by one outlet. This has been formed by a deep cut through the rim of the basin, in which the gates are placed in substantial headworks of cut-stone masonry. The outlet to Nee Skah is of a similar plan. The King reservoir as yet has no outlet provided for it.

**Natural Gravel-bed Storage-reservoirs.**—It may be said that all the soil of the earth is a storage-reservoir, which receives a large proportion of the precipitation from the clouds and gives it off slowly to feed the natural springs by which the normal flow of the streams is maintained. These natural reservoirs are increased in capacity and useful function by a maintenance of the forests, which shade the ground, lessen the force of the winds, increase the humidity of the air, diminish evaporation, and knit the soil together with a network of roots and so enable it to resist erosion.

In many parts of the country the storm-waters from the mountains flow over great beds of coarse gravel, extending from the foot-hills out into the valleys, for many miles. These gravel beds constitute natural storage-reservoirs of enormous capacity, and if, at some lower point, a contraction occurs in the stream-channel, or some natural barrier intercepts the flow, the water is again forced to appear on the surface and feeds the stream by a constant outpouring from the gravel reservoir, long after the feeders of the reservoir have gone dry.

In southern California there are a number of such natural reservoirs, one of the most notable of which is in the San Fernando Valley, north of Los Angeles, and supplies, by its natural overflow, the Los Angeles River. The San Fernando Valley has an area of 182 square miles, about one-fourth of which is a deep bed of coarse gravel, constituting a natural storage-reservoir. The valley is surrounded by mountains, of which about 300 square miles in the area drains into the valley. At its outlet the valley narrows down to a width of about 2 miles, and at this first contraction the Los Angeles River begins to appear, growing by rapid accretions in the space of a mile or more, at the rate of 10 to 25 miner's inches per 100 feet of channel. All the streams flowing into the valley are intermittent, and for months at a time have practically no surface-flow. The overflow of the gravel reservoir, however, is practically constant through all seasons, wet and dry, maintaining a discharge of from 70 to 90 second-feet. Even after three seasons of drouth the river at the present writing shows a diminution of but about 15% from the normal.

**The Upper San Gabriel Valley,** some 15 miles east of Los Angeles, constitutes another natural reservoir, of somewhat greater discharge than that of the Los Angeles River. The passage of the stream through the coast range of hills is but one mile in width, and contracts the basin sufficiently to cause the reservoir to overflow at the surface, producing a never-failing water-supply for irrigation in the valley below. Near the outlet of the upper valley a number of artesian wells have been bored which pierce strata of impervious clay and add considerably to the natural output of the reservoir.

**The San Bernardino Valley** is another interesting example of nature's storage-reservoirs, whose overflow at the narrows below yields a large and unfailing supply to the adjacent irrigated districts. This valley also produces a large artesian flow to augment the supply which naturally seeks outlet to the surface, as the overflow of the gravel reservoir.

Only second in importance to these natural reservoirs which retain water and let it out to the surface at a uniform rate, where it may be diverted by gravity to the lands, are the great artesian basins fed by underground streams, which require to be tapped by the boring of wells, and the more numerous and widespread subterranean basins from which water in wells may be pumped in practically immeasurable quantities.

## CHAPTER VI.

### PROJECTED RESERVOIRS.

If all the reservoirs which have been surveyed and projected in arid America within the past ten years were to be constructed, the water-supply which they would conserve for irrigation would doubtless far exceed in volume all the water which has ever been made use of from the natural streams, or from the reservoirs already built, while there are still vast numbers unexplored which may be developed in the future.

In 1890, '91, and '92 a comprehensive series of reservoir locations were made by the U. S. Geological Survey, and by Act of Congress the lands covered by the sites selected were segregated and withdrawn from public entry. The detail of this work is found in the 11th, 12th, and 13th Annual Reports of the U. S. Geological Survey.

In the appendix will be found tables giving the data of these various reservoir-surveys, the height of dams required, the area of reservoirs and their storage capacity. The work was distributed over the following States and Territories, viz.:

| | | |
|---|---|---|
| California | 45 | reservoir-sites. |
| Nevada | 2 | " |
| Colorado | 55 | " |
| Montana | 48 | " |
| New Mexico | 39 | " |
| Utah | 13 | " |
| Wyoming | 1 | " |
| Idaho | 1 | " |
| Total | 204 | " |

The most capacious reservoir-site discovered by the survey at this time, and doubtless the largest in the United States, was the Swan Lake reservoir, on Snake River, Idaho, covering an area of over 32 square miles, and capable of impounding 1,500,000 acre-feet, with a dam 125 feet in height. The cost of the dam was estimated at $500,000. This considerably surpasses the proposed Swift River reservoir in Massachusetts, whose capacity is given at 1,245,000 acre-feet, or 406 billions of gallons.

**Projected Reservoirs in Wyoming.**—Reference has been made in a previous chapter to the able report of Capt. H. M. Chittenden, U.S.A., to the Secretary of War, on reservoir-sites in Wyoming and Colorado. The examination of this matter was authorized by the River and Harbor Act of June 3, 1896, providing for "the examination of sites, and report upon the practicability and desirability of constructing reservoirs and other hydraulic works necessary for the storage and utilization of water, to prevent floods and overflows, erosion of river-banks, and breaks of levees, and to reenforce the flow of streams during drought and low-water seasons, at least one site each in the States of Wyoming and Colorado.

A number of the views which appear in this book have been kindly loaned by the public printer, having first been used to illustrate Capt. Chittenden's report, for which the writer makes due acknowledgment.

Five reservoir systems were examined under the provisions of the Act of June 3, 1896,—three in Wyoming, two in Colorado. The Wyoming reservoirs reported on were the Laramie site, the Sweetwater site, and the Piney Creek system, comprising three reservoir-sites, viz., the Cloud Peak, the Piney, and the Lake De Smet sites. The sites examined in Colorado were the Loveland site, already described in a previous chapter, and the South Platte site, 50 miles above Denver. At the latter site the Denver Union Water Company is constructing a high dam, which is described in the chapter on Rock-fill Dams.

The Laramie and Lake De Smet sites have already been referred to in a previous chapter, in the class of natural basins.

**The Sweetwater Site** is located on the Sweetwater River, at a point known as the Devil's Gate, about 65 miles north of the town of Rawlins, Wyo. The river here cuts through a granite ridge with a remarkably narrow gorge, and only about 35 feet wide at the water-surface, 330 feet deep, and 400 feet wide on top. The top length of the dam at the 100-foot level will be but 150 feet. Here it is proposed to build a masonry dam about 100 feet high, which would form a reservoir 13 miles long, covering an area of 10,578 acres, and having a storage capacity of 326,965 acre-feet. The cost of the work is estimated at $276,484.80 or 85 cents per acre-foot of capacity. The available supply for storage is stated at about 100,000 acre-feet annually.

The profile of the dam proposed is of heavy dimensions, the base width being 94 feet and the thickness at crest 25 feet, yet with these dimensions the entire cubic contents of the dam are but 21,534 cubic yards. The proposed outlet is by a tunnel 1000 feet long in the solid rock around the base of the dam. The estimate includes an item of $75,000 as the value of the land flooded by the reservoir.

Capt. Chittenden says of the dam-site: "It stands almost without exception as the most favorable site for a masonry dam in the world."

The accompanying photograph, Fig. 139, corroborates this statement. A gap in the ridge at one side of the dam limits the height to 100 feet, and affords a natural spillway of any desired capacity.

**The Cloud Peak Site** is a natural lake, about 1½ miles long and ½ mile wide, covering 173 acres. Its elevation is nearly 10,000 feet above sea-level, and it is surrounded by high mountains densely clothed with forests. The dam proposed for this site is the combination earth and rock-fill of the Pecos Valley type. The rock-fill is planned with side slopes of 1 : 1, and a top width of 5 feet. Against this is to be built an embankment of puddled earth, with a crest width of 20 feet, and inner slope of 3 : 1. The total height is 34 feet, top length 820 feet. A wasteway, 100 feet wide, 5 feet deep, is planned. The high-water mark will be 4 feet below the crest of the dam. By means of a sluiceway, cut 10 feet deeper than the base of the dam, it is proposed to draw down the lake-level 10 feet, giving a total available capacity of 6800 acre-feet. The drainage-area is 30 square miles in extent, from which the run-off will fill the reservoir every year. The estimated cost of the work was $31,048, or $4.56 per acre-foot of storage capacity.

**The Piney Site** is located 6 miles below the Cloud Peak site, at an altidude of 8800 feet. It requires a dam 54 feet high to store 11,020 acre-feet, covering a surface area of 328 acres. The dam proposed is about 1000 feet long, and is planned to be of the same type as the Cloud Peak dam. Its cost is estimated at $70,226.25, or $6.37 per acre-foot. The total drainage-area above this site is 65 square miles.

Capt. Chittenden has given in his report the ablest and most convincing arguments in favor of the construction of storage-reservoirs in the arid West by the U. S. Government that have yet been advanced by the most ardent advocates of that policy. He says:

"Of the very great importance of irrigation, not only to the West but to the country at large, there would seem to be no room for doubt. To one who has seen the changes wrought in the once desert regions of California, Arizona, Utah, Wyoming, and Colorado, in what used to be as forbidding regions as any still remaining in that country, there can be no doubt that the destiny of the arid section of America is more dependent upon the waters that flow from its mountains than upon the minerals that lie concealed within them. Already in the greatest mineral-producing States of the West, California and Colorado, irrigated agriculture yields a greater wealth of product than the mines. . . . Already in many sections the natural flow has been used as far as it is practicable to do so. . . . Here, then, is a definite reason of the highest validity for the construction of reservoirs. . . . The inevitable tendency of Western development is there-

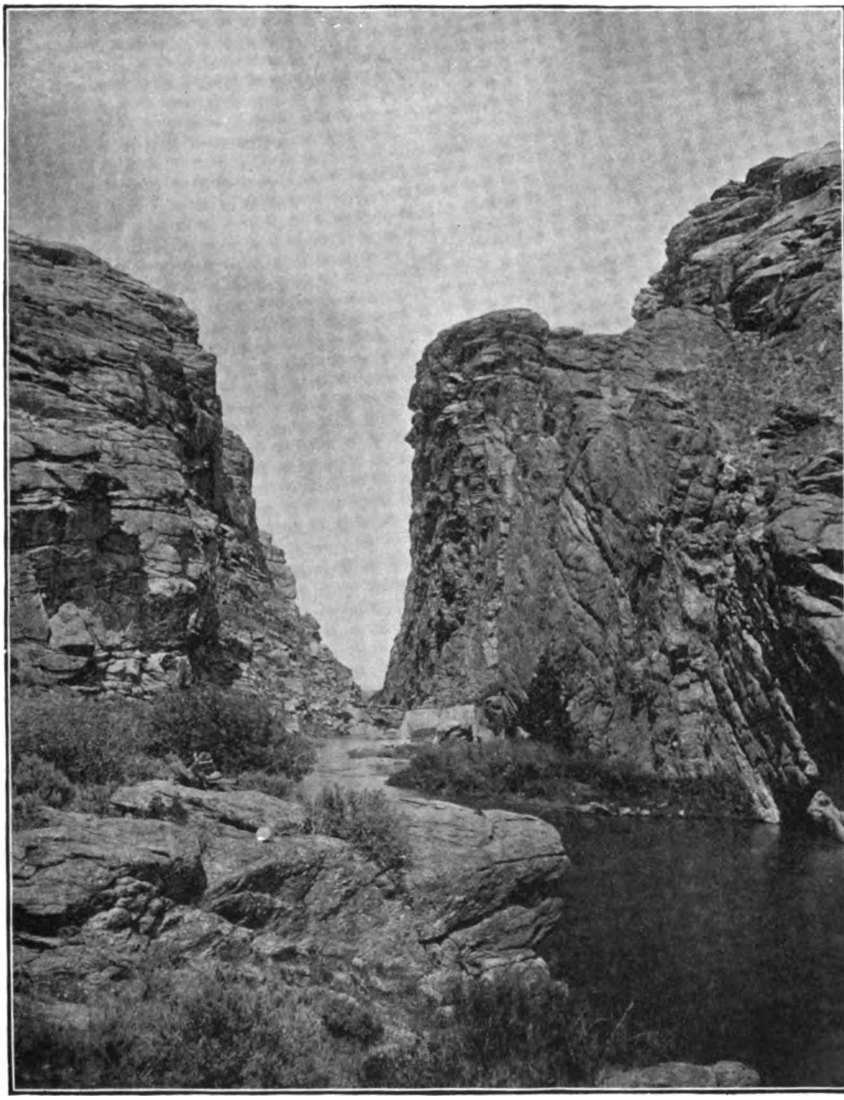

FIG. 139.—THE "DEVIL'S GATE," SWEETWATER RIVER, WYOMING.

fore to store the waters of the streams, and the limit of development in this direction seems certainly to be nothing less than the final utilization of all their flow. As reservoirs are indispensable aids to this end, it will be seen that their construction as an element of growth of the Western country is not merely 'desirable'—it is absolutely necessary. What is the proper agency to do the work?"

After discussing the financial, legal, commercial, and physical difficulties in the way of these works being carried out by private individuals or corporations on any adequate scale, he says:

"The matter of private or corporate construction of these storage-works is therefore seen to be one of very doubtful practicability from a financial point of view alone, while in neither case is it likely that reservoir-sites would be developed to their full capacity, as they should be, but only to the extent that would be most advantageous to the investment itself. . . . It is becoming more and more apparent in the course of irrigation development in the West that the waters of the streams should not be made the subject of private property, but they should inhere in the land to which they are applied, and that purchase or sale of water as a commodity should not be allowed. Although in most States the contrary doctrine has hitherto prevailed, the disposition of the courts at present and the views of practical irrigators seem to incline more and more to the doctrine of the public character of all streams. . . . It is clear that this principle can best be promoted, so far as stored waters are concerned, by having the storage-works public property. A proper development of a storage system for the waters of Western streams, it is thus seen, cannot be expected through private agencies. It must be accomplished through some form of public control."

The writer then shows that the irrigation district system of public control, though theoretically advantageous, has practically failed, and though the system may be improved, it could not be sufficiently comprehensive to produce best results. The question is thus resolved to State and national agencies as the only ones qualified to deal with or create a comprehensive reservoir system. He concludes that "the work is distinctly interstate in character, and is therefore less properly a State than a national enterprise. Already the interstate character of some of these streams is giving rise to troublesome questions, which only Federal authority can answer. In the case of reservoirs it not infrequently happens that some of the very best sites are to be found close to State lines, where the waters so stored will flow immediately into neighboring States. In these extreme cases the States where they are located could not, of course, be expected to construct reservoirs, and the States to be benefited would not be likely to go outside their own borders to do so. The function clearly pertains to that sovereignty which covers all the country and embraces the streams from their sources to the sea. It alone can store these waters and be sure that it is reaping the full benefit.

"Another reason why the government should have an interest in this work is that it is the largest landowner in the arid West. In Wyoming over 90 per cent of the soil belongs to the government, and its holdings throughout the West include millions of acres which can be reclaimed from their present desert condition and made productive lands. In this respect government assistance in providing water for irrigation is a simple business proposition for the enhancement of its own property."

In summarizing the arguments of which but brief extracts have been given in the foregoing, Capt. Chittenden draws conclusions from which the following extracts are taken:

"Reservoir construction in the arid regions of the West is an indispensable condition to the highest development of that section. It can be properly carried out only through public agencies. Private enterprise can never accomplish the work successfully; as between State and nation, it falls more properly under the domain of the latter.

"Reservoir construction by the General Government need not in any way involve government control of irrigation-works. These should be left in the hands of the States and private individuals under State laws.

"The total extent of a reservoir system in the arid regions which shall render available the entire flow of the streams will not exceed 1,161,600,000,000 cubic feet. If the construction of such a system were to consume a century in time, it would represent an annual storage of 266,300 acre-feet. At $5.73 per acre-foot this would cost $1,430,031 per annum. This amount distributed among the seventeen States and Territories of the arid section gives an average annual expenditure in each of $84,119. The annual value of the stored water would return the original cost and maintenance in an average period of three years."

The latter statement is based on the estimate that the future average annual value of stored water for irrigation alone throughout the arid West is not less than $2 per acre-foot, which is certainly conservative.

**Government Reservoir Surveys in Arizona.**—The waters of the Gila River in Arizona have been used for irrigation by the Pima and Maricopa Indians from time immemorial, on the lands now included within the limits of the Gila River Reservation. They are peaceable, pastoral tribes of Indians, accustomed to derive their livelihood from the cultivation of the soil. Within the past decade, however, the settlement of the upper valleys of the Gila by white farmers has been followed by such a complete diversion of the summer flow of the stream on the irrigated fields above that the Indians have been practically deprived of their accustomed water-supply, and reduced to a condition of dependence upon the government for bare subsistence. In response to an urgent appeal on their behalf made by the Indian Agent and the Commissioner of Indian Affairs to the Secretary of the Interior, an investigation was made in 1896 by Mr. Arthur P. Davis, of the U. S. Geological Survey, of the feasibility and cost of building storage-reservoirs to supply the Indians. The sites examined and reported upon were the Queen Creek site, and a site on the main Gila River at the Buttes, 14 miles above Florence.

The lack of suitable apparatus for determining the depth to bed-rock at these sites led Mr. Davis to recommend that "thorough exploration should be made with a core-drill before beginning the construction of the dam." July 1, 1898, an appropriation of $20,000 was made to continue the investigation, the money to be expended by the Director of the U. S. Geological Survey, under the direction of the Secretary of the Interior. The work was placed in the hands of Mr. Davis, and the investigation thoroughly outlined by him, the writer acting as Consulting Engineer; but before the field-work was completed, Mr. Davis was obliged to resume his studies of the water-supply of Central America with the Isthmian Canal Commission. The responsible oversight of the work was then intrusted to Mr. J. B. Lippincott, whose report was published as No. 33 of "Water-supply and Irrigation Papers." The report of the writer as Consulting Engineer was transmitted to the U. S. Senate, as Document No. 152, 56th Congress, 1st Session.

In conducting these investigations the depth of bed-rock at the various sites selected was tested by two machines, which had been successfully used on the Nicaragua Canal, and were loaned by the Nicaragua Canal Commission for the purpose. The machine consisted of a light, portable pile-driver, by which pipe from 2 to 4 inches diameter could be driven through sand, gravel, and bowlders, to bed-rock, with a diamond core-drill for penetrating the rock and bringing up a core for testing its quality. The cost of each outfit delivered in Arizona was about $1600. Six men were required to operate each machine which was capable of boring 200 feet in rock, and making 6 to 8 feet per day in hard rock, and 10 to 15 feet per day in softer rock. The average cost per foot of drilling done was $2.46. The entire amount of drilling done was 3254 feet, of which 322 feet was in rock. Five dam-sites were thus tested, as follows: Queen Creek, The Buttes, The Dikes, Riverside, and San Carlos.

The maximum depth to bed-rock at the Buttes site was 123 feet, while at the Riverside and San Carlos sites the greatest depth was found to be about 75 feet below the surface.

The net results of the investigation are summarized in the following conclusions taken from the report of the writer:

"1st. That a minimum of 40,000 acre-feet of water annually should be stored for the supply of the Indian reservation.

"2d That it is not feasible to obtain this supply from Queen

Creek, although the dam and reservoir proposed on the stream are feasible of construction if a sufficient water-supply were available.

"3d. That the Gila River is the only available source of permanent supply.

"4th. That it is not feasible or advisable to build a dam and reservoir on the Gila for storing so small a quantity as 40,000 acre-feet of capacity on account of the rapidity with which a small reservoir must be filled with silt.

"5th. That it is not feasible to construct a reservoir outside of the immediate channel of the Gila of sufficient capacity to provide for the wants of the Indians, filling the same annually by a conduit from the river.

"6th. That it is not advisable to build a dam and reservoir on the channel of the river of less capacity than one-half the total annual flow of the river in minimum years.

"7th. That feasible reservoir- and dam-sites exist on the Gila at the Buttes, Riverside, and San Carlos.

"8th. That it is not feasible to build a masonry dam at the Buttes on account of the rotten quality of the rock, the great depth to bed-rock, and the excessive height of dam required to obtain a storage of 174,000 acre-feet, or about one-half the minimum flow of the stream.

"9th. That a combination rock-fill and masonry dam is feasible to construct at the Buttes at a cost of $2,643,327, storing 174,040 acre-feet, but that it is not feasible to construct a dam of any type of greater height or capacity.

"10th. That the Buttes reservoir of the stated capacity may be expected to fill with solid matter in eighteen years, unless dredged or sluiced out.

"11th. That it is feasible to construct a masonry dam at Riverside at a cost of $1,989,605, including damages for right of way and the cost of diversion-dam at the head of the Florence Canal, forming a reservoir with a capacity of 221,134 acre-feet.

"12th. That it is feasible to increase the height of the Riverside dam at least 70 feet higher than the one estimated upon, giving an ultimate reservoir capacity of about 650,000 acre-feet, which would not be filled with solid matter short of sixty-seven years.

"13th. That it is feasible to construct a masonry dam at San Carlos at a cost of $1,038,926, including damages for right of way and the cost of new diversion-dam at the head of the Florence Canal, forming a reservoir of 241,396 acre-feet capacity; that the water-supply is ample to fill such a reservoir in the years of minimum flow, and that the volume of storage will irrigate at least 100,000 acres in addition to the irrigation of the lands of the Indians.

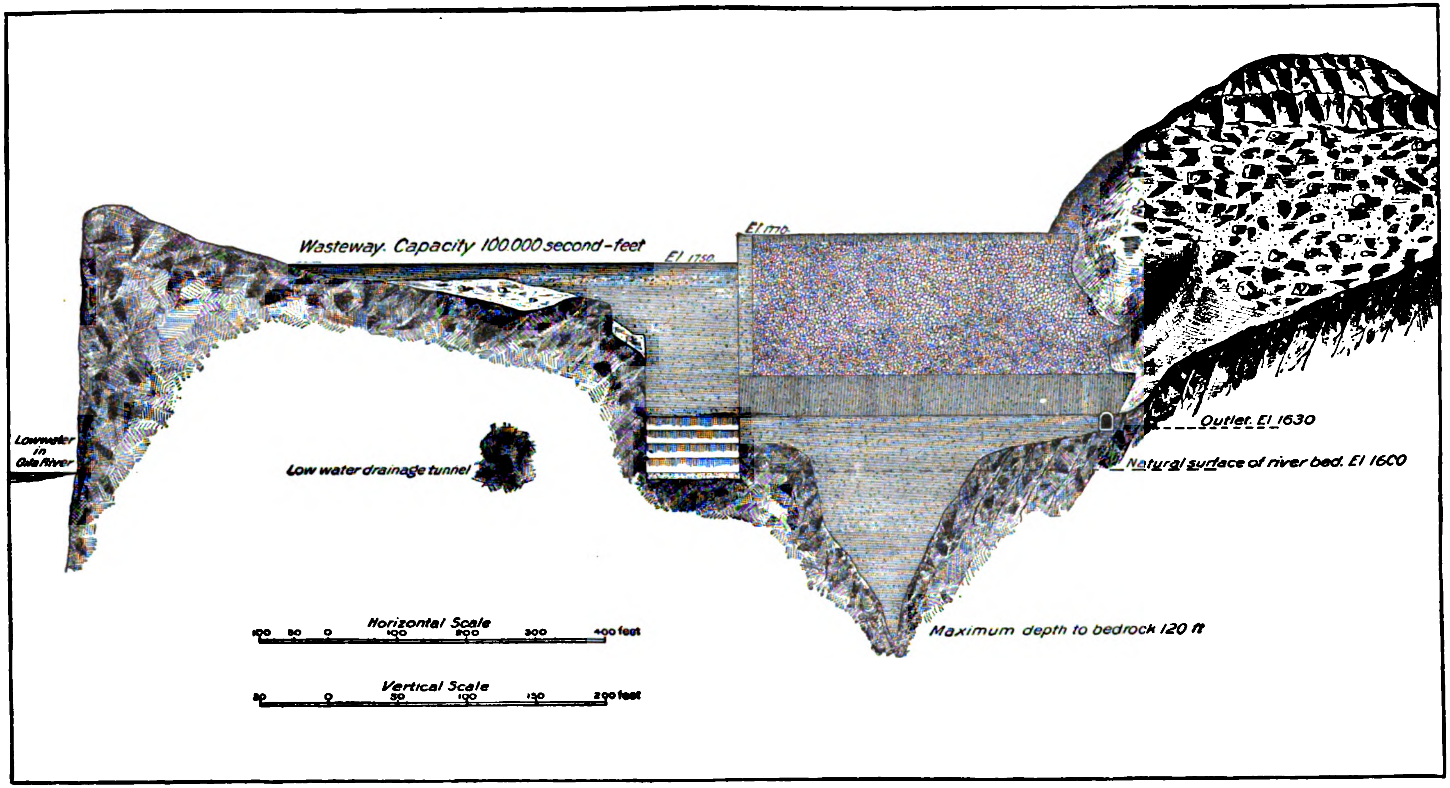


FIG. 141.—LONGITUDINAL SECTION OF BUTTES DAM-SITE, GILA RIVER, ARIZONA.

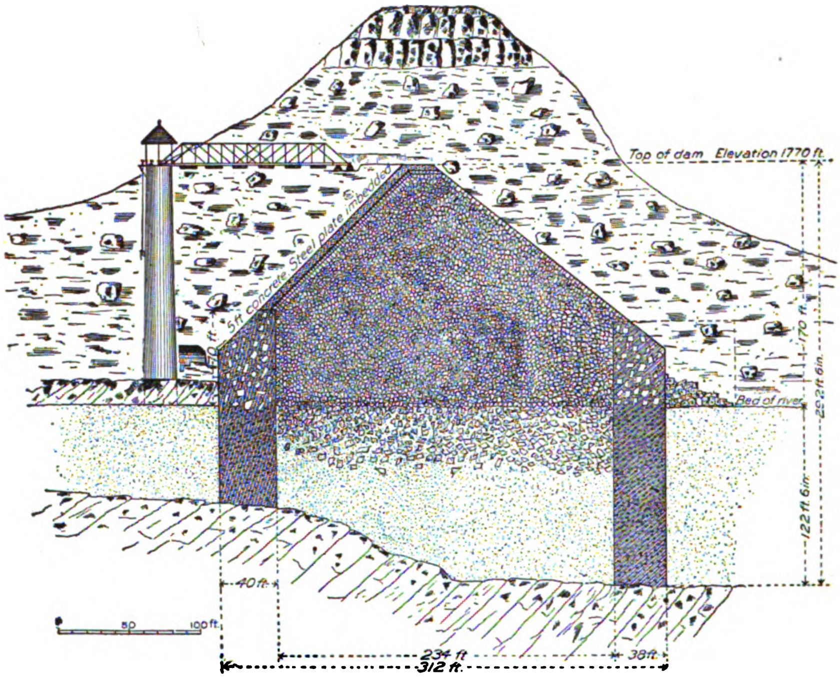


**Fig. 142.—Section of Proposed Rock-fill Dam at the Buttes, Gila River, Arizona.**

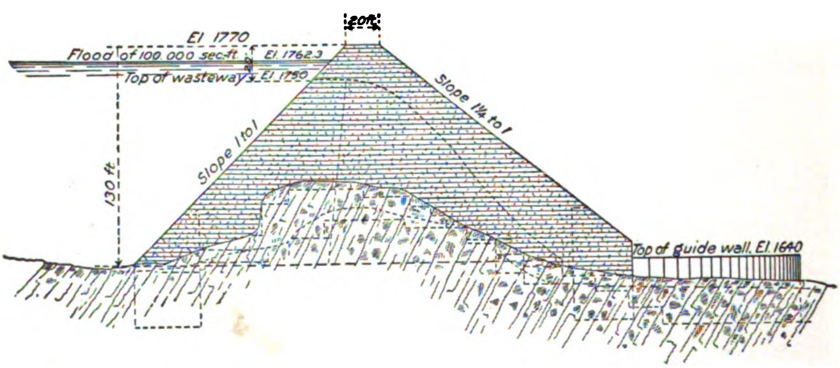


**Fig. 143.—Section of Proposed Buttes-dam through Spillway, showing End Wall of Rock-fill, Gila River, Arizona.**

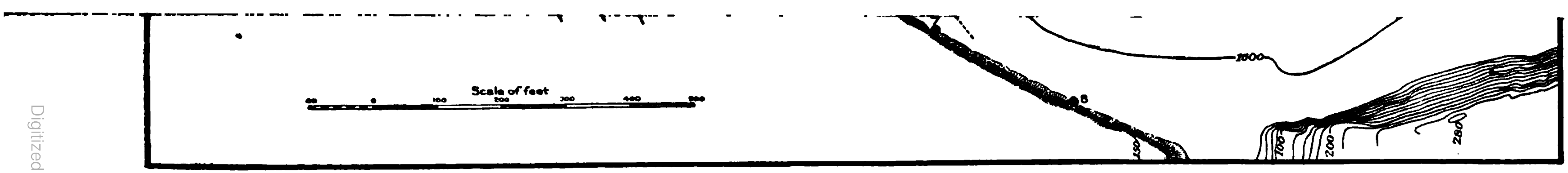


FIG. 144.—PLAN OF BUTTES DAM-SITE, SHOWING LOCATION SELECTED FOR ROCK-FILL DAM, GILA RIVER, ARIZONA.

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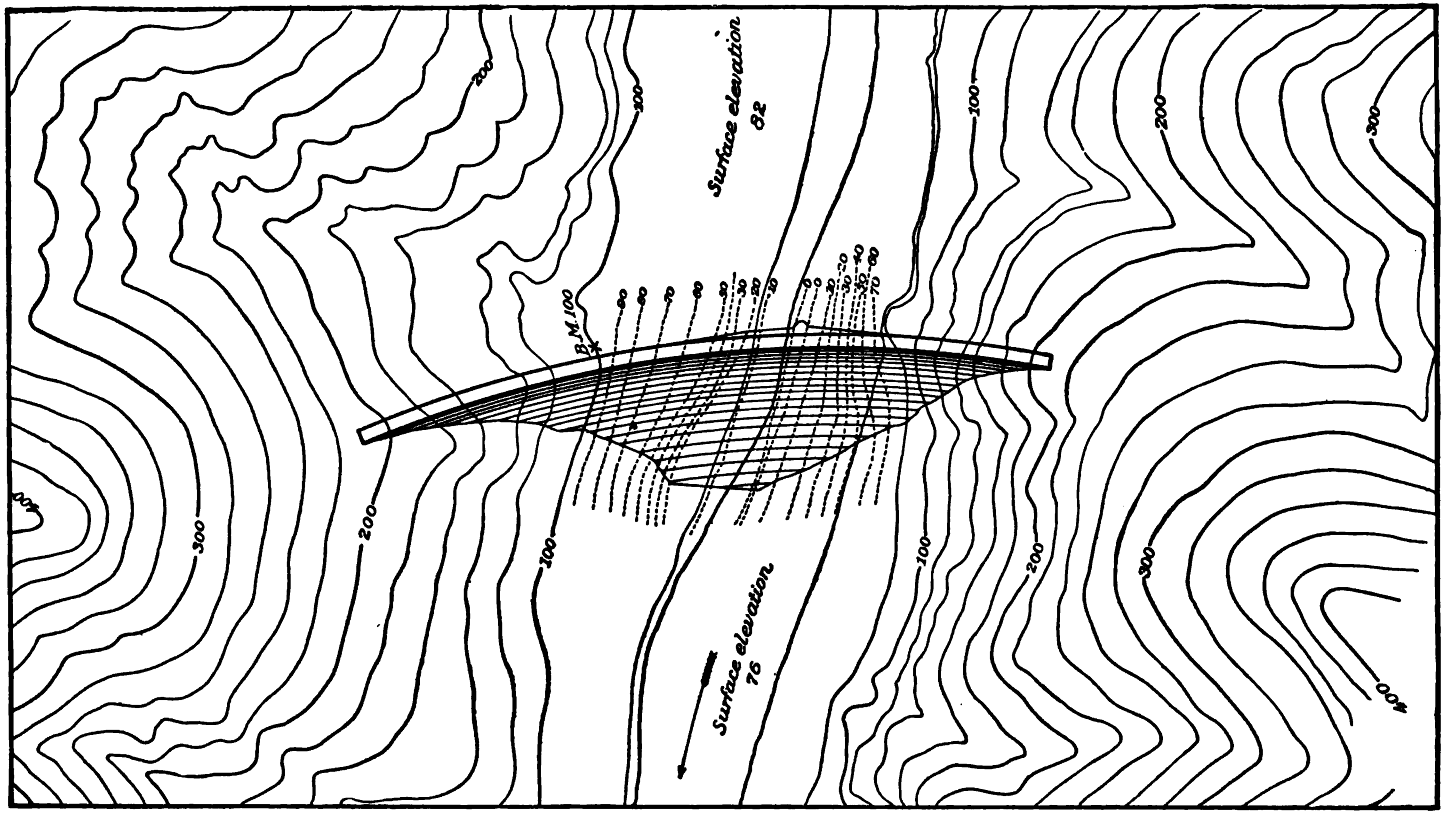



FIG. 145.—PLAN OF RIVERSIDE DAM-SITE, GILA RIVER, ARIZONA, SHOWING LOCATION SELECTED FOR A PROPOSED MASONRY DAM.

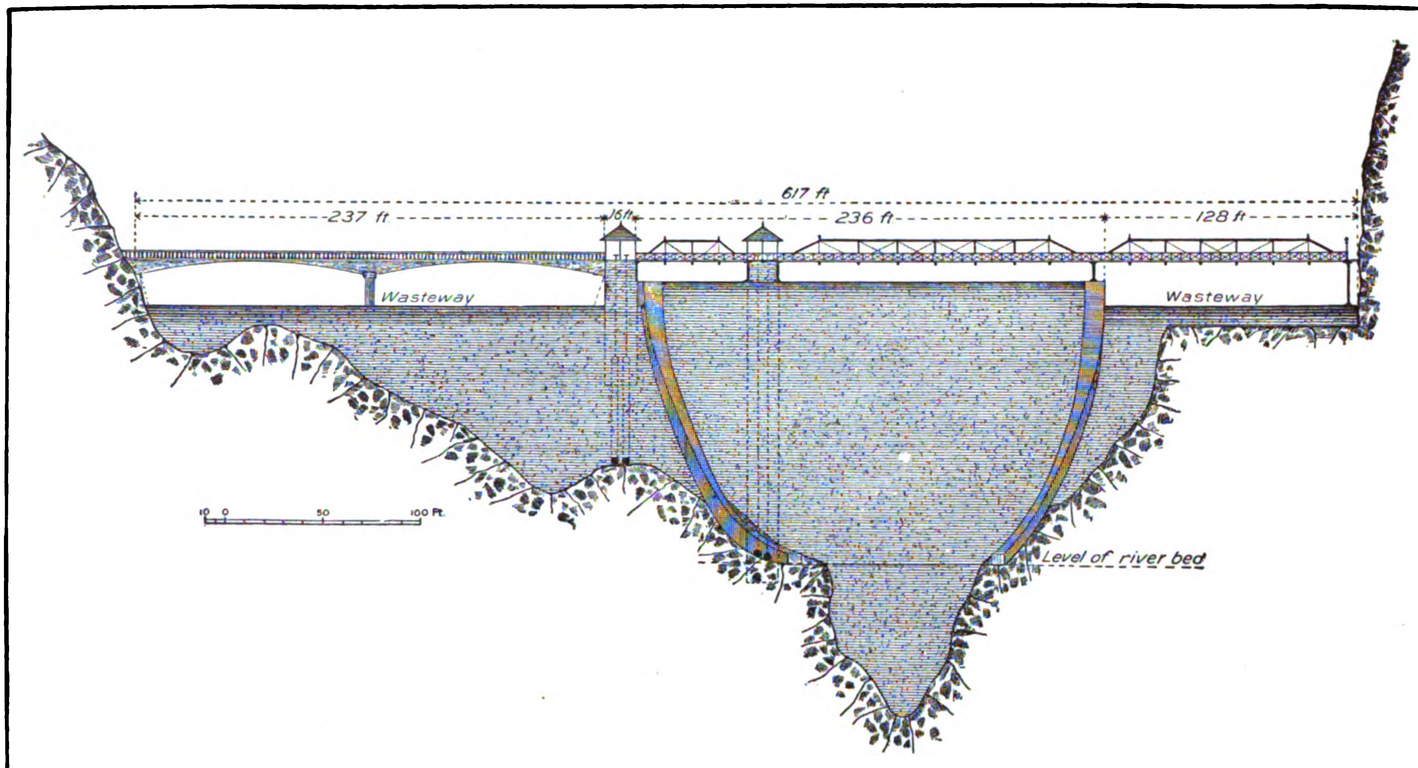
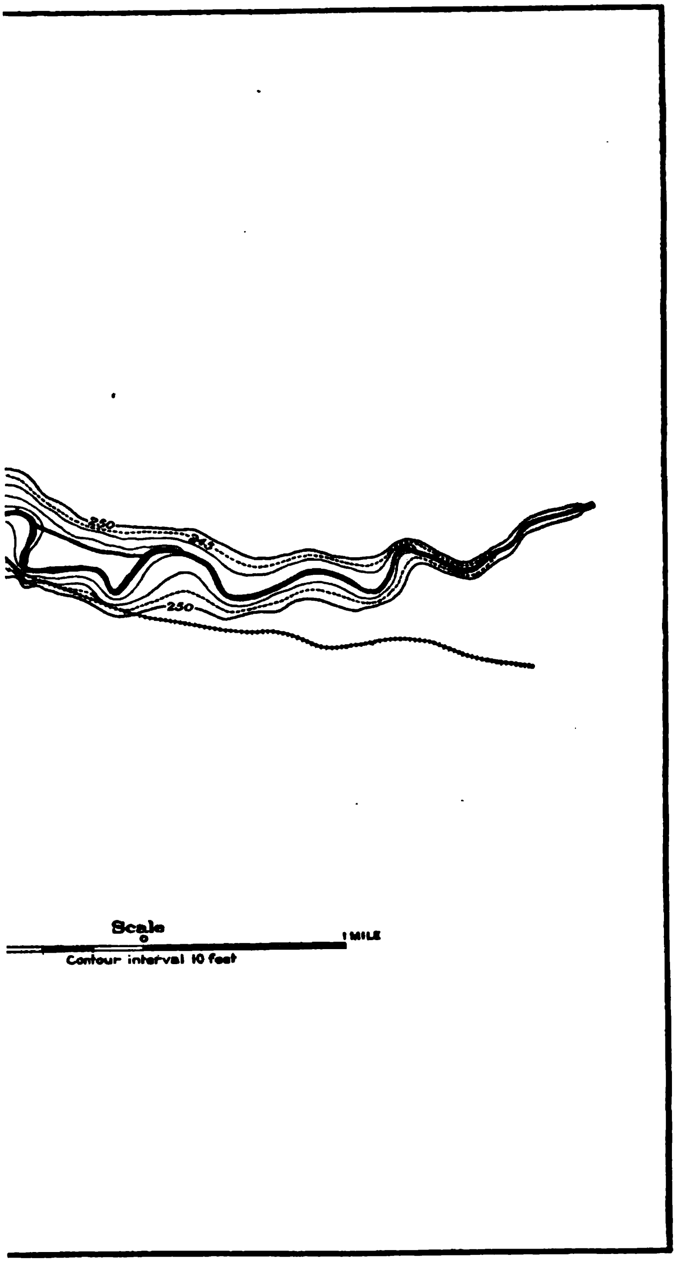



FIG. 147.—LONGITUDINAL PROFILE OF SAN CARLOS DAM-SITE, SHOWING ELEVATION OF PROPOSED MASONRY-DAM.


245
250
Scale
0
1 MILE
Contour interval 10 feet

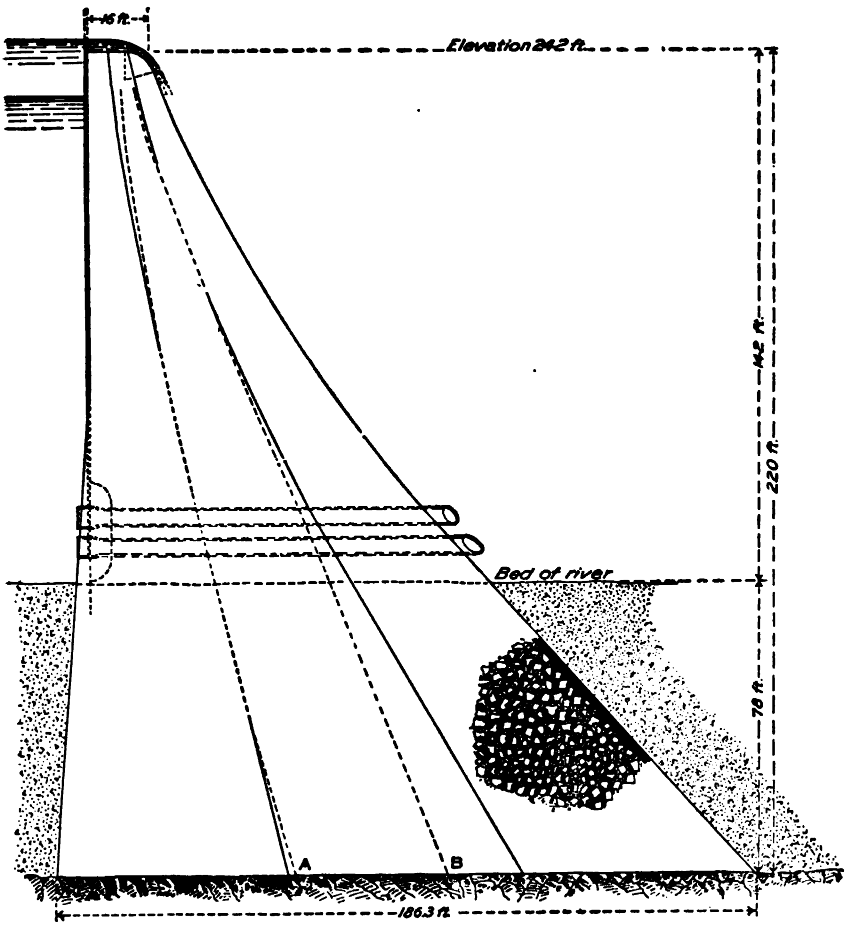



FIG. 149.—MAXIMUM PROFILE OF PROPOSED SAN CARLOS-DAM OF MASONRY, GILA RIVER, ARIZONA.

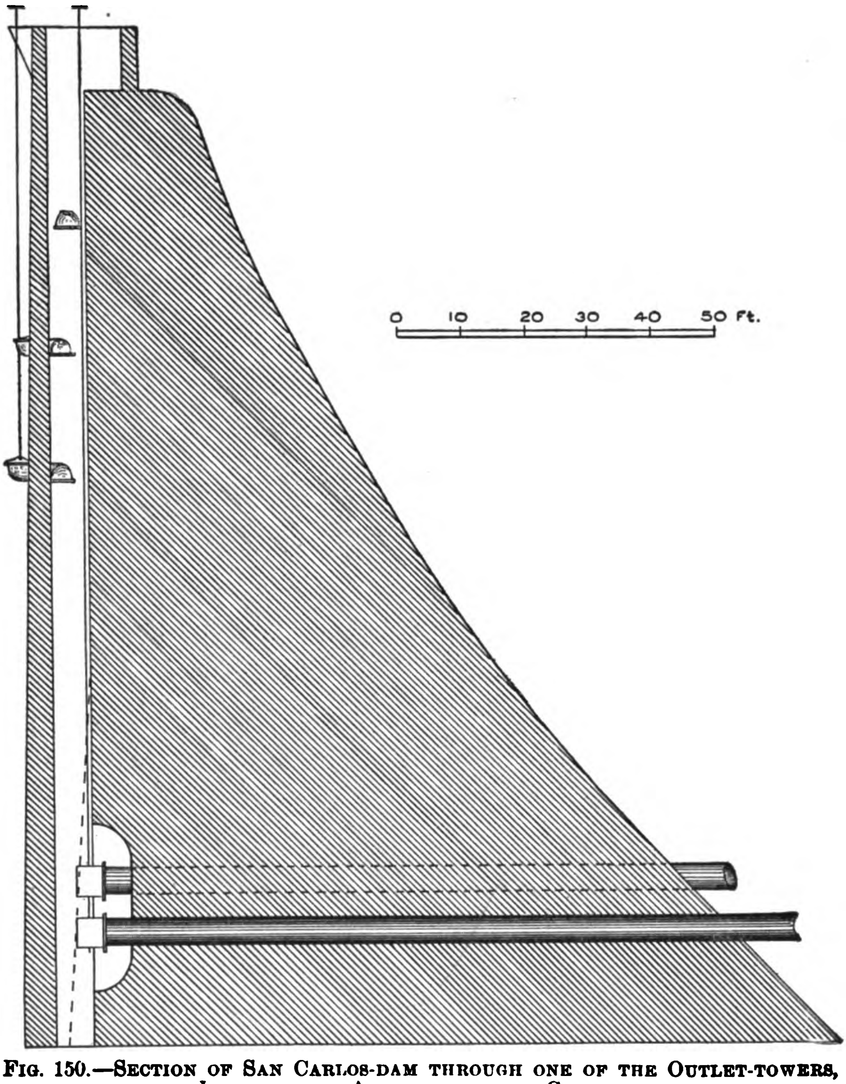



FIG. 150.—SECTION OF SAN CARLOS-DAM THROUGH ONE OF THE OUTLET-TOWERS, ILLUSTRATING ARRANGEMENT OF CONTROL.

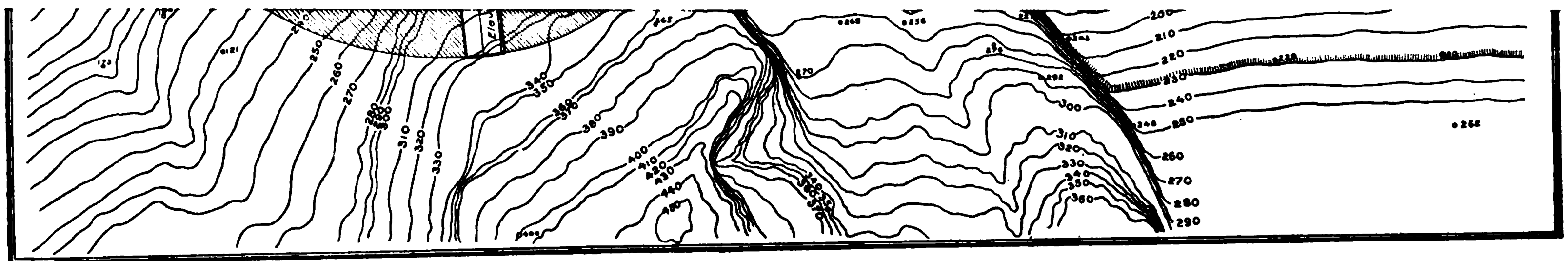


FIG. 148.—CONTOUR PLAN OF SAN CARLOS DAM-SITE, SHOWING LOCATION SELECTED FOR PROPOSED MASONRY DAM.

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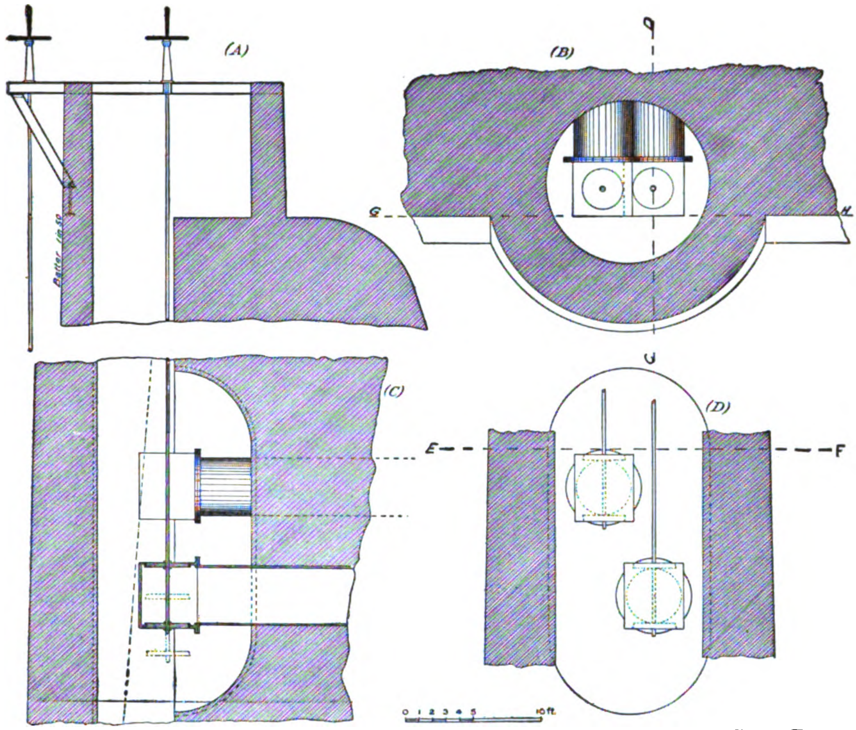



**Fig. 151.—Details of Outlet tower and Gates, San Carlos dam, Gila River, Arizona.**

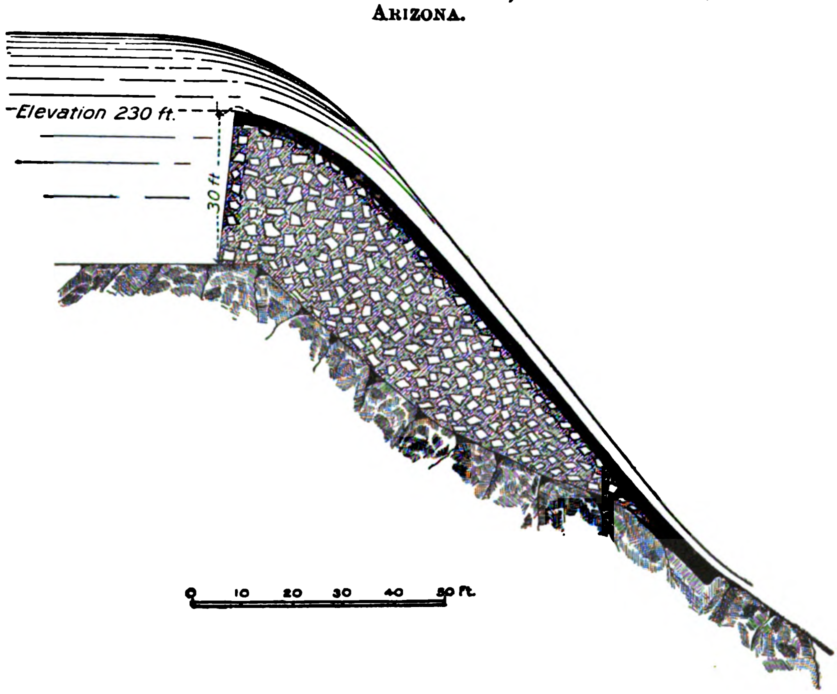



**Fig. 152.—San Carlos-dam, Arizona, Section through Spillway.**

"14th. That it is feasible to construct a dam at San Carlos at least 70 feet higher than that contemplated in the estimates, forming a reservoir whose ultimate capacity would be approximately 550,000 acre-feet, and whose probable life of usefulness would be sixty-three years before becoming filled with silt."

Unquestionably the best dam-site yet discovered is that located in the narrow canyon immediately below the San Carlos Apache Indian reservation. The walls of the canyon are but little more than 100 feet apart at the level of the river-bed, and are composed of hard limestone, the lowest stratum being a pink color, and the upper layers dark gray, both of high specific gravity, and affording very satisfactory foundation for a high masonry dam. The maximum height of dam planned for this location from deepest bed-rock to the top of the central portion of the dam is 216 feet, and the maximum length, including spillways, is 617 feet. The spillway on the left bank is excavated almost wholly out of the solid cliff, and is 128 feet in length. That on the opposite side of the dam is 237 feet in length, and is approached by a channel excavated largely from the mountainsides. The rock from these spillways will be used in constructing the dam. The central portion of the dam is 236 feet long, and is raised 12.5 feet above the crest of the spillways. The latter have a discharging capacity of 57,000 acre-feet at that depth. Three feet additional depth would give a discharge of 79,000 second-feet over the spillways and 1000 second-feet over the body of the dam, which is so greatly in excess of the probable volume to be cared for in flood, owing to the equalizing effect of the large reservoir above, that no water will, in all probability, ever pass over the central portion of the dam. The section, however, has been planned heavy enough to withstand the shock of any overflow that may occur in addition to the normal water-pressure. The crest width is to be 16 feet, and the extreme base 183.6 feet.

It is proposed to construct the dam of concrete masonry made with Portland cement ground with silica and to constitute what is known as "sand cement," as the binding material, which will be used with sand and broken stone in the usual manner. In the body of the concrete, large blocks of stone will be embedded as closely together as possible consistent with a perfect ramming of the concrete. The lines of pressure, with reservoir full and empty, are well within the inner third of the dam, resulting in a safe gravity structure. Expansion and contraction are provided for by arching the dam up-stream. The maximum pressure on the downstream toe is computed at 12.5 tons per square foot, and at 12 tons per square foot on the upper toe.

The outlets to the dam are to be made through two semicircular towers. The intakes into the towers are a series of elbows, with plain cap or cover, six in number to each tower, each 3 feet in diameter.

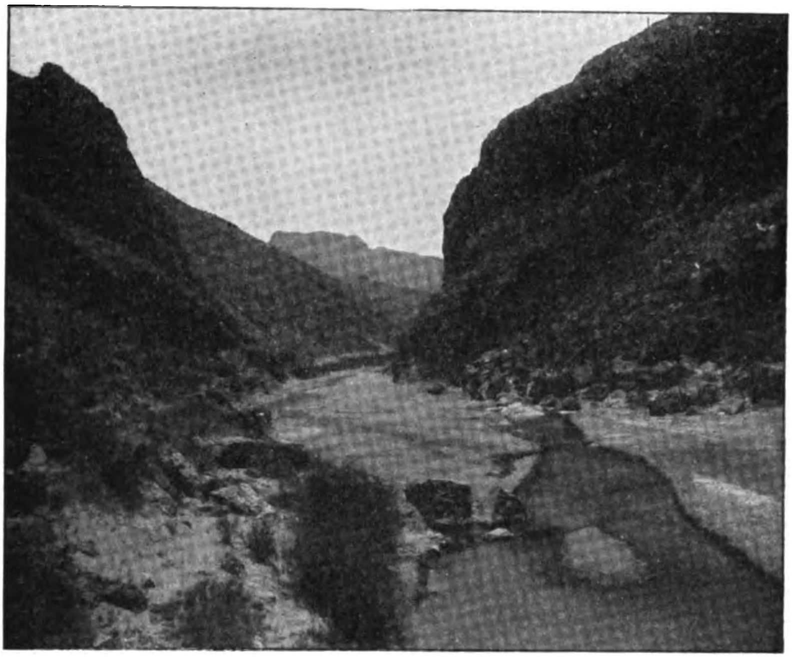


FIG. 152a.—SAN CARLOS DAM-SITE, LOOKING DOWN-STREAM.

FIG. 153.—BORING APPARATUS, CONSISTING OF PILE-DRIVER AND DIAMOND-CORE DRILL AT WORK. USED FOR TESTING BED-ROCK AT GILA RIVER DAM-SITES, ARIZONA.

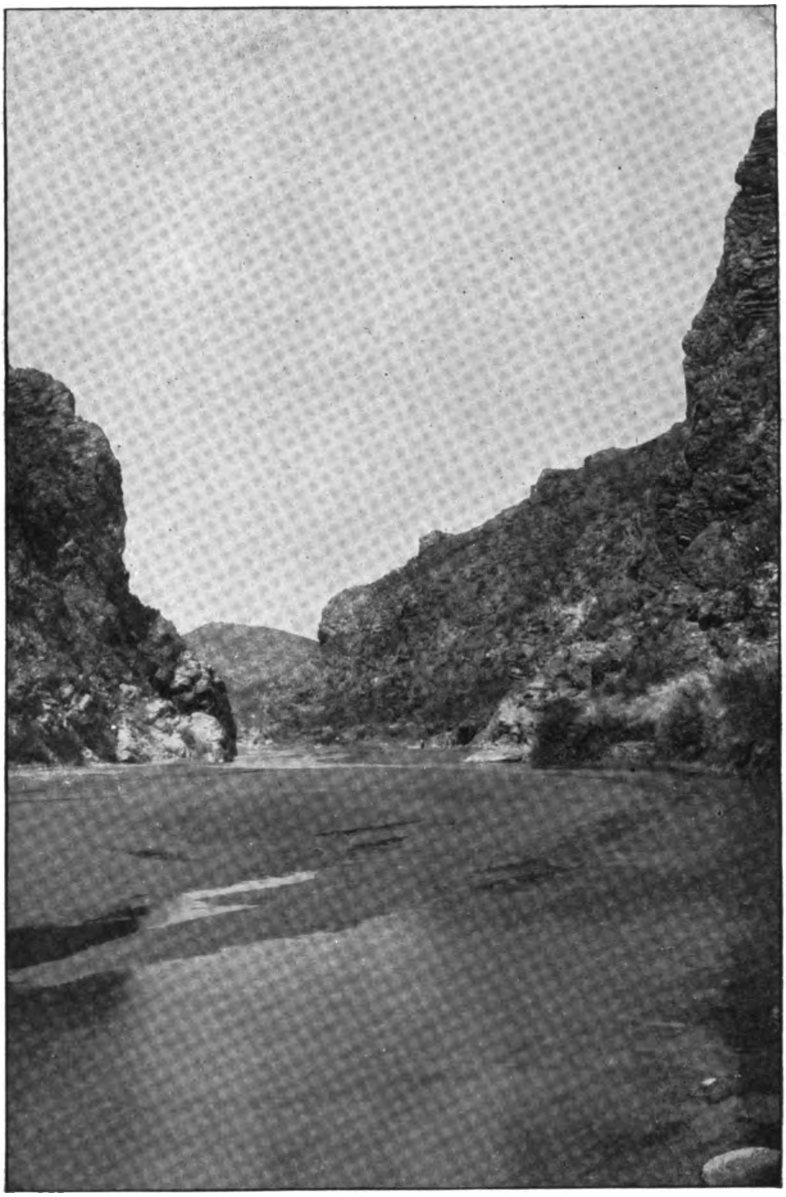


FIG. 154.—VIEW OF THE SAN CARLOS DAM-SITE, GILA RIVER, ARIZONA.

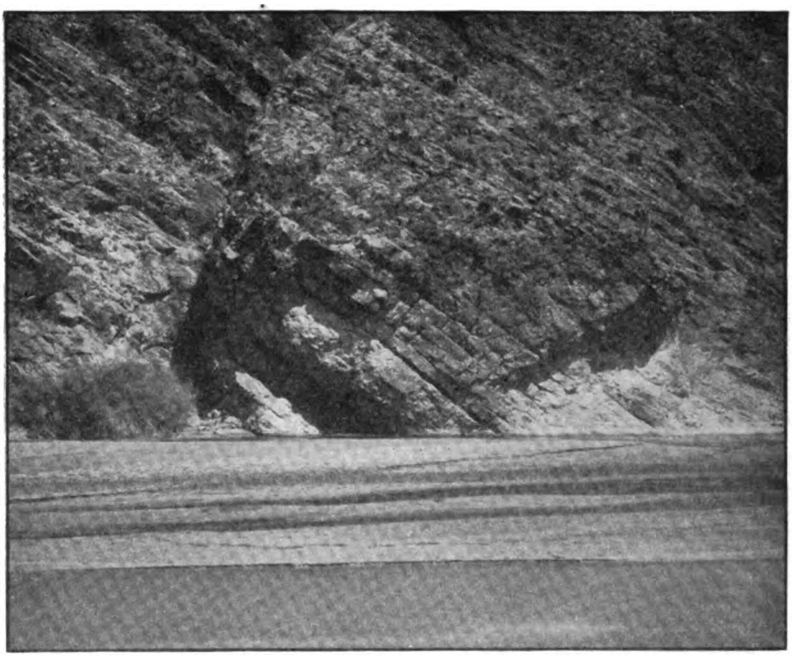


FIG. 154*a*.—VIEW OF LEFT ABUTMENT WALL, SAN CARLOS DAM-SITE, SHOWING DIP OF LIMESTONE.

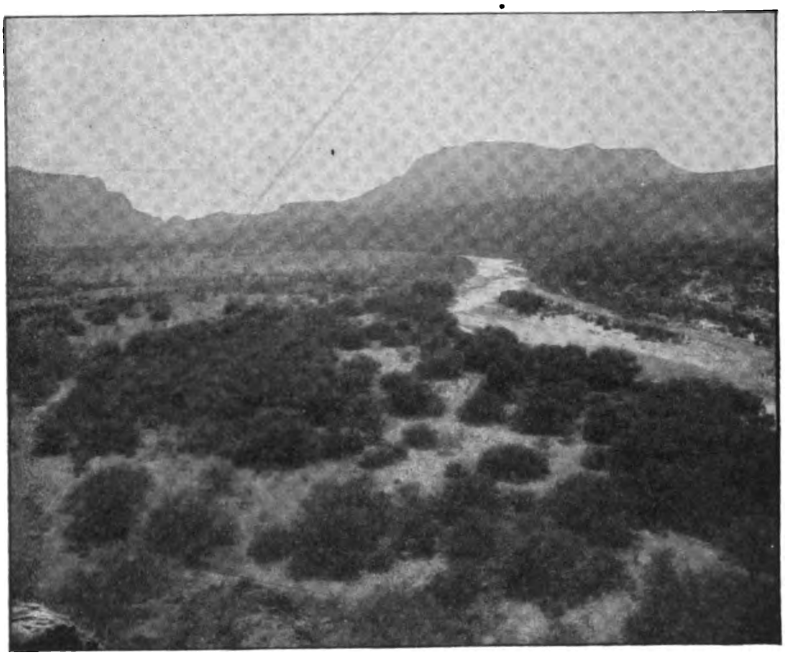


FIG. 155.—VIEW OF THE BUTTES DAM-SITE LOOKING DOWN-STREAM.

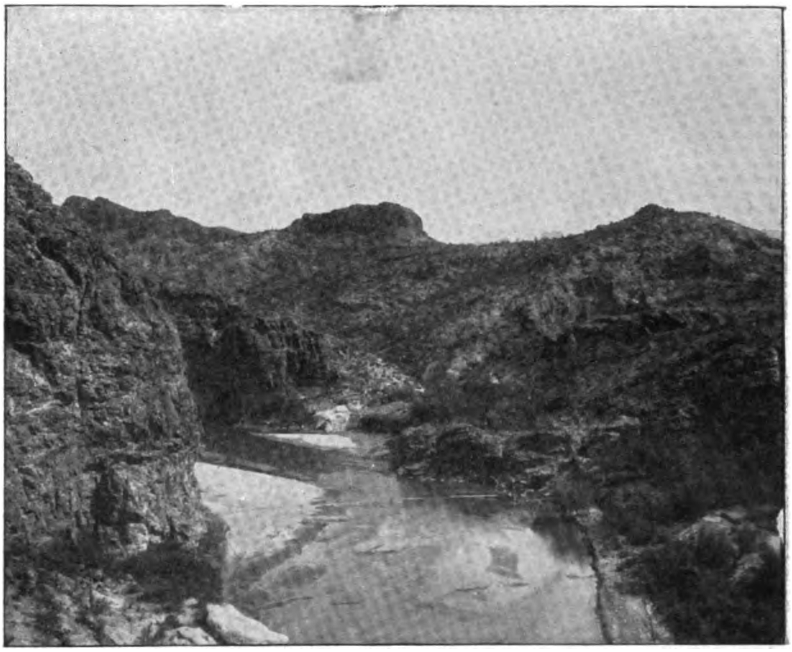


FIG. 155*a*.—BUTTES DAM-SITE, LOOKING UP-STREAM FROM UPPER TOE.

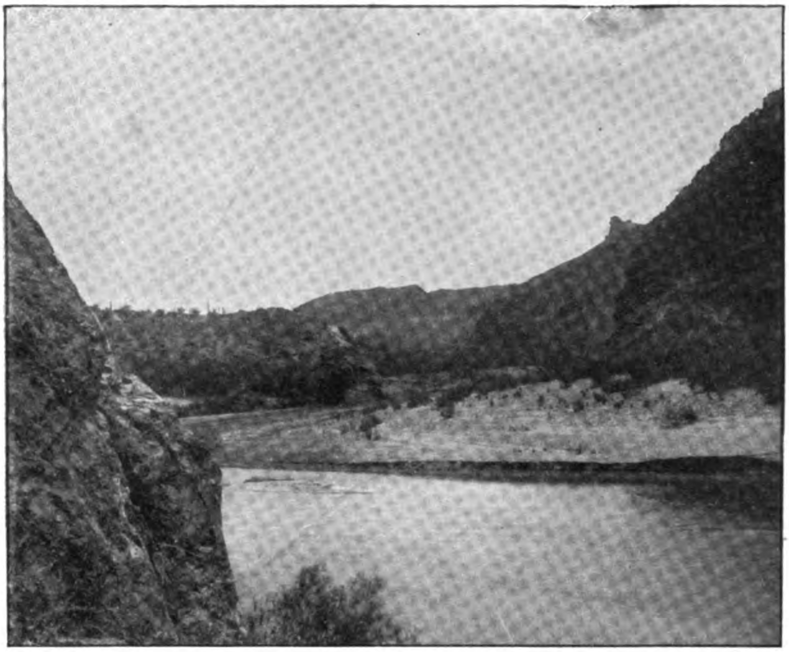


FIG. 156.—BUTTES DAM-SITE, LOOKING UP-STREAM; PROPOSED QUARRIES ON LEFT; SPILLWAY ON LEFT OF CENTER OF FIELD.

From each tower two 48-inch pipes pass through the dam, discharging into the river-bed below. These are controlled by balanced valves placed inside the tower.

The reservoir will cover an area of 6230 acres at the 130-foot contour above river-bed at the dam, to a mean depth of 39.2% of the maximum. This will be entirely on the Apache Indian reservation, and will flood 587 acres of land that has been irrigated and farmed by the Indians. Of the remaining area, 1405 acres are irrigable and 3360 acres cannot be tilled. An abundance of equally good land on the reservation can be provided with facilities for irrigation above the reservoir-site. The estimate includes

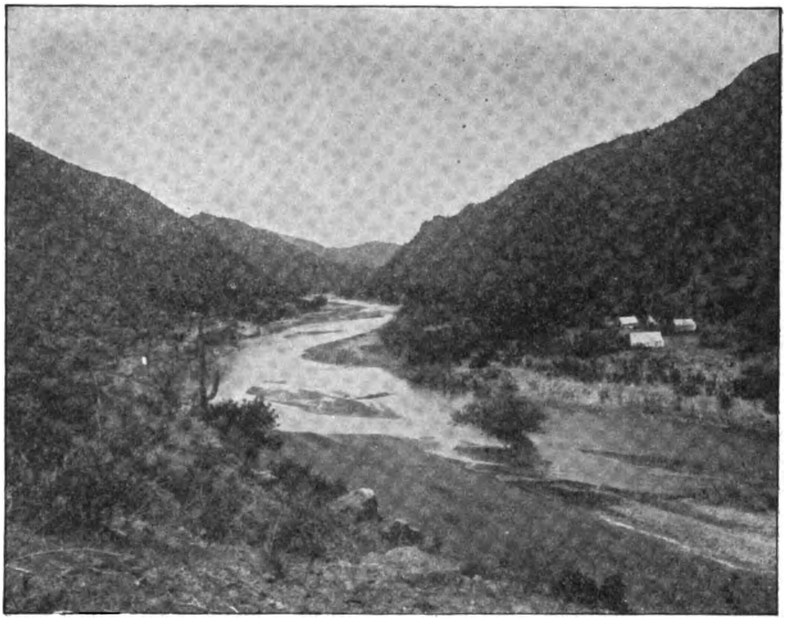


FIG. 137.—VIEW OF RIVERSIDE DAM-SITE, GILA RIVER, ARIZONA.

$20,000 for these substitute works. The removal and reconstruction of the buildings of the Indian agency is estimated to cost $60,000, and the rebuilding of five miles of the Gila Valley, Globe and Northern Railway is estimated at $50,000, including the removal of two bridges. The entire cost of the dam and the contingent expenses noted, including the cost of new head-works for the canal to convey water to the reservation, located on the river, 60 miles below, is estimated at $1,038,926, or $4.30 per acre-foot of storage capacity.

For the details of the entire system of proposed reservoirs on the Gila River the reader is referred to the able and interesting report of Mr. J. B. Lippincott, M. Am. Soc. C. E., in "Water-supply and Irrigation

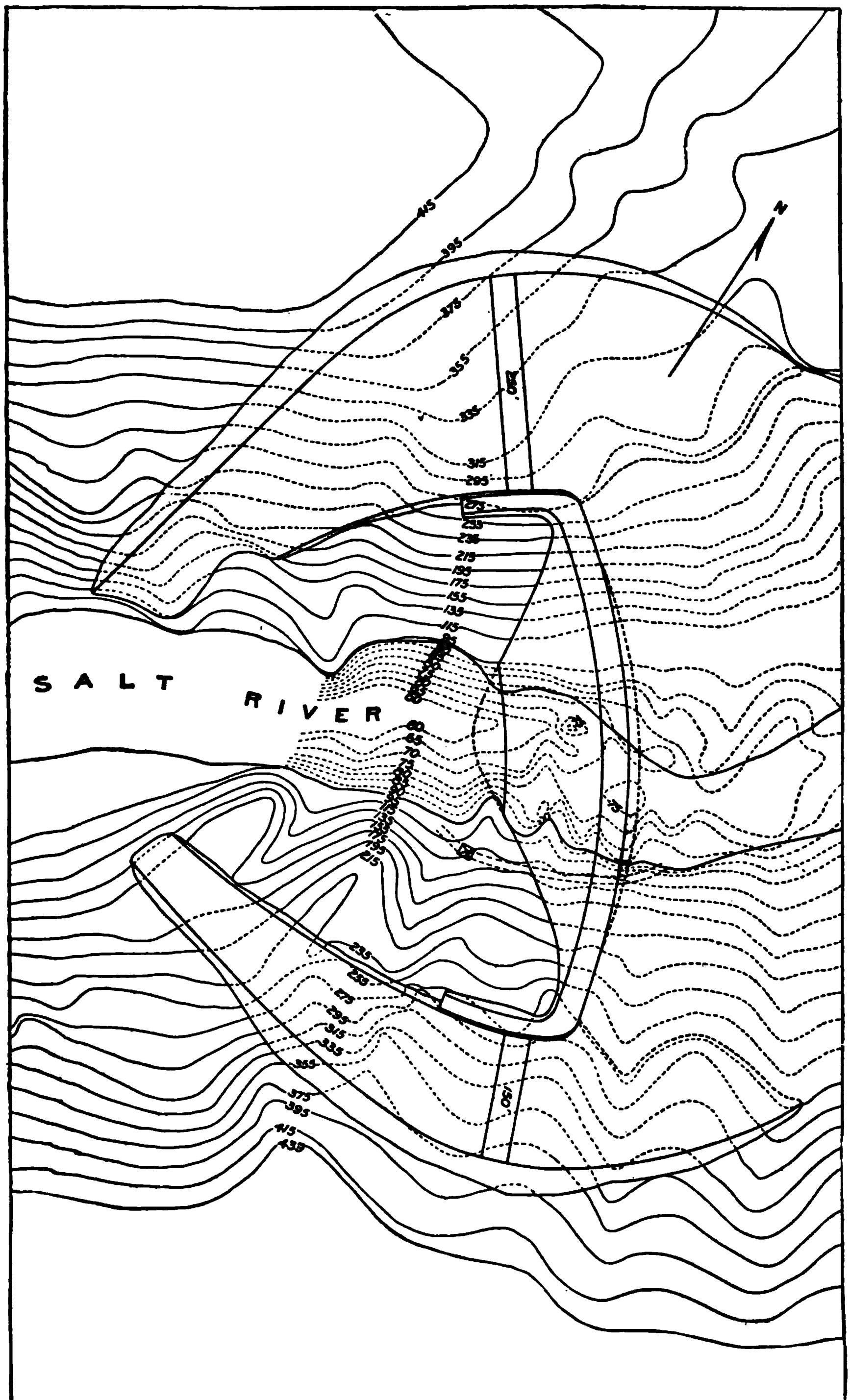



FIG. 158.—PLAN OF TONTO DAM.

Papers," No. 33, from which the cuts illustrating the plans, prepared by Mr. J. H. Quinton, M. Am. Soc. C. E., in collaboration with the writer and Mr. Lippincott, have been obtained by courtesy of the Director of the U. S. Geological Survey.

The manifest duty of the government to provide a water-supply for the impoverished and dependent Indians, which will enable them to become again self-supporting, has been used as a lever to commit the government to the policy of reservoir-construction in the arid West, and it is hoped by the advocates of this policy that the entering wedge will be formed by the construction of the San Carlos dam on the Gila. It has been shown by Mr. Lippincott's report that sufficient water may be impounded by the dam to irrigate over 100,000 acres of valuable land belonging to the

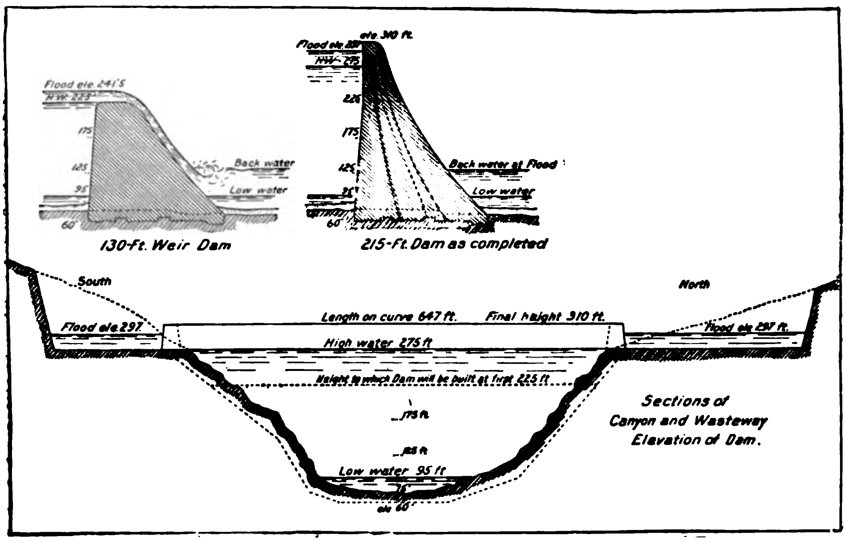



FIG. 159.—SECTIONS OF DAM AND CANYON OF TONTO RESERVOIR.

government, in addition to supplying the Indians, the value of which, with such permanent water-rights, will exceed $5,000,000. In addition the expense of feeding the Indians, amounting to $109,500 per annum, would be saved.

The relative estimates of the cost of the dams reported upon on the Gila River show that the Buttes dam would cost $15.19 per acre-foot; the Riverside dam, $9.01 per acre-foot; and the San Carlos dam, $4.30 per acre-foot of storage capacity.

**Tonto Basin Dam, Arizona.**—Of all the reservoir projects for irrigation-storage in Arizona, the largest and most extensive is that of building a high masonry dam on Salt River, and converting the great Tonto Valley

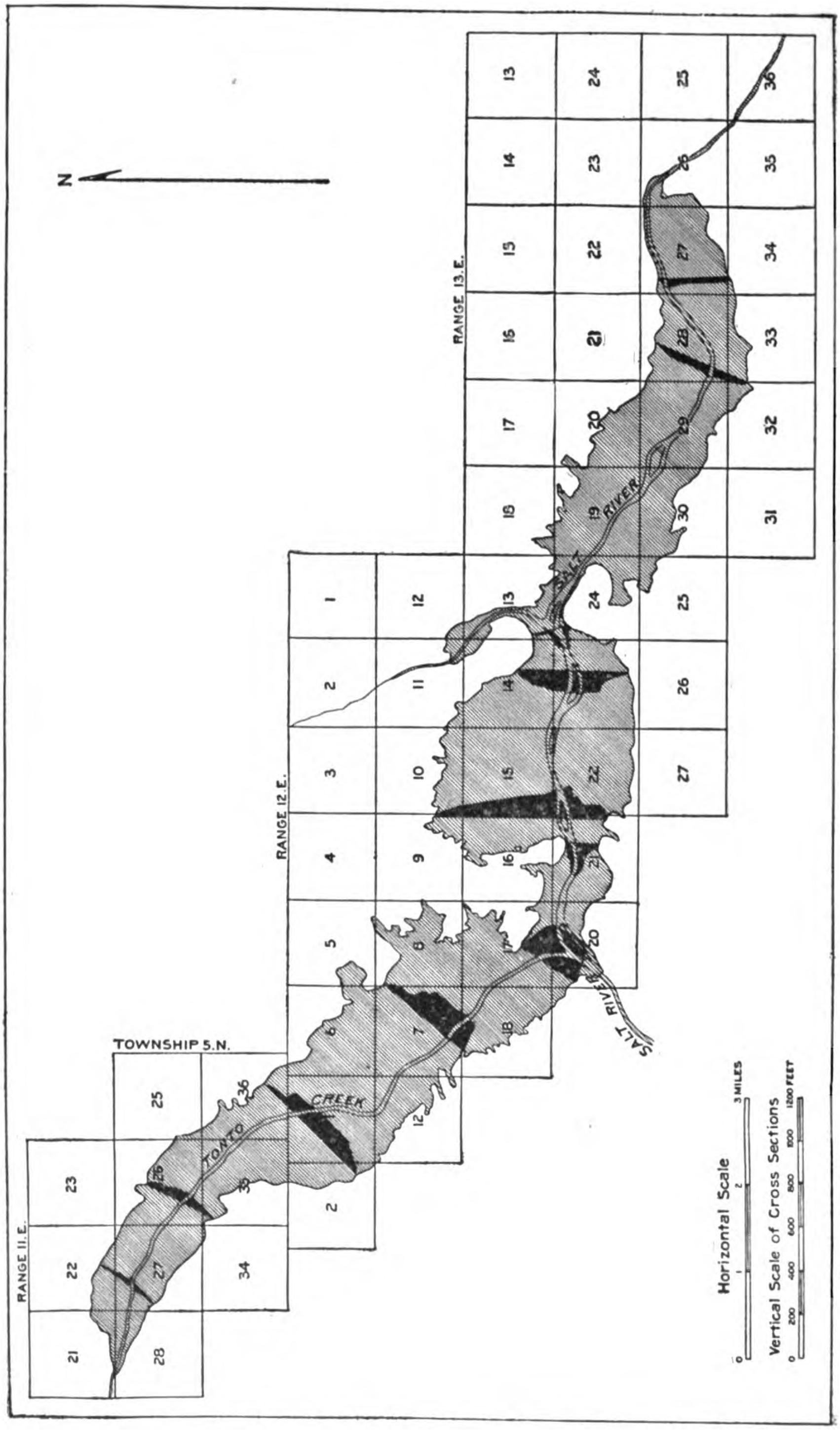



FIG. 160.—MAP OF TONTO BASIN RESERVOIR, SHOWING ELEVATIONS OF TEN CROSS-SECTIONS OF THE RESERVOIR.

into an enormous reservoir, covering 14,200 acres and impounding over one million acre-feet of water. The dam projected will be 200 feet in height above the ordinary low-water level of the stream (Figs. 158 and 159). The extreme height of the dam above its foundation will be 250 feet, and its length on top will be 647 feet, measured on the arc of its curvature up-stream, which is to be on a radius of 818.5 feet.

The scheme is projected by the Hudson Canal and Reservoir Company of New York, and is a combined irrigation and electric-power project, the

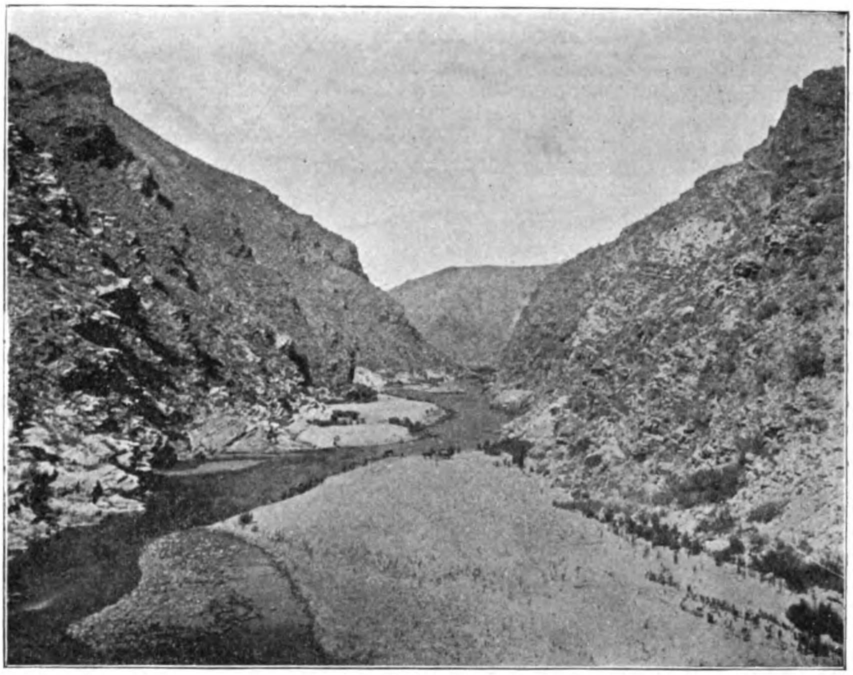


Fig. 161.—Tonto Basin Dam-site, Salt River, Arizona, looking down-stream. The Carriage is standing on the Line of the Dam.

same water being used for both purposes. The estimated cost of the reservoir and dam, capable of storing water for the irrigation of 500,000 acres of land, is $2,450,000. The cost of the electric plant and transmission lines for developing and delivering 6768 H.P. is estimated at $1,152,000, a total of $3,602,000, including interest on capital invested during construction. The estimated net revenue, based partly on actual contracts, is $1,134,000 per annum, of which $560,000 would be derived from the sale of water to canal companies and new lands in the lower Salt River and Gila River valleys, and the remainder from the sale of power to mining companies.

The outline of the reservoir (Fig. 160) is mapped only to the 180-foot contour, and the ultimate height of the water-level will cover a much greater surface than is shown by the map. Mr. A. P. Man, Chief Engineer of the company, by whose courtesy the plans and maps have been made available for this work, furnishes information as to the hydrography of the basin, from which the following data are compiled:

The area of the watershed above the dam is 6260 square miles; the elevation of the base of the dam at low-water level is 1925 feet above tide-water. The maximum altitude of the watershed is about 7000 feet, and the mean precipitation upon the shed is estimated at 23 inches per annum. The run-off for seven years has been computed as follows:

| Year. | Acre-feet. | Year. | Acre-feet. |
|---|---|---|---|
| 1889 | 1,111,790 | 1894 | 297.704 |
| 1890 | 1,659,726 | 1895 | 1.124,196 |
| 1891 | 1,999,093 | | |
| 1892 | 663,025 | Mean..... | 1,125,466 |

The mean of these seven years would represent about 15 per cent of a mean precipitation of 23 inches. The maximum flood yet recorded, that of February, 1891, was 180,000 second-feet for 24 hours. This would have filled the spillways to a depth of 22 feet, while the crest of the dam is intended to be 13 feet higher than this miximum-flood height. Maps of the region to be irrigated by the water from this reservoir are given in Figs. 163 and 164.

The mean annual run-off from the Salt River basin has been computed from the records of gaugings made of the streams at 177 acre-feet per square mile of watershed, while the flow of the Gila above the Buttes averages but 26 acre-feet per square mile of shed. The difference is doubtless due to the great elevation of the Salt River shed.

The project is regarded with great favor by all irrigators in the lower Salt River valley, for the reason that their present supply from the normal flow of the river is often greatly diminished in midsummer and early fall, so that the full productive capacity of their lands can only be reached by having a supply of stored water to draw upon during the low-water stages of the river. The canal companies are eager to purchase all the reservoired water to insure a constant supply. The reservoir company is thus in the fortunate position of being able to sell their water at wholesale to an established community of irrigators, who are in urgent need of the supplementary supply. This is a rarely favorable position for a private enterprise. The majority of such large projects have to meet with the long delay incident to the settlement of the country, which they are to provide with water before any adequate revenue can be derived from it. During

FIG. 162.—DAM-SITE ON SALT RIVER BELOW MOUTH OF TONTO CREEK.

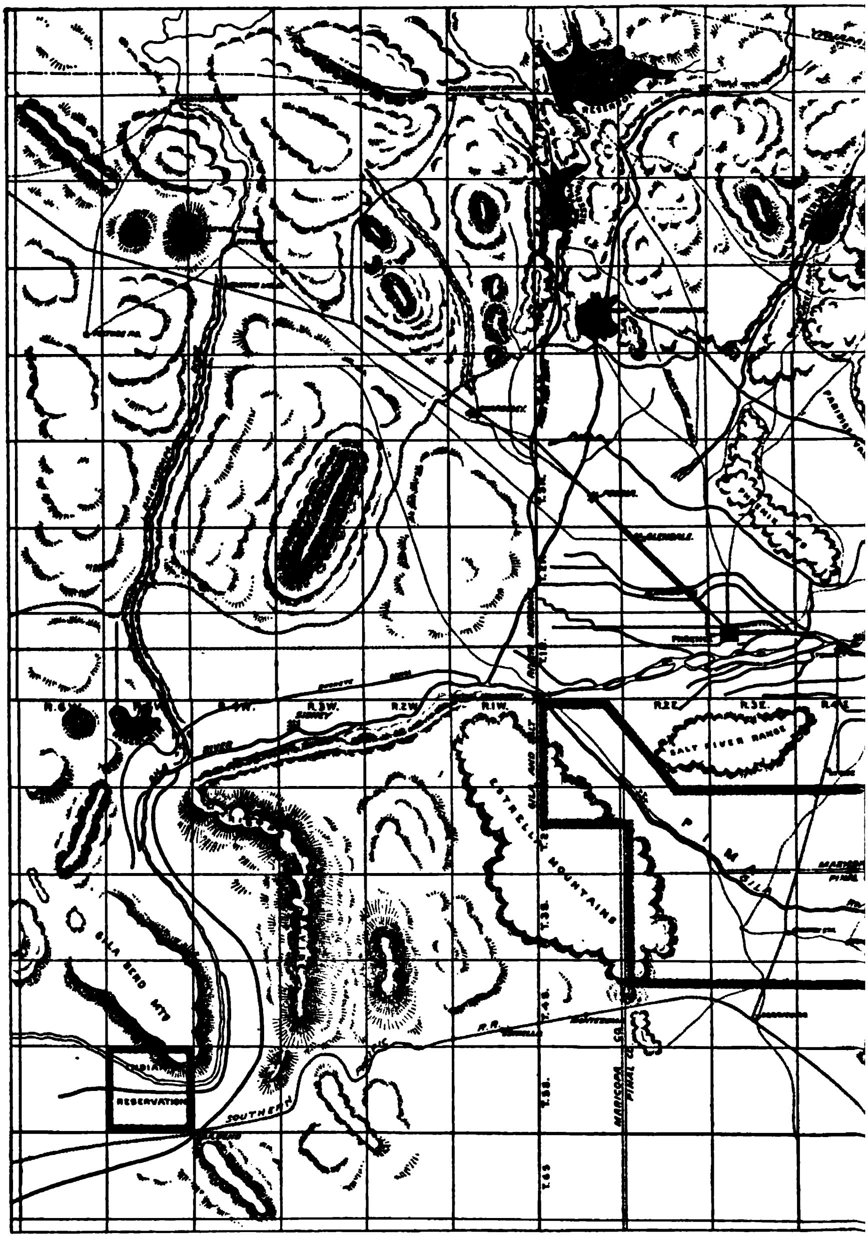
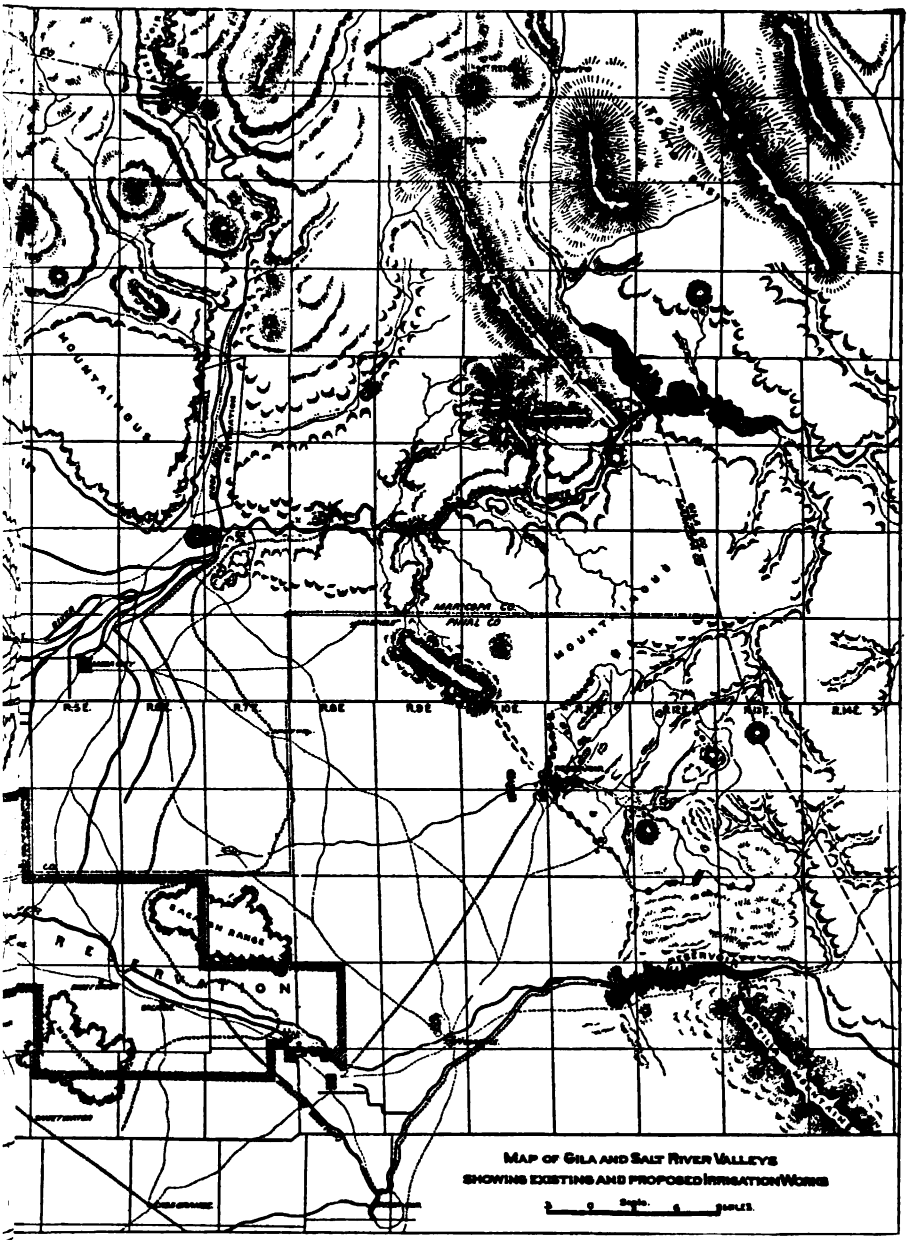



FIG. 163.—MAP OF GILA AND SALT RIVER VALLEYS




SHOWING EXISTING AND PROPOSED IRRIGATION WORKS.

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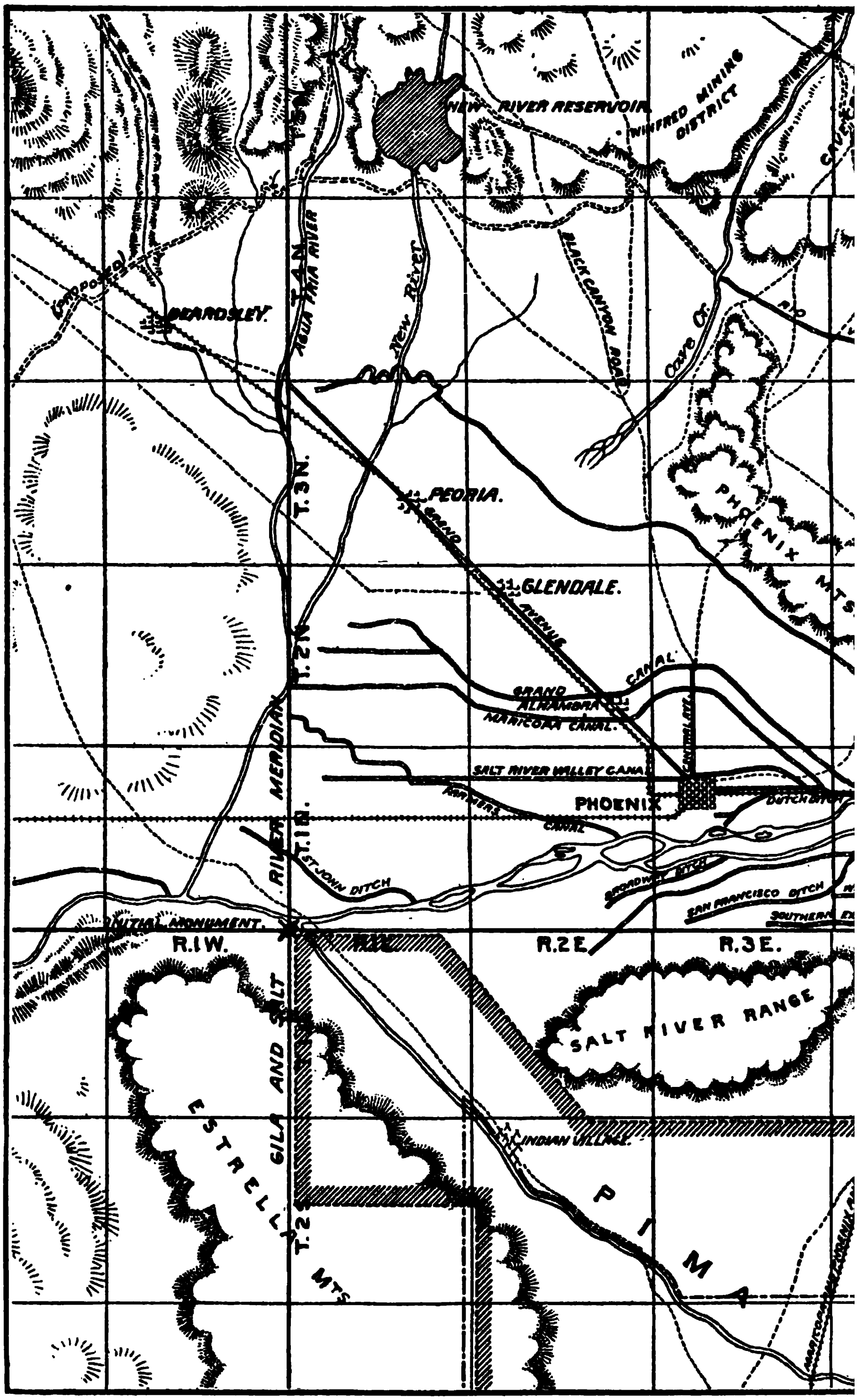
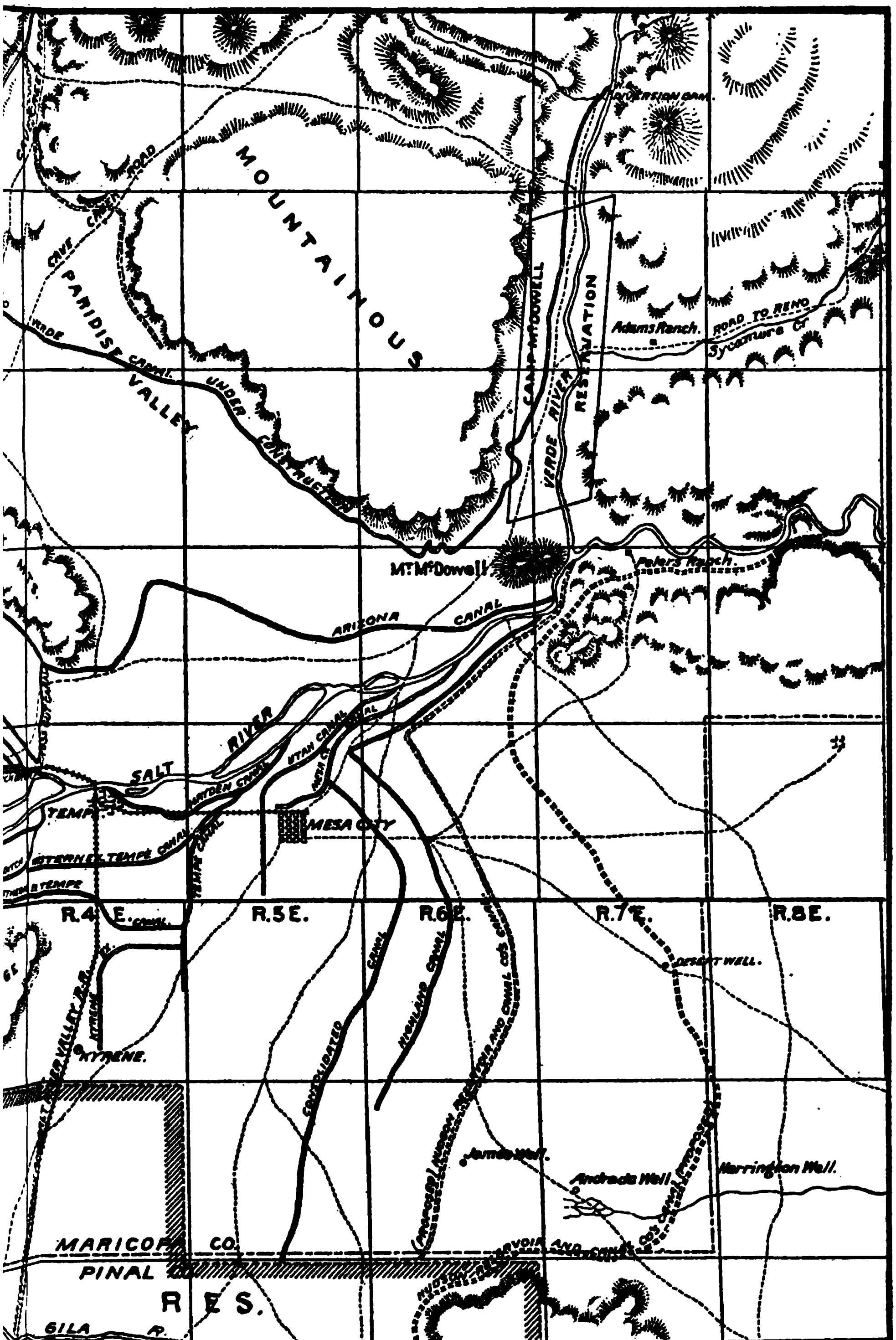



FIG. 164.—MAP OF SALT RIVER VALLEY, S




SHOWING CANALS CONSTRUCTED AND PROPOSED.

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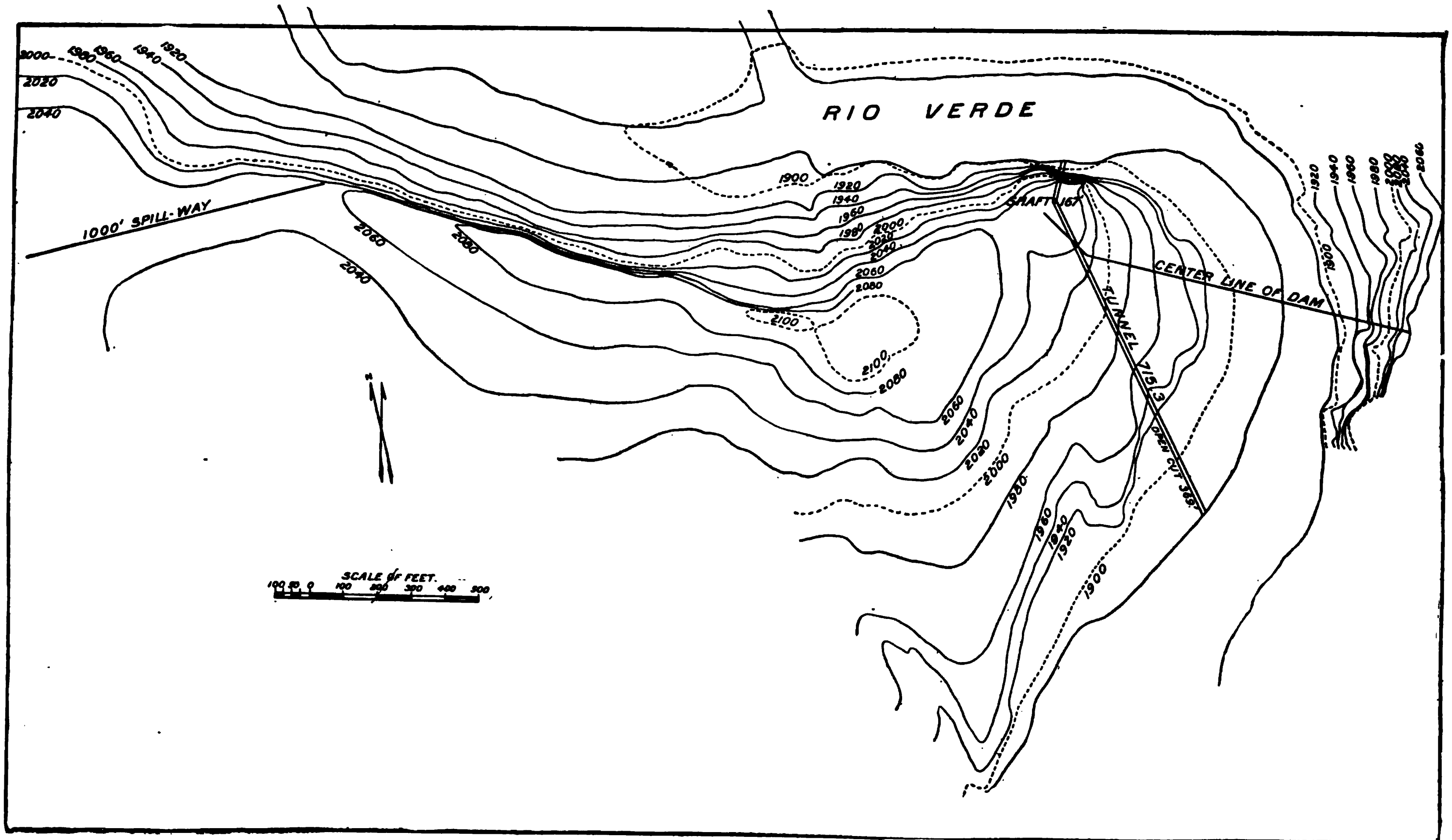


FIG. 165.—MAP OF SITE OF HORSESHOE RESERVOIR, ON VERDE RIVER.

this period of waiting the interest account accumulates, and if this cannot be met, the enterprise, though intrinsically meritorious, is destined to failure.

**Projected Reservoirs on the Rio Verde, Arizona.**—The Rio Verde, which has a watershed of 6000 square miles above its junction with the Salt River of Arizona, supplies a large surplus flood flow, which the Rio Verde Canal Company is organized to utilize as far as possible. The principal reservoir-site is located some 40 or more miles above the mouth of the stream, and is called the "Horseshoe reservoir," where a dam 170 feet in height will close a reservoir of 205,000 acre-feet capacity (Fig. 165). The length of this dam will be 1250 feet on top, the length at the stream-bed being 360 feet. Soundings taken along the line of the dam indicate that the greatest depth to bed-rock is 24 feet below low-water line, which will therefore make the extreme height of dam 194 feet. A spillway 1000 feet long, over a solid rock ledge, located 2200 feet away from the dam, is a commendable feature of the work.

The elevation of the top contour of the reservoir is 2052 feet above tide-level, and it covers an area of 3402 acres. Water released at the dam will flow down the river-channel for 25 miles to a diverting-dam, 70 feet high and 480 feet long at the crest-line, of which the elevation is 1614 feet above sea-level. Both dams are of the same type—rock-fills with a facing of asphaltum concrete. A canal with a capacity of 800 second-feet starts at the lower dam and skirts the northern edge of the Salt River Valley, practically parallel with the Arizona Canal, but extending far beyond the lower end of the latter. It is to be 69 miles in length, of which 25 miles, from the mountains to Cave Creek, are practically completed. The outlet-tunnel to the Horseshoe reservoir, 715 feet long, through solid granite rock, is also finished. It is 12 feet wide and 13 feet high, and has a gate-shaft near its upper end for controlling the supply to the canal. The estimated cost of the work is as follows:

| | |
|---|---|
| Horseshoe reservoir | $600,000 |
| Diverting-dam | 200,000 |
| Main canal to New River | 560,000 |
| Extension of main canal, 19 miles | 180,000 |
| Miscellaneous | 60,000 |
| Total | $1,600,000 |

The area of tillable land above the highest canals that would be irrigated by the works herein mentioned (which are only those noted in the company's prospectus as the works to be built on "Initial Construction") is given as 220,000 acres, of which 15,000 acres are in the Verde Valley and

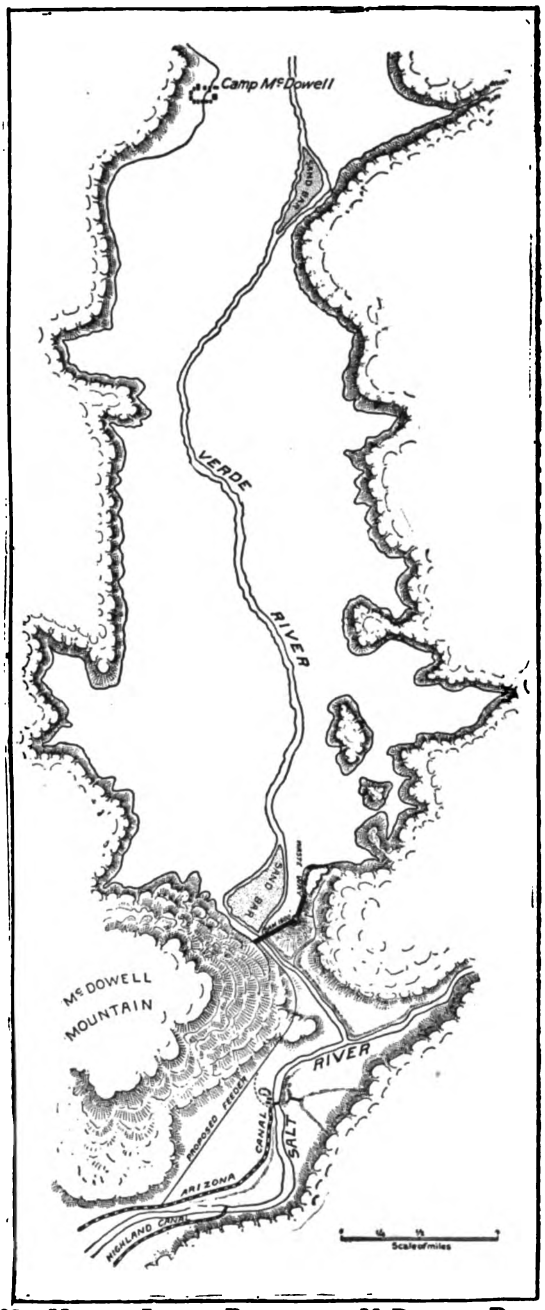


FIG. 166.—MAP OF LOWER PORTION OF MCDOWELL RESERVOIR.

may form a part of another reservoir to be built by the Arizona Improvement Company, 110,000 acres are between old Fort McDowell and the Agua Fria River, and 95,000 acres are west of the Agua Fria.

The plans of the company also contemplate the construction of the following: A reservoir on New River, to be fed by the canal and the rather limited drainage of the stream, and to have a capacity of 133,500 acre-feet, covering 3416 acres; "Reservoir No. 3," covering 1000 acres, with a capacity of 10,000 acre-feet; and "Reservoir No. 4," with an area of 2493 acres and a capacity of 68,093 acre-feet. The cost of these is not included in the above estimate. The entire system will cost from $3,000,000 to $4,000,000. All of the dams proposed are to be of the rock-fill, asphaltum-covered type.

The company proposes to guarantee to the irrigators, in their water-right contracts, the delivery to them of 2 acre-feet per acre, if demanded, in any one irrigating season; if more water is required, it will be paid for extra, and the company does not guarantee to furnish it if there is a shortage. The annual rates are to be on a sliding scale of increase up to the eleventh year, when the maximum will be $2.42 per acre-foot, the first two years being one-half that rate. Water-rights are sold at $10 per acre, of which $1 is paid down and $1 per acre per annum thereafter until fully paid, with 8 per cent interest on deferred payments.

**McDowell Reservoir Project, Arizona.**—The Arizona Improvement Company, the owner of the Arizona Canal, which heads in Salt River half a mile below the mouth of the Verde, has in contemplation the erection of a storage-reservoir dam a short distance above the mouth of the Verde, on the Verde River, to afford a means of fortifying their canal during low-water periods. The reservoir (Fig. 166) will flood a large part of the abandoned military reservation of Fort McDowell, from which it takes its name. The capacity of the reservoir is computed by Mr. F. P. Trott, county surveyor, of Phœnix, as 15,000,000,000 cubic feet, or 344,350 acre-feet. The height of dam proposed is 140 feet; extreme length, 1594 feet. A spillway, 800 feet long and 10 feet deep, will be excavated in the crest of a ridge of rock east of the dam. The computation of contents is made from a contour-line run at 114 feet above the low-water level at the dam, or 1430 feet above tide. Bed-rock is exposed across the site with the exception of 200 feet, where soundings made with rods locate it at a depth of from 1 to 22 feet below the surface. Plans for the dam have not been definitely adopted, and no estimates of cost have been made.

**Bear Canyon Dam, near Tucson, Arizona.**—The Santa Catalina range of mountains, a few miles north of Tucson, Arizona, reaches to an altitude of over 10,000 feet, in the culminating peak called Mt. Lemon. From the southern slopes of this mountain two torrential streams of considerable magnitude at times debouch into the valley 12 miles from Tucson. These are called Bear and Sabina canyons. The Catalina Reservoir and Electric Company, of Tucson, has projected a high dam in Bear Canyon, to impound the waters of these streams, diverting a fork of Sabina into the reservoir. The dam will be of masonry, 200 feet in height, and will require about 90,260 cubic yards of masonry to construct it. The width between the solid granite walls of the canyon is but 20 feet at base, 130 feet at the 50-foot level, 230 feet at the 100-foot level, and 435 feet at the crest of the dam. The wall will be arched up-stream on a radius of 400 feet. The reservoir will cover 214.8 acres, and impound 14,762 acre-feet of water. The outlet will be placed 50 feet above the base of the dam, discharging into a cement-pipe conduit, 32 inches diameter, 3.65 miles long, laid on a grade of 3 feet per 1000. This pipe will connect with the head of a steel pressure-pipe, 22 inches in diameter, 5000 feet long, laid down the slope of the mountain to the power-house, with a total drop of 1470 feet. This fall will be utilized to generate power, which will be transmitted electrically to Tucson and vicinity, where it is worth $150 per H.P. per annum. The average available power to be delivered for sale is estimated at 2445 H.P.

The water will be used for irrigating land in the vicinity of the power-house to the extent of about 4000 acres.

The cost of the project is estimated by the writer as follows:

| | |
|---|---|
| Masonry dam | $596,530 |
| Power conduit | 81,210 |
| Pressure-pipe | 45,764 |
| Power-stations and transmission-lines | 120,340 |
| Total | $843,844 |

The net revenue is estimated at about $100,000, on the basis of using but one-half the storage capacity of the reservoir in any one year.

The elevation of the base of the dam above sea-level is 4200 feet.

**Proposed Reservoirs on the Rio Grande.**—*The El Paso International Dam.*—The impounding of water on the Rio Grande River at El Paso, Texas, has long been discussed as an international enterprise to be jointly entered into by the governments of the United States and Mexico for the purpose of making a division of the river for irrigation purposes on either side of the international boundary. The Mexican authorities have claimed a grievance against the American people on account of the absorption of the stream in Colorado and New Mexico, by means of which their irrigation-supply has in recent years been greatly impaired and diminished, and representations have been made to the effect that the stream should be either permitted to flow as it was wont to do when the Mexican canals were first used, or that the flood-waters should be impounded by a reservoir of large capacity at the expense of the American people, and the wonted supply freely furnished to the Mexican canals as of yore. A survey of a mammoth reservoir-site was made in 1889 by Major Anson Mills, U. S. Engineer Corps, the site of the dam being located a short distance above El Paso, in American territory. A masonry dam was here proposed, to be 65 feet high above the river-bottom, the construction of which would create a reservoir 14.5 miles long by 4 miles maximum width, with a surface area of 26,000 acres, an average depth of 23.6 feet, and a capacity of 537,000 acre-feet. The estimated cost is a little over $300,000, to which must be added the cost of removing the tracks of the Southern Pacific and the Atchison, Topeka and Santa Fé railroads, which traverse the basin for a number of miles below the water-level, and their reconstruction on higher ground, above the flow-line. This was estimated to cost $590,000, while the lands overflowed were valued at about $69,000. The total investment would therefore be about $1,060,000. This work has never been undertaken.

*The Elephant Butte Dam.*—Other sites for water-storage in large volume were known to exist in the Rio Grande Valley between San Marcial and El Paso, and in 1890 two of them were surveyed and segregated by the U. S. Irrigation Survey. They are described in the 18th Annual Report of the U. S. Geological Survey and are designated as reservoir-sites Nos. 38 and 39. Site No. 38 forms a lake of 5540 acres, having a storage capacity of 175,000 acre-feet, with a dam 80 feet high. The length of the reservoir is 21 miles, its maximum width a little less than 2 miles, and its mean depth 31.7 feet, or 39.5% of the maximum. The dam-site is located in rock.

Reservoir-site No. 39 is in Paradise Valley, some 25 miles above Rincon, and is of little value, as the dam-site is without rock foundation. A dam 40 feet high to the water-line would here form a reservoir covering 6380 acres, with a capacity of 102,000 acre-feet, having a mean depth of 16 feet.

Nearly midway between these sites is the location selected by the Rio Grande Dam and Irrigation Co. for the erection of a masonry dam called the Elephant Butte, from its proximity to a well-known landmark on the river by that name. This corporation was organized in 1893, and its principal offices and stockholders are in London, England. The plans of the company are very comprehensive and contemplate the irrigation of the Val Paraiso above Rincon, the Mesilla Valley, reaching from Fort Selden to El Paso, and the lands below El Paso on the Texas side of the border as far down as Fort Quitman, Texas, in all some 230,000 acres. Thus the principal areas covered by Reservoir Site No. 39, and the reservoir basin of the International dam above El Paso, are proposed to be irrigated. Of the total area of 230,000 acres proposed to be watered, it is estimated that 48,300 acres are now irrigated, but in a somewhat uncertain and intermittent fashion, from lack of storage facilities for equalizing the flood-flow. The construction of the reservoir is expected to provide facilities for the complete irrigation of these lands as well as the larger areas of fertile, untilled valley soil commanded by the new system.

The Elephant Butte dam is located 112 miles above El Paso at a point where the river enters a narrow canyon, 300 feet in width between sandstone walls, at the level of the river-bed. On the right bank the wall rises abruptly 250 to 300 feet above the river, while on the left the height is 95 feet to a flat bench, 450 feet wide, which is to be utilized as a spillway. The dam will be 100 feet high, the crest being 10 feet thick in center and 16 feet thick at abutments. The thickness of the base will be 63.5 feet at center and 66.5 feet at the sides of the stream-bed. The length will be 570 feet, on a curve of 637 feet radius, at the upper face, which will be vertical. The bed of the canyon at the site is covered with large limestone bowlders, but the surface indications lead to the belief that solid bed-rock will be found not deeper than 10 feet below the top of these bowlders. The elevation of the dam is 4325 feet above sea-level at the crest.

The dam is estimated to contain 49,980 cubic yards of rubble masonry and 1005 cubic yards of concrete, and to cost $281,515, including foundations, outlet-pipes, sluice-gates, and valves. The spillway is designed to be cut in solid rock, 450 feet wide, with a sill placed 15 feet below the crest of the dam. The capacity of the spillway is computed at 108650 second-feet, at 10 feet in depth, which is regarded as ample, in view of the fact that the maximum recorded discharge of the river at El Paso is less than 17,000 second-feet.

The outlets of the dam are planned to have a maximum discharging capacity of 1200 second-feet, and consist of ten cast-iron pipes, 40 inches in diameter, passing through the dam at the bottom, in parallel lines, 6 feet apart between centers. These pipes are reduced at the upper end by short reducers to 30 inches in diameter at the gates. The gates are to consist of hinged flap-valves of cast iron, resting on seat-rings of bronze, and are to be raised by iron screws reaching to the top, the motion of the valve extending over an arc of 90°. An ingenious cylinder for controlling the motion of the valve and preventing it from suddenly opening or closing by the eddying currents of outrushing water is attached to the valve in the form of a quadrant, with a loose-fitting piston which allows water to escape from the cylinder slowly. Between each of the gates a pilaster is built the full height of the dam, eleven in all, projecting from its face 5½ feet. These pilasters are grooved near the outer face, sufficiently to receive a series of loose flashboards, or check-planks of cast iron, which slide up and down in the grooves. When these check-planks are in place they form open chambers from top to bottom, called penstocks, which separate the water supplied to each gate from the others. These penstocks are 2 × 3 feet in dimension, and are lined throughout with cast iron. The water enters them by overflowing the top of the check-planks, of which a sufficient number are left out to give the required depth of overflow. As the reservoir lowers, additional planks are removed. When these planks are placed so as to reach above the level of the water each penstock forms a shaft, through which a man can descend to the gate below to make repairs. The check-planks are 2 feet square, and rest on bronze seats. They are put in place and removed by a carriage sliding down in the same grooves, and provided with automatic clutches that engage in lugs cast upon the sides of the planks, near the top. This carriage is hoisted and lowered by means of a geared hand-hoist, placed over the penstock at the top of the dam. The plan thus contemplates drawing off water from the top of the reservoir at all times.

An alternative plan provides for closing the pipes by means of circular gates fitted with roller bearings to reduce friction. These can be raised entirely to the top and removed if desired.

On Fig. 167 is shown a plan of the dam-site locating the position of the dam and spillway, a profile of the masonry structure designed with lines of pressure, reservoir full and empty, and a cross-section of the dam-site and spillway.

*The Reservoir.*—The reservoir formed by the dam is 25 miles long on the 75-foot contour, covers an area of 7965 acres, and has a capacity of 253,368 acre-feet. (See Fig. 168.) It reaches to the dam-site of the U. S. Res. Site No. 38. Of the lands embraced in the reservoir, 2549 acres are public lands, while those in private ownership cover 5416 acres and are valued at $7517.

The dip of the rock strata is toward the river from each side. The sandstone when tested developed a weight of 147 to 160 lbs. per cubic foot, and a crushing-strength of 216 to 360 tons per square foot.

From the dam the water will be released into the channel of the river, which it will follow for 6 miles to a diverting-weir at the head of Paradise Valley. This weir is to be built of rubble masonry, faced with cut-granite blocks, and have 300 feet of overfall for the passage of floods. Here are placed the head-gates of a canal to be constructed for the irrigation of 40,000 acres of Paradise Valley, in a solid rock cut, affording rock for the construction of the dam.

Below Paradise Valley the river is again inclosed in a rocky canyon, near the lower end of which a second diversion-weir is located, the construction of which has begun, as shown in Fig. 169. This dam is 5½ miles above Fort Selden, N. M., and about 50 miles below the storage-reservoir at Elephant Butte. Its purpose is merely the diversion of water for the irrigation of the Mesilla Valley, extending from Fort Selden to El Paso. It is a concrete structure, combining an overfall waterway for the passage of the river, and head-gates for the canal. The height of the crest of the overflow-weir is 5 feet above the river-bed, or the exact depth of the water

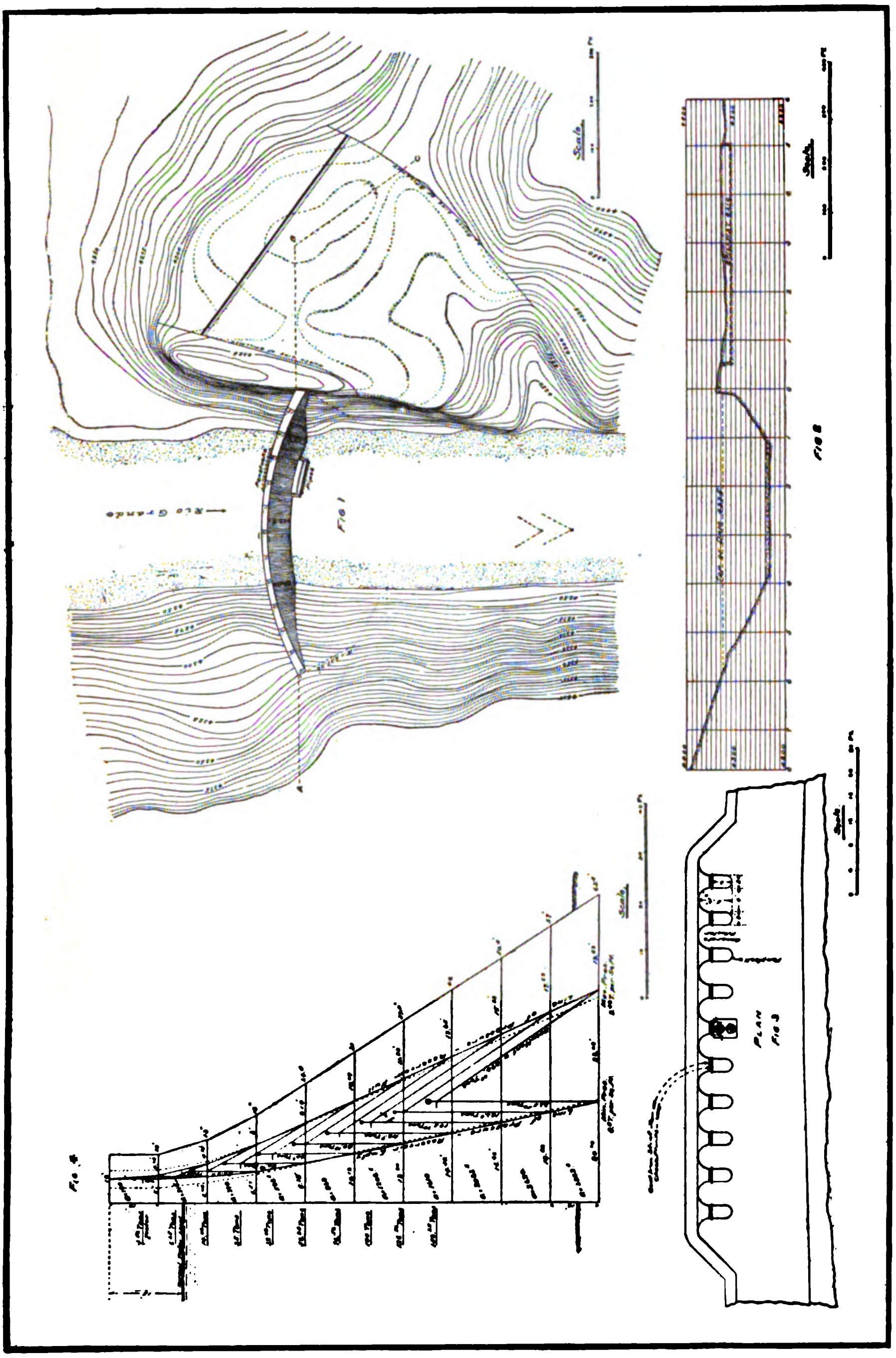

FIG. 167.—ELEPHANT BUTTE DAM ON RIO GRANDE, ABOVE EL PASO, TEXAS. PLAN AND SECTION OF DAM-SITE, PROFILE OF DAM, AND PLAN OF OUTLETS.

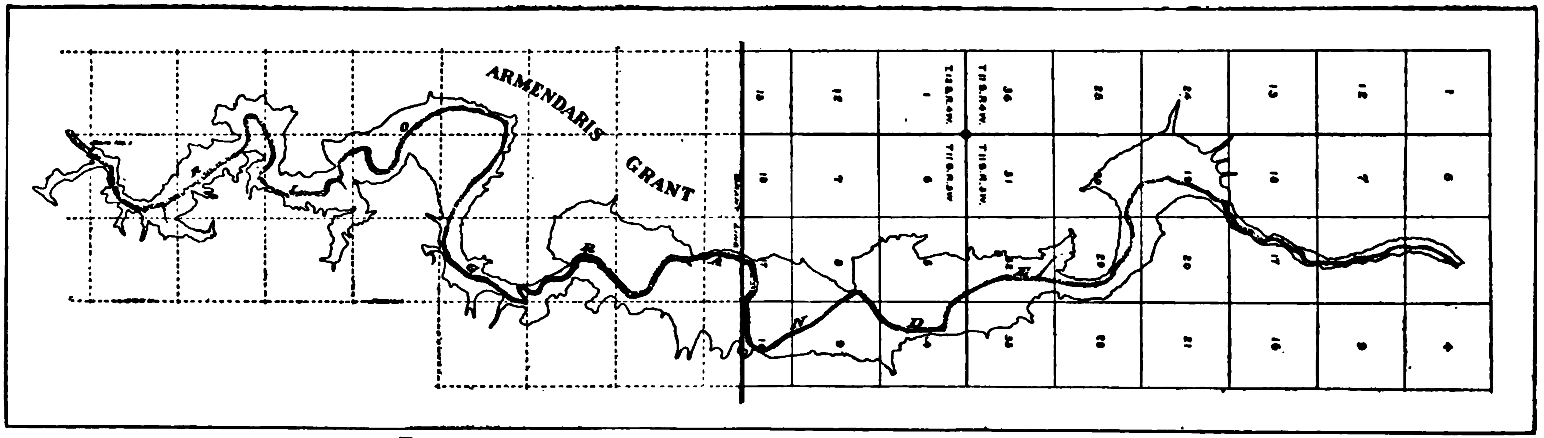


FIG. 168.—MAP OF ELEPHANT BUTTE RESERVOIR ON THE RIO GRANDE.

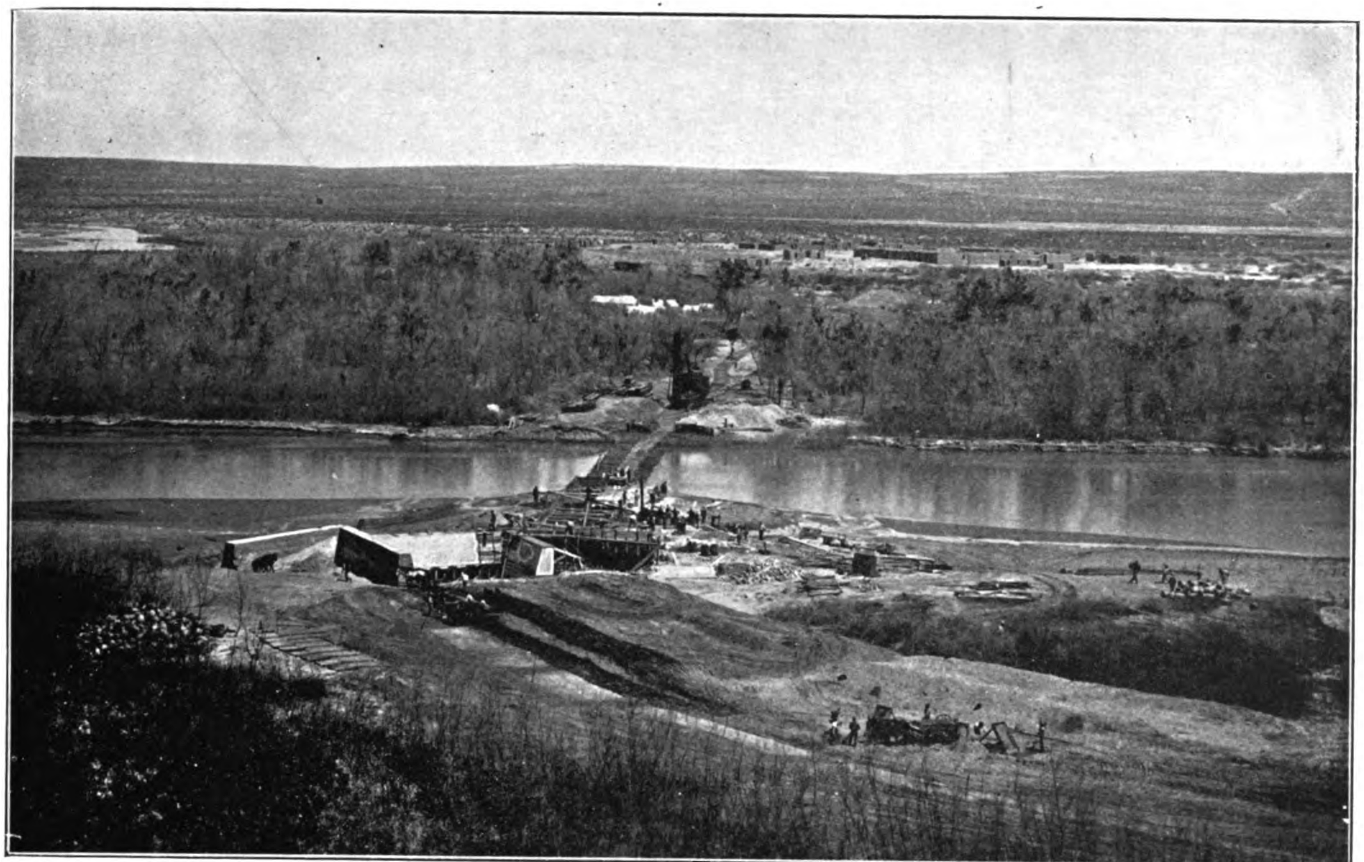

Fig. 169.—Diverting-dam near Fort Selden, Texas, in Process of Construction.

in the canal, whose grade is coincident with the bed of the river. The length of the weir-channel is 300 feet. The thickness of the concrete at base is 20 feet, and the crest is in the form of a rollerway curve. The abutments are 7 feet high above the crest of the weir. The water is admitted to the canal through six cast-iron pipes, 48 inches diameter, set in a concrete wall, and closed with sluice-gates. The entire structure, including wing walls and abutments, is founded on piles, driven by hydraulic jet into the sand bed of the river, and inclosed with triple-lap sheet-piling above and below. Fig. 169 gives a view taken during construction. The weir is estimated to contain 2450 cubic yards of concrete and to cost $19,653.50.

A third diversion-weir, to be built of masonry on bed-rock foundation, is also contemplated for the supply of canals below El Paso, the location selected being the site of the proposed "international dam," 5 miles above El Paso. It is believed that the latter structure, as originally contemplated, will never be built, but that the Elephant Butte dam, when finished, will serve as an efficient substitute, at less cost, and without interference with the railways.

Some 200 miles of main canal and primary laterals are projected from the two diversion-weirs above El Paso. The entire enterprise is estimated as follows:

| | |
|---|---|
| Elephant Butte storage-dam.................... | $281,515 |
| Diversion-weir, 6 miles below.................. | 27,874 |
| Diversion-weir, 50 miles below................. | 19,653 |
| Canal system above Rincon, N. M............... | 75,749 |
| Canal system in Mesilla Valley................. | 249,682 |
| Canal system below El Paso.................... | 196,000 |
| Total ................................ | $850,473 |

This is an average cost of $3.70 per acre for the 230,000 acres to be supplied with water, although the estimate does not include the diverting-dam near El Paso.

Construction began in 1897 with the concrete weir near Fort Selden, but has been interrupted by litigation. From this weir, a canal 34 feet wide on bottom, 5 feet deep, on a grade of 1 : 5000, was excavated 7 miles down the west side of the Rio Grande Valley, where it was carried across the river by a series of four inverted siphon pipes, 50 inches in diameter, laid in a trench 11 feet below the bed of the stream. These pipes are made of long-leafed Texas yellow-pine staves, held in place with round rods of steel at intervals of 12 inches from center to center. They are each 388 feet long, and have a fall of 3.06 feet from the water-level in the canal on the west side to that of the canal on the east. They pass through wooden bulkheads or wing walls, which confine the river on either side to its natural banks. They have a combined capacity equal to that of the canal, or 465 cubic feet per second. The plan of the crossing and the method of construction are well illustrated by the accompanying photograph, Fig. 170.

The chief engineer of this work, which when completed will be one of the most important and extensive irrigation projects in the arid region, is Mr. J. L. Campbell of El Paso.

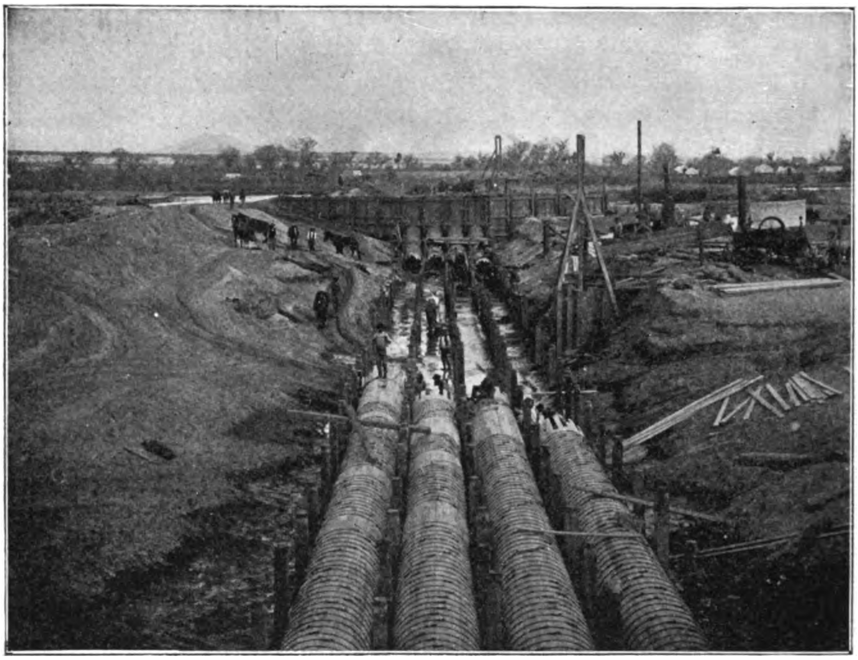

FIG. 170.—WOOD-STAVE PIPES, LAID UNDER BED OF THE RIO GRANDE, FOR SIPHONING CANAL ACROSS THE RIVER, BY RIO GRANDE DAM AND IRRIGATION COMPANY.

*Water-supply of the Rio Grande at El Paso.*—Gaugings of the flow of the Rio Grande River at El Paso, made by the U. S. Geological Survey and published in their annual reports since 1890, give the following data of the discharge of the stream:

| | | |
|---|---|---|
| May 10, to Dec. 31, 1889 (no flow during the months of August, September, October, or November).... | 367,266 | acre-feet |
| 1890, flowing the entire year...................... | 963,466 | " |
| 1891, January to June, inclusive.................... | 1,567,172 | " |
| 1897, stream dry during a part of August and September .................................. | 1,360,360 | " |

From these data it is apparent that the reservoir at Elephant Butte would have filled during any one of the years during which these gaugings were made.

Gaugings made at San Marcial, some 50 miles above Elephant Butte, give the following as the discharge of the stream at that point:

| | | |
|---|---|---|
| 1895, February to August, inclusive | 1,246,509 | acre-feet |
| 1896, February to December, inclusive | 541,499 | " |
| 1897, February to December, inclusive | 2,215,257 | " |

In 1897 the stream was practically dry during August and September, yet the total discharge of the year was sufficient to have filled the Elephant Butte reservoir nearly ten times.

In comparing the discharges given in 1897 at San Marcial with those at El Paso, nearly 200 miles below, one cannot but be struck with the enormous loss of water in the stream in traversing that distance, amounting to 854,897 acre-feet during the year, or 38.5% of the total flow. A small part of this may be due to the diversions for irrigation and to evaporation, but the greater portion must find some subterranean escape. A possible explanation of this source of loss is given in the following extract from the printed report of Mr. J. L. Campbell upon the Elephant Butte reservoir site. He says (p. 9):

"Barring the existence of possible subterranean fractures, open sufficiently to carry away considerable amounts of water, the character of the reservoir-site topographically and geologically is peculiarly adapted for storage purposes."

These fissures may, and probably will, in time be entirely closed by the deposit of silt in the reservoir, and thus the supply may be augmented by the prevention of this source of loss.

*The Silt Problem.*—From 118 samples of the water of the Rio Grande, taken by Major Anson Mills, at El Paso, the conclusion was reached that the silt carried in suspension averaged 0.345 of 1% of the volume, or in other words 1 acre-foot for each 290 acre-feet of water. The determinations of the Geological Survey during 1889 and 1890 at the same point show a somewhat less percentage.* It is there stated that "the total sediment for the year ending June 30, 1890, is in round numbers 3,830,000 tons; this earth, at a weight of 100 lbs. per cubic foot, would cover a square mile 2¾ feet in depth."

This would be equivalent to 1760 acre-feet of sediment, and as the discharge of the river during this period was 820,425 acre-feet, the ratio of silt to water is therefore as 1 to 466. A mean of these ratios would

* 11th Annual Report, U. S. Geological Survey, Part II, page 57.

be 1 to 388. If, on this basis, all the sediment carried by the stream be assumed to deposit in the Elephant Butte reservoir, it would catch but 650 acre-feet every time its full capacity were carried through it. If the river carries sufficient volume to fill the 253,000 acre-feet of its capacity five times per annum on an average, it would require 130 years to fill the reservoir. Long before this result could occur it would be profitable to add a few feet to the height of the dam, or construct the large reservoir in the adjoining basin above, or take measures for sluicing out a portion of the accumulated sediment. It does not appear that the silt problem is one which need give serious concern in this situation.

*Evaporation.*—The loss by evaporation from the surface of the reservoir is estimated by the chief engineer to be 7 feet in depth per annum, based on the observations of the U. S. Geological Survey at El Paso during 1889–91. From this he computes the annual loss from the reservoir at 50,000 acre-feet, and from the surface of the canals at 22,000 acre-feet.

**Proposed Reservoirs in Texas.**—In "Water-supply and Irrigation Papers," No. 13, published by the U. S. Geological Survey, Mr. Wm. F. Hutson describes some large projected storage-reservoirs on the Nueces River, in Texas, which are important in their dimensions and of general interest.

*The Caimanche Reservoir.*—Caimanche Lake lies to one side of the Nueces River, and gathers the water of a large drainage-basin extending from the Rio Grande divide on the south to many miles beyond the Southern Pacific Railroad on the north, a region containing springs and an easily obtainable supply of artesian water. It is proposed to convert Caimanche Lake into a storage-reservoir by means of an earthen dam 1¾ miles in length and 20 or 25 feet in height. It will store about 132,750 acre-feet of water at the spillway-level. In addition to the natural drainage-basin tributary to the lake it is proposed to turn into it the water of the Nueces River by a short canal, 1¾ miles long, from a point called Rock Falls.

The area of the reservoir will be about 10,000 acres. The promoters expect to irrigate from this reservoir about 50,000 acres of land.

*The Nueces Reservoir.*—Some 45 miles below Rock Falls, on Nueces River, a masonry dam has been projected across the river, 2600 feet in length, 50 feet in height, which will form a reservoir of 12,700 acres in area and impound 222,250 acre-feet.

*Lower Reservoirs.*—About 100 miles further down the Nueces, at the junction of Frio River and below, surveys have been made by private capital for an enormous system of storage-reservoirs for irrigation. These are fourteen in number, having a combined storage capacity of 1,792,300 acre-feet. The two largest of these will be formed by masonry dams across the Nueces and Frio rivers. The total area to be brought under irrigation by the system of canals to be supplied by these reservoirs is something over 1,000,000 acres.

*Sand Lake Reservoir, Western Texas.*—About 9 miles north of Pecos City, Texas, a natural basin, called Sand Lake, has been selected as an available reservoir-site for impounding water to be used for irrigating lands in the vicinity of Pecos City and Barstow. The basin now contains a pond of 300 acres, maintained by the run-off from the local watershed. The basin can be filled to a depth of 28 feet before overflowing, impounding 55,000 acre-feet and covering a surface area of 3740 acres. A dam on the rim of the basin, 12 feet in maximum height, 4000 feet long, would increase the area to 5080 acres, and the storage capacity to 79,200 acre-feet. The outlet to the reservoir would require a cut 3 miles long, 18 feet deep, to draw off 72,500 acre-feet. The reservoir would be fed by a canal from the Pecos River, 23 miles long, having a capacity of 450 second-feet, from which the reservoir could be filled in ninety days. The total cost of the canal and reservoir-outlet is estimated at $130,000.

*Upper Pecos Reservoir-site.*—Some 50 miles above the town of Roswell, N. M., a notable reservoir-site exists on the Pecos River, where a dam 50 feet high would impound 250,000 acre-feet of water, forming a lake 12 miles long, 2 miles wide. The dam-site is at a point where the river has cut through a ledge of limestone to a depth of 58 feet on the west side and 75 feet on the east. The cost of a masonry dam at this site would be about $300,000, or $2.20 per acre-foot of storage capacity. A rock-fill and earth dam, of the type described in a previous chapter as having been built lower down on the Pecos, would be about one-half the cost of a masonry dam.

The area of arable, irrigable land in the valley of the Pecos between Roswell, N. M., and Grand Falls, Texas, is as follows:

| | | |
|---|---|---|
| Land commanded by the Pecos Irrigation and Improvement Co.'s canals and reservoirs | 174,000 | acres |
| Land between State line and Riverton, Texas | 15,000 | " |
| Land under the unfinished Mentone Canal, east side | 36,000 | " |
| Land under the Highland Canal, west side | 50,000 | " |
| Land under the Pioneer Canal, constructed | 38,000 | " |
| Land under the Pioneer Canal, extension | 15,500 | " |
| Additional area below Barstow | 1,500 | " |
| Total | 330,000 | " |

The volume of water annually passing the head-gates of the Pioneer Canal at Barstow, as determined from records kept for several years, is approximately 700,000 to 1,000,000 acre-feet. This volume is sufficient

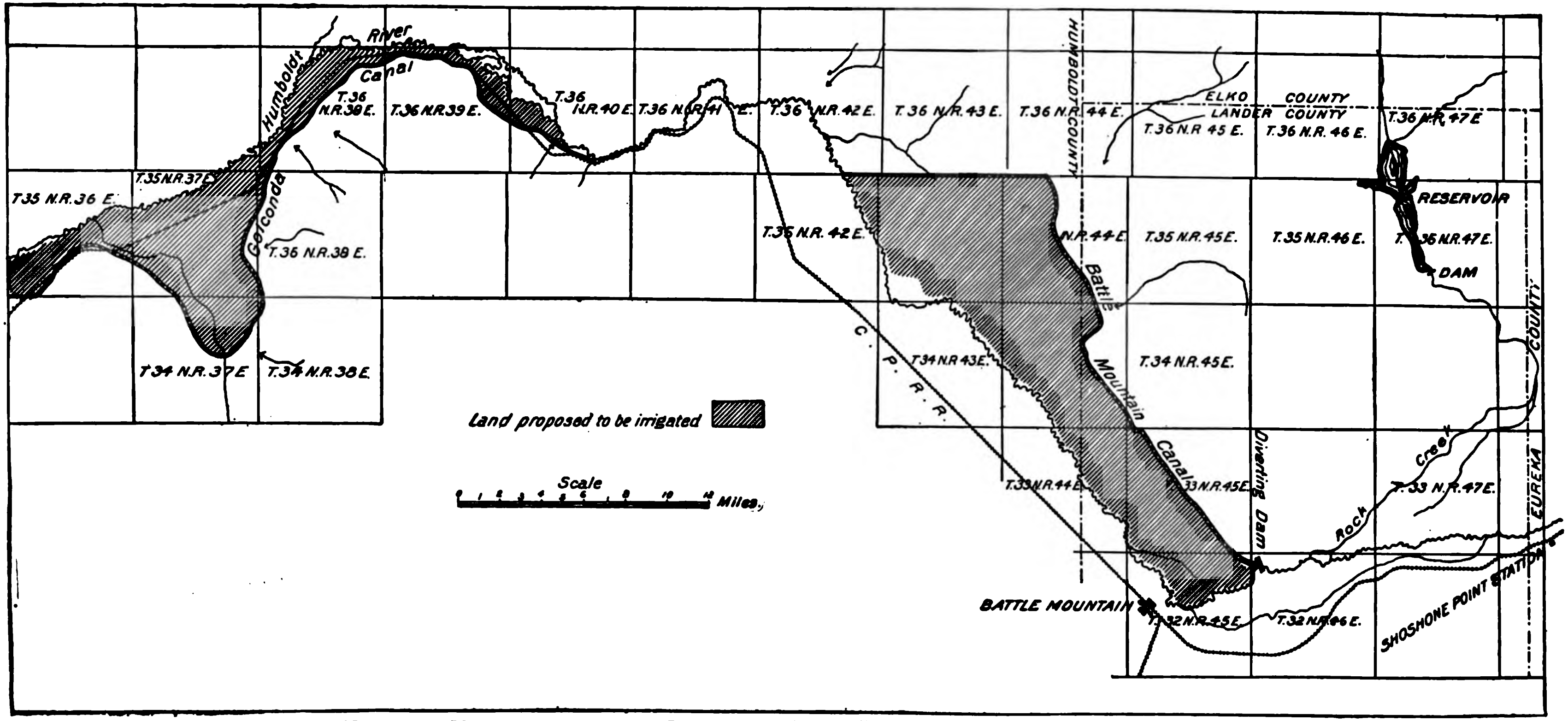


Fig. 171.—Map of Rock Creek Reservoir, Canal Lines, and Lands to be Irrigated.

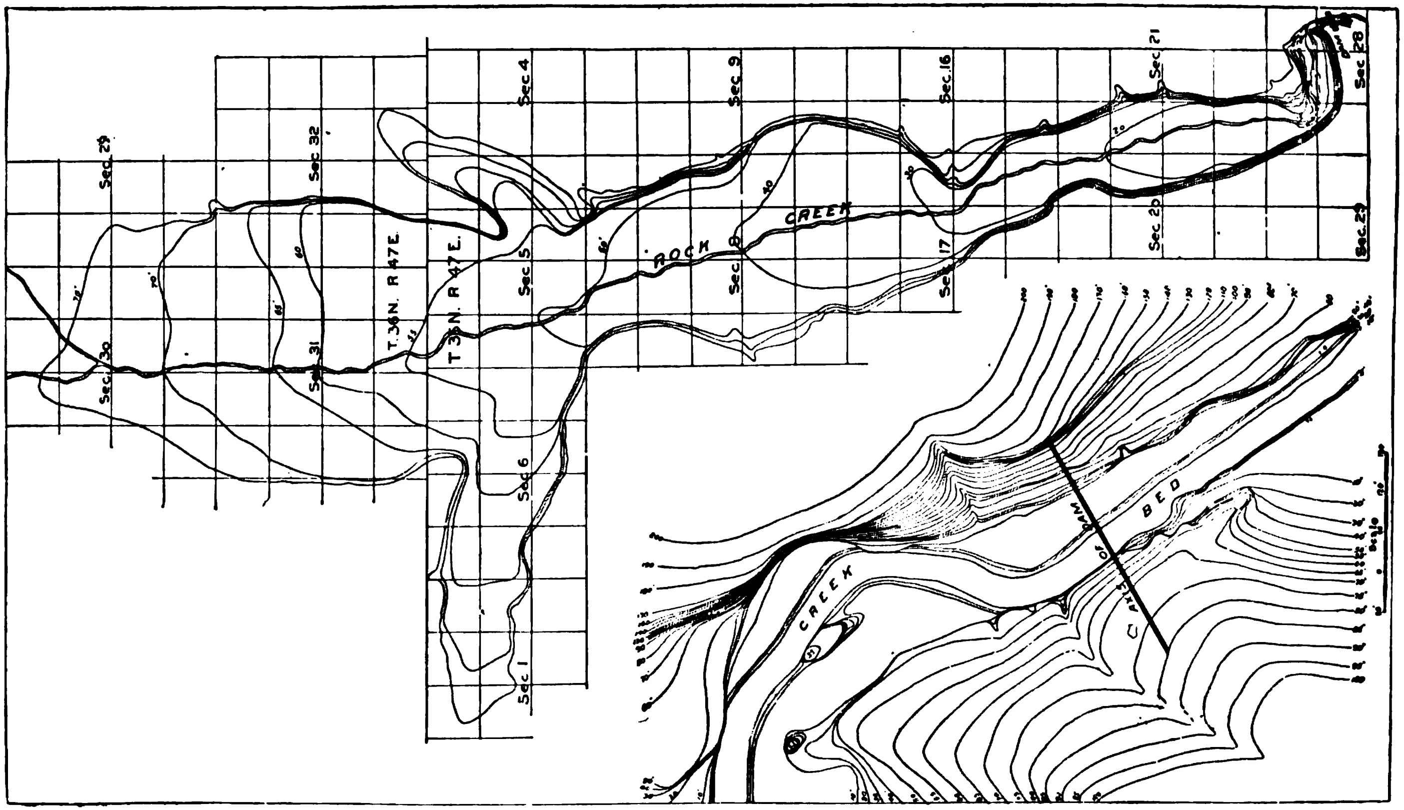


FIG. 172.—PLAN OF DAM-SITE AND RESERVOIR-SITE, ROCK CREEK, NEVADA.

for the irrigation of all the lands of the valley if properly stored and utilized.

The data concerning reservoir-sites on the Pecos River are taken from a report by the writer made in 1898.

**Rock Creek Reservoir, Nevada.**—One of the tributaries of Humboldt River, which enters that stream a few miles above Battle Mountain, Nevada, from the north, is known as Rock Creek. It drains a watershed of 750 square miles, whose altitude ranges from 5000 to 13,000 feet above tide-level. As it debouches into Humboldt Valley it passes through a narrow gorge, 5 miles long, cut deeply through a volcanic range of hills, at the head of which is a favorable site for a dam and reservoir, as the stream passes through a large open valley. The capacity of this reservoir at the 75-foot contour above the base of the dam is 80,000 acre-feet, covering 3670 acres (Fig. 171). The canyon at the dam-site is but 120 feet wide

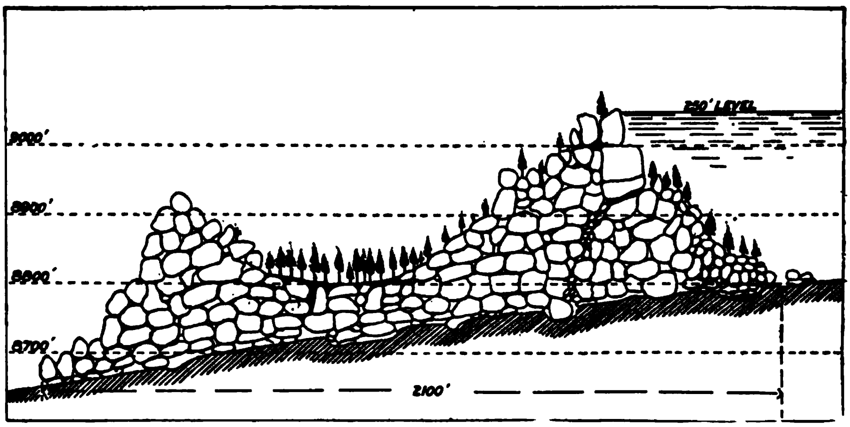


FIG. 173.—SKETCH OF LONGITUDINAL SECTION OF LOST CANYON NATURAL DAM

at bottom and but 300 feet at the 75-foot level. On the left bank the canyon wall rises abruptly to a height of over 250 feet (Fig. 172). The material is a hard porphyry at the dam-site, capped at a few hundred feet height by a layer of basalt of great depth. The character of dam proposed for the site is a rock-fill, of the Pecos type, faced with an embankment of earth. The estimated cost of the dam is about $80,000.

The run-off from the watershed is estimated to exceed 150,000 acre-feet per annum, or about 200 acre-feet per square mile. The precipitation on the shed varies from 7 inches annually at the dam, to over 40 inches in the higher mountain-ranges.

Used as a needed supplement to the normal summer flow of the Humboldt, the reservoir is expected to irrigate about 100,000 acres of the valley lands, bordering the river, between Battle Mountain and Golconda.

**Lost Canyon Natural Dam, Colorado.**—The region of Lost Park and Lost Canyon, on Goose Creek, Colorado, a tributary of South Platte River, is one of rugged grandeur, characterized by scenery of the wildest imaginable description, abounding in high cliffs and rock-masses of fantastic shapes and colors and of Titanic dimensions. Nature has here made an effort at rock-fill dam-construction on a grand scale by filling in the canyon to a maximum depth of 250 feet with an aggregation of enormous bowlders thrown from the neighboring cliffs. This remarkable rock-fill is

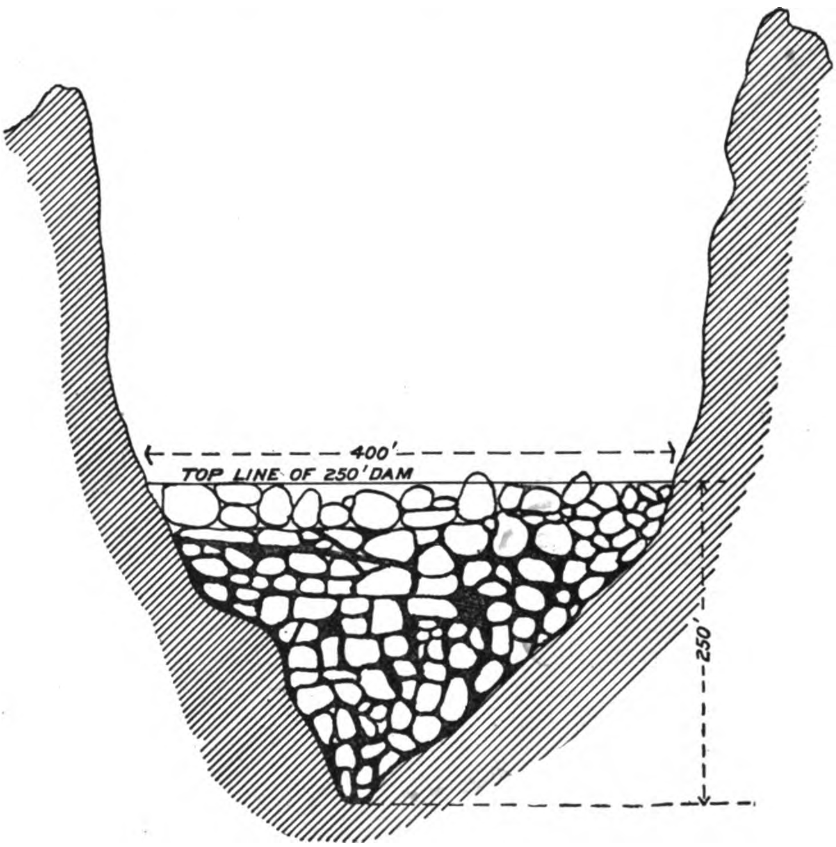


FIG. 174.—SKETCH OF CROSS-SECTION AT UPPER END OF LOST CANYON NATURAL DAM.

2100 feet in length, and is fairly well represented in a general way by the longitudinal and cross sections shown in Figs. 173 and 174. The maximum height above the upper toe is, as stated, 250 feet; but as the bed of the canyon falls 150 feet in the length of the dam, the height of the crest is 400 feet above the lower toe, where the stream emerges from underneath the bowlders. The extreme width on top is 400 feet, although the bulk of the fill is less than 100 feet in width, and at the bottom the canyon width between well-polished walls is but 20 to 25 feet, at such places as it is possible to go underneath and inspect it.

Some of the bowlders that form the embankment are as large as an ordinary two-story dwelling-house, and the stream finds its way through them with little apparent obstruction, although the presence of a pile of driftwood at the mouth of a cave on the upper face, 150 feet above the bottom, is an indication that occasionally the volume is too great to find exit in the lower passages and is forced to rise to this higher outlet. It is possible to descend in this cave, by means of ladders and ropes, into the interior of the dam almost to the water-level. The crest of the solid mass of the dam proper is at the 200-foot level, although a chain of huge bowlders, 25 to 50 feet high, lying near together, extends across the canyon from side to side. The entire surface of the natural embankment is dotted over with large fir-trees, growing in the soil that has lodged in the crevices. As the stream emerges from the foot of the dam it has the appearance of a spring flowing out from beneath an old glacial moraine.

Surveys of the site have developed the fact that a reservoir with a capacity of 24,000 acre-feet can be made available for storage and use by making nature's dam water-tight. This may readily be done by filling the crevices and cavities on the upper face with concrete and providing a proper outlet for the water by means of a tunnel.

The latter has been projected on the 75-foot level, and will require to be 1200 feet long to reach a neighboring canyon. The cost of this work has been estimated at $104,000, or $4.35 per acre-foot of storage capacity in the reservoir. An addition of 20 feet to the top of the dam would increase this capacity to 27,700 acre-feet, and the cost to $144,000, the work to be done in Portland-cement masonry. The reservoir has been in contemplation for some years as a storage for irrigation and domestic supply in and around Denver, from which city it is some sixty miles distant.

**California Reservoir Projects.**—*Little Bear Valley Dam.*—The Arrowhead Reservoir Company of Cincinnati, whose headquarters are located at San Bernardino, Cal., began construction some years ago on a masonry dam of large proportions which is to store water in a mountain valley, called the "Little Bear," on the head waters of the Mojave River. This stream flows northward into the Mojave Desert, and its water runs to waste. The project of the Arrowhead Company is to gather together a number of the tributaries of the stream above an elevation of 4800 feet, store the water in reservoirs and convey it across the San Bernardino Mountains for irrigation in the San Bernardino Valley. A contour map of the reservoir is shown in Fig. 175.

The dam, of which a portion of the foundation only has been laid, is designed to be carried to an extreme height of 175.5 feet above the assumed "base" of the dam, although the lowest foundations will be 20 to 30 feet lower than the "base." The outlet-tunnel is 15.5 feet above "base." The dam is intended to be a monolithic structure of Portland-cement concrete, arched up-stream, with a radius of 550 feet to the up-stream face. Its top length will be 747 feet, and its base thickness 133 feet.

The reservoir will cover an area of 884 acres and impound 60,179 acre-feet of water.

The company has been at work on the main conduit leading from the reservoir since 1892, their efforts being directed chiefly to the opening of

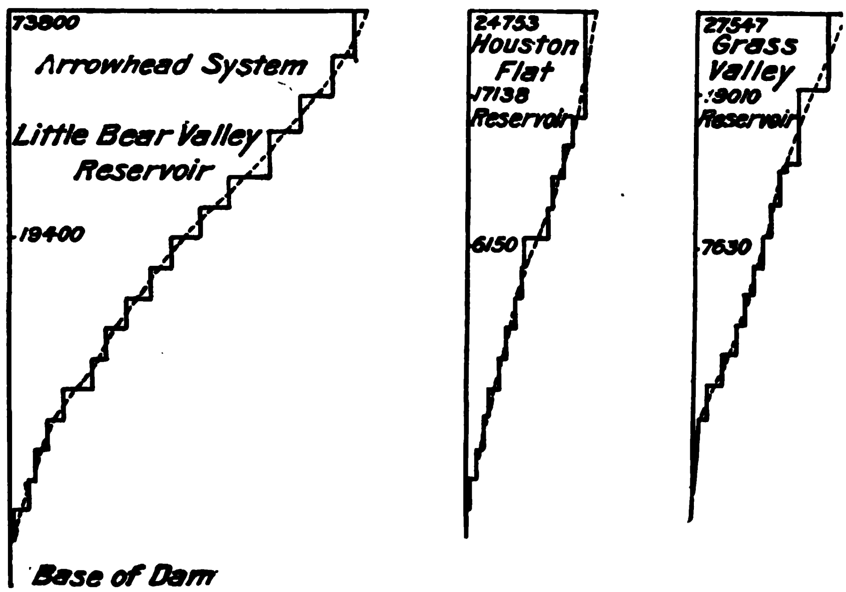


Fig. 174a.—Comparison of Dams of the System of the Arrowhead Reservoir Co. in the San Bernardino Mountains, California.

the principal tunnels on the line, of which there are a number. The longest of these is the outlet to the reservoir, 4957 feet in length exclusive of approaches. This was made necessary to avoid 10 miles of canal around a long mountain-ridge. It has been completely lined and arched with concrete. Two other tunnels, 1844 and 1792 feet long, have been completed, and are to be lined during the summer of 1900.

The total length of conduit required to turn the water over the summit of the mountain-divide is 13 miles. From the summit crossing to the grade of the conduit at the base of the mountains skirting the upper slopes of the valley north of San Bernardino the total descent is 2700 feet, which will be utilized to develop power.

The volume of water which the company expect to develop and supply is 5000 to 6000 miner's inches (100 to 120 second-feet) of continuous flow during 200 days each year.

The determination of the volume of supply which can be impounded and sold from the system has been the result of eight years of continuous stream measurements and precipitation records. The company maintains 26 rain-gauges, located at different points on their watersheds, and a large number of self-registering devices for measuring the depth of overflow on their weirs. It is doubtful if any such systematic and intelligent study of probable available water-supply from the catchment of flood run-off prior to the construction of works has ever before been attempted in the West, and the final result must prove of great value to the company, as well as an invaluable addition to the general store of knowledge on such subjects when finally made public.

The area of the watershed directly tributary to the Little Bear Valley reservoir is but 6.6 square miles, but it will be fed by a large conduit diverting the water from Holcomb Creek, Deep Creek, and intermediate streams. This conduit will consist mainly of a large tunnel from Deep Creek. The entire area of shed from which the system will be supplied is about 77 square miles, all of which is above 5000 feet in altitude, on a well-forested mountain-crest, and is among the most productive areas in southern California in stream run-off. The Little Bear Valley drainage-basin shows the greatest amount of precipitation and stream-flow, and in the period of observation has given a minimum of 600 and a maximum of 2200 acre-feet of run-off per square mile per annum. An intercepting-canal 13 miles in length, including the tunnel mentioned above, to gather the stream-flow from 61.43 square miles of watershed lying east of Little Bear Valley and empty it into the main reservoir, is an essential part of the general system. This canal will have a capacity of 200 to 400 second-feet, increasing as it takes in each successive stream on its way.

Two other reservoirs are contemplated, one at Grass Valley, 4 miles west of Little Bear, elevation 5108 feet, where a dam 175 feet high will give 27,547 acre-feet of capacity on a reservoir area of 382 acres; the other at Huston Flat, 5 miles west of Grass Valley, elevation 4450 feet. The 175-foot contour at the latter site will give a capacity below it of 24,753 acre-feet. This dam, being near the line of the conduit from Little Bear reservoir, which would pass the dam-site at an elevation of nearly 300 feet above the 175-foot contour, could be built advantageously by the sluicing and hydraulic jet process, as an abundance of material for the purpose can be had conveniently on both sides of the canyon where the dam would be located. To utilize this reservoir will necessitate a tunnel-outlet 5900 feet long, and it has been proposed to make this tunnel a part of the main conduit, by which means 4½ miles of canal would be saved, the

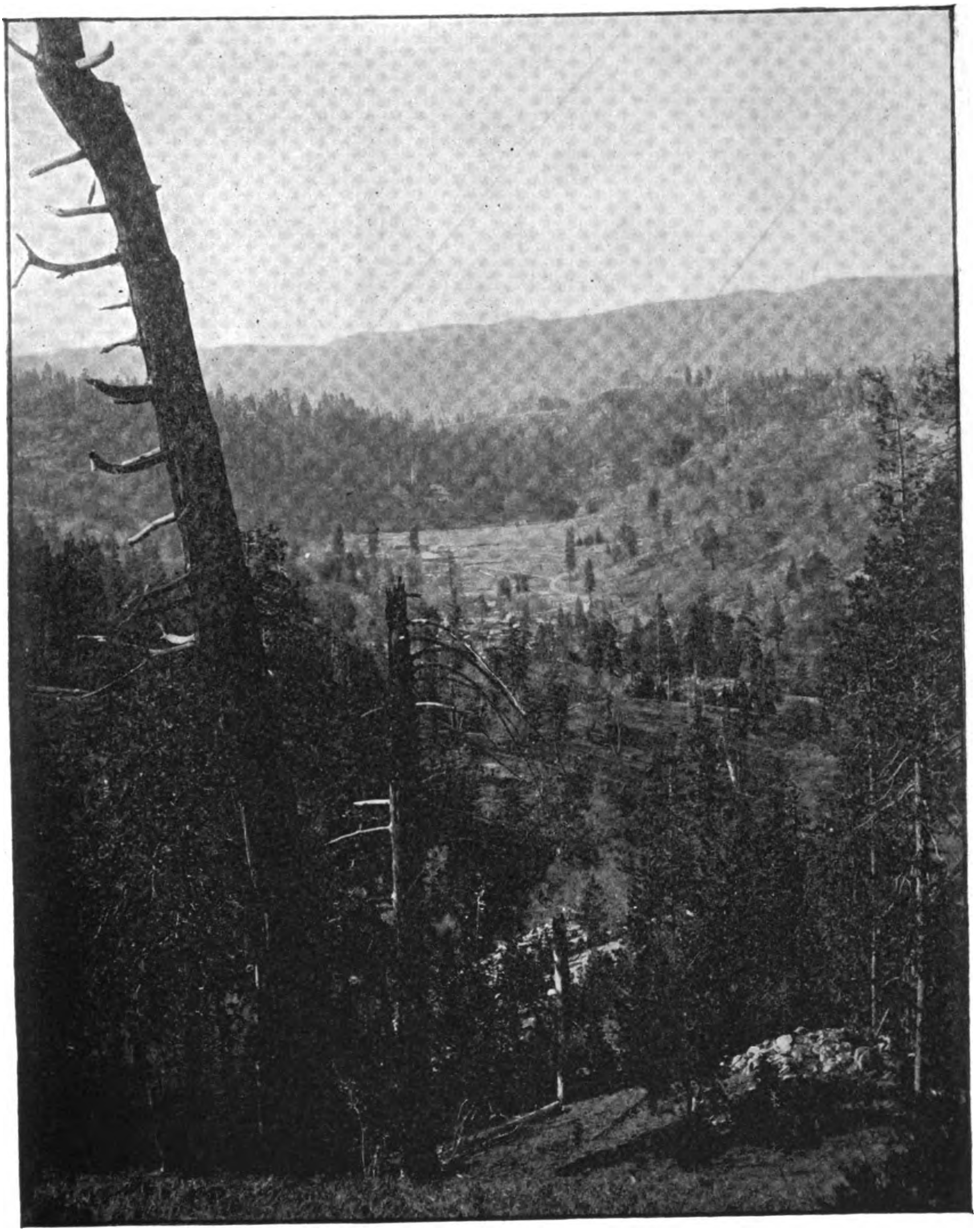

FIG. 174b.—VIEW OF HUSTON FLAT RESERVOIR-SITE, ONE OF THE SYSTEM OF THE ARROWHEAD RESERVOIR CO.
This dam is to be built by the hydraulic-fill process.

cost of which would be about 60 per cent of the cost of the tunnel. These plans are, however, somewhat indeterminate. The cost of the entire system, not including the Huston Flat reservoir dam and outlet, is estimated in round numbers at $1,600,000.

*Projected Reservoirs in San Diego County.*—The last few years have been fruitful in the projection of numerous storage enterprises throughout the arid region which are yet awaiting the necessary capital for their construction. The map of San Diego County (Fig. 176) shows the position of a number of capacious and favorable sites which have been surveyed, in addition to those already described, for storing the storm-water of that region. The topography of the country is more favorable for storing water than many parts of the State better supplied with permanent streams. Cross-sections of several of these sites are given in Fig. 177, and

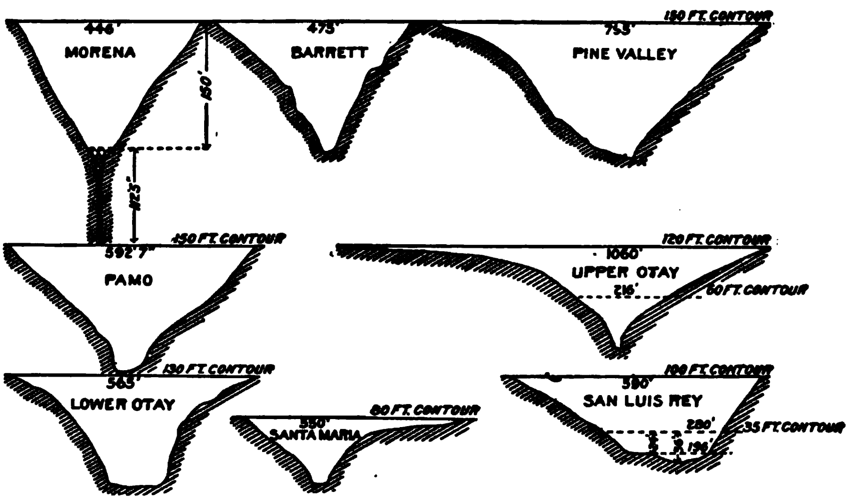


FIG. 177.—CROSS-SECTION OF DAM-SITES IN SAN DIEGO COUNTY, CALIFORNIA.

tables of capacity of the reservoirs to be inclosed by them will be found in the Appendix.

The Linda Vista Irrigation District, covering an area of 44,000 acres, embracing a part of the corporate limits of San Diego, owns the Pamo, Santa Maria, and Dye Valley sites, and has projected rock-fill dams for each of them. The Pamo is considered most favorable for immediate construction, as it is also the most capacious.

In Riverside County a masonry dam has been planned to span a narrow canyon on the Pauba Rancho at the outlet to a large valley on Temecula Creek which drains a catchment-area of 372 square miles. The elevation of the dam is 1350 feet at the base, and it commands an extensive territory of valuable agricultural and horticultural lands. The dam is projected to a height of 130 feet, at which it will have a capacity of 61,500 acre-feet, covering 1214 acres. Its cost has been estimated at $400,000, and the 28 miles of canals for distribution to 40,000 acres of land at $230,000, an average cost for the system of about $16 per acre.

The capacity of the drainage-basin for run-off has been demonstrated in a striking way on two notable occasions when floods from this section destroyed the Southern California Railway through the Temecula Canyon, causing enormous loss and destruction of property. The track has not been restored since the last time it was destroyed, in 1890–91.

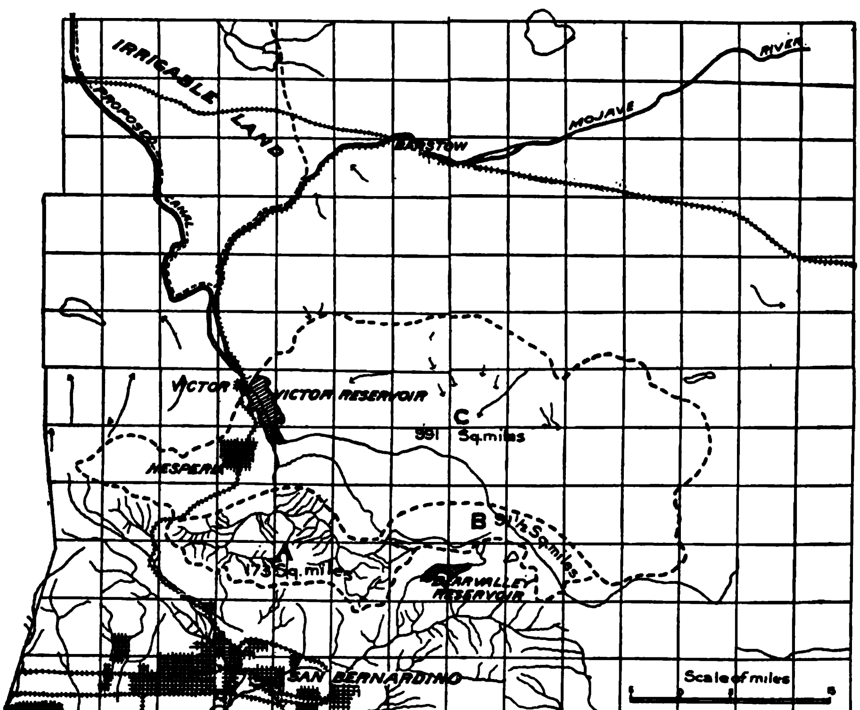


FIG. 178.—MAP OF WATERSHED AND THE LANDS TO BE IRRIGATED FROM VICTOR RESERVOIR.

*Victor Dam, California.*—Doubtless the most capacious reservoir projected in California is that of the Columbia Colonization Company, located on the Mojave River in San Bernardino County, at the Upper Narrows, near the town of Victor (Fig. 178) on the line of the Southern California Railway, which now passes through the site of the dam, and will have to be rebuilt for 5½ miles to clear the reservoir. The pass at the Narrows is in a granite ridge, which affords most admirable buttresses for a masonry dam, and is a remarkable one, favorable in all respects for such a structure.

The width at the stream-bed is but 140 feet, while at the height of 150 feet the walls of the canyon are but 360 feet apart. Soundings have been taken with steel rods driven through the sand, which show the maximum depth to what is believed to be bed-rock at 52 feet. Fig. 179 is a cross-section of the site, showing the soundings, and Fig. 180 is a view looking

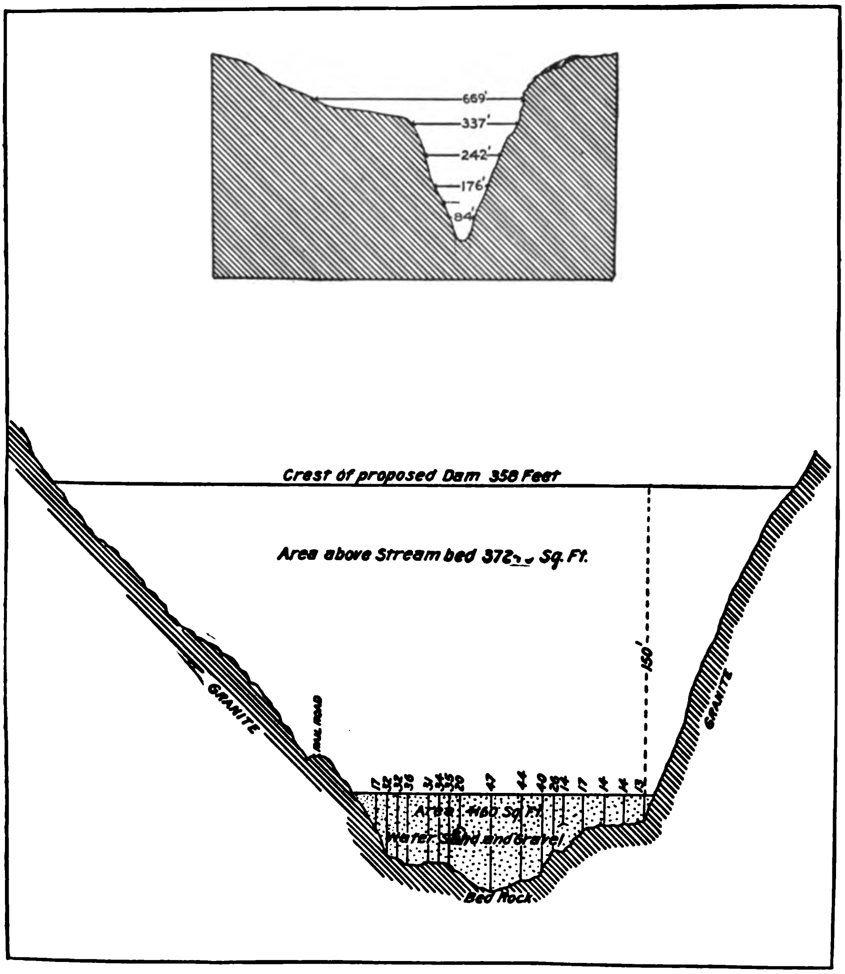


FIG. 179.—CROSS-SECTION OF VICTOR DAM-SITE.

up-stream from the county bridge through the dam-site, the stakes shown in the water marking the positions of the various soundings. The reservoir-basin is shown in Fig. 181, and Fig. 178 is a general map of the watershed and the lands proposed to be irrigated.

As planned, the dam will contain about 70,000 cubic yards of masonry, including the filling of a narrow gap in the rim rock above the 105-foot contour, some 500 feet west of the dam proper. On the opposite side a natural spillway of ample dimensions exists at a height of 145 feet, by which the waste will be returned back to the channel at a safe distance below over a ledge of solid granite. The reservoir at the 145-foot contour covers an area of 7718 acres, and has a capacity estimated at 17,000,000,000 cubic feet, or 390,000 acre-feet, the mean depth being 50½ feet, or 34.86 per cent of the maximum. The ratio between mean and maximum depth in all large commodious reservoir-basins which have a fairly uniform slope of stream-bed from the dam-site up, and do not show a series of rapids for a distance above the dam, is found to range from 28 to 45 per cent, and it is often customary on preliminary estimates, after determining the area of the highest contour embracing the reservoir, and before making detailed survey of the interior of the basin, to apply such a percentage of the height of the dam for computation of contents as the engineer may consider safe within these limits, taking into consideration the general topography of the site. Such has been the method of determining the capacity of the reservoir in question.

The watershed area draining out through this dam-site is somewhat indeterminate from lack of surveys in the eastern part, but it has been roughly computed as 1250 square miles, of which the drainage from the greater portion of 77 square miles on the mountain-crest may be diverted by the works of the Arrowhead Reservoir Company. The precipitation has a wide range of variation, from 60 inches and upward on the summits of the mountains to 5 or 6 inches at the dam. Measurements made by F. W. Skinner, civil engineer, between Januarv 1 and August 1, 1893, gave a maximum discharge of 8500 second-feet and a minimum of 38 second-ieet, from which the mean flow from August 1, 1892, to August 1, 1893, was computed as 825 second-feet. This would be equivalent to an annual run-off of 597,300 acre-feet, or nearly double the proposed reservoir capacity. At the same time it was noted, by the appearance of the drift along the banks and the statements of the residents of Victor, that the highest floods of that season lacked several feet of reaching the high-water marks of previous years.

In connection with the laying of the foundations of the dam, it is interesting to consider the probable volume of underflow in the stream at this point. The area of cross-section shown by the soundings below the surface is approximately 4160 square feet. The rate of percolation determined by the Agua Fria dam-construction (p. 234), if applied to this area, would give an underflow of 11 miner's inches; and even if this were multiplied by 10, the flow to be handled by pumps during construction would be but little more than 4 second-feet, which is not a formidable amount to contemplate taking care of.

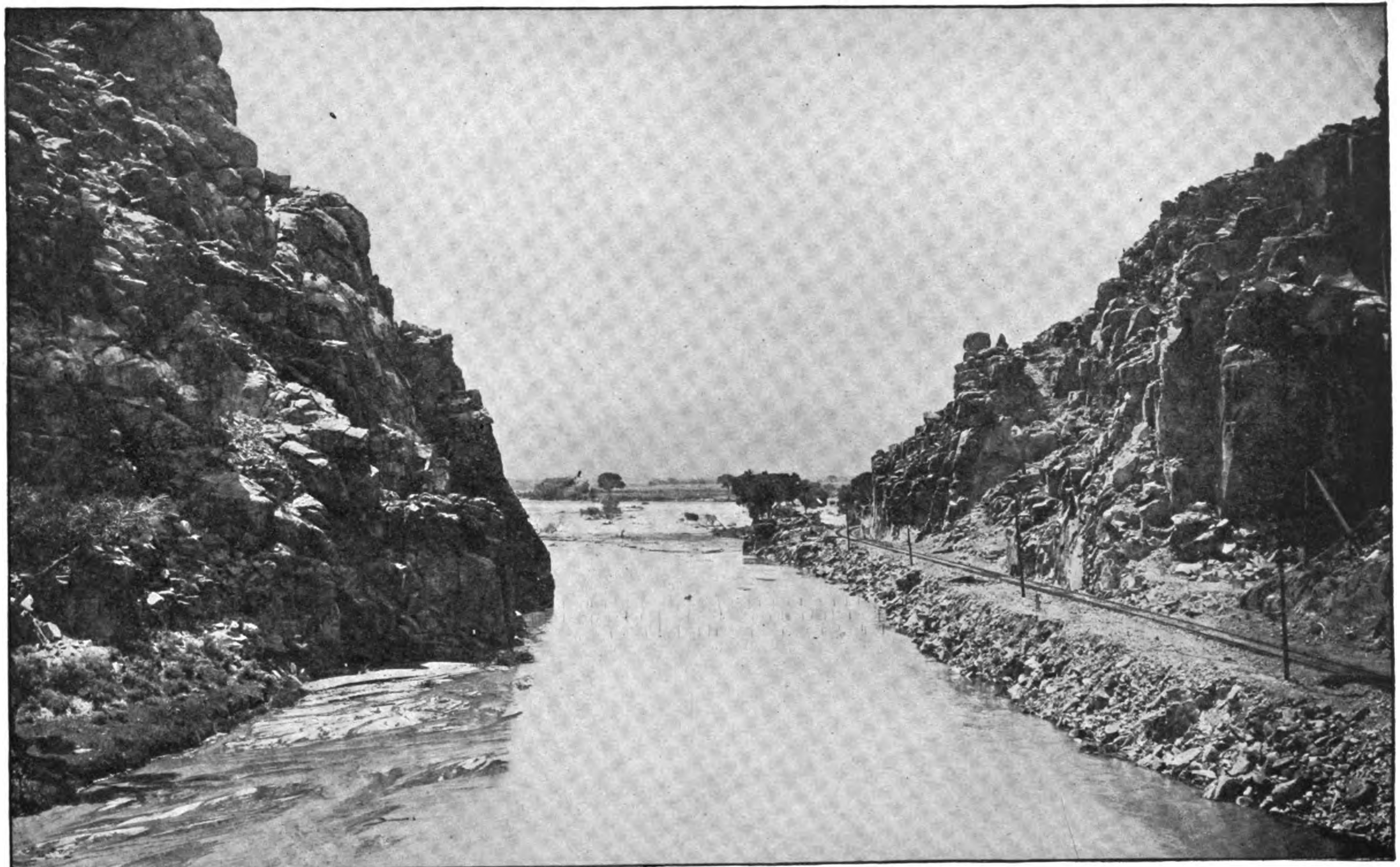

FIG. 180.—VIEW OF VICTOR DAM-SITE LOOKING UP-STREAM.

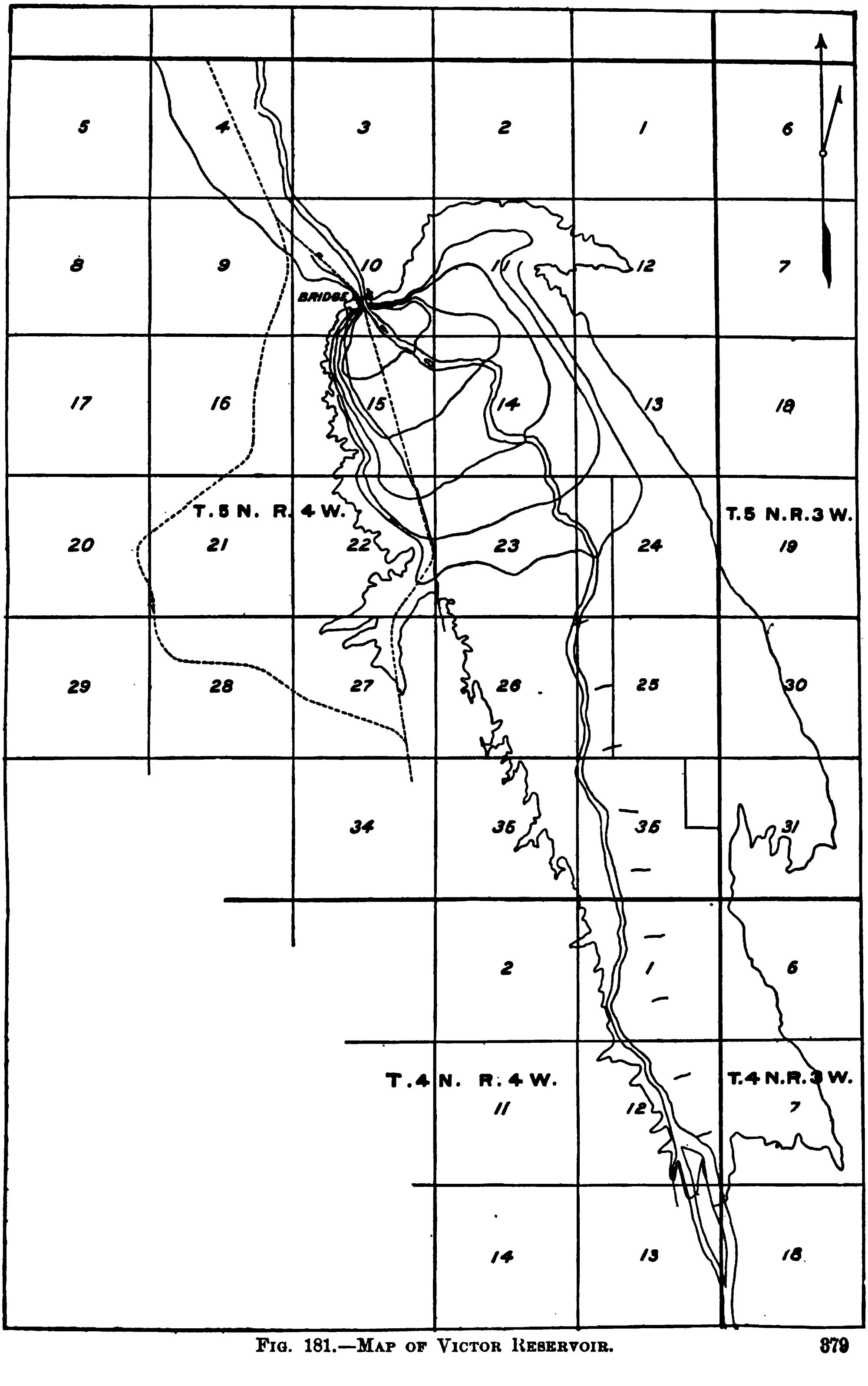


FIG. 181.—MAP OF VICTOR RESERVOIR.

The lands to be irrigated from the reservoir lie west of the river, between the Southern California Railway and the Atlantic and Pacific Railroad, and north of the latter. The area of good land in this region requiring water is greatly in excess of the probable water-supply. The cost of the entire system of storage and distribution, including canals and laterals delivering water to 200,000 acres, is estimated at $1,742,000, or $8.46 per acre, although the company states that it has secured bids from reliable contractors which will greatly reduce these figures of cost. It appears to be an enterprise which would reclaim so large an area of the

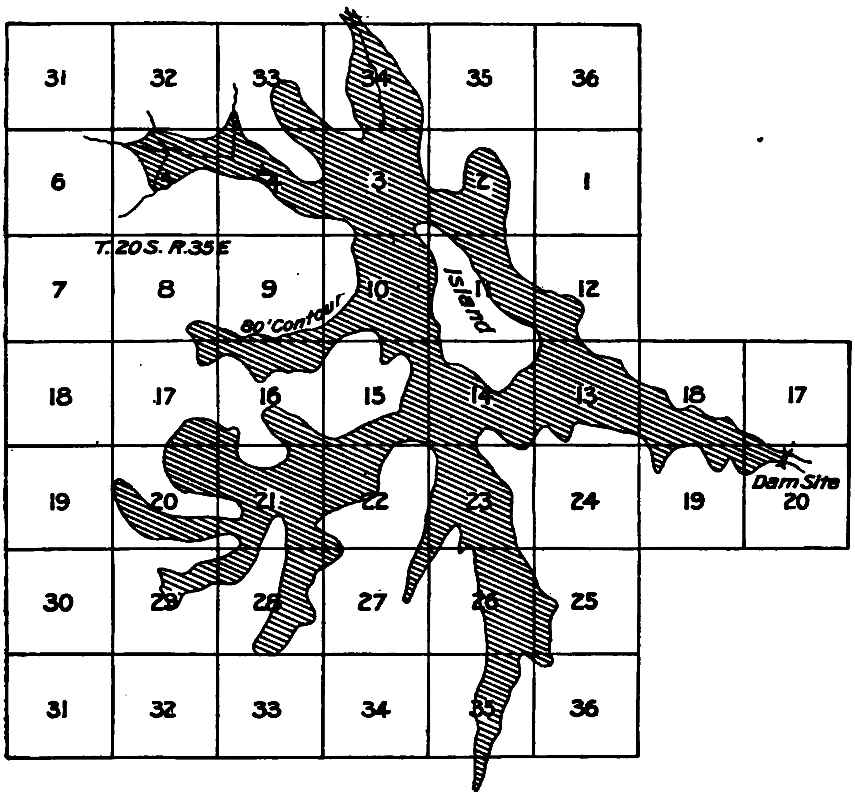


FIG. 182.—MAP OF MANACHE MEADOWS RESERVOIR.

public domain that is now a desert as to entitle it to be classed among those which should be carried to successful completion.

Since the above article was written in 1897, the U. S. Geological Survey has made borings, in 1899, to determine the depth to bed-rock, with the diamond drill-core, and practically confirmed the correctness of the original soundings.

**Projected Reservoirs on Kern River, California.**—A number of available sites for impounding a considerable volume of the flood-waters of Kern River have been surveyed in the mountains near the sources of that noble stream the "Rio Bravo of the South," as it was known to the native

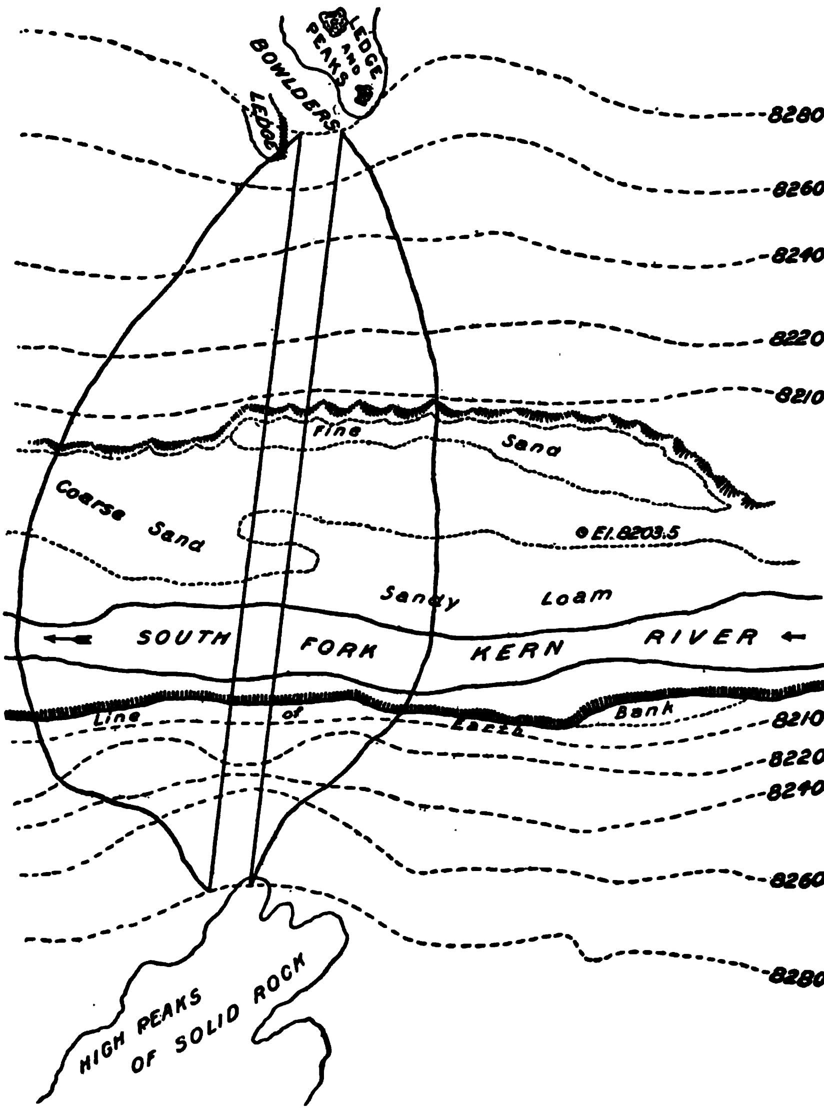


FIG. 183.—MAP OF MANACHE MEADOWS DAM-SITE.

Californias, the largest of which is in the Manache Meadows, on the south fork of Kern River, at an elevation of 8200 feet above sea-level (Fig. 182). A rock-fill dam at this site, estimated to cost $150,000, will create a reservoir of 5830 acres and impound 248,850 acre-feet, from which it is apparent that the site takes front rank among the most capacious sites that have come to public notice in the West. The locality has the appearance of having been a large lake in a comparatively recent geological period, and the basin is so flat that it is classed, and has been surveyed and segregated, as "swamp and overflowed land." The highest peaks in the catchment-area are over 13,000 feet high, and Mount Whitney, 15,000 feet in altitude, is drained on one side by Whitney Creek, the water of one branch of which can be diverted into the reservoir by an inexpensive cut. The area of drainage naturally tributary is 155 square miles.

The dam-site (Fig. 183) shows solid ledges of granite on each side, and soundings indicate that bed-rock is but 8 to 10 feet below the surface across the canyon-bed, which is but 160 feet wide at the bed of the stream and 460 feet wide at a height of 85 feet. Lime can be burned for use on Whitney Creek, 20 miles distant, and there is a great abundance of timber which clothes all the surrounding mountains.

The Manache Meadows reservoir-site has been located by the Kern-Rand Reservoir and Electric Company of Los Angeles, with the view of utilizing it to equalize the flow of the stream sufficiently to enable them to use the water continuously for power. The fall available at the middle power-station is 2250 feet, which it is proposed to utilize in one drop, generating 24,000 H.P. and transmitting it electrically to Los Angeles, 125 miles distant. The upper station has an available drop of about 1900 feet, requiring a conduit of 15 miles to reach it. The lower station has a drop of 200 feet and would deliver water to the highest of the irrigation-canals in South Fork Valley. The total theoretical power available for all three stations is estimated at 45,870 H.P., of which about 30,000 H.P. may be delivered to points of intended use.

The mountain valley of the South Fork, above its junction with the North Fork, has an altitude of about 3600 feet, and contains some 25,000 acres of good arable land, of which about 15,000 acres are irrigated, chiefly for alfalfa. There are thirty ditches, each from 1½ to 3 miles in length, 5 to 6 feet wide on bottom, and carrying 1 to 2 feet depth of water. The reservoir in the Manache Meadows would interfere with the supply to these ditches only during the last half of July and the months of August and September. During the remainder of the year the streams below the Meadows are adequate for this service. In fact, the Manache is but one-fifth the total area of the South Fork drainage above the South Fork farming community, and probably does not supply more than 40 per cent of the flow of the stream.

The main characteristics of the North and South forks of Kern River are as widely different as though the streams were in separate States. The North Fork rises in very high, rugged, and precipitous mountains on which the snow lies late in summer. Its canyon is a deep, narrow gorge throughout its entire length, from its source to Kernville, near its junction with South Fork, with only here and there a narrow strip of meadow-land along the stream, not in any way resembling the expansive meadows and open plains which characterize the South Fork for so great a part of its course. The North Fork drains 1069 and the South Fork 754 square miles of watershed, but the precipitation and run-off of the two sheds vary so greatly that the normal flow of the former is ten to twelve times greater than the latter at their point of junction. Unfortunately the relative advantages of the two forks respecting sites for storage seem to be in inverse ratio to their volume of flow and capacity for filling reservoirs.

**Kern Lake Reservoir.**—One of a large number of sites surveyed in 1881 by the State Engineering Department of California is at the "lake" on North Fork, where a landslide has filled the canyon some 20 feet and created a pond 40 acres in area. This place has been viewed with the idea of constructing a high rock-fill dam, to be formed by a few huge blasts from the cliffs that tower almost vertically above it for 2000 to 3000 feet. The capacity of a reservoir at this place would be 46,600 acre-feet at the 220-foot level, covering about 600 acres. The outlet would be made by means of a tunnel of sufficient capacity to carry the river during construction of the dam. The plan suggested contemplates filling the canyon for several hundred feet with such an enormous mass of rock as to give it unquestionable stability, and after it is thrown down, to lay up a dry wall on its upper face and cover it with asphalt concrete, excavating a spillway entirely around the dam so created. The canyon width at the site is but 100 feet at bottom and 400 feet at a height of 230 feet. The work is estimated to cost $225,000.

One of the advantages of the reservoir in this locality would be that it could be filled twice a year or oftener. Experience has demonstrated that the usual shortage in supply to the Kern Valley canals occurs twice a year—in February and March, and in August and September. In these months a reinforcement of the stream is very much needed. Between each of these periods the North Fork reservoir could be filled and its contents made available for the next low stage.

It may be considered, therefore, that the reservoir, if built and operated in the manner suggested, would practically add 46,000 acres to the irrigable area of the valley, at a cost of about $5 per acre.

**Big Meadows Reservoir.**—Located on Salmon Creek, a branch of the North Fork of Kern River, at a point known as Big Meadows, is a site where a dam of 75 feet height will form a reservoir of 870 acres that would impound 31,150 acre-feet of water. The dam-site is in a granite canyon with clean bed-rock on bottom and sides, the width at bottom between walls being but 25 feet, while the top width at the 75-foot level would be 390 feet. A rock-fill dam is estimated to require 26,000 cubic yards of material, and to cost $80,000. The area of watershed is estimated at 14 to 25 square miles.

Throughout the higher Sierra Nevada are innumerable lakes of considerable area and capacity, generally so high as to be above the timber-line, which can be utilized as storage-reservoirs at small expense. They may be counted by the hundreds on the headwaters of Kings, San Joaquin, Merced, and Tuolumne rivers, although it cannot be said that any of them are so extensive or capacious as to be distinctly noticeable or require special description. Preparations are being made by people living in Visalia to utilize two such lakes on the headwaters of the Kaweah River in a somewhat novel manner. By means of a number of 10-inch pipes they propose to siphon the water out of the lakes to a depth of about 20 feet, and as one of them, called Moose Lake, is about 300 acres in area, it is expected to draw from it in the season of greatest shortage about 5000 to 6000 acre-feet of water. The other, known as "Big Lake," has almost as large an area. This method of utilizing the lakes without the expense of building dams may have more than a local application.

On the eastern slope of the Sierra, near the town of Independence, a high mountain lake of this sort has been tapped by a cut about 10 feet in depth, which has given a flow, as reported, of several hundred inches more than customarily came from it before.

## ACKNOWLEDGMENTS.

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# APPENDIX.

**CONTAINING TABULATED DATA OF RESERVOIR SURVEYS MADE BY THE U. S. GOVERNMENT; TABLES SHOWING THE COST OF RESERVOIR CONSTRUCTION PER ACRE-FOOT IN THE UNITED STATES AND IN FOREIGN COUNTRIES, AND TABLES OF RESERVOIR CAPACITIES AND AREAS.**

U. S. Reservoir Surveys in California.

| No. of Site. | Location. | Altitude. Feet. | Water-shed Area. Sq. Mi. | Reser-voir Area. Acres. | Reser-voir Capac-ity. Acre-ft. | Area Segre-gated. Acres. | Height of Dam. Feet. | Length of Dam. Feet. |
|---|---|---|---|---|---|---|---|---|
| 1 | Clear Lake.......... ... | 5,808 | 418 | 40,821 | 885,300 | 50,921 | None | None |
| 2 | Independence Lake ..... | 6,997 | ....... | 984 | 23,707 | ....... | 40 | 1,328 |
| 3 | Webber Lake.......... | 6,769 | ....... | 778 | 11,152 | ...... | 30 | 812 |
| 4 | Donner Lake........... | 6,095 | ..... | 1,337<br>2,006 | 22,205<br>42,827 | .......<br>....... | 26<br>18 | 3,021<br>... ... |
| 5 | Soda Springs ........... | 6,750 | 6 | 300 | 2,400 | 680 | 20 | ....... |
| 6 | Truckee River ......... | 6,190 | 12 | 225 | 1,350 | 560 | 16 | 530 |
| 7 | Little Yosemite Valley .. | 5,980 | 132.5 | 862 | 45,195 | 1,694 | 115 | 915 |
| 8 | Lake Tenaya........... | 7,990 | 11 | 597 | 23,000 | 1,400 | 35 | 1 075 |
| 9 | Tuolumne Meadows..... | 8,339 | 169 | 1,081 | 43,185 | 1,880 | 75<br>18<br>45<br>65 | 870<br>.......<br>.......<br>....... |
| 10 | Lake Eleanor .......... | 4,561 | 48 | 1,127 | 45,770 | 1,910 | 65 | 1,300 |
| 11 | Kennedy's Meadows..... | 6,182 | 67.5 | 128 | 7,408 | 860 | 102 | 410 |
| 12 | Kennedy's Lake ....... | 8,009 | 5.4 | 110 | 2,000 | 440 | 31 | 900 |
| 13 | Blood's Creek. ......... | 6,911 | 4.7 | 348 | 6,917 | 881 | 55<br>20<br>15 | 1,670<br>300<br>240 |
| 14 | Red Lake.............. | 7,850 | Small | 80 | 1,050 | 360 | 35. | ....... |
| 15 | Pleasant Valley .... .. | 5,900 | " | 60 | 790 | 402 | 35 | ..... . |
| 16 | East Carson Creek ...... | 6,000 | ....... | 40 | 975 | 200 | 65 | 450 |
| 17 | Indian Pool, Deer Creek. | 8,000 | ....... | 20 | 160 | 25 | 22 | 400 |
| 18 | Heenan Lake........... | 7,100 | Small | 130 | 1,460 | 400 | 30 | 530 |
| 19 | Silver King Valley...... | 6,400 | " | 255 | 5,740 | 722 | 60 | 344 |
| 20 | Wolf Creek ............ | 6,500 | " | 190 | 4,630 | 600 | 65 | 660 |
| 21 | Dumont's Meadows...... | 7,500 | Extens. | 225 | 5,480 | 680 | 65 | 425 |
| 22 | Mokelumne River....... | 7,020 | ....... | 75 | 1,120 | 820 | 40 | 315 |
| 23 | " " ...... | 6,840 | ....... | 80 | 430 | 200 | 38 | 344 |
| 24 | Pacific Valley .. ....... | 7,000 | Small | 75 | 980 | 320 | 35 | 317 |
| 25 | Bell'sMeadows,CanyonCr | 5,500 | ....... | 280 | 6,300 | 800 | 60 | 1,200 |
| 26 | Coffin's Hollow, " " | 5,000 | ....... | 175 | 2,200 | 480 | 35 | 770 |
| 27 | Hull's Meadows......... | 5,000 | ....... | 115 | 2,160 | 379 | 50 | 555 |
| 28 | Granite Lake ....... ... | 5,040 | ....... | 220 | 3,300 | 520 | 40 | 290 |
| 29 | Cherry Valley.......... | 4,500 | ....... | 165 | 2,500 | 720 | 40 | 530 |
| 30 | Lake Vernon .......... | 6,530 | ....... | 480 | 5,700 | 920 | 30 | 660 |
| 31 | Big Meadows .......... | 7,500 | Small | 980 | 11,000 | 400 | 30 | 320 |
| 32 | Errarar's Meadows...... | 5,000 | " | 95 | 1,070 | 812 | 80 | 800 |
| 33 | Hetch-Hetchy Valley.... | 1,500 | 410 | 680 | 25,500 | 1,440 | 100 | 320 |
| 34 | Little Truckee River .... | 6,430 | ....... | 450 | 10,100 | 1,043 | 60 | 318 |
| 35 | Stampede Valley........ | 5,800 | ....... | 120 | 2,250 | 440 | 50 | 370 |
| 36 | Twin Valley .. ....... | 6,200 | 12 | 310 | 3,480 | 840 | 30 | 530 |
| 37 | Little Truckee River.... | 5,550 | Ample | 350 | 6,500 | 880 | 50 | 400 |
| 38 | Monument Peak........ | 7,700 | " | 160 | 4,800 | 483 | 80 | ....... |
| 39 | Young's Crossing ....... | 5,200 | " | 150 | 3,370 | 640 | 60 | 525 |
| 40 | Grass Lake............ | 7,800 | Small | 350 | 4,000 | 920 | 30 | ....... |
| 41 | Hope Valley............ | 7,050 | Ample | 1,808 | 90,810 | 2,953 | 163 | 1,560 |
| 42 | Harvey's Meadows ...... | 5,900 | Small | 40 | 600 | 280 | 40 | ....... |
| 43 | American River......... | 7,800 | " | 135 | 2,400 | 440 | 47 | ....... |
| 44 | Twin Lakes ............ | 7,900 | ....... | 420 | 4,700 | 884 | 30 | ...... |
| | **U. S. Reservoir Surveys in Nevada.** | | | | | | | |
| 1 | Truckee River, lower.... | 4,250 | 1,000 | 400 | 7,500 | 1,000 | 63 | 1,000 |
| 2 | " " upper.... | 4,300 | 1,000 | 395 | 7,400 | 1,040 | 50 | 870 |
| 17 | Long Valley Creek...... | ....... | ....... | 1,086 | 34,425 | ....... | 60<br>100 | .......<br>....... |
| 18 | West Carson River...... | 7,050 | ....... | 1,800 | 90,810 | ....... | 163 | ....... |

**U. S. Reservoir Surveys in Colorado.**

| No. of Site. | Location. | Altitude. Feet. | Water-shed Area. Acres. | Reservoir Area. Acres. | Reservoir Capacity. Acre-ft. | Area Segregated. Acres. | Height of Dam. Feet. | Length of Dam. Feet. |
|---|---|---|---|---|---|---|---|---|
| 1 | Twin Lakes, Arkansas R. | 9.194 | 387 | 3,475 | 103,500 | 4,716 | 73 | 3,650 |
| 2 | Leadville, " " | 10,000 | ....... | ....... | 8,875 | 760 | 105 | 1,162 |
| 3 | Clear Creek............ | ....... | ....... | ....... | 7,000 | 720 | { 65<br>{ 30 | 1,560<br>725 |
| 4 | Hayden ................ | 9,240 | ....... | ....... | 45,000 | 2,292 | 120 | 1,445 |
| 5 | Sugar Loaf............. | 10,000 | ....... | ....... | 45,000 | 1,915 | 50 | 1,800 |
| 6 | Seven-Mile Creek....... | 8,400 | 30 | 160 | 4,550 | 560 | 100 | |
| 7 | Tennessee Park......... | 9,870 | ....... | ....... | 37,000 | 2,396 | 68 | 825 |
| 8 | Wet Mt. Valley......... | 8,000 | 380 | 2,540 | 119,100 | 3,636 | 140 | |
| 9 | Pine Creek............. | 7,900 | 30 | 80 | 1.520 | 384 | 100 | |
| 10 | Slate Creek............ | 8,100 | 25 | 560 | 8,570 | 1,294 | 86 | |
| 11 | West Oil Creek......... | 8,500 | 20 | 200 | 2,250 | 640 | 67 | |
| 12 | Oil Creek.............. | 8,500 | 160 | 1,400 | 56,200 | 2,731 | 159 | |
| 13 | West Beaver Creek...... | 9,000 | 60 | 1,820 | 28,450 | 2,400 | 96 | |
| 14 | Beaver Creek........... | 9,000 | 25 | 50 | 620 | 160 | 68 | |
| 15 | Oil Creek.............. | 5,800 | 270 | 167 | 4,500 | 480 | 100 | |
| 16 | Wilson Creek .......... | 5,900 | 35 | 80 | 2,900 | 481 | 90 | |
| 17 | Sand Creek ............ | 5,450 | 30 | 115 | 1,950 | 360 | 84 | |
| 18 | Six-Mile Creek......... | 5,500 | 10 | 50 | 3,100 | 320 | 100 | |
| 19 | Eight-Mile Creek....... | 5.500 | 50 | 210 | 4,550 | 520 | 70 | |
| 20 | Beaver Creek........... | 5,100 | 130 | 215 | 7,100 | 516 | ....... | |
| 21 | Turkey Creek........... | 5,400 | 70 | 520 | 9,800 | 1,000 | 80 | |
| 22 | " " ........... | 5,000 | 70 | 90 | 1,920 | 356 | 60 | |
| 23 | Arkansas, 8 m. ab. Pueblo | 4.840 | ....... | 1,920 | 359,000 | 3,643 | 90 | |
| 24 | Rush Creek ............ | 5,400 | 10 | 335 | 2,100 | 680 | 50 | |
| 25 | Cottonwood Lake........ | ....... | ....... | ....... | 8,400 | 686 | 110 | 1,268 |
| 26 | St. Charles River....... | 4,980 | 180 | 170 | 2.640 | 440 | 27 | |
| 27 | " " " ........ | 6,300 | 65 | 200 | 3,340 | 660 | 77 | |
| 28 | Graneros Creek......... | 5,892 | small | 760 | 27.200 | 1,406 | 165 | |
| 29 | Huerfano River......... | 6,895 | 500 | 115 | 1,960 | 400 | 49 | |
| 30 | Cucharas River......... | 7,800 | 40 | 130 | 4,125 | 400 | 132 | |
| 31 | Arapahoe Creek......... | 7,200 | 25 | 450 | 13,300 | 1,040 | 139 | |
| 32 | Santa Clara River....... | 6,700 | 45 | 420 | 10,150 | 1,240 | 142 | |
| 33 | Apishapa River......... | 6.850 | 100 | 440 | 12,790 | 920 | 115 | |
| 34 | Purgatoire River........ | 6,620 | 320 | 450 | 6.200 | 956 | 120 | |
| 35 | Stonewall Valley........ | 8,300 | 50 | 240 | 11,200 | 222 | 135 | |
| 36 | " " | 8,200 | 65 | 762 | 22,700 | ....... | 142 | |
| 37 | Apishapa River.......... | 5,600 | 420 | 250 | 3,840 | 720 | 31 | |
| 38 | Monument Creek......... | 6.950 | ....... | ....... | 5.630 | 480 | 47 | 1,160 |
| 40 | Smith Canyon Creek.... | 4,700 | 220 | 1,400 | 34,230 | 3,003 | 98 | |
| 41 | Rule Creek ............ | 4 250 | 140 | 1,560 | 32,780 | 2,360 | 83 | 3,069 |
| 42 | Cottonwood Creek....... | 4,300 | 110 | 1,000 | 25.680 | 1,806 | 58 | |
| 43 | Two Butte Creek........ | 4,500 | 250 | 480 | 5,900 | 1,000 | 50 | |
| 44 | Nat. Basin, n. Rocky Ford | 4,250 | none | 700 | 14,720 | 1,234 | 20 | |
| 45 | " " " La Junta.. | 4,150 | " | 1,680 | 21,407 | 2,420 | none | |
| 46 | " " " Arlington.. | 4,150 | " | 4,160 | 43,300 | 5,922 | " | |
| 47 | Arkansas River......... | 10,600 | 20 | 420 | 9,600 | 714 | 50 | |
| 48 | " " ......... | 10,100 | 30 | 250 | 4,100 | 600 | 45 | |
| 49 | Pine Creek, n. Arkansas. | 8,600 | 25 | 90 | 1,500 | 240 | 70 | |
| 50 | " " " " | 8,545 | 20 | 130 | 2,500 | 319 | 60 | |
| 51 | Arkansas River.......... | 8,000 | 600 | 420 | 11.940 | 1,202 | 120 | |
| 52 | Oak Grove ............. | 6,425 | 30 | 80 | 1,310 | 960 | 84 | |
| 53 | Rock Creek............. | 5,200 | 30 | 300 | 6,600 | 960 | 70 | |
| 54 | Timpas Creek........... | 4,950 | 75 | 840 | 13,640 | 1,520 | 88 | |
| 55 | Las Animas River....... | 4,450 | 2,400 | 3,360 | 43,330 | 4,040 | 108 | |

## U. S. Reservoir Surveys in Montana.

| No. of Site. | Location. | Altitude. Feet. | Water-shed Area. Sq. Mi. | Reser-voir Area. Acres. | Reser-voir Capac-ity. Acre-ft. | Area Segre-gated. Acres. | Height of Dam. Feet. | Length of Dam. Feet. |
|---|---|---|---|---|---|---|---|---|
| 1 | Sun River | ....... | 1,172 | 275 | 5,249 | 1,014 | 15 / 57 | 630 / 590 |
| 2 | " " | ....... | 1,136 | 367 | 13,018 | 1,240 | 99 | 380 |
| 3 | " " , North Fork | ....... | 668 | 1,102 | 50,056 | 1,760 | 122 | 470 |
| 4 | " " , South Fork | ....... | 318 | 570 | 19,591 | 1,080 | 113 | 677 |
| 5 | Willow Creek | ....... | 87 | 1,560 | 36,605 | 2,360 | 84 | 573 |
| 6 | " " | ....... | 87 | 340 | 6,081 | 1,120 | 15 / 74 | 855 / 690 |
| 7 | Sun River | ....... | small | 285 | 5,226 | 880 | 41 | 3,160 |
| 8 | " " | ....... | " | 140 | 2,091 | 440 | 23 | 523 |
| 9 | " " | ....... | none | 70 | 727 | 360 | 35 | 481 |
| 10 | Benton Lake | 3,632 | ....... | 9,130 | 140,200 | 11,937 | ....... | |
| 11 | Near Martinsdale | 5,015 | 10 | 80 | 160 | 210 | 15 | |
| 12 | " " | 4,900 | ....... | 40 | 800 | 120 | 40 | |
| 13 | Daisy Dean Creek | 5,000 | 40 | 20 | 105 | 160 | 15 | |
| 14 | " " " | 4,830 | 18 | 80 | 390 | 200 | 35 | |
| 15 | N. Fork, Musselshell R. | 5,435 | 60 | 40 | 520 | 240 | 35 | |
| 16 | S. " " " | 5,000 | 95 | 100 | ....... | 320 | 55 | |
| 17 | " " " " | 5,100 | ....... | 25 | ....... | 120 | 20 | |
| 18 | Sixteen-Mile Creek | 5,550 | 90 | 1,055 | 19,781 | 2,279 | 50 | |
| 19 | S. Fork, Smith River | 5,625 | 12 | 120 | 1,125 | 440 | 25 | |
| 20 | " " " " | 5,330 | 50 | 110 | 1,230 | 360 | 30 | |
| 21 | Confederate Gulch | 4,000 | ....... | 15 | ....... | 80 | 10 | |
| 22 & 23 | Mitchell Creek | ....... | ....... | 50 | ....... | 240 | 15 | |
| 24 | Big Hole River | 5,000 | ....... | 11,800 | ....... | 10,705 | 100 | |
| 25 | Black-tail Deer Creek | 6,000 | ....... | 600 | ....... | 1,155 | 40 | |
| 26 | Beaver Head River | 5,500 | ....... | 1,400 | ....... | 2,640 | 125 | |
| 27 | Red Rock River | ....... | ....... | 1,200 | ....... | 1,894 | 40 | |
| 28 | Ruby River | 5,300 | ....... | 400 | ....... | 920 | 35 | |
| 29 | Nat. Basin, Choteau Co. | ....... | ....... | 2,800 | ...... | 3,944 | 20 | |
| 30 | " " " " | ....... | ....... | 200 | ....... | 520 | 15 | |
| 31 | Box Elder Creek | 3,600 | 85 | 180 | 3,000 | 960 | 46 | |
| 32 | West Otter Creek | 5,000 | ....... | 70 | 1,500 | 360 | 66 | |
| 33 | Sage Creek | 4,900 | 25 | 80 | 250 | 160 | 21 | |
| 34 | Judith River | 5,000 | 120 | 100 | 3,000 | 360 | 76 | |
| 35 | Dry Basin near Utica | 4,900 | ....... | 35 | 200 | 160 | ....... | |
| 36 | " " " " | 4,900 | ....... | 55 | 350 | 160 | 8 | |
| 37 | Lebo Lake | 5,000 | ....... | ....... | ....... | 676 | 10 | |
| 38 | Near Martinsdale | 6,000 | ....... | 250 | ....... | 649 | 35 | |

## U. S. Reservoir Surveys in Utah.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | Bear Lake, partly in Idaho | 5,949 | 2,400 | 69,120 | 208,000 | 6,014 | 8 | 55 |
| 2 | Silver Lake | 8,734 | 3 | 140 | 2,500 | 440 | 52 | 5,200 |
| 3 | Twin Lakes | ....... | [illegible] | 25 | 450 | 160 | 20 | 180 |
| 4 | Mary's Lake | 9,000 | [illegible] | 25 | 550 | 160 | 25 | 140 |
| 5 | Sevier River, near Oasis | 4,600 | 5,000 | 940 | 10,000 | 2,878 | 16 | 475 |
| 6 | Sanpitch River | 5,100 | 500 | 830 | 9,000 | 2,001 | 22 | 580 |
| 7 | Sevier River | 5,700 | 2,500 | 290 | 1,600 | 920 | 10 | 250 |

U. S. RESERVOIR SURVEYS IN UTAH.

| No. of Site. | Location. | Altitude. Feet. | Watershed Area. Sq. Mi. | Reservoir Area. Acres. | Reservoir Capacity. Acre-ft. | Area Segregated. Acres. | Height of Dam. Feet. | Length of Dam. Feet. |
|---|---|---|---|---|---|---|---|---|
| 8 | East Fork, Sevier River.. | 6,200 | 700 | 460 | 3,000 | 1,120 | 12.5 | 280 |
| 9 | Otter Creek............. | 6,200 | 500 | 1,860 | 14,000 | 3,360 | 15 | 260 |
| 10 | East Fork, Sevier River.. | 7,000 | 575 | 3,050 | 76,000 | 4,956 | 50 | 225 |
| 11 | " " " " ... | 7,200 | 300 | 770 | 3,500 | 1,278 | 10 | 6,325 |
| 12 | Panquitch Lake......... | 8,100 | 80 | 1,280 | 10,700 | 1,560 | 10 | 110 |
| 13 | Blue Spring............ | 8,200 | 25 | 440 | 13,000 | 845 | 48 | 250 |

U. S. RESERVOIR SURVEYS IN NEW MEXICO.

| No. of Site. | Location. | Altitude. Feet. | Watershed Area. Sq. Mi. | Reservoir Area. Acres. | Reservoir Capacity. Acre-ft. | Area Segregated. Acres. | Height of Dam. Feet. |
|---|---|---|---|---|---|---|---|
| 1 | Horse Lake............. | ....... | ....... | 1,120 | 21,000 | Unsg.? | 40 |
| 2 | Bowlder Lake. .......... | 7,500 | ....... | 2,250 | 51,000 | " | 100 |
| 3 | Stinking Lake........... | 7,500 | ....... | 3,630 | 125,000 | " | 50 |
| 4 | Vallecitos Creek ........ | 7,000 | ....... | 100 | 3,500 | " | 100 |
| 5 | Near El Rito............ | 7,000 | ....... | 60 | 3,000 | 200 | 150 |
| 6 | Vallecitos Creek......... | 7,000 | ....... | 60 | 1,800 | 60 | 80 |
| 7 | Rio Caliente............ | 7,000 | ....... | 330 | 10,000 | 1,059 | 80 |
| 8 | Rio Hondo.............. | ....... | ....... | 50 | 1,000 | ....... | 100 |
| 9 | Rio Colorado............ | ....... | ....... | 270 | 9,000 | ....... | 100 |
| 10 | Rio Picuris ........... | 7,000 | ....... | 62 | 1,200 | 62 | 60 |
| 11 | Rio Picuris and Rio Lusio | ....... | ....... | 236 | 6,000 | 236 | 80 |
| 12 | Rio Grande..... ........ | 6,000 | ....... | 1,500 | 30,000 | 1,500 | 50 |
| 13 | Rio Jemez, East Fork.... | ....... | ....... | 4,030 | 13,000 | ....... | ....... |
| 14 | " " ..... .. ..... | 9,000 | ....... | 256 | 5,000 | 256 | 53.5 |
| 15 | " " ... ......... | 8,500 | ....... | 212 | 4,500 | 212 | 57 |
| 16 | " " ............ | 8,400 | ....... | 575 | 13,000 | ....... | 58 |
| 17 | " " ............. | ....... | ....... | 1,046 | 32,000 | 1,046 | 70 |
| 18 | Rio Salado............. | 7,000 | ....... | 155 | 3,700 | 155 | 60 |
| 19 | Rio Jemez. ............ | ....... | ....... | 1,640 | 60,000 | 1,640 | 90 |
| 20 | Santa Fé Creek.......... | 8,000 | ....... | 40 | 1,100 | 200 | 72 |
| 21 | Rio Medio and Rio Frijole | ....... | ....... | 45 | 800 | 45 | 50 |
| 22 | Rio Mora............... | 7,000 | ....... | 620 | 5,400 | 620 | 60 |
| 23 | " " ............... | ....... | ....... | 1,770 | 38,000 | 1,770 | 90 |
| 24 | Manuelitos Creek......... | ....... | ....... | 1,037 | 41,000 | 1,037 | 100 |
| 25 | Cherry Valley Lake...... | 6,000 | ....... | 800 | 15,000 | 1,400 | none |
| 26 | Rio Gallinas .......... | 6,000 | ....... | 170 | 5,800 | 170 | 100 |
| 27 | Rio Pecos.............. | ....... | ....... | 370 | 8,800 | 370 | 75 |
| 28 | " " .............. | ....... | ....... | 250 | 7,800 | ....... | 82 |
| 29 | Rio Grande............. | 6,000 | ....... | 4,452 | 87,000 | 198 | 31 |
| 30 | Rio San José........... | 6,000 | ....... | 900 | 20,000 | 900 | 46 |
| 31 | San Mateo Creek........ | ....... | ....... | 880 | 5,500 | 880 | 43.5 |
| 32 | Blue Water Creek....... | ....... | ....... | 490 | 3,000 | 960 | 19 |
| 33 | " " " ....... | ....... | ....... | 1,900 | 53,000 | 3,540 | 74.5 |
| 34 | Agua Fria Creek........ | ....... | ....... | 293 | 2,740 | 960 | 21<br>36<br>24 |
| 35 | Rio Colorado............ | ....... | ....... | 420 | 11,000 | 877 | 72 |
| 36 | Rio Salado.............. | ....... | ....... | 2,800 | 63,000 | 4,120 | 68 |
| 37 | Rio Alamosa............ | ....... | ....... | 1,185 | 59,000 | 371 | 125 |
| 38 | Rio Grande............. | ....... | ....... | 5,540 | 175,000 | 8,507 | 80 |
| 39 | " " .............. | ....... | ....... | 6,380 | 102,000 | 6,760 | 40 |

U. S. RESERVOIR SURVEYS IN WYOMING.

| No. of Site. | Location. | Altitude. Feet. | Watershed Area. Sq. Mi. | Reservoir Area. Acres. | Reservoir Capacity. Acre-ft. | Area Segregated. Acres. | Height of Dam. Feet. |
|---|---|---|---|---|---|---|---|
| 1 | Jackson Lake............ | ........ | 840 | ........ | 500,000 | ....... | 25 |

U. S. RESERVOIR SURVEYS IN IDAHO.

| No. of Site. | Location. | Altitude. Feet. | Watershed Area. Sq. Mi. | Reservoir Area. Acres. | Reservoir Capacity. Acre-ft. | Area Segregated. Acres. | Height of Dam. Feet. |
|---|---|---|---|---|---|---|---|
| 1 | Swan Valley, Snake River | ....... | 5,365 | ....... | 1,500.000 | ........ | 125 |

COST OF RESERVOIR CONSTRUCTION PER ACRE-FOOT. AMERICAN RESERVOIRS.

| Name. | Character of Dam. | Capacity of Reservoir. Acre-feet. | Cost. | Cost per Acre-foot. |
|---|---|---|---|---|
| Sweetwater dam, California...... | Masonry | 22,566 | $264,500 | $11.72 |
| Bear Valley dam, " ...... | " | 40,000 | 68,000 | 1.70 |
| Hemet dam, " ...... | " | 10,500 | 150,000 | 14.29 |
| Escondido dam, " ...... | Rock-fill | 3,500 | 110,059 | 31.44 |
| Lower Otay dam, " ...... | Rock-fill, steel core | 42,190 | .......... | .......... |
| La Mesa dam, " ...... | Hydraulic-fill | 1,300 | 17,000 | 13.10 |
| Cuyamaca dam, " ...... | Earth | 11,410 | 54,400 | 4.76 |
| Buena Vista Lake, " ...... | " | 170,000 | 150,000 | 0.88 |
| Yosemite Lake, " ...... | " | 15,000 | .......... | ........ |
| English dam, " ..... | Rock-fill crib | 14,900 | 155,000 | 10.40 |
| Bowman dam, " ...... | " " | 21,070 | 151,521 | 7.19 |
| San Leandro dam, " ....... | Earth | 13,270 | 900,000 | 68.00 |
| Eureka Lake dam, " ...... | Rock-fill | 15,170 | 35,000 | 2.32 |
| Fancherie dam, " ....... | " | 1,350 | 8,000 | 5.92 |
| Lake Avalon, Pecos River, N. M.. | Rock-fill and earth | 6,300 | 176,000 | 27.94 |
| Lake McMillan " " " .. | " " " | 89,000 | 180,000 | 2.02 |
| Tyler, Texas.................... | Hydraulic-fill | 1,770 | 1,140 | 0.64 |
| Cache la Poudre, Colorado........ | Earth | 5,654 | 110,266 | 19.50 |
| Larimer and Weld, " ........ | " | 11,550 | 89,782 | 7.77 |
| Windsor, " ........ | " | 23,000 | 75,000 | 3.26 |
| Monument, " ........ | " | 885 | 33,121 | 38.69 |
| Apishapa, " ........ | " | 459 | 14,772 | 32.18 |
| Hardscrabble, " ....... | " | 102 | 9,997 | 97.78 |
| Boss Lake, " ........ | " | 205 | 14,654 | 71.39 |
| Saguache, " ........ | " | 954 | 30,000 | 31.45 |
| Seligman, Arizona............... | Masonry | 703 | 150,000 | 169.50 |
| Ash Fork, " ............... | Steel | 110 | 45,776 | 416.30 |
| Williams, " ............ ... | Masonry | 338 | 52,838 | 156.35 |
| Walnut Canyon, Arizona......... | " | 480 | 55,000 | 114.60 |
| New Croton, New York.......... | Masonry and earth | 98,200 | 4,150,573 | 42.27 |
| Titicus, " .......... | " " " | 22,000 | 933,065 | 42.42 |
| Sodom, " .......... | " " " | 14,980 | 366,990 | 24.50 |
| Bog Brook, " .......... | Earth | 12,720 | 510,430 | 40.12 |
| Indian River, " .......... | Masonry and earth | 102,548 | 83,555 | 0.81 |
| Wigwam, Conn.................. | Masonry | 1,028 | 150,000 | 145.90 |

ESTIMATED COST OF RESERVOIR CONSTRUCTION PER ACRE-FOOT. PROJECTED AMERICAN RESERVOIRS.

| Name. | Character of Dam. | Capacity of Reservoir. Acre-feet. | Estimated Cost. | Cost per Acre-foot of Capacity. |
|---|---|---|---|---|
| Tonto Basin, Arizona | Masonry | 757,000 | $2,450,000 | $3.24 |
| San Carlos, " | " | 241,396 | 1,038,926 | 4.30 |
| Riverside, " | " | 221,138 | 1,992,605 | 9.01 |
| Buttes, " | Rock-fill & mas'ry | 174,040 | 2,643,327 | 15.19 |
| Horseshoe, " | Rock-fill | 205,000 | 600,000 | 2.93 |
| Bear Canyon, " | Masonry | 14,762 | 596,580 | 40.40 |
| Victor, California | " | 390,000 | 450,000 | 1.15 |
| Manache Meadows, California | Rock-fill | 146,400 | 130,000 | 0.89 |
| Rock Creek, Nevada | " | 80,000 | 80,000 | 1.00 |
| Columbus, Ohio | Masonry | 17,440 | 324,177 | 18.60 |
| Elephant Buttes, New Mexico | " | 253,368 | 281,515 | 1.11 |
| Pecos River, " | Rock-fill | 200,000 | 150,000 | 0.75 |
| Sand Lake, Texas | Natural basin | 72,500 | 36,000 | 0.50 |
| Laramie, Wyoming | " " | 414,000 | 1,416,254 | 3.42 |
| Sweetwater River, " | Masonry | 326,965 | 276,485 | 0.85 |
| Cloud Peak, " | Rock-fill and earth | 6,800 | 31,049 | 4.56 |
| Piney, " | " " " | 11,020 | 70,226 | 6.37 |
| Lake De Smet, " | Natural basin | 67,628 | 113,110 | 1.67 |
| Loveland, Colorado | " " | 45,741 | 262,106 | 5.73 |
| Tarryall, " | Masonry | 46,000 | 550,000 | 12.00 |
| Lost Canyon " | Natural rock-fill | 24,000 | 104,000 | 4.35 |

COST OF RESERVOIR CONSTRUCTION PER ACRE-FOOT. FOREIGN RESERVOIRS.

| Name. | Character of Dam. | Capacity of Reservoir. Acre-feet. | Cost. | Cost per Acre-foot of Capacity. |
|---|---|---|---|---|
| Couzon, France | Masonry | 1,297 | $247,600 | $190.00 |
| Furens, " | " | 1,297 | 318,000 | 245.00 |
| Ternay, " | " | 2,433 | 204,872 | 84.00 |
| Ban, " | " | 1,499 | 190,000 | 127.00 |
| Pas du Riot, " | " | 1,054 | 256,000 | 243.00 |
| Chartrain, " | " | 3,647 | 420,000 | 115.10 |
| Lake Oredon, " | Earth | 5,894 | 142,000 | 24.00 |
| Moucne, " | Masonry | 7,011 | 1,003,657 | 143.00 |
| Liez, " | Earth | 13,051 | 598,418 | 46.00 |
| Wassy, " | " | 1,740 | 138,942 | 80.00 |
| Patas, India | " | 325 | 15,925 | 49.00 |
| Ekruk, " | Earth and masonry | 76,175 | 666,000 | 8.74 |
| Ashti, " | Earth | 32,660 | 270,000 | 8.26 |
| Lake Fife, " | Masonry | 75,500 | 630,000 | 8.34 |
| Bhatgur, " | " | 126,500 | ........ | ........ |
| Tansa, " | " | 52,670 | 988,000 | 18.76 |
| Betwa, " | " | 36,800 | 160,000 | 4.35 |
| Chumbrumbaukum, India | Earth | 63,780 | 312,000 | 4.89 |
| Villar, Spain | Masonry | 13,050 | 390,000 | 28.88 |
| Gilleppe, Belgium | " | 9,730 | 874,000 | 89.83 |
| Remscheid, Germany | " | 811 | 91,154 | 112.45 |
| Vyrnwy, Wales | " | 44,690 | 3,334,000 | 74.61 |
| Beetaloo, Australia | Concrete | 2,945 | 573,300 | 194.70 |

## TABLES OF RESERVOIR CAPACITIES AND AREAS.

### Escondido Irrigation District Reservoir, California.

[Area of tributary watershed, 8 square miles; elevation of base of dam above sea-level, 1300 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 20 | ............ | 46 | Capacity of reservoir as completed in 1895, 3,500 acre-feet. Outlet of reservoir is 16 feet above base. |
| 35 | ............ | 288 | |
| 50 | ............ | 970 | |
| 65 | ............ | 2,400 | |
| 80 | 174 | 4,576 | |
| 90 | ............ | 6,455 | |
| 100 | ............ | 8,693 | |
| 110 | 285 | 11,355 | |

### Lower Otay Reservoir, California.

[Area of tributary watershed, 100 square miles; elevation of base of dam above sea-level, 345 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 30 | 40 | 321 | Outlet tunnel 48 feet above base of dam. For cross-section of dam-site see Fig. 177, p. 373. |
| 40 | 96 | 1,002 | |
| 50 | 160 | 2,284 | |
| 60 | 239 | 4,281 | |
| 70 | 276 | 6,860 | |
| 80 | 308 | 9,756 | |
| 90 | 452 | 13,530 | |
| 100 | 567 | 18,623 | |
| 130 | 1,000 | 42,190 | |
| 150 | 1,414 | 66,455 | |

### Morena Reservoir, San Diego County, California.

[Area of tributary watershed, 135 square miles; elevation of base of dam above sea-level, 3100 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 50 | 46 | 460 | Outlet tunnel is at 30-foot contour. Rock-fill dam, with asphalt concrete facing. For cross-section of dam-site see Fig. 177, p. 373. |
| 60 | 73 | 1,079 | |
| 70 | 111 | 2,029 | |
| 80 | 152 | 3,316 | |
| 90 | 225 | 5,188 | |
| 100 | 304 | 7,831 | |
| 110 | 438 | 11.466 | |
| 120 | 624 | 16,804 | |
| 130 | 850 | 24.107 | |
| 140 | 1,137 | 34.358 | |
| 150 | 1,370 | 46,733 | |

### La Mesa Reservoir, San Diego County, California.

[Area of tributary watershed, 5 square miles; elevation of base of dam above sea-level, 433.5 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 30 | 12 | 110 | Hydraulic-fill dam, completed 1895, to 66-foot contour. Outlet at base of dam. |
| 35 | 18 | 190 | |
| 40 | 24 | 290 | |
| 45 | 30 | 430 | |
| 50 | 41 | 610 | |
| 55 | 53 | 850 | |
| 60 | 62 | 1,190 | |
| 65 | 70 | 1,460 | |
| 70 | 83 | 1,850 | |
| 75 | 96 | 2,290 | |
| 80 | 113 | 2,820 | |
| 85 | 129 | 3,420 | |
| 90 | 152 | 4,120 | |
| 95 | 181 | 4,950 | |
| 100 | 205 | 5,920 | |
| 140 | 444 | 18,890 | |

### Pine Valley Reservoir, San Diego County, California.

[Area of watershed, 45 square miles; elevation of base of dam, 3700 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 40 | 90 | 550 | Dam proposed to be constructed by hydraulic process as a rock-fill earth-dam. For cross-section of dam site, see Fig. 177, p. 378. |
| 50 | 160 | 1,800 | |
| 60 | 240 | 3,800 | |
| 65 | 277 | 5,100 | |
| 70 | 300 | 6,530 | |
| 80 | 315 | 9,610 | |
| 90 | 330 | 12,835 | |
| 100 | 349 | 16,230 | |
| 110 | 397 | 19,960 | |
| 120 | 520 | 24.540 | |
| 125 | 586 | 27,080 | |
| 130 | 640 | 30,380 | |
| 140 | 720 | 37,180 | |
| 150 | 784 | 44,695 | |

LAKE HEMET RESERVOIR, RIVERSIDE COUNTY, CALIFORNIA.

[Area of watershed, 65 to 100 square miles; elevation of base of dam, 4200 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 40.0 | 2.0 | 33 | |
| 45.0 | 2.3 | 73 | Lowest outlet at 45 feet. |
| 50.0 | 3.0 | 113 | |
| 60 0 | 29.0 | 332 | |
| 70.0 | 62.0 | 773 | |
| 80.0 | 108.0 | 1,603 | |
| 90.0 | 133.0 | 2,787 | |
| 100.0 | 187.0 | 4,391 | |
| 110.0 | 252.0 | 6,598 | |
| 120.0 | 328.0 | 9,512 | |
| 122.5 | 365.0 | 10,500 | Top of dam as completed 1895. |
| 130.0 | 486.0 | 13,590 | |
| 140.0 | 601.0 | 19,077 | |
| 150.0 | 738.0 | 25,836 | |

LITTLE BEAR VALLEY RESERVOIR (ARROWHEAD RESERVOIR COMPANY), SAN BERNARDINO COUNTY, CALIFORNIA.

[Area of tributary watershed, 6.6 square miles; elevation of base of dam, 4946.3 feet.]

| Height above Tunnel Outlet. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 10 | 29.7 | 198 | Bottom of outlet tunnel is 15.5 feet above bed of creek at base of dam; lowest foundations about 15 feet lower. |
| 20 | 55.8 | 619 | |
| 30 | 77.0 | 1,280 | |
| 40 | 109.6 | 2,207 | |
| 50 | 191.8 | 3,680 | |
| 60 | 236.9 | 5,830 | |
| 70 | 286.0 | 8,414 | |
| 80 | 336.3 | 11,518 | |
| 90 | 395.8 | 15,170 | |
| 100 | 452.0 | 19,401 | |
| 110 | 535.0 | 24,326 | |
| 120 | 626.0 | 30,094 | |
| 135 | 716.0 | 40,144 | |
| 147 | 800.0 | 49,238 | |
| 160 | 884.0 | 60,179 | |
| 175 | 932.0 | 73,800 | |

### Sweetwater Dam, San Diego County, California.

[Area of tributary watershed, 186 square miles; elevation of lowest outlet above sea-level, 140 feet.]

| Height above Lowest Outlet. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 0.0 | 3.5 | ............ | Lowest outlet is 24 feet above lowest foundations of dam. |
| 10.0 | 17.1 | 94 | |
| 20.0 | 75.2 | 540 | |
| 30.0 | 153.7 | 1,679 | |
| 40.0 | 272.2 | 3,748 | |
| 50.0 | 398.0 | 7,066 | |
| 60.0 | 539.0 | 11,737 | |
| 70.0 | 722.0 | 18,053 | |
| 75.5 | 895.0 | 22,500 | |

### Grass Valley Reservoir-site (Arrowhead Reservoir Company) San Bernardino County, California.

[Area of tributary watershed, 2.7 square miles; elevation of base of dam-site, 5103.3 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. |
|---|---|---|---|---|---|
| 22 | 5.4 | 37 | 92 | 159.7 | 5,946 |
| 32 | 29.5 | 196 | 102 | 180.4 | 7,632 |
| 42 | 52.8 | [illegible]02 | 112 | 200.2 | 9,550 |
| 52 | 72.8 | 1,225 | 122 | 210.0 | 11,635 |
| 62 | 100.7 | 2,090 | 125 | 234.0 | 12,329 |
| 72 | 115.7 | 3,180 | 150 | 301.8 | 19,010 |
| 82 | 138.0 | 4,460 | 175 | 331.7 | 27,547 |

### Huston Flat Reservoir (Arrowhead Reservoir Company), San Bernardino County, California.

[Elevation of creek-bed at dam-site, 4450 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Height above Base Reservoir. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. |
|---|---|---|---|---|---|
| 20 | 8.0 | 60 | 100 | 157.1 | 6,150 |
| 30 | 20.8 | 200 | 110 | 180.5 | 7,616 |
| 40 | 37.0 | 486 | 120 | 206.0 | 9,762 |
| 50 | 55.8 | 947 | 130 | 234.0 | 11,975 |
| 60 | 74.5 | 1,595 | 140 | 257.9 | 14,411 |
| 70 | 93.5 | 2,430 | 150 | 283.2 | 17,138 |
| 80 | 112.7 | 3,459 | 175 | 329.5 | 24,753 |
| 90 | 135.6 | 4,700 | | | |

## Pauba Reservoir-site, San Diego County, California.

[Area of tributary watershed, 372 square miles; elevation of base of dam, 1350 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 10 | 10.7 | 54 | Maximum depth to bed rock about 25 feet in center of channel. |
| 20 | 62.3 | 441 | |
| 30 | 110.5 | 1,262 | |
| 40 | 190.7 | 2,760 | |
| 50 | 282.8 | 5,150 | |
| 60 | 340.7 | 8,250 | |
| 70 | 447.0 | 12,200 | |
| 80 | 584.2 | 17,355 | |
| 90 | 689.4 | 24,723 | |
| 100 | 805.9 | 32,200 | |
| 130 | 1,214.0 | 62,496 | |
| 140 | 1,441.0 | 75,770 | |

## Warner's Ranch Reservoir-site, San Luis Rey River, San Diego County, California.

[Area of tributary watershed, 210 square miles; elevation of base of dam, 2618 feet. For cross-section of dam-site see fig. 177, p. 373.]

| Height above Stream-bed. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. |
|---|---|---|
| 10 | 42 | 200 |
| 20 | 228 | 1,565 |
| 30 | 739 | 16,415 |
| 40 | 1,200 | 16,140 |
| 50 | 1,582 | 29,830 |
| 60 | 2,036 | 47,710 |
| 70 | 2,695 | 71,410 |
| 80 | 3,237 | 108,500 |
| 90 | 4,437 | 142,740 |
| 100 | 5,535 | 198,200 |

### SANTA MARIA VALLEY RESERVOIR-SITE, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 60 square miles; elevation of base of dam, 1300 feet. For cross-section of dam-site see Fig. 177, p. 373.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. |
|---|---|---|
| 20 | 7.6 | 45 |
| 30 | 23.2 | 199 |
| 40 | 41.3 | 522 |
| 50 | 80.3 | 1,108 |
| 60 | 154.3 | 2,305 |
| 70 | 285.9 | 4,500 |
| 80 | 561.3 | 8,736 |

### PAMO VALLEY RESERVOIR-SITE, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 125 square miles; elevation of base of dam, 803 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 40 | ............ | 204 | Outlet of reservoir to be at the 40-foot level. For cross-section of dam-site, see Fig. 177, p. 373. |
| 50 | ............ | 438 | |
| 60 | ............ | 766 | |
| 70 | ............ | 1,242 | |
| 80 | ............ | 2,049 | |
| 90 | ............ | 3,805 | |
| 100 | ............ | 5,083 | |
| 110 | ............ | 7,374 | |
| 120 | ............ | 10,425 | |
| 130 | 401.4 | 14,127 | |
| 140 | 476.5 | 18,527 | |
| 150 | 614.8 | 24,065 | |
| 160 | 708.8 | 31,700 | |
| 170 | ............ | 38,300 | |
| 185 | ............ | 49,100 | |

### DYE VALLEY RESERVOIR-SITE, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 5 square miles; elevation of base of dam, 2200 feet.]

| Height above Base of Dam. Feet. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|
| 80 | 4,800 | To be fed by diversion of Santa Ysabel Creek, draining 30 square miles of mountain territory. |

**Cuyamaca Reservoir, San Diego County, California.**

[Area of tributary watershed, 11.03 square miles; elevation of dam, about 4850 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 10 | 6 | 12 | Top of dam, 41.5 feet above base. Floor of wasteway at 35-foot contour above base. |
| 12 | 44 | 60 | |
| 14 | 106 | 200 | |
| 16 | 178 | 490 | |
| 18 | 255 | 900 | |
| 20 | 346 | 1,520 | |
| 22 | 423 | 2,290 | |
| 24 | 519 | 3,240 | |
| 26 | 605 | 4,360 | |
| 28 | 684 | 5,650 | |
| 30 | 768 | 7,100 | |
| 32 | 842 | 8,710 | |
| 34 | 919 | 10,470 | |
| 35 | 959 | 11,410 | |

**Barrett Reservoir-site, San Diego County, California.**

[Area of tributary watershed, 250 square miles; elevation of base of dam, 1600 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre feet. | Remarks. |
|---|---|---|---|
| 60 | 70 | 586 | Used as a diverting-dam, to the height of 60 feet, for diverting Morena reservoir water to the Lower Otay reservoir. For cross-section of dam-site, see Fig. 177, p. 373. |
| 70 | 97 | 1,412 | |
| 80 | 147 | 2 611 | |
| 90 | 183 | 4,312 | |
| 100 | 231 | 6.322 | |
| 110 | 285 | 8 975 | |
| 120 | 363 | 12,123 | |
| 130 | 469 | 16,345 | |
| 140 | 576 | 21,530 | |
| 150 | 602 | 27,835 | |
| 160 | 784 | 35,160 | |
| 170 | 871 | 43,440 | |
| 175 | 936 | 47,970 | |

UPPER OTAY RESERVOIR-SITE, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 8 square miles; elevation of base of dam, 480 feet. For cross-section of dam-site see Fig. 177, p. 373.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. |
|---|---|---|
| 60 | 89 | 643 |
| 80 | 178 | 3,236 |
| 100 | 293 | 7,871 |
| 120 | 452 | 15,842 |

BEAR VALLEY RESERVOIR, SAN BERNARDINO COUNTY, CALIFORNIA.

[Area of tributary watershed, 56 square miles; elevation of base of dam, about 6200 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. |
|---|---|---|---|---|---|
| 15 | 10 | 52 | 53 | 1,859 | 26,463 |
| 20 | 35 | 159 | 55 | 1,960 | 30,010 |
| 25 | 141 | 411 | 57 | 2,069 | 34,040 |
| 30 | 295 | 1,558 | 60 | 2,251 | 40,476 |
| 35 | 428 | 3,347 | 65 | 2,582 | 52,428 |
| 40 | 1,060 | 7,166 | 70 | 2,812 | 65,065 |
| 45 | 1,425 | 13,357 | 80 | 3,300 | 95,500 |
| 50 | 1,691 | 21,139 | | | |

SOUTH ANTELOPE VALLEY IRRIGATION COMPANY'S ALPINE RESERVOIR, LOS ANGELES COUNTY, CALIFORNIA.

[Area of tributary watershed, 6 square miles; elevation bottom of reservoir, 2779 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 6 | 106 | 415 | Filled by 8 miles of conduit from Little Rock Creek, with drainage of 61 square miles. |
| 5 | 140 | 1,031 | |
| 16 | 170 | 1,807 | |
| 21 | 202 | 2,734 | |
| 26 | 228 | 3,808 | |
| 31 | 252 | 5.008 | |
| 36 | 277 | 6,332 | |

### Victor Reservoir-site, San Bernardino County, California.

[Area of tributary watershed, 1200 square miles; elevation of base of dam, 2708 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. |
|---|---|---|
| 145 | 7,718 | 890,000 |

### San Leandro Reservoir, Lake Chabot, Oakland Waterworks, California.

[Area of tributary reservoir, 50 square miles; elevation of base of dam above sea-level, 115 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 80 | ........... | 0 | Outlet level. |
| 50 | 82 | 1,154 | High-water mark at present, 120 feet above base; capacity, 18,115 acre-feet, or 5,825,845,000 gallons. |
| 70 | 165 | 3,635 | |
| 90 | 259 | 7,886 | |
| 110 | 355 | 14,038 | |
| 180 | 468 | 22,290 | |
| 150 | 576 | 32,780 | |
| 170 | 715 | 45,740 | |

### Manache Meadows Reservoir-site, South Fork Kern River, California.

[Area of watershed, 155 square miles; elevation of dam-site, 8200 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. |
|---|---|---|
| 10 | 22 | 110 |
| 20 | 146 | 954 |
| 30 | 812 | 4,563 |
| 40 | 1,865 | 18,827 |
| 50 | 2,599 | 40,732 |
| 60 | 3,254 | 69,885 |
| 70 | 3,814 | 105,236 |
| 80 | 4,420 | 146,419 |
| 100 | 5,830 | 248,852 |

BIG MEADOWS RESERVOIR-SITE, SALMON FORK KERN RIVER, CALIFORNIA.

[Area of watershed (estimated), 25 square miles.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. |
|---|---|---|
| 20 | 81 | 409 |
| 30 | 468 | 3,174 |
| 40 | 603 | 8,530 |
| 50 | 723 | 15,169 |
| 60 | 802 | 22,784 |
| 70 | 870 | 31,148 |
| 80 | 930 | 40,036 |
| 100 | 1,020 | 59,311 |

NORTH FORK LAKE RESERVOIR-SITE, UPPER KERN RIVER, CALIFORNIA.

[Elevation, 6500 feet.]

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 20 | 46 | ............ | Outlet level. |
| 70 | 104 | 3,763 | |
| 120 | 189 | 11,101 | |
| 170 | 318 | 23,770 | |
| 220 | 598 | 46,614 | |

BUENA VISTA LAKE RESERVOIR, LOWER KERN RIVER, CALIFORNIA.

[Elevation above sea-level, 260 feet.]

| Height above Outlet. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 0 | 23,570 | 0 | A depth of 6 feet below the bottom of outlet-canal is never drawn upon. |
| 10 | 25,000 | 170,000 | |

## Tonto Basin Reservoir-site, Salt River, Arizona.

[Area of watershed, 6260 square miles; elevation of base of dam, 1925 feet.]

| Height above Dam at Low-water Mark. Feet. | Area Flooded. Acres. | Capacity of Reservoir. Acre-feet. | Height above Dam at Low-water Mark. Feet. | Area Flooded. Acres. | Capacity of Reservoir. Acre-feet. |
|---|---|---|---|---|---|
| 25 | 330 | 4,400 | 120 | 5,860 | 241,800 |
| 30 | 420 | 6,100 | 125 | 6,210 | 272,800 |
| 35 | 570 | 9,000 | 130 | 6,570 | 303,900 |
| 40 | 730 | 11,900 | 135 | 6,950 | 338,600 |
| 45 | 890 | 16,200 | 140 | 7,350 | 373,400 |
| 50 | 1,030 | 20,000 | 145 | 7,930 | 413,000 |
| 55 | 1,280 | 26,900 | 150 | 8,530 | 453,000 |
| 60 | 1,510 | 33,300 | 155 | 9,110 | 498,000 |
| 65 | 1,740 | 42,000 | 160 | 9,680 | 544,000 |
| 70 | 1,980 | 50,700 | 165 | 10,170 | 594,000 |
| 75 | 2,300 | 62,100 | 170 | 10,680 | 645,000 |
| 80 | 2,610 | 73,500 | 175 | 11,240 | 701,000 |
| 90 | 3,430 | 103,600 | 180 | 11,750 | 757,000 |
| 95 | 3,820 | 122,700 | 185 | 12,300 | 820,000 |
| 100 | 4,210 | 141,800 | 190 | 13,000 | 880,000 |
| 105 | 4,610 | 164,700 | 195 | 13,600 | 950,000 |
| 110 | 4,990 | 187,700 | 200 | 14,200 | 1,020,000 |
| 115 | 5,430 | 214,700 | | | |

## Queen Creek Reservoir-site, Arizona.

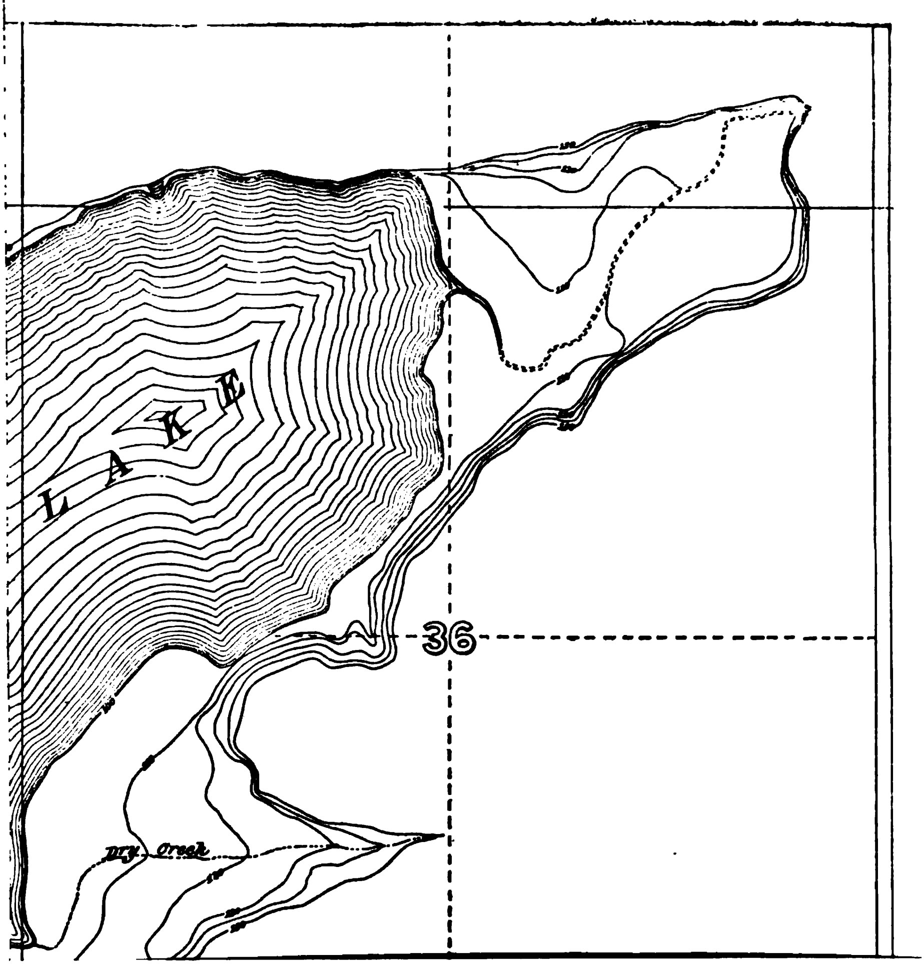
[Area of watershed, 30 to 250 square miles; elevation of base of dam, creek bed, 2050 feet.]

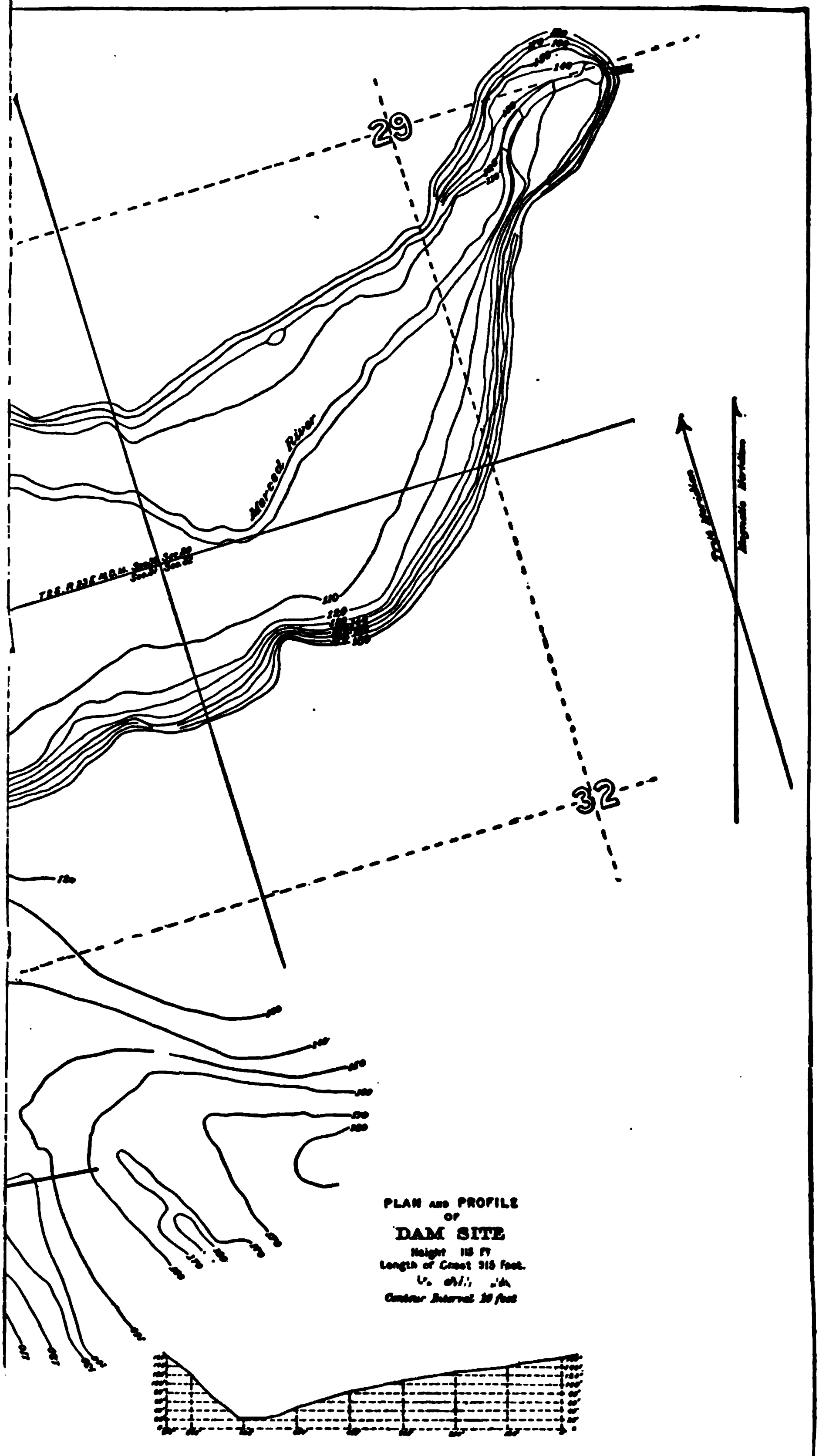
| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 20 | 22 | 190 | Height of dam suggested, 115 feet, would flow to the height of 110 feet. |
| 30 | 52 | 560 | |
| 40 | 112 | 1,380 | |
| 50 | 209 | 2,985 | |
| 60 | 279 | 5,425 | |
| 70 | 356 | 8,600 | |
| 80 | 445 | 12,605 | |
| 90 | 538 | 17,520 | |
| 100 | 630 | 23,360 | |
| 110 | 757 | 30,795 | |
| 120 | 894 | 39,050 | |
| 130 | 1.019 | 48,615 | |
| 140 | 1,191 | 59,665 | |

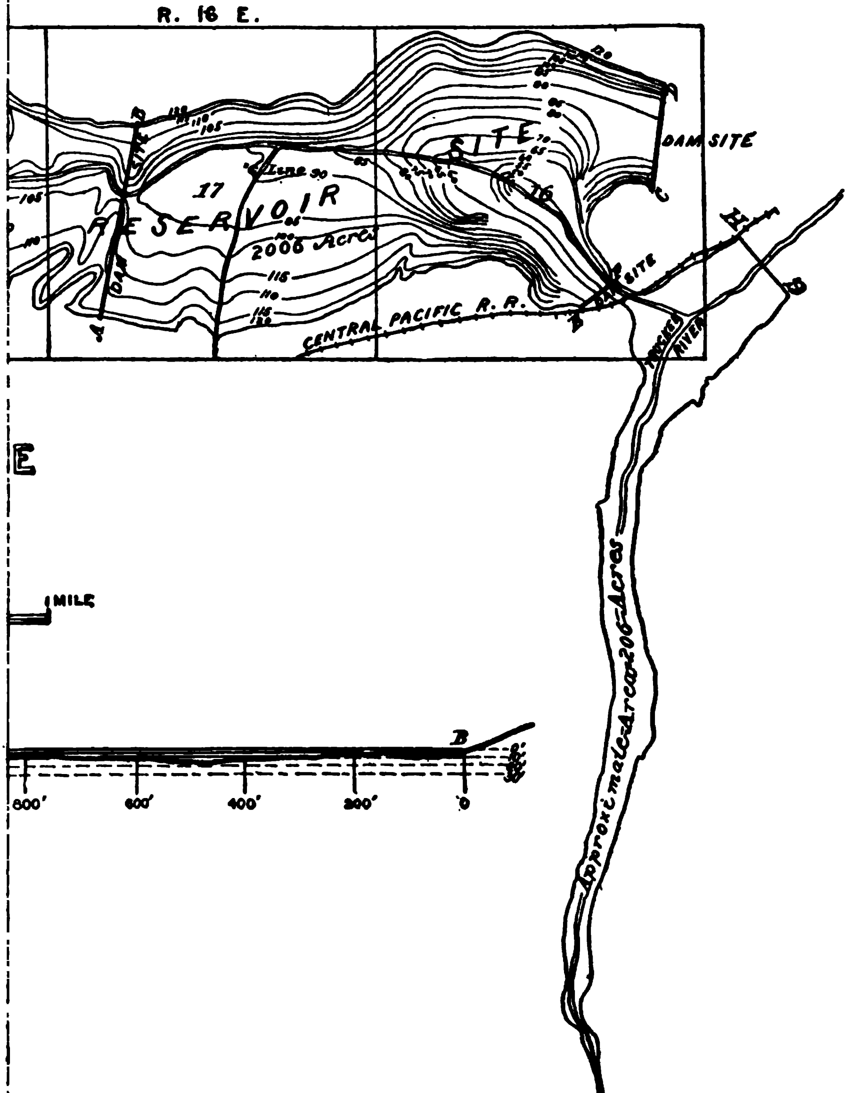
### BUTTES RESERVOIR-SITE, GILA RIVER, ARIZONA.

**[Area of tributary watershed, 13,750 square miles; elevation of base of dam (low water), 1600 feet.]**

| Height above Base of Dam. Feet. | Surface Area. Acres. | Capacity of Reservoir. Acre-feet. | Remarks. |
|---|---|---|---|
| 10 | 20 | 100 | |
| 20 | 71 | 550 | |
| 30 | 229 | 2,050 | |
| 40 | 397 | 5,180 | |
| 50 | 533 | 9,830 | |
| 60 | 741 | 16,200 | |
| 70 | 928 | 24,545 | |
| 80 | 1,105 | 34,710 | |
| 90 | 1,329 | 46,880 | Height of dam proposed, 170 feet, will carry 160 feet depth of water. |
| 100 | 1,566 | 61,355 | |
| 110 | 1,769 | 78,030 | |
| 120 | 2,029 | 97,020 | |
| 130 | 2,367 | 119,000 | |
| 140 | 2,746 | 144,565 | |
| 150 | 3,149 | 174,040 | |
| 160 | 3,602 | 207,795 | |
| 170 | 4,118 | 246,895 | |
| 180 | 4,609 | 290,000 | |
| 190 | 5,133 | 338,740 | |
| 200 | 5,651 | 392,660 | |

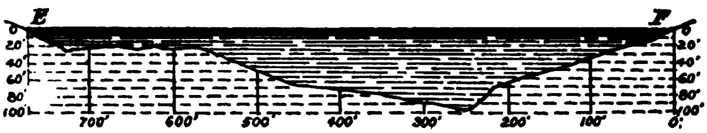

LAKE
36
Dry Creek


29
Merced River
32
PLAN AND PROFILE
OF
DAM SITE
Height 115 FT
Length of Crest 315 Feet.
Contour Interval 10 feet

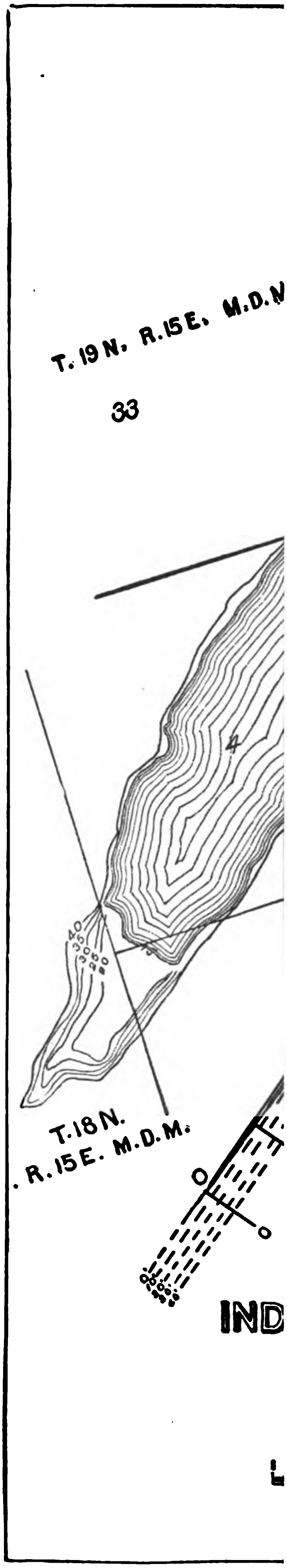



5 Acre Ft
27 " "

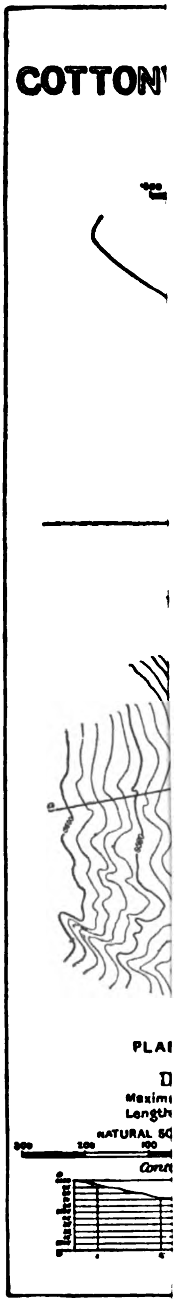
**PROFILE OF DAM SITE**
**Maximum Height 98 Ft.**
**Length of Crest E,-F. 770 Ft**

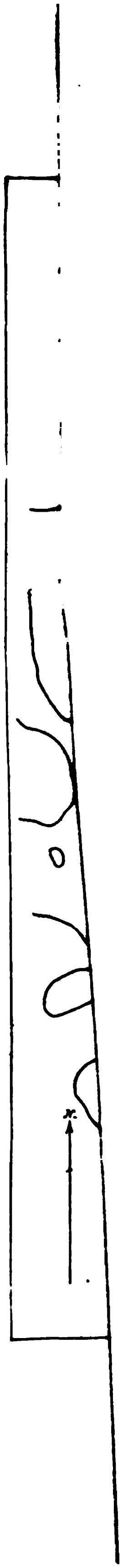


1889.

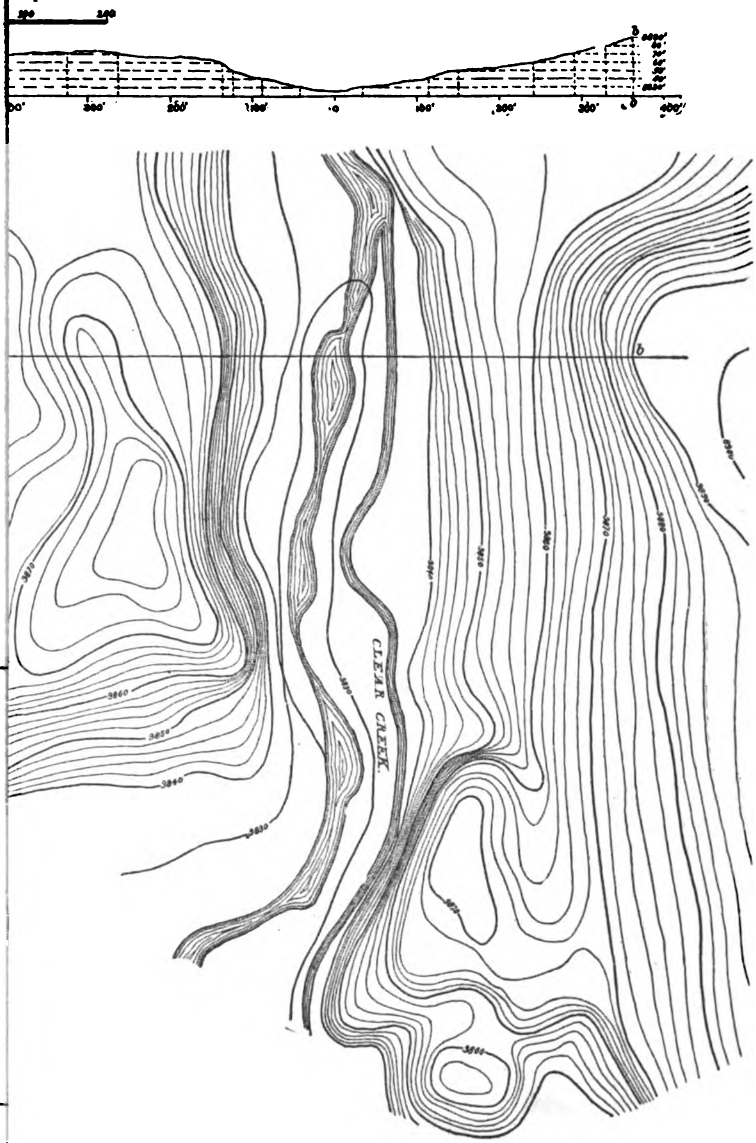


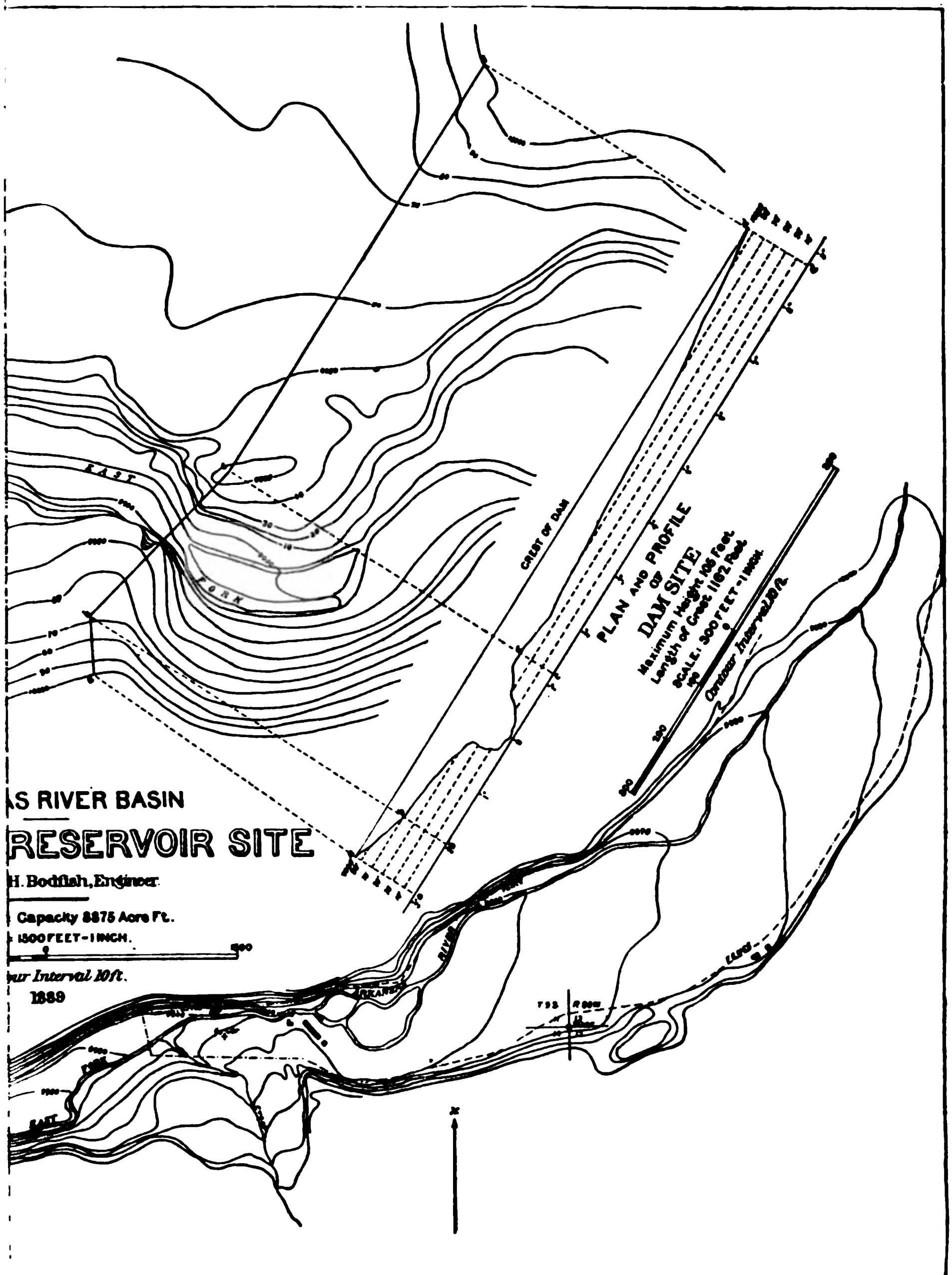
T. 19 N. R. 15 E. M.D.M
33
4
T. 18 N.
R. 15 E. M.D.M.
IND





ND PROFILE
OF
M SITE
a - b.





S RIVER BASIN
RESERVOIR SITE
H. Bodfish, Engineer
Capacity 8875 Acre Ft.
1500 FEET - 1 INCH.
0
1500
ur Interval 10 ft.
1889
PLAN AND PROFILE
OF
DAM SITE
Maximum Height 105 Feet
Length of Crest 1162 Feet
SCALE: 300 FEET - 1 INCH
Contour Interval 10 ft.
CREST OF DAM
EAST
FORK
RIVER

# INDEX.