FIG. 255.—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, PLANS AND COST OF THEIR CONSTRUCTION

ALSO CONTAINING MISCELLANEOUS DATA UPON

THE AVAILABLE WATER-SUPPLY FOR IRRIGATION IN VARIOUS SECTIONS OF ARID AMERICA; DISTRIBUTION, APPLICATION, AND USE OF WATER; RAINFALL AND RUN-OFF FROM VARIOUS WATERSHEDS; EVAPORATION FROM RESERVOIRS; EFFECT OF SILT UPON THE USEFUL LIFE OF RESERVOIRS; AVERAGE COST OF RESERVOIRS PER UNIT OF CAPACITY, ETC.

BY

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To the Memory of My Brother,

HOWARD SCHUYLER,

LATE M. AM. SOC. C. E.,

AN ENGINEER OF BRILLIANT ATTAINMENTS AND CHARMING CHARACTER, WHO SACRIFICED HIS LIFE IN UNTIRING DEVOTION TO THE CONSTRUCTION OF THE MEXICAN CENTRAL RAILWAY AS ITS FIRST CHIEF ENGINEER, THE INSEPARABLE COMRADE OF MY CHILDHOOD, AND IN YOUTH MY "GUIDE, PHILOSOPHER, AND FRIEND," INSPIRING MY AMBITION TO THE ACHIEVEMENT OF EVER HIGHER IDEALS,

THIS BOOK IS AFFECTIONATELY DEDICATED

BY

The Author.

PREFACE TO THE SECOND EDITION.

The kindly reception given to the first edition of this book, which appeared in 1901, and which has been in sufficient demand to necessitate a return of the forms to the press several times to supply the unanticipated call for it, has been so flattering to the author that he has been encouraged to accept the urgent advice of his publishers and many friends among the engineering profession, and attempt such a revision of the work as will bring it more nearly up to date. In the past ten or twelve years, since the first compilation of data on the construction of dams in western America was undertaken, the world in general appears to have entered upon a new era of dam and reservoir creation, and there has been such a remarkable degree of activity displayed in the conservation and utilization of water, that it may be quite reasonable to state that more dams have been built in the decade that has just passed than during any fifty years of previous history. This is true not only of the United States but also of Europe and other countries. The present appears to be an age of dam construction, and there has developed an eager demand for information regarding the actual works accomplished, their dimensions, character, plan, materials, methods of construction and cost. The author has been gratified to find his book in the hands of engineers in every part of the globe he has visited, which may be accepted as an attestation of the fact that there is a wide field for such a work. He has therefore felt it to be a duty to make it more complete, and more worthy of the interest taken in it.

Much new matter has been added and some of the old has been taken out as obsolete and of little present value. The chapter on Hydraulic-fill Dams has been greatly extended by descriptions of later constructions, and two new chapters have been added, descriptive of reinforced concrete dams, the latest claimant to public attention, and of structural steel dams, which have increased in numbers and size.

The developments made in hydraulic-fill dams in the past few years, and the wide-spread interest manifested in this novel utilization of the forces of Nature to construct enduring barriers of unprecedented height, at moderate cost, would alone have justified the publication of a separate volume on that subject, embodying all the experiences of the author and other engineers in that most fascinating and interesting field of construction.

The chapter on Masonry Dams has been increased twofold by an attempt to make some mention of all the most notable dams of the world, and many that are very little known. Attention is particularly directed to Plates 1, 2, and 3, in which profiles are shown of all of the leading and better known masonry dams in existence, drawn to uniform scale for easy graphical comparison. No such complete collection of dam profiles has ever before appeared in print, assembled together on a common basis.

The endeavor has been made to give the book greater attractiveness by the addition of 234 new cuts and photographs,—some of which have been taken by the author's pocket camera—an inseparable companion.

Thus over sixty per cent of all the illustrations in the book are new, and probably as great or a greater proportion of the reading matter is also new or rewritten.

The labor involved in this revision has been enormous, but if his efforts shall prove of value to the engineering profession the author will feel amply repaid.

JAMES D. SCHUYLER.

LOS ANGELES, CALIFORNIA, October, 1908.

PREFACE TO THE FIRST EDITION

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 capacity 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 about the middle of the last century 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 a vertical central core of steel plates, protected with a coating of asphaltum and burlap, and supported by thin concrete walls on each side.

2. Rock-fill dams with a facing of steel plates riveted to I-beams laid on the inner slope of the embankment at an angle varying from about 20° off the vertical to about 45°, the wall being hand-laid to a sufficient thickness to give requisite stability.

3. Rock-fill dams, with face of masonry, built vertically or slightly inclined, backed with earth or rock, and protected on the lower slope by a covering of stone laid in mortar.

4. Rock-fill dams with facing of Portland cement-concrete, either reinforced with steel rods or expanded metal, or without such reinforcement.

5. Rock-fill dams with facing of earth.

6. Rock-fill dams with inner core-wall of wood, faced with earth sluiced in position, filling the voids in the rock above the wood partition; generally called the "combination rock-fill and hydraulic-fill dam."

7. Rock-fill with facing of concrete.

Existing examples of these various types and their variations 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-

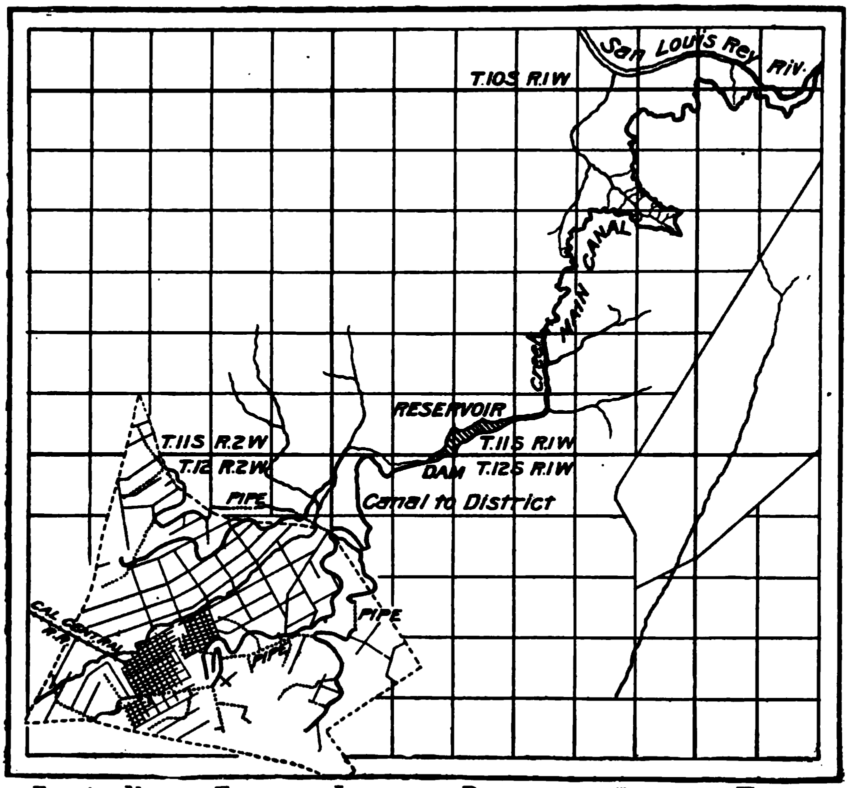


FIG. 1.—MAP OF ESCONDIDO IRRIGATION DISTRICT AND SYSTEM OF WORKS.

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. 177, 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-fect 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 indiscrimiuately 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

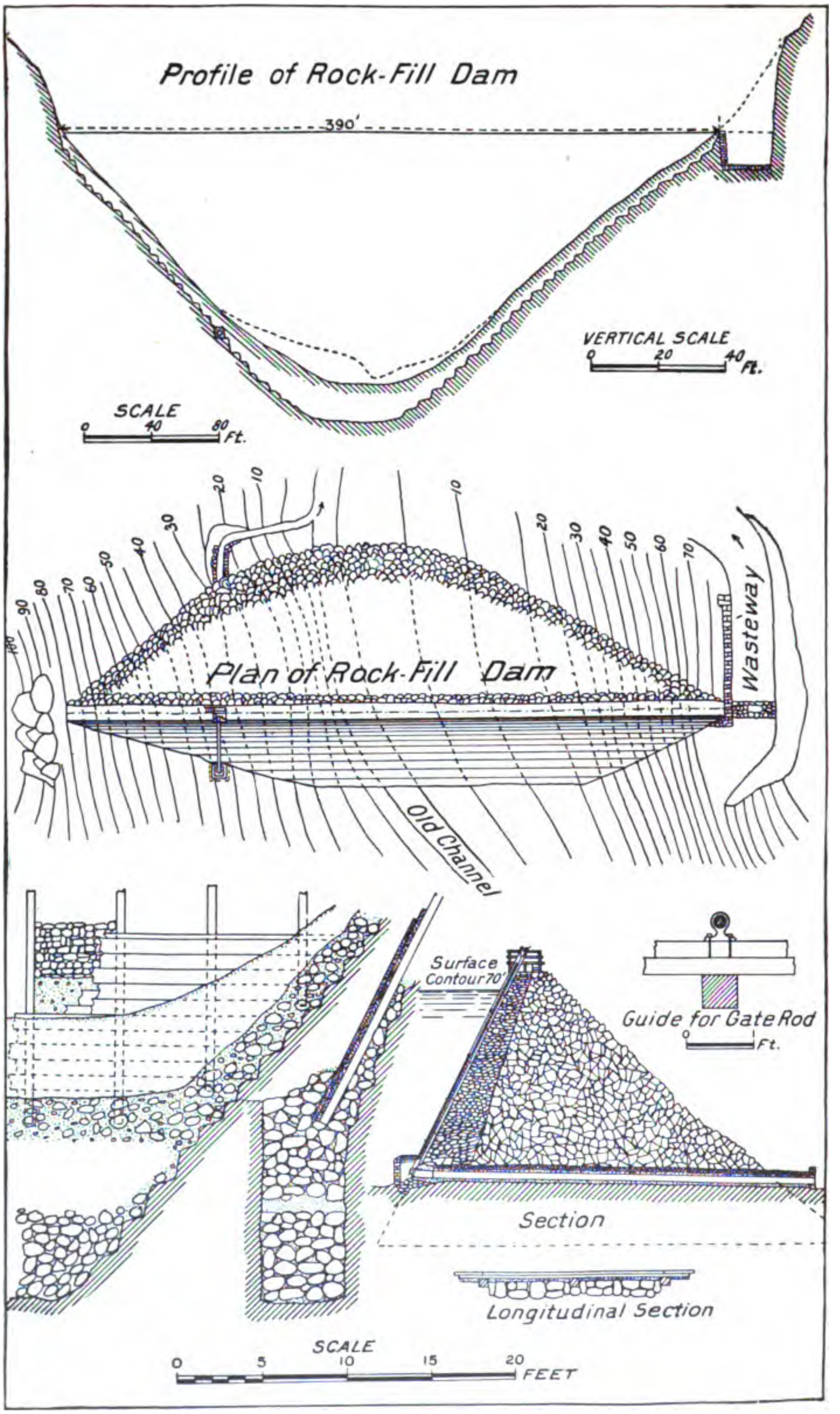
FIG. 5.—BACK OF ESCONDIDO IRRIGATION DISTRICT DAM.

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,



10 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

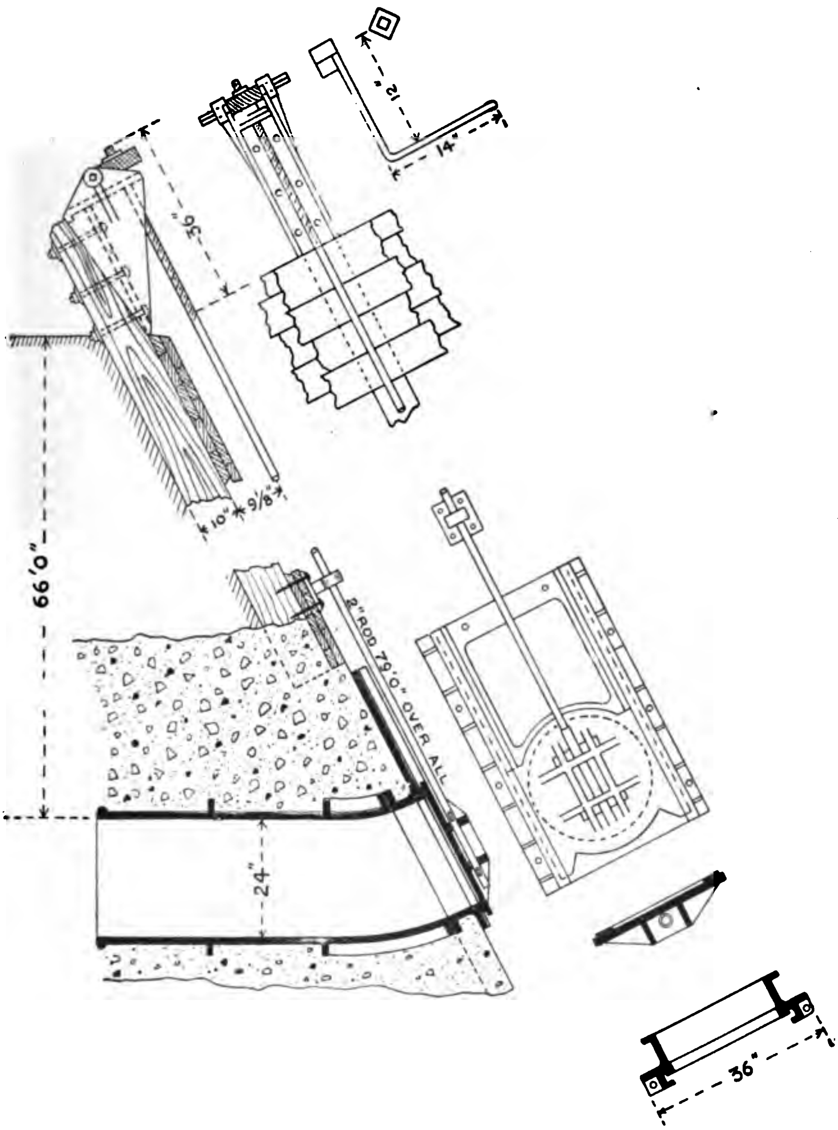


Fig. 7.—Details of Gate of Escondido Dam.

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 the site cost in addition $23,112.88, including clearing. The total cost was therefore $110,059 09, or $38.41 per acre-foot of capacity. The prices paid were unusually high for such work, and were the following per cubic yard: earth excavation, 30 cents; rock excavation, $1.10; rock-fill, $1.50; dry stone masonry, $3.75; rubble masonry in cement mortar, $8; concrete, $14; lumber, $50 per thousand feet board measure.

The detail of this work is given with special fullness, as it is the first rock-fill dam to be constructed in California for irrigation storage, and is of a type which is likely to be employed quite commonly in the future in localities better adapted for its use than in this particular case, where stone was comparatively scarce in the immediate vicinity of the dam.

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 catchment of the reservoir has been approximately as follows:

1895, 48	feet depth	= 880	acre-feet
1896, 60	" "	= 1925	"
1397, 74	" "	= 3700	"
1898, 59.5	" "	= 1000	"
1899, 47	" "	= 830	"
Total		8335	acre-feet, or an average of 1667 per annum.

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. The Lower Otay dam was completed in August, 1897.

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 forma-

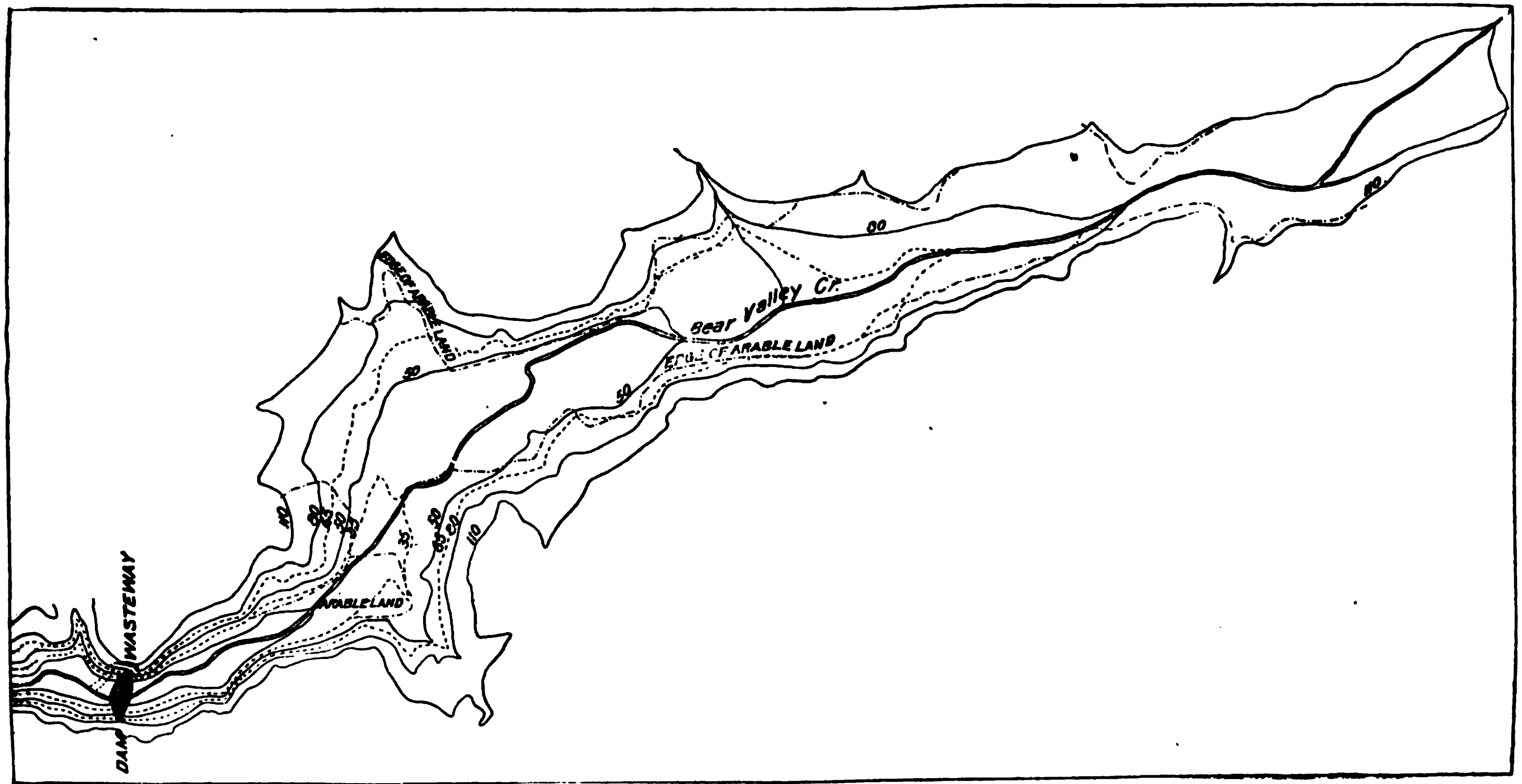


FIG. 8.—CONTOUR MAP OF RESERVOIR OF ESCONDIDO IRRIGATION DISTRICT.

Fig 9.—Construction of Facing of Escondido Dam.

Fig. 10.—Escondido (Cal.) Rock-fill Dam. Wooden Lining.

tion, 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 since the completion of the dam, and until it 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 former president of the water company, Mr. E. S. Babcock, of San Diego. 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. 14 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. 12.—Otay (Cal.) Rock-fill Dam—Steel Core.

FIG. 13.—OTAY (CAL.) ROCK-FILL DAM—STEEL CORE.

Fig. 14.—Steel Web-plate and Anchor-trench at West End of Lower Otay Dam.

FIG. 15.—OTAY (CAL.) ROCK-FILL DAM -STEEL CORE.

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 downstream 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. 16.—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

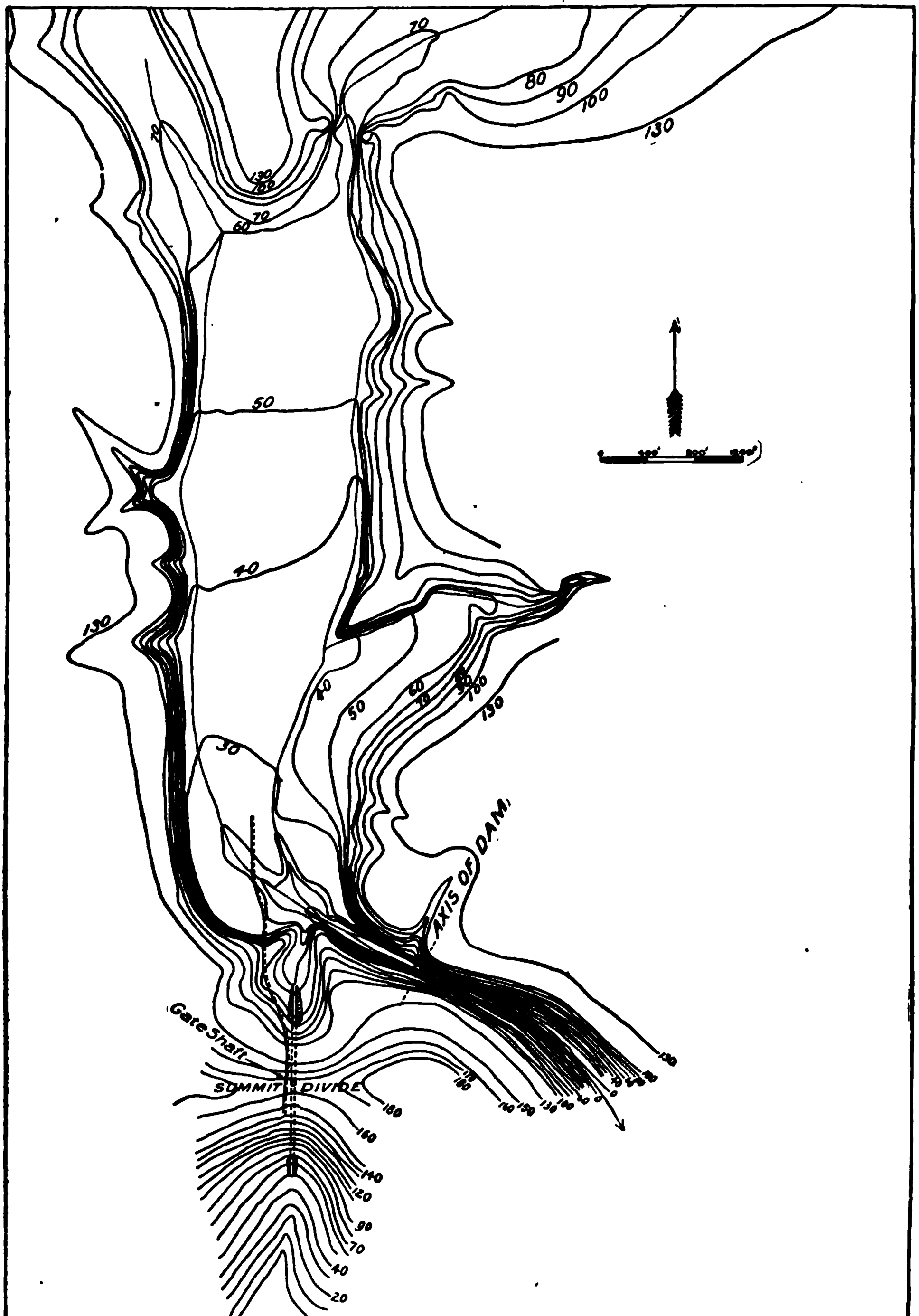


FIG. 17.—MAP OF LOWER OTAY RESERVOIR.

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. 18 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 used was 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. 19. 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, did not exceed 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

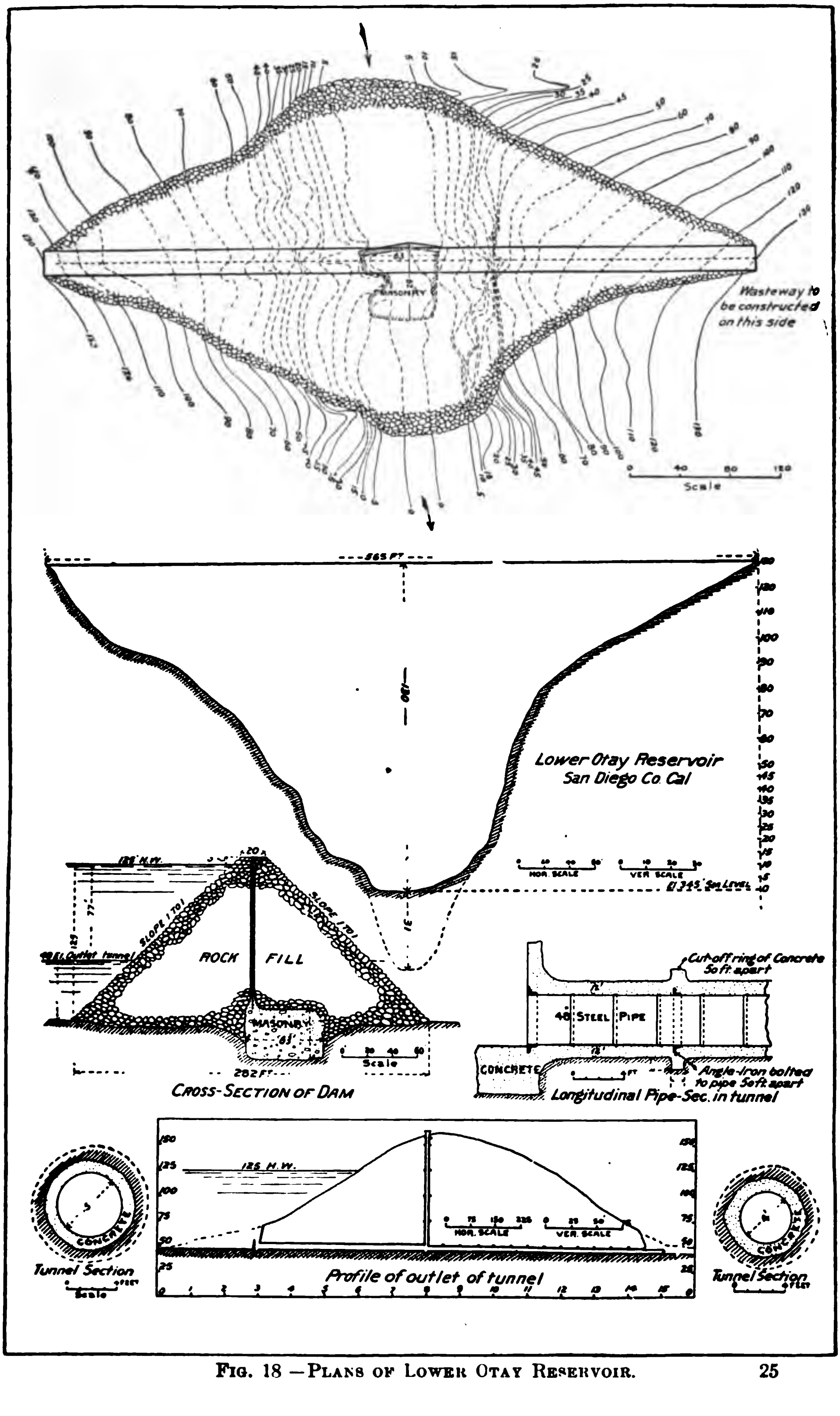


Fig. 18 —Plans of Lower Otay Reservoir.

Fig. 19.—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, the latter having been projected as a rock-fill dam, while the former is to be a concrete structure of gravity type.

Spillway.—The spillway excavated at the east end of the dam is of liberal dimensions considering the limited run-off of the stream. It is cut in solid rock for a distance of 400 feet, is 40 feet wide, 6 feet deep, lined with concrete. The reservoir has never filled higher than within 15 feet of the spillway level, or 109 feet above base. This height was reached during the winter of 1906-7. The storage at that height is about 24,000 acre-feet, or 64 per cent of the full capacity to the overflow (37,460 acre-feet). When the water reached the maximum stage a small leak appeared below the dam, on the west end, 20 feet above the base, measuring about 225,000 gallons per day.

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 was 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 was done cement grout was pumped into the cavities at one of the bolt holes, an inside band was inserted covering the heads of the patch-bolts, and the space filled with cement. 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 consists of a 36" and 42" wood-stave pipe, 20 miles long, operating under a maximum head of 391 feet and terminating in the city reservoir, on University Heights.

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 Mexican 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.

In 1897 the company erected a masonry dam, shown in Fig. 20, 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 built 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 "
" " top	13 "

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

FIG. 20.—THE BARRETT DAM-SITE, SHOWING THE BEGINNING OF MASONRY FOUNDATIONS.
The material on left bank above the rock here shown is disintegrated granite to such depth as to require change of plans from original design.

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 was never started, and after a delay of several years plans were prepared for a dam of concrete, and work of stripping begun. This developed such soft material on the south side of the canyon above the stream-bed as to necessitate some material modification of design, which has not been definitely announced. 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 of 250 square miles 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 for 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 water-shed. Under favorable 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. 21 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. 22) 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

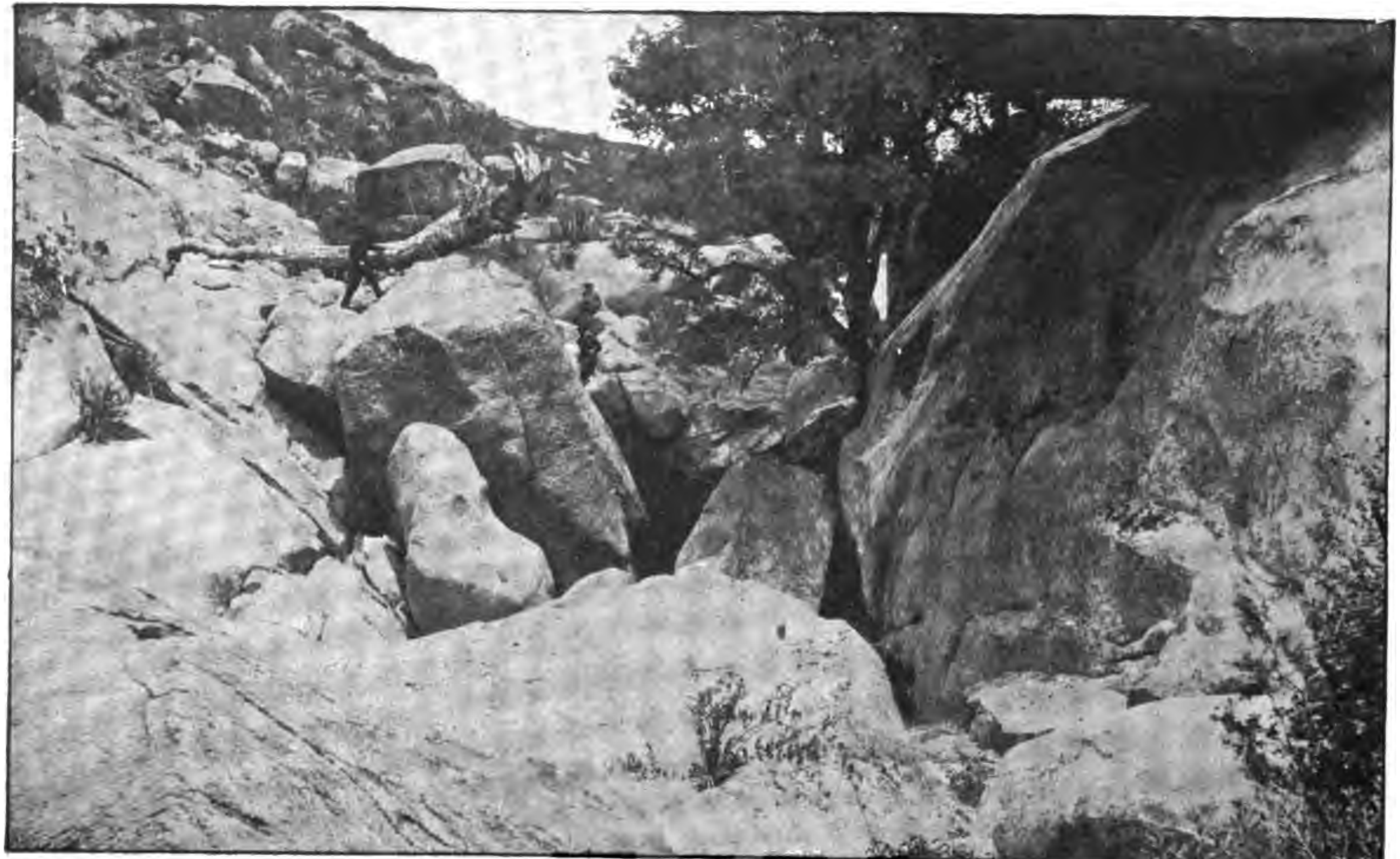


FIG. 21.—MORENA DAM-SITE, LOOKING EAST.

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. 22.—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.

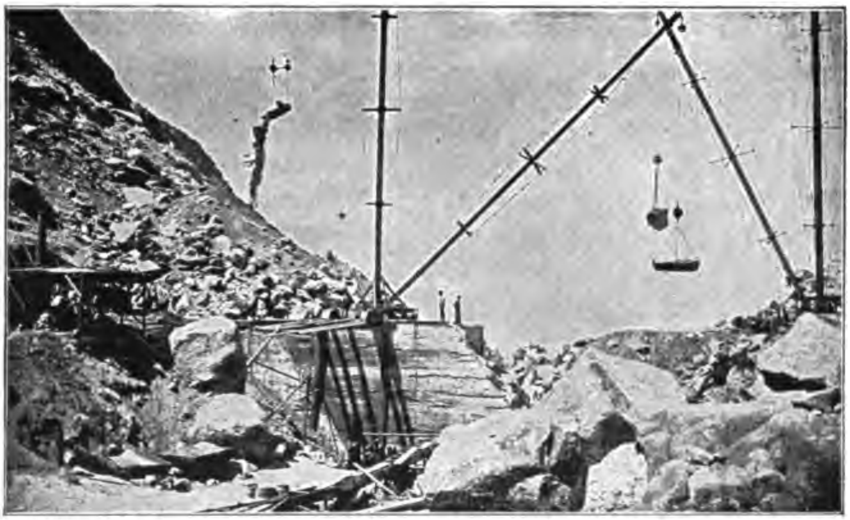


FIG. 23.—MORENA ROCK-FILL DAM, SHOWING A PORTION OF TOE-WALL UNDER CONSTRUCTION.

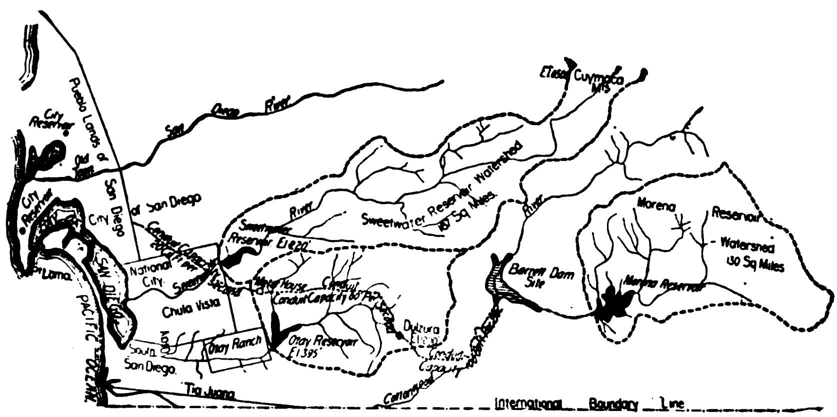


FIG. 24.—RESERVOIRS NEAR SAN DIEGO, CALIFORNIA.

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 secondry reservoir of

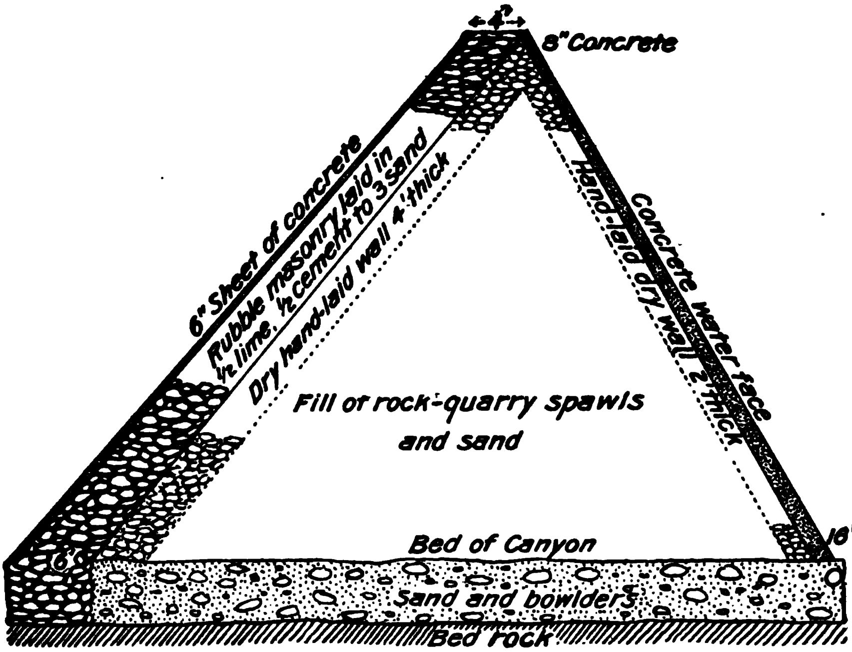


FIG. 25.—SKETCH OF RECONSTRUCTION OF CHATSWORTH PARK ROCK-FILL DAM.

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. 25, 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 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

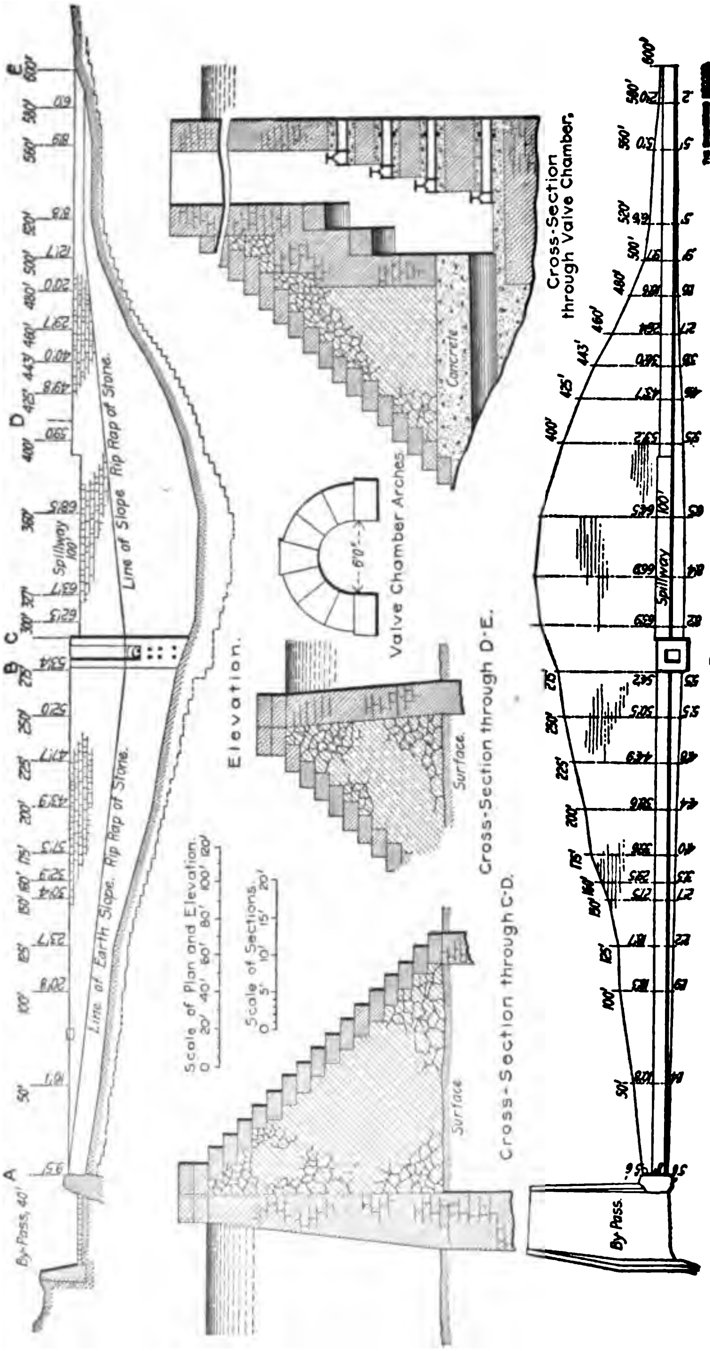


FIG. 26.—CASTLEWOOD DAM, COLORADO; PLAN, SECTIONS, AND ELEVATION.

Fig. 27.—View of Castlewood Dam, Colo., during Construction, looking North.

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

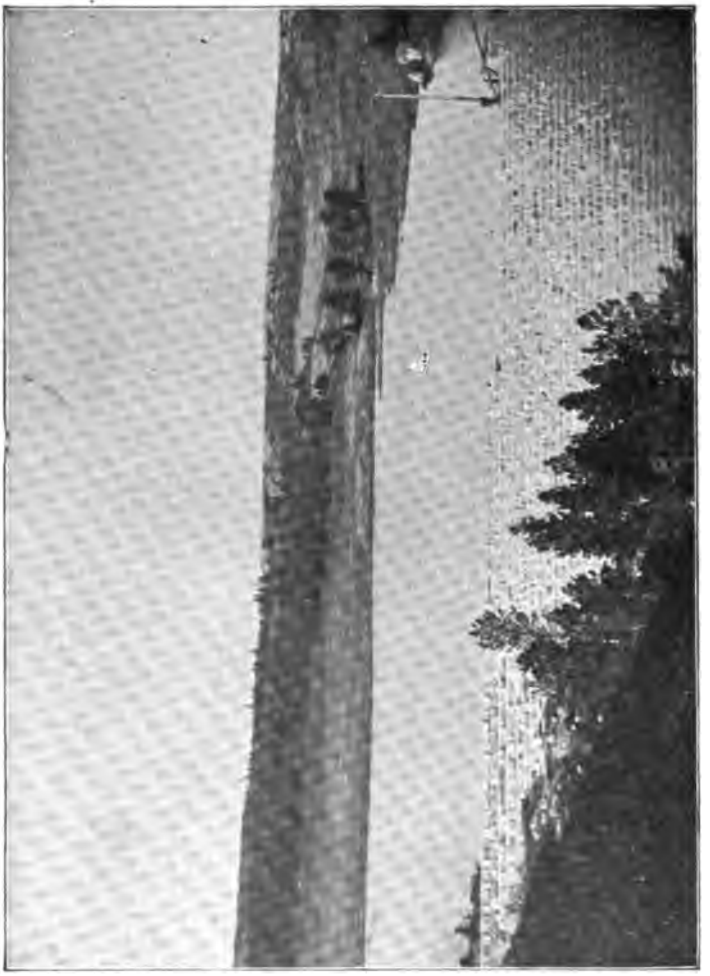


FIG. 28.—VIEW OF CASTLEWOOD DAM AND RESERVOIR, COLORADO.

safety and severely criticised the plan. Unsuccessful attempts were made to enjoin the construction, but it was finally permitted to be completed.

On April 30, 1900, after a very heavy rainfall exceeding all previous records, the reservoir was filled, and it was reported that 500 cubic feet per second passed over the top of the dam, and through the 40-foot

FIG. 29.—CASTLEWOOD DAM, COLO.

FIG. 30.—CASTLEWOOD DAM, COLO., SHOWING LEAKAGE THROUGH ROCK-FILL.

spillway at the side, while the discharge pipes were wide open. At the same time a large volume of water found its way through the cracks in the masonry wall, and poured out in large streams through the rock-fill for 10 to 15 feet above the base.

The photograph, Fig. 30, shows an enormous amount of this leakage, and the cause for the alarm created in Denver, which lies directly in the path of the escaping water. That the dam was able to withstand such a volume of leakage is a testimonial to the stability of rock-fill dams, which in this case afforded such complete drainage as to be unaffected by leakage that would immediately have destroyed an all-earth dam.

Subsequently repairs were made in the manner illustrated by Fig. 31, taken from *Engineering Record.*

An earth embankment, 8 feet wide on the crest, was built on the up-stream side to the full height of the rock-fill, with slope of 3 on 1,

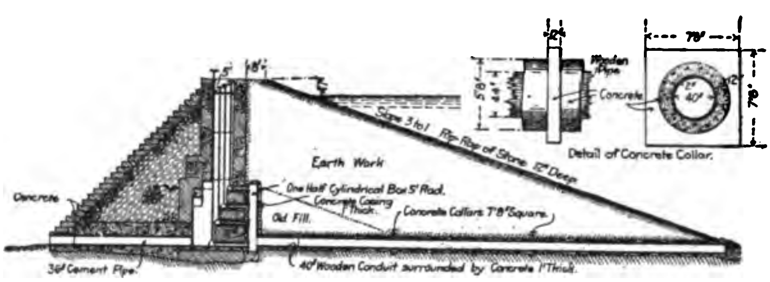


FIG. 31.—CASTLEWOOD DAM, COLO. SECTION AFTER RECONSTRUCTION.

faced with 12 inches of riprap. Underneath this embankment the outlet pipe was extended from the valve chamber to the up-stream toe by building a 40-inch woodstave pipe, surrounded with reinforced concrete 1 foot thick. This pipe connects with a steel box encased in concrete, into which all of the eight 12-inch pipes that pass through the masonry make connection.

The 40-foot spillway, which had been seriously damaged in the flood, was repaired, and another one, 12 feet wide, with side slopes 1 on 1, was built at the opposite end. The dam in its present condition, as reconstructed, is practically a combination rock-fill and earth embankment, having a masonry core-wall throughout, and is manifestly a safe and substantial structure. The dam was planned and built by A. M. Welles, C.E., of Denver, with Mr. Alfred P. Boller, M. Am. Soc. C. E., of New York, as consulting engineer.

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 Carlsbad, 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

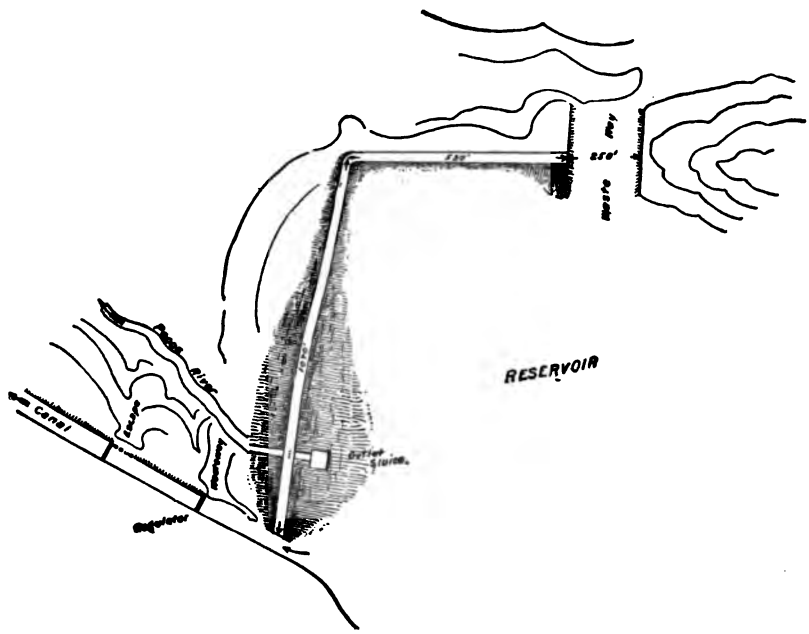


FIG. 32.—SKETCH-MAP OF DAM AT HEAD OF PECOS CANAL.

a considerable volume of storage in the reservoir thus created. The dimensions of the dam were as follows: length on crest, 1050 feet; maximum height, 48 feet; outer slope of rock-fill, 1½ 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 3.5 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. 33, a view taken during construction. Fig. 34 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. 35 is a view of the main canal and headgates, taken from the lower side.

FIG. 33.—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 maximum flood discharge being 42,500 sec.-feet. 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. 34.—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. 36, 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 5578 acre-feet. When filled to the 23-foot level

FIG. 35.—CANAL HEADGATES, LAKE AVALON DAM.

it had a length of about 5 miles and a maximum width of 1.5 miles. It submerged an area of 934 acres.

Water-tightness of Lake Avalon Dam.—The dam for some time after completion was apparently free from direct leakage through it, although water stood in a pool at the base of the dam, which was 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 Carlsbad, 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 reser-

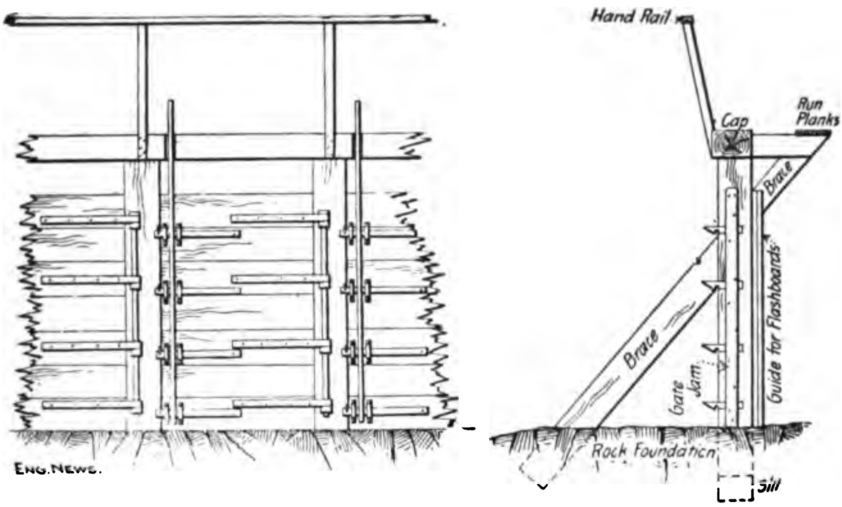


Fig. 36.—Quick-opening Gates in Spillway of Lake Avalon Reservoir, Pecos Valley, N. M.

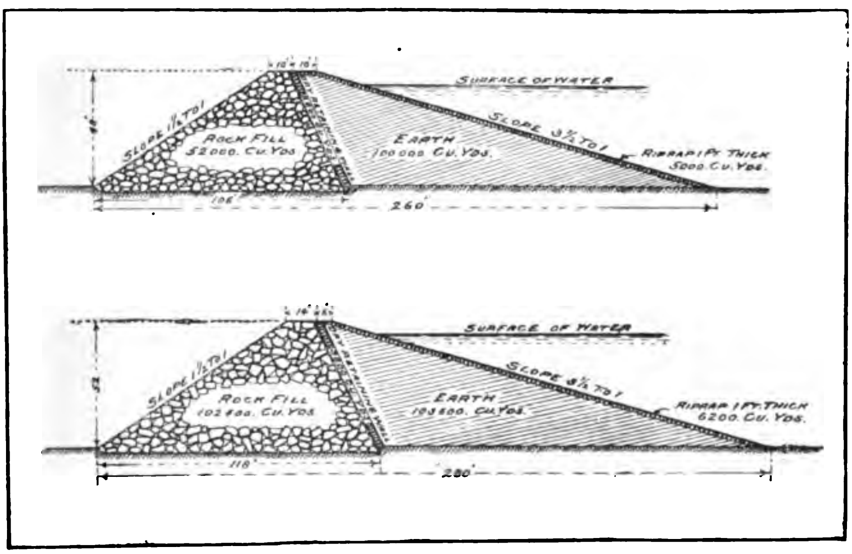


Fig. 37.—Sections of Lake Avalon and Lake McMillan Rock-fill and Earth Dams, Pecos Valley, N. M.

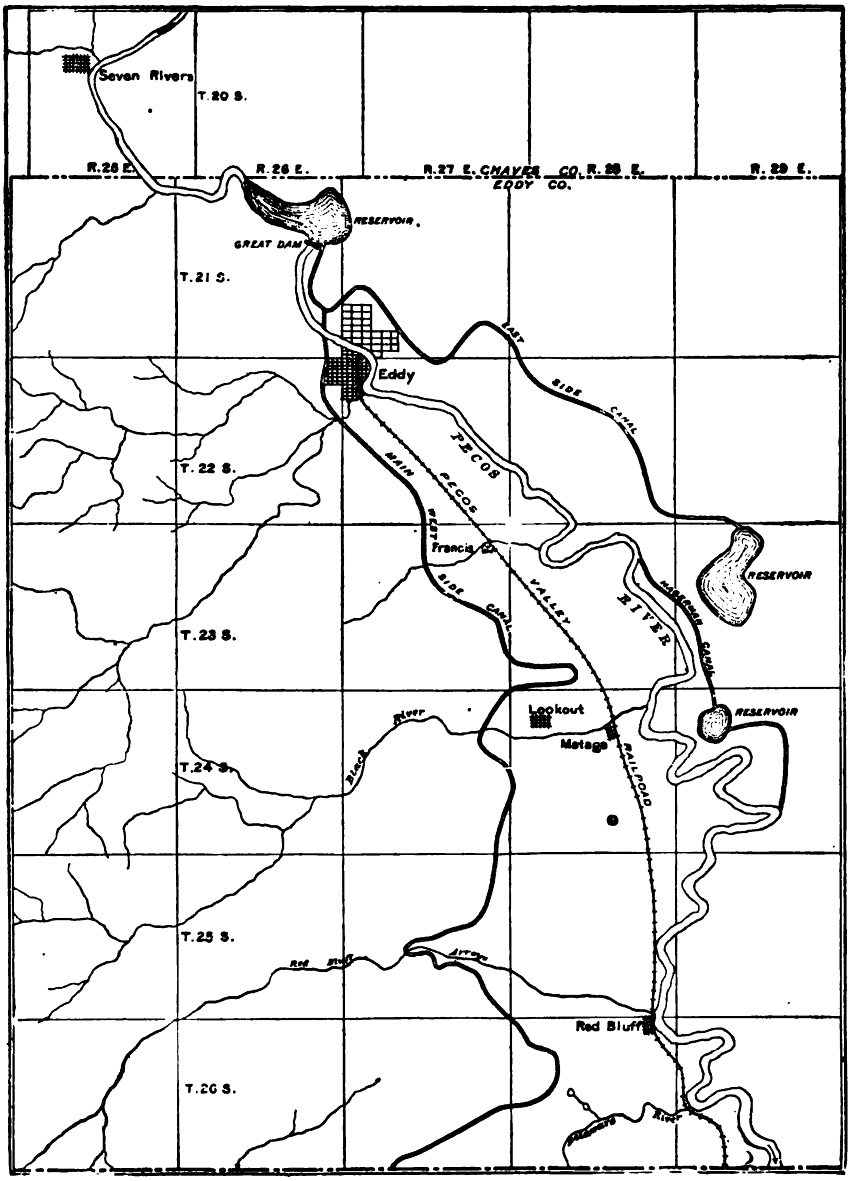


FIG. 38.—MAP OF PECOS VALLEY, N. M., SHOWING LOCATION OF RESERVOIRS AND CANALS.

voirs, 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 the building of the dams.

This leakage did not apparently affect the stability of the dams, although it may have been the contributing cause of the second failure of Lake Avalon dam, which occurred at 11 P.M., Oct. 1, 1904. An account of this failure, prepared by E. C. Murphy, Assoc. M. Soc. C. E., for *Engineering News* (July 6, 1905), states that the dam failed by the water forcing a passage through the dam, and not by flowing over the top. He says: "There are two opinions as to the cause of the failure. One is that animals burrowed into the earth part of the down-stream side and

FIG. 39.—SKETCH-MAP OF PECOS VALLEY CANALS.

weakened the earth facing; the other is the failure occurred near the base at the right back, due to a faulty connection of the dam with the bank." The flood discharge at the time was estimated at 82,000 cubic feet per second.

After the partial destruction of the dam the entire irrigation project passed into the control of the United States Reclamation Service, and the Avalon dam, which was an indispensable link in the system, was reconstructed on the plans and under the supervision of Mr. B. M. Hall, M. Am. Soc. C. E., as engineer in charge. The old dam was increased in top width from 20 feet to 43 feet by a substantial addition to the earth-fill on the up-stream side, and a core-wall of concrete, heavily reinforced with ½-inch square steel rods, 12 inches apart, both vertically and horizontally, was built through the dam its entire length of 1050 feet. This reinforced section of the core-wall is 24 feet high from the top down, is 8 inches thick on top, 12 inches at bottom, and rests on a concrete base wall over a portion of the length, and for the remainder on top of a line of steel sheet piling driven to bed-rock, a total depth of 65 feet below the crest, or 12 to 19 feet below the river-bed. The maximum length of these piles is 45 feet. They were driven where the depth of excavation through the old fill to reach bedrock would have been excessive and rendered an open trench for the core-wall inadvisable. The portion ot the core-wall made of rubble masonry was 7 feet thick at the base, 3 feet thick at the top, and had a maximum height of 45 feet. The position of the core-wall is at the up-stream edge of the embankment roadway.

Lakė McMillan Dam.—The Upper Pecos River reservoir is called Lake McMillan, and is formed by a rock-fill dam of the same general type as the lower one. This was built in 1893 under Mr. Louis D. Blauvelt as chief engineer. The dam has a top length of 1686 feet, and a maximum height of 52 feet. The rock-fill portion was made 14 feet wide at top, and the earth-fill 6 feet at top—making the total width 20 feet as in the lower dam, the slopes being the same, viz., 1½ to 1 on lower and 3.5 to 1 on upper side. The inner face of the rock-fill against which the earth rests has a batter of 0.5 to 1, the wall being laid up 2 feet thick by hand. The dam contains 102,400 cubic yards of rock, 103,600 yards of earth, 3800 yards of dry retaining wall, and 6200 yards of riprap. Its cost complete is stated to have been $200,000. An auxiliary embankment, 5200 feet long, 10 feet wide on top, 18.8 feet maximum height, with slopes of 1.5 to 1 and 3 to 1, and containing 78,400 cubic yards, was thrown up to close a gap in the ridge near the dam, at a cost of $10,000. It was made entirely of earth, paved with stone for a portion of its height on the water-side. When visited by the writer in the fall of 1895, and again in 1897, the dam showed no signs of leakage, or settlement, or any form of weakness, although the reservoir was more than half full. The works have never been completed to store more than 50,000 acre-feet, covering an area of 5500 acres, and it will be necessary to construct an expensive spillway before a material addition can be made to the volume of storage. At present the limit of storage is 17 feet below the crest of the dam, above which the water passes off through a gap of such dimensions as to carry 200,000 second-feet before the dam could be overtopped. The plan proposed is to close this gap with an embankment and excavate a small spillway through solid limestone on the right bank, with a capacity of 10,000 second-feet. When this is done the water-level will be raised 7 feet, or 10 feet below the crest, and the volume of storage will be approximately 89,000 acre-feet, covering 8331 acres of surface.

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

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

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

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

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

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

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

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

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

The estimated discharge of the stream past the southern boundary of New Mexico was approximately 700,000 acre-feet in 1890, 1,300,000 acre-feet in 1891, and 1,000,000 acre-feet in 1897. In 1893 the discharge exceeded that of 1891.

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

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

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

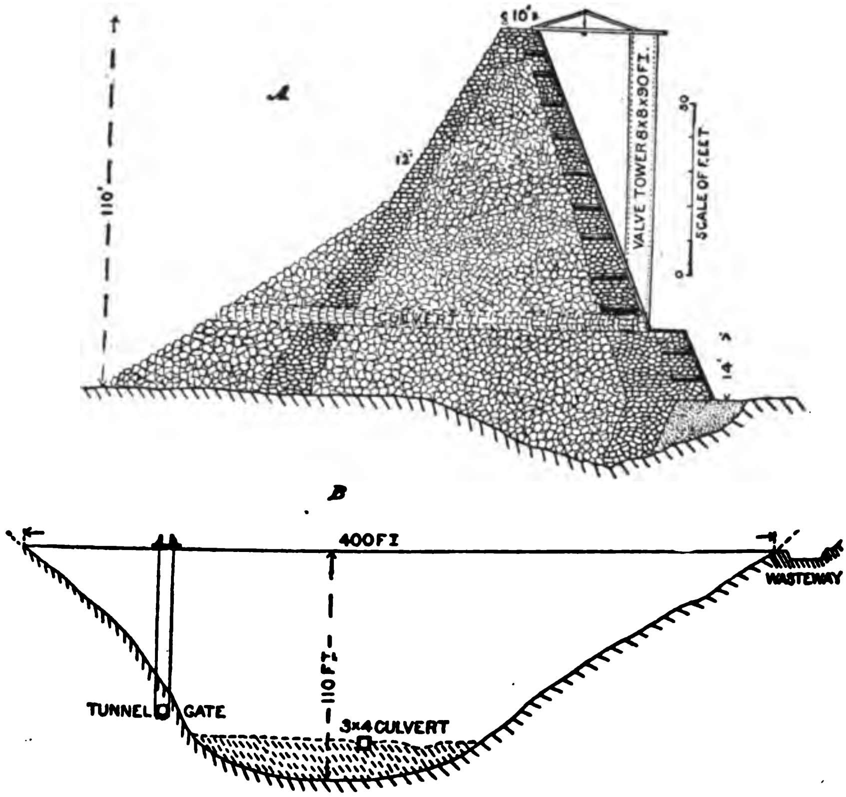


FIG. 40.—CROSS-SECTION AND ELEVATION OF WALNUT GROVE DAM, ARIZONA.

wall near the mid-height, and states that he "advised the company to cut a large wasteway and put the loose rock below the dam to strengthen this weak place." The following is extracted from Mr. Wagoner's paper: "The history of the construction of the dam is one full of blunders, mainly caused by the officers of the company in New York. Work was commenced on company account by Prof. W. P. Blake, who carried a wall across the canyon to bed-rock through about 20 feet of sand and gravel. He was succeeded by Col. E. N. Robinson as chief engineer, and the work was contracted for by Nagle & Leonard of San Francisco. Under Col. Robinson the dam was commenced in the rear of the Blake wall, and was described in the specifications as being composed of front and back walls 14 feet at the base and 4 feet at the top, with loose rock-filling between, the dam to be made water-tight by a wooden skin or sheathing.

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

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

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

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

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

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

The outlet provided for the reservoir was a culvert made partly in tunnels through a spur on the left bank, and partly as an arched masonry conduit, in which were laid two 20-inch iron pipes with gate-valves at the lower end below the dam. These pipes terminated above the dam in a square wooden tower 90 feet high built of 8″ × 8″ timbers, 8 feet long, notched one-half at each end, secured by a $\frac{5}{8}$-inch rod through each corner, the joints calked with oakum, and the outside painted with paraffine paint. Two wooden valves were placed to admit water into this tower, one at the bottom and the other 20 feet higher. They were arranged to slide on wood, on the outside of the tower, with wooden valve-stems, 6 inches square, running up the outside to the top, where the operating device consisted of two pinions, a spur-wheel, and a rack. The openings were each about 15 square feet in area, against which the pressure with full reservoir amounted to a resistance or load of nearly 40,000 lbs. (estimating the coefficient of friction of wood on wood at 0.40), while the lifting-device gave a maximum power of less than 1000 lbs. These were put in regardless of the protest of Mr. Wagoner, for the reason assigned that "they were designed by an engineer and must work."

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

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

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

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

* "American Irrigation Engineering," page 298.

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

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

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

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

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

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

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

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

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

A concrete wall, 15 feet thick, was carried down through the gravel bed of the canyon to bed-rock, a depth of 30 feet, and in the center of this wall the steel web-plates were anchored. These are $\frac{5}{16}$ inch thick for the lower 20 feet, $\frac{1}{4}$ inch for the middle 20 feet, and $\frac{3}{16}$ inch for the upper 28 feet. The rock-fill is given a slope of $\frac{3}{4}$ 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. 42. The down-stream portion also settled somewhat, causing the concrete to part from the steel plates about 6 inches at the top.

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

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

The outlet to the reservoir is by means of a tunnel 200 feet long, the bottom of which is 10 feet above the original stream-bed. At the entrance to the tunnel two 30-inch riveted steel pipes $\frac{3}{8}$ inch thick are imbedded in concrete, controlled by 30-inch Ludlow valves bolted to them, operated from a platform projecting from the face of the cliff above. The valve-stems are 2½-inch steel pipes. The main control of the outlet is by means of two other valves of the same size, placed at the bottom of a shaft, 50 feet back from the mouth of the tunnel, between two lengths of cast-iron pipe, the whole being imbedded in concrete which completely fills the tunnel. These are the working valves, the others being used only in emergency.

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

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

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

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

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

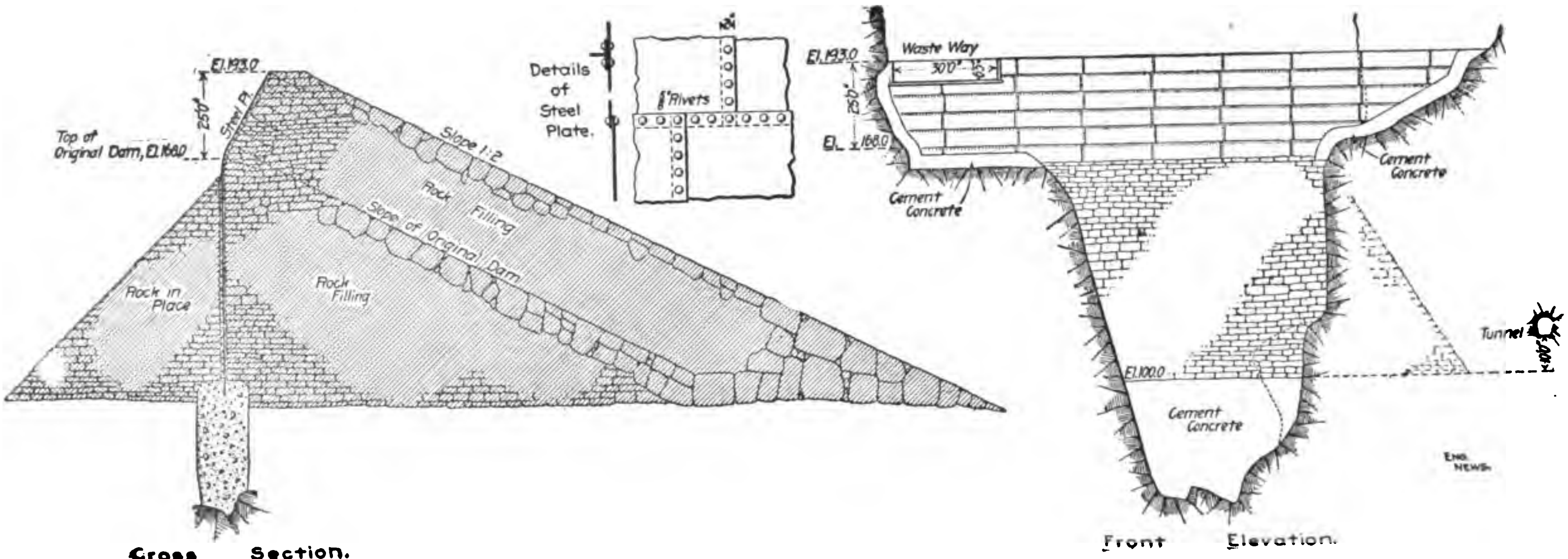


Fig. 42.—East Canyon Dam.

The exposed portion of the plates was covered with a plank sheathing to protect it from the sun, and from falling rocks. Plans are being prepared to still further extend the dam to a height of 150 feet, enlarging its storage capacity nearly three times. The investment has been profitable, as the value of the crops produced by the reservoir water the first year was estimated at $40,000.

Cheesman Rock-fill Dam.—On the site of the dam which has since become famous the world over as one of the highest and finest types of masonry dam in existence the Denver Union Water Company started in 1900 to build a rock-fill dam with a facing of steel plates, riveted together on the up-stream slope. This dam was located on the South Platte River in Colorado, and was to have been 210 feet high, and 600 feet long on top, with a base width of 450 feet,—the lower slope being 1½ to 1 and the upper slope, hand laid, ½ to 1. This was to be covered with 12 inches of concrete as a backing for the steel-plate face, which was to be riveted to 6-inch I-beams, to be anchored into the rock-fill with anchor rods 5 feet long.

Work was begun in 1898, and continued until May 3, 1900, at which time the masonry toe wall had reached to a height of 38 feet above the stream-bed, and the rock-fill behind it was 26 feet higher at the crest. During this construction the water of the river was diverted through a tunnel which was to be used as the main outlet of the reservoir. This tunnel is 7 feet wide, and 6 feet high, for about half its length, to its junction with an inclined spillway tunnel, whence its size increased to 8 feet wide, and 9 feet high, the total length being 470 feet. This tunnel was controlled at the upper end by a balanced valve, set over the tunnel mouth, at an incline of 30° from the horizontal. Fig. 43 shows the construction of this valve, which consists of four hoods or chambers of cast iron, resting on a heavy framework of T-beams, and opening out into the tunnel at the bottom. A continuous shaft passes through all the hoods from end to end, upon which are fastened heavy disks of cast iron, so placed as to close all the openings in the hoods when the valve is shut, and uncover openings at each end of each hood when the shaft is moved. The valve closes by gravity, but is opened by hydraulic pressure conveyed to the cylinder at the upper end of the gate through lead-lined steel pipes from a small reservoir located at a considerable height on the adjacent mountain side above.

Destruction of the Dam.—In the latter part of April, 1900, an unprecedented rainfall of 9 inches, added to the melting snows, caused a flood on May 3, so far exceeding the capacity of the outlet tunnel as to overtop the masonry toe wall, and wash away the loose rock-fill below. But for this unforeseen contingency the dam would doubtless have been successfully completed, and would have had every prospect of enduring stability, as ample spillway capacity had been anticipated in the plans, to provide against future overtopping. When thus completed it would have been the highest rock-fill dam in the world. The failure of the structure naturally discredited that particular type of dam for that locality, and the engineer who had planned it. New engineering talent was brought into requisition and a masonry dam was built on the site which is a structure entirely creditable to its builder, but involving a very much greater capital outlay. The existing dam is described in the chapter on masonry dams.

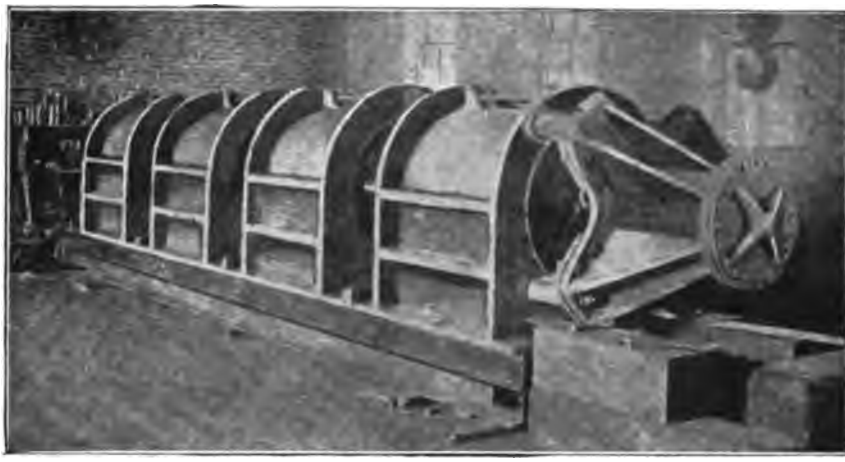


FIG. 43.—BALANCED VALVE USED FOR RESERVOIR OUTLET, CHEESMAN DAM, COLO

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 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

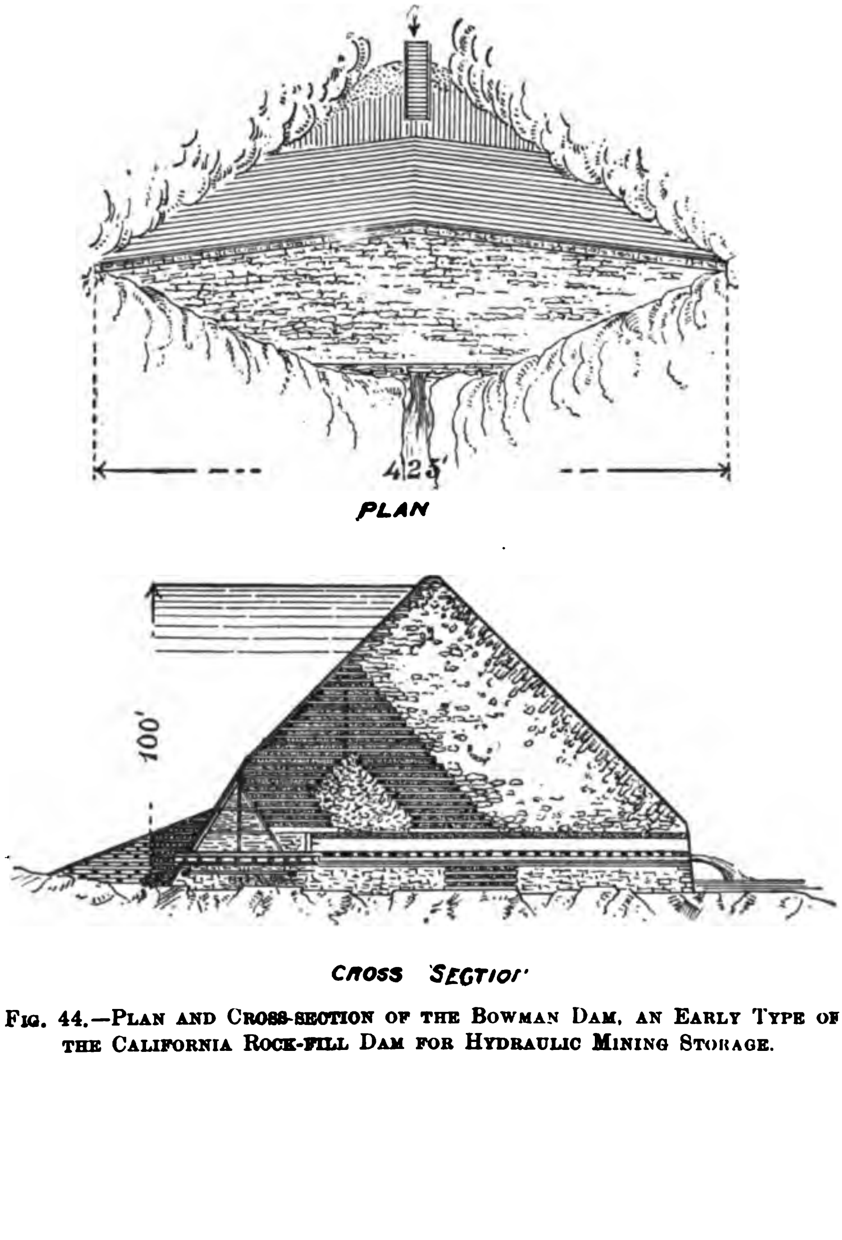

FIG. 44.—PLAN AND CROSS-SECTION OF THE BOWMAN DAM, AN EARLY TYPE OF THE CALIFORNIA ROCK-FILL DAM FOR HYDRAULIC MINING STORAGE.

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.

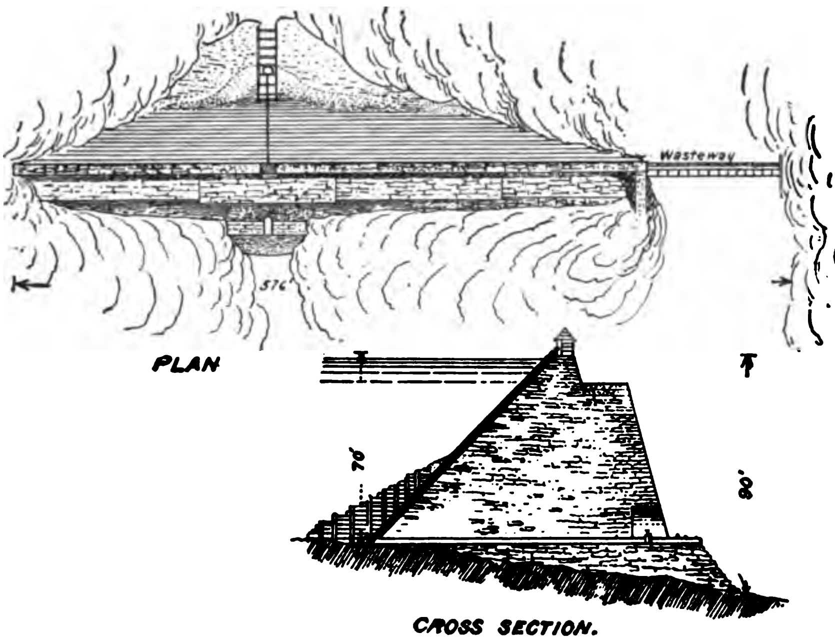

FIG. 45.—PLAN AND CROSS-SECTION OF THE FORDYCE ROCK-FILL DAM, CALIFORNIA.

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.	918,000,000	500.0	54.0 100.0	210 425
Shotgun Lake	Do.	3,423,000	26.2	14.0	50
Island Lake	Do.	23,028,000	48.8	12.8	....
Middle Lake	Do.	2,395,800	11.2	12.0	....
Round Lake	Do.	2,907,700	8.1	11.0	....
Weaver Lake	Summit Lake Water & Irr. Co.	150,000,000	83.5	21.8	....
Eureka Lake	Do.	661,000,000	337.3	70.0	250
Faucherie Lake	Do.	58,800,000	90.0	21.0	....
Jackson Lake	Do.	75,000,000	20.0	5.0	250
Smaller lakes	Do.	50,000,000	....	....	....
English dam	Kate Hayes Co.	650,000,000	395.0	131.0	331
Fordyce dam	South Yuba Mining Co.	1,075,525,000	474.0	90.0	476
Meadow Lake	Do.	107,950,000	300.0	40.0	1100
Sterling Lake	Do.	53,975,000	....	20.0	200
Spaulding Lake	Do.	266,000,000	215.0	67.0	290
Bear Valley Reservoir Do.	Do. Do.	19,400,000	60.0	35.0 15.0	140 160
Summit Reservoir	Do.	258,000,000	400.0	35.0	1580
Sawmill Lake	N. Bloomfield Mining Co.	2,000,000	80.6	39.2	....
South Yuba Reservoir	Excelsior Water & Mining Co.	....	....	26.0	120
Union Reservoir	Do.	13,000,000	40.0	30.0	700
Boyer Reservoir	Do.	2,200,000	20.0	20.0	600

Combination Rock-fill and Hydraulic-fill Dams at Milner, on Snake River, Idaho.—An improved type of rock-fill dam, with a central core of Oregon-pine planks, built as a tight fence, from the foundation concrete wall to the water-line, and faced with an earth embankment sluiced into the voids of the rock above the wooden core partition, was employed by the Twin Falls Land & Water Co. for the construction of the largest and most important diversion works for irrigation on the continent. The three dams form one main structure and were begun in 1903, and completed and put in service in March, 1905, the writer acting as consulting engineer throughout the work. The dams are in Cassia County, Idaho. They raise the water from the normal level of the Snake River to a height of 49 feet, and divert it into the canals for the irrigation of nearly 400,000 acres.

These dams have some special features which put them in a class by themselves as the first of a type, whose simplicity and cheapness recommend them for many locations where they could be built to advantage. At the point selected for the headworks of the canals the river is divided into three channels by two islands of basaltic rock, which were of suitable

Length of Dam.
Feet.
210
425
50
....
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....
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250
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250
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331
476
100
200
290
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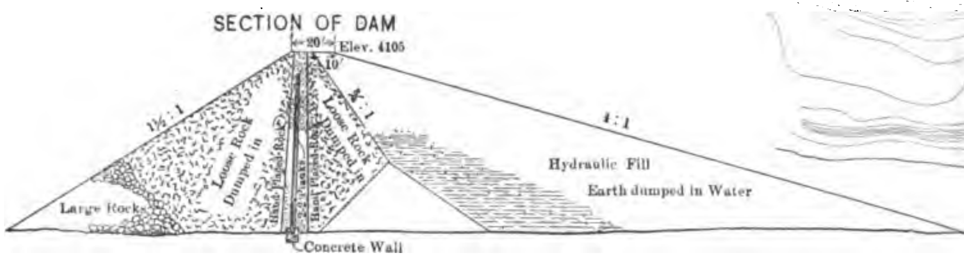
PLAN OF
THREE COMBINATION HYDRAULIC-FILL AND ROCK-FILL DAMS,
MILNER, IDAHO
AT HEAD OF TWIN FALLS CANAL ON SNAKE RIVER.



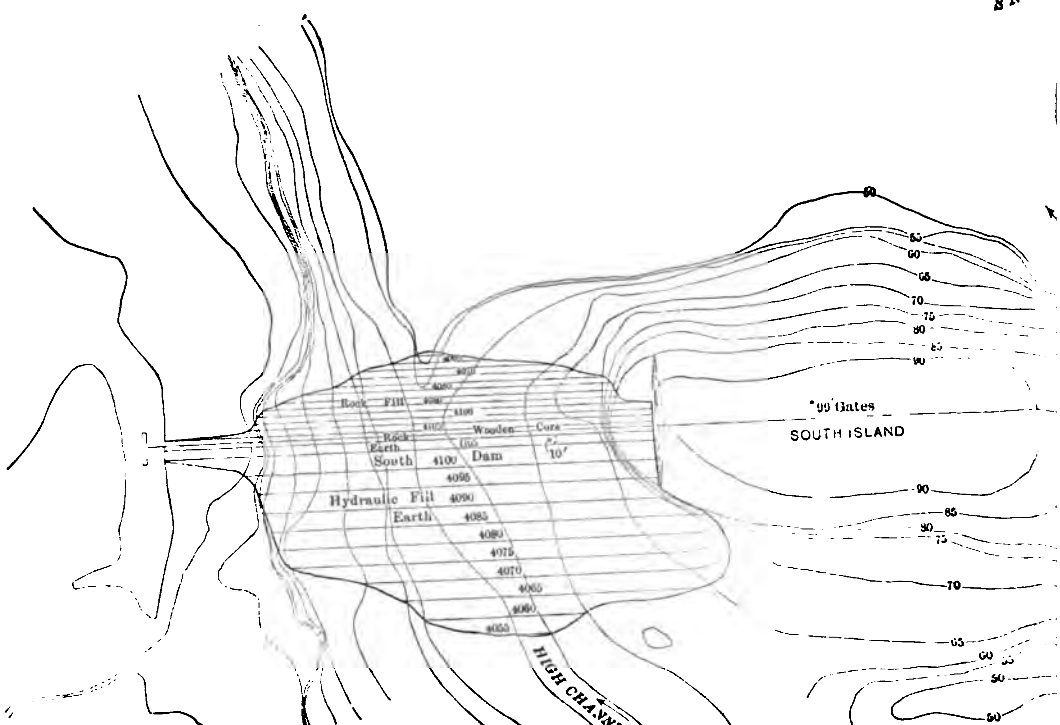
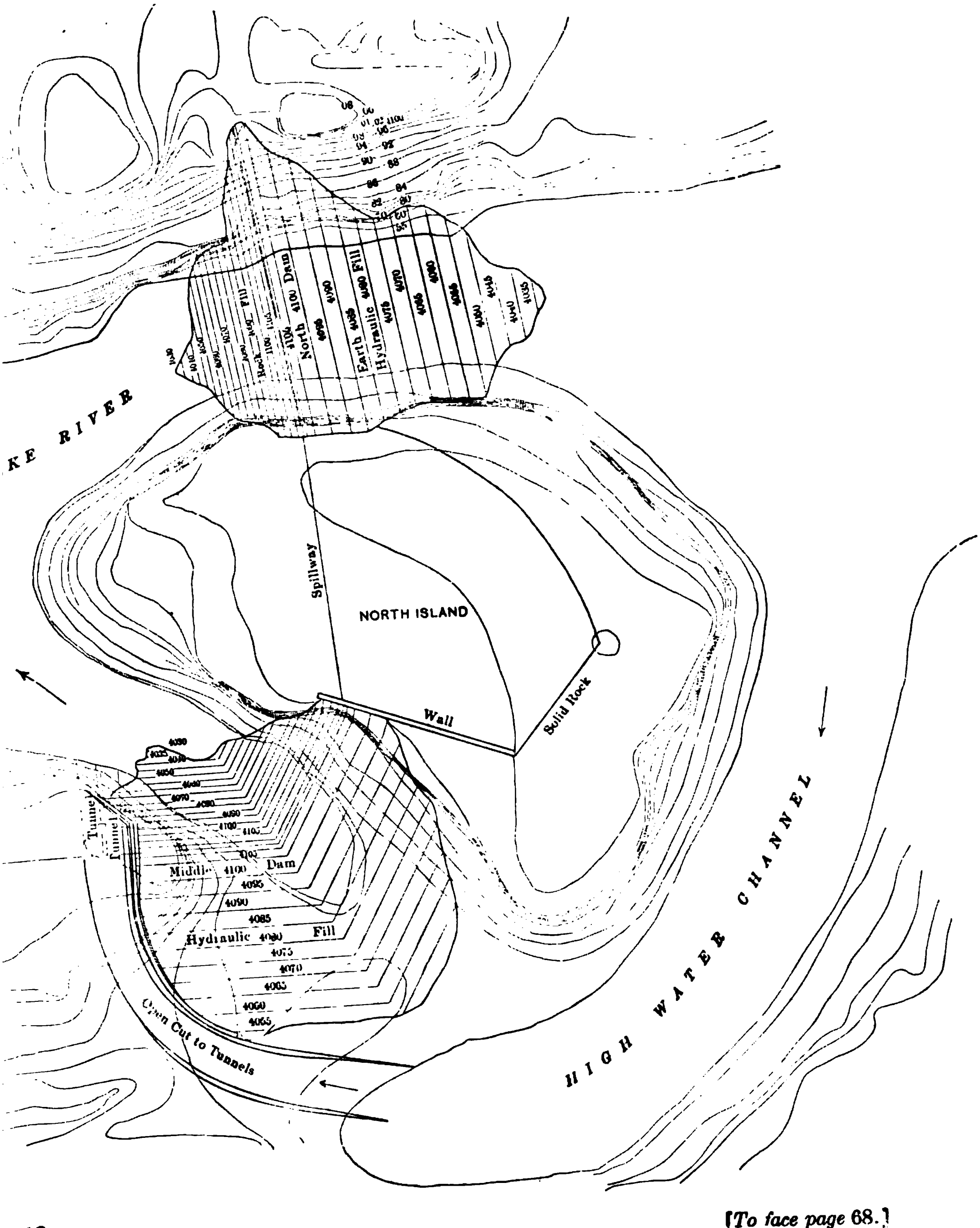


FIG.



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. 46.

character and height to be utilized as spillways,—one of them taking the natural overflow when the canals are full, and the other affording a location for a battery of 99 regulating gates, by which all excess water not required for diversion could be turned back into the channel. The maximum flow of the river in flood is about 60,000 second-feet, which can be carried by the gates. The main channel dam has the following dimensions: length on crest, 340 feet; height above lower toe, 86 feet; height above upper toe, 80 feet; width of rock-fill on crest, 10 feet; down-stream slope of rock-fill, $1\frac{1}{2}$ on 1; up-stream slope of rock-fill, $\frac{3}{4}$ on 1; crest width of earth-fill, 10 feet; slope of earth-fill, 4 on 1; volume of rock-fill, 39,650 cubic yards; earth-fill, 58,000 cubic yards. The middle dam is 335 feet long on top, 81 feet high above lower toe; 56 feet above upper toe, and contains 42,800 cubic yards of rock, and 62,850 yards of earth.

The south dam has a top length of 560 feet; a maximum height of 66 feet, and contains 34,700 cubic yards of rock, and 48,000 cubic yards of earth. The entire cost of the three structures was approximately $500,000. The total length of the three dams, spillway, and regulating gates, considered as one structure, is 2100 feet.

The method of construction of each dam was practically the same, although the south and center dams being in high-water channels were simple and easy as compared with the channel dam, where the water at the beginning was 20 to 30 feet deep, and over 5000 second-feet was flowing at the minimum. In the high-water channels, the ground being first stripped of all loose material, trenches, 5 feet wide, were dug to bed-rock and filled with concrete, into which the posts of the wood-partition were imbedded. These were $3'' \times 6''$ pine, placed vertically, 2 feet apart, center to center, against which 2-inch planks were spiked, in two layers, carefully breaking joints. The planks were surfaced on one side and both edges, and were of uniform thickness. The rock-fill was built up on either side of this fence, hand-laid for 5 feet in each direction. The remainder of the embankment was loosely filled by dropping the rock from a cableway spanning the gorge. The rock was quarried from the main canal within a mile of the dams by electric drills, hauled by electric locomotive, and hoisted and placed by electricity, power being furnished by a temporary contractors' plant of 500 H.P., on the river-bank. The rock is a hard basalt, which broke in large masses, with unusually small percentage of fine spawls.

To build the channel dam it was first necessary to construct a tunnel through the point of the South Island, of sufficient size to carry the low-water flow during the period of erection of the dam. This tunnel was cut in a layer of hard clay about 9 feet thick, underneath the main mass of basalt constituting the island. It was made in eight sections, each

5 feet wide, by 9 feet high, with heavy side walls of concrete, and partitions of timber and plank between them. Heavy gates of cast iron, with powerful hoisting gear, were set at the upper vertical face of the tunnel, on line with the battery of 99 gates for river control after completion of the works. The diversion of the river was effected in the following manner: An earth embankment, or coffer-dam, was placed across the channel approaching the head of the tunnel to keep out water during its construction. At the same time rock in large blocks, was deposited in the river channel, forming two lines of embankment at the up-stream and down-stream toes of the rock-fill, leaving a space between wide enough to permit the sinking of 24′×12′ timber cribs, with the upper faces on the longitudinal center of the rock-fill crest. The water found its way through and over these parallel levees of rock, which were built up until the water-level was 13 feet higher above than below. By this time the tunnel was completed, the coffer-dam was blown up by dynamite, and as much of the river turned through the tunnel as would go. About 4000 second-feet found exit that way and 1000 second-feet passed through the loose rock of the channel dam. With the aid of divers the timber cribs were sunk on the center line of the rock-fill, and a double thickness of sheet-piling was spiked to the upper face of the cribs, which were loaded with stone. This piling was fitted to the bed-rock bottom as carefully as possible, and the joints made tight by means of concrete in bags, placed against the upper footing of the sheet-piles. This work was done in a maximum depth of 40 feet of water, and finally all the water was forced through the tunnel. The remainder of the work above the water-line was similar in plan to the other two dams—the wooden fence being built as a continuation of the sheet-piling.

Much difficulty was encountered in making the wooden core-wall sufficiently tight to prevent loss of earth sluiced into the rock-fill above it. The material used for the earth-fill was exceedingly fine in texture, free from grit, and an almost impalpable powder. It is the soil of that country, classed by geologists as loess or æolian soil. When packed it makes a water-tight embankment, but when in suspension in water would flow as freely as any liquid through a hole or crack in the fence. After final completion the dams were found to be absolutely water-tight, and have shown no subsequent leakage or settlement. The work was done by contract with the State of Idaho for the reclamation of lands granted to the State by the United States Government under the terms of the Carey Act. The project has been remarkably successful in every respect, not only from an engineering standpoint, but as a commercial and agricultural enterprise.

The main canal on the south side of the river is about 70 miles long, and has a capacity of 3000 second-feet, carrying a depth of 10 feet. It

FIG. 47.—MILNER DAM, SNAKE RIVER, IDAHO. DISCHARGE THROUGH THE GREAT BATTERY OF 99 WASTE-GATES FORMING "IRRIGATION FALLS," 40 FEET HIGH.

FIG. 48.—MILNER DAM, SNAKE RIVER, IDAHO. SHOWING WASTE-WAY GATES AND DISCHARGE OF RIVER OVER "IRRIGATION FALLS."

FIG. 49.—MILNER DAM, SNAKE RIVER, IDAHO. NORTH CHANNEL DAM BEFORE COMPLETION OF SHEET PILING. ABOUT 500 SECOND-FEET IS PASSING THROUGH ROCK-FILL, UNDER HEAD OF 13 FEET.

FIG. 50.—MILNER DAM. DIVERS AT WORK PLACING SHEET PILING IN 40 FEET OF WATER.

FIG. 51.—MILNER DAM, SNAKE RIVER, IDAHO. SHOWING ROCK-FILL WITH WOOD-CORE IN MAIN CHANNEL OF RIVER.

FIG. 52.—MILNER DAM, IDAHO. SHOWING A PART OF THE BATTERY OF 99 WASTE-GATES.

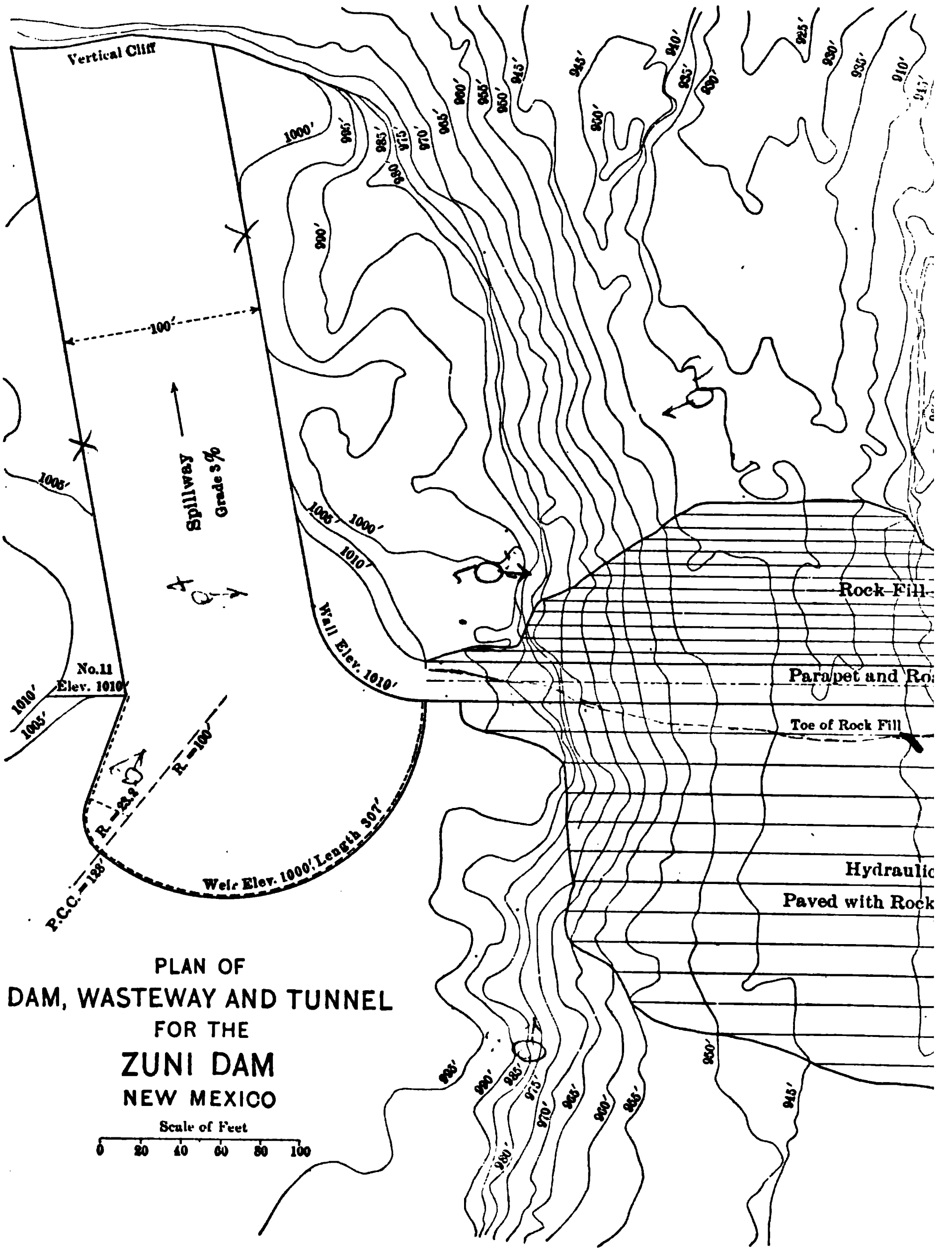
supplies 240,000 acres. On the north side of the river the canal has not yet been constructed, but surveys have determined the feasibility of irrigating about 150,000 acres. Two or more reservoir basins of large capacity will be utilized along the canal line for storage of water during the non-irrigation season.

Figs. 47, 48, 49, 50, 51, and 52 illustrate the construction of these notable dams, and Fig. 53 shows the type of head-gates successfully

FIG. 53.—FIRST OPENING OF HEAD-GATES OF TWIN FALLS CANAL, MARCH 1, 1905.

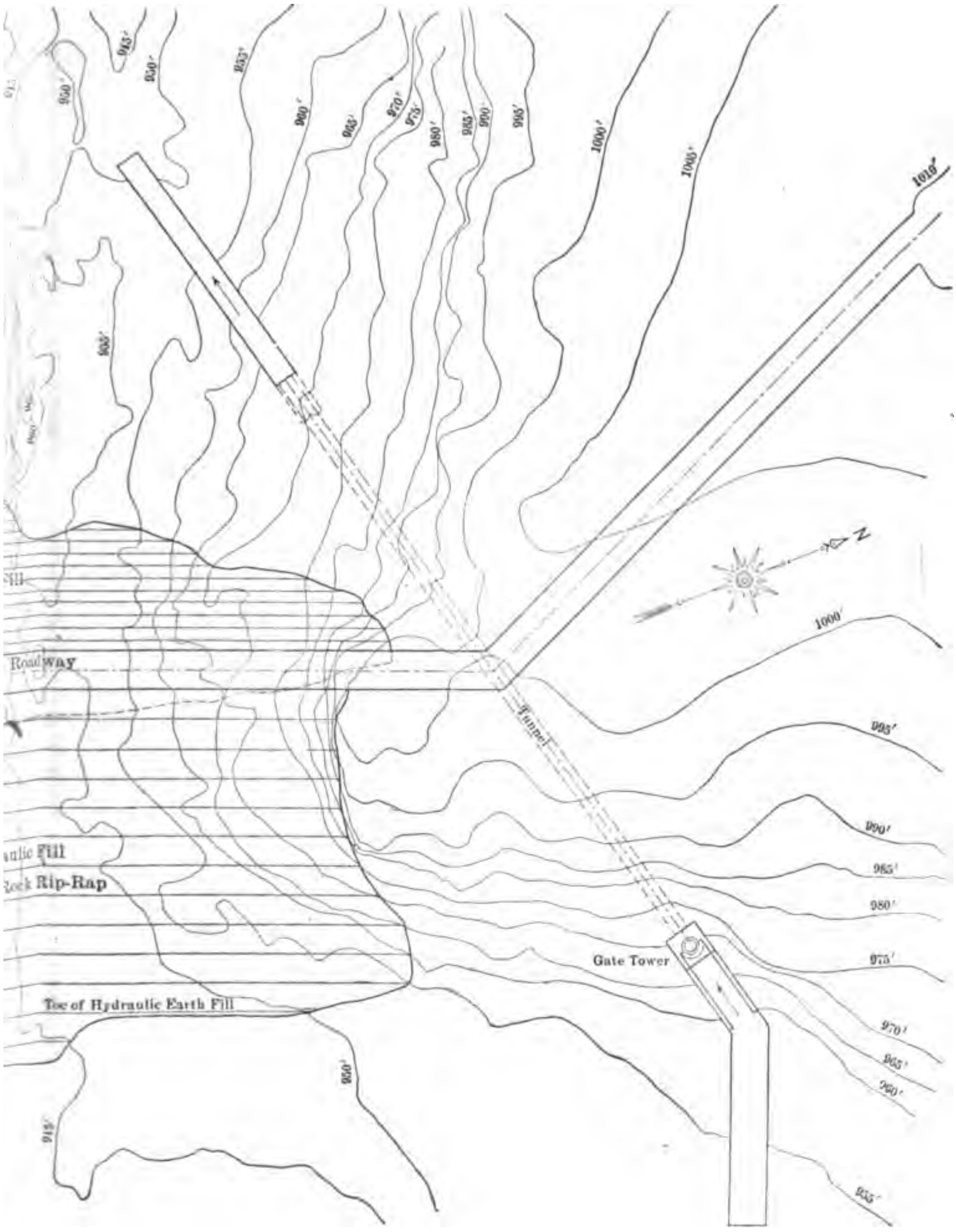
used in the canal. They are eight in number, each 12 feet wide and 11 feet high. For description of hydraulic filling of these dams see pages 125 and 126.

The Zuñi Dam, New Mexico.—Near the western boundary of New Mexico, on the Zuñi Indian Reservation, 45 miles south of Gallup, a coal-mining town on the line of the Santa Fé railway, the United States Indian Bureau has built a dam 70 feet in height for the storage of water to be used in the irrigation of the lands of the Indians. The work was done under the general direction of W. H. Code, Chief Engineer United States Indian Service, by J. B. Harper, C.E., Superintendent of Irrigation, the writer acting as consulting engineer. As originally planned the dam was designed to be an earth-fill throughout, the material to be placed by hydraulic sluicing. In view of the torrential character of the stream and the possible occurrence of freshets exceeding the capacity of the outlet tunnel during construction, it was finally decided to change the



PLAN OF
DAM, WASTEWAY AND TUNNEL
FOR THE
ZUNI DAM
NEW MEXICO

Fig. 5



IG. 54.

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plan to the combination type of rock-fill and hydraulic-fill. The fact that there was an abundance of basaltic rock on the site of the dam, overlaid by fine earth of a suitable character for hydraulic sluicing, rendered the selection of these materials in combination a natural one.

The rock-fill was built as a dry wall, with all the stones in the outer faces placed by derricks operated by steam-engines, while the interior of the mass was chinked carefully with small stones. The dimensions of the rock-fill were as follows: Crest length, 720 feet; crest width, 5 feet; down-stream slope, 1.25 on 1, in regular steps of 18 inches height; up-stream slope, 0.5 on 1. The total volume of the dry wall so placed is 40,160 cubic yards. All the work was performed by Indian labor, with white foremen. This made the work very slow and expensive, as the Indians are entirely unskilled and inefficient, and ready to throw down their tools at any time to perform their religious dances and observe their numeorus feast days. The total cost of the rock-work averaged $2.50 per cubic yard. The embankment was built up to the top from either end, leaving a gap of about 75 feet in the center, at the stream channel for the passage of floods. This was a fortunate provision, as a freshet occurred April 24, 1905, of greater volume than had been previously known, estimated at 14,000 cubic feet per second for four hours, and over 9000 second-feet for 20 hours following—the total discharge of 24 hours exceeding the entire capacity of the reservoir. This great flood scoured the bed of the stream 10 feet deeper than it had originally been and increased its width, so that the volume of rock required in the dam was increased 24% above the original estimate. No damage was done to the rock-fill, however, and after it was over the gap was closed and preparation made to sluice in an earth-fill against the up-stream face of the rock-fill, with a slope of 3 on 1, on the water side. A levee was first built at the up-stream toe of the earth embankment by hauling in earth by teams, and, to prevent the liquid earth from passing through the voids in the rock-fill, a narrow embankment of earth was placed against the rock, as no core-wall of wood or concrete had been provided in the rock-fill. The layer of earth next to the rock was from 5 to 10 feet thick. It was found that when fine sand was used no water found its way through this layer, although at the outset when moist clay was placed against the rock shrinkage cracks appeared which permitted leakage and loss before they would soak up and close.

For sluicing purposes there was no gravity water available, and a steam-pumping plant was installed with a capacity of delivering 2.5 cubic feet per second, under a pressure of 90 to 95 pounds per square inch at the nozzle of the hydraulic monitor, the maximum lift to the monitor being 73 feet from the level of the pond above the dam. The total volume of earth in the dam is 60,120 cubic yards, of which about 40,000

FIG. 55.—DOWN-STREAM FACE OF ZUÑI DAM. SHOWING CHARACTER OF DRY MASONRY IN THE ROCK-FILL.

FIG. 56.—HYDRAULIC-FILL SIDE OF ZUÑI DAM. SHOWING GRAVEL COVER OF STONE RIPRAP.

yards were placed by the sluicing process. This work was accomplished in a total working time of 800 hours, distributed over 232 working days. The average ratio of solids delivered to water pumped was 15% and the total cost of the work, including labor, pumping, fuel, and operation

Fig. 57.—Zuñi Dam, N. M., looking North, Showing Tower and Bridge in Distance, Spillway Guard-wall in Foreground.

of sluicing was 12 cents per cubic yard, of which one-third was for pumping. The material was delivered along the dam by a "V" flume, measuring 20 inches on the sides, laid on a grade of 3%, and consisting of a

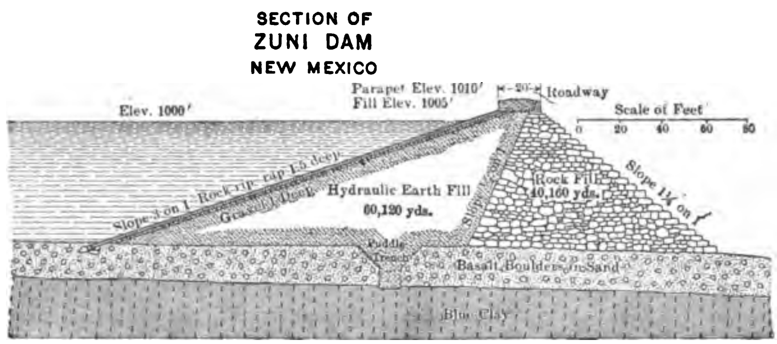


Fig. 58.

succession of sections, each 16 feet long, overlapping at the ends, and made to deliver material at any point by lifting out a section and inserting a lateral flume, directing the stream to either side as desired. Nearly one-half the entire amount of earth sluiced was deposited in the month of May, 1907, when the average delivery was 750 cubic yards per day of 8 hours. During this period the ratio of solids was nearly 28% of the water used.

Owing to the fact that all of the earth used was either very fine sand or clay, both equally impervious in an embankment placed and solidified

FIG. 59.—ZUÑI DAM, N. M., ILLUSTRATING METHOD OF DELIVERY OF SLUICED MATERIALS BY "V" FLUME, AGAINST FACE OF ROCK-FILL.

by water, no attempt was made to separate the particles, or segregate the clay from the sand, as is customary in building hydraulic-fill dams,

FIG. 60.—ZUÑI DAM, NEW MEXICO, SHOWING HYDRAULIC MONITOR IN ACTION.

where the available materials are an admixture of gravel, rock, clay, and sand. Hence it was immaterial at what point against the rock-fill the material was discharged, so long as no horizontal stratifications appeared.

Fuel for producing steam was obtained from a coal-mine opened for the purpose on the reservation, a few miles above the dam. The power thus provided averaged about 120 H.P.

The geological formation of this locality is quite peculiar. The Zuñi River has here broken through a sheet of lava which at some remote period flowed from a volcano to the north of the valley and spread in a wide, horizontal blanket over the country, covering the alluvial soil to a depth of about 30 feet. Underneath the lava cap (the top of which is at the crest of the dam) are successive layers of sand and clay, while at a depth of 20 feet below the river-bed dense blue clay is encountered, forming the impervious sub-floor of the reservoir. The erosion of the sand strata in the canyon and the breaking down of the lava cap by undermining had left the stream-bed filled with masses of hard basalt. This gave the impression of a canyon cut in rock from top to bottom, and was good ground for the presumption that a masonry dam would be best adapted to the site. Excavation, however, proved the unsuitability of the foundations for such a structure, and led to the final adoption of a type of dam which is flexible, and at the same time impervious to water. A spillway has been excavated in the solid rock on the south side of the dam, 100 feet wide, 10 feet deep.

The reservoir has a capacity of 16,000 acre-feet (700,000,000 cubic feet) covering an area of 623 acres, and receiving the run-off from 650 square miles of watershed, whose maximum elevation at the Continental Divide is 9200 feet.

The measured run-off of this shed at the dam was 15,115 acre-feet in 1904, and 106,630 acre-feet in 1905.

Fig. 58 is a section of the dam, and Figs. 55, 56, 57, 59, 60, and 61 are photographs taken during construction.

The Minidoka Rock-fill Dam, Idaho.—One of the projects of the United States Reclamation Service for the ultimate irrigation of about 150,000 acres from Snake River, involved the construction of a diverting dam, located about 8 miles southwest of Minidoka, Idaho, at a cost of $425,923.

The dam is a rock-fill structure, with earth facing and concrete core-wall. The length of the dam is 625 feet, its maximum height 80 feet above bed-rock, and about 60 feet above the original bed of the stream. The width on the crest is 25 feet, its base averages about 300 feet, and its total volume 191,000 cubic yards. The concrete core-wall is built upon a solid rock foundation throughout the entire length of the dam, and at each end reaches to within about 11 feet of the top of the earth and rock part of the dam, while through the central portion its top is 44 feet below the crest of the dam. The downstream portion of the dam was built of large rocks, of 1000 pounds minimum weight, dropped in place from a cableway stretched across the stream.

In construction, a diversion channel was first excavated, and then two separate lines of fill were extended across the river about 150 feet apart, the upper one of earth, the lower of rock. By this means the natural channel was gradually contracted and the water forced through the by-pass channel. When the rock-fill was thus carried across, the leakage through it was estimated at 1000 second-feet, but this was gradually cut off by dumping gravel and earth on the up-stream slope

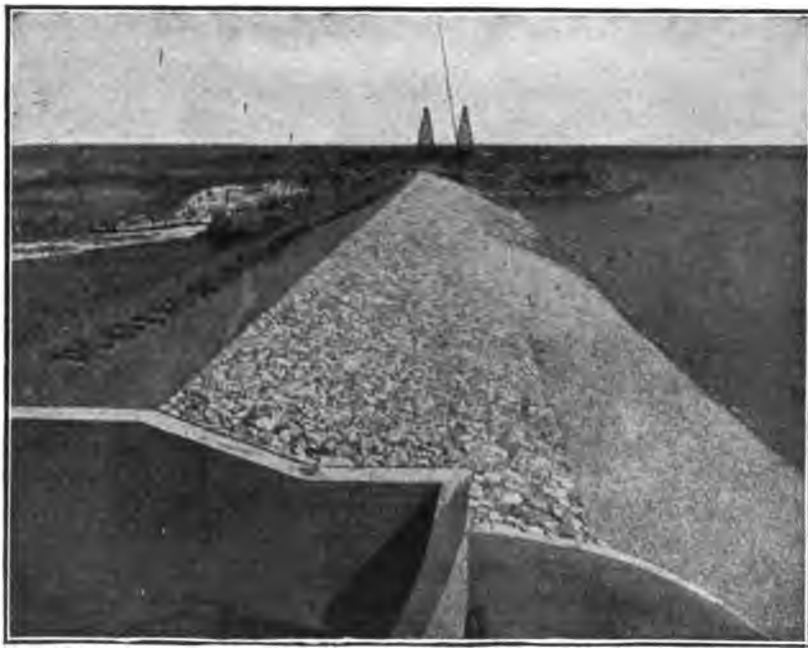


FIG. 61.—MINIDOKA DAM, IDAHO, LOOKING NORTH.

from cars running on a track laid across the rock-fill. The earth-fill was then made by a second cableway and by cars, and the core-wall was built in the trough between them. Upon its completion the fill was carried up on both sides and over the top of the core-wall until the required dimensions of the dam were made. The earth and gravel used in the fill were loaded into cars by means of a steam-shovel. The closure and diversion by the rock-fill were made in April, 1906, and the entire flow discharged through regulating gates, and the dam was completed Sept. 14, 1906, under the supervision of F. C. Horn, construction engineer. The dam was planned by John H. Quinton, M. Am. Soc. C.E.

The dam is provided with a concrete spillway of irregular alignment, built on solid lava rock, and having a maximum height of 14 feet and a crest length of 26,000 feet, containing 4000 cubic yards of concrete. The crest of the spillway is 10 feet below the top of the dam, 7 feet above the sill of gates of the north side canal, 6 feet above the grade of the south side canal, and 48 feet above the bottom of the diversion sluice-way, in which a concrete dam is built with five Coffin sluice-gates, each 8 feet wide, 12 feet high. This structure is provided with penstock openings for the future development of power to be utilized for pumping water to higher lands above the south side gravity canals. It is estimated that 10,000 to 30,000 H.P. may be so developed.

About 70,000 acres of land are irrigable by the gravity canals, mostly on the north side, and 80,000 acres may be watered by pumping to higher levels on the south side.

The entire project is estimated to cost $2,600,000.

The Alfred Dam, Maine.—The highest dam in the State of Maine was completed in December, 1905, at Alfred, Maine, to provide storage

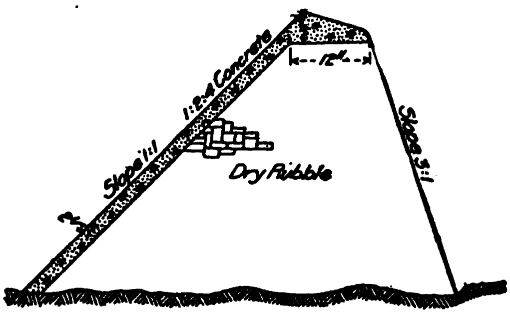


FIG. 62.—SECTION OF ALFRED DAM.

to equalize the flow of the Mousam River for power purposes for the Alfred Light & Power Co. The dam is of rather novel design, as it consists of dry rubble, built with split stone, the three lower courses laid in Portland cement and the up-stream face and crest covered with concrete 2 feet thick. See section Fig. 62.

The dam is 39 feet high, 995 feet in length, with a spillway section in center 580 feet long. It contains 12,150 cubic yards of dry rubble, and 2790 cubic yards of concrete. The stream was handled during construction by diversion through the penstocks of the power plant, by a coffer-dam thrown across the entire river.

The rock being dimension stone, laid by hand, the dam is not strictly to be classed as a rock-fill, but is interesting as a cheap type of permanent construction of a better grade than the ordinary rock-fill.

The dam was completed in 90 days after stone-laying began, and in 105 days from the beginning of clearing.

FIG. 63.—ALFRED DAM, ME. DRY ROCK MASONRY WITH CONCRETE FACING AND CREST.

The Idaburn Dam, New Zealand.—An overfall dam, 50 feet high, of similar construction to the Alfred dam just described, was built in 1904, across a canyon known as the Idaburn gorge, for the formation of a reservoir to irrigate 10,000 acres. The dam is but 42 feet thick at the base, 6 feet at the top, 100 feet long on the crest. The up-stream face batter is 1:24, while the down-stream face forms a series of tangents as points on a vertical curve of long radius. The structure is laid up as a dry wall, with a face of 2 feet thickness of concrete on the crest and down-stream slope, while the base and up-stream face are roughly squared blocks of stone laid in mortar to a thickness of 2 to 4 feet. This is the extreme of economy in dam construction, and must be regarded as having an exceedingly small factor of safety. (See Plate 3.)

The Roswell Rock-fill Dam, Georgia.—Sometime before the Civil War a rock-fill dam was built at Roswell, Georgia, for power purposes, having a height of about 28 feet, and a base width of 30 feet, the down-stream face being vertical, while the up-stream face was laid a few inches depth in Rosendale cement or lime mortar. This was used continuously until 1892 when the dam was repaired and the water slope covered with cement mortar, on which a plank face was laid. Ten years later the dam was raised about 6 feet above its former crest level, by the addition of dry rubble to the down-stream face, resting on a masonry base, laid on bed-rock, with the upper face sloping toward the crest at a ratio of 2 on 1. This base reaches to an extreme height of 9 feet, and is 12 feet wide. On this the dry rubble wall was laid in courses with a batter of 1:3.5. The up-stream slope and crest are faced with 3″×6″ yellow pine planking. The length of the spillway is 138 feet and its depth 5 feet. The total length of the dam is 251 feet, and its extreme height 38 feet.

The original dam was laid of flat stratified rock, the interior of the fill being made up of a very poor quality of slate. The last construction on the down-stream face was done while the water filled the reservoir to the top of the dam, the level being kept below the spillway by means of sluicing gates. The crest and up-stream facing was built with the pond drained during a time when the mill was shut down for repairs.

The Victor Rock-fill, Steel-faced Dam, Colorado.—In 1901 the Pike's Peak Power Co. built a unique dam on the West Fork of Beaver Creek, 5½ miles east of the town of Victor, and 10 miles south of the summit of Pike's Peak, to form a storage reservoir for power purposes. The dam is a rock-fill, with a facing of steel plates as a water-tight skin on the reservoir side. It has a maximum height of 70 feet, is 220 feet long at the bottom, 405 feet long at top, 20 feet wide on the crest, and has a base width of 148 feet. The up-stream slope is 30° from the vertical (0.577 on 1), while the down-stream slope is 50° from the vertical, or 1.22 on 1. The foundation is a granite bed-rock.

The novel feature of the dam is the use of sheet-steel plates to form the facing, the first structure of this type that has ever been constructed. The plates are uniformly 15 feet long, 5 feet wide, laid horizontally, their thickness being ½ inch for the lower 30 feet, then diminishing to ⅜ inch and ¼ inch at the top. The horizontal seams are riveted with butt-straps, while the vertical seams are riveted to angle-bars, 5″×½″, which are placed in pairs at the seams and riveted together, with a ⅜″×2″ filler placed between them. The seams were all calked as thoroughly as in boiler work by the use of pneumatic riveters and calkers. At the base is riveted to the plate a pair of 5″×8″ angle-bars, and a foot above another pair, both of which are imbedded in the concrete toe-wall. The ends are treated in a similar manner, with angle-bars riveted on up the slope. The plates are painted with a protective coating to protect them from rusting.

The granite back-fill against which the steel plate rests is a dry wall of granite blocks, of 20 to 80 cubic feet each, chinked with fine quarry sprawls. A space of 6 inches was left between the plates and the back wall, which was filled with sand and gravel packed with water and thoroughly drained before water pressure was applied.

The outlet of the reservoir is a 24-inch wood-stave pipe, built in concrete through the base of the dam and extending into the reservoir for 240 feet. The reservoir formed by the dam covers an area of 130 acres, with a capacity of 102,000,000 cubic feet (2340 acre-feet). The surface elevation of the water is 9018 feet, giving a maximum depth of 63 feet to be drawn upon.

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

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

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

CHAPTER II.

HYDRAULIC-FILL DAMS.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

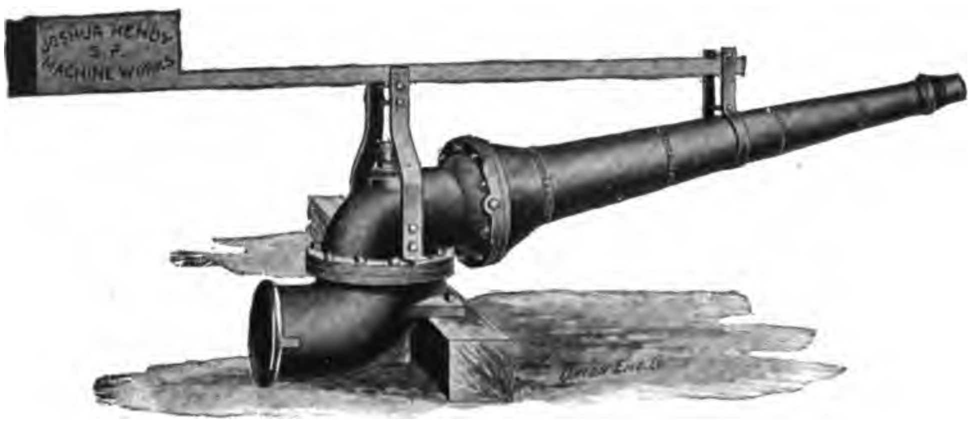


FIG. 64.—DOUBLE-JOINTED HYDRAULIC GIANT.

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

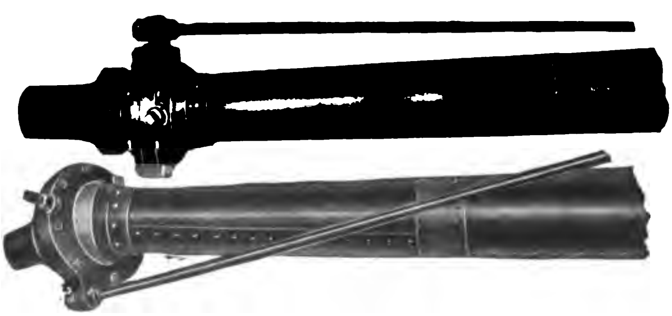


FIG. 65.—THE DEFLECTING NOZZLE OF GIANT.

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

The earliest form of hydraulic giant is known as the single-jointed monitor, in which the movement is confined to one direction in a vertical plane, and the machine had to be shifted by bars to change the horizontal direction.

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

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

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

The Temescal dam was built in 1868. It is 105 feet high, 18 feet wide on top, with original slopes of 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 125 feet above the stream-bed. It is located 9.5 miles east from Oakland, 1.5 miles above the village of San Leandro, at an elevation at base of 115 feet above tide. The dam is 500 feet long on the crest and 28 feet in width. The width of base from toe to toe of slopes is 1700 feet. The original slopes were 2½ to 1 on the down-stream side, and 3 to 1 on the reservoir side. Subsequent additions to these slopes were made by hydraulic sluicing. The extreme depth of puddle core is 30 feet, making the total height of dam from bottom of puddle core to crest, 155 feet. The total volume of the dam is 542,700 cubic yards, of which about 160,000 yards were deposited by the hydraulic process. The water was brought 4 miles in a ditch, and the sluiced materials were conveyed in a flume, lined with sheet-iron plates and laid on a grade of 4% to 6%. The water used was 10 to 15 second-feet, and the ground-sluicing method was alone employed, as it was not convenient to get water under pressure. The cost was estimated at one-fourth to one-fifth that of putting the earth in place with carts or scrapers. The entire cost of the dam proper was about

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

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

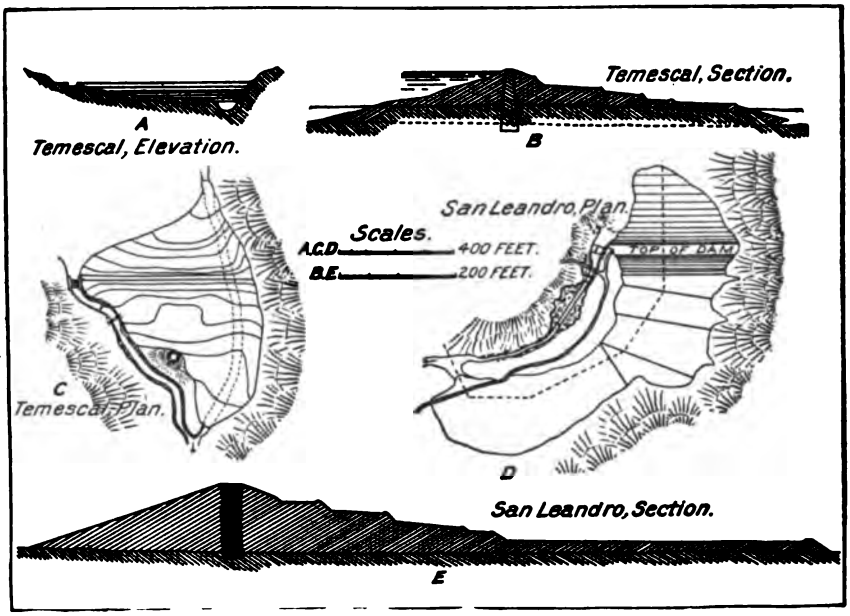


FIG. 66.—PLANS AND CROSS-SECTIONS OF SAN LEANDRO AND TEMESCAL DAMS.

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

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

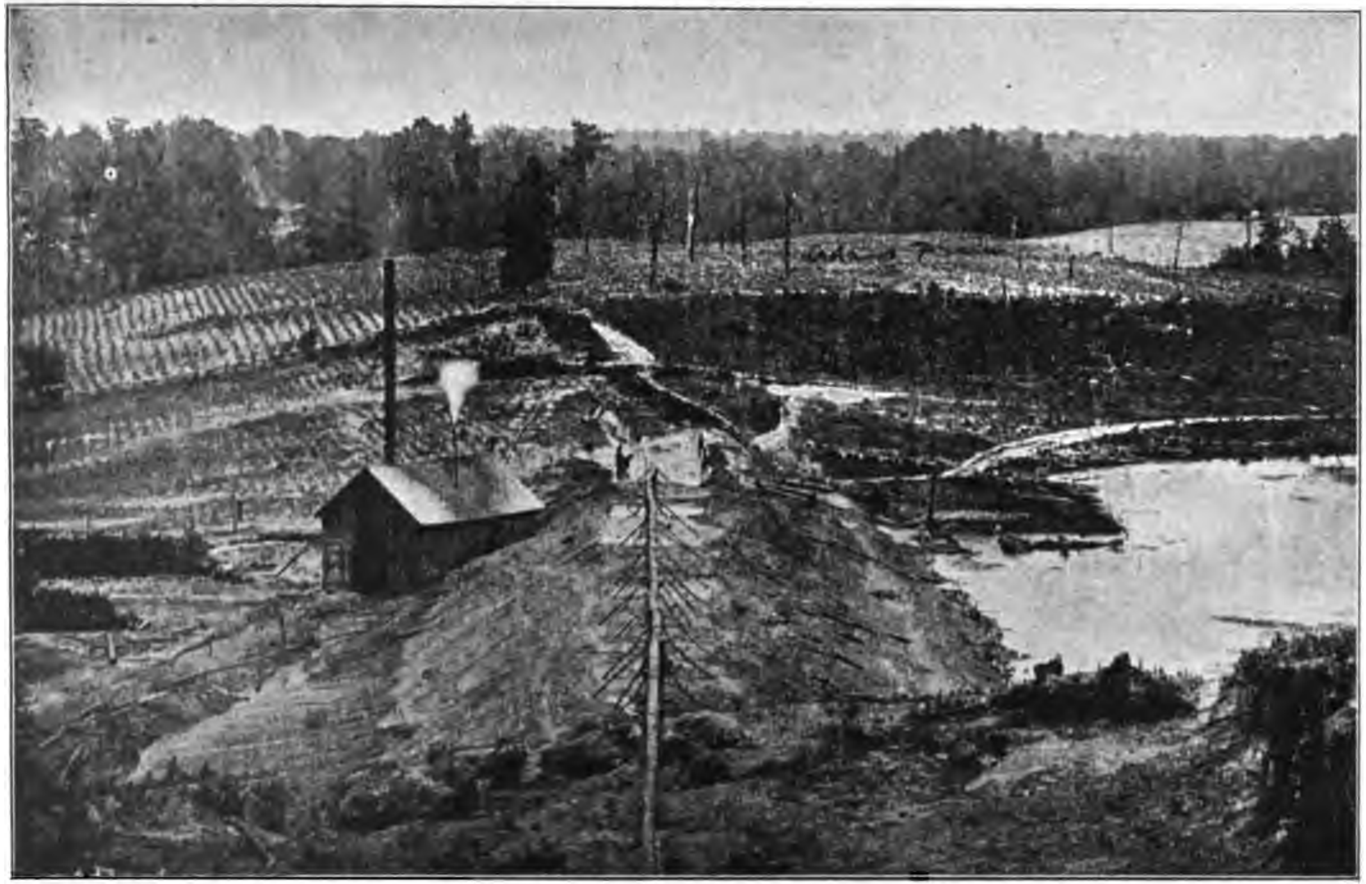


Fig. 67.—Hydraulic-fill Dam at Tyler, Texas, showing Delivery-pipe Supported on a Grade-line, carrying Material to Opposite Side, and Spill-way Cut made by sluicing the Earth into Base of Dam.

FIG. 68.—HYDRAULIC SLUICING FOR BUILDING DAM AT TYLER, TEXAS.

was but 4¾ cents per cubic yard. The dam, Fig. 67, is 575 feet long on top, 32 feet high, and contains 24,000 cubic yards, the inner slopes being 3 on 1, and the outer 2 on 1, with a 4-foot berm on the inside 10 feet below the top. The maximum depth of water is 26 feet; the reservoir covers 177 acres and impounds 576,800,000 gallons, or 1770 acre-feet. The water used in sluicing was forced through a 6-inch pipe by a Worthington steam-pump of 750,000 gallons daily capacity, belonging to the old city pumping-station situated on the opposite side of the valley from the hill which supplied the material. This hill is 150 feet high, and the pipe terminated about half-way up from its base, where a common fire-hydrant was placed to which was attached an ordinary 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. 68). The washing was carried rapidly into the hill on a 3% up-grade which soon gave a working face of 10 feet or more, increasing gradually to 36 feet vertical height. By maintaining the jet at the foot of the cliff the latter was undermined as rapidly as the earth could be broken up and carried away by the water. The material found in the hill consisted of a soft, friable sandstone infiltrated with ocher of varying shades of yellow, brown, and red, alternating with clay and sand, the whole overlaid by a surface soil of sandy loam, 2 to 6 feet deep. Experiment and observation led to the conclusion that 65% of the entire mass washed into the dam was sand, and 35% was clay.

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

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

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

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

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

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

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

FIG. 69.—HYDRAULIC-FILL DAM, AT TYLER, TEXAS, IN PROCESS OF CONSTRUCTION. Water supplied by pump in building at right of picture.

Fig. 70.—View of Finished Dam and Wasteway of La Mesa Reservoir.

FIG. 71.—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. 72, 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. 73, 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. 70.) 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. 72.—La Mesa Reservoir. Beginning of the Construction of Hydraulic-fill Dam.

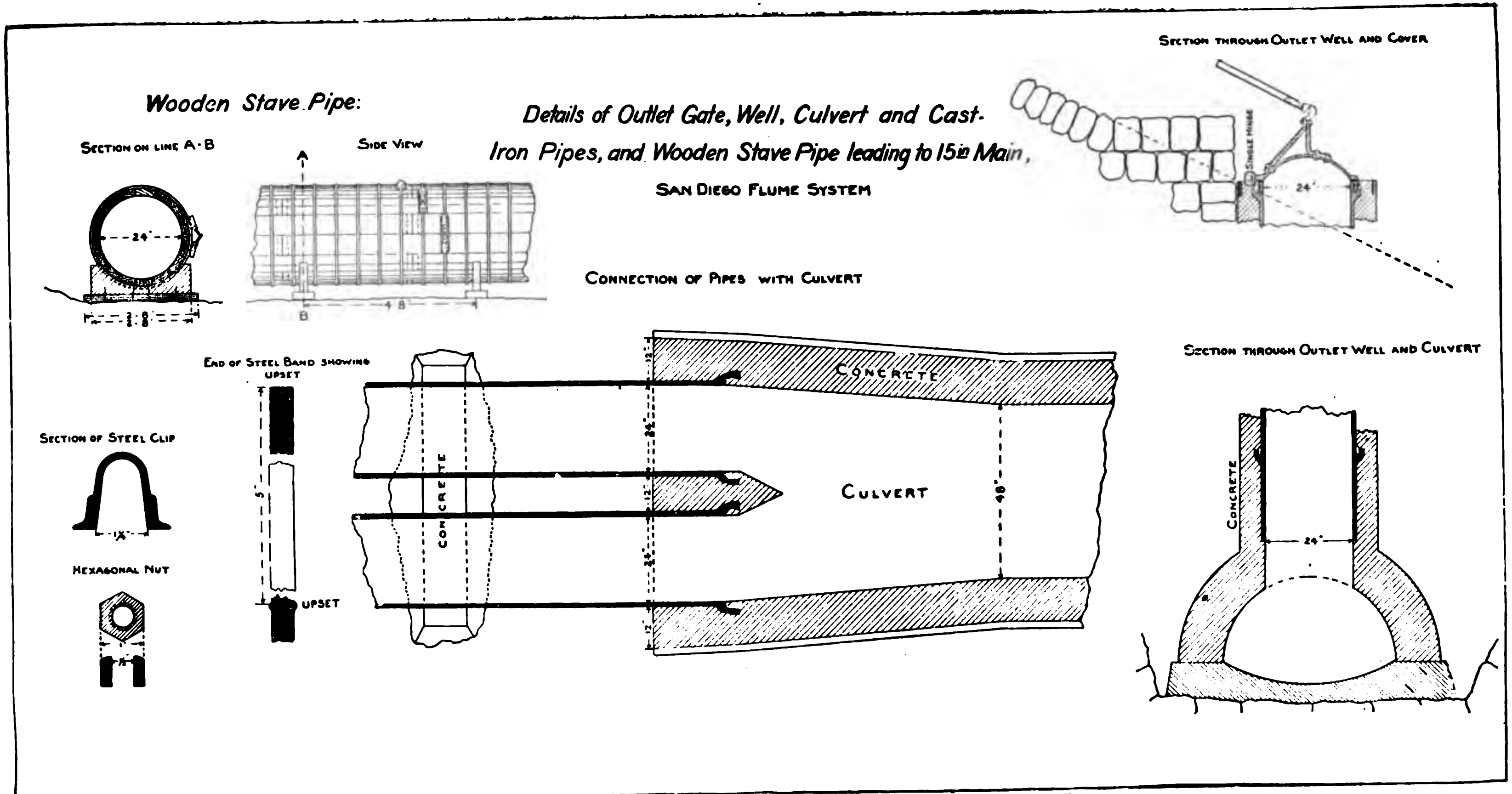


Fig. 73.—Details of Outlet-gate and Well-culvert of La Mesa Dam.

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. 74 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. 74.—Construction of Hydraulic Dam, La Mesa Reservoir, illustrating the Method ot 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. 75), and therefore more of the coarse and permeable bowlders and gravel are placed on the outer half of the embankment, where they afford

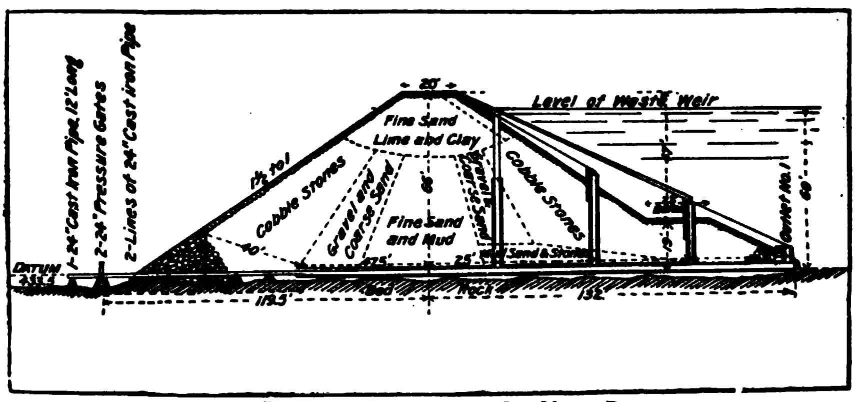


FIG. 75.—CROSS-SECTION OF LA MESA DAM.

ready drainage to the percolation that might find its way through the dam. (See Fig. 75.) 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. 76.—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.

Crane Valley 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. 77.—VIEW OF CRANE VALLEY DAM-SITE, SHOWING OUTLINES OF HYDRAULIC-FILL DAM.

Fig. 78.—View of Crane Valley Dam-site, Fresno County, California.

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 a severe 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, and the annual shortage during three or four months in average years, the company undertook the erection of a storage-dam for impounding the flood run-off of the North Fork. The dam was planned and supervised by J. M. Howells, C.E., and is a structure purely of the hydraulic-fill type. The general dimensions of the original plan were as follows:

Maximum height	100 feet.
Length on top	720 "
Width on top	20 "
Slope on water-side	2 : 1.
" " lower side	1.5 : 1.
Width of canyon at base	50 feet.
Width 60 feet higher	300 "

Water for sluicing was brought to the dam-site a distance of 5 miles, by flumes and ditches. The volume used was 15 second-feet (750 miner's inches), which was delivered to the summit of a hill overlooking the dam and 200 feet above it. This hill, which furnished the materials for building the dam, was 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 has made 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 was arched over with masonry for the entire width of the dam, and served to carry the flow of the stream during construction. Gates were set in this cut on the center line of the dam, to be closed when the dam was finished and storage began. The gate-stems 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, 6 to 12 inches in height, which were added one at a time, as the dam rose. During construction this shaft served to draw off the surplus water from the pond formed on top of the embankment, after its load of material had dropped on the rising dam.

In preparing the foundations the center line of the dam was excavated to bed-rock and all loose material removed for a width of 20 feet from the center line on the up-stream side. Then a concrete wall, 2 feet in thickness, and about 2 to 5 feet in height, was built on bed-rock, into which was firmly imbedded the footings of a wooden core-wall, of doubled

FIG. 79.—CRANE VALLEY DAM. SHOWING WOODEN FENCE, OR CENTER DIAPHRAGM, WHICH WAS CARRIED UP TO A HEIGHT OF 30 FEET ABOVE BED-ROCK.

1-inch surfaced sheeting. This wooden partition was continued to a height of some 30 feet above the base of the dam, its object being mainly to prevent the stratification of material deposited by the water from extending across the center of the dam from either side. It was also designed as a check against percolation through the dam.

It had been intended to carry this partition to the top, but as the dam building progressed it was found that stratification could be effectually prevented by a system of cutting into the plastic material of the central part of the dam by pushing down broad wedge-shaped planks or paddles, 1 inch thick, 12 inches wide. This was systematically carried on while sluicing was in progress, and in continuous lines, at intervals of 2 feet, parallel with the center of the dam on the up-stream side, for a width of 20 feet out. As the workmen were able to shove the paddles into the mushy mass to a depth of 10 feet or more, the cleavage across the stratification was repeated over and over again. On the withdrawal of the paddle the fine silt would immediately fill the hole, and thus alter the composition of the mass.

The result of this kneading process was so satisfactory that on the sides of the canyon, at an elevation of 60 feet from the base, the wooden

FIG. 80.—CRANE VALLEY DAM SHOWING DISCHARGE OF SLUICED EARTH AT END OF CONVEYING FLUME.

core-wall was carried no higher than 6 feet above the concrete foundation.

A porous cement conduit, or pipe 3 inches diameter, was laid on top of the concrete wall against the wooden sheeting on the downstream side, throughout its entire length. At the lowest point in the stream-bed the pipe from either side connected with a 6-inch cement pipe laid on the bottom outward to the toe of the lower slope. These pipes were designed for drainage, but through a series of mishaps they came near causing the destruction of the dam. During a sudden freshet which threatened to overtop the dam, it became necessary to use powder to blow out a wooden gate that had accidentally closed the outlet culvert. The explosion shattered the 3-inch drainage pipe at one point over the culvert, and started leakage of muddy water carrying sand through the 6-inch outlet. This continued until it carried out sufficient material to produce a crater in the dam, conical in shape, reaching to the top, and discharging over 1000 cubic yards of the finer material of the center portion of the dam before it was finally checked. As the dam had then reached a height of 70 feet, and the reservoir was nearly full the situation was alarming. The cavity was hastily filled with gravel, sandbags, etc., and the leakage finally ceased. A shaft was

FIG. 81.—CRANE VALLEY HYDRAULIC-FILL DAM. SHOWING METHOD OF LOOSENING THE MATERIALS SLUICED INTO THE DAM.

then sunk down to the break, and the fact discovered that the break had been self-mended by being plugged with roots and leaves that had been washed into the dam in the process of sluicing, rather than by the sandbags and other fillings that had been thrown into the cavity.

Owing to long delay in securing permission to use the ditch, which passed through a United States Forest Reserve, it was necessary to begin sluicing by means of a pump. A steam-pump with a capacity of 2.25 second-feet was installed on the bank of the stream, above the dam-site, and delivered water through an 11-inch riveted steel pipe to a "Little Giant" monitor with 2½-inch nozzle at the borrow-pit, 75 to 110 feet above the stream.

About two-thirds of the total amount of material placed in the dam was conveyed by the water pumped. When the permit to use the ditch was finally granted, the remaining third was ground sluiced in by the use of the flumes that were employed for the conveyance of pumped water. These flumes were laid on a grade of 6%, which was the minimum permissible for free operation with the comparatively small volume of water delivered by the pump. The flumes were made of 1-inch pine boards, 12 inches wide, 10 inches deep, covered on top except across the dam, where the cover was omitted. With this small flume, and the small quantity of water used, it was not possible to convey any rock to the dam, or material coarser than fine gravel, even on 6% grades.

Two sets of flumes were used, one on either side, in alternation. When one side of the embankment was raised to a height from which the heavier particles, making their own gradients toward the center, approached the center as closely as was deemed expedient the stream of material was shifted to the flume on the opposite side, which was then raised accordingly. At the base of the dam the coarser sand was not allowed nearer than about 40 feet from the center line, but as the dam rose and its top width decreased this distance was decreased correspondingly.

After both sides had been raised to the same level, by an even distribution on each, all the way across, the water-level of the pool, always remaining in the center of the embankment, was then raised by adding one of the cement rings to the circular drainage shaft, through which the surplus water was allowed to escape. This raised the water-level of the central pool about 13 inches. The process of sluicing was then repeated. As the dam approached the 60-foot level this was found to throw the water-line too near the edges of the dam, and rings 6 inches in depth were added thereafter. The flumes were so placed that when the dam had reached an elevation equal to the lower end of the flume, which was of course on the further side of the dam from which the excavation was taking place, the line of the flume was at the outer edge of the embankment. The flume was then raised, moving it toward the center of the dam sufficiently to allow the process to be repeated on the higher level. The trestles supporting the flumes were made of 2″×4″ plank, which could generally be pried out of the sand and used again. A handspike with a sharp iron spur bolted to the end would suffice to start any one of the posts of the trestle from its bedding in the sand. The flumes were thus raised about 10 feet in elevation each time.

At short intervals slotted openings were made in the bottom of the flume through which a driblet of water was allowed to run. This carried with it a large percentage of the coarser sand, which was thus deposited where it could be cast by shovels to the slope line.

The discharge from the flume to the dam of the greater portion of the water with its load, was made at convenient points by side gates in the flume, formed of a short section of the side board sawed in such a way that it could be swung across the flume, turning out the entire flow at that point. From these points of discharge the sand and silt were distributed on light grades until the central pool was reached, when precipitation of the sand took place at once, forming bluff banks under the water near its edge, while the fine silt particles were distributed across the pool.

The construction was suspended when the dam reached a height of about 70 feet, where a temporary spillway was available over a gap

FIG. 82.—BORROW-PITS FROM WHICH MATERIAL WAS SLUICED TO THE CRANE VALLEY DAM IN BACKGROUND.

in the crest of the horseshoe shaped hill, around which the river formerly flowed. It is planned to be extended later to the full height of 100 feet.

On completion of sluicing, the embankment was rip-rapped on both faces with broken stone, partially taken from the temporary spillway, and partly gathered from the adjacent hillsides.

The preliminary estimates of cost of the dam contemplated an expenditure of $25,000 for the 100-foot structure. At that time the necessity for pumping was not considered. The actual cost of the work done could not be definitely ascertained.

This example of hydraulic-fill dam building, considering the class of material available and the conditions under which it was constructed, affords a most valuable illustration of the flexibility of the hydraulic process in adapting itself to the building of a stable dam at small cost with materials from which it would otherwise or by other methods have been impossible to secure stability or water-tightness in an embankment of similar height. In this locality the cost of either a masonry or rock-fill dam would have been so great as to be commercially unprofitable, while the materials which might have been used for the ordinary type of earth dam occurred in such irregular pockets, interspersed between huge granite bowlders, as to be difficult of access and consequently expensive. The material was also of doubtful value for earth-dam construction, built in the usual way, with plows and scrapers, because of the difficulty of securing solidity and compactness and proper bond with the bed-rock, with such material, without a segregation of the fine from the coarse, as by the hydraulic process.

There were occasional pockets of red clay mixed with sand which had been filled in by the action of water, instead of originating from the disintegration of granite rock in place as the bulk of the material was formed. When the material from the clay pockets came onto the dam it gave trouble to the workmen to keep the outer edges of the embankment up to the steep slopes at which they were designed, owing to the tendency of the slippery clay to slide down to flatter angles of repose. The decomposed granite, however, was regarded as ideal material for hydraulic dam building, as it was found to contain 70% to 80% of sand and gravel of all grades, from a hazelnut size down to very fine grains. The remaining 20% to 30% was still more finely divided, discoloring the water like clay and requiring considerable time to settle. Such material, when once settled and drained, offers enormous resistance to the percolation of water, and its behavior in this case at the time of the break is not easily understood. The leakage through the bottom pipe was small—never more than 30 to 40 gallons per minute, but even that amount of water passing through the core material should have been impossible if the central portion had been composed exclusively of the fine silt or clay. There must have been some unbroken lines of coarser sand crossing the central zone as far as the partition. It is doubtless true that drainage of the central impervious zone of hydraulic-fill dams should be made exclusively through the porous friction-bearing materials composing the outer slopes, and not by any defined channel of considerable size, such as the cement pipes laid under the base of this dam, which, as this example shows, may become a source of dangerous concentration of drainage.

The dam has been in service ever since its completion, and is regarded as a safe structure.

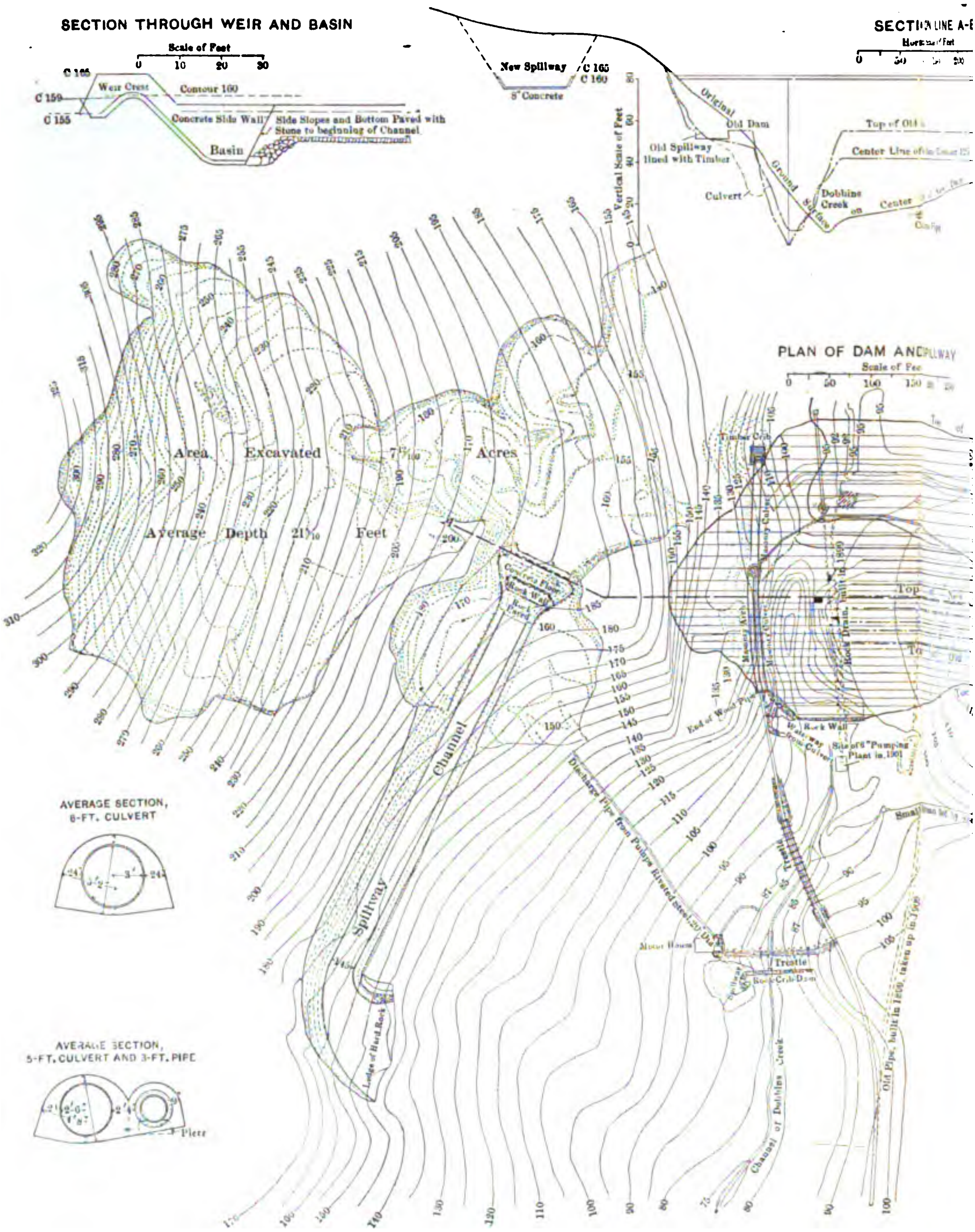
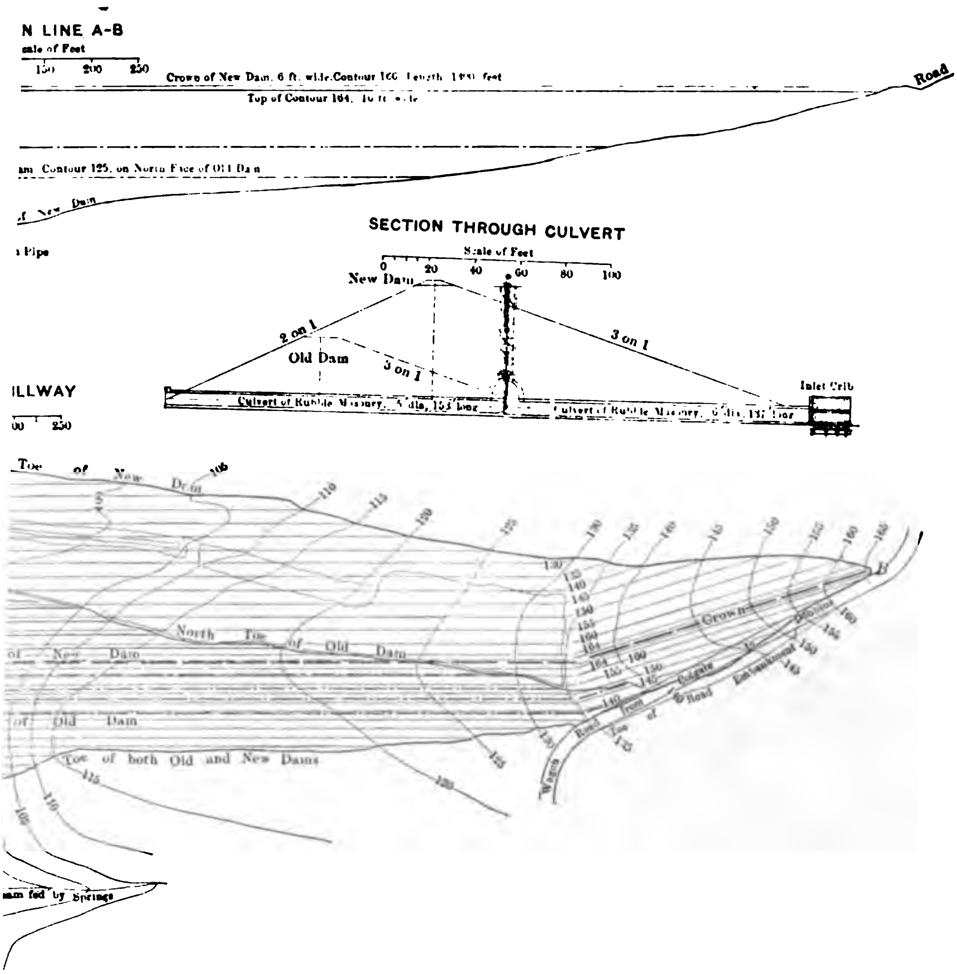

SECTION THROUGH WEIR AND BASIN
Scale of Feet
0 10 20 30
C 165
C 159
C 155
Weir Crest
Contour 160
Concrete Side Wall
Side Slopes and Bottom Paved with Stone to beginning of Channel
Basin
New Spillway
C 165
C 160
8" Concrete
Vertical Scale of Feet
Original
Old Dam
Old Spillway lined with Timber
Culvert
Ground Surface
Dobbins Creek
Top of Old
Center Line
Area Excavated
Acres
Average Depth
Feet
Channel
Spillway
Ledge of Hard Rock
PLAN OF DAM AND SPILLWAY
Timber Crib
Rock Wall
End of Wood Pipe
Site of 6" Pumping Plant in 1901
Motor House
Trestle
Rock Crib Dam
Channel of Dobbins Creek
Discharge Pipe from Pumps
AVERAGE SECTION, 6-FT. CULVERT
AVERAGE SECTION, 5-FT. CULVERT AND 3-FT. PIPE
Pier

FIG. 8



PLAN AND SECTIONS,
OF THE
DOBBINS CREEK HYDRAULIC-FILL DAM,
YUBA CO., CAL.
BUILT FOR THE BAY COUNTIES POWER CO.

[*To face page* 115.]

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

This dam was originally built as an ordinary earth dam, by the Bay Counties Power Company, two miles above the Colgate Power House, on a little tributary of the Yuba River, called Dobbins Creek. It is located about 35 miles from Marysville, in the mountains of Yuba County, at an elevation of 1500 feet above sea-level. The watershed intercepted

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

is but 6.5 square miles above the dam, from which the run-off fluctuates from a mere trickle of 3 or 4 miner's inches to an extreme flood flow of about 1000 second-feet. The dam was intended to form a small reservoir for emergency service, and is located 400 feet higher than the penstock of the power-house, which receives its water supply from the North Fork of Yuba River through a wooden flume nine miles long, built in the rocky canyon of that stream. The flume is subjected to occasional interruption from falling rocks, and in such an emergency the small reservoir storage of the Lake Frances reservoir is drawn upon for a few hours at a time to maintain the operation of the plant. It was originally planned to utilize the power at certain hours of the day when the demand was less than the output by pumping water from the flume up to the higher reservoir, and a 4-stage 10-inch centrifugal pump was ordered built for this purpose. This plan was not carried out, but one-half the pump was subsequently finished up and used for the hydraulic-fill work which will be described.

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

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

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

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

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

Rupture of Original Dam.—A few days after the fill had been completed, a rainfall of 9 inches in 36 hours caused the reservoir to fill rapidly,

Fig. 86.—Toe Levee of North Face, Lake Frances Dam, and Inlet Crib at Head of Five-foot Outlet Culvert.

and when the water had risen to within six feet of the spillway level, at 11 A.M., Oct. 21, 1899, the dam was suddenly ruptured, and a hole washed through it 100 feet wide at top, extending down to and below the original stream-bed. The dam originally contained 80,265 cubic yards, of which 16,160 cubic yards, or about 20%, were washed away.

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

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

of the dam. The filling of the break and the 125 feet facing required 133,782 cubic yards of material, while the increase in height proposed involved but 81,371 cubic yards additional for which the plant would have been already installed. As the storage would be increased three and one third times the extra cost was manifestly justifiable, and the work was ordered on that plan.

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

The pump had a capacity for delivering 6 cubic feet per second, under a pressure of 120 pounds per square inch, through a line of 20-inch

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

pipe, 300 to 700 feet long. The pump was belt-connected with a 350 H.P. synchronous motor, using alternating electric current at 2400 volts.

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

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

During all this filling of the break as well as in all subsequent work

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

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

Owing to the great length of the dam (1300 feet on the crest) and the necessity for securing all the material of construction from one end, it was necessary to use gradients as low as possible, to avoid excessive height of trestle supporting the flume and pipe for delivering the material. The minimum was found to be 2.2%. For this reason it was not possible to transport much of the rock encountered in the borrow-pits, and there was constant lack of sufficient coarse material to maintain the slopes, and prevent slides. It was finally found necessary to resort to the use of pine and cedar boughs and other brush 6 or 8 feet long laid into the slopes with the butts inside, to prevent the tendency to slip. This was effectual in knitting the mass together sufficiently to overcome the sliding and sloughing tendency.

The general plan of building the north face and the top embankment was to deliver the sluiced materials that had been loosened and washed out by the hydraulic giants, under pressure of 40 to 75 pounds per square inch at the nozzle, through a 22-inch riveted steel pipe, placed on a high trestle running parallel with the axis of the dam, and far

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

enough inside the slope lines to make delivery through lateral flumes of moderate length, terminating at the edges of the rising embankment. They were of varying length, according to the height at which they were designed to deliver, and were made about 25 feet in average height. The longest trestle with which the additional height of 25 feet above the original dam was built was 1560 feet long, with 13 branch trestles, as shown in Fig. 92. The highest bent in this trestle was 40 feet high.

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

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

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

FIG. 91.—LAKE FRANCES DAM CONSTRUCTION. PUMPING STATION, SHOWING SUCTION PIPE CONNECTED TO TANDEM CENTRIFUGAL PUMP. CRIB DAM IN FOREGROUND BUILT TO STORE WATER FOR EARLIER OPERATIONS.

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

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

FIG. 92.—LAKE FRANCES, CAL., HYDRAULIC-FILL DAM BUILDING. SHOWING OUTER LEVEES MAINTAINED WITH BRUSH, DEFLECTING BOARDS FOR DISTRIBUTING SLUICINGS ALONG SLOPE, GENTLE SLOPES TOWARD CENTER OF DAM, AND GRADUAL MOVEMENT OF DRAINAGE TOWARD EXTREME END.

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

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

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

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

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

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

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

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

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

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

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

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

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

4-inch centrifugal pumps was about 1.5 second-feet. The flumes were about 12 inches square, open at top. No determinations were made of the percentage of solids carried in this way, but the water seemed to be well loaded at all times, and flowed freely on grades of 2% to 5%.

In building the two dams in the high-water channels there was no difficulty in maintaining a levee of dry earth at the outer toe of the slope with teams, the earth being hauled in by wagons and scrapers. All of the earth for the south dam and a large part of that for the middle dam, except for the base, was hauled by cars and electric locomotives from borrow-pits a mile or more away, on the south side of the river. It was loaded into the cars either by teams through traps, or by an electric shovel, and dumped at the nearest end of the dam at such an elevation that the water would carry it on a grade to the further end. The grade naturally assumed by the earth thus sluiced was from 2% to 4%. The liquid mud freely entered the voids of the rock-fill, and filled them solidly as far as the center core-wall of wood. As it rose in height some slight leakage would show below for a time, but the joints in the wood quickly swelled and filled with mud and became entirely tight. The earth was always twenty feet or more below the top of the rock-fill, and the work progressed at such a moderate rate that the embankments had ample time to settle and solidify. The earth packed so readily that in four days' time after sluicing was suspended a team could be driven over the embankment without sinking in, although while sluicing was in progress a pole could be pushed down into the mud to a depth of 10 feet or more, particularly at the extreme end where the water stood longest in the pool.

Very little surface drainage was required to get rid of the surplus water. It seemed to be absorbed and disappear, without showing up either above or below the dam. The earth came to the dam in a pulverized, dusty condition, and the water was sprayed upon it and at once saturated it to the softest of mud. About 80% of the earth in the south and middle dams was sluiced in place, and 20% put in by teams at the outer slope. This dry portion constantly absorbed moisture from the adjacent mass of mud, and thus became equally hard and solid.

The hydraulic-filling of the north or channel dam was principally delivered from the north side of the river through a flume into the upper end of which a receiving-box was placed, into which the earth was dumped from wagons through a trap where the pumped water sluiced it down to the dam.

The earth was loaded into the wagon by means of a travelling excavator with belt conveyors that delivered a continuous stream of earth to the wagons travelling by its side until each received its load.

In this case the water used was about 1 second-foot and the lower end of the flume discharged along the upper side of the wooden core-wall, on top of the rock-fill, first filling the voids in the rock and then extending up-stream into deep water 20 to 30 feet in depth. On reaching the water it assumed a very flat slope under the water-line of 6 or 7 to 1. When the fill had reached the top of the water by this process the slopes were drawn in to the regular 4 on 1 slope.

The contract prices for this work were as follows:

Dry earth embankment—..........	27.5 cents per cu. yd.
Earth embankment placed by sluicing	37.5 " " "

These prices were necessarily high on account of the remoteness of the locality, the high cost of fuel, labor, supplies, and materials.

Waialua Dam, Hawaii.—Beginning about the year 1889, extensive development in the growth of sugar-cane was made upon the island of Oahu by means of irrigation with water from artesian wells located near the seashore, the water being forced by powerful pumps to varying levels up to 650 feet above the sea-level. Costly pumping stations were installed and provision made for the delivery of very large volumes of water. The fertility of the soil is such that an expenditure of $50 to $75 per acre per annum for pumping water was amply justified by the yield of cane to be secured by that means. One of the latest and largest of the pumping systems installed on the island is on the Waialua Sugar Plantation, 22 miles from Honolulu, stretching for several miles along the north shore, and extending back to an elevation of 700 to 800 feet. The aggregate capacity of the pumps in the four great pumping-stations on this plantation is 72,000,000 gallons per 24 hours, their average lift being from 231 to 540 feet, with an extreme lift of 650 feet. The cost of pumping runs into high figures. The fuel bill for irrigation pumping alone in 1902, before the introduction of California oil, was over $180,000, and the average cost of water was $63.36 per acre for that year. To reduce this cost of lifting water to the higher levels, as well as to increase the water-supply and extend the irrigable area, the plantation manager decided in 1903 to undertake the storage of flood water by the building of a dam on an intermittent stream, called the Kaukonahua Gulch, which flows through the property, and in May of that year the author was engaged to report on the construction of the dam, which had been projected by the Wahiawa Water Co. This company had been organized by Mr. L. G. Kellogg some years before to supply water to the Wahiawa Colony lands, located on a high plateau between the two forks of the Kaukonahua Gulch, where a colony of Americans were engaged in growing pineapples. The company built a ditch to the Colony, and subsequently surveyed the reservoir-site and contracted with the Waialua

Sugar Plantation to take stock in the Water Company to supply funds for building the dam, and purchase the reservoir water at an agreed rate.

The Kaukonahua heads in the Koolau Mountains at an elevation of 2360 feet, where the annual rainfall is about 180 inches, well distributed through the year. The watershed is of limited area, but the run-off is at times very great, fluctuating spasmodically between wide extremes, so that storage is needed to utilize the stream to any advantage. From the limited data available it was estimated that the total annual run-off was about 50,000 acre-feet, so distributed through the year that the reservoir, which has a capacity of but 7800 acre-feet (2,500,000,000 gallons) could be filled and emptied several times each year, and therefore be as serviceable as a much larger reservoir filled less frequently, inasmuch as the irrigation season is practically continuous. The reservoir occupies two forks of the stream which join immediately above the dam, water backing up in each from 4 to 6 miles. They are generally parallel, and are practically two miniature canyons cut down through a sloping plain to a depth of 150 to 200 feet. The formation thus exposed in section is all of volcanic origin and consists of decomposed lava, in alternating layers and of all shades of color from red to reddish brown and purple to bright yellow. This formation is generally quite free from any tendency to slide, and will often stand vertically in trenches or tunnels without timbering for an indefinite time. It is so free from grit that it resists the erosive action of water in a remarkable manner. It was apparently not sufficiently stable to afford a reliable foundation for the masonry dam that had been originally considered, and after examining the site the author recommended the adoption of a combination rock-fill and hydraulic-fill, with a wooden diaphragm in the rock-filled portion, to be imbedded at the bottom in a concrete wall, the latter to be carried down in a trench far enough to intercept various strata of porous, cinder-like material encountered in the test-pits; the earth-fill to be sluiced into place against the rock-fill and the diaphragm and to have an up-stream slope of 4 on 1. Mr. H. Clay Kellogg, C.E., of Santa Ana, California, who had made the original surveys and test-pits of the dam and reservoir-site, was employed to build the dam, and carried out the work in a very efficient manner, substantially on the plans described. The dam has the following dimensions:

Maximum height above stream-bed	98 feet
" " above base of core-wall	136 "
Length on crest	460 "
Width on crest	25 "
Total width of base, up- and down-stream	580 "

The rock-fill portion has a base width of 80 feet, crest width 11.5 feet, down-stream batter 0.75 : 1, up-stream face vertical; volume 26,000 cubic yards. The wood diaphragm is located two feet below the up-stream face of the rock-fill, which is chiefly composed of a hand-laid dry wall. The diaphragm consists of double 2-inch redwood plank, laid horizontally and spiked to 3 by 6 inch posts, placed two feet apart, center to center, with a double layer of burlap dipped in hot asphaltum between the two layers of plank. This latter precaution secured absolute water-tightness to the diaphragm during construction, preventing any leakage of liquid earth through the rock-fill.

The rock was brought to the site by a train of cars and locomotive from a distance of one to six miles, and consisted of basaltic boulders

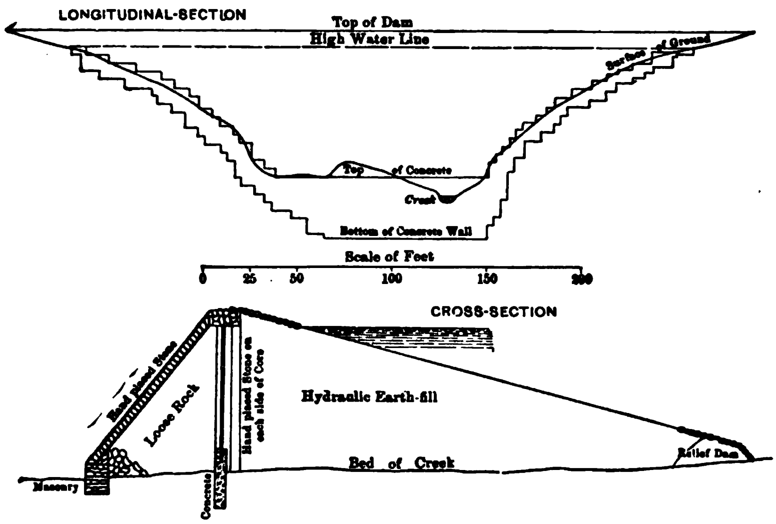


FIG. 93.—WAIALUA DAM SECTIONS.

found in the dry-stream channels of the Waianae Mountains, many of which required blasting for convenience of loading by hand.

They were dumped from the top of a trestle built at the outset to the full height of the dam (see Fig. 95), and the larger stones selected from the dump for laying up the faces of the wall. The height from which the rocks were dropped consolidated the embankment quite effectively, so that little or no settlement has been noticeable since the completion of the dam, although shortly before completion the outer facing wall, some 2 feet thick, bulged out about a foot beyond the slope line over a limited area, indicating that some settlement had occurred. This was corrected by relaying the bulged portion to the true line, after which no further movement was observed.

The concrete core-wall, as shown by the longitudinal section (Fig 93) extends to a depth of 38 feet entirely across the bottom of the valley. and into the hillsides laterally from 10 to 20 feet.

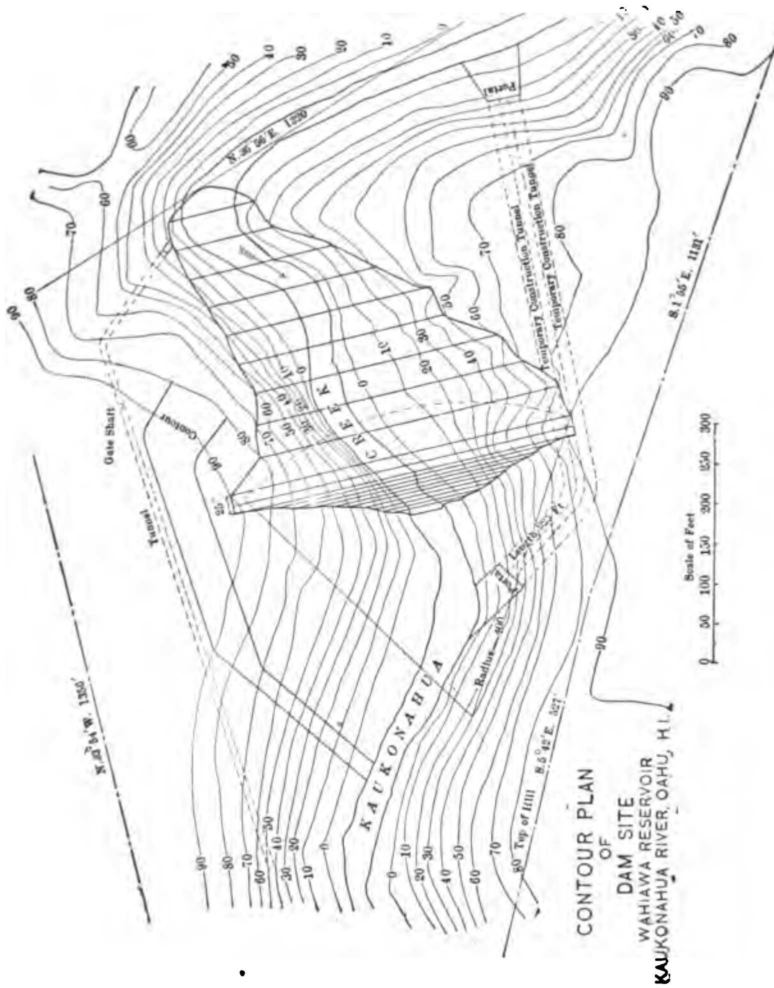


FIG. 94.—CONTOUR PLAN OF WAIALUA DAM.

The trench was cut about 5 feet wide and entirely filled with concrete. The wall extends 2 to 4 feet above the surface, stepped down the sides of the canyon in horizontal and vertical steps as indicated. During construction the flood-waters were handled by a large flume, supplemented by three capacious tunnels, one of which was subsequently utilized for the permanent outlet of the reservoir by a 48-inch pipe laid through it.

Water for hydraulic sluicing was delivered by a pipe laid from the lower end of the Colony ditch to a point about 50 feet higher than the top of the dam and 2000 feet distant from it. Between this point of delivery and the dam was a body of earth, consisting of the decomposed lava described, which was considered suitable for the embankment. The method employed for moving the earth was that known in placer mining parlance as "ground sluicing." As the head available was in-

FIG. 95.—WAIALUA DAM, SHOWING HYDRAULIC-FILL BEING SLUICED IN AGAINST THE ROCK-FILL.

sufficient to do effective work in cutting and loosening the earth by the hydraulic jet usually employed, and as the material was peculiarly resistent to erosion, it became necessary not only to plow the ground, but to devise means for placing the loosened material into the flowing stream of the ditch in order to accomplish its delivery to the dam. Ordinary soils can be washed very readily by flowing water over the surface, even without plowing. In this case, however, the peculiar cohesiveness and unctuous character of the soil made it exceedingly difficult to sluice, and the method finally adopted was to dig a ditch about 4 feet deep at the upper end, and 12 to 16 feet deep at the lower end next to the dam, having a bottom gradient of about 4%, through which the water was turned to the amount of 8 cubic feet per second.

This ditch was 1300 feet long. The soil was then plowed to a width of 12 feet on either side by means of plows drawn by cables from portable winding engines stationed at each end—the ordinary English steam plow. After plowing the ground, the traction-engines of the plow were used to drag a V-shaped scraper or "Crowder," as it was called, along the plowed surface, thus crowding the loosened earth into the running water of the ditch alongside. Receiving its load of earth in this way, the velocity of the water was sufficient to carry the material to the dam, although when merely turned over the surface of the plowed ground the water ran over it clear without picking it up and washing it away, for lack of the gritty, cutting-tools of erosion, such as sand or gravel. This process of alternately plowing and crowding was continued until the ditch grade was reached, when a new strip was plowed, and the ditch shifted over to the bluff bank on either side of its original position. This work of loosening and delivering the soil to the ditch was done by Japanese under contract for eight cents per cubic yard. The cost of distributing it on the dam averaged 3 cents per cubic yard, a total of 11 cents per cubic yard. The total volume of the earth-fill was 141,000 cubic yards, of which 100,000 cubic yards were put in by the aid of the four steam-plows borrowed from the plantation. The remaining 41,000 cubic yards were put in by hand labor, blasting, picking, and shovelling into the ditches. An area of eleven acres was stripped to an average depth of 8 feet to secure the material for the dam. The total cost of the dam was $281,000, including a diverting or relief dam, 29 feet high, built at the up-stream toe of the main dam, with sheet-piling core, and also including four long tunnels around the dam, the regulating-gate tower, 48-inch outlet-pipe and gate, and the spillway, which is 135 feet in width, 6 feet deep, lined with concrete, stone rip-rap on the upper face, 18 inches thick, etc.

The material composing the hydraulic-fill had the remarkable quality of settling so rapidly that the water flowing off at the further side of the dam was clear enough to drink, while the fill immediately became hard enough to walk upon, and within a few days the outer surface became so firm that stakes could be driven into it with difficulty. There appears to have been no settlement of the embankment whatever after completion of the dam, and when examined by the author in May, 1907, a year after it had been filled and in service, the water-line along the slope was an absolutely straight line, without deviation or distortion whatever.

During the first year of service a stream of clear water measuring about 0.4 second-foot issued from the lower toe of the dam, apparently coming from the sides, and probably around the dam. Since that time, this leakage is reported to have materially diminished and practically

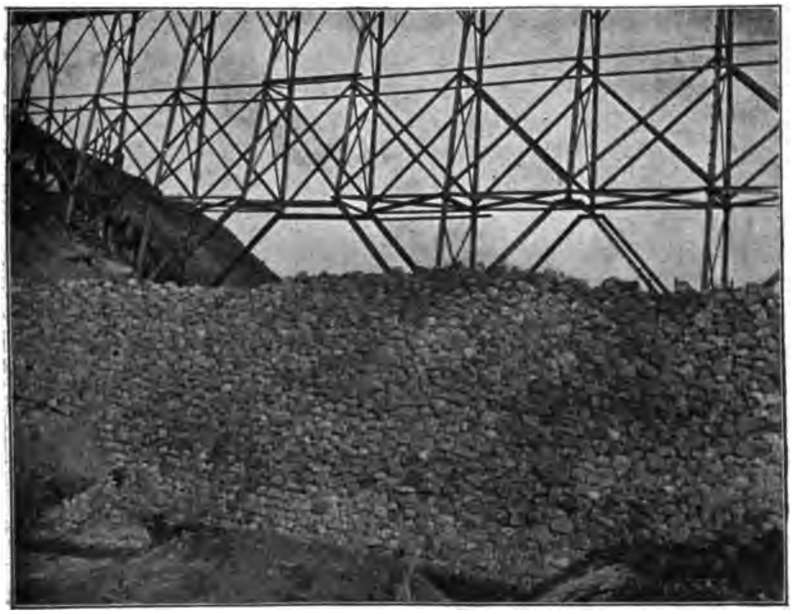


Fig. 96.—Rock-fill on Down-stream Side of Waiaula Dam.

Fig. 97.—Waialua Dam, Hawaii, Showing Flood Discharge through Outlet Tunnels during Construction, under Head of 8 Feet at Upper End of Tunnels.

ceased. The elevation of the spillway of the dam is 844 feet above sea-level, and the ditch taken from the outlet commands all lands on the plantation below the 700-foot level.

After the completion of the dam in 1905, it was decided to widen the spillway from 50 feet to 125 feet and the material excavated was sluiced to the lower toe of the dam against the rock-fill, where it assumed a natural slope of about 5 on 1, reaching to a height of 25 to 30 feet upon the down-stream face of the dam. This addition was considered of doubtful value because it was not previously underdrained, and tended to cut off the drainage afforded by the rock-fill although increasing the stability of the steep rock-slope. Inasmuch as seepage has steadily decreased, however, since this work was done, it must be admitted that the toe embankment is unobjectionable. During the freshets in the summer of 1907 the reservoir was filled to overflowing, and water poured through the enlarged spillway to a depth of 2 feet for a considerable time.

The ditch from the reservoir was built a distance of eleven miles, with a capacity, of 96 sec. ft. It involved the excavation of twenty-one tunnels, $6' \times 6'$, aggregating 20,780 feet, the longest being 1700 feet. They were excavated by contract at a cost of 40 cents per linear foot in earth, 60 cents to $1.00 per foot in soft rock, and $4.00 per linear foot in solid rock. Open ditch excavation cost 16.5 cents per cubic yard. It also required the building of three notable inverted siphons of riveted steel pipes of following dimensions:

Pohamoho Gulch,	54 inches diameter,	1320 feet long,	400 feet max. head.
Halemano "	54 " "		300 " " "
Opaeula "	48 " "	900 " "	200 " " "

All work was done by Japanese laborers and artisans, including the placing and field riveting of the pipes.

At one point a ravine was crossed with a temporary flume, 50 feet high, which was subsequently substituted by an earth dam sluiced in place by the water from the ditch and forming a convenient service reservoir for night-water storage. This work was planned and executed by Mr. W. W. Goodale, manager of the Waialua Plantation, the entire dam being finished in about three weeks to a height of 50 feet. It has slopes of about 2 on 1 on each side. It is composed entirely of the red volcanic soil of the country.

The description of the work has been given somewhat *in extenso* because it is unique in many respects, and is a successful example of the marked advantages of the hydraulic-sluicing system in overcoming natural difficulties that were generally regarded as insurmountable. With the experience derived from the behavior of the soil under hydraulic sluicing, it is apparent that there would have been no risk in building

FIG. 98.—RIP-RAP ON FACE OF HYDRAULIC-FILL, WAIALUA DAM.

FIG. 99.—WAIALUA DAM, HAWAII. LOOKING DOWN-STREAM THROUGH DAM-SITE, SHOWING DIVERTING DAM AT UPPER TOE, AND TRESTLE FOR MAKING THE ROCK-FILL.

the entire dam of earth by this method, and at much less cost, as the scarcity of rock and the distance from which it had to be gathered rendered the cost of the rock-fill excessive. The sole reason for its use was to secure drainage, and because it was considered that the soil composing the embankment, even though deposited under water, might not prove to be wholly impervious. The author is indebted to Mr. L. G. Kellogg, of Honolulu, for many of the photographs used in the illustrations, as well as for the data of methods of work employed under his superintendence.

The Nuuanu Dam, Honolulu.—The territorial government of Hawaii is engaged in the construction of a dam in the Nuuanu Valley, four miles from the city of Honolulu, for the storage of water for the domestic supply of the city and incidentally for the development of power, as the reservoir is over 1000 feet higher than the city, the water surface elevation being 1030 feet above the sea-level.

The area of watershed directly supplying the reservoir is but 930 acres, but as the mean observed rainfall for 15 years has been 136.3 inches the volume of run-off is very large, amounting to an average of over 11,000,000 gallons daily. The stream has been utilized to the extent of 4,490,000 gallons per day by a pipe line supplying three small reservoirs at a lower elevation. By the reservoir under construction, it will be possible to utilize a further amount, estimated at 3,300,000 gallons per day, which has now to be supplied by pumping from artesian wells at sea-level.

The dam is to have a maximum height of 77 feet above the bed of the stream, and a crest length of about 2100 feet. It is to be 10 feet wide on top, at a height of 6 feet above the spillway level, and will create a reservoir of 84.4 acres, impounding 629,340,000 gallons.

The dam was designed by S. G. Walker, M. Am. Soc. C. E., who intended it as an earth embankment with a central core-wall of wood, the material to be principally deposited by the hydraulic-sluicing method, and a contract was let in 1905, under specifications prepared by him. After the work had progressed a year, H. C. Kellogg, C.E., was called to consult on the plans and recommended a number of changes in design, among which was the substitution of a rock-fill on the down-stream side of the core-wall, over the channel section, about 150 feet in length. In 1907 the author was employed to report upon the work, and suggested raising the dam 10 feet higher to give 60% increase in capacity.

A core-wall trench was excavated throughout the entire length of the dam, from 10 to 45 feet in depth below the original surface, through successive layers of porous lava and volcanic ash material, to an impervious hardpan or bed-rock base, and in this trench a diaphragm of Oregon pine, consisting of double 2-inch planks, spiked to 4″×4″

uprights, was built. In the center section of 152 feet the trench was filled with a concrete wall, reaching from elevation 935 at the west end up to elevation 972, on top of which the diaphragm was continued with California redwood to the top. The deep trench either side of the diaphragm was refilled with clay. The rock-fill was laid on a slope of 1 on 1 on the down-stream side, as a hand-laid wall, the up-stream face being made vertical, 10 feet away from the wood core-wall, the space between being filled with clay. The volume of rock required was 17,000 cubic yards, which was brought by gravity from a quarry about 2500 feet distant, the empty cars being hauled up by a winding

FIG. 100.—NUUANU DAM, HONOLULU, SHOWING TOE OF ROCK-FILL PORTION OF DAM.

engine. The surface outlet of the reservoir is a 30-inch wood-stave pipe, heavily reinforced with concrete, 9 to 12 inches thick, extending through the embankment from a square valve tower placed at the up-stream toe of the dam. This pipe connects with the main leading to city distributing reservoir No. 1, a distance of 10,900 feet, of which the upper 3400 feet is wood-stave, the remainder being of lock-bar steel. A washout pipe of the same size and construction also passes through the dam.

On account of the lack of sufficient water under gravity head with which to do hydraulic sluicing, a steam-pump with a capacity of 3.5 second-feet was installed with which about 170,000 cubic yards was expected to be deposited. The contract price for hydraulic-fill was

16 cents per cubic yard, while the portion of the embankment placed by other mechanical means was contracted for at 60 cents per yard, or nearly four times the cost of hydraulic filling, a ratio which may be taken as a fair one between the two classes of work on the average run of earthen dams.

The quality of earth available for sluicing was quite similar to that used in the Waialua dam, a clay soil produced from the decomposition of lava.

The original contract having expired by limitation, work was suspended for some time during the latter part of 1907. Meanwhile Judge Frear was appointed to succeed Mr. Carter as Governor of the Territory, and the new Governor appointed Marston Campbell as Superintendent of Public Works, to take the place of C. S. Holloway. New specifications were prepared at once for the completion of the dam, and in Febrnary, 1908, a second contract was let for finishing the structure for the following unit prices:

Earth filling	$0.314	per cubic yard.
Rock filling	1.73	" " "
Stone riprap	1.36	" square "
Broken stone under stone riprap	0.28	" " "
Concrete riprap	2.18	" " "
Broken stone under concrete riprap	0.14	" " "
Concrete in corewall	15.26	" cubic "
Concrete in spillway	20.41	" " "
Paving in spillway	2.50	" square "
Masonry wall in spillway	7.52	" cubic "
Lumber in corewall	56.32	" 1000 ft. B.M.
Excavation in corewall trench	0.54	" cubic yard.
Excavation in spillway	0.33	" " "
Clearing reservoir basin	259.00	" acre
Clearing dam site	450.00	" "

The new specifications called for the earth embankment to be "constructed by the method known as hydraulic sluicing" and required the contractor to designate the general plan of work and type of machinery he proposed to employ. The original contractor proved to be the lowest bidder on the new work. He proceeded to erect a pumping plant with two centrifugal pumps, driven by two gas engines of 125 H.P. capacity each, to lift 5 cubic feet per second from the pool behind the dam to a height of 150 feet, delivering the water into the suction side of duplicate pumps located at the upper station. These pumps are driven by engines of equal size to those at the lower plant, and will force the water through hydraulic giants to excavate and disintegrate the earth in the mountain side under adequate pressure to do effective work.

The material so excavated is delivered to the dam through sheet steel flumes of prismoidal form, 10 inches deep, 27 inches wide on top, 13½ inches wide on bottom, placed on 3% grade.

The cost of the work under the second contract is within the estimate made by the author.

Power.—The net head on the pipe at the lower reservoir, after deducting friction, is about 500 feet, which will produce 1100 H.P. during 8 hours daily, the capital value of which for city lighting, sewage pumping, etc., is safely estimated at $400,000. The saving in pumping the increased supply given by the reservoir will amount to $37,000 per annum.

Terrace Dam, Alamosa River, Colorado (Fig. 101).—The highest hydraulic-fill dam yet projected in the United States, in vertical height as well as in altitude above sea-level, has been under construction each summer since 1905, and is expected to be completed in the season of 1908 or 1909. It is designed for the storage of water for use in irrigation in the San Luis Valley. The location is at the head of the lower canyon of the Alamosa River, a few miles above the point where the river enters the valley. The dam-site is most unusual in its topography, as the lower 70 feet of the dam occupies a narrow, tortuous slit in the bed-rock from 20 to 60 feet wide, where the river had worn down through a ledge of hard trachyte, forming a canyon with vertical side walls.

Above this ledge the section across the canyon has a bowl-shaped form like the end of an ellipse. The dam was originally projected to a height of 180 feet and a tunnel 10 feet wide, 7 feet high, 725 feet long, was excavated through the solid rock on the north side of the canyon, discharging at the lower toe of the projected dam. This tunnel was intended to carry the stream during construction and subsequently serve as the only outlet to the reservoir. A shaft 75 feet deep was sunk at a point about 200 feet down stream from the crest of the dam, and gates for controlling the discharge of the tunnel were placed at the bottom of this shaft. After the first season's work it was decided to increase the height of the dam to 225 feet above the lower toe, which rendered an extension of the outlet tunnel necessary. The height at the center line will be 210 feet; crest width, 25 feet at an elevation of 20 feet above the high-water or spillway level; up-stream slope, 3 on 1; downstream slope, 2 on 1; length of crest, 605 feet. The change in height necessitated a removal of the crest-line of the dam down stream about 100 feet, the up-stream slope remaining unaltered. A concrete core-wall was built on the original center line, extending from the stream-

TERRACE RESERVOIR DAM
ALAMOSA RIVER, CONEJOS CO., COLORADO

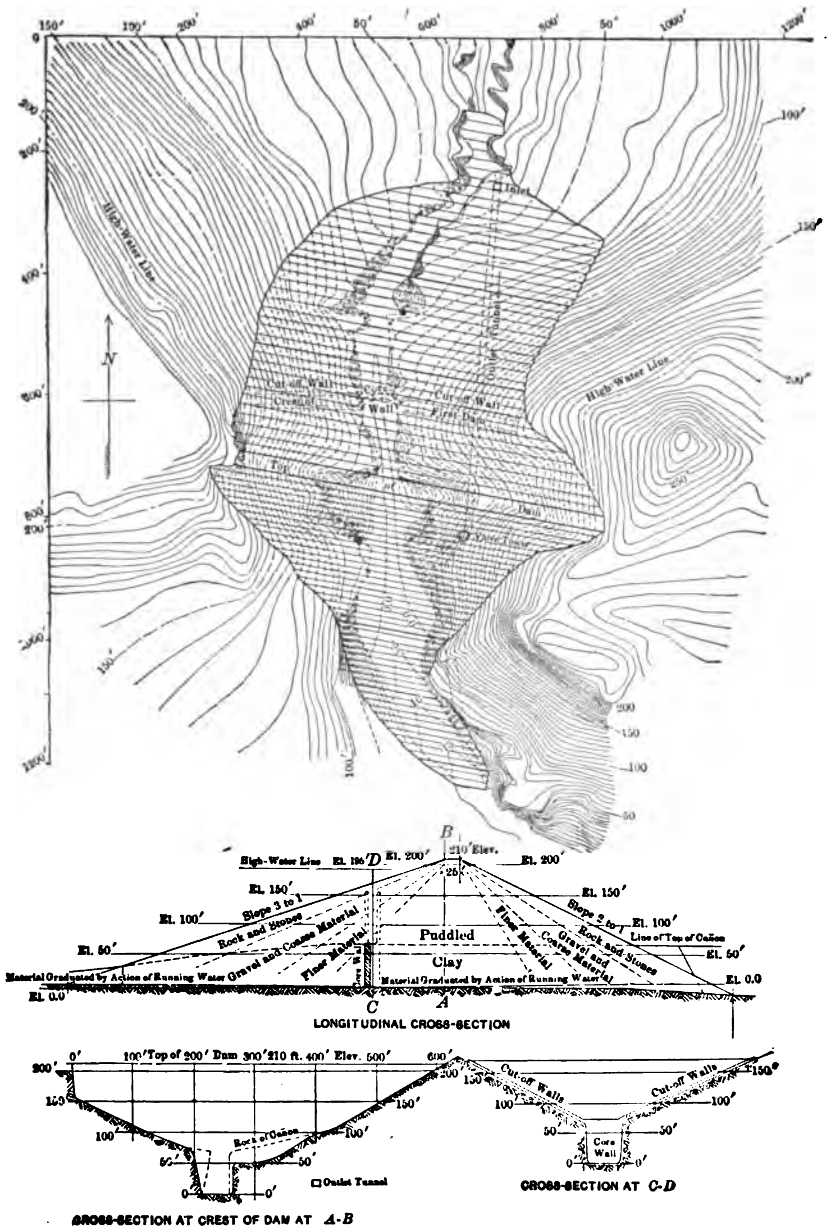


FIG. 101.

bed to the top of the narrow part of the canyon. This was made 15 feet thick throughout, curved on a radius of 50 feet.

Connecting with this wall and extending up the slopes, two parallel concrete walls were built 25 feet apart and reaching 2 feet above the

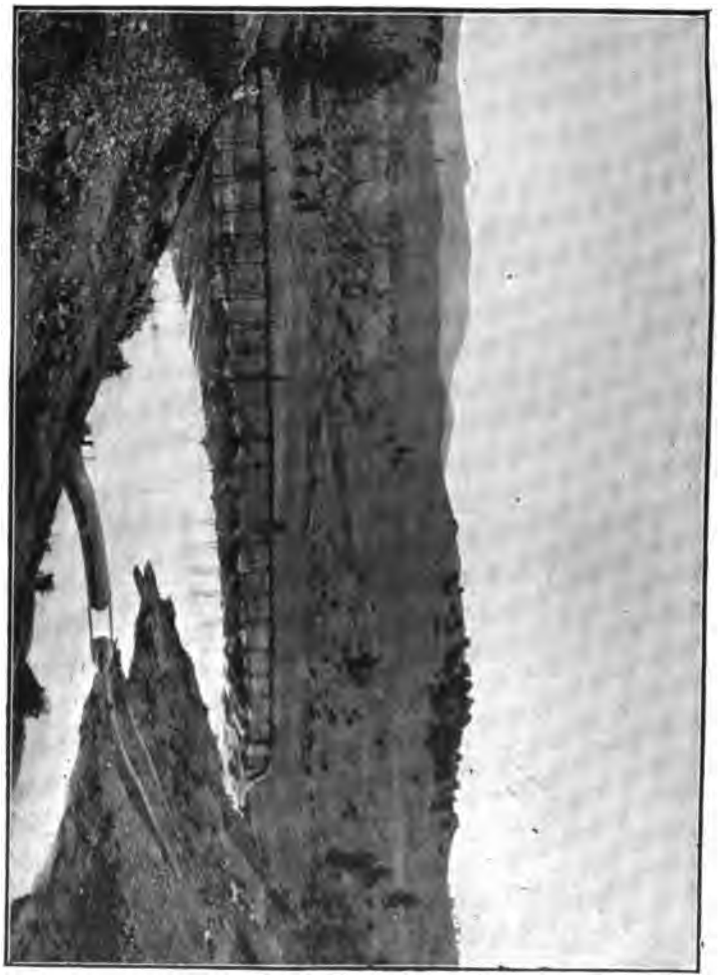


FIG. 102.—TERRACE DAM, COLO., SHOWING DEPOSIT OF SLUICED MATERIAL ON UP-STREAM TOE OF DAM. THE ABANDONED CORE-WALL, 70 FEET HIGH, SHOWS JUST OUT OF WATER.

original surface. These walls were all intended to be founded on hard bed-rock, and were designed to intercept seepage along the surface of the rock and be enveloped in the body of the puddle clay composing the center core of the dam. Unfortunately, they were built by contract under such careless supervision that subsequent examination proved them to be worthless and they were abandoned. They do not rest on bed-rock, and are composed of porous, rotten concrete. When this determination was reached, several cross trenches were made through the bowlders in the river-bed to the solid bed-rock, and these were refilled with the finest quality of puddle clay, upon which reliance will be placed for an impervious connection with bed-rock.

The method of building the dam by hydraulic sluicing was first suggested by Mr. T. W. Jaycox, M.A. Soc. C.E., State Engineer of Colorado, by whose recommendation the author was engaged to make an examination and report upon the project in June, 1905. At that time, a contract had been let for the entire work to one of the stock-

FIG. 103.—HYDRAULIC SLUICING ON THE TERRACE DAM, COLORADO.

holders of the company at a price of 18 cents per cubic yard, the contractor to furnish his own plant and materials. He first built a ditch and flume five miles in length, with a capacity of 40 second-feet, a sufficient elevation to deliver water to a penstock 325 feet higher than the crest of the dam, at the south end. The cost of the ditch and flume and all the pipe and plant for hydraulic sluicing, was $34,500. Two pressure-pipes of No. 16 riveted steel, each 15 inches in diameter, convey water from the penstock to hydraulic giants located in the sluice fields on the south side of the canyon. The ditch was completed too late in the fall of 1905 to begin sluicing, but in the following season about 120,000 cubic yards of material were sluiced in place from August 1st

FIG. 104.—TERRACE DAM, COLORADO, LOOKING UP-STREAM. ILLUSTRATING GRADATION OF MATERIAL TOWARD THE CENTER OF THE DAM FROM THE POINT OF DEPOSIT AT THE SLOPES.

FIG. 105.—TERRACE DAM. DEPOSIT OF HYDRAULIC FILLING ON THE UPPER TOE SLOPE.

to November 1st, when freezing weather forced a suspension of operations. The best average work for 30 days was 46,000 cubic yards delivered at a cost of 6.5 cents per cubic yard for labor.

The depth of filling at the down-stream toe was 55 feet, at the up-stream toe, 43 feet, and in the center, 18 feet. The material delivered

FIG. 106.—WASTEWAY FLUME FOR FLOOD DISCHARGE OVER LOWER SLOPE OF TERRACE DAM. SUMMER OF 1907.

at the two slopes was clean rock and gravel of all sizes up to about 2 cubic feet, while in the center the puddle clay was of fine texture, leaving little to be desired as an impervious core, whose base measurement exceeds 500 feet up and down stream. The material was delivered to the dam through square flumes, lined with slabs and round poles to take the wear, and laid on a grade of 7%. The volume of water used was about 26 second-feet.

As the depth of material in the borrow-pits has often been less than 6 feet considerable difficulty has been experienced in loosening it with sufficient rapidity to give fair efficiency to the carrying power of the water. Many flat, angular rocks were encountered which impeded the free flow of the approaches to the flumes and often necessitated

FIG. 107.—VIEW OF LOWER TOE FILLING, TERRACE DAM, COLORADO, SHOWING HYDRAULIC SLUICING IN BACKGROUND.

turning the monitors from the face of the bank to driving the material into the head of the flume.

At the opening of the season of 1907, the company took over the contractor's plant and continued work through the season on its own account. Owing to the small size of the outlet tunnel, it became neces sary to build a large flume (Fig. 106) over the top of the unfinished dam and down the lower slope to care for the June freshet, an expedient which was successful, although sluicing could not be resumed until the river subsided to the capacity of the tunnel. This flume was 72 feet wide, 4 feet deep, and at times carried a flood discharge of 450 second-feet. The total volume of the dam will be approximately 500,000 cubic yards. The progress of the work was about as follows:

Prior to 1907	120,600	cubic	yards
March and April, 1907	25,846	"	"
May	15,654	"	"
June and July	20,140	"	"
August	11,435	"	"
September	11,325	"	"
Total	205,000	"	"

At the close of the season of 1907 the dam had reached a height of 100 feet at the down-stream toe and 70 feet at the up-stream toe. With nearly 300,000 cubic yards yet to be deposited, it will be necessary to increase the rate of the past season about three times to complete the work in 1908.

The reservoir formed by the dam will have a storage capacity in excess of 25,000 acre-feet. The water will have high value, as the duty to be accomplished by it will be the irrigation of nearly one acre for each acre-foot of water impounded.

The Terrace Dam presented a situation where the cost of a masonry dam was prohibitive, where the materials for an earth dam of the usual type were not available because the earth is so intermingled with stone as to be practically inaccessible, and where the sole resource was to separate and deposit the materials at hand by the aid of water, which was to be had in abundance, under sufficient head or pressure to do the work. The results so far accomplished appear to the author to warrant the forecast that the dam when completed will be entirely successful. The work is under the general engineering direction of Mr. T. W. Jaycox, to whom the author is indebted for drawings and photographs used in illustration.

The Santo Amaro Dam, Brazil.—The São Paulo Tramway, Light & Power Company, Ltd. (a Canadian corporation) in 1895 erected a dam and installed a power-plant with a head of 70 feet at Parnahyba, on the Tieté River, in the State of São Paulo, Brazil, 22 miles below the thriving city of São Paulo, where 15,000 H.P. is generated and transmitted to the city for tramway service and for light and power. To partially equalize the flood flow and make up for shortage in dry seasons, the company, on the advice of its vice-president and consulting engineer,

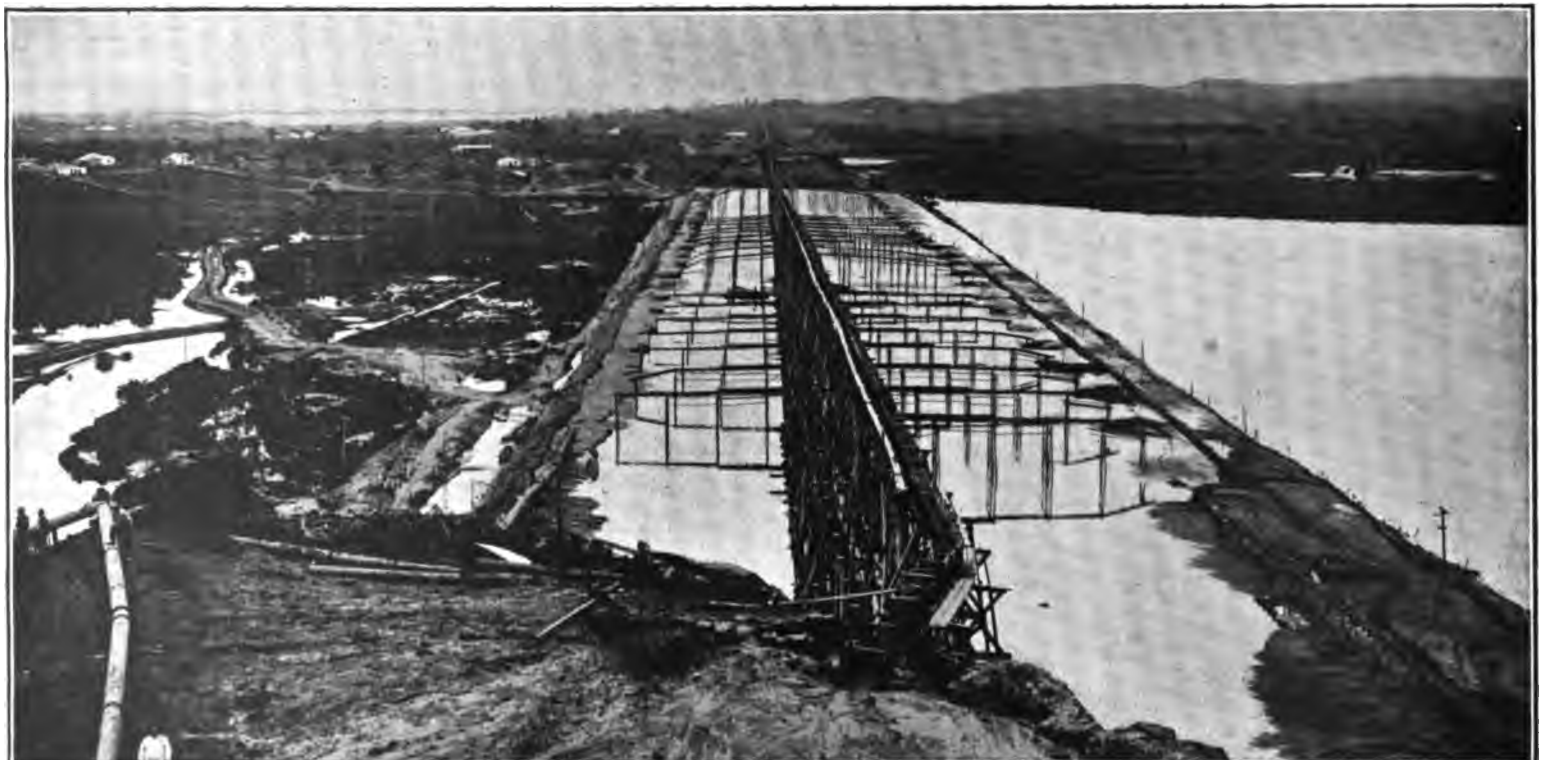


Fig. 108.—Santo Amaro Dam, Sao Paulo, Brazil. (1 Mile Long.) Showing Method of Delivery of Sluiced Material through Flumes and Laterals.

Fig. 109.—General View of Santo Amaro Dam, Brazil, Aug. 21, 1907. Showing Three Levels of Delivery on Central Trestle. Total Length 5300 Feet, Maximum Height 63 Feet.

F. S. Pearson, Dr.Sc., M. Am. Soc. C. E., has undertaken the construction of a dam 14 miles above the city, on a branch of the river known as the M'Boy Guassu. The dam will have a total length on the crest of about 5300 feet, a maximum height of 63 feet, and a volume of 715,000 cubic yards. The crest width will be 10 meters (32.8 feet) at a height of 3 meters above the spillway level. The up-stream slope is 3 on 1, down-stream slope 2 on 1. The dam is being built of clay and disintegrated granite obtained from a ridge 150 feet high at the west end of the dam, the materials being loosened by hydraulic jet under 75 pounds pressure at the nozzle of the monitor, with water supplied

FIG. 110.—SANTO AMARO DAM, BRAZIL, SHOWING HYDRAULIC MONITOR AT WORK, DELIVERING 8 SECOND-FEET UNDER 85 POUNDS PRESSURE THROUGH 4-INCH NOZZLE.

by a four-stage centrifugal pump, actuated by an electric motor, with current from the Parnahyba power-house.

The river here flows in a low-water channel, 80 feet wide, 8 feet deep, at the foot of the hills on the west side of the valley. At flood time, when the discharge exceeds 2500 second-feet, it spreads over the broad bottoms for nearly 2000 feet to the eastward. On the east of this level flat, the land rises gently for 3300 feet to the elevation of the crest of the dam. The bottom lands are swampy and covered with tropical grass and trees, and material for an earth dam could not have been obtained from borrow-pits at the sides. It was evident that the most suitable material was that of the high ridge to the west, and the simplest way of loosening and distributing it was by water pumped from the river and conveyed through flumes built lengthwise of the dam with lateral flumes at intervals leading to the slopes. The site of the dam was first stripped of sod, which was placed in the form of rectangular levees, 6 to 8 feet high, at or just outside the toe of the slope on either side. Hardwood triple-lap sheet piles were then driven to a depth of 10 to 15 feet over a distance of 2600 feet from the river bank easterly, beyond which similar piles were set in a deep trench and puddled in place for the remaining distance. Steel-sheet piles were driven in the channel section to a depth of 22 feet over a distance of 125 feet, connecting with

FIG. 111.—UPPER TOE FILLING ON THE SANTO AMARO HYDRAULIC-FILL DAM, BRAZIL, SHOWING LATERAL FLUMES.

the concrete work of the outlet culverts, built at the foot of the high ridge, and founded on granite bed-rock. These piles penetrate the bed-rock 2 to 4 feet. The culverts are three in number, each 8 feet wide, 18 feet high, controlled by radial gates of steel at the down-stream end. The culverts are built in an excavation made in solid granite bed-rock, and have partition walls and abutments 6 feet thick. The thickness at the crown of the arches is 2 feet. About 5000 cubic yards of concrete were used in these culverts and the wing-approach walls. The stream has a low-water discharge of about 10 second-meters (353 second-feet), which was diverted through the culverts before work on sluicing began. The sheet piles referred to extend a few feet above the stripped surface and are connected to a diaphragm of corrugated steel plates that reach above the water-line of the reservoir as a check to the burrowing of animals or ants. These plates are spiked to horizontal wale-pieces bolted to the center post of the main trestle supporting the sluice flumes.

The year 1906 and the first half of 1907 were consumed in the preliminary work of preparation, but finally the work of hydraulicking began in July, 1907. From that time until Dec. 1st, sluicing continued day and night for 128 days, during which the interruptions amounted to 39% of the total time. The work accomplished was the delivery of 381,000 cubic yards with an average volume of water of 7.94 second-feet, giving an average ratio of solids conveyed to water used of 19.2%. The main flume was placed on a grade of 3%, and reached a distance of 2000 feet from the west end of the dam. East of this point for 700 feet to the end of a dry earth levee built as the extension of the dam, where the height is less than 20 feet, the material was delivered by a booster pump, discharging through a closed flume.

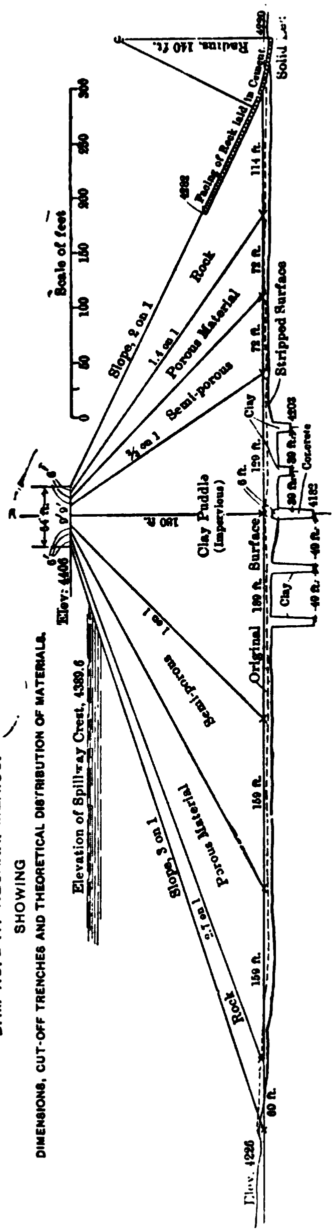
The best work done was in the month of October, when a delivery of 156,000 cubic yards was accomplished with a mean of 8.35 second-feet. The interruptions amounted to but 18 hours during the month, or 2.4% of the total time. The cost of power at the rate charged of ⅓ cent per K.W. did not exceed one cent per cubic yard for the month. The dam was to be completed by May, 1908. The construction since January, 1907, was in charge of Thos. Berry, C. E. The preliminary plans were prepared by the author after a visit to the site in October, 1905. The plans for the outlet-gates were drawn in the New York office of F. S. Pearson, Dr.Sc., M. Am. Soc. C.E.

Reservoir.—The reservoir formed by the dam covers a total area of 8320 acres, and has a capacity of 192,400,000 cubic meters (156,600 acre-feet). It therefore ranks among the largest reservoirs of the world.

The mean annual rainfall at São Paulo for 12 years, 1890 to 1901, was 1319 millimeters (54 inches) and the mean rainfall of the watershed was estimated at 2500 millimeters, with an average run-off of 50%. As the area is 244 square miles (63,200 hectares) the yearly run-off was computed at 780,000,000 cubic meters, or 4 times the reservoir capacity. During nine months, from March to November, 1907, the measured run-off was 419,515,000 cubic meters, with three months of rainy season to complete the year.

The power-plant at Parnahyba utilizes a total fall of 72 feet, and under full load requires 70 cubic meters per second (2470 second-feet). The function of the reservoir will be to supply a shortage in supply during the dry season, when a maximum deficit of 85,000,000 cubic meters in one such season has been experienced.

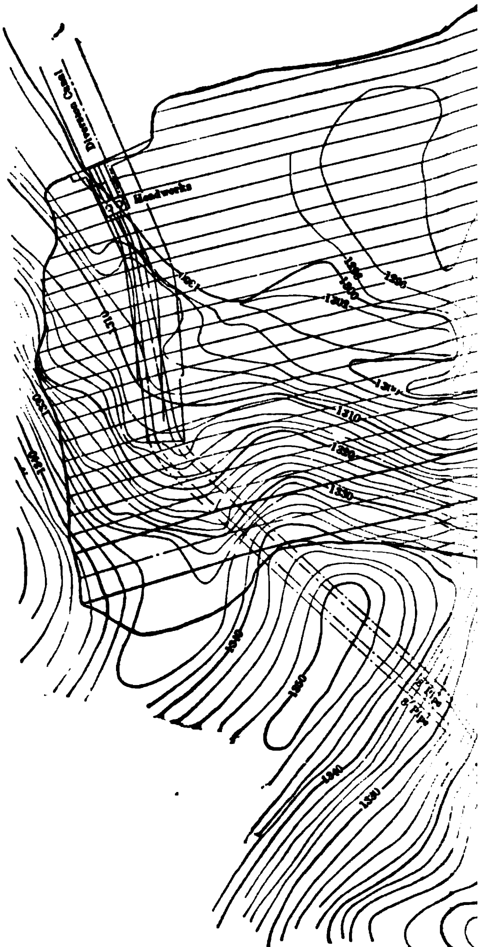
Hydraulic-fill Dams in Mexico.—The Mexican Light & Power Co., Ltd., a Canadian corporation, organized by F. S. Pearson, Dr.Sc., has installed a power-plant at the foot of the falls of the Necaxa River, State of Puebla, 100 miles northeast of the city of Mexico, where a maximum drop of 1400 feet is utilized, developing 40,000 H.P. which is transmitted to the capital of the Republic and to the mining camp at El Oro, a total distance of 170 miles. To equalize the flood flow of the streams and store water for use in the dry season, the company has been engaged since 1904 in the erection of five storage-reservoir dams of earth, which when completed will create an aggregate storage capacity of 123,000,000 cubic meters (100,000 acre-feet). Two of these dams, at Necaxa and Tezcapa, are to be of unprecedented height, and of enormous volume, 190 and 175 feet respectively, while a third, on the Los Reyes River, is to be 100 feet high. The hydraulic-fill process is being employed on all but one of these dams, for the adoption of which the responsibility rests with the author, who was called upon in January, 1905, to report on the subject, and has since been retained as consulting engineer to supervise their construction.



CROSS-SECTION OF DAM NO. 2 AT NECAXA, MEXICO. SHOWING DIMENSIONS, CUT-OFF TRENCHES AND THEORETICAL DISTRIBUTION OF MATERIALS.

FIG. 112.

The highest and most important dam of the group is that at Necaxa, whose chief function is to serve as a penstock reservoir at the head of the pressure-pipes, and afford a storage of over 43,000,000 cubic meters (34,850 acre-feet) on the main Necaxa River, a stream which fluctuates between extremes of 2 and 200 cubic meters per second.


Diversion Canal
Headworks
1310
1320
1330

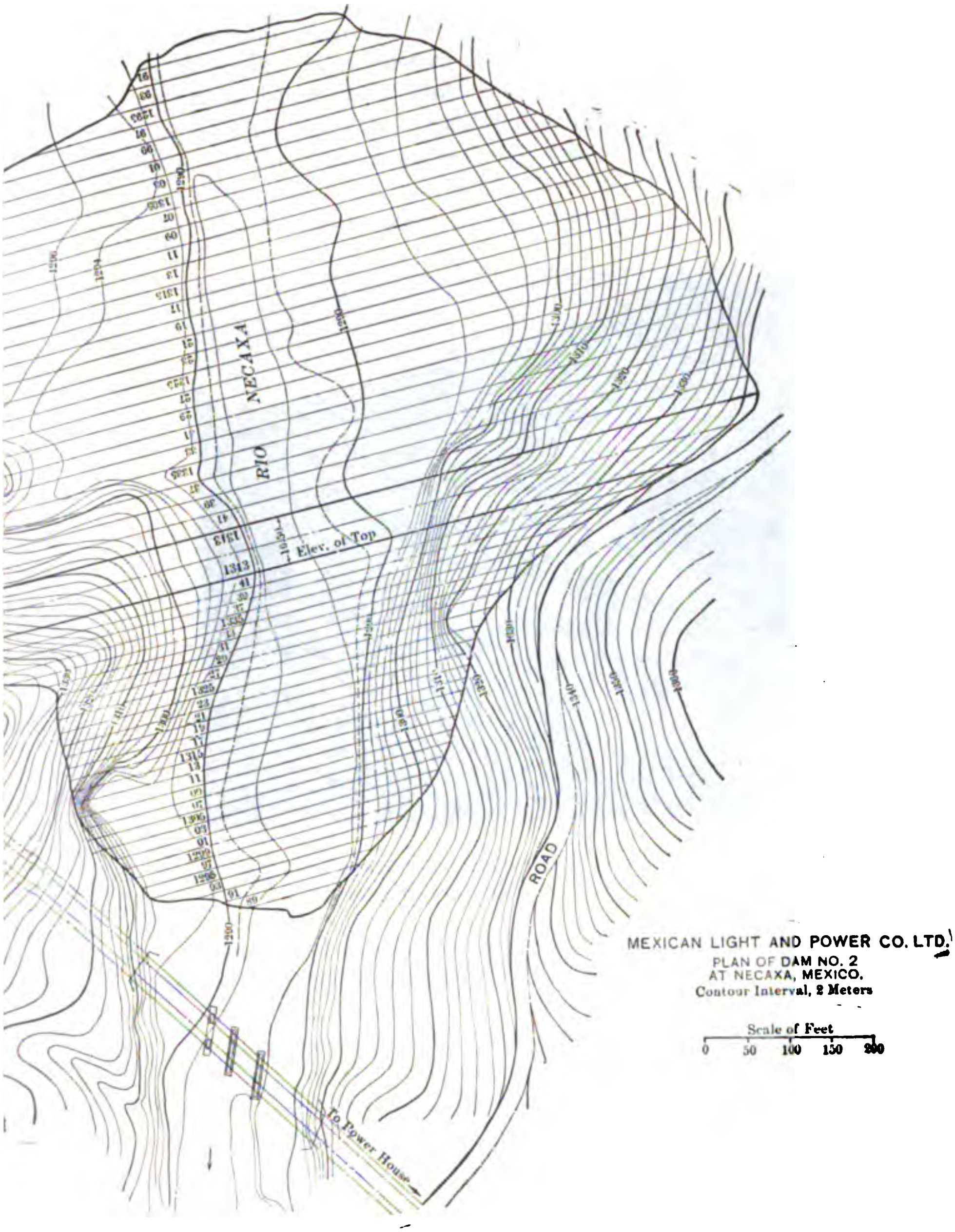


FIG. 113.

[To face page 152.

The dam-site is of peculiar geological formation at the line of juncture between the original limestone and the succeeding lava flow which has partially filled the valleys between the limestone mountains. The lava is in all stages of decomposition, varying between hard basalt and light cinders, in successive layers, some of which are very porous and will pass water freely while other layers are firm and impervious. In stripping for the dam irregular masses of hard basalt were encountered here and there which gave rise to the hope that the foundation would prove suitable for a masonry structure, but these were underlaid by soft, treacherous material at slight depth.

FIG. 114.—LOOKING UP STREAM AT SITE OF DAM NO. 2, AT NECAXA, SHOWING STRIPPED ABUTMENTS FOR THE DAM ON EACH SIDE.

The tunnel excavated through a spur against which the south end of the dam rests revealed the existence of pockets of quicksand, which further indicated that it was unworthy of confidence as the abutment of a high masonry dam. The only apparent alternative was to build the dam of earth, and plans had been prepared to build the earth dam by the usual methods, excavating with steam-shovels, hauling by cars and locomotives, spreading the earth in layers, and wetting and rolling it after the usual fashion. There was an abundance of clay to be had on the adjacent mesa, of purely volcanic origin, but the enormous quantity to be moved and the cost of building as high a dam as was required for necessary storage, caused the management to hesitate. The solution of the difficulty was afforded by the existence right at hand in the slopes of the high limestone ridge to the northwest of the dam of a sufficient mass of broken fragments of stone of all sizes intermingled with pure yellow clay of superior quality to build the dam by the hydraulic-mining process, using powerful jets of water under high pressure to be brought to the site by a ditch. This material could not be handled economically or sorted and deposited in a way to produce stability and drainage of slopes, and compact imperviousness to the core of the dam in any manner except by the hydraulic method.

FIG. 115.—NECAXA DAM, MEXICO. HYDRAULIC MONITOR WORKING UNDER 180 POUNDS PRESSURE, 6-INCH NOZZLE, 30 SECOND-FEET OF WATER.

Somewhat similar arguments applied to all of the other dams of the group.

The proportions of rock and clay are about equal, and their distribution can be so controlled and regulated by the varying velocities of the water as to permit of the formation of two rock dams at either slope resting against and confining an enormous mass of dense, impervious clay between them. In this manner the dam when completed cannot fail by slipping or sliding, and must be proof against leakage.

The dam will contain 1,639,690 cubic meters (2,143,520 cubic yards), and will have the following dimensions:

Length on crest	1220 feet
Height above lower toe	190 "
Height above up-stream toe	178 "
Width of crest	54 "
Super-elevation above spillway	16.4 feet
Up-stream slope	3 on 1
Down-stream slope	2 on 1
Base width	975 feet

FIG. 116.—HYDRAULIC MONITOR IN ACTION, WITH 30 SECOND-FEET UNDER 180 POUNDS PRESSURE, 6-INCH NOZZLE. UP-STREAM TOE OF DAM SHOWN, WITH TAILING POND AT LEFT.

Sluice Ditch.—The supply-ditch for sluicing is 17.5 km. long, and as it passes the site of Dam No. 3 on Necaxa River, 6 miles above Dam No. 2, will furnish water for building both dams. It has a capacity of 70 second-feet as far as Dam No. 3, and 53 second-feet, the remaining distance, delivering water to Dam No. 2 at a height of 728 feet above its base. The elevation gives most effective and powerful cutting-jets at all working levels, above the crest of the dam as well as below. The ditch was extremely difficult to construct, as it was excavated on steep mountain sides in rock, requiring cement lining in many places and one long siphon with head of over 400 feet. Its total cost was about $250,000 gold, but as it can be utilized to generate 1700 H.P. after the dams are finished, its cost is not entirely chargeable to the building of the dams. The drawing, Fig. 113, illustrates the location of the dam and the general process of construction. Fig. 112 is an ideal section of the dam, showing the cut-off core-trenches, two on each side of the concrete core-wall.

Stripping Foundations.—The preparatory work of stripping at Dam No. 2 consisted of the removal of all surface soil to a depth of 2 to 3 feet over the entire base of the dam, and the excavation of all loose, pervious material over the middle third down to hard-pan or bed-rock. The hard-pan is a species of soft lava, locally called "tepetate," and

FIG. 117.—HYDRAULIC MONITOR WORKING ON LINE OF CONTACT BETWEEN LIMESTONE AND LAVA IN SPILLWAY CUT, NECAXA DAM, MEXICO.

the rock is basalt that was encountered in the form of thin layers, or kidneys, disconnected and of irregular masses. The depth of this stripping in the valley was from 10 to 15 feet. It was a tedious work, occupying more than two years, part of the time with two steam-shovels and two locomotives and trains of dump-cars. Part of the material was placed at the upper and lower slopes of the dam, to the extent of 75,000 cubic yards, but the greater portion was wasted. It amounted in all to 272,487 cubic yards. The trench for the concrete core-wall was excavated to a depth of 40 feet below the stripped surface across the valley portion and from 5 to 20 feet deep on the slopes. It cut through various strata of porous, rotten tepetate, and finally ended in a hard, impervious layer. It was about 6 feet wide and filled with concrete made of

FIG. 118.—STONE CARRIED THROUGH FLUME TO UP-STREAM SLOPE OF THE NECAXA DAM.

FIG. 119.—ILLUSTRATING THE SIZE OF STONE DELIVERED BY FLUME TO THE NECAXA DAM. THE LARGEST ONE MEASURED CONTAINED 18 CUBIC FEET.

Fig. 120.—Lower Toe of Necaxa Dam, looking North, showing Delivery of Rock and Clay by Flume.

Fig. 121.—Down-stream Slope of Necaxa Dam, showing Masonry Pavement on Face and Character of Sluiced Material.

Portland cement and hydraulic lime in proportions to insure water-tightness. It was carried about 2 meters in height above the stripped surface, finishing with a width of 1 meter on top. It contains in all about 5600 cubic yards of concrete. The exterior of the exposed part of the wall which is enveloped in clay puddle was made very rough by projecting small stones to form a bond and to avoid the smooth surfaces which water may follow. The two trenches up-stream from the core-wall, and parallel with it, were excavated to the clay floor of the valley, and were refilled after sluicing began with the clay puddle that forms the heart of the dam.

The preliminary plant for the delivery of material to the dam con-

FIG. 122.—NECAXA DAM FROM BELOW, AT HEIGHT OF 85 FEET. JANUARY 1, 1908.

sisted of two trestles, 40 to 60 feet high, built parallel with the center line and supporting two lines of 20-inch riveted steel pipe laid on a grade of 5% from the borrow-pits on the mountain side, opened by the hydraulic "giants." These trestles were located about 100 feet in from either toe, and the material carried was delivered to the outside by branch pipes, 16 inches in diameter, which were supported by cables suspended across the dam between the exterior footings and the trestles. As a larger quantity of rock was desired on the down-stream slope, one of the pipes was laid to the lower trestle from borrow-pit No. 2, yielding about 95% of broken stone, while the other pipe to the up-stream face was taken from borrow-pit No. 1 where the material consisted of clay to the extent of 60% to 70% mingled with stones of all sizes. The photographs, Figs. 118, 119, 120, 121, and 124 show the nature of the materials delivered to each and the manner of delivery.

A striking feature of this work, as illustrated by the photographs, Figs. 118 and 119, taken by the author in January, 1908, is the large size of rocks which have been transported through the flumes and deposited on the dam. Many of these contain upwards of 15 cubic feet and weigh over 1 ton. In this respect the magnitude of the operation exceeds any hydraulic sluicing ever before attempted. The down-stream slope is being covered with 2 feet of masonry laid in Portland cement, using

FIG. 123.—NECAXA DAM AND RESERVOIR. SLUICE DITCH IN UPPER RIGHT-HAND CORNER OF PICTURE.

the larger stones brought down by the flume. The purpose of this is to protect the work from the consequence of a sudden freshet, which might exceed the capacity of the flood discharge outlet-pipes provided. These are two in number, one of which is of steel 8 feet in diameter, in the main outlet tunnel, the other is 10 feet in diameter of concrete, built for construction purposes only and to be plugged when the dam is finished. Two overflow towers 8 feet diameter are built at the head of this pipe in successive layers, as the lake across the dam rises, permitting of storage following up the construction. The solidity of the rock-fill is attested by the lack of settlement cracks in the masonry facing built on the slope of the fill.

The rocks transported by the water are carried along at a velocity of about 20 feet per second, and as they drop in place they act as powerful rammers to consolidate the embankment. The material leaves the end of the raceway at such a velocity as to pile up several feet higher than the top of the flume. It has been the practice to build up the dump from the extreme end of the flume, retreating and removing section by section as the embankment is formed until the ridge is made entirely across the valley along the slope line, to be followed by another line of flume, 15 to 20 feet higher, built a little nearer the center line. There

FIG. 124.—NECAXA DAM, UP-STREAM SLOPE, LOOKING TOWARD SLUICING PIT AND SPILLWAY GAP.

is great wear and tear in the flumes and linings, but the material is used over and over until worn out.

When working in clay the ratio of solids carried to water used has reached as high as 70%, but in rock the ratio is as low as 3%, and the average falls below 10% of solids.

The cost for labor alone averages from 3 to 10 cents gold per cubic yard.

Sluicing began in April, 1907, and continued throughout the year, with many interruptions due to drought and shortage of water, breaks in the ditch, etc. By May 1, 1908, a total volume of 622,990 cubic meters had been delivered, and it is estimated that the dam may be entirely completed before the end of the year.

After the borrow-pits had been well opened, it was found that a much greater percentage of large rock would have to be handled than was anticipated, and to save the cost and delay involved in breaking the rocks to a size that would pass through the sluice-pipes, it was determined to substitute open flumes. Two lines of flumes were accordingly built on 8% grade, crossing the dam about midway between the first lines of trestle and the outer slopes. When these were put in service they were able to carry rock of a maximum size of 12 to 18 cubic

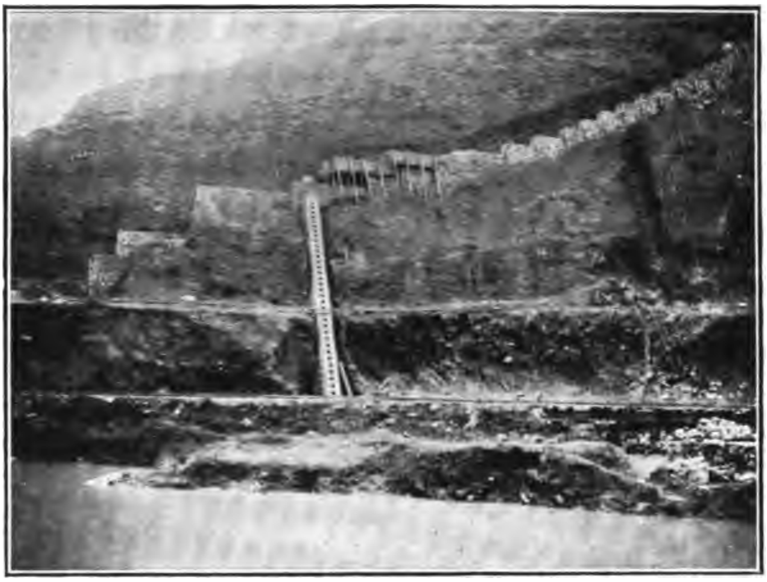


FIG. 125.—NECAXA DAM. INCLINED PIPE WITH PERFORATIONS FOR DRAINAGE OF WATER AFTER SETTLEMENT OF SLUICED MATERIAL ON DAM. ALSO CORE-WALL AS COMPLETED.

feet weighing a ton or more. The velocity of the water through the flumes was about 20 feet per second. They were made rectangular, 4 feet wide with V-shaped bottom, lined with sheet steel and T-rails. The maximum volume of water carried is about 30 second-feet. The hydraulic monitors, or "giants," discharge varying amounts, according to the pressure and the size of nozzle used. The nozzles employed vary from 4 to 6 inches, according to the work required, and discharge from 15 to 30 second-feet. Experienced hydraulic miners from California are employed to manipulate the monitors. Visitors to the work find a peculiar fascination in watching these powerful jets of water, issuing at a velocity of 200 to 300 feet per second, tearing down the mountains, ripping up the ledges of stratified limestone, and tossing about huge stones weighing tons as though they were pebbles. The greater portion of the material for the dam will come from the excavation of the spillway, which requires a cut over 150 feet deep. The surplus

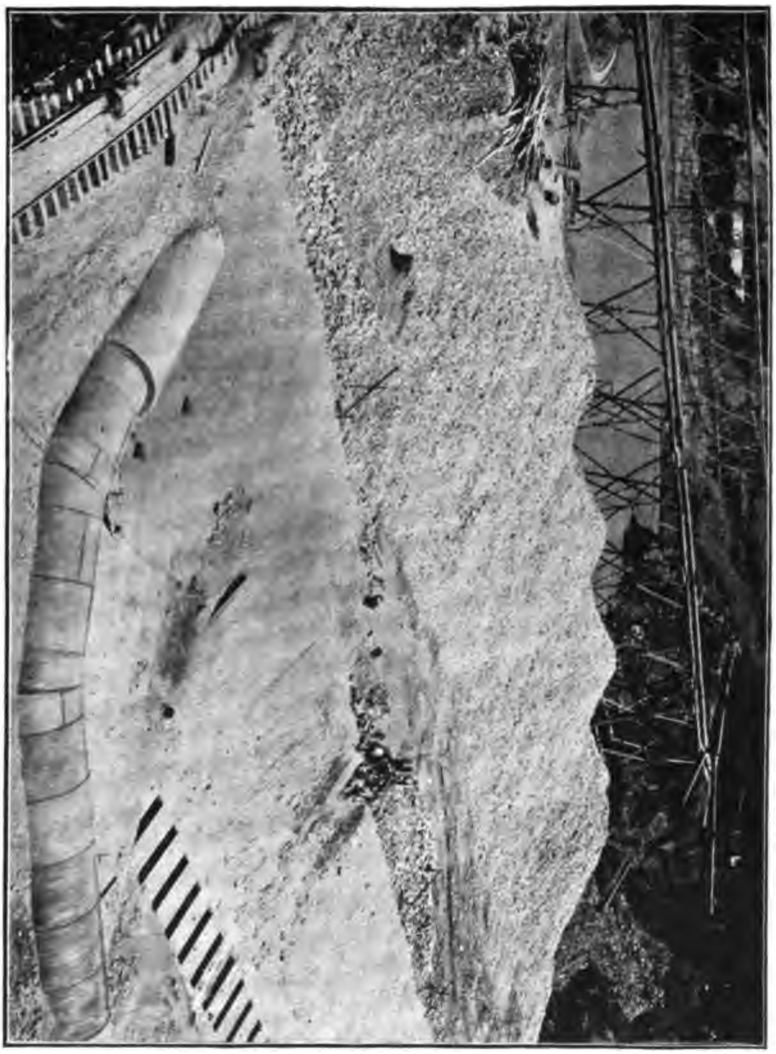


FIG. 126.—LOWER TOE OF NECAXA DAM, MEXICO, SHOWING CHARACTER OF HYDRAULIC-FILL MATERIAL. PIPE IN FOREGROUND IS 10 FEET IN DIAMETER, USED ONLY FOR FLOOD DISCHARGE DURING CONSTRUCTION.

water, draining from the pond, which is maintained on the center of the dam, is carried off through holes in an inclined concrete pipe (Fig. 125), built up the steep slope near the south end of the dam on the opposite side from the borrow-pits. To raise the pond it is only necessary to close the lower of these holes with wooden plugs. In this manner,

Fig. 127.—Hydraulic Sluicing at Necaxa, June, 1907. Showing Tilted Limestone Ledges in Pit No. 1, overlaid by Clay and Loose Rock.

Fig. 128.—Necaxa Dam, Mexico, Oct. 26, 1907, showing Material being Deposited by Flume. Also Hydraulic Elevator Operating under 700 Feet Head, Lifting Water from Pond into Power Canal at Headworks at End of Pipe.

Fig. 129.—Up-stream Toe of Necaxa Hydraulic-fill Dam, Dec. 9, 1907, showing Delivery of Materials by Flumes. The Core-wall is shown in Center of Dam.

the line separating the central clay puddle, from the semi-porous mixture of clay and rock can be controlled, as it is found that the deposit drops off under water at a slope of 1 on 1. Under the water of the pond, the fine clay is deposited almost absolutely level. The water in the pond is usually from 12 to 15 feet deep over the bed of clay beneath. In this manner two stable dams of rock are being built up with an enormous core of clay, having a maximum thickness of 500 to 600 feet between them.

Dam No. 1, at Acatlan.—This structure was completed in June, 1906. It serves as a diverting weir to turn the water of the Tenango River to the Necaxa, through a 3000 foot tunnel. Its extreme height is about 30 feet and it was built of earth by the ground-sluice method, with water taken from the stream through a short ditch. Figs. 130, 131, and 132 illustrate the construction of the dam, and Fig. 133 shows the finished dam viewed from the tunnel portal. It is divided into two sections by a concrete weir located in the stream channel at the deepest portion. When examined with an earth auger to a depth of 20 feet below the crest six months after completion the core material was found in a plastic but compact condition. The dam has shown no sign of leakage or seepage and but very slight settlement.

Dam No. 3, at Tezcapa.—This dam, the second in height of the series, is located six miles above Necaxa, and will form a reservoir of 19,000,000 cubic meters, or less than half the capacity of Necaxa reservoir. After the site had been partially stripped, work was suspended pending the completion of the Laguna and Los Reyes Dams, Nos. 4 and 5, where subsequent surveys proved that greater storage can be secured at less cost and in shorter time. For this reason it will probably be the last of the group to be finished. In many respects it will present fewer difficulties of construction than any of the others, and can be completed with the plant in use at the Necaxa dam.

Laguna Dam.—A large natural basin near the end of one of the tributaries of the Necaxa River was acquired by the company and utilized as a storage-reservoir by building a long low dam across its outlet. It is fed by a 5-mile canal of 10 second-meters capacity from Necaxa River. This site is 20 miles distant from Necaxa, and 3000 feet higher. The dam was planned to have an ultimate height of 66 feet with a crest width of 25 feet and slopes of 3 on 1 and 2 on 1 respectively, and was to have been made as a hydraulic-fill, with water pumped from the lake. The urgent necessity for securing a storage of 12 to 15,000,000 cubic meters in the shortest possible time, led to the adoption of a plan for building the up-stream toe of the large dam to the height of 40 feet of the material chiefly obtained from stripping the middle third of the main dam. As there was a large amount of loose

Fig. 130.—Liquid Earth being Deposited through Pipes on Outer Slopes of Dam No. 1, Tenango River.

Fig. 131.—Ground-sluicing on Dam No. 1, Tenango River.

FIG. 132.—METHOD OF DISTRIBUTING SLUICED MATERIALS THROUGH PIPES, DAM No. 1, AT ACATLAN, TENANGO RIVER.

FIG. 133.—DAM No. 1, AT ACATLAN, TENANGO RIVER, COMPLETED JULY, 1906. THE MATERIALS FOR THE DAM WERE GROUND-SLUICED FROM THE BORROW-PITS IN THE BACKGROUND.

rock in this stripping, it was decided to build the lower half of the dam as a loose rock-fill, with down-stream slope of 1 on 1, and crest width of 2 meters, while the up-stream half was to be of earth. Between the two materials a diaphragm of double 2-inch pine planks spiked to round poles set vertically was built, backed by a layer of choice puddle clay 2 meters thick, on the up-stream side. This diaphragm was started in the bottom of a trench in the bowlder and tepetate formation beneath the surface soil, the trench being 2 to 5 meters deep. Considerable water was developed in the trench but was drained off without difficulty. All the material in the dam was put in place by peon laborers with "chiquihuites," or baskets which they carry upon their backs with a leather strap passing across the forehead. The earth was moist enough to pack well under the thousands of trampling feet, and though no roller was ever placed upon it, the dam has shown no perceptible settlement. The dam was completed before the end of the rainy season of 1905 sufficiently to store the desired volume of 10,000,000 cubic meters, and proved to be entirely tight with the exception of one rather serious leak near the outlet-pipe, which was shut off by driving sheet-piling in the clay puddle. The reservoir proved to be so useful that it was resolved in January, 1907, to enlarge it as quickly as possible by the addition of 4 meters to the height of the dam, giving a capacity of 44,000,000 cubic meters to the lake. To make this enlargement most economically it seemed best to change the center line to that of the temporary core-wall and build a permanent core-wall of concrete, 1 meter thick, on the up-stream side of the plank diaphragm. This was done by excavating one half of the clay puddle and bracing the trench from the diaphragm to planking placed on the opposite side. This was done and the trench solidly filled between the forms which were not removed. The up-stream slope was changed to 2 on 1 and covered with a blanket of selected clay puddle 1 meter thick. The slope of the down-stream half was increased to 2 on 1 and the filling made of the best material available, well under-drained from the interior rock-fill by trenches filled with rock reaching to the lower toe, at intervals of 20 meters.

Cost of Basket Earthwork.—To those who are unfamiliar with methods in vogue in parts of Mexico in handling of earth and rock on men's backs by baskets and other home-made receptacles, a brief account of it may be of interest. In northern and western Mexico the peons use a basket made of raw hide, while in the central and southern portions the basket is made of bamboo about 19 inches deep, 17½ inches in diameter at top, 7½ inches at the bottom, and containing 1.4 cubic feet. These cost 40 cents (Mexican) each, and unless reinforced will not wear longer than 3 or 4 weeks. By stringing wires through them or putting rawhide over the outside, they are made to last two to four times as long. These are carried on men's backs with a loop of leather or fiber passing over the basket and across the forehead. The most satisfactory method of working the laborers is to give them a task of a certain measured quantity to be excavated, loaded in baskets and delivered as a day's work. This varies from 2 to 5 cubic meters, according to the distance. The average wage is 75 cents per day. With a "tarea" of 3 cubic meters carried a distance of 150 meters from the pit, up a 2 on 1 slope a part of the way, which is a fair day's work, the cost would amount to 9.5 cents gold per cubic yard, pit measurement, or about 12 cents per cubic yard measured in the settled embankment. With such cheap labor as is available in Mexico the economy of hydraulic-fill construction is not so pronounced as elsewhere, and it is to be preferred chiefly on the ground of the superior quality of the embankment produced by the process.

Los Reyes Dam.—The fifth dam of the system is located on a stream to the north of Laguna, and not tributary to the Necaxa River. A tunnel through the intervening ridge was required to make its water available to the power-plant. This diversion was made before the work on the dam was begun. The site is a favorable one for a dam of 100 feet height, forming a reservoir of 28,000,000 cubic meters capacity. The gorge is narrow, and the volume of material required for an earth dam is but 183,000 cubic meters, which is small in comparison with the storage secured. Here, too, the emergency of maintaining a water-supply to the power-plant, already taxed to its limit, necessitated the employment of the temporary expedient of building a toe dam while the foundations of the larger structure were being prepared. This was made in a similar manner to the Laguna Dam with a combination of rock-fill, wood core-wall and earth-fill on the up-stream side, with a much thicker clay puddle against the diaphragm.

The concrete core-wall in the center of the main dam is being carried down through soft, seamy sandstone to a maximum depth of 60 feet. When finished up to the top above the stripped surface, it will be enveloped in clay puddle sluiced in by water supplied by a larger pump capable of delivering water under sufficient head to afford a cutting stream for loosening the earth and then do away with handwork. The down-stream slope will be composed of loose rock 50 feet thick at base, 5 feet at the top, resting against the clay puddle and affording the requisite stability and drainage.

In building the toe dam the principal part of the earth was put in place with baskets, and a plant was not installed for sluicing until the work was two thirds completed. Then a couple of Cameron steam-pumps, with combined capacity of 500 gallons per minute, were coupled together and water to the amount of about 300 gallons per minute was pumped from the pond above the dam to the head of a 10-inch V-flume laid on 10% grade, terminating on the dam above the wood core-wall. Earth was brought in baskets and dumped into a box at the head of the flume, whence the water carried it to the dam. The maximum work of this crude apparatus was 540 cubic meters (700 cubic yards) delivered in 10 hours, with a ratio of 75% of solids carried by the water. The cost of earthwork done in this manner during the month of December, including basket delivery of earth not sluiced, was under 11 cents gold per cubic yard.

These various works are being executed under the control of R. F. Hayward, M. Am. Soc. C. E., general manager, by Mr. F. S. Hyde, chief engineer.

The Yorba Hydraulic-fill Dam, California.—H. Clay Kellogg, C.E., of Santa Ana, Cal., who built the Waialua combination dam near Honolulu, described in the foregoing pages, has constructed an earth dam chiefly by the hydraulic process near Yorba Station, 30 miles south of Los Angeles, which has many interesting features and illustrates the adaptability of the method to conditions apparently unfavorable. The dam is 47 feet high, 800 feet long on the crest, having a slope of 3.5 on 1 on the water-face and 2 on 1 outside, with a crest width of 16 feet. Its contents are about 100,000 cubic yards, of which 80% was excavated, conveyed, and placed by the agency of water. The dam is located at the edge of a mesa, where it breaks off at the side of the valley of the Santa Ana River, and the top of the dam is but little lower than the level of the mesa. It closes the outlet of a small valley in the mesa, and forms a reservoir of 51,000,000 cubic feet capacity (1170 acre-feet) to be used for irrigation as an adjunct of the main canal of the Anaheim Union Water Co. This canal, from the Santa Ana River, feeds the reservoir and passes around it at an elevation but a few feet higher than the top of the dam, and the water used in sluicing was that supplied by this canal. The work was begun in February and completed in November, 1907, with a small force.

Owing to the lack of head for hydraulicking under pressure, the lower half of the dam was built up by the ground-sluicing method, the materials being loosened by plows, picks, and bars and washed into the dam through flumes, one on each side, laid on grades of 4% to 7% and using 3 to 4 second-feet in each flume. The side levees were built up at the beginning 4 to 8 feet high, with earth scraped from the center. Subsequently they were maintained by earth brought in from either end by cars and scrapers. The average cost of ground sluicing was about eight cents per cubic yard.

July 1st, when the dam reached a height above which it was no longer possible to secure the required gradients for conveying the mate-

FIG. 134.—YORBA DAM, CALIFORNIA. HYDRAULICKING AN EARTH BANK WITH WATER PUMPED THROUGH 1-INCH NOZZLE UNDER 25 POUNDS PRESSURE.

FIG. 135.—YORBA DAM, CALIFORNIA. SHOWING DISCHARGE OF PUMPED MATERIAL, ALONG UP-STREAM TOE LEVEE.

rial by gravity, a single stage centrifugal pump, operated by gasoline engine of 60 H.P., was installed to deliver sluiced material through an 8-inch pipe to and along the dam, a maximum distance of 800 feet from the pump. The latter was located at one end 20 feet below the crest height of the dam, and had a capacity of 3 cubic feet per second. A second centrifugal pump, with a capacity of 0.5 second-foot, was installed near the ditch for supplying the hydraulic stream used for cutting the earth bank, delivering the water through a nozzle 1 inch in diameter at the end of a 2-inch hose, under a pressure of 35 pounds per square inch. This small stream, easily controlled by two men, sufficed to do the mining, clear water being added to the extent of 2.5 second-feet to convey the loosened earth to the lower pump. In this manner about 600 cubic yards was delivered daily in 10 hours, at a total cost of about 12 cents per cubic yard.

The material consisted of adobe clay soil, sand and gravel. A goodly proportion of the material is gravel ½ inch to 4 inches in size. The average ratio of solids delivered to water pumped is about 15%. The dam has no core-wall, but has a deep puddle trench excavated through the top-soil into hard blue clay. This trench is refilled with fine clay segregated from the soil in the sluicing operation, which constitutes so large a proportion of the heart of the dam as to insure water-tightness of the structure. The material left on the slopes is coarse enough to afford good drainage during construction and insure the exterior of the dam from future super-saturation.

Fig. 134 shows the operation of hydraulic sluicing, and Fig. 135 illustrates the method of delivery of earth upon the dam. The surplus water was drained from the pond through stand-pipes built up in successive layers and connecting with the main outlet-pipe through which the water was fed into the reservoir. The entire cost of the dam was about $38,000.

Silver Lake Dam, Los Angeles.—In constructing an earth dam in the city limits of Los Angeles, for storage and domestic distribution service, Mr. Wm. Mulholland, M. Am. Soc. C. E., superintendent of the city waterworks, made notable use of the hydraulic system in somewhat novel ways which further illustrate the flexibility of the sluicing method of dam building, and the fact that it is not essential to go outside the limits of the reservoir or above the high-water line to secure material for a hydraulic-fill dam. The dam is 900 feet long on the crest, 56 feet maximum height, and contains 146,000 cubic yards, all of which was taken from the reservoir basin and the greater portion of which was handled with pumps through the medium of water. The elevation of the crest of the dam is 450 feet above sea-level. The reservoir is fed by a conduit from Los Angeles River, and has a storage capacity of 156,-000,000 gallons (479 acre-feet).

For the purpose of cutting off percolation underneath the dam a trench was excavated to bed-rock on the central axis of the embankment, throughout its entire length, reaching a depth of 40 feet below the original surface in the center of the valley. This trench was filled with a concrete core-wall, which was carried up into the body of the dam a height of 3 to 6 feet above the original surface. In the deepest part, for a considerable distance, this wall was built between parallel lines

Fig. 136.—Silver Lake Dam, Los Angeles. The Earth, Loosened by the Hydraulic Jet, is Conveyed to the Pumping Station Shown and Pumped to the Dam.

of steel sheet-piling about 6 feet apart, driven into the sandstone bed-rock in advance of the excavation of the earth between them.

At the lower levels the material used to build the dam was loosened and dissolved by ground sluicing with water taken from a grade-line pipe passing through the reservoir. The liquefied earth flowed by gravity down the slope to a sump whence a centrifugal pump forced it through a pipe to the dam, where it was distributed by flumes and lateral branch pipes. At a later stage the hydraulic jet was used for loosening the earth, the water being pumped by a single-stage centrifugal pump through 4-inch pipe, and delivered under pressure of 70 to 100 pounds through 2-inch nozzles, controlled by a local modification of the more expensive hydraulic monitor used in the mines.

When the material within 2000 feet of the dam was exhausted on one side the plant was removed to the other, and successive settings of the pumps were made, retreating further away each time, until before the dam was finished the material was being forced through 4000 feet of 8-inch pipe, with the main pump working under 40 pounds pressure, and a "booster" pump, located midway on the line, operating under 12 to 15 pounds per square inch. The actual lift represented only about 20% of the total head pumped against, the remainder being the friction in the pipes. During the later stage of the work the water used was about 2.5 second-feet, and the rate of delivery of material was about 500 cubic yards in 9 hours. The ratio of solids to water was therefore about 17%. At the earlier stages this ratio was as high as 28%. When the material was being delivered through 1500 feet of pipe, a careful summary of the data showed the cost to average 11 cents per cubic yard. Toward the end of the work, a careful account of cost on the delivery of 8000 cubic yards showed the average to be 16 cents per cubic yard, including all labor, materials, fuel, etc., including the work of building up the side levees by shovelling.

The water used was returned to the reservoir, which was half filled before the dam was finished. The main pump was always located at the water edge, where it could take additional water to dilute the stream of mud from the jets.

The material consisted solely of surface-soil, 3 to 4 feet deep (overlying hard-pan), of a heavy sandy loam quality, containing a considerable percentage of clay, which was carefully separated and placed in the center of the dam by the action of water, the sand being left on the sides of the embankment.

To prevent a slipping of the outer slope while it was saturated from the pond on top of the dam, six 2-inch drain-pipes were driven horizontally into the down-stream face of the embankment, a distance of 60 feet. Each was provided with a well-point and strainer at the inner end. They were about evenly spaced over a length of 200 feet of the highest part of the dam, and 6 to 10 feet above the surface. The greatest amount of seepage from any one of these drain-pipes measured two gallons per minute, which diminished to one fourth in a few weeks. These drains were effective in keeping the face of the dam dry and stable.

This dam is of special interest as a demonstration of what can be done with a cheap "pick-up" plant in gathering low-lying material from a distance, and forming a dam of superior compactness at moderate cost.

Swink Hydraulic-fill Dam, Colorado.—The Apishapa River is a torrential stream, which drains an area of 837 square miles, ranging in elevation from 4600 to 14,000 feet, and enters the Arkansas River from the south a few miles above Rocky Ford. Its mean annual run-off is from 80,000 to 100,000 acre-feet, but it is so irregular and flashy in flow as to require storage to utilize it for irrigation. Owing to the absence of good storage-sites on the stream, the plan formed by Senator G. W. Swink, of Rocky Ford, for impounding the water is to build a diverting canal, 24 miles long, 31 feet wide on bottom, 6 feet deep, with a capacity of 1100 second-feet, from the stream to a flat basin in Patterson Hollow, where he designs to construct a reservoir covering an area of 2300 acres, with a capacity of over 46,000 acre-feet, by means of a dam 7150 feet long, 40 feet high, with inner slope of 9 on 1, outer slope 2 on 1, crest width 200 feet, and cubic contents of 2,800,000 cubic yards.

The materials for this huge dam are to be brought to it by the canal in its descent from the crest of the ridge between the valley of the Apishapa and that of the reservoir, a distance of 7 miles, where the fall is 147 feet to the top of the dam.

The soil is an extremely fine sand which has great cohesion when compacted under water. The depth to shale bed-rock over the area to be sluiced is from 8 to 15 feet. The canal will speedily cut down to bed-rock, and the soil must be carried forward to the dam. The dam slope levees were built to a height of 12 feet by scraping from the space between them. They are 644 feet apart from out to out. The canal will flow the entire length of the dam between these levees and discharge into the reservoir at the far end. The plan is quite unique, and the scale of the work is so ambitious that much time may be required to complete it, although the cost should be very moderate, and will chiefly consist in building up of the side levees from time to time, as the canal will only need intelligent guidance to excavate all the material it can carry. The construction will, in a measure, be automatic.

The reservoir will have 16 outlet-pipes through the dam at varying levels, in 8 pairs on either side.

The dam is estimated to cost about $100,000.

Croton Hydraulic-fill Dam, Michigan.—In constructing a power-plant on the Muskegon River, at Croton, Mich., in the winter of 1906–7, the Grand Rapids-Muskegon Power Co. employed the hydraulic-sluicing process most effectively and economically for the erection of an earth embankment 200 feet long, 40 to 60 feet high, containing 104,000 cubic yards. The total cost of the work* averaged but 6.8 cents per cubic yard, including all expense for plant, materials, supplies, labor, power, etc. The detail of cost was as follows:

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* See *Engineering News*, of Oct. 14, 1907, illustrated article, by W. G. Fargo, C.E.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

fill in the center of the dam. This is built in a trench 20 feet deep and is uniformly 20 feet thick up to the stream-bed, thence it batters to 3 feet at the water-line in 185 feet of height above stream-bed. The volume of concrete in the core-wall is to be about 30,000 cubic yards, while the earth will have a total volume of nearly 1¼ million cubic yards, two thirds of which was in place at the end of the working season of 1907, reaching to a height of about 110 feet.

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

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

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

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

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

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

* *Engineering News*, October 20, 1898.

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

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

The simplest and most elementary precautions in dam building appear to have been neglected, and no attempt was made to prepare the foundations by the removal of mining tailings in the bed of the ravine, the excavation of a trench to bed-rock, or the construction of any sort of core-wall or seepage barrier. A wooden culvert, $4' \times 4'$ in the clear, of 2-inch Oregon pine, was built through the dam at the bottom resting on 6×8-inch stringers. A shaft of wood was built up at the upper toe as an overflow for draining the reservoir during construction. Connecting with this box was an inclined wooden shaft $2' \times 4'$, laid parallel with the outer slope, 10 feet from the exterior surface, to take off the overflow from the pond on the dam. When the embankment reached a height of 40 feet, the main culvert was crushed by the weight above it, and no longer served as a waste channel. At this stage, therefore, hydraulic filling was substituted by earth brought in by carts, by which means the fill was completed. But the dam always leaked badly, as might have been expected. With but a few feet of water in the pond there was a stream of 1 second-foot passing under the dam, issuing from the broken waste-box. This at first ran muddy, but afterwards diminished and became clearer as the result of sluicing in material from the hillside upon the upper toe of the dam. Later, when the pond was filled, there was more leakage through the material deposited by carts than through the stratified material that was sluiced into position.

After the second failure the building of a dam was abandoned, and the ravine was crossed with a flume.

The case is cited as an example of the misuse of a most favorable opportunity for building a permanent construction with the greatest possible economy and with the best of materials for lack of experienced and intelligent supervision. The work was done without an engineer, by a so-called "practical" contractor, upon whom fell the entire loss.

General Principles of Hydraulic-fill Dam Construction.—From the various experiences in actual works detailed in the foregoing pages, the general principles involved in successful dam building by the hydraulic process may be gleaned, or inferred by the careful reader, but to make these principles clear the conclusions of the author from his personal experiences and years of observation are summarized as follows:

Materials.—The material best adapted for hydraulic-fill dams is an admixture of rounded bowlders, of all sizes that can be transported with the water and grades available, gravel, sand and clay, the latter to comprise 10% to 30% of the whole. The rounded rocks roll more readily than angular stone, and create less wear and tear in the pipes or flumes used to transport them while the clay acts as a lubricant to assist in transporting the heavier materials.

The most difficult material with which to build such a dam is pure clay unmixed with sand, because it is unstable until the water conveying it is drained from the mass, and if the entire embankment is formed of clay its complete drainage and maturity to a solidified mass is a slow process. Shrinkage is much greater in clay than in all other materials, and there is greater likelihood of the opening of cracks during the process of maturing. The difficulties of maintaining the slopes during construction are also greatly increased by the absence of coarse materials on the slopes, as in the Lake Frances dam. However, as is truly said by a good authority, "Wet clay under pressure will part with its water even though the mass be entirely surrounded by that liquid," * and when finally consolidated, as it will become within a reasonable time after being deposited under water, it makes a dam which can have no superior for water-tightness and solidity.

The preferable use of clay in a hydraulic-fill is as a core between overlying, overlapping masses of sand, gravel, and rock, which rest upon the clay and exert such constant pressure upon it as to assist in squeezing out its surplus water, for which the porous rock affords required drainage. In this condition clay, no matter what its original character, whether it be a "fat" clay, subject to excessive shrinkage, or a clay which readily slacks when exposed to the weather, will mature and ripen to a condition where it will neither absorb water or permit of percolation through it. Surface clays and soils which are thoroughly weathered are preferable to deep-seated clays in beds of such depth as to have undergone few of the changes produced by the action of the elements. In the opinion of the author, fine sand, glacial flour, rock dust, or any finely-pulverized non-plastic material is really preferable to clay as core material for a hydraulic-fill dam, for the reason that when settled in water it is not subject to shrinkage or further settlement, and is practically impervious to water if the particles are fine enough to pass a 100-mesh sieve. A combination or admixture of clay and fine sand is still better and less subject to shrinkage than pure clay.

Stratification.—An important feature of construction is the avoidance of the deposit of the material in such a manner as to permit strata of coarse sand and gravel from passing through the dam, giving porous passages from side to side. This may be regulated and controlled by an even distribution of the material along the slopes, avoiding the formation of high cones, extending beyond certain safe limits toward the core, and by keeping the pond on the dam as high as possible at all times. It is observed that sand and gravel with a lubricant of clay will take a natural slope of 5% to 8%, but on passing into the quiet pool will drop and deposit at a slope of about 1 on 1, while the clay spreads through the water practically level.

Contact with Foundation.—The preparation of the foundations by stripping all loose and porous material from at least the center third of the base down to impervious bed-rock, hard-pan, or clay is the first essential to secure a satisfactory contact with the foundation. In case the base material should be of the least doubtful character or show in test pits that there may be porous strata beneath the stripped surface, one or more trenches, extending longitudinally parallel with the center

* "Clays, their Occurrence, Properties and Uses," by Heinrich Ries, Ph.D. New York, John Wiley & Sons, 1906.

line should be excavated to the depth required to give reasonable assurance of impermeability, or that the porous strata may have no direct connection with the reservoir above so as to permit of water passing beneath the dam. This trench should then be filled with a dense quality of concrete, and the core-wall carried a sufficient height above the stripped surface to enable the clay core material to envelop and form a bond with it as the plastic matter settles and consolidates. In some cases, as in dams of moderate height, not over 50 feet, the concrete may be omitted entirely and the trench allowed to fill with the natural puddle of the sluiced material. Where the foundation is clay, hard-pan, or rock overlaid to a considerable depth by permeable sand and gravel which would be expensive to excavate, a satisfactory joining with the impervious base may be made by driving a continuous line of sheet-piling from end to end of dam through all porous matter into the base material.

Should the hydraulic-fill be lacking in impervious material it is good modern practice to build a reinforced concrete core-wall through the body of the fill, founded on the sheet-piling below.

Concrete or Masonry vs. *Clay as a Core-wall.*—The essential difference between the practice of English and American engineers in the building of ordinary earth dams is that the former rely for water-tightness on a specially prepared puddle core-wall of clay in the center of the dam, deeply founded in a trench below the lowest surface, and carried up to the original surface in form of a widening wedge, which narrows thence to the top of the dam. American engineers, on the contrary, seldom use clay in this manner, either because of its scarcity and high cost of the quality desired, or for other constructive reason, but prefer a central core-wall of masonry or concrete backed on either side by the most impervious material available well rolled in layers. Investigations made of a number of these dams of the best American types a few years since revealed the fact that the core-walls are seldom water-tight. Mr. E. Sherman Gould, late M. Am. Soc. C. E., in commenting on the revelations of the borings made in various high earth dams during the investigation of the new Croton dam by Messrs. Croes, Smith, and Sweet, in 1901, says:* "It is to be feared that in many cases the masonry center walls of earth dams are built too light. They should be more than mere diaphragms: they should be *walls* in fact as well as in name. My own rule is to give the center wall a bottom thickness equal to one-quarter of the greatest depth of water in the reservoir, and to draw in by offsets 2 feet in every 10 feet of height. I would never

* *Engineering News*, February 9, 1902.

voluntarily reduce this thickness, although I might increase it, except perhaps to draw in more rapidly near the top in the case of a very high wall."

This expression represents the extreme of conservatism from the standpoint of the American engineer. The way in which masonry or concrete core-walls are regarded by English engineers is partly expressed by the language used by the late James Mansergh, F.R.S., when President Institution of Civil Engineers, in an address to the society, in which he said: "I am not sure that such a core may not be made from end to end of an earth dam, if very special precautions are taken by well rolling the bank to insure that *unequal settlement* or *surging* does not take place. *I have never yet ventured to try it,* but if I do not get nervous as I grow older, I may some day." Reginald E. Middleton, M. Inst. C. E., of London,* writes on this subject: "Where masonry alone is used, should there be any movement in the bank, the wall will be fractured, serious leakage may take place and the dam be so much weakened thereby that its unforeseen destruction may result, and it is exceedingly difficult to make a thin, or even a thick, masonry wall perfectly water-tight."

Hydraulic-fill dams offer a safe and satisfactory middle ground of compromise between the American earth dam with concrete core-wall or diaphragm and the English type of earth dam with its elaborate mixed and tamped puddle-wall of selected clay. By no other process can such a large proportion of the entire dam be made of puddle clay at practicable cost.

The apparent effect of hydraulic sluicing upon most soils, the natural process of sorting out the finer particles, is to produce a clay of marked uniformity. Mr. Joseph Morgan, consulting engineer, Cambria Steel Works, Johnstown, Pa., in making a series of analyses of core material from various hydraulic-fill dams in widely separated sections of the country, noticed a curious similarity between them, and first called attention to it in correspondence with the author. The analyses were practically identical, except in the absence of sulphur, with those of average English blue clays, which show the following ratio of constituents:

Silica	63.35
Alumina and iron	18.50
Lime	6.60
Sulphur	4.32
Loss by ignition	7.23
	100.00

† *Engineering Record,* March 29, 1902.

It would seem from these analyses that the natural result of the process is the automatic segregation and deposition of puddle clay of a quality equal to the best puddle-core material used in English dam construction, at a small fraction of the cost. This being true no other core-wall can possibly be required. There have been no failures of earth dams on record within the knowledge of the author due to the lack of water-tightness of the puddle-core.

The hydraulic process, therefore, affords the means of segregating and assembling the puddle-cores from all classes of soils, and when intelligently employed will make a safe dam from the most unpromising materials.

Limiting Height of Hydraulic-fill Dams.—The highest earth dam in the world, the San Leandro dam, near Oakland, California, is but 125 feet from base to crest, and this was partially constructed as to exterior slopes by the hydraulic-sluicing process. It is without masonry core-wall. Until within the past few years engineers have been inclined to consider 100 feet as about the safe limit of earth dams. The author does not subscribe to this doctrine, but believes that nature has given too many examples of glacial lakes many hundreds of feet deep formed by dams of moraine deposits to discourage the engineer from building earth embankments by the improved hydraulic process of any height desired, limited only by practical considerations of cost and time required for construction, provided suitable conditions are presented. E. Sherman Gould, M. Am. Soc. C. E.,* touched the keynote to this question in the following: "It would seem that whatever water gets into an earth bank must be introduced by simple soakage, *the pressure exercising but a slight influence upon the penetration beyond a small depth.* If this view be correct, then it appears reasonable to suppose that the greater the mass of earth the less danger of its being saturated by the water, which, as the area increases approximately as the square of the height, would lead to the conclusion that as far as soakage is concerned the higher the dam the less liability is there of general saturation."

In its applicability to the design and construction of high hydraulic-fill dams the author indorses the following editorial expression of *Engineering Record* (vol. 46, p. 121): "With reasonable care in founding an earth embankment upon such solid and impervious foundation as rock or its equivalent for such a purpose, and with other features so designed as to shut off absolutely the flow of water underneath and with a practically impervious bank, which it is perfectly practicable

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* *Engineering News*, February 20, 1902.

to attain, guarded with pavements on both the up-stream and down-stream sides if advisable, *there seems to be no basis as yet on which a limiting height of earth dam may be placed.* The design of these structures has been born of conditions under which they have been imperative, as the expense of solid masonry work would have been prohibitive. They have served sound engineering purpose, and they point the way to further economical development of high dam construction under circumstances where earth embankments, or even earth embankments combined with rock-fill and other accompanying features of design are justifiable by the canons of the best engineering practice." In the author's opinion there is no limit, except one of cost, to the height to which it is possible and safe to build hydraulic-fill dams, provided they be made of sufficient dimensions to fulfill the simple requirement that frictional resistance to the passage of water shall be practically insuperable, or if water in moderate amount does find its way through the mass, that it shall be robbed of all velocity and power to transport any of the particles of the embankment with it, issuing clear as water issues from a filter.

Drainage.—The stability of hydraulic-fill dams as well as that of, all earth dams, depends to a large extent upon the proper drainage of the down-stream portion of the embankment. Unless the lower third of the foundation consists of gravel, loose rock, or other porous material, through which water will percolate freely, artificial drains should be provided to lead the water draining from the center third to the outer toe. These drains should not approach nearer the center than the line between the middle and outer thirds of the base, and they should be so prepared as to act in the nature of a filter, grading from fine to coarse, in a way to avoid displacement of the core material during the process of drainage and consolidation.

A covered gathering well at the head of each drain, to concentrate seepage, and so arranged as to force the water to rise in the bottom against a certain slight head, boiling up, as in a spring, can be recommended as an efficient and satisfactory device. The well should be surrounded with fine gravel and sand, and when properly made will always be found effective in preventing percolating water from washing out channels through the dam.

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. 141.) 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. 140.—Hydraulic Sluicing, Canadian Pacific Railway. View of Pit, and Hydraulic Giant at Work

Fig. 141.—Hydraulic Fills, partially completed, at Mountain Creek, B. C., Canadian Pacific Railway.

FIG. 142.—HYDRAULIC FILLING OF HIGH TRESTLE AT MOUNTAIN CREEK, B. C., ON CANADIAN PACIFIC RAINWAY, 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. 143.—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. 143, 144, 145, and 146), 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. 144.—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. 145.—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 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. 146.—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."

Mr. Herschel further describes gravel as "a natural mixture of earth and pebbles; of various attributes and consistencies, some of which are good for building dams and some not. The best for that purpose is gravel that will puddle or 'binding gravel.' To tell whether any given gravel would puddle and to judge of its fitness for use in a dam, it should be mixed with water in a pail to the consistency of moist earth, about to be used in a dam or before rolling. If on turning the pail upside down the gravel remained in the pail it was fit for use, but if it dropped out it should be discarded." ‡

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. §

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

† *Ibid.*, vol. xxvi. p. 684.

‡ *Engineering News*, Sept. 6, 1905.

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

Fig. 147.—Site of Cheesman Dam, looking Down-stream

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, 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 maxima 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 tensile 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 fifth edition was issued in New York in 1907. 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 15 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. 148), the three highest and most

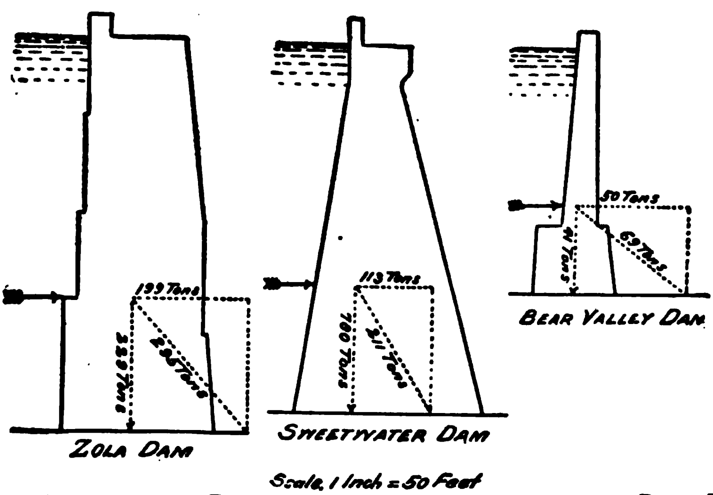


FIG. 148.—COMPARISON OF PROFILES OF ZOLA, SWEETWATER, AND BEAR VALLEY DAMS.

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. (50° 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.

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."

In recent years a number of independent investigations have been made by engineers in different parts of the world in the attempt to determine by experiments with models of dams made of various materials the character and distribution of the stresses on masonry dams. In 1904 Mr. L. W. Atcherley, Stud. Inst. C. E., assisted by Karl Pearson, F.R.S.,* prepared two model dams of a fairly heavy wood cut to the profile which had been used in an actual construction of a dam considered to be mathematically correct in its lines.

In one case the model was divided into a series of horizontal strata and in the second case into a series of vertical strata. In the first case the pull representing the water pressure was communicated by a cord to a stiff lath which bore on the ends of the horizontal strata through two longitudinal strips of india-rubber tube; the attachment of the cord being one-third up the lath and the cord adjusted to pull in a direction perpendicular to the front of the model, so that the resultant force was applied at a point corresponding to the center of pressure of the water. In the case of the model stratified vertically, much the same arrangement was adopted, except that the pull of the cord was applied directly to the first vertical stratum, which included the battered front. The angle of friction of the wood strips on each other varied from 25° to 30°, and a shearing strength more nearly corresponding to the masonry was obtained by pasting tissue paper round the battered fronts and curved flanks of the models.

The weight of a section one foot wide of the dam from which these models were reproduced was 505,000 pounds, and the corresponding water pressure 312,500 pounds. The weight of the horizontally stratified model was 12.40 pounds and of the vertically stratified model was 13.85 pounds. The corresponding value for the pulls representing the water pressure would therefore be 7.70 pounds and 8.57 pounds respectively. Trusting merely to the friction of the wood on wood, the model made up of horizontal layers slid on its base at 5.70 pounds pressure, and the one vertically stratified opened up at the third section from the tail

* *Vide* a monograph "On some Disregarded Points in the Stability of Masonry Dams," Drapers Company Research Memoir. London, 1904.

or up-stream toe, and then the whole thing sheared with a pressure of only three pounds. When the models were strengthened for shearing resistance by tissue paper, as described, the respective pulls corresponding to the water pressure before collapse were 6.5 and 4.2 pounds.

The conclusions drawn from these experiments were that a dam collapses first by the tension on the vertical sections of the up-stream toe; that shearing of the vertical sections over each other follows immediately on this opening up by tension, and that the shear on the horizontal sections is also a far more important matter than was generally supposed. In the case cited from which the models were prepared there probably exist considerable tensions in the masonry amounting to 3 or 4 tons per square foot.

In commenting on these experiments in a commendatory way, Sir Benj. Baker, K.C.B., Past President Inst. C. E., described experiments he had made with models of dams made of jelly with horizontal and vertical lines drawn upon the side to show the location of distortion produced by applying pressure. These indicated that the elastic deformation of the dam was transmitted into the rock on which it was resting for a distance equal to half the height of the dam before it became undetectable. In discussing the paper of Charles S. R. Palmer, M. Inst. C. E., on the Coolgardie Water Supply, in which the construction of the Helena River dam is described,* Sir Benjamin Baker refers to experiments he had made with a number of stiff jelly models of the Assouan dam, with a view to determining some of the problems involved in the contemplated increase of height of the dam. He did not agree entirely with the conclusions reached by Messrs. Atcherley and Pearson. He concluded his discussion by saying:

"The result of experience so far with thermometers buried in the masonry of dams confirmed the common sense view that the different portions of masonry built during the year at varying temperatures settled down finally to uniform temperature in the interior of the dam, while the face-work was affected even by diurnal changes; so that internal strains exist in a dam as in a large unannealed casting. Whatever theory mathematicians might evolve, engineers would not be relieved from the obligation to use no material for dams which would not stand, say 50 tons per square foot in compression and 10 tons per square foot in tension without splintering, and in some cases concrete dams might probably with advantage be partially reinforced with steel bars."

* Proc. Inst. C. E., vol. clxii, p. 125.

More recently, in 1905, experiments have been made on stresses in dams by means of India-rubber models, by John Sigismund Wilson and William Gore, Assoc. M. M. Inst. C. E., who exhibited their model at the Institution in July of that year. A series of weights hung to the base of the model represented gravity, and other weights suspended from cords passing over pulleys and leading to bearings on the up-stream face represented water pressure. The models were made to represent dams with 125 feet of water against them and having a top width of 8 feet, at a height of 4.5 feet above the flow line.

These experimenters confirmed Messrs. Atcherley and Pearson in finding tensile stresses in the up-stream toe of the dam, notwithstanding that they were designed with the lines of pressure well within the middle third, and conclude that to eliminate tensile strains it is desirable to either give greater super-elevation, wider top width, or make the upstream face vertical, so as to bring the center of gravity nearer to the wetted face, or to increase the section materially and back the dam with an embankment of earth on the reservoir side.

Experiments with models of dams made of "plasticine," a kind of modelling clay, were recently made by Sir John W. Ottley, K.C.I.E., M. Inst. C. E., and Arthur W. Brightmore, D. Sc., M. Inst. C. E. The model was 30 inches high, with a base of 26 inches and a length of 12 inches. It was moulded in a frame with plate-glass sides, which were ruled vertically and horizontally with lines scratched on both the glass and the plasticine, and made to coincide. Slight clearance was given between the glass and the model, so that there was no lateral friction to support the clay. Actual water pressure was applied through a thin rubber bag made to fit the face of the dam.

The results of these experiments will shortly be published in the Proceedings Inst. C. E., but it may be stated that they confirm in a general way the conclusions reached by the experiments with rubber models.

These various investigations serve to emphasize the fact that the engineering profession is not fully satisfied with the profile types of dams as they have been evolved by previous mathematical computation, but is still striving to reach a more conclusive and satisfactory solution of the intricate and indeterminate problems of the stresses on masonry dams. Meanwhile the ultra conservative ones pile up masses of materials to greater and greater volumes, and a few of the bolder ones build daring structures that appear to defy all theories of stability.

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. 149 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

Fig. 149.—Old Mission Dam, near San Diego, Cal. The First Irrigation Dam built in the United States.

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 author 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. 150, and its profile is shown in dotted lines in the middle section on Fig. 151. It was built in steps on the back with a view to adding to its height, as was subsequently done. The dam had a maximum thickness of 35 feet at

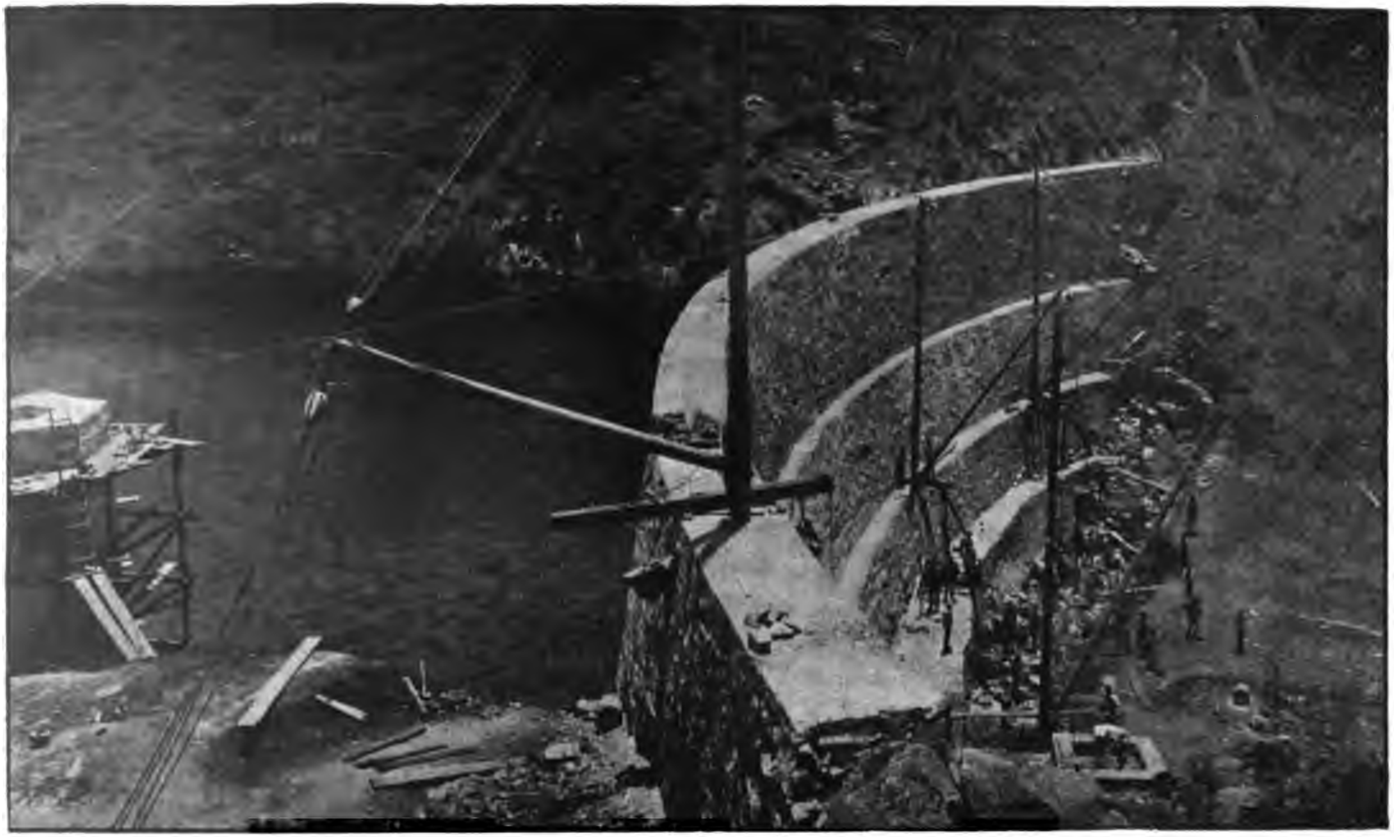


Fig. 150.—Original Sweetwater Dam as Completed to the Sixty-foot Contour.

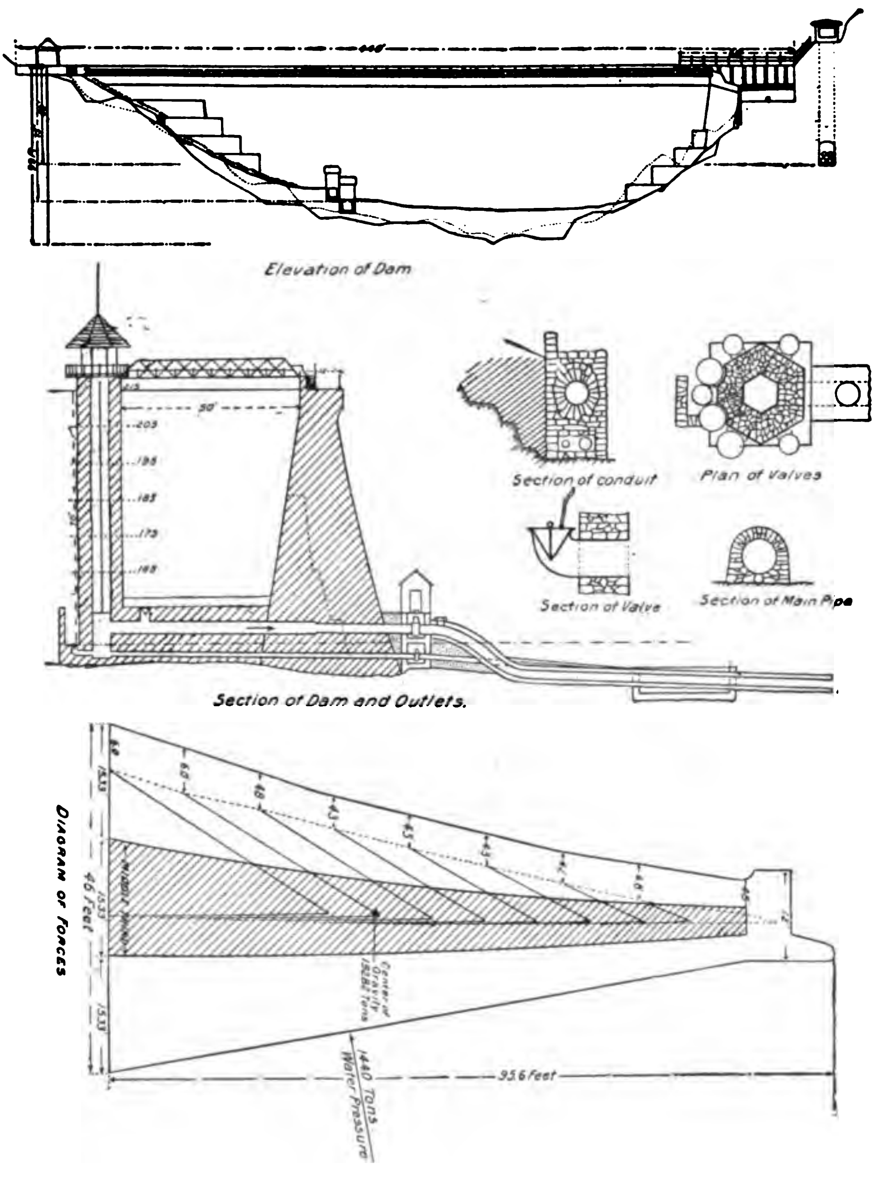


FIG. 151.—ELEVATION AND SECTIONS OF SWEETWATER DAM.

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, placed against the upper side and well tamped in place. A portion of this embank-

FIG. 152.—FACE OF SWEETWATER DAM IN 1899. AFTER TWO YEARS OF DROUTH.

ment above the water-line is shown in Fig. 152, 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. 151. 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. 153), and connected with the dam by a foot-bridge of iron (see Fig. 154).

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, $\frac{1}{2}$ 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 1300 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

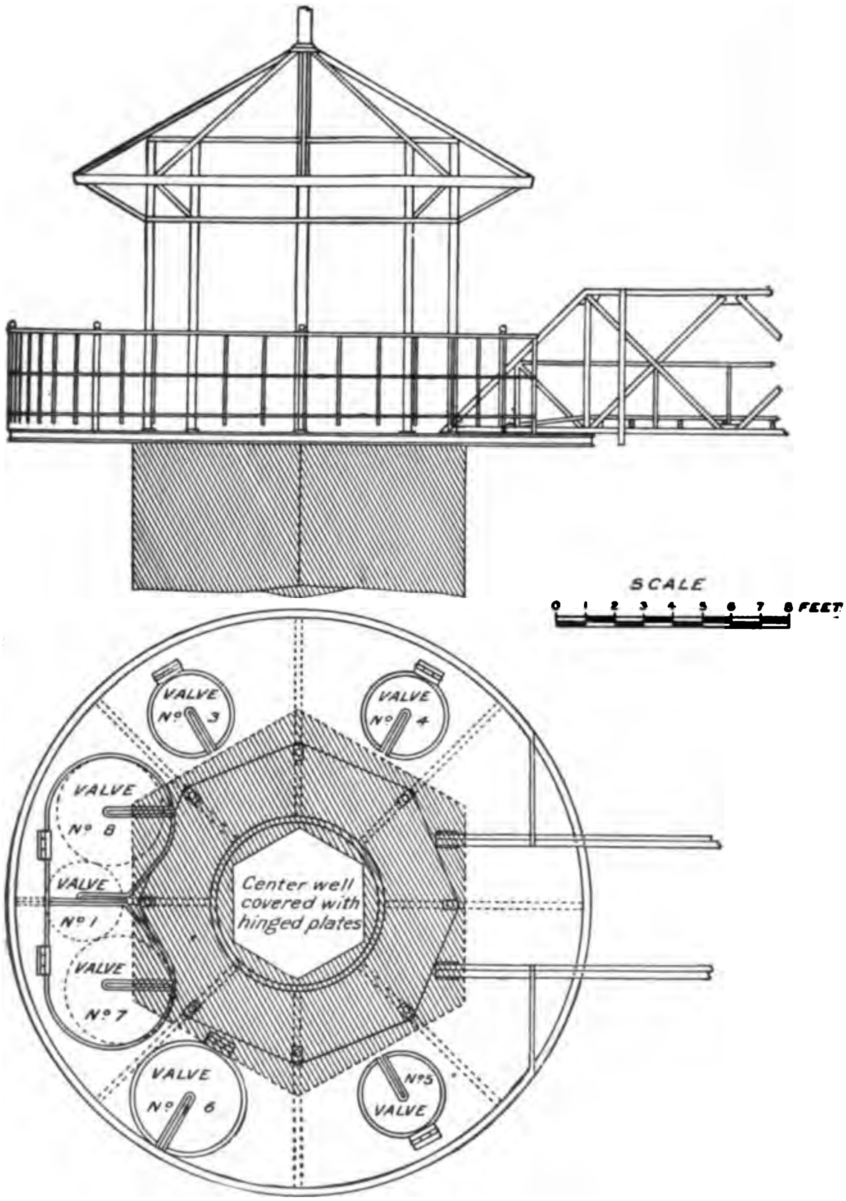


FIG. 153.—DETAILS OF TOWER OF SWEETWATER DAM.

Fig. 154.—Sweetwater Dam as Finished, April, 1888.

FIG. 155.—SWEETWATER DAM DURING THE GREAT FLOOD OF JANUARY 17, 1895.

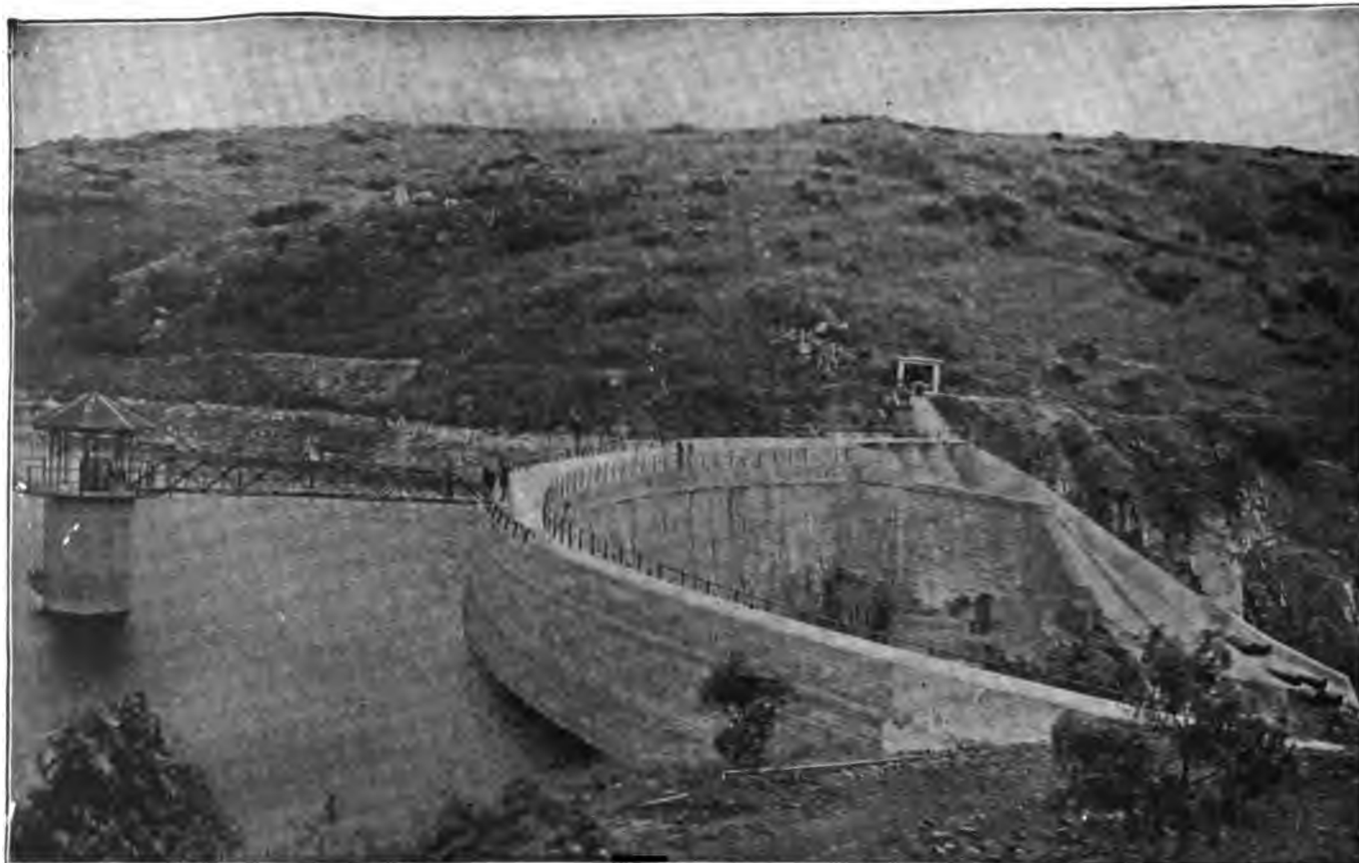


FIG. 156.—SWEETWATER (CAL.) MASONRY DAM.

FIG. 157.—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 bombard ment of the stones rolled down the canyon during the flood uopn the pipeline 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 author 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. 157.

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. 159, 160, and 161). 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. 161.

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

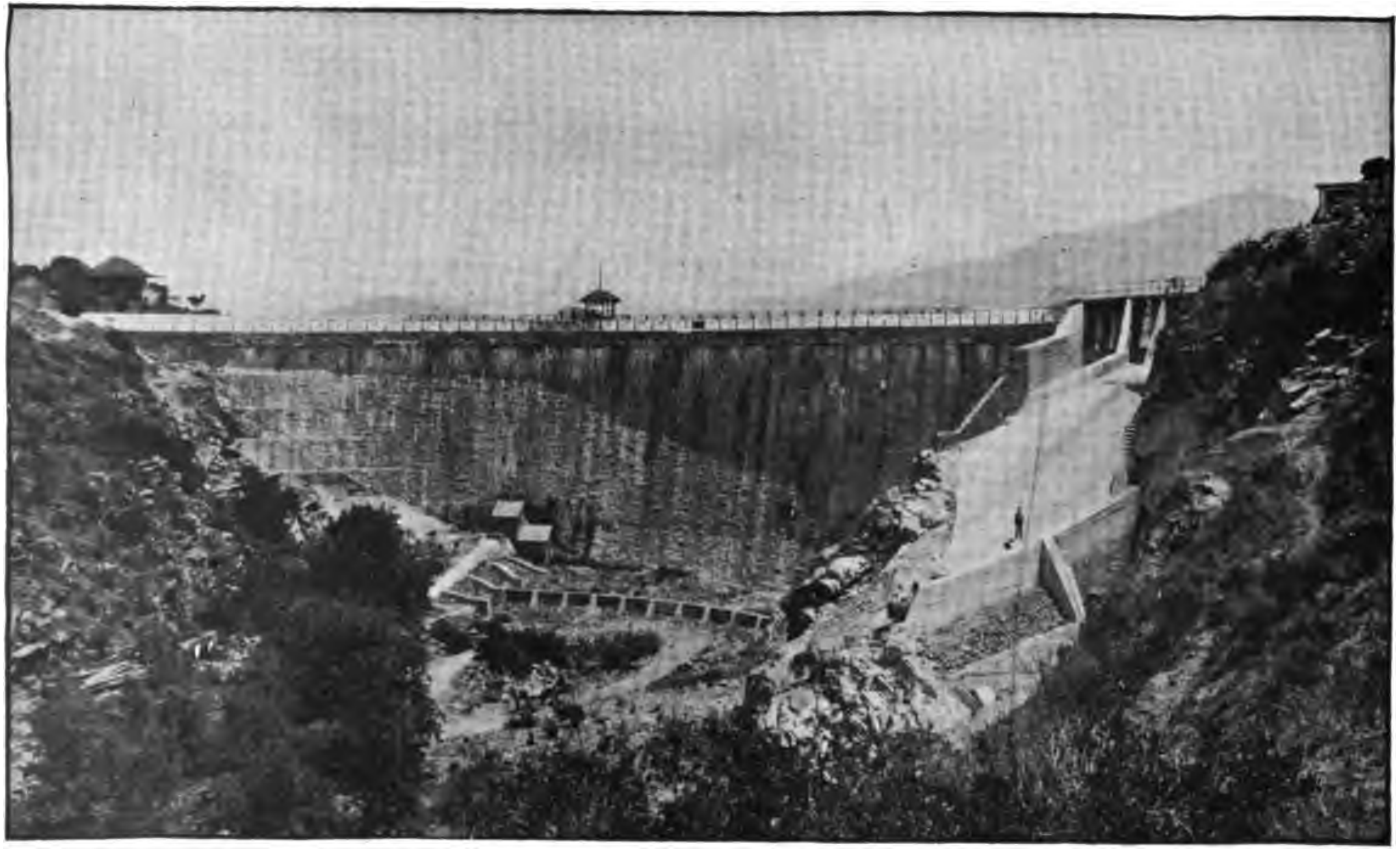


FIG. 158.—SWEETWATER DAM, SHOWING NEW APRON OF SPILLWAY AND PROTECTING SPUR-WALLS ON PIPE-LINE.

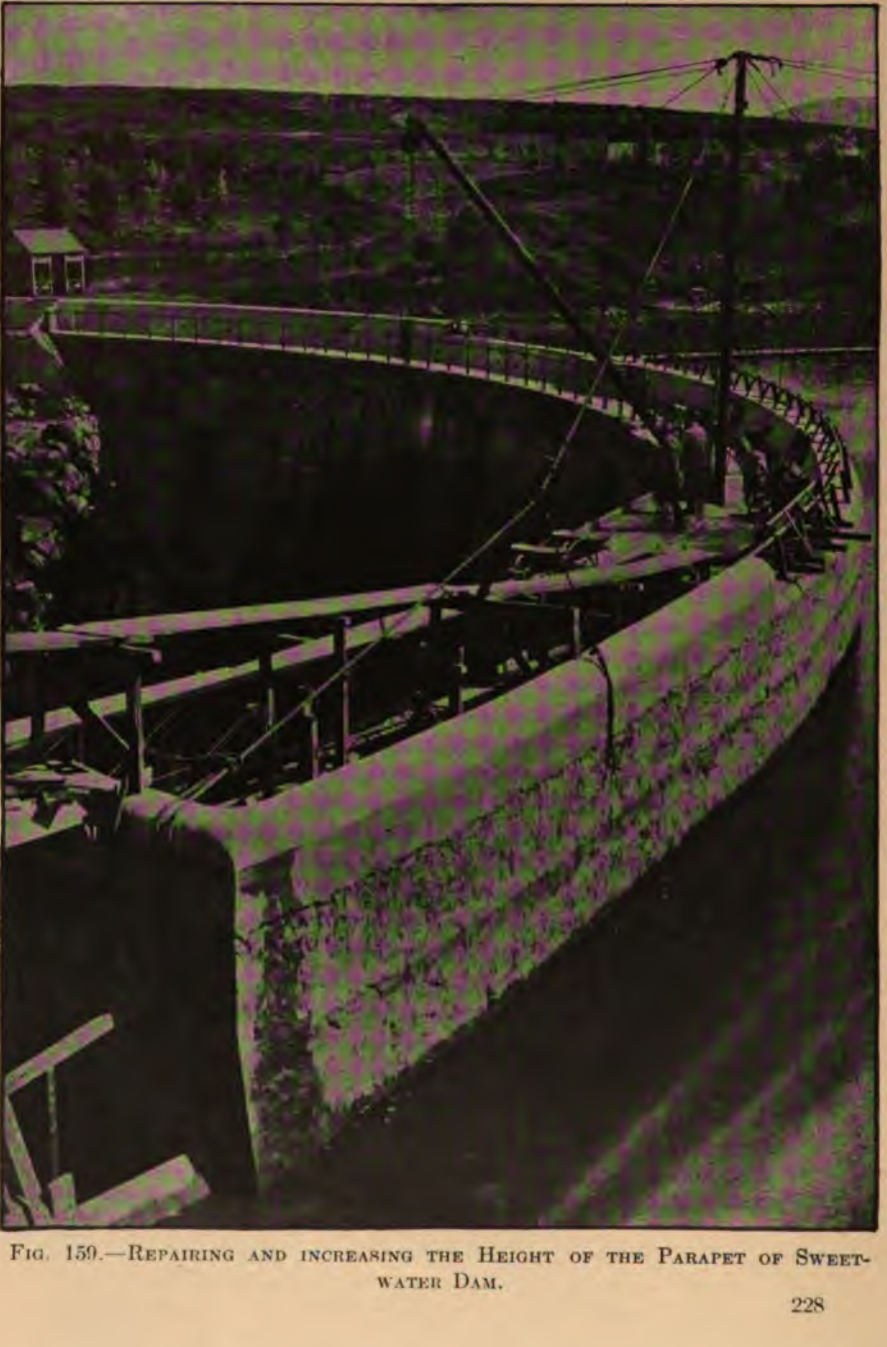


Fig. 159.—Repairing and increasing the Height of the Parapet of Sweetwater Dam.

thickness of 3 feet, and is designed to prevent all future erosion of the bed-rock (Figs. 158 and 162).

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

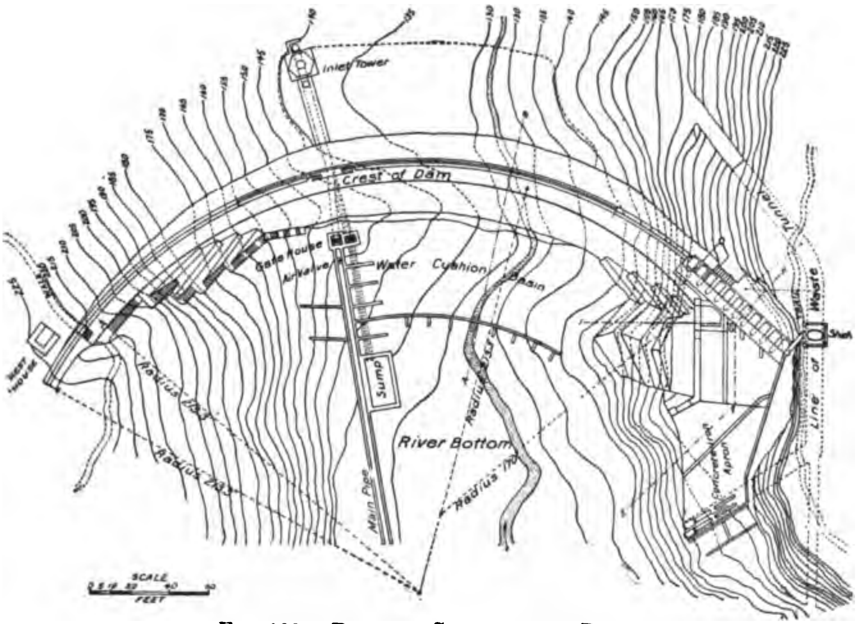


FIG. 160.—PLAN OF SWEETWATER DAM.

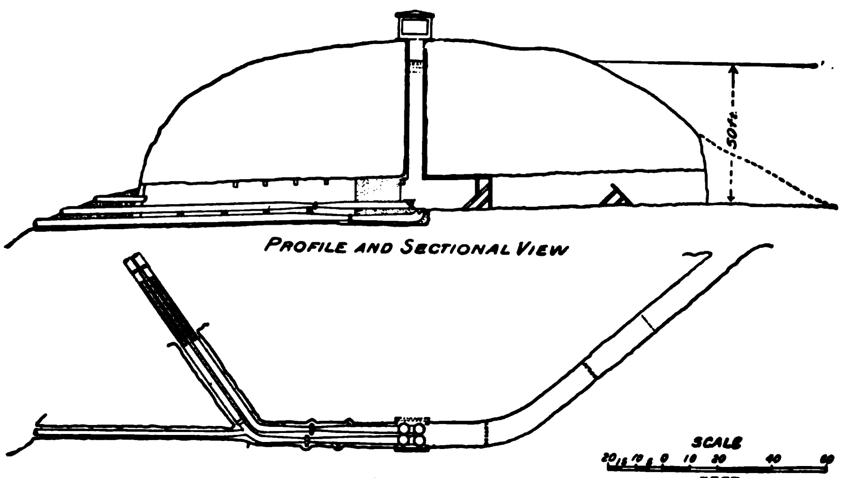


FIG. 161.—PROFILE AND SECTIONAL VIEW AND PLAN OF WASTEWAY TUNNEL, SWEETWATER DAM.

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. 160.

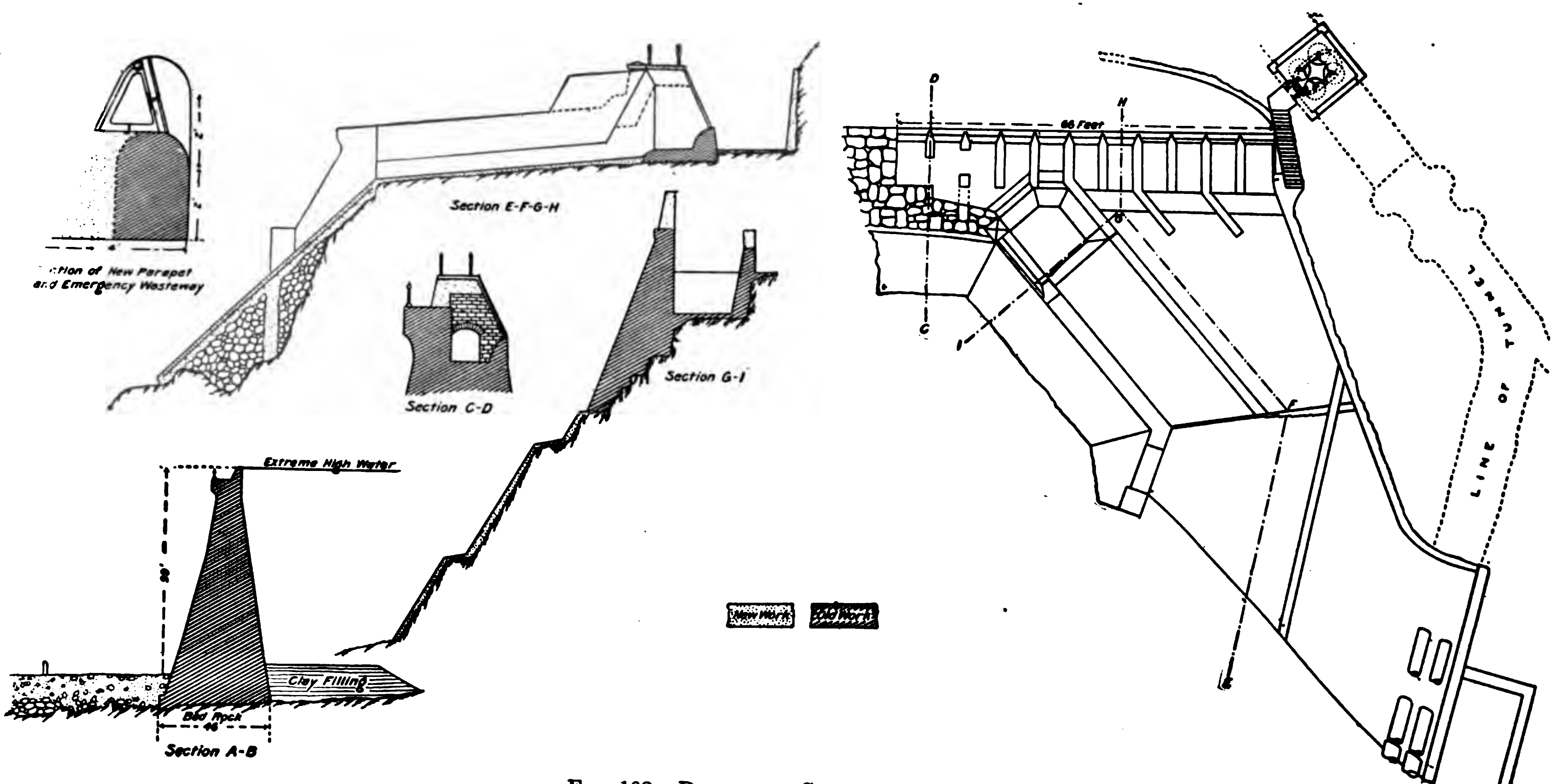


Fig. 162.—Details of Sweetwater Dam.

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. 163.—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	0.5452	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	5.54	0.0	0.0000	0.00
1900–01	7.05	828	0.0061	1.14
1901–02	4.86	0	0.0	0.0
1902–03	5.72	0	0.0	0.0
1903–04	6.39	0	0.0	0.0
1904–05	15.55	13,760	0.1022	19.00
1905–06	15.52	35,000	0.2600	48.35
1906–70	12 88	30,000	0.2228	41.44
Totals	190.46	259,654		
Mean for 20 yrs.	9.52	12,982.7	0.0964	17.93

The average annual run-off for twenty years has been 69.8 acre-feet per square mile of watershed area, while the maximum has been 395 acre-feet per square mile.

Of the entire period of twenty years recorded the run-off has exceeded the capacity of the reservoir in but four seasons. The remaining sixteen seasons have been so far below tthe 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'

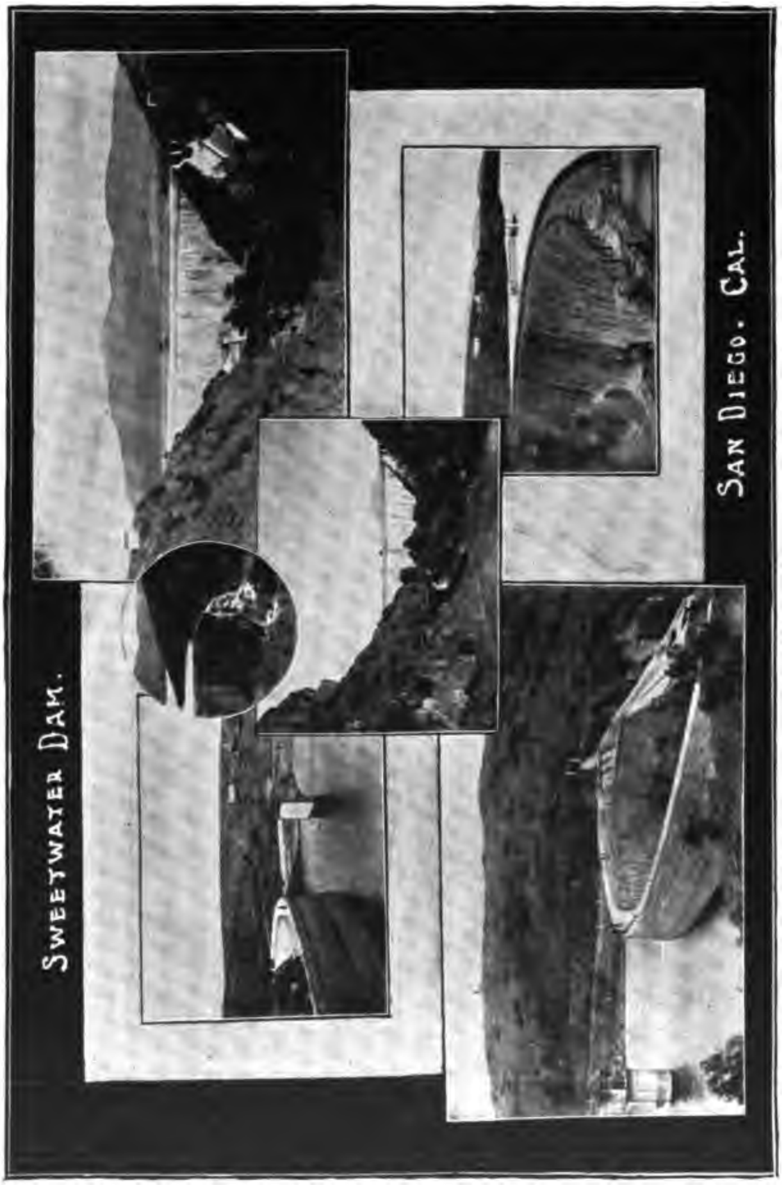


FIG. 164.—SWEETWATER DAM, CALIFORNIA, DURING FLOOD OF 1895, AND AFTER SUBSEQUENT RECONSTRUCTION OF SPILLWAYS.

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 had not experienced a season of sufficient run-off to fill the reservoir, and had 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 3.⅜ 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 they managed 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 the first 12 years was 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 America 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. 165. The view in Fig. 166 is rather an imperfect representation of the appearance of the dam from below. Fig. 167 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

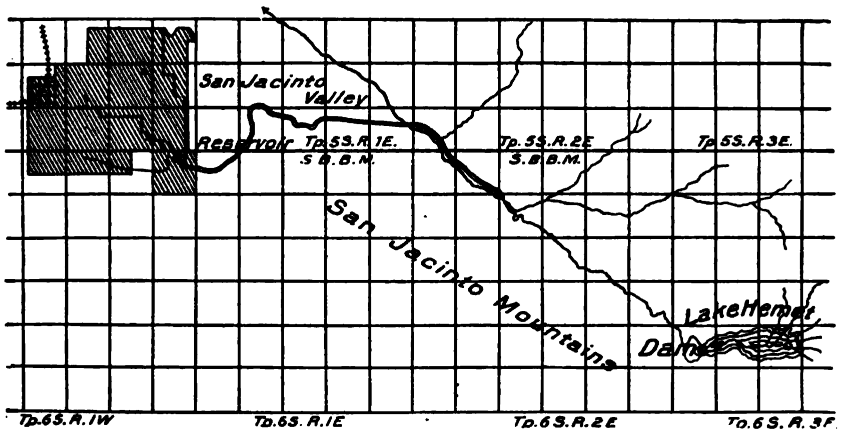


FIG. 165.—MAP SHOWING LOCATION OF LAKE HEMET, THE MAIN CONDUIT, AND IRRIGATED LANDS.

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. 169.

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.

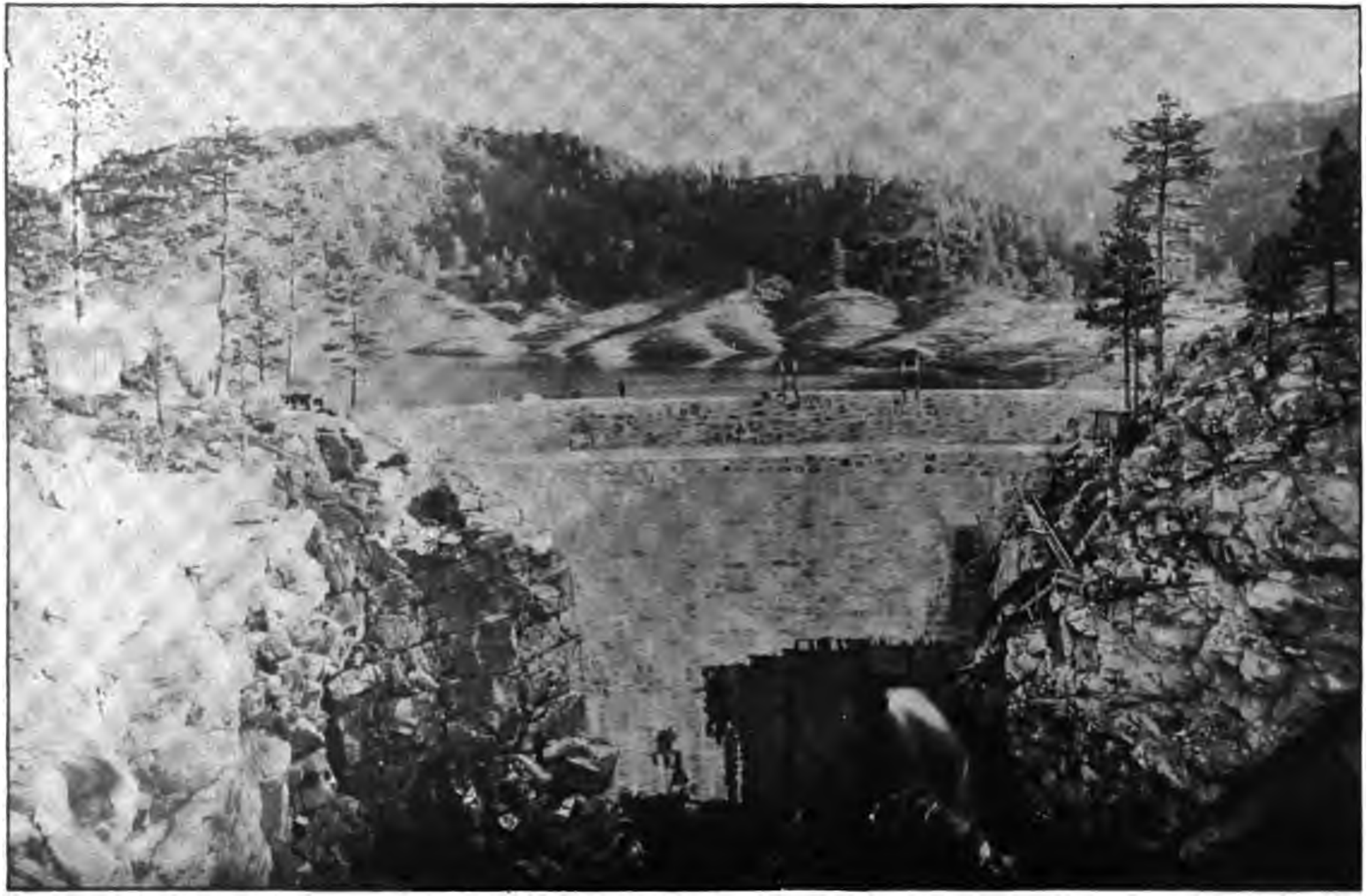


FIG. 166.—HEMET DAM, RIVERSIDE COUNTY, CALIFORNIA.

FIG. 167.—HEMET DAM AS FINISHED, SHOWING THE SPILLWAY RIDGE SOUTH OF THE DAM.

FIG. 168.—CONTOUR MAP OF THE LAKE HEMET RESERVOIR.

170 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

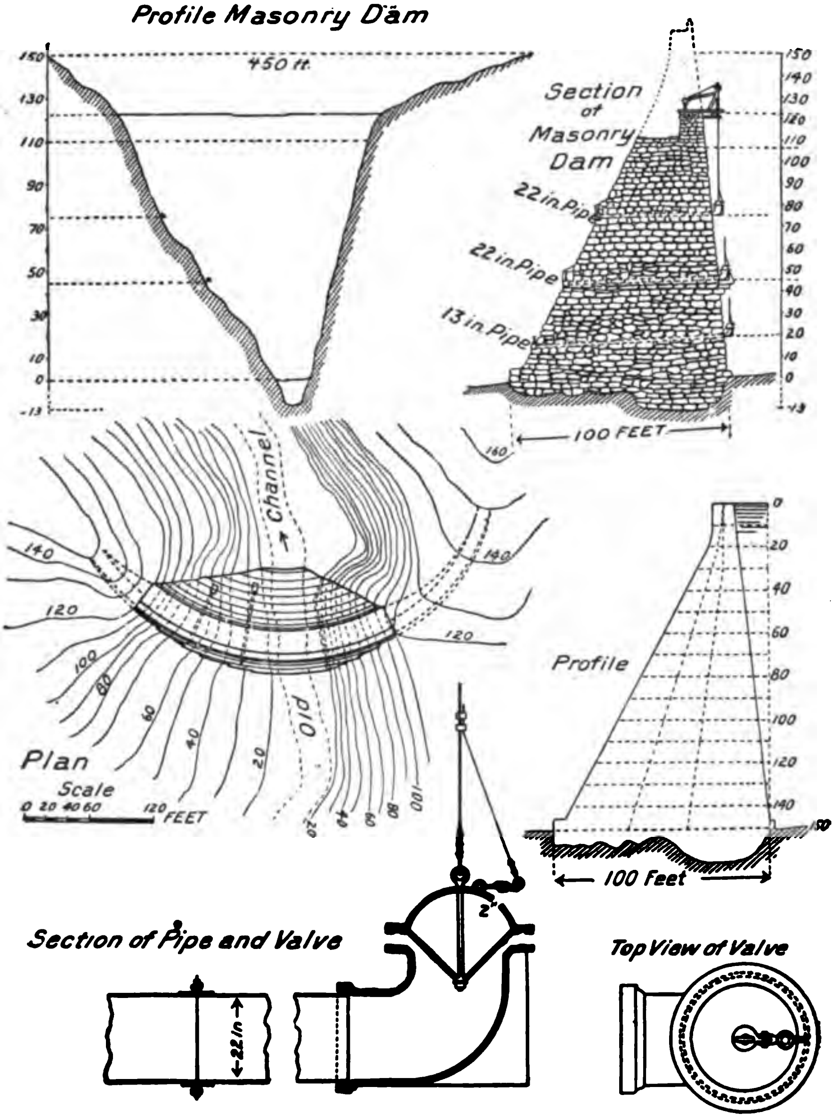


FIG. 169.—HEMET DAM, RIVERSIDE COUNTY, CALIFORNIA.

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. 170.—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 fraternity the "eighth wonder of the world," and has no parallel on the globe. The dam has no stability to resist water-pressure except that due to its arched form, and it has been expected to yield at any time, although it has successfully withstood the pressure against it for fifteen years, and is apparently as stable as it ever was. The probabilities are that nothing but an extraordinary flood or earthquake, or a combination of unusual movements, will ever accomplish its destruction. Such vast interests are now dependent upon the water stored by the dam that its failure would be a public calamity, greatly to be deplored. The settlements of Redlands, Crafton, and Highlands, which are among the choicest of the orange-growing regions of southern California, and the irrigation districts of Alessandro and Perris, are the outgrowth of this water-storage, although the Perris district receives but a small portion of its supply from this source. Prior to the construction of the dam in 1883–84, the natural streams entering the San Bernardino Valley had been entirely appropriated and used in irrigation, and had apparently reached the limit of their irrigable duty. No storage-reservoirs were then in service, and the creation of the Bear Valley reservoir for conserving the flood-waters of the Santa Ana River has more than doubled the area of land irrigated previous to its construction in the territory covered by its water, and has increased the valuation of property in far greater ratio The useful function of the storage-reservoir was never more fully exemplified than in this case. The Bear Valley dam was designed and built by F. E. Brown, C.E., a graduate of Yale Scientific School. The construction of the dam was a bold and difficult undertaking, as it was the pioneer enterprise of California for irrigation-storage, and the site is in a remote locality, to which the cement, tools, and supplies had to be hauled over a rough mountain-range from San Bernardino, descending on the opposite side to the Mojave Desert and again climbing the mountain to Bear Valley, a total distance of 70 miles. The cost of hauling cement was $10 per barrel, and its total cost delivered was $14 to $15 per barrel. Under such conditions, and with a scarcity of funds for what was considered a questionable experiment, it is not surprising that economy of masonry was practiced to such an extent that it is quite without a parallel for boldness of design. The dam is curved up-stream with a radius of 335 feet, and is 64 feet high from base to crest. The length on top is about 300 feet, and the thickness but 2.5 to 3 feet on top, and 8.5 feet at a point 48 feet below the crest, where it rests on a base of masonry that is 13 feet wide, making an offset of about 2 feet on each side at the center; but as the base was built with a curve of shorter radius than the upper 48 feet of the dam, the offset is not uniform, but tapers to nothing on the waterside at the ends of the base, and is fully 4 feet wide on the back. The lowest foundation of the base is 20 feet wide, as shown in Figs. 168 and 169. The entire dam contains about 3400 cubic

FIG. 171.—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

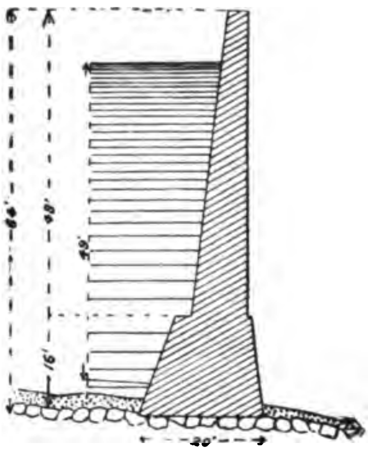


FIG. 172.—CROSS-SECTION OF BEAR VALLEY DAM.

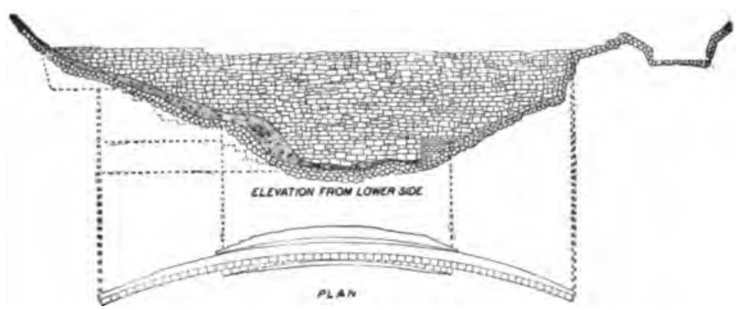


FIG. 173.—PLAN AND ELEVATION OF BEAR VALLEY DAM.

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. 170. 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. 175).

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

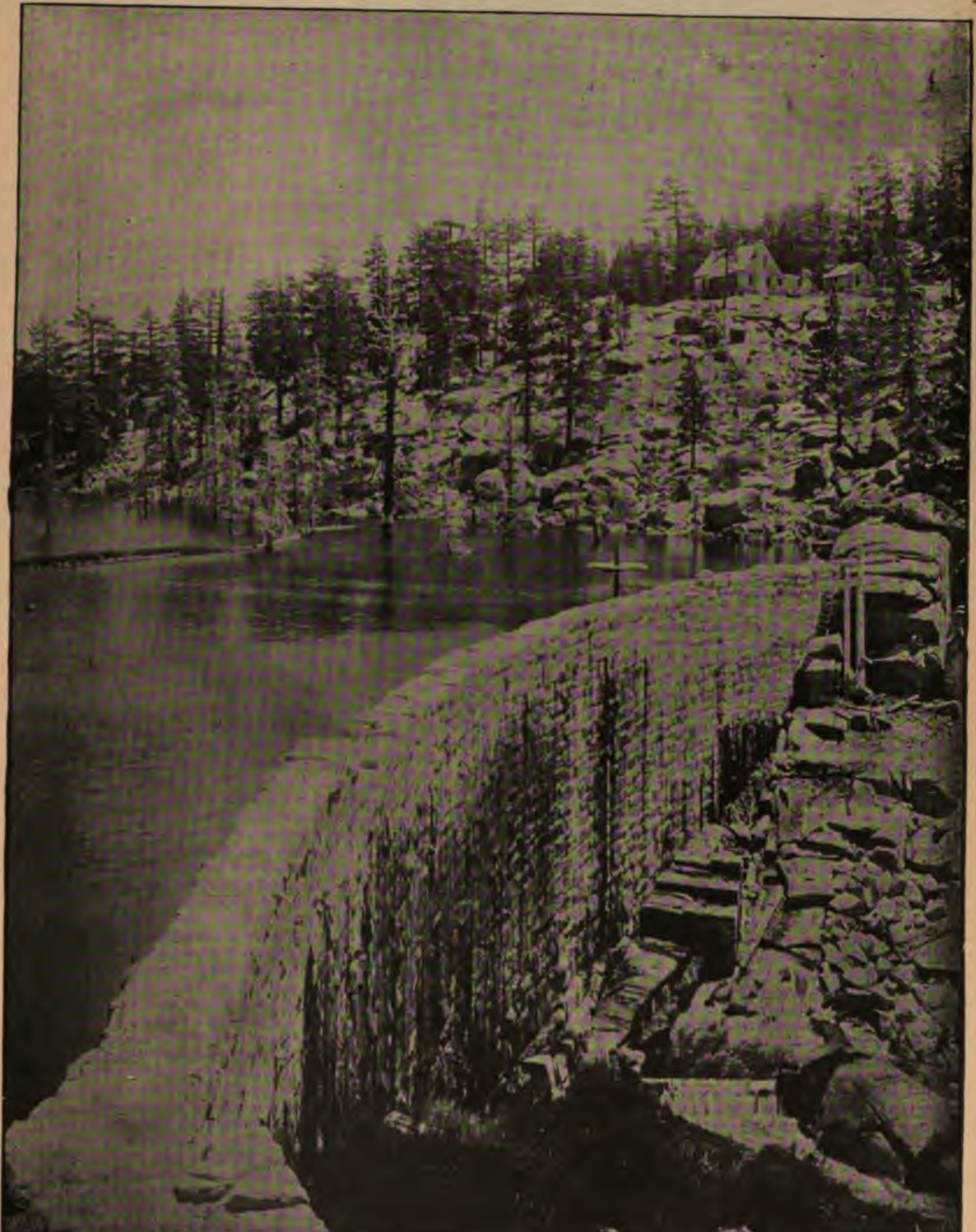


FIG. 174.—BEAR VALLEY DAM, LOOKING SOUTH, TOWARD SPILLWAY

Fig. 175.—Spillway of Bear Valley Dam, with Flashboard Gates.

Fig. 176.—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. 176). 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

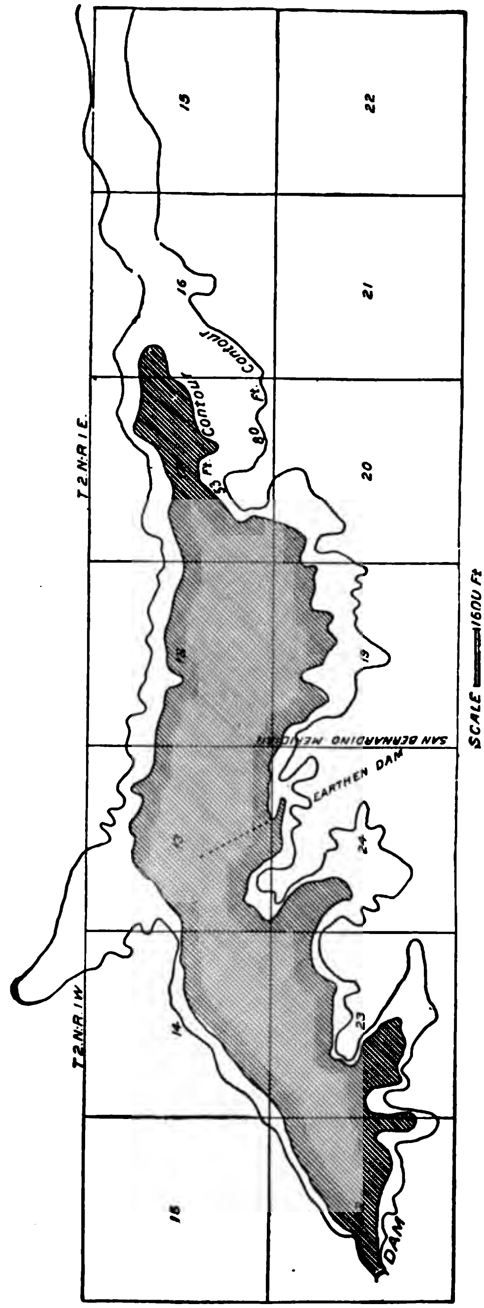


FIG. 177.—MAP OF BEAR VALLEY RESERVOIR.

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. 177.

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.

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 $\frac{1}{2}$ 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.

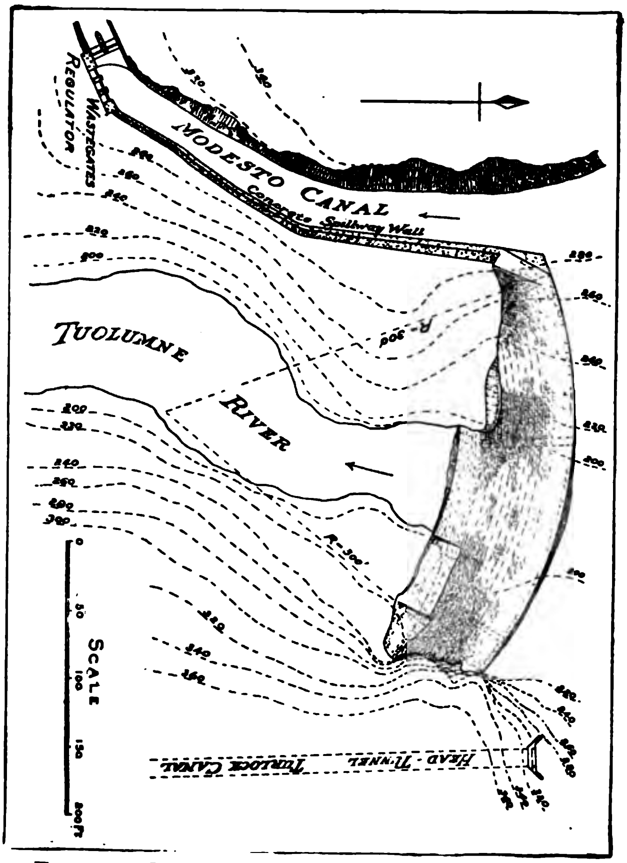


FIG. 178.—PLAN OF LA GRANGE DAM, CALIFORNIA.

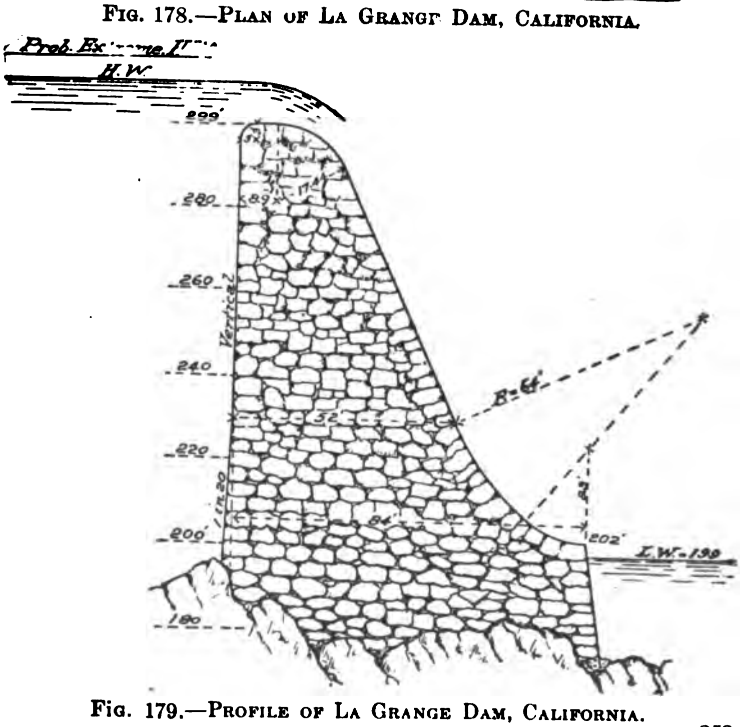


FIG. 179.—PROFILE OF LA GRANGE DAM, CALIFORNIA.

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. 180.—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

FIG. 181.—LA GRANGE DAM, CALIFORNIA, DURING CONSTRUCTION—FINISHING THE CREST.

FIG. 182.—LA GRANGE DAM, CALIFORNIA.

Fig. 183.—La Grange Dam, California

Fig. 184.—La Grange Dam, California, during Flood.

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.

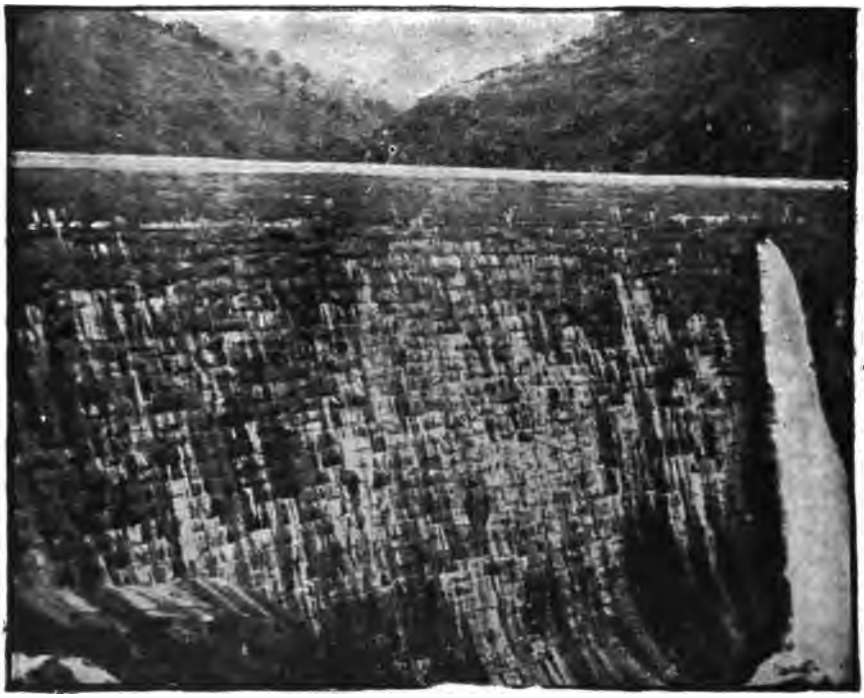


FIG. 185.—LOWER FACE OF LA GRANGE DAM.

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. 180 to 185 are 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

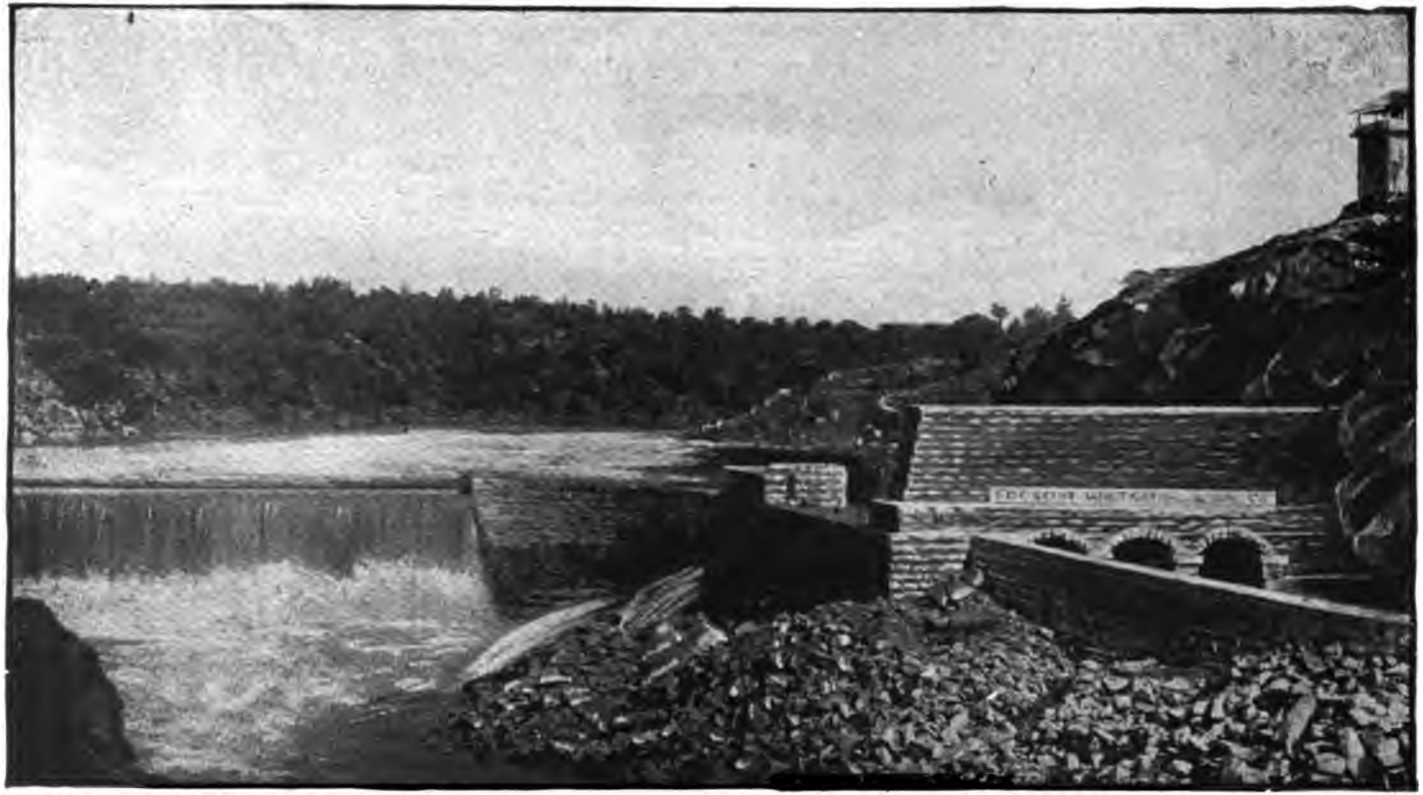


Fig. 186.—View of Masonry Dam on American River, California, at the Folsom State Prison, showing Canal Head-gates. Dam built by prison labor.

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. 187, and a photograph taken by a convict during construction is given in Fig. 188.

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. 189, 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.

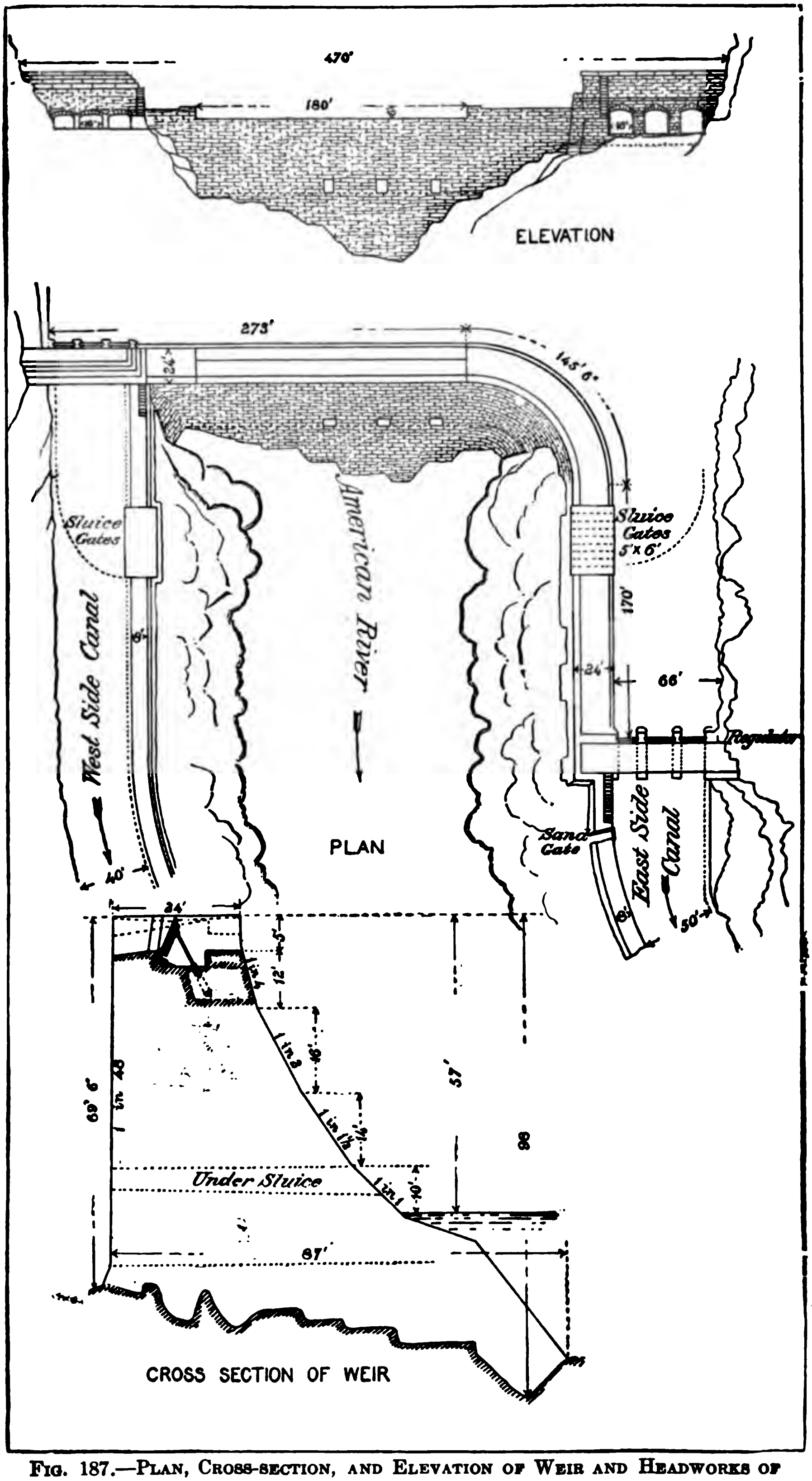


FIG. 187.—PLAN, CROSS-SECTION, AND ELEVATION OF WEIR AND HEADWORKS OF FOLSOM CANAL.

Fig. 188.—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.

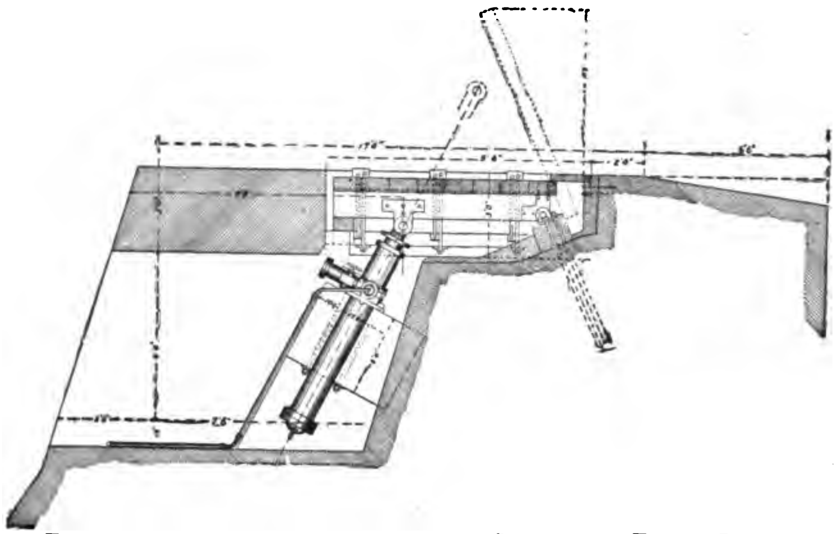


FIG. 189.—HYDRAULIC JACKS FOR RAISING SHUTTER ON FOLSOM DAM.

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. 190. 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, $6\frac{1}{2}$ parts broken stone, and $\frac{2}{3}$ 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. 192 and 193 show the general method of forming the blocks and preparing them to receive fresh concrete, and Fig. 194 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. 191. 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

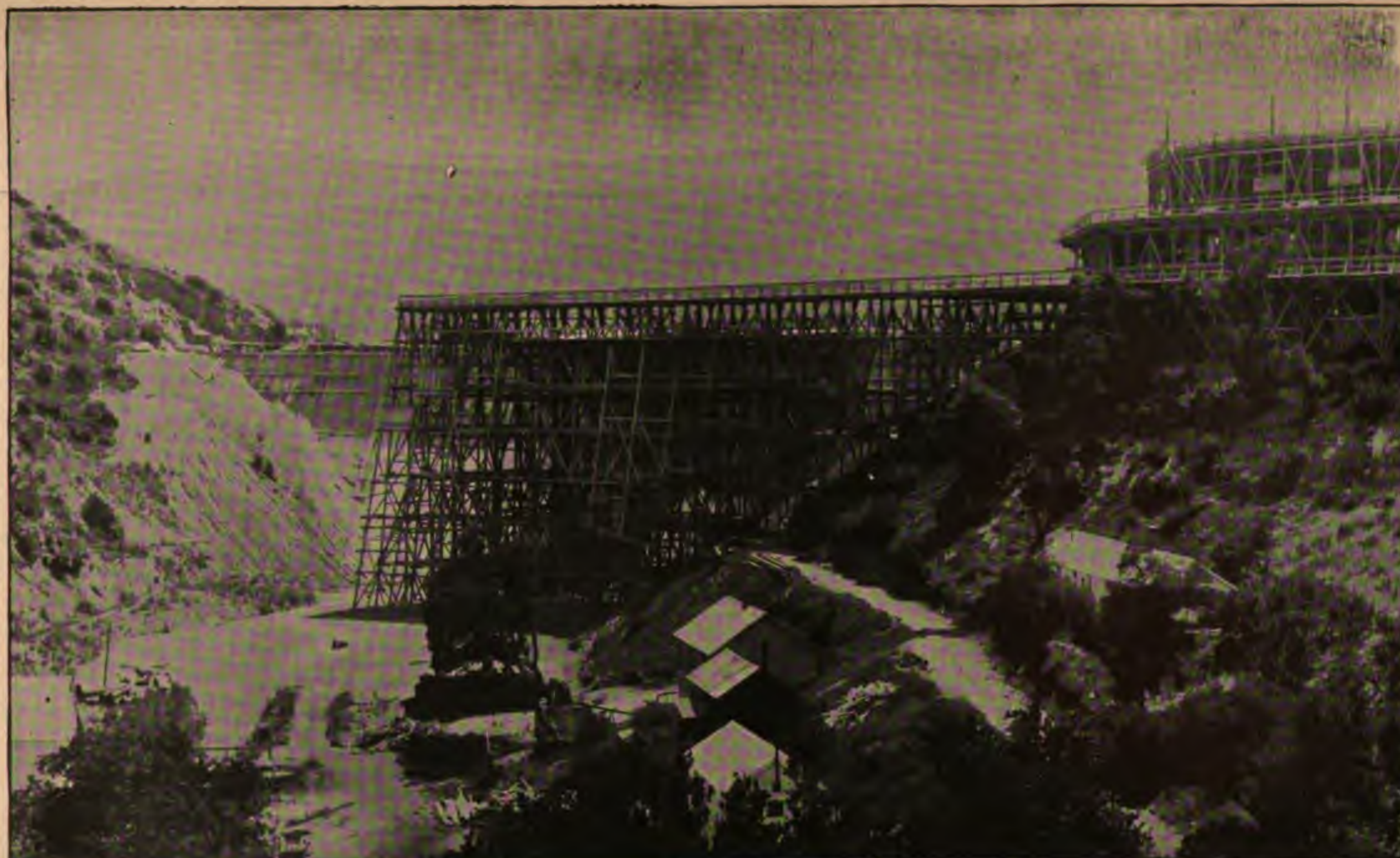


Fig. 190.—Plant for Mixing and Handling Concrete at San Mateo Dam.

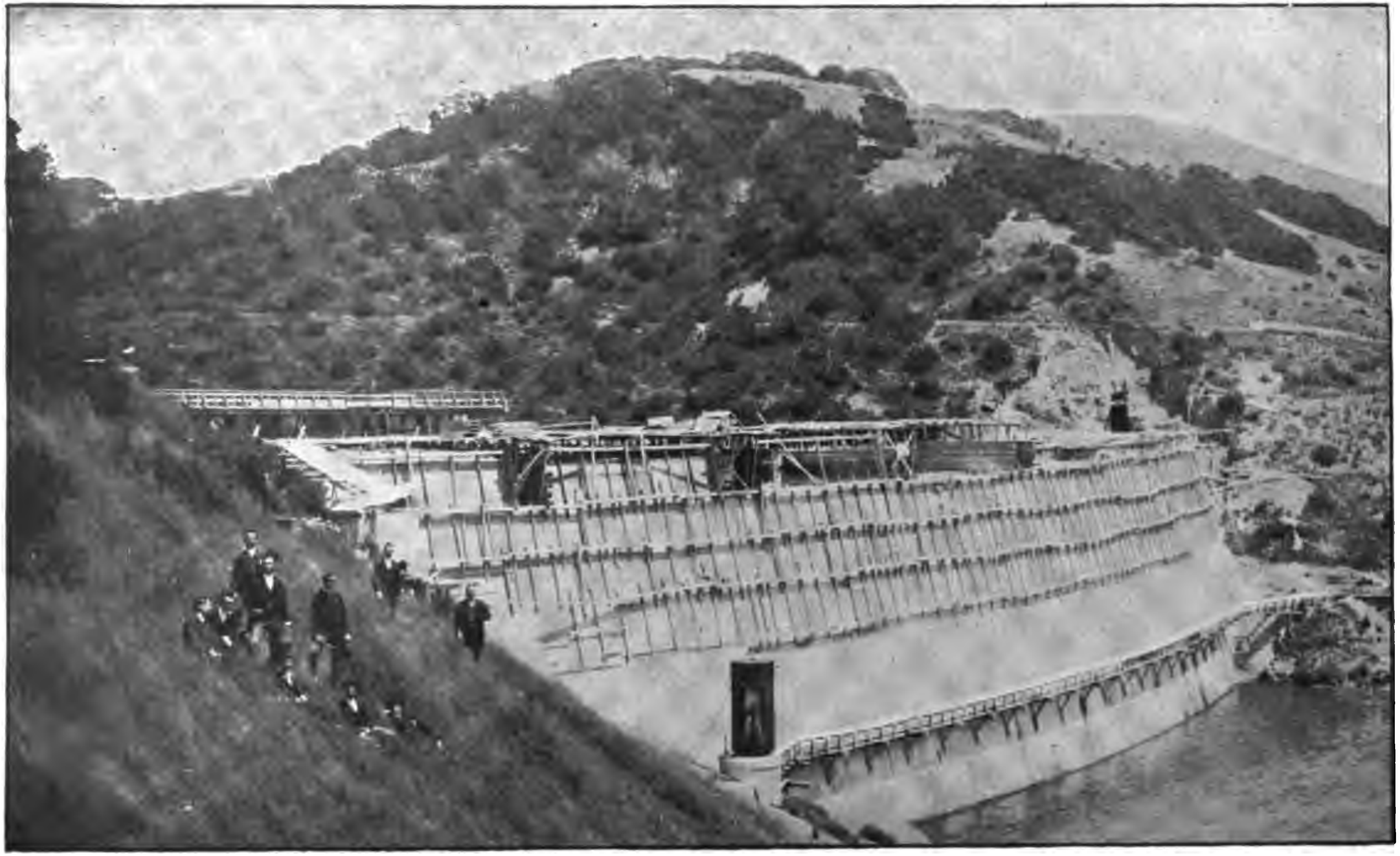


FIG. 191 —CONSTRUCTION OF INTAKE OF SAN MATEO DAM.

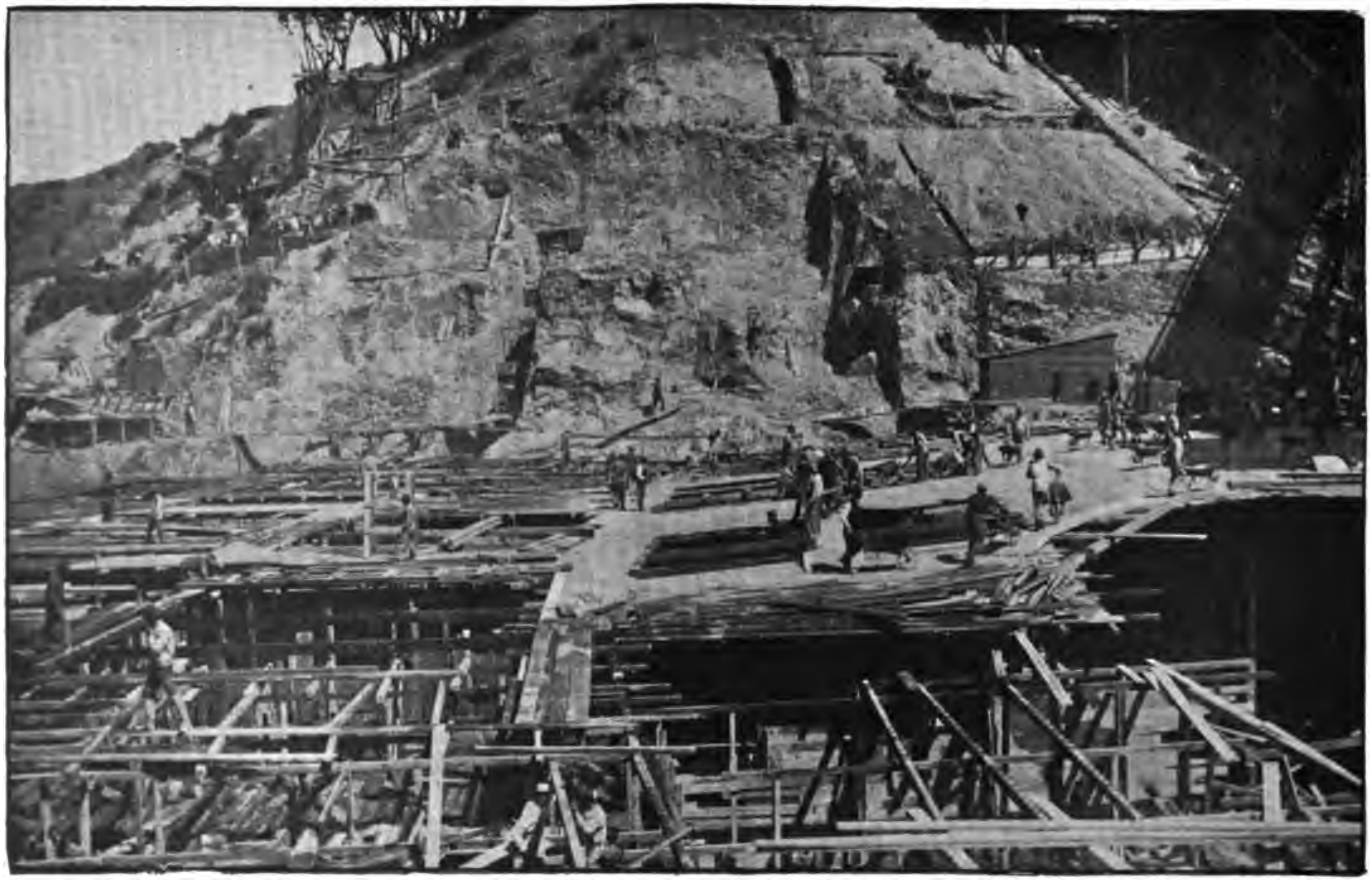


Fig. 192.—Moulds for Concrete Blocks, San Mateo Dam.

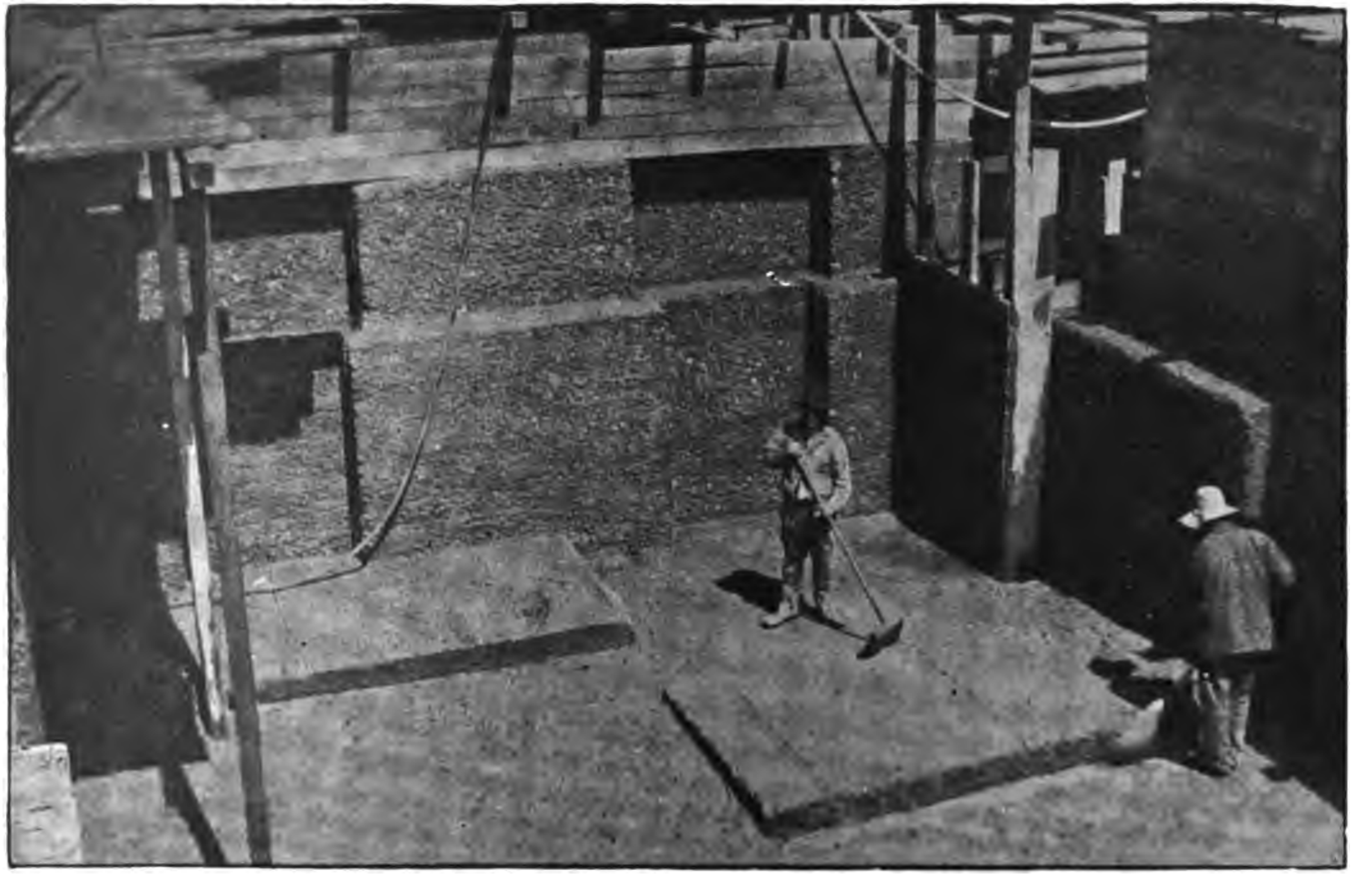


Fig 193.—Roughening Surface of Concrete Blocks to Receive fresh Cement, at San Mateo Dam.

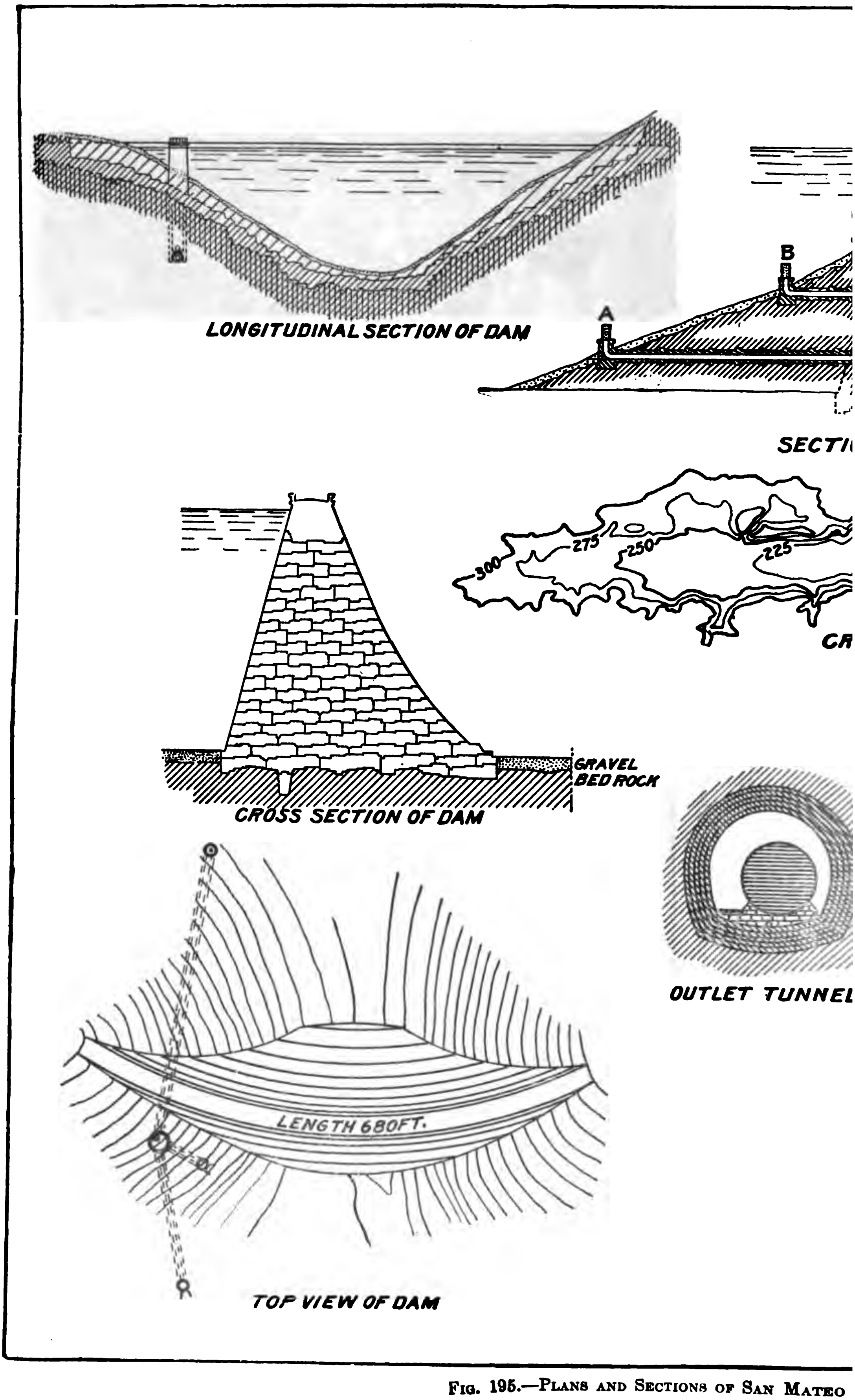
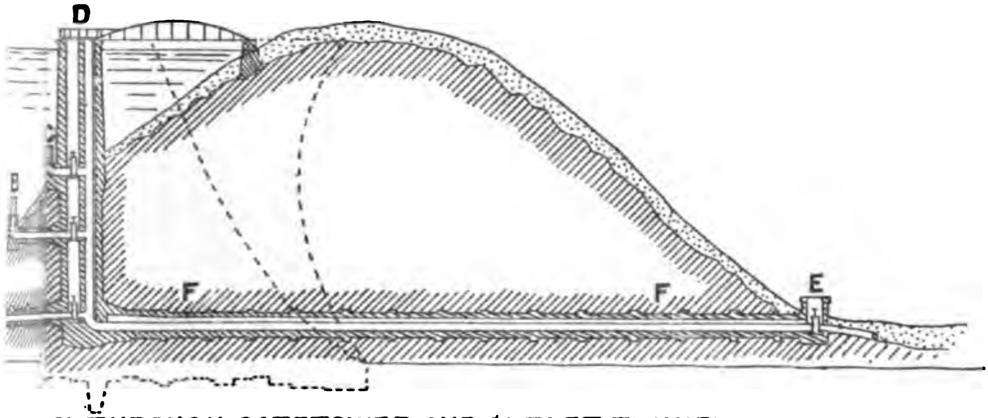
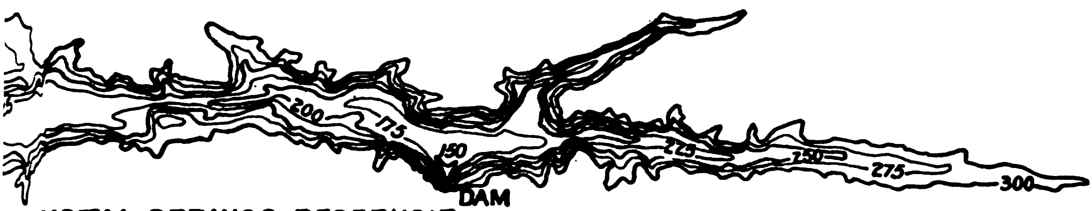


FIG. 195.—PLANS AND SECTIONS OF SAN MATEO



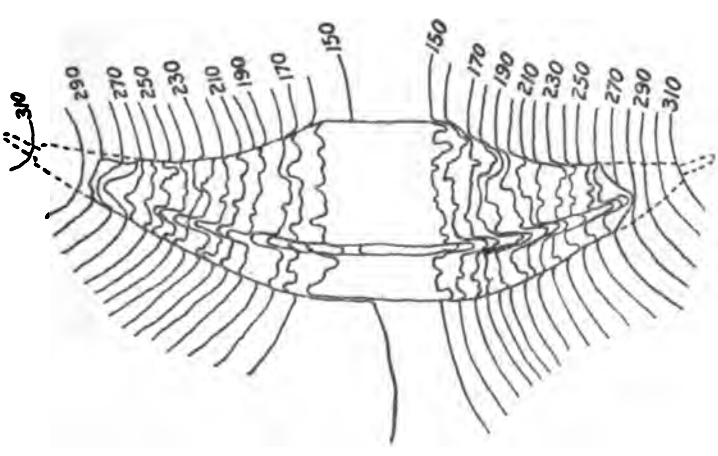
SECTION THROUGH GATETOWER AND OUTLET TUNNEL



CRYSTAL SPRINGS RESERVOIR

NNEL F-F

PLAN SHOWING LAYER OF CONCRETE BLOCKS



ROCK EXCAVATION FOR FOUNDATION OF DAM

ATED DAM AND MAP OF CRYSTAL SPRINGS RESERVOIR.

[To face page 273.]

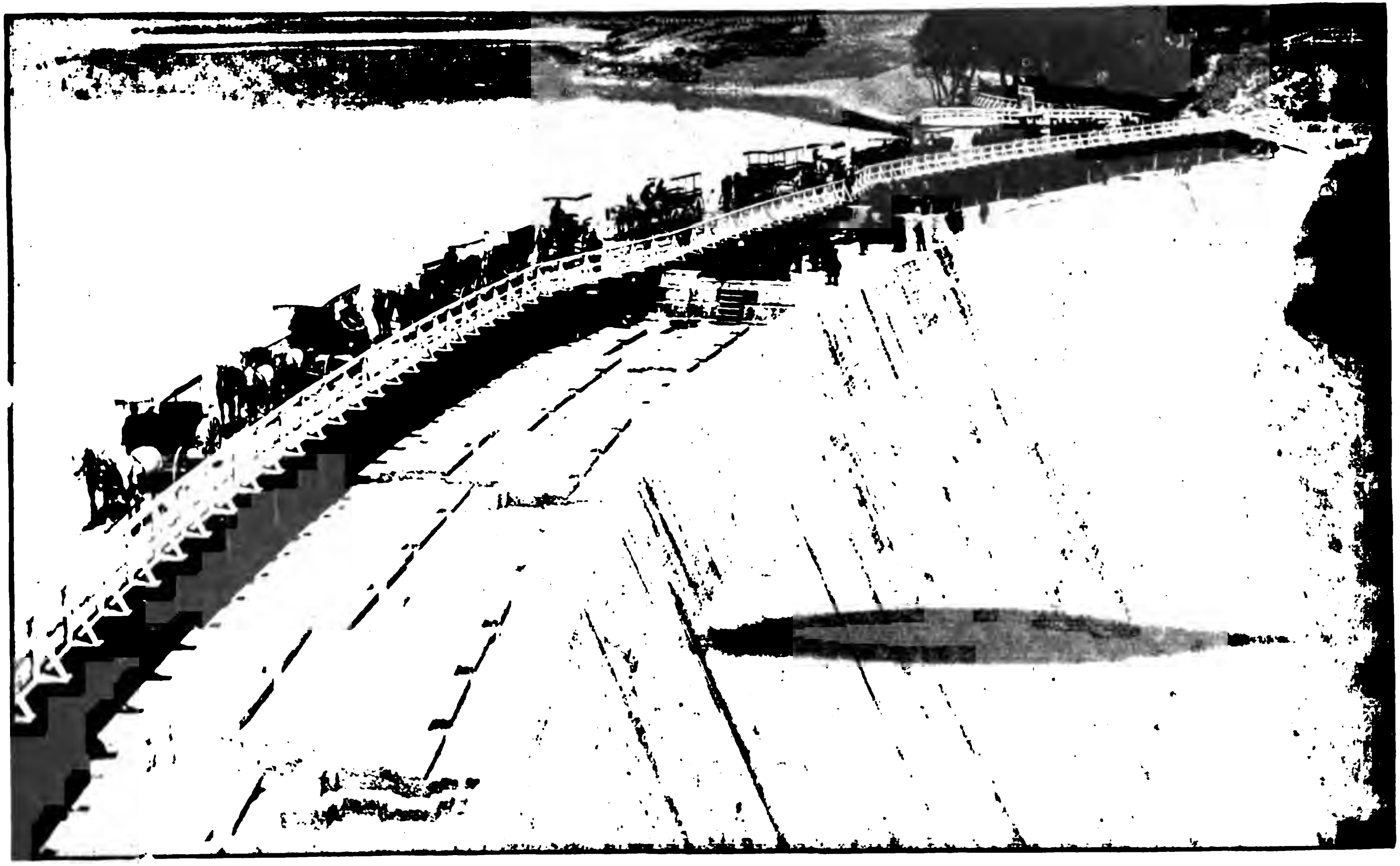


Fig. 194.—San Mateo Dam being Inspected by American Society of Civil Engineers, in July, 1896.

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 7½ 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.

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. 196), 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. 198. 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.

FIG. 196.—EXCAVATION OF TRENCH FOR PACOIMA SUBTERRANEAN DAM.

Fig. 197.—View of Flood passing over Pacoima Subterranean Dam.

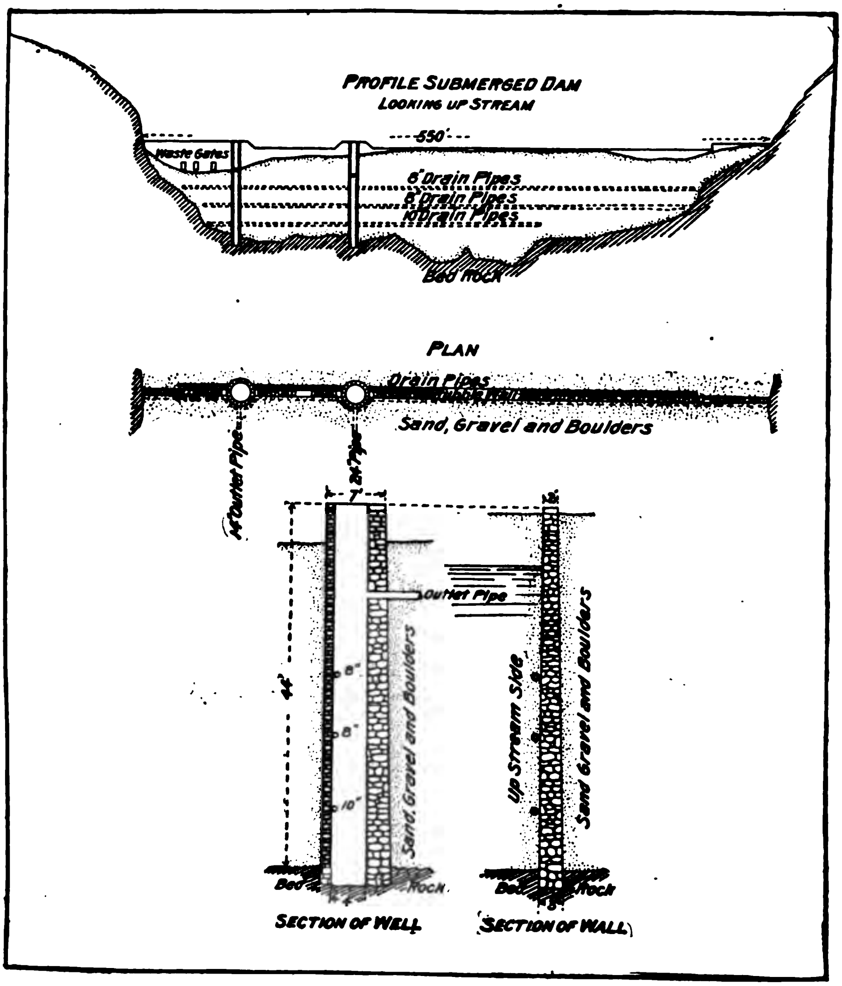


FIG. 198.—PLAN AND PROFILE OF PACOIMA DAM.

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. 201. 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.

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 four miles of the heaviest work was completed 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

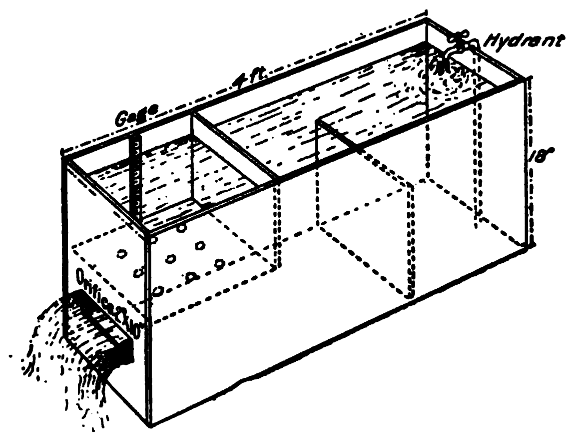


FIG. 199.—MEASURING-BOX USED BY MACLAY RANCHO WATER COMPANY.

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. 200.—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.

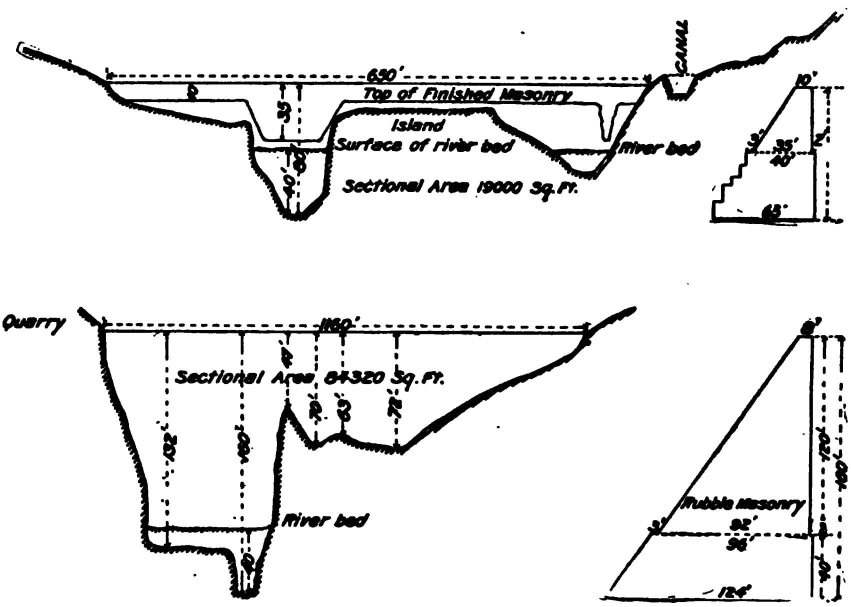


FIG. 201.—CROSS-SECTIONS OF AGUA FRIA DIVERTING-DAM AND STORAGE-RESERVOIR DAM, ARIZONA.

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. 200 and 202.) 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

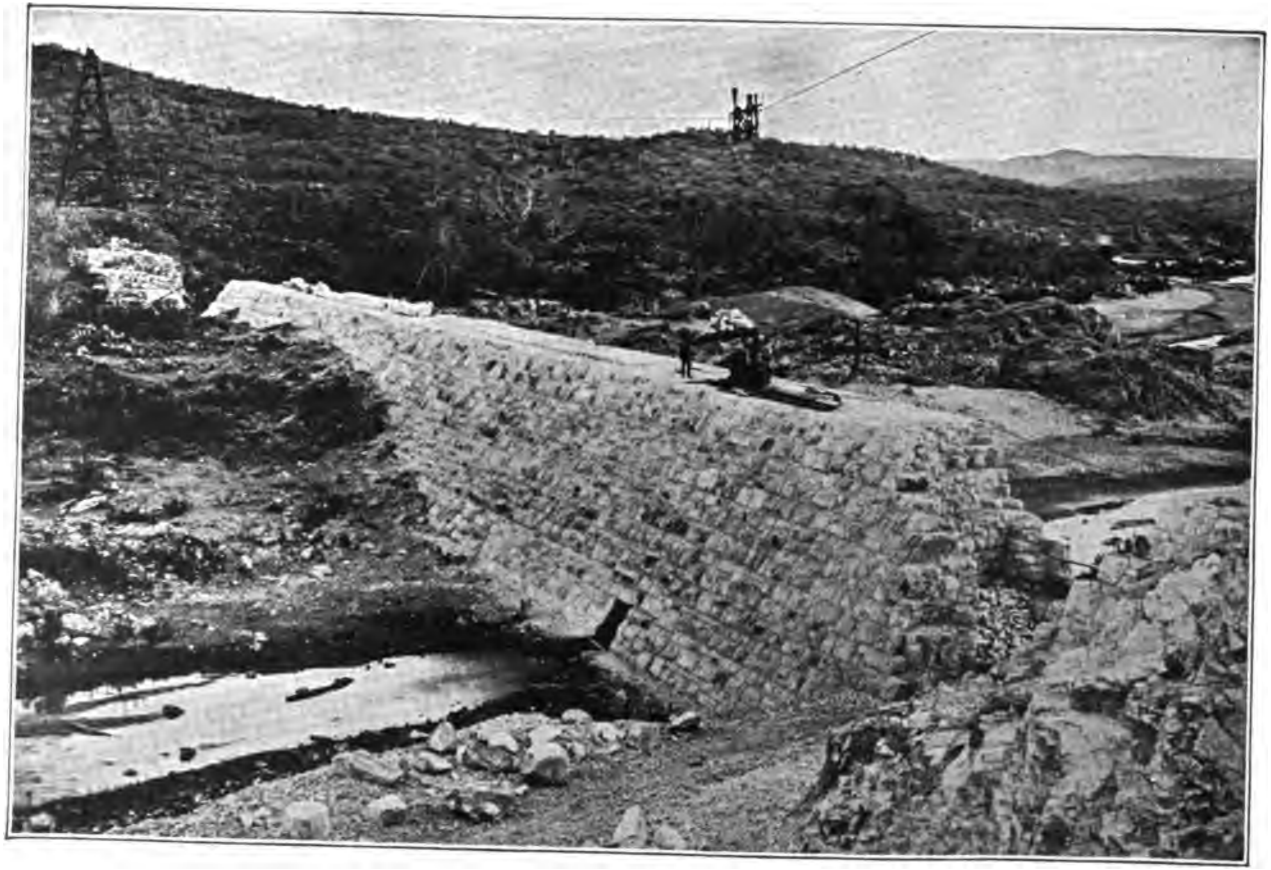


Fig. 202.—Diverting-dam on the Agua Fria.

the canal bank, is shown in Fig. 202, 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	5384
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

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

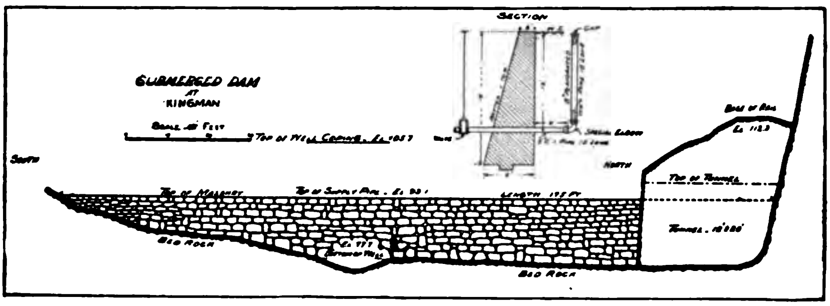


FIG. 203.—SUBMERGED STORAGE- AND DIVERTING-DAM, NEAR KINGMAN, ARIZONA.

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. 203.)

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

5104 feet above sea-level. The dimensions of the dam are as follows: Length at base, 145 feet; length on crest, 643 feet; height, 68 feet; thickness at base, 47.77 feet; thickness 3.1 ft. below the over flow or 5.1 ft. below the crest, 5.14 feet; thickness at top, 1.75 feet. It is arched up-stream with a radius of 800 feet from the line of the water-face. The cubica contents are 18,161.4 cubic yards, divided as follows:

Concrete in foundation	300	cubic	yards.
Rough rubble in core	13,843.4	"	"
Dressed ashlar	3,817.7	"	"
Coping	200.3	"	"

The work was done by contract, the railway company furnishing the cement and delivering the stone, sand, and cement on cars to the dam-site, the contractor quarrying and loading the stone. The rubble sandstone was

FIG. 204.—SELIGMAN DAM, ARIZONA.

hauled 43 miles from Rock Butte. on the S. F., P. & P. R.R., the facing-stone was hauled 175 miles from Holbrook, and the sand 150 miles from the Sacramento Wash. The contract prices were: $9 per yard for coping, $6.50 per yard for facings, $4.62 for rubble, and $2.81 for concrete. The total cost of the dam was in excess of $150,000.

The character of the masonry is well shown by the photograph (Fig. 204) of the lower face during erection. Fig. 205 shows the water-face and end buttresses. The water appearing in the foreground is retained by a low earth dam that had been in use for some time prior to the construction of the masonry dam. The center of the dam is depressed two feet below 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

FIG. 205.—SELIGMAN DAM, ARIZONA. VIEW OF UPPER FACE DURING CONSTRUCTION.

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.

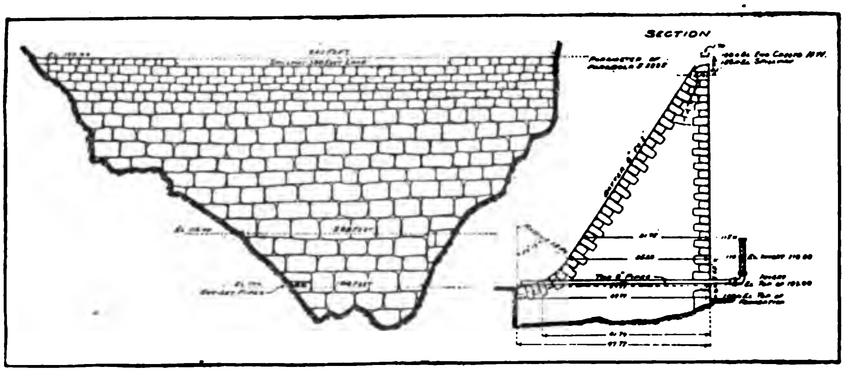


FIG. 206.—SECTION AND PROFILE OF SELIGMAN DAM, ARIZONA.

They are of wrought iron, capped at top and perforated with $\frac{3}{8}$-inch holes, bored $\frac{1}{2}$ 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 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. 206 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 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 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 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 dam is 77.6 feet. Its thickness at base is 61.5 feet. The water-face is vertical, while the upper face has a batter of 7½ inches to the foot between the vertical curves at top and toe. The top is rounded in parabolic form to a thickness of 13 feet at a point 10.4 feet below the crest, to form an easy overflow for surplus waste water, while at the base the wall is vertical for 10 feet, above which is a vertical curve, tangential to the horizon, passing through 58° of arc, to a point 46.4 feet below the top, where the thickness is 35.5 feet. This design forms an exceedingly massive structure with unusually large factor of safety. The dam is arched up-stream with a radius of 400 feet to the line of the water-face. The masonry consists of 5244 cubic yards of heart rubble, 1572 cubic yards of facing ashlar masonry in irregular courses, with dressed beds, and 80 cubic yards of cut coping-

FIG. 207.—WALNUT CANYON DAM, ARIZONA.

stone—a total of 6986 cubic yards. There were 6070 barrels of Portland cement used in construction. The total cost, exclusive of excavation,

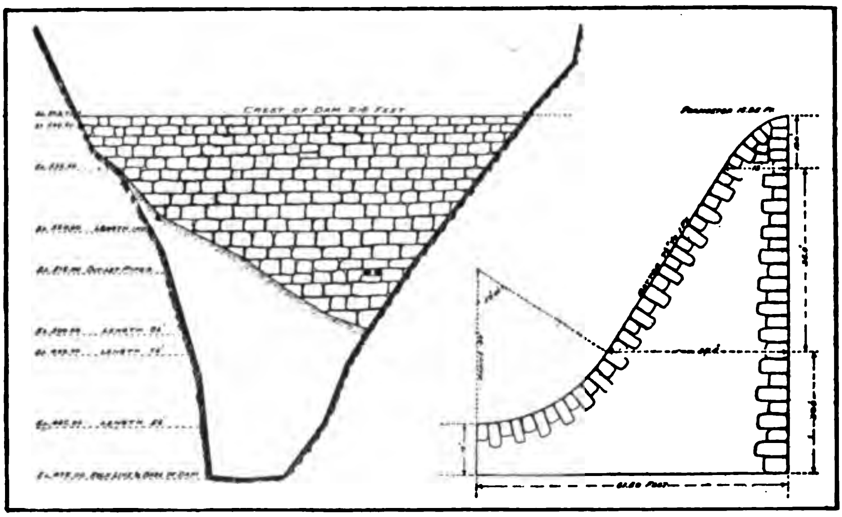


FIG. 208.—SECTION AND PROFILE OF WALNUT CANYON DAM, ARIZONA.

was about $55,000. The stone used was quarried at the dam-site and was of good quality.

The outlets consist of two 10-inch cast-iron pipes, placed 6 feet apart, at an elevation of 30.4 feet below the top of the dam, 10 feet above the stream-bed. Vertical strainer-pipes, 10 feet high, are placed over the upper ends of the outlets in the reservoir, 6 feet from the face of the dam. Outside, the pipes are controlled by 10-inch Ludlow gates, and are reduced to 8 inches diameter below the gates. The main pipe-line from the dam follows the canyon for 4½ miles to the railroad crossing, and thence follows the track easterly 12 miles further to a tank.

Fig. 207 is a view of the dam from below when nearly completed. Fig. 208 shows the profile of the dam as constructed, and a section of the canyon at the dam-site.

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 evaporation 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 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. 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. 209, 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

FIG. 209.—LYNX CREEK DAM, ARIZONA, AFTER RUPTURE BY FLOOD. VIEW FROM BELOW.

FIG. 210—LYNX CREEK DAM, ARIZONA. SECTION SHOWING FACING WALLS AND CONCRETE HEARTING.

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. 210). Considerable 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 author 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. 211, 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. 216, and the other two are five miles away, across the Willamette River, and designated as reservoirs 3 and 4 (Fig. 213). 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

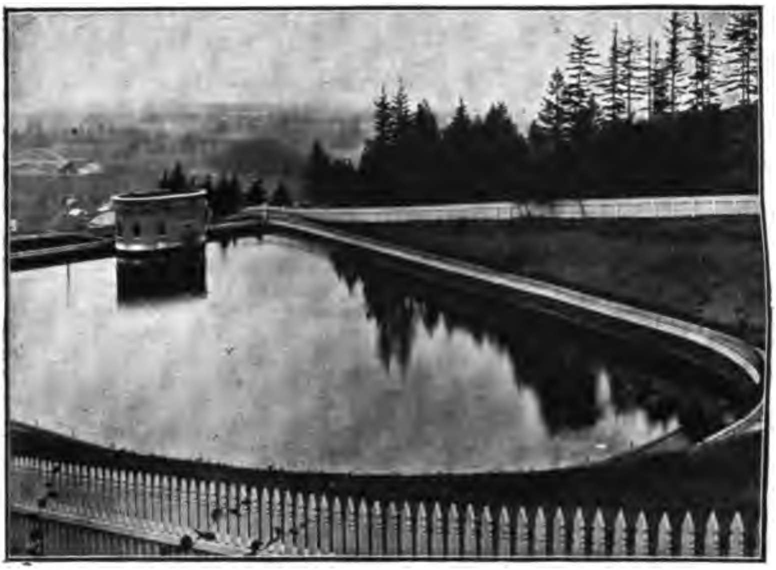


FIG. 211.—RESERVOIR NO. 1, PORTLAND, ORE., WATERWORKS. CONCRETE DAM WITH EARTH BACKING.

FIG. 212.—CONCRETE DAM, 60 FEET HIGH, AT RESERVOIR NO. 3, PORTLAND, ORE. POWER-HOUSE IN FOREGROUND.

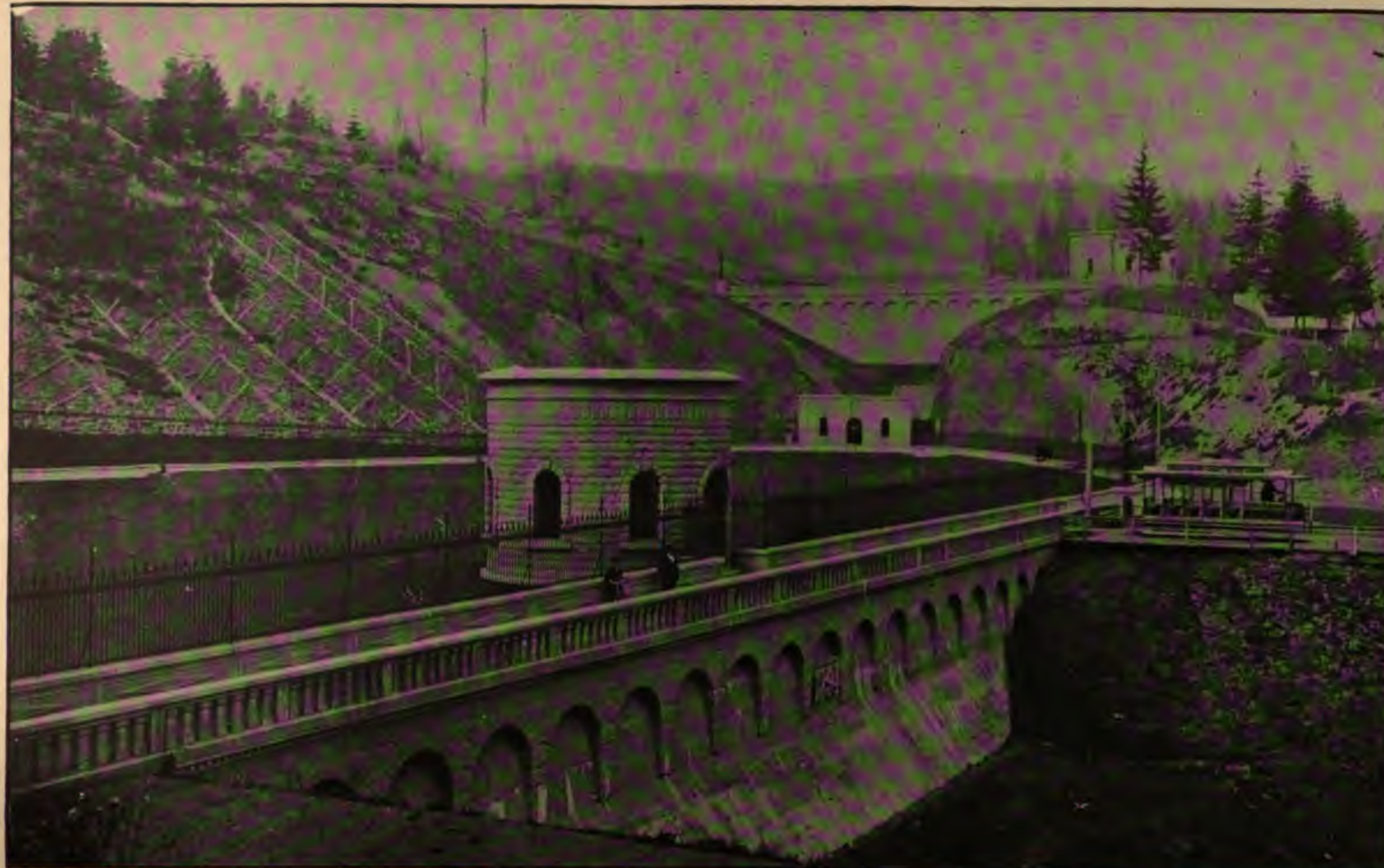


Fig. 213.—Exterior View of Reservoir Dams at Portland, Oregon.

Fig. 214.—Concrete Dam at Reservoir No. 3, Portland, Oregon, Waterworks, showing Power-house below.

Fig. 215.—Concrete Dam of Reservoir No. 4, Portland, Oregon., Waterworks.

Fig. 216.—Reservoir No. 2, Portland, Oregon, Waterworks, showing Aeration Fountains.

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. 213, 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 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 $2\frac{1}{4}$ inches diameter, suspended 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, now supervising Engr. U. S. Rec. Service, was manager and engineer.

High Pressure Mining Dams.—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. 217) 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 the most extraordinary precedent on record of masonry under such extremely high pressure.

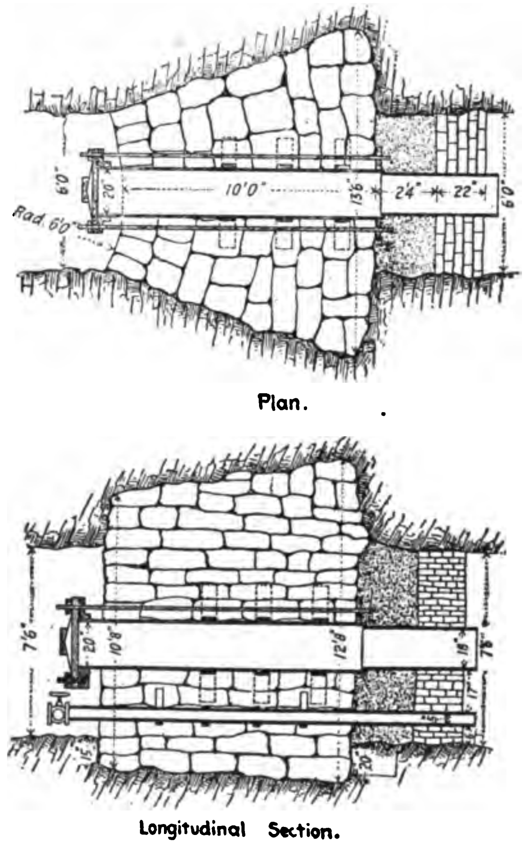


FIG. 217.—MASONRY DAM UNDER 640-FOOT HEAD, THE GREATEST RECORDED WATER-PRESSURE ON MASONRY.

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.)

High-head Dams in Chapin Mine, Michigan.—Subsequent to the construction of this dam, two others of similar character and purpose, but under still higher pressure, were built in the Chapin Mine, Michigan.

One of these, on the east branch of the twelfth level, is at a depth of 960 feet from the surface, and resists a pressure of 355 pounds per square inch, equal to a head of 816 feet. The dam was made in the form of a circular arch, 6 feet in thickness, with an inner radius of 7.3 feet. It is set into deep skewbacks, cut into the walls of limestone surrounding it, and is formed of blocks of sandstone, laid in 1:2 cement mortar. This was backed up by concrete 5 feet in thickness on the crowning side of the arch. A 3-inch extra heavy pipe with gate-valve passes through the dam. The total load upon the dam is 1840 tons.

The second dam, in the west branch of the twelfth level tunnel, is under the same head, but being slightly higher withstands a total load of over 2500 tons. It is a simple plug of concrete, 20 feet long, about 10×10 feet in size, with an 8-inch outlet-pipe passing through it. The concrete is braced on the outer face by two heavy vertical girders of steel, behind five horizontal steel rails of heavy weight, all cemented into off-sets or recesses cut into the walls of the tunnel. The drift is 10 feet wide by about the same height.

The New Croton Dam, New York. (Fig. 218.)—It is perhaps appropriate that the commercial metropolis of the United States should have the highest dam in the world, embodying the most enormous mass of masonry in existence, and costing more money than any dam ever built. The dam occupied fourteen years in construction, having been begun September, 20, 1892, and completed January 1, 1907, at a total cost of $7,631,185.69, which included the construction of 20 miles of new highway and the reinforcing of 3 miles of the old Croton aqueduct.

The excavation for the foundations involved the removal of 1,821,400 cubic yards of earth and 400,250 cubic yards of rock. The masonry in the structure has a total volume of 855,000 cubic yards.

The dam has a maximum height of 297 feet above the lowest foundations, a base width of 296 feet at the level of 131 feet below the original river-bed, and a length of 2200 feet on the crest, including a masonry waste-weir 1000 feet in length. The width on the crest is 18 feet at a height of 14 feet above the spillway level, but a roadway 19.5 feet wide is carried over the top of the dam by corbeling out near the top to get the necessary width, which is accomplished by a series of ornamental arches, which greatly add to the architectural effect. The area of the reservoir formed by the dam is about 3360 acres, and its capacity is about 180,000 acre-feet. The average cost per unit of storage is therefore about $42 per acre-foot.

The dam was designed by the late Alphonse Fteley, Past President Am. Soc. C. E., who carried on construction for nearly eight years, until January 1, 1900, when he resigned and was succeeded by W. R. Hill, M. Am. Soc. C. E. After the resignation of Mr. Hill as chief engineer of the Aqueduct Commission, J. Waldo Smith, M. Am. Soc. C. E., was appointed and served for two years, succeeded by Walter H. Sears,

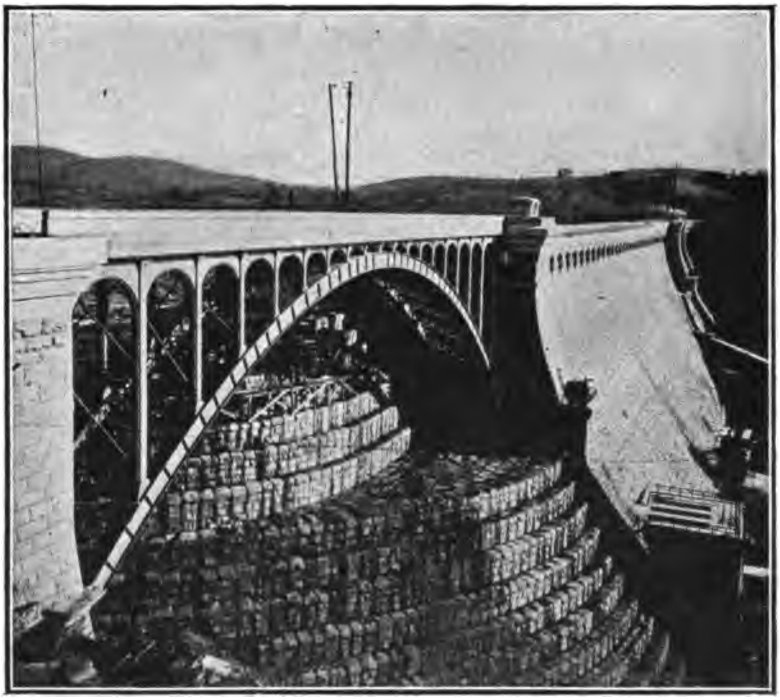


FIG. 218.—NEW CROTON DAM, N. Y. SPILLWAY IN FOREGROUND SPANNED BY BRIDGE.

M. Am. Soc. C. E. The work was directly supervised for the first twelve years by Chas. S. Gowen, M. Am. Soc. C. E., as division engineer.

The Cross River Dam, New York (Figs. 219 and 220).—The Aqueduct Commission of New York City have under construction and practically completed a high masonry dam for storage of water on Cross River, a branch of the Croton River, near Katonah, N. Y., to the extent of a total capacity of 9,000,000,000 gallons (27,540 acre-feet) at a cost under the contract awarded to MacArthur Bros. Company and Winston & Co. of $1,246,211.60.

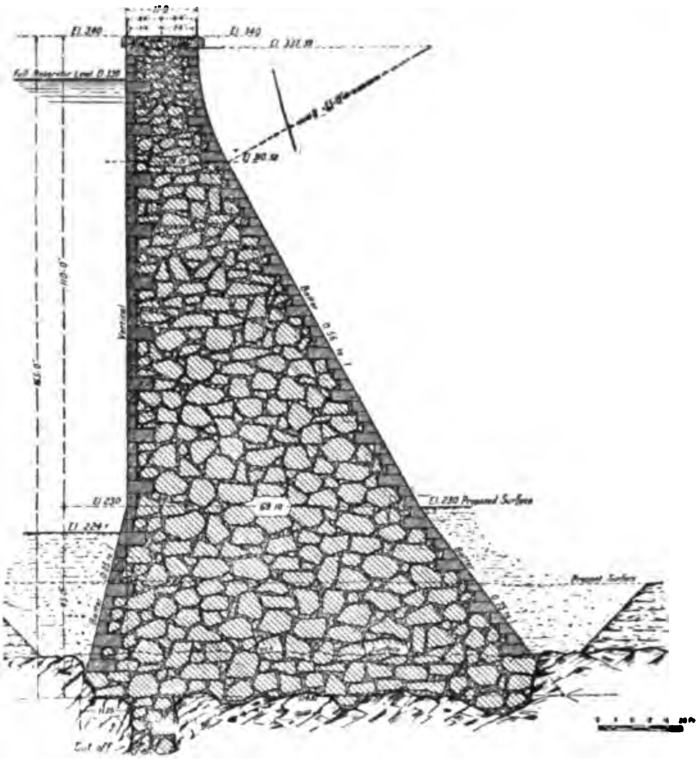


FIG. 219.—PROFILE OF CROSS RIVER DAM, NEW YORK WATERWORKS.

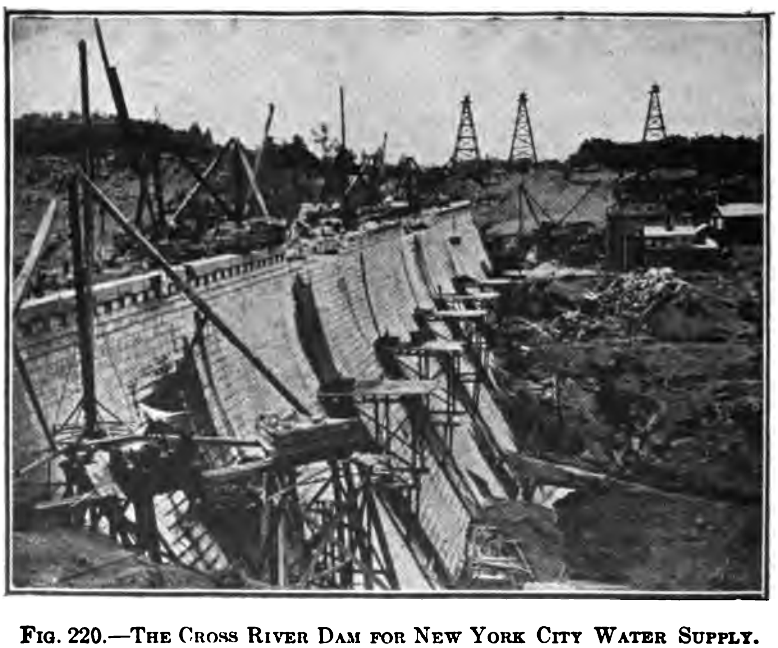


FIG. 220.—THE CROSS RIVER DAM FOR NEW YORK CITY WATER SUPPLY.

The dam will have a maximum height of 170 feet above the foundation, and a crest length of 772 feet. The width on top is 23 feet, and at base 127.7 feet. The total volume of the masonry is computed at 155,000 cubic yards. It consists of cyclopean rubble, laid between facing walls of concrete blocks, 2 to 3 feet wide, 3 feet in depth at bottom courses, diminishing to 2 feet at the top. The concrete of those blocks is mixed in the proportions of 1 of cement, 2.3 sand, and 4.7 broken stone, moulded in steel-faced moulds to produce a smooth surface. These blocks are set in rich mortar, consisting of 1 of cement to 2.5 of sand and pointed with 1:1 mortar. The blocks have a maximum weight of 6 tons. The concrete of the heart of the dam is mixed in the proportion of 1:3.2:5.8 into which large blocks of stone are imbedded.

The work was constructed under the charge of Walter H. Sears, M. Am. Soc. C. E. J. Waldo Smith, M. Am. Soc. C. E., is chief engineer of the Aqueduct Commission, Prof. Wm. H. Burr, consulting engineer.

The profile of the dam is shown on Plate No. 3. At its southerly end it is continued by an earth embankment with masonry core-wall 150 feet long, while at the northerly end is located a spillway constructed along the hillside a distance of 240 feet.

The Croton Falls Dam, New York.—Quite similar in design and height to the Cross River dam is the structure also being built by the Aqueduct Commission of New York City on the west branch of Croton River, near Croton Falls, N. Y. The dam will have the same profile and crest width, but its length will be 1095 feet, terminating at the north end with an abutment from which an earth dam with masonry core-wall will be continued 100 feet further. The spillway is to be 700 feet long, constructed along the hillside nearly at right angles to the direction of the dam.

Mr. Walter H. Sears is also chief engineer of this work. The reservoir will have a capacity of 14,000,000,000 gallons (42,840 acre-feet).

Spier Falls Dam, New York.—The Hudson River Water-Power Company in 1900 to 1905 constructed a high masonry dam across the Hudson River, 9 miles above Glen Falls, N. Y., having a height of 154 feet, a base width of 112 feet, and a thickness of 17 feet at top, which is 10 feet above the full reservoir level. At the original surface, which is 64 feet above the lowest foundation, the thickness is 74.1 feet. The up-stream side is vertical for 41 feet from the top, thence batters 5.7% to the bottom. On the down-stream side it is vertical for 4 feet, where a vertical curve of 81.74 feet radius continues 58.4 feet further, to where a batter of 1 to 1.045 begins. From the original ground level to the base the slope is 65%. The main dam, a section of which is shown in Plate III, extends across the river channel a length of 552 feet. This is continued by an overflow rollway weir section in masonry 817 feet long, 10 feet lower than the crest of the main dam. The total volume of masonry was 180,000 cubic yards. It is of the class known as cyclopean masonry, composed of large blocks of granite imbedded in a mortar of concrete, comprising about 30% of the mass.

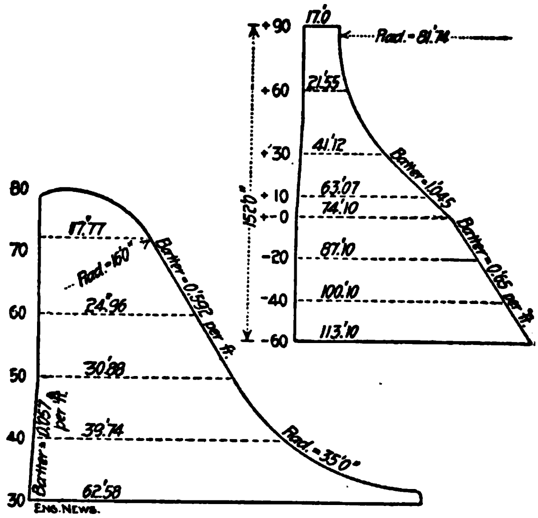


FIG. 221.—SPIER FALLS DAM, N. Y. PROFILES OF OVERFALL AND ABUTMENT SECTIONS.

The dam creates a reservoir 5.5 miles long, from which a power-head of 80 feet is derived, furnishing 20,000 H.P. at the minimum low water.

The dam was built under the supervision of Mr. Charles F. Parsons, chief engineer.

The Ithaca Dam, New York (Figs. 222 and 223).—One of the curiosities of recent dam construction is situated two miles from the city of Ithaca, on Six-Mile Creek, in a narrow rock gorge, with vertical walls but 90 feet apart. The dam was designed by Prof. Gardner S. Williams, M. Am. Soc. C. E., of Cornell University, who was inspired by the narrowness of the site to attempt a structure of most unusual slenderness and peculiar form.

It was intended to be 90 feet in height, with a radius of 57.75 feet on the down-stream face, in the shape of a section of a spherical shell, with overhanging crest. In deference to popular distrust of the safety of the structure, it was finally reduced to the height of 30 feet above base, and finished off with an up-stream batter of 45° and a top thickness of 1 foot. The maximum thickness is 7.75 feet. The dam is composed of concrete, mixed in the proportion of 1 part cement, 2 parts sand, 2 parts gravel, and 2 parts broken stone, crushed to pass a 4-inch ring. The concrete was placed between thin walls of vitrified paving-brick, laid in a single course on each face, in cement mortar anchored into the body of the concrete by flat steel bolts, $1\frac{1}{2}\times\frac{1}{8}\times7$ inches, turned up $\frac{1}{2}$ inch at each end and placed at every fifth brick in every fifth course.

FIG. 222.—ITHACA DAM, NEW YORK, ILLUSTRATING CONCRETE CONSTRUCTION BETWEEN BRICK-FACING FORMS.

Inside the brick facings is a layer of rich cement mortar, 3 inches thick, in which are imbedded bands of steel, 3 inches wide, $\frac{3}{8}$ inch thick, placed 4 feet apart, extending entirely around the structure, and tied through the dam every 4 feet by $\frac{5}{8}$-inch steel rods, having a nut on each side of the bands. Over the steel frame thus formed is a wire netting with 4-inch mesh imbedded in the mortar.

The dam cost $25,000 and required the following quantities: Excavation, 500 cubic yards; concrete, 1000 cubic yards; brick, 120,000 (240 cubic yards); steel, 5000 pounds; cement, 1800 barrels. All concrete was put in very wet. The brick walls were laid flat, 3 to 4 feet in advance of the concrete and obviated the use of other forms.

The structure was built for the Ithaca Water Co. to provide storage for city supply from an area of 48 square miles.

The Ashokan Dam, New York.—The City of Greater New York is engaged in the most costly work ever undertaken by a municipality for the increase of its water-supply to the extent of 500,000,000 gallons daily by [the gathering of water in huge reservoirs in the Catskill Moun-tains, to be conveyed by an aqueduct of enormous size, 82

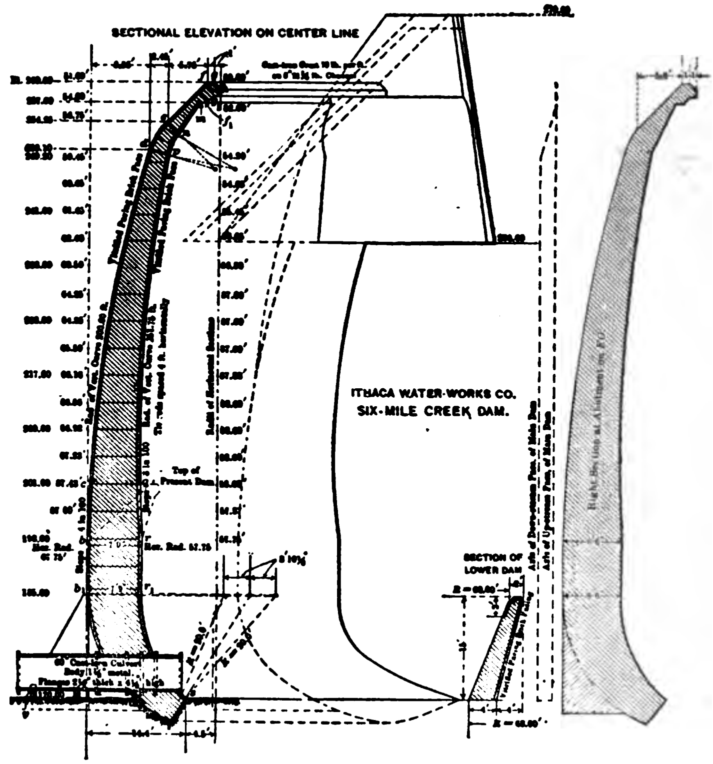


FIG. 223.—ITHACA CONCRETE-BRICK FACED DAM. SECTIONS OF DAM AS PLANNED.

miles long, to the city. The works are estimated to cost upwards of $162,000,000.

The principal reservoir, called the Ashokan reservoir, will cover an area of 8300 acres, and have a capacity of 368,030 acre-feet. Its maximum depth will be 180 feet, and its mean depth 45 feet, or 25% of the maximum. It will receive its supply from the run-off of 255 square miles of watershed area. A masonry dam to contain 884,000 cubic yards of masonry, called the Olive Bridge dam, is to be erected, and in addition there are required five earth dams or dikes to complete the inclosure of the basin, involving the handling of about 7,000,000 cubic yards of earth. The excavation required for these structures is enormous in quantity, amounting to 1,910,000 cubic yards of earth, and 425,000 cubic yards of rock. The specifications require all of the work to be completed in eighty-four months.

Bids were received for this work August 6, 1907. The lowest bidder was the John Peirce Company of New York in the aggregate sum of $10,315,350, but the contract was awarded to the next bidders, MacArthur Bros. Co. and Winston & Co., for $12,669,775, on the recom-

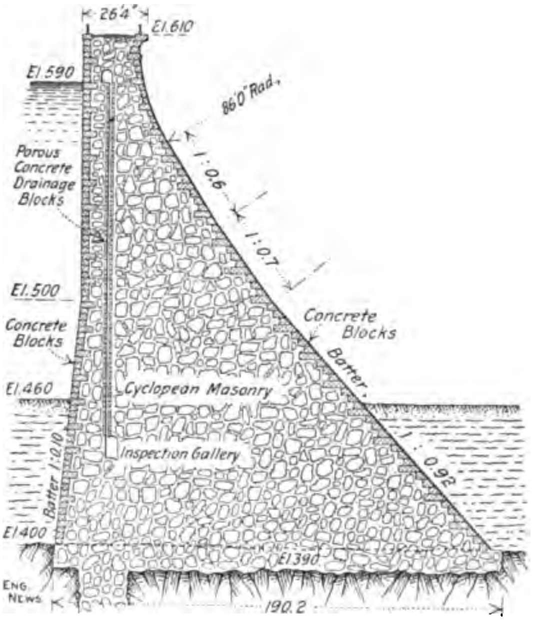


FIG. 224.—ASHOKAN DAM, MASONRY.

mendation of the Chief Engineer, J. Waldo Smith, M. Am. Soc. C. E., and the Board of Consulting Engineers, Messrs. John R. Freeman, Frederic P. Stearns, and Wm. H. Burr, M. M. Am. Soc. C. E., on the ground that the lowest bid was below cost in the earthwork portion. The data of actual construction cost kept during the first year of the work under the contract as awarded are said to justify the recommendation of the board of engineers.

The Olive Bridge dam, with crest elevation of 610 feet, will consist of a central masonry structure, 1000 feet long, straight in plan, with an earth dam on the same line, 2100 feet long on the north side, and a south wing of 1540 feet length. These embankments will have concrete core-walls reaching to elevation 596, or 6 feet above the flow line of the reservoir.

The masonry structure will be built of cyclopean rubble masonry between face walls of large concrete blocks, and will have a maximum height of 220 feet, a base of 190.2 feet, and a top width of 23 feet below the coping. It will carry a roadway, for which the top is corbeled out to an extreme width of 26 feet 4 inches.

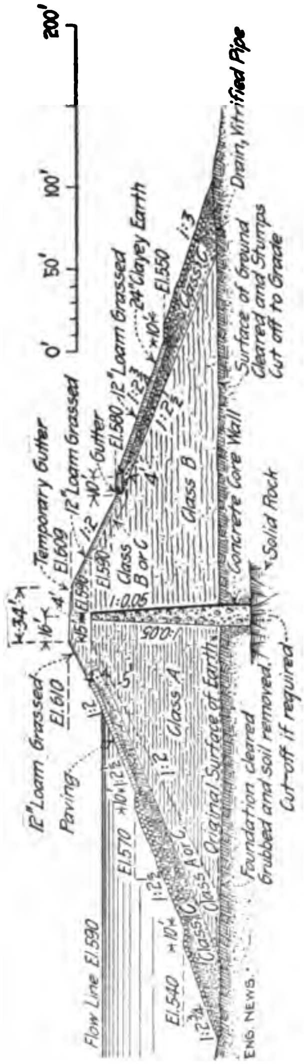


FIG. 225.—ASHOKAN DAM, EARTH.

One of the special features of the design, which shows an inclination to follow the precedents established by German engineers, is the elaborate provision made for drainage of the masonry by building inspection galleries at the water-line and near the bottom running the entire length of the dam, and connected by vertical or slightly inclined porous concrete drain-pipes, at intervals of about 11 feet.

By this means all possibility of upward pressure upon the base of the dam or any portion above the base through the transmission of pressure by communication seams or cracks or open joints from the reservoir, will be avoided, and any water that may find passage through the face will be intercepted and drained away. The designing engineer was Mr. C. E. Gregory; Mr. Benj. S. Wever is assistant engineer in charge, and Mr. Alfred D. Flinn, department engineer.

The precedent established at the Wachusett reservoir of stripping all surface soil from the basin was not followed in this case, but after investigation was declared to be an unnecessary expense.

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 $2\frac{1}{2}$ 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 21 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. 128.

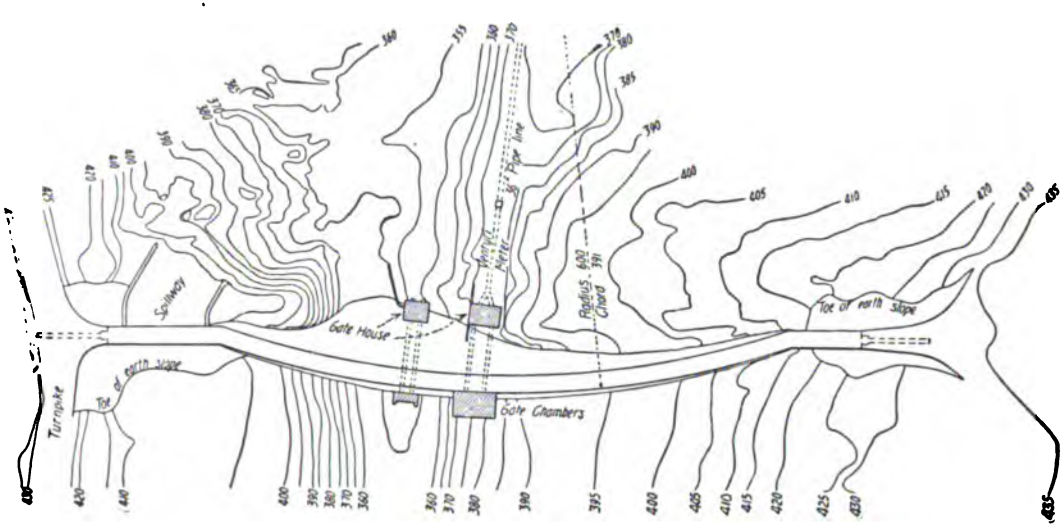


FIG. 226.—PLAN OF WIGWAM DAM, CONNECTICUT.

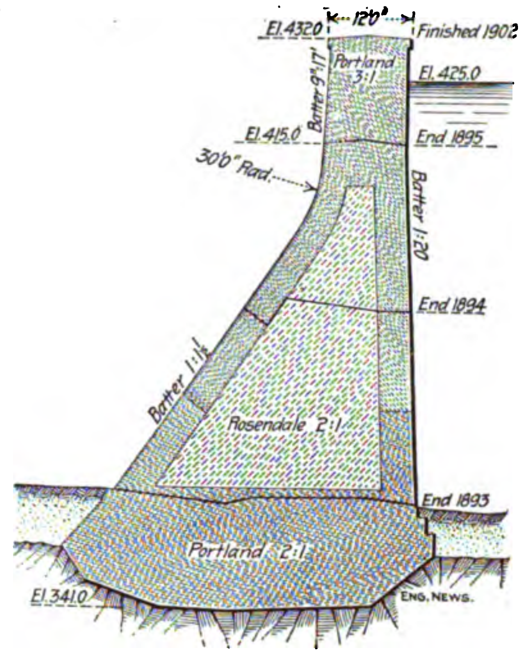


FIG. 227.—SECTION OF WIGWAM DAM.

The Wigwam Dam, Connecticut.—The city of Waterbury, Conn. (pop. 30,000 in 1897), 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. 228, 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. 228.—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.

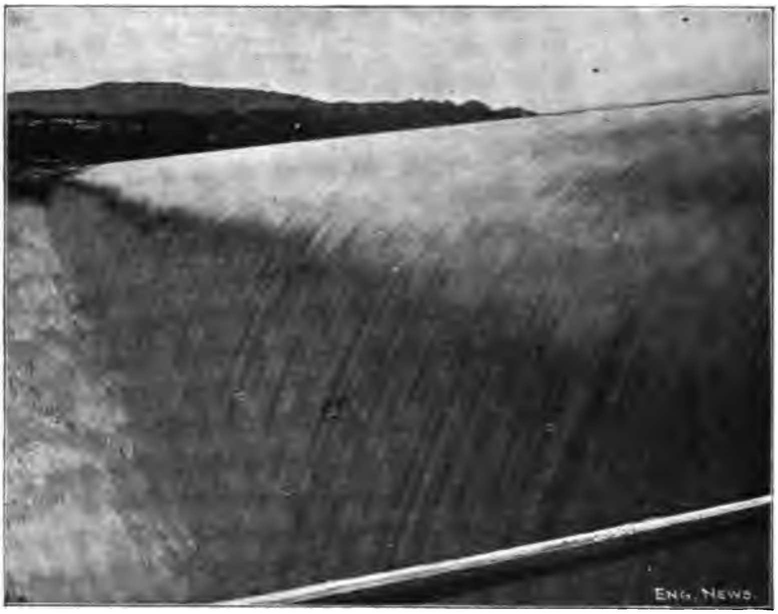


FIG. 229.—AUSTIN DAM DURING FLOOD OF APRIL 7, 1900, AND IMMEDIATELY BEFORE THE BREAK.

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. 230.—Austin Dam, Texas. View taken during Flood, a few Minutes after the Break

Fig. 231.—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. 229. Figs. 230 and 231 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 thsse three cuts.

Granite Springs Masonry Dam, Wyoming.—There are few dams in Western America more correctly representing the principles of modern science as applied to dam construction, and more generally satisfactory in economy of design and execution than the dam erected in 1903–04 by the City of Cheyenne, Wyoming, for the storage of a domestic water-supply at Granite Springs, on Middle Fork of Crow Creek, 12 miles from the city. The work was designed and built by A. J. Wiley, M. Am. Soc. C. E., to whom the author is indebted for the facts regarding the work, and the accompanying illustrations. (Figs. 232, 233, and 234.)

The dam has an extreme height from foundation to parapet of 96 feet, and is constructed in arch form, with a radius of 300 feet. It is but 10 feet long on the base, and 410 feet in length on top, where its thickness is 10 feet. The base is 56 feet in width, up and down stream. Although curved in plan it is of gravity section and the resultant lines of pressure and weight are within the limits of the middle third, assuming the masonry to have a specific gravity of 2.5, when the reservoir is filled. The dam is built throughout of uncoursed rubble masonry laid in Portland cement mortar, and its cubic contents are 14,422 cubic yards, including a parapet wall 2 feet thick, 3 feet high.

The rock was found to weigh 177 pounds per cubic foot and the mortar was estimated at 138 pounds per cubic foot. The proportions of each entering into the composition of the wall gave the estimated weight of the masonry at 165 pounds per cubic foot, corresponding to a specific gravity of 2.64.

The spillway is located apart from the dam in a saddle or gap, 200 feet away, the height of the saddle being 85 feet above the creek bed. Here a masonry spillway structure was erected with its crest 90 feet above the bed of the stream. The discharge from the spillway returns to the stream 500 feet below the dam. The spillway wall is 180 feet long over all, with an overflow crest 52 feet long, 3 feet lower than the top of the parapet. Its discharge capacity is approximately 900 second-feet or 12 times the maximum observed discharge of the stream. The spillway structure is also curved, on a radius of 200 feet.

The watershed area of the stream above the dam is 27.5 square miles, from 7000 to 10,000 feet in elevation, reaching to the Continental

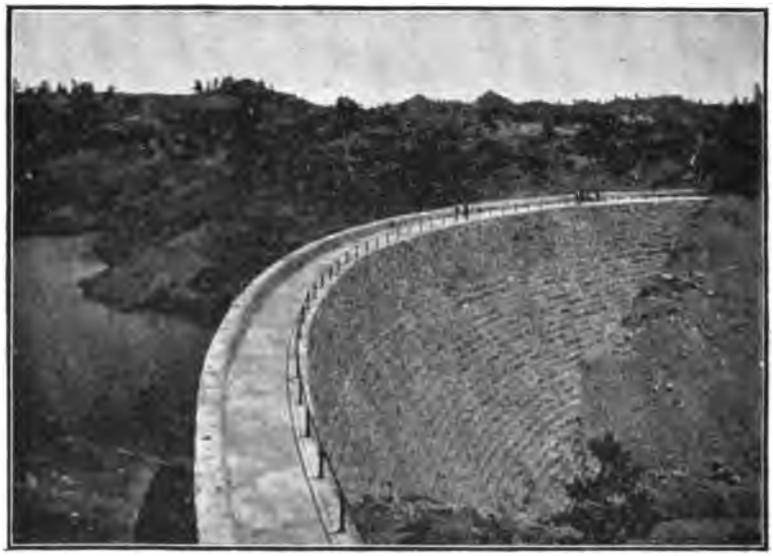


FIG. 232.—GRANITE SPRINGS DAM, CHEYENNE, WYOMING.

Divide. The measured run-off from this watershed, as determined by the U. S. Geological Survey for the year 1903, aggregated 7344 acre-feet, or 41% of the precipitation of 12.25 inches of that year in the City of Cheyenne. The mean of thirty-four years' record in that city is 13.23 inches. Two thirds of the total annual run-off occurred in the months of April and May.

The capacity of the reservoir is 5321 acre-feet, covering a surface of 185 acres, to a mean depth of 28.76 feet.

Construction.—The entire base of the dam, except that part of the east end which lies more than 50 feet above the creek-bed, is a dense hard variety of granite, classified as gabbro, and entirely free from seams or cracks, and almost devoid of defined cleavage planes. Above elevation

50 at the north end the gabbro is overlaid, by a different variety of granite, with regular cleavage planes, soft at the surface but increasing in hardness with depth. At the contact with the underlying gabbro there was no apparent seam, although a marked difference in hardness and texture distinguished the two varieties of rock. Excavation was made into the softer rock as deep as 30 feet in places before a satisfactory

FIG. 233.—GRANITE SPRINGS DAM, WYOMING, SHOWING GENERAL CHARACTER OF RUBBLE MASONRY.

foundation was secured. The gabbro, where exposed, had been worn to a smooth glassy surface, which was roughened by shallow blasts previous to laying masonry upon it.

The rock used for the masonry was taken from a granite quarry 100 feet below the dam, and as taken out by blasting ranged in size from spawls to irregular shaped blocks of 4 cubic yards, averaging about 2 cubic yards. The largest rock placed in the wall contained 5 cubic yards and weighed nearly 12 tons, but rock over 3 cubic yards in size were unprofitable to use on account of extra care required in handling. All drilling was done by hand. The rock was taken from the quarry by a guyed derrick with 40-foot boom, and loaded upon platform cars, on a track laid with a grade on which loaded cars ran by gravity to the dam, and the empties were pushed back by hand.

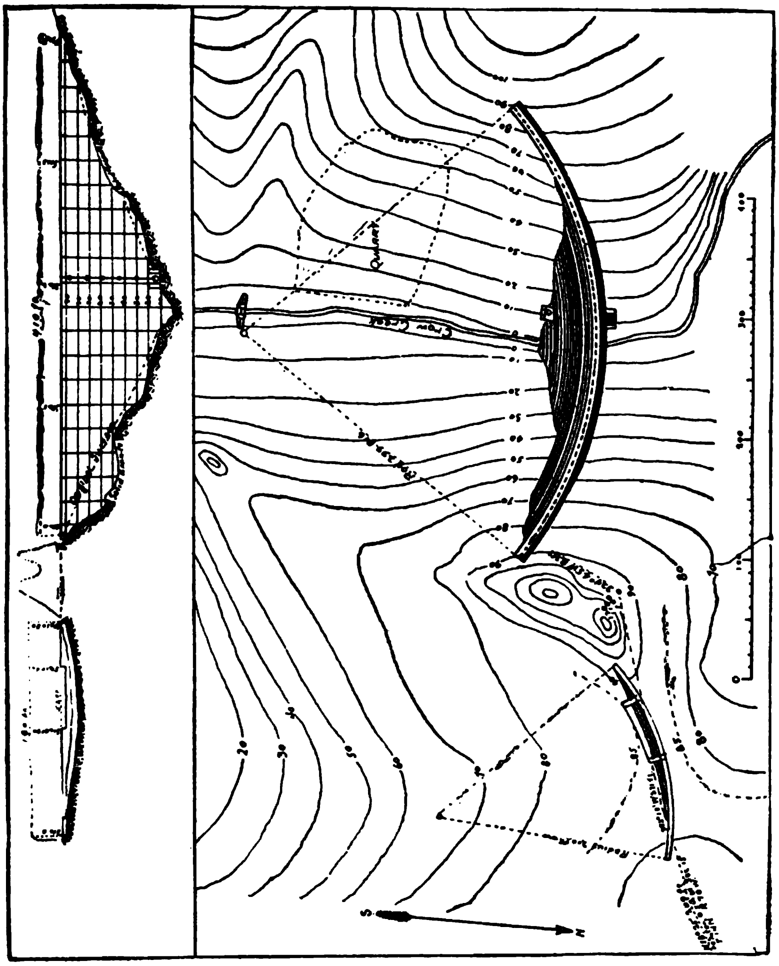


FIG. 234.—PLAN AND PROFILE OF GRANITE SPRINGS DAM, WYOMING.

A trestle carrying the track along the curved down-stream face of the dam was supported on one side by the steps in the masonry. Upon the top of the dam were located two derricks with 40-foot booms similar to the quarry derrick. Each derrick was operated by a 10-ton hoisting-engine, located in an engine-house near the south end of the dam. The derricks on top of the dam took the rock from the cars on the lower side of the wall and set them in the position desired in the masonry. They also hoisted the mortar buckets from cars on the up-stream side of the dam and dumped them where the mortar was needed on top. The mortar was mixed with a Smith mechanical mixer in half yard batches, and distributed by long-handled shovels. To insure the filling of the voids the mortar was mixed very wet, even sloppy, requiring but little tamping.

The face stones and those laid in contact with the bed-rock were laid in mortar in the proportion of 1 of cement to 3 of sand. All the interior of the dam was laid in 1 to 4 mortar.

In setting the large rock a bed was prepared with spawls and mortar, and then a considerable excess of mortar was placed on the bed. The rock was then slowly lowered and settled in place by working it with bars. The excess mortar would ooze from under the rock which would then float upon an even layer of mortar, filling all the irregular spaces beneath. The large rocks were set as closely as possible to each other without being in contact, the intervening spaces being filled with mortar and small stones, which were crowded down into the wet mortar until submerged.

The proportions of rock and mortar were determined to be 64.8% and 35.2% of the entire mass respectively. The total quantity of cement used was 8843.75 barrels, an average of 0.613 barrels of cement to the cubic yard of masonry. The average rate of progress was 60 cubic yards of masonry per day of ten hours or 240 working days for the entire work.

Alpha cement of American manufacture was used exclusively on the work. It was shipped in sacks and test samples taken from every twentieth sack. The average time of initial set was 45 minutes, varying from 30 to 60 minutes. The final set invariably occurred within ten hours. The average fineness was 93% passing through a sieve of 10,000 meshes per square inch. Neat cement tests showed a tensile strength of 654, 792, and 806 pounds respectively in 7 days, 28 days, and 90 days. For 1 to 3 hand-mixed mortar the results were respectively 233, 312, and 345 pounds in the same period. The 1 to 4 mixture gave tests of 226, 306, and 361 pounds respectively.

The sand was obtained from the adjacent dry stream-beds, and hauled in wagons an average distance of half a mile. It was passed through screens with ⅜-inch openings and used without washing. The voids in the sand were determined by depositing it slowly in a measured depth of water in a cylindrical vessel. After compacting the sand by light blows on the side of the vessel the depth of the sand and the depth of the water above the sand was measured. The difference between this latter and the original depth of the water was taken to represent the voids, and divided by the depth of the sand to determine the percentage of voids. The result of twenty-five tests gave an average of 23.4% of voids.

Cost.—The entire work was done by contract at a total cost to the city of $109,194.50, including water-rights, land, clearing, building, excavation, outlet-pipes, and valves, spillway, measuring weirs, engineering, superintendence and general expense. For the body of the dam the average cost to the city was $6.04 per cubic yard exclusive of engineering, etc., while the contractor's profit was 85 cents per cubic yard, or 14%. The cost to the contractor was as follows, per cubic yard of masonry in the dam:

				Per Cu. Yd. Masonry.
Rock..........	9,414 cubic yards delivered,	at $1.96	$18,452.60	$1.28
Mortar.........	5,008 " " "	" 1.93	9,676.08	0.67
Laying........	14,422 " " "	" 1.11	16,017.90	1.11
Total..................................		....	....	$3.06
8844 barrels cement, delivered,		at 3.58	31,665.38	2.13
Total..................................		....	....	$5.19

The contractor's plant was estimated to have cost $10,700, and to have depreciated 50% in two years of use, which depreciation is included in the above estimate of cost.

The outlet of the reservoir is a 24-inch cast-iron pipe laid through the masonry on bed-rock at a height of 12 feet above the stream-bed. The pipe is 1¼ inch thick, with bolted flanged joints, and provided with a 24-inch high-pressure Rensselaer standard gate-valve at each end, operated by hand-wheels. The up-stream valve is protected by a timber screen, and operated by a hand-wheel with an indicating stand mounted on the crest of the dam, and connecting with the valve by a vertical non-rising stem supported at intervals of 14 feet by brass boxes set in stones projecting from the face of the dam. This valve is usually kept wide open, the regulation being done by the down-stream valve, which is more accessible.

The conditions under which this dam has been built appear to have been extremely favorable for economy and safety of construction, with first-class materials immediately available, excellent foundations, and an entire absence of complications of an unusual or embarrassing nature in the preparation of foundations or the conduct of the work.

The excellent character of the construction and the skill and care with which it was executed, are shown by the absence of leakage further than the usual unimportant sweating which is observed at times on the

down-stream face, when the water-level rises in the reservoir. This sweating stops when the water-level ceases to rise for about thirty days, and on a hot day is offset by evaporation, when it practically disappears.

Lake Cheesman Dam, Colorado.—A storage reservoir for the domestic water supply of the City of Denver, Colorado, was formed in the heart of the Rocky Mountains, 48 miles southwest from Denver, on the south fork of the Platte river, by the building of a masonry dam of notable height and dimensions, called Lake Cheesman, after the President of the Denver Union Water Co. The dam was begun immediately after the destruction by flood of the rock-filled dam begun on this site (page 62) in May, 1900, and completed in July, 1904.

The dam has an extreme height of 234 feet, and carries a maximum depth of water of 224 feet, which exceeds that of any dam ever constructed. Its thickness at the base is 176 feet, and for the upper 30 feet it is 18 feet thick. It is built on a semi-circular arch, with radius of 400 feet at the up-stream face. The length on the crest is 710 feet. The gorge is exceedingly narrow, being only 30 feet wide at the base of dam, 40 feet wide at 40 feet above base, and 130 feet wide at 100 feet height. The width of the canyon is equal to the thickness of the masonry at the height of 70 feet above the base. The volume of masonry in the dam is 103,000 cubic yards. The work was done under contract by the Geddes & Seerie Stone Co., of Denver, at a total cost of about $1,000,000. The excavation of foundations required the removal of about 26,000 cubic yards of rock, sand and gravel. The spillway is located 200 feet north of the dam, in a natural gap of the ridge of granite forming the abutment on that side, and is about 300 feet in length. Its capacity is greatly in excess of the maximum recorded discharge of the stream, 1945 second-feet. Its crest is 6856 feet above sea level, or about 1600 feet higher than the Denver City Post-office.

The quality of the masonry is of unusual excellence, and the dam is said to be entirely free from leakage or the appearance of seepage on the down-stream face.

The reservoir formed by the dam covers an area of 874 acres, and has a capacity of about 3,500,000,000 cubic feet (80,000 acre-feet) fed by the flow from a catchment basin of 1796 square miles, including almost the whole of South Park.

The dam was designed and built by Charles L. Harrison, M. Am. Soc. C. E., Chief Engineer, Mr. L. E. Cooley, M. Am. Soc. C. E., acting as consulting engineer.

The work is described in detail in a paper prepared by Mr. Harrison for the American Society of Civil Engineers, and published in December, 1904, accompanied by a mathematical analysis of stresses by Silas H. Woodard, Assoc. M. Am. Soc. C. E.

FIG. 235.—DE WEESE DAM, COLORADO

FIG. 236.—DE WEESE DAM, WET MOUNTAIN VALLEY, COLORADO.

The De Weese Dam, Colorado.—A masonry dam was built in 1905 across Grape Creek, in the Wet Mountain Valley, by Mr. Dal De Weese, for the irrigation of a tract of choice fruit-growing land on the mesa south of the Arkansas river, opposite Canyon City. The dam is curved in plan, and has a maximum height of 44 feet, the crest being at an elevation of 7755 feet above sea level. The dam is arched in plan, of gravity section, and used as an overflow weir for the greater portion of its length. The outlet of the reservoir is 31 feet below the crest. It forms a reservoir of 150 acres area, and has a storage capacity of 1700 acre-feet. Plans have been prepared by the owner for increasing the height 40 feet, and other claimants to the surplus flood waters have proposed making a still higher extension to store water to the level of 80 feet above the present crest, giving a total capacity to the reservoir of about 65,000 acre-feet.

The photographs, Figs. 235 and 236, were taken by the author in January, 1907, and show the general character of the structure.

Boonton Dam, New Jersey. (Fig. 237.)—A reservoir covering an area of 800 acres, and impounding 8,600,000,000 gallons (26,400 acre-feet) was created for the water supply of Jersey City by the construction in 1900-1905 of a dam of masonry, with an auxiliary dyke of earth with concrete core-wall, both of unusually large dimensions. The masonry structure, which is 2150 feet long, has a maximum height of 114 feet, is 77 feet wide at the base and 17 feet wide on top. The up-stream face is vertical for 55 feet from the top down, then batters 1 in 20. The lower face batters 0.56 to 1 to within 22 feet of the top, and thence is vertical. It contains a total of 255,000 cubic yards of masonry, and is built almost wholly of cyclopean rubble. At each end the masonry dam is extended to the hills on either side by earth embankments, 450 and 500 feet long, respectively. A portion of the masonry, 300 feet long, is built as an overflow spillway, 5 feet below the crest of the dam, the elevation of which is 305.25 feet above mean tide. The down-stream face of the wall is covered with an embankment of earth, reaching to within 65 feet of the top of the dam, above which line the down-stream face is laid in ashlar masonry in courses from 18 to 36 inches in thickness.

This dam is one of 24 of the great dams of the world, and is only exceeded in length by the Tansa and Bhatgur dams in India. It is remarkable for the rapidity with which it was built, 85% of the masonry having been placed in 15 working months, from May, 1892, to November, 1894. The stone used is syenite, quarried four miles from the dam, and brought in large rough blocks, which were dropped into place closely together into a bed of very soft wet concrete, the spaces between the stones being filled with spawls to secure as large a percentage of rock as possible. The concrete was mixed in the proportion of 1 cement, 2.75 sand and 6.25 of crushed rock. The two faces of the dam were laid in advance of the concrete and kept always two to four feet higher. The average weight of masonry was 166 pounds per cubic foot, the unusual weight being due to the fact that the "plums" constitute 50% to 55% of the mass.

The core-wall of concrete in the center of the earth extensions of the dam is 4 feet 8 inches thick, carried well into the hills on either side. These dykes were made of earth, rolled in layers and paved. They have a maximum height of 35 feet.

To complete the reservoir on the south side an embankment, called the Parsippany dyke, was built with a maximum height of 30 feet, a total

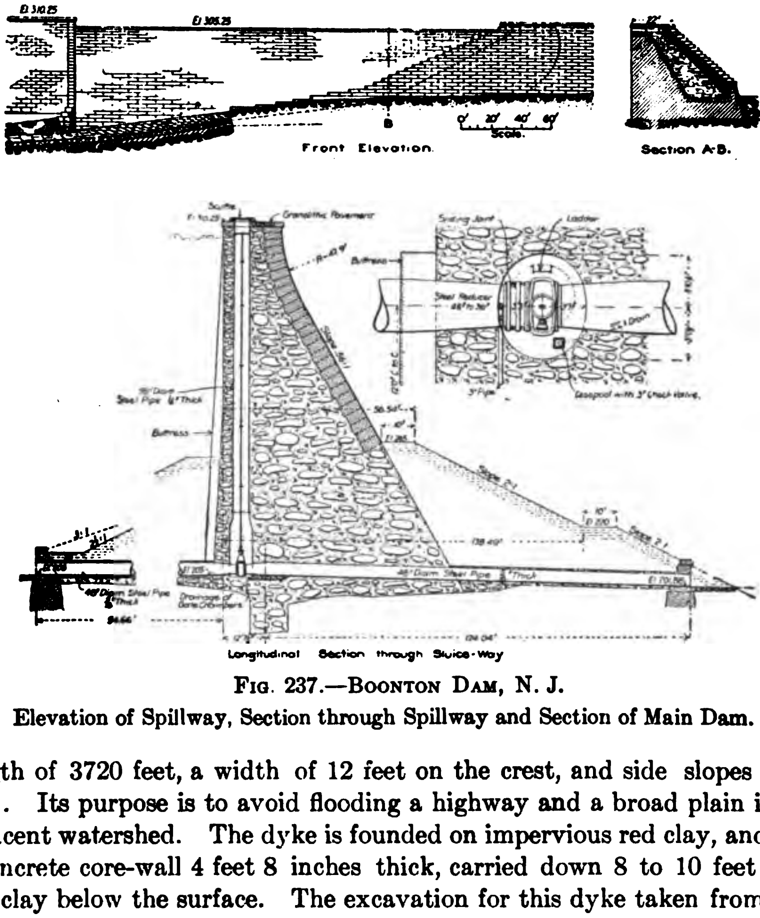


FIG. 237.—BOONTON DAM, N. J.

Elevation of Spillway, Section through Spillway and Section of Main Dam.

length of 3720 feet, a width of 12 feet on the crest, and side slopes of 2 on 1. Its purpose is to avoid flooding a highway and a broad plain in an adjacent watershed. The dyke is founded on impervious red clay, and has a concrete core-wall 4 feet 8 inches thick, carried down 8 to 10 feet into the clay below the surface. The excavation for this dyke taken from the reservoir basin increased the storage capacity about 30,000,000 gallon (150,000 cubic yards).

The plans for the Boonton dam were prepared under the direction of E. W. Harrison, M. Am. Soc. C. E., the chief engineer of the Jersey City Water Supply Company, contractors for the new water works of Jersey

City, acting with J. Waldo Smith, M. Am. Soc. C. E., consulting engineer. The works were built under Wm. B. Fuller, M. Am. Soc. C. E., the resident engineer in charge.

The dam is built on the Rockaway river, near Boonton, and the conduit to convey the water to Jersey City is 22.81 miles in length, laid on a hydraulic grade of 6 inches per mile.

The Wachusett Dam, Mass.—To provide for an essential increase in the water supply of the City of Boston and surrounding towns, the Metropolitan Water Board built the Wachusett dam on the south branch of the Nashua

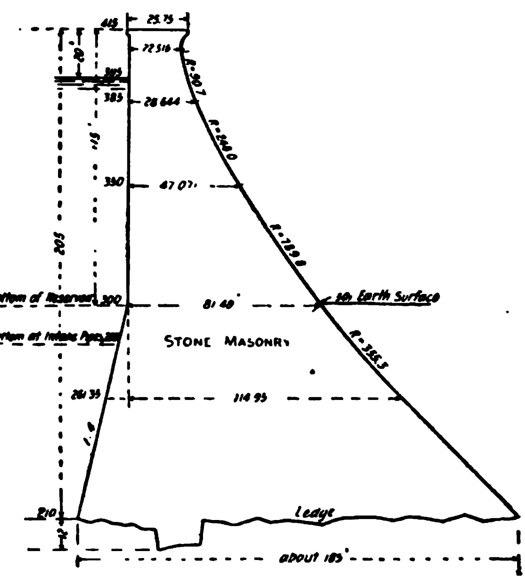


FIG. 238.—PROFILE OF WACHUSETT DAM.

river, creating a reservoir of 4195 acres, with a maximum depth of 129 feet, an average depth of 46 feet and a storage capacity of 193,300 acre-feet, or 63,068,000,000 gallons. The watershed area intercepted by the dam is 118.3 square miles.

The preparations for building the dam began in 1895, by borings to ascertain the depth to bedrock. This was a very thorough exploratory work, consisting of 806 separate borings to rock, aggregating 15,308 feet and 38 diamond drill borings in bedrock, with a total length of 2489 feet,

* For full data on the construction of the dam, see annual reports of the Metropolitan Water Board for 1900 to 1907; also a paper, by Dexter Brackett, M. Am. Soc. C. E., presented at the 26th Annual Convention of the American Water Works Association.

Fig. 239.—Wachusett Dam.

the holes over the site being 10 to 20 feet apart in each direction. Considerable work of stripping was done by the Board prior to the letting of contracts.

Contracts were let for construction of the masonry dam October 1, 1900, and completed in 1906. The contractors were McArthur Bros. Company. The total cost of the dam was $2,270,116.85. The dam is a granite masonry structure, 944 feet long, including abutments at each end, with its crest 20 feet above high water level, and a waste-weir 452 feet long. The height of the top of the dam above the point of deepest excavation is 228 feet, and the maximum thickness is 185 feet. It is 22.5 feet thick at the top under the projecting cornice, which gives it a total top width of 25.75 feet. It does not carry a roadway over the top, as is customary with many dams of that class. The dam is straight in plan. It contains a total volume of 266,663 cu. yds. of masonry of all classes, viz., rubble, 251,920; ashlar, 9,037; dimension stone masonry, 2742; brick, 1065; and concrete 1899 cubic yards.

About three-fourths of the heart of the dam is laid with natural cement mortar, mixed 1:2, the remainder being laid with Portland cement. The rubble consists of 54% large stones, 17% small rock and 29% mortar.

In constructing the reservoir the soil was stripped from 3943 acres to an average depth of one foot, the quantity removed being 6,900,000 cubic yards. This material was chiefly used in the building of the north dike, which is an embankment in two sections, respectively 4300 and 6700 feet long, required to complete the reservoir. This dike contains 5,861,814 cubic yards, of which 85% came from stripping the reservoir. The maximum height of this dike is 80 feet, or 65 feet to full reservoir level. The south dike is a similar structure, 2800 ft. long, 30 ft. maximum height.

The cost of the north dike was $749,811.36, the south dike $136,871.10, and the removal of soil from the reservoir $2,528,155.10. The total cost of all the works, including $3,179,060.57 paid for real estate, and the relocation of railroads, the building of bridges, damages, etc., was $10,797,537.17. The sum of $188,035.81 was further spent on improving the watershed by the drainage of marshes, etc.

The outlets to the reservoir consist of four 48-inch cast iron pipes, built through the body of the dam, at elevation 284, or 111 feet below the high water level of the reservoir. They supply water to the Wachusetts aqueduct, and to power turbines below the dam. The water may be wasted through them as well, their combined capacity with full reservoir being about 2500 sec.-ft.

The work was constructed under the direction of Frederic P. Stearns, chief engineer of the Metropolitan Water Board, and Messrs. Hiram F. Mills, Jos. P. Davis and Alphonse Fteley as consulting engineers. The designing engineers were Reuben Shirreffs and Alfred D. Flinn. The resident engineer was Thos. F. Richardson. All the engineering staff are members of the American Society of Civil Engineers.

The Connellsville Dam, Pa.—The Mountain Water Co., of Connellsville, Pa., completed a masonry and concrete dam in 1906 across Indian Creek, to form a reservoir of 230,000,000 gallons (700 acre-feet) capacity. It is 650 feet long on top, of which 300 feet in the center is used as an overflow waste weir, 6 feet lower than the remainder of the dam. It is about 39 feet maximum height, with a crest width of 6 feet and a base of 26 feet. It is

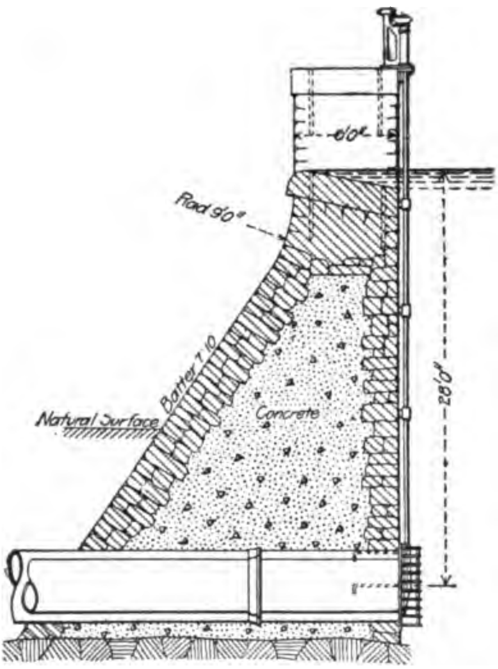


FIG. 240.—CONNELLSVILLE DAM, PENN., ACROSS INDIAN CREEK.

vertical on the up-stream side. The structure has a face on either side of about 3 feet thick of ashlar masonry, of sandstone, the interior being composed of 1:3:5 Portland cement concrete, with about 25% of bowlders embedded as "plums." The sand used was obtained by crushing the sandstone. Each finished layer of concrete was grouted with liquid neat cement before the next layer was deposited.

A section of the dam is shown in Fig. 240. The Indian Creek dam is one of a number similar structures built by the American Pipe Co. The experience with all of them is that where cracks have appeared they extend

* *Engineering Record*, January 27, 1906.

completely through the body of the masonry. Several cracks appeared in th Indian Creek dam, extending from face to face, and from top to bottom, the largest being one-sixteenth inch in width. The chief engineer of this work was Mr. J. W. Ledoux.

The Round Hill Dam, Wilkesbarre, Pa.—The water supply in Wilkesbarre and other towns in the Wyoming Valley is controlled by the Spring Water Supply Co., by whom a masonry dam was constructed in 1899 to 1901, on Spring Brook, six miles from Moosic, a station on the Delaware & Hudson railroad, having a maximum height of 104 feet, a thickness at base of 77.9 feet, and a width of 9 feet on top. The total length of the dam is 500 feet, of which 280 feet of the higher portion is masonry, beginning at a vertical cliff on one side, while the remainder, 220 feet, is an earth embankment with concrete core-wall. The crest of the masonry is 5 feet higher than the spillway. The batter of the upper face is 12.5% from the bottom up for 70 feet, thence vertical to the top. The down stream face has a batter of 75% below the 70 ft. level, thence a compound vertical curve to the top. The dam and wingwall contains 37,710 cu. yds. of masonry, in which 25,085 bbls. of cement were used. It was built of sandstone in blocks up to 3 cu. yds. in size, laid in mortar of 1:3 Portland cement and sand. The cost of the masonry averaged $5.98 per cu. yd.

The extension of the dam in earth is an embankment with slopes of 2.5:1, on each side. In its center is a core-wall of concrete 3 ft. thick at top (which is two feet below the crest of the dam), reinforced by counterforts or buttresses on each side, built on a slope of 1:6. The embankment is riprapped with stone for a depth of 18 ft. below the spillway crest.

The reservoir formed by the dam covers an area of 118.7 acres, receiving the drainage of 36 sq. miles of watershed. It has a capacity of 1,322,000,000 gallans (4050 acre-feet). The entire cost of the dam was $240,547.93, or $59.39 per acre-ft. of storage capacity.

Two 30-inch discharge pipes pass through the masonry portion of the dam, with two gate valves on each line, 30 ft. apart.

The dam was designed and built by John Lance, C. E., chief engineer of the company.

The Trap Falls Dam, Bridgeport, Conn.—In 1905 a dam of cyclopean rubble masonry was built to form a reservoir of 236 acres area, having a capacity of impounding 1,400,000,000 gallons (4340 acre-feet) for a portion of the water supply of the City of Bridgeport, with a population of 85,000. The dam is of gravity section. 8 feet wide on top, is 900 feet long, straight in plan, and 48 feet in maximum height, founded on granite or gneiss. The concrete in which the large rock were embedded was mixed in the proportion of 1 of cement, 2.5 sand, and 5 crushed rock, and made quite wet. About 20% of the dam is of large "plums," weighing up to 2 tons placed not less than 4 inches apart. About 11,000 cubic yards of this class of masonry were required.

McCalls Ferry Dam, Pa.—Power is being developed to the extent of 100,000 H. P. on the Susquehanna river, 40 miles north of Baltimore, 60

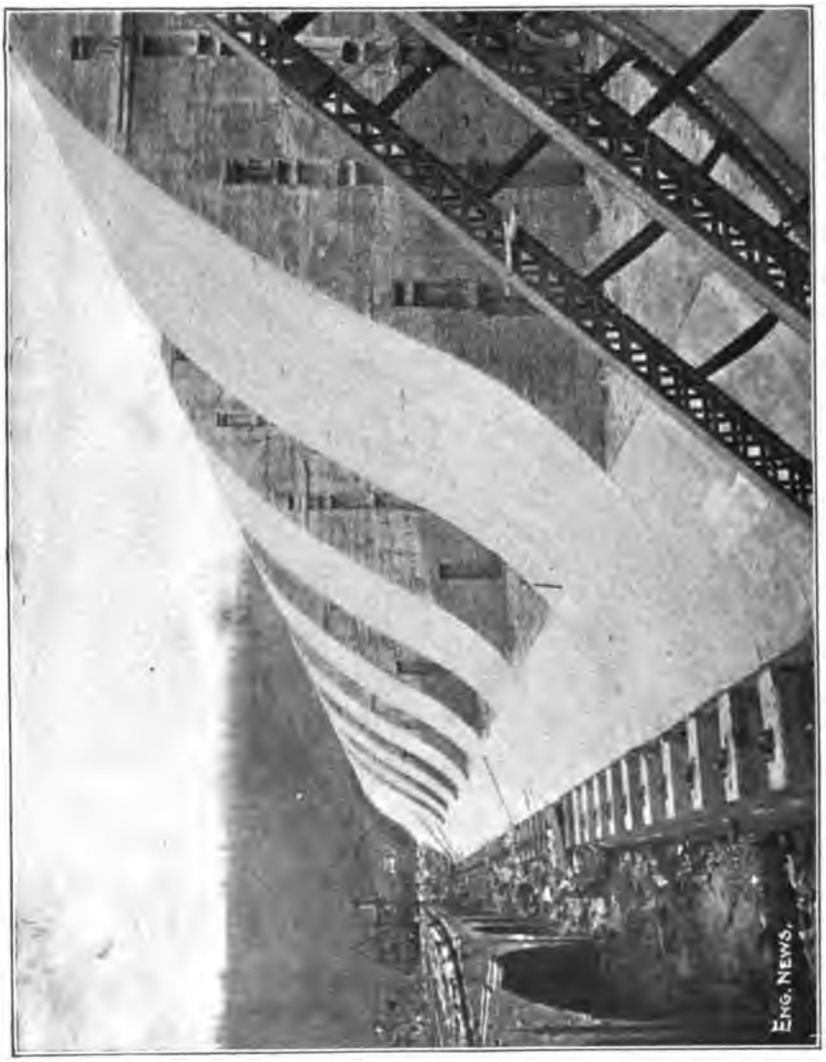


FIG. 241.—MCCALLS FERRY DAM, PENNSYLVANIA.

miles west of Philadelphia, by the erection of a masonry dam, 55 feet maximum height, 2350 feet in length, with a base width of 65 feet. The dam is of ogee form, and is to be used as an overflow for its entire length. The dam when completed will contain 330,000 cubic yards of concrete, including that in the power house and the construction bridge.

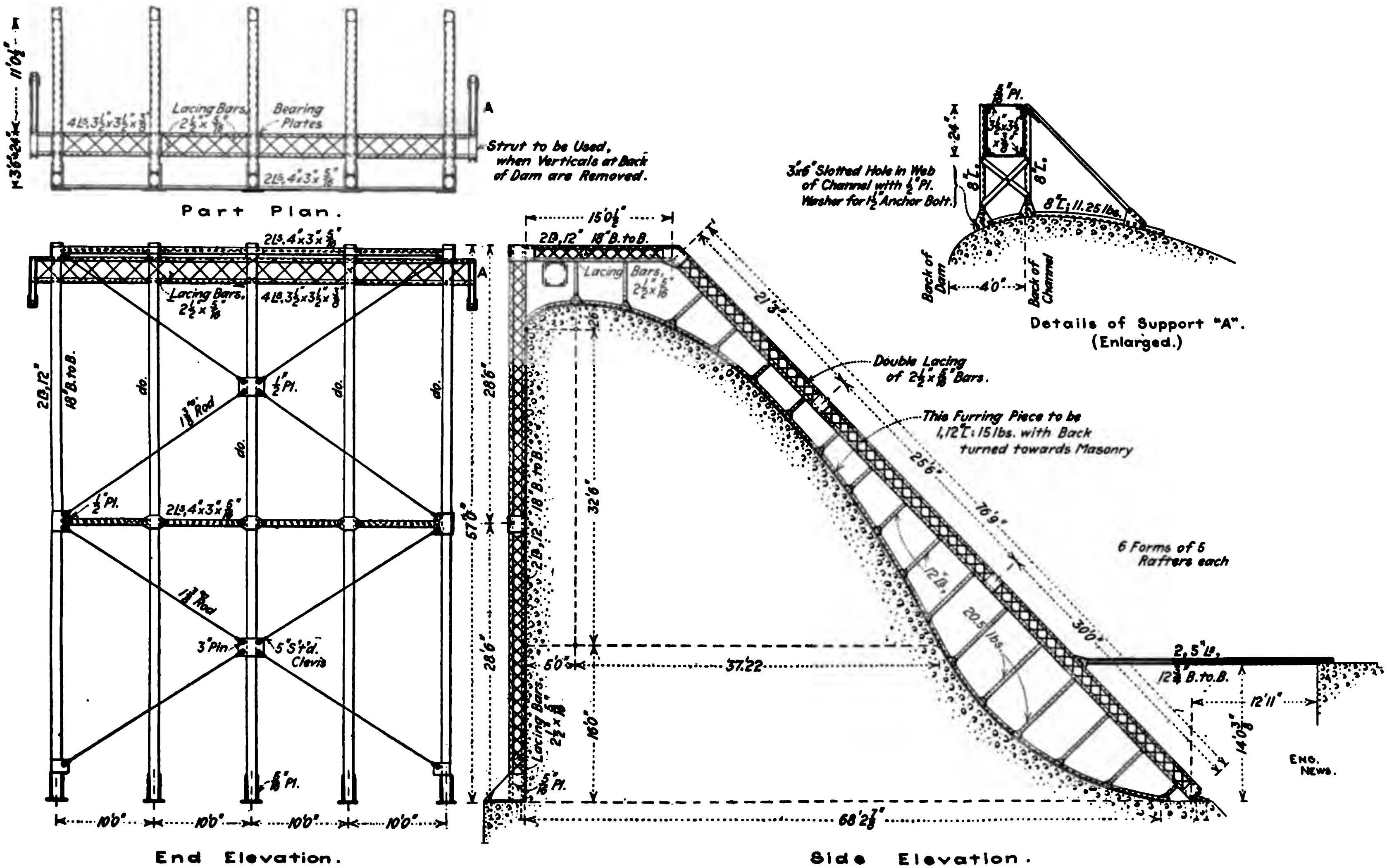


FIG. 242.—MCCALLS FERRY DAM, PENNSYLVANIA.

[To face page 332.]

One of the most interesting features of construction was the substantial concrete bridge thrown across the river on a series of arches, to serve as a working platform from which to build the dam. This bridge is 50 feet wide, 2300 feet long, parallel to and 16 feet downstream from the edge of the dam

FIG. 243.—McCALLS FERRY DAM, PENNSYLVANIA.

and power house. Four railway tracts of standard gauge were laid on the bridge, on which three travelling cranes, spanning all four tracks, with a base of 44 feet, are used for handling the steel forms of the dam and the material. They stand so high that cars and engines can pass underneath them, and each crane has four outriggers with a horizontal reach of 94 feet, and a capacity of lifting 5000 lbs. at the extreme end.

The dam is composed of cyclopean rubble, with huge blocks embedded in concrete, and is founded on hard gneiss bedrock. The total cost of the dam and power house, and electric plant, including the reconstruction of the Pennsylvania R. R. for a number of miles, is estimated at $10,000,000

Dr. Cary T. Hutchison is chief engineer, Wm. Barclay Parsons, M. Am. Soc. C. E., consulting engineer, Hugh L. Cooper, hydraulic engineer, and B. R. Value, engineer in charge.

The Pedlar River Dam, Lynchburg, Va.—A concrete dam has been erected across the Pedlar river, Va., to form a storage reservoir of 365,000,000 gallons capacity (1,115 acre-feet) for the water supply of Lynchburg, a city of 22,000 inhabitants.

The dam is 415 long, straight in plan, with 150 feet near the southern end used as an overflow spillway. The maximum height of the structure is 73.5 feet, the parapets 2.5 feet above the crest being 12.5 feet higher than the spillway level. It has a base width of 42.5 in the spillway section. The main portion is 39.2 feet thick at the bottom, 10 feet at top.

The contract for the dam was let in May, 1904, to C. G. Williams, of Brooklyn, for $103,708.

Several novel and interesting features have been introduced in the construction of this dam, one of which is the precaution taken to avoid the formation of a vacuum under the sheet of falling water over the spillway, as the maximum depth of overflow is expected to reach 6 feet. The down-stream face of the spillway is laid in steps of granite blocks, 18 to 27 inches deep (Fig 244), and large enough to extend 2 feet under the next step above. Under each of the steps 6-inch vitrified pipes are embedded, each extending the full length of the spillway and through the two wing walls. These pipes are open at the ends, and each have three 4-inch branches, with open ends extending to the faces of the steps, so as to supply air to the back of the sheet of falling water. (Fig. 245).

The concrete of the heart of the dam was laid in large blocks, about $10 \times 10 \times 15$ feet in dimensions, inside of wooden forms, with vertical and horizontal offsets locking them together, after the general plan employed on the San Mateo dam. The wing walls on each side of the spillway are reinforced concrete.

The heart of the dam was made of natural cement concrete, with large stone embedded.

The dam was designed by H. L. Shaner, city engineer of Lynchburg.

The Morgan Falls Dam, Atlanta, Ga.—The Atlanta Water and Electric Power Co. in 1902-04, erected a dam on the Chattahoochee river, 16

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* *Engineering Record*, Septmeber 21, 1907.

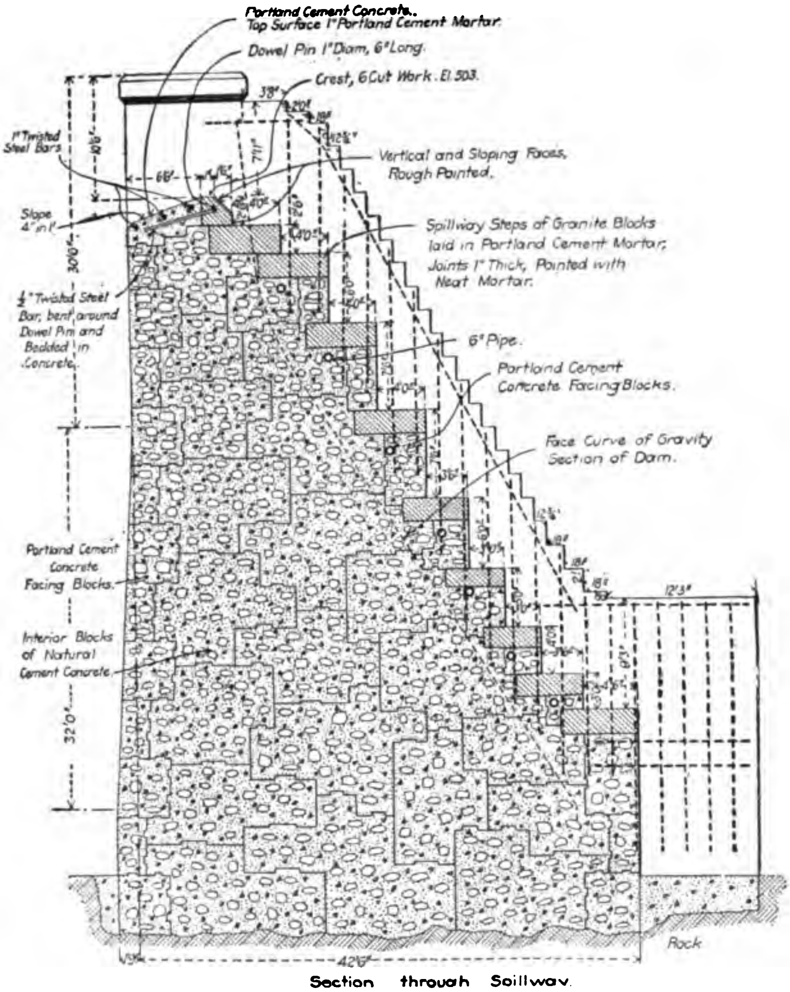

Fig 244.—Pedlar River Dam, Virginia, illustrating Concrete Block Construction.

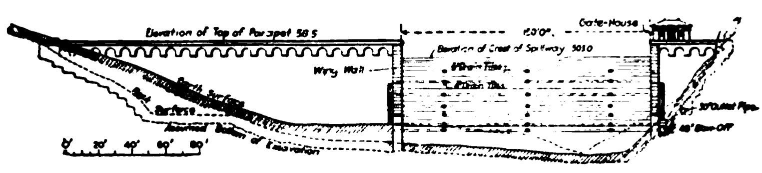

Fig. 245.—Pedlar River Dam, Virginia, showing Position of Air-vent Pipes to Prevent Vacuum on Face of Dam.

miles from Atlanta, about 900 feet long, 50 feet high, for the development of power transmitted to the city. The dam is founded on hard gneiss rock all the way across the river, and is straight in plan, divided into two main portions, one of which is a rollway overflow, 700 feet long, from the abutment on the west side. The other portion, 10 feet higher than the overfall crest, is vertical on the up-stream face. The rollway portion has a total width of 64 feet at the base, including the toe of the dam; is 43 feet thick at the base of the main prism, above the curved toe, and 15 feet thick at a point 8 feet below the top.

The up-stream face of the rollway section is built of rubble masonry, laid in Portland cement mortar, while the down-stream face and crest are of concrete, trowelled to a true, smooth surface. The interior, between these faces, is of cyclopean masonry, of the usual type of large blocks embedded in concrete, consisting of 1 part Portland cement, 2.5 parts sand and 5 parts crushed rock. The facing concrete was mixed 1:2:4, with a skin of richer mixture 1:2.

The dam was built on the plans of George B. Francis, M. Am. Soc. C. E., of the firm of Westinghouse, Church, Kerr and Co., of New York, contracting engineers for the entire plant. The plant has a capacity of 10,500 K.W. generated in seven units of 1500 K.W. each.

The Catawba River Dam, South Carolina.—This structure, built in 1903-04, for power development, 6.5 miles from Rock Hill, S. C., consists of an earth dam, 306 feet long, having a central masonry core-wall connecting with a masonry dam, 585 feet long across the main channel of the river, in two tangents with a central arc between them. The maximum height of the overflow rollway section is 55.5 feet with a base width of 33 feet, and up-stream face vertical. The up-stream face is built up with roughly coursed quarry-faced stone, 18 to 28 inches thick, laid in cement, while the heart of the dam is cyclopean rubble, in which stones of all sizes up to 8 tons weight were used, bedded in 1:3 mortar. Between the largest ones a concrete of 1 part of cement, 3 of sand and 5 of broken stone was tamped in. The face of the overfall was a concrete mixed 1:2:4. The structure contains about 60,000 cubic yards of masonry in all.

The earth dam is separated from the masonry by a heavy abutment wall, acting as a retaining wall for the earth, and carried to a height of 22 feet above the crest of the masonry dam. Into this abutment a masonry core-wall for the earth fill is bonded. This has a thickness of 18 feet at the base, 4 feet at the top, and at the junction with the abutment it is 58 feet high. At a point 70 feet from the retaining wall the core-wall narrows to 4 feet at the base, and carries the same width throughout the remainder of its length and height.

Against this core-wall on the up-stream side is a filling of puddle clay,

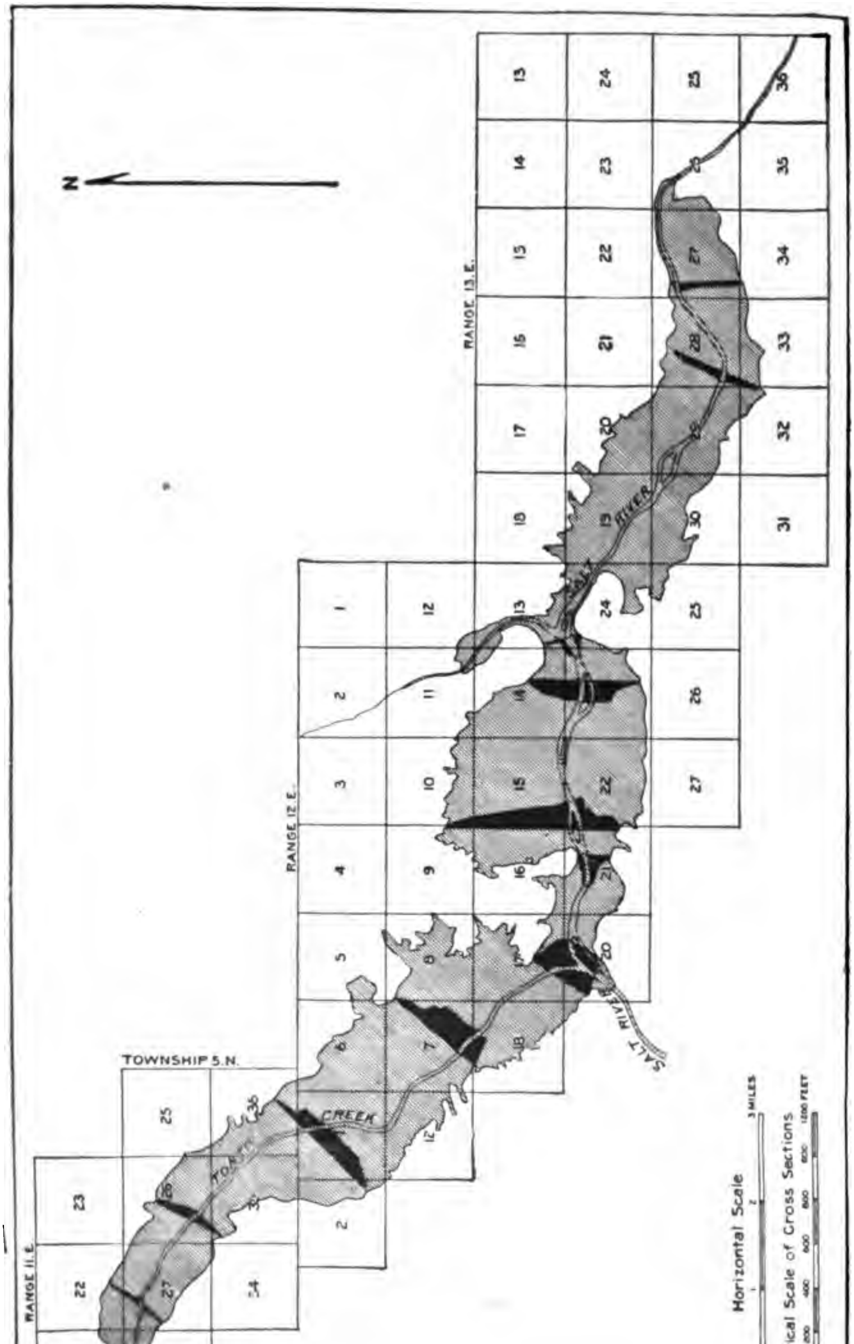

FIG. 246.—MAP OF ROOSEVELT RESERVOIR, SALT RIVER, ARIZ., SHOWING ELEVATIONS OF TEN CROSS-SECTIONS OF THE RESERVOIR.

12 feet wide at base, 4 feet at top. Outside of this is a body of selected clay, 8 feet at base, narrowing to nothing at the top. The remainder of the embankment is clay.

The river is reported to have a minimum discharge of 2100 sec.-feet, draining from 3000 square miles of watershed area, in which there is an annual precipitation of 50 inches. The highest recorded discharge, May, 1901, was 150,000 sec.-feet.

Roosevelt Dam, Arizona.—The United States Reclamation Service is engaged in the construction of a dam on Salt river, Arizona, for the formation of a mammoth reservoir, having a capacity of 1,284,000 acre-

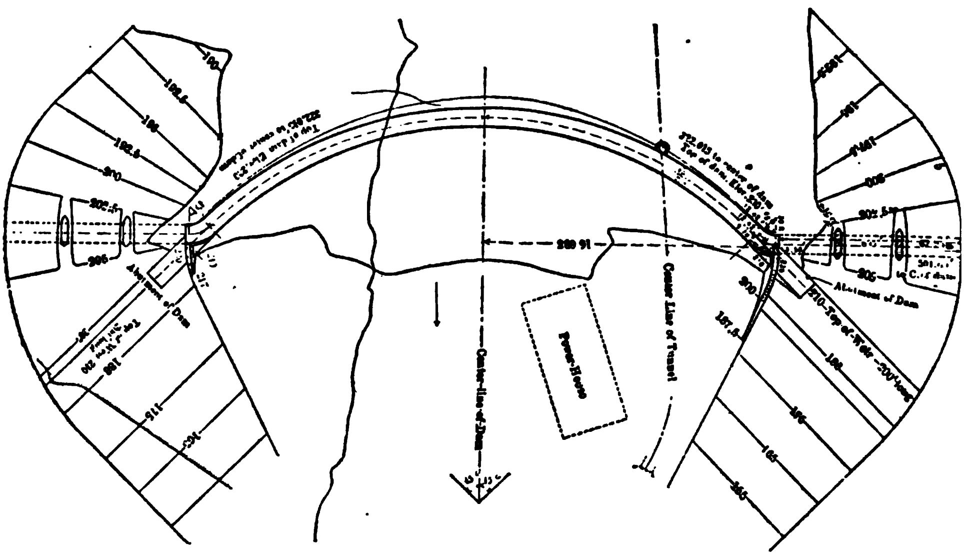

FIG. 247.—PLAN OF ROOSEVELT DAM, ARIZONA.

feet, for the purpose of irrigating about 200,000 acres in the Salt River Valley near Phœnix (Fig. 246). The dam is located below the junction of Tonto creek and Salt river, on the site of the reservoir projected many years prior by a private corporation called the Hudson Canal and Reservoir Co. of New York. It is situated 78 miles above Phœnix.

The dam is to have a maximum height of about 280 feet from the lowest foundation to the parapet of the roadway on the top. The length on top will be 644 feet, and at low water level 210 feet. It will be 170 feet thick at bottom, and 16 feet at top. The roadway will be 20 feet above the overflow level, which is 220 feet above the low water level of the reservoir. It is curved up-stream on a radius of 400 feet from the center at the crest. Spillway channels at each end of the dam will each have a width of 200 feet, and will be excavated from the solid rock (Figs. 247 and 248).

About 340,000 yards of cyclopean rubble masonry will be required to complete the structure. The geological formation of the canyon consists of alternating strata of hard red and yellow sandstone and pink limestone, generally quite thick and massive.

The masonry is being made with cement manufactured on the ground in a mill erected by the Government. The two faces of the dam are made

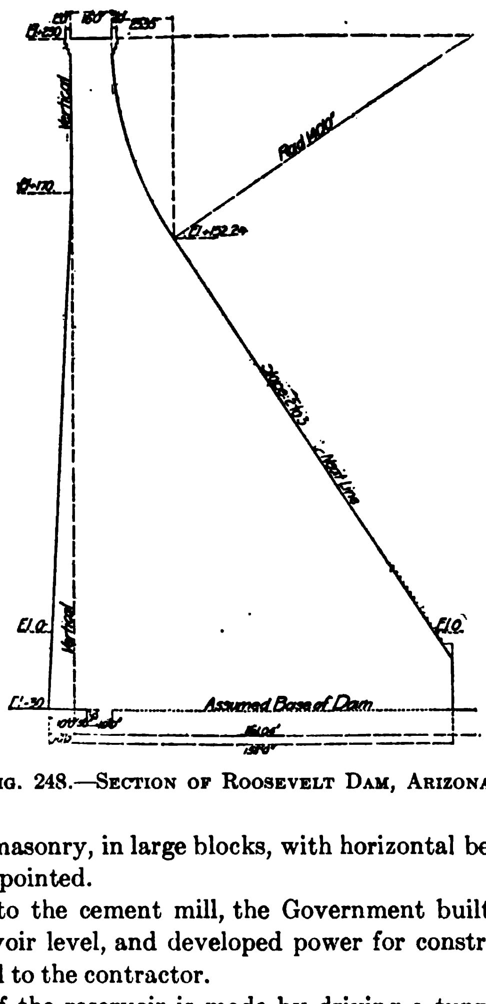

FIG. 248.—SECTION OF ROOSEVELT DAM, ARIZONA.

of range rubble masonry, in large blocks, with horizontal beds and vertical joints, carefully pointed.

In addition to the cement mill, the Government built a power canal above the reservoir level, and developed power for construction purposes, which is supplied to the contractor.

The outlet of the reservoir is made by driving a tunnel 500 feet long through the solid rock at one side of the dam, in which six large gates, weighing about 800,000 pounds and operated by electric motors, will control the outflow. The capacity of discharge with full reservoir will be 10,000 sec.-feet. The gates were manufactured at the Llewellyn Iron Works, Los Angeles.

The expenditure by the U. S. Government prior to the letting of contracts for the building of the dam thereafter and up to Sept. 30, 1905, were as follows:

Power canal and power plant	$580,402.55
Sluicing tunnel	23,828.80
Cement plant	246,583.00
Waterworks, refrigerating plant, buildings and shops	67,367.11
Roads	327,615.69
Telephone lines	41,137.95
Lands and rights of way	79,825.00
Machinery, lumber, fuel, supplies, etc.	133,363.22
Engineering	75,497.67
Administration	79,000.00
Total	$1,654,620.99

The contract for the dam was let to J. M. O'Rourke & Co., of Galveston, Texas, January, 1905, for an estimated total of $1,147,600 on the basis of 300,000 cubic yards as the contents of the dam. The final cost will considerably exceed this amount. The Government furnishes the contractor with cement, sand and power, which items alone will amount to nearly $1,000,000.

The dam was designed by Mr. F. Teichman, under the supervision of F. H. Newell, chief engineer U. S. Reclamation Service, and a board of consulting engineers. Mr. Louis C. Hill is supervising engineer. Mr. Newell is now director U. S. Geological Survey, and was succeeded by Arthur P. Davis, as chief engineer of the U. S. Reclamation Service.

Shoshone Dam, Wyoming (Plate 3).—The highest masonry dam yet projected by the United States Reclamation Service for storage of water for irrigation, is under construction on the north fork of the Shoshone river, Wyoming, in a gorge of solid granite, presenting a rare opportunity for a dam of unusual height because the walls are but 70 feet apart at the stream level, and the gorge is but 200 feet wide at a height of 250 feet. The canyon was found to be filled with detritus to a depth of 65 feet, so that a dam of 305 feet maximum height will be required. The dam will be arched in plan with a radius of 150 feet at center, having a top width of 10 feet, a batter on the up-stream face of 15% for 245 feet from the top, an on the down-stream side 25% for the same vertical distance. Below this elevation, coinciding with the stream bed, it will extend vertically on both faces to the bedrock. The base will therefore be 108 feet in width.

The elevation of the crest of the dam will be 5370 feet above sea level, at a height of 10 feet above the high water line of the reservoir. The length of the dam on top will be but 175 feet.

The volume of masonry required was computed at but 69,000 cubic yards. The contract for the construction was let September 18, 1905, to Prendergast & Clarkson of Chicago, for the sum of $515,730, including outlet and spillway tunnels.

Mr. H. N. Savage, M. Am. Soc. C. E., is supervising engineer. The reservoir will have a capacity of 456,000 acre-feet. The water will be used for irrigation in the Bighorn Valley, Wyoming. The river heads partly in the Yellowstone Park, and carries a minimum flow of 250 sec.-feet, with a maximum of 10,000 sec.-feet.

The Pathfinder Dam, Wyoming (Plate 3).—For the storage of water to irrigate lands in the fertile valley of the North Platte river in eastern Wyoming and western Nebraska, the United States Reclamation Service is constructing a dam in the heart of the Rocky mountains, below the junction of the Sweetwater and North Platte rivers. The dam is to be 210 feet high, from lowest foundation to the crest, with parapets 4 feet higher on either side. The width on the crest is to be 16 feet, at a height of 10 feet above the spillway level, which is 5850 feet above mean tide. The thickness at the base is 100 feet. It is curved up-stream with a radius of 150 feet at center of crest, with up-stream batter of 15% and down-stream batter of 25%, uniform throughout. The length on top is approximately 390 feet. The location is in a narrow gorge of red granite, with vertical side walls, quite similar to that of the Shoshone dam.

The cubic contents of the dam are estimated at 55,000 cubic yards. The outlet for the reservoir is through a tunnel, to be used for the diversion of the river during construction of the dam. This tunnel is 480 feet long, and was completed August 15, 1905, by Kilpatrick Bros. & Collins Contracting Co., of Beatrice, Neb., at a cost of $33,259.75.

The contract for the dam was awarded September 1, 1905, to the Geddes & Seerie Stone Co., of Denver, the contractors who built the lake Cheesman dam, for the sum of $482,000.

A spillway about 600 feet in length, designed for a discharge capacity of 43,000 sec.-feet will be constructed at the north end of the dam, and excavated in solid rock with the exception of 150 feet.

The reservoir will extend 23 miles up the North Platte and 15 miles up the Sweetwater river, covering an area of 21,774 acres, and having a capacity of 1,025,330 acre-feet.

In connection with this work, the Interstate canal is being built, starting on the river about 55 miles above the Nebraska-Wyoming line, with a capacity of 1400 sec.-feet at the head, 1200 sec.-feet at the 95th mile, and 500 sec.-feet at the 100th mile. The total length will be about 168 miles, and the area to be irrigated will be about 282,000 acres.

The Upper Otay Dam, California.—Next to the Bear Valley dam, which has been the marvel of the engineering world for twenty-four years, and still in service, the slenderest dam in California or any other part of the globe, is undoubtedly the concrete structure erected in 1900, sixteen miles southeast from San Diego, California, in connection with the other storage works of the Southern California Mountain Water Co. Although it has an extreme height of 84 feet, it is but 14 feet thick at the base, 4 feet thick at top, and 350 feet long on the crest. It is curved up-stream with a radius of 359 feet (Fig. 249).

The dam site is in a porphyry rock gorge, on the west fork of the Otay creek, at such an elevation that the full water line of the Lower Otay res-

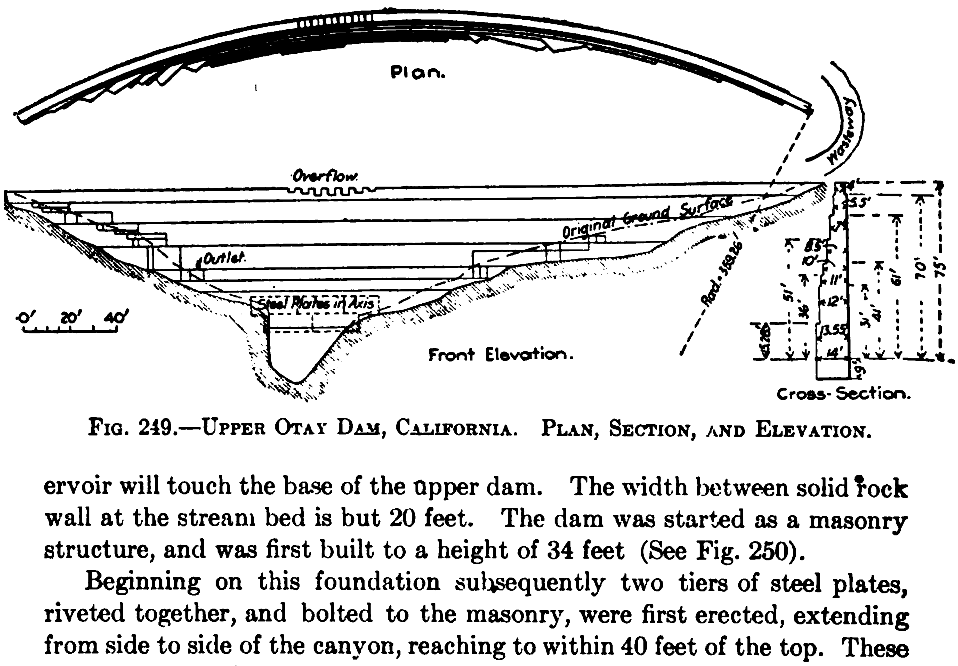

FIG. 249.—UPPER OTAY DAM, CALIFORNIA. PLAN, SECTION, AND ELEVATION.

ervoir will touch the base of the upper dam. The width between solid rock wall at the stream bed is but 20 feet. The dam was started as a masonry structure, and was first built to a height of 34 feet (See Fig. 250).

Beginning on this foundation subsequently two tiers of steel plates, riveted together, and bolted to the masonry, were first erected, extending from side to side of the canyon, reaching to within 40 feet of the top. These were enveloped in concrete on both sides. Above the top of these plates a line of old railway cables, 1¼ inch in diameter, was placed in the center of the concrete wall every two feet in height to the top the entire length of the dam. No other reinforcement was used. The wall was built vertical on the up-stream face, and stepped off on the down-stream side, with seven square offsets of 1 to 1.5 feet at irregular intervals. The reservoir has a storage capacity of nearly 2000 acre-feet, but the watershed area is so small that it is never expected to be filled from its own run-off, and will be supplied by a conduit from the Barrett dam, on Cottonwood creek.

If the dam should break under full reservoir pressure no very serious consequences could ensue, on account of the large size of the Lower Otay reservoir, into which the water would be discharged. Neither of the reservoirs have ever been filled.

The dam must be regarded as one of the most interesting of modern structures in that line, whose ultimate fate will always be looked upon with curiosity by the profession.

FIG. 250.—UPPER OTAY DAM. FOUNDATION MASONRY.

Fig. 251 is a recent photograph of the dam, for which the writer is indebted to Mr. N. L. Hall, one of the engineering staff of the company. Fig. 252 was taken shortly after the completion of the dam.

The Mariquina Dam, Manila, P. I.—The new water supply of the City of Manila, Philippine Islands, is to be taken from the Mariquina river, about sixteen miles northeast of the city, in connection with which a masonry dam was erected in 1906, in a narrow gorge of the river, creating a reservoir of about 2,000,000,000 gallons capacity (6100 acre-feet). The dam is 400 feet long on the crest, and has a maximum height above the stream bed of about 75 feet. The central portion of the dam for160 feet is designed as an overpour rollway, the crest of which is 15 feet lower than the re-

FIG. 251.—UPPER OTAY DAM, IN JANUARY, 1908.

FIG. 252.—UPPER OTAY DAM.

mainder of the dam. The dam is 17 feet wide on the crest. The section (Fig. 253) shows the profile of the structure and its principal dimensions. The dam is founded on solid bedrock, to which it is bonded by stepping and grooving the rock after all unsound and fissured portions had been removed.

The body of the dam is built of rubble concrete masonry containing about 50% of large stones, laid so irregularly as to avoid continuous joints or courses. The stone used is a hard crystalline limestone or marble. The concrete is a 1:2½:5 mixture, the aggregate being gravel and broken stone up to two inches diameter. The faces are built of coursed rubble, the

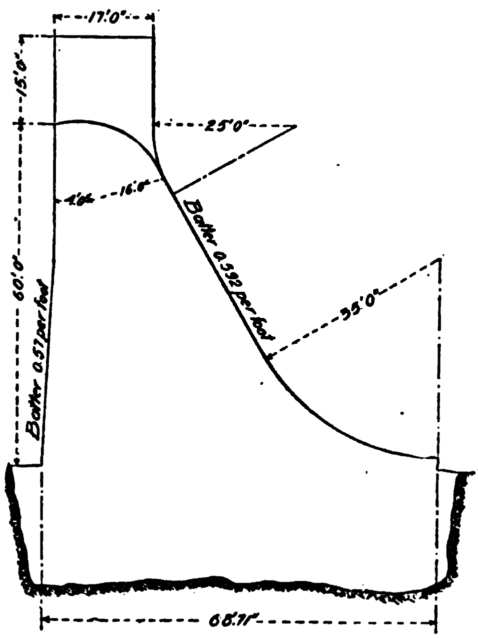

FIG. 253.—PROFILE OF MARIQUINA DAM, MANILA, P. I., WATERWORKS.

stones being dressed so as to make ¾ inch joints for a depth of at least 4 inches. These were raked out and pointed with 1:1 mortar. The total volume of the dam is about 28,000 cubic yards.

The gate house controlling the flow from the reservoir to the pipe line is built as a part of the dam at one end of the spillway section. It is 27×40 feet in size, the longest dimension being parallel with the dam. Two pipes pass through it, one of which is 42 inches in diameter, carrying the supply to the city and the other 36 inches in diameter, serving as a waste pipe.

The main pipe line from the reservoir is 42 inches in diameter, of riveted steel, 10½ miles long, discharging into an aqueduct built on a hydraulic grade to its terminus in the city distributing reservoir of 112 feet above sea level. This reservoir is excavated largely in rock, and has a capacity of 50,000,000 gallons. The flow into and out of the reservoir is controlled by a gate house with semi-circular ends, 47′ 8″×26′ 8″, quite similar in design and detail of controlling tank and gates to the four reservoir gate houses in the distributing system of Portland, Oregon.

The works were built under the direction of Maj. J. F. Case, M. Am. Soc. C. E., chief engineer of the Department of Sewers and Waterworks Construction, formerly assistant engineer on waterworks construction in Portland, Oregon.

Dams in Mexico.

THE OLD AND NEW DAMS OF LA JALPA, GUANAJUATO, MEXICO.

The Old Dam.—Scattered over the Republic of Mexico are many venerable masonry dams which date back to the Spanish régime, whose history and description would make an entertaining chapter were complete data obtainable. They were generally built on private estates or haciendas to store water for irrigation.

One of these is situated on the Hacienda La Jalpa, 25 miles from the city of Leon, in the northwestern portion of the State of Guanajuato, now the property of Mr. Oscar J. Braniff, of Mexico City. The dam was built about 250 years ago, and was regarded at the time as such a notable structure that the King of Spain created for its owner a special hereditary title, called the "Conde de la presa La Jalpa"—the Count of Jalpa dam. Unfortunately it was not as permanent a structure as anticipated, and was destroyed seventy years ago by a tremendous flood, which stripped the country, so that there are no trees now in its path over seventy years of age. The dam was immediately rebuilt, and is now in service.

The New Dam.—Alongside of the old reservoir and separated from it by a long narrow strip of land, is another reservoir site where Mr. Braniff is building a new and more important masonry modern dam of gravity type after the Wegmann profile. The two watersheds are quite independent, but the overflow from the old reservoir is taken into the new one by an artificial channel through the ridge. The new dam is nearing completion, and is expected to be dedicated within a year with appropriate ceremonies by President Diaz and his wife. It is located on the river Turbio, a tributary of the Lerma river, and intercepts a watershed area of 116 square miles, on which the average annual rainfall is about 30 inches, yielding a run-off about double the reservoir capacity.

It was projected over fifty years ago on a small scale, and work begun on the foundations in 1888, but after working a year operations were suspended until 1902, when active construction was resumed and has continued ever since.

The dimensions of the dam are as follows:

Length on top	1800 feet
Maximum height	85.4 "
Thickness at base	65.6 "
Thickness at crown	9.1 "
Height of crest above spillway level	6.6 "

The cubic contents will be about 92,000 cubic yards and cost complete about $500,000 gold.

The new dam surrounds and envelops the old foundations of twenty years ago, to which it is joined with a base laid in Portland cement mortar. The body of the dam is a rough rubble, formed of large blocks of hard limestone, up to 3 tons weight, laid in a mortar of native hydraulic lime and sand.

There are five outlets to the reservoir, on four different levels, consisting of cast-iron pipes built through the masonry. Three meters above the base are two 36-inch cast-iron pipes, having a discharge capacity of over 1000 sec.-feet under full head. At the six-meter level, a 24-inch pipe and valve are placed for operating a flour mill by water power. Above this at the 11.5 and 18 meter levels are two other pipes, delivering water to lands that cannot be reached from the main outlets below.

On the up-stream face of the dam an embankment of clay has been built against the dam on a slope of 2 on 1 to a height of 33 feet. This is for the purpose of cutting off filtration into the lower levels of the masonry, and corresponds to modern German practice in such structures. Before building this dike of earth the joints in the masonry, which had been left open for several years, were carefully pointed with Portland cement mortar. Care has been taken to keep the masonry wetted during the period of setting, and for this purpose the water in the reservoir has been allowed to follow up the building of the dam to or near the top of the work.

The wasteway will be excavated in rock at one end of the dam. It will be 250 feet long, 6.5 feet deep.

In connection with the two dams, about 18 miles of canals have been built on the hacienda, providing for the irrigation of 25,000 acres. The plant is doubtless the most costly and important reservoir irrigation work in Mexico.

The author is indebted to the courtesy of Mr. Oscar J. Braniff for the data concerning these works.

The capacity of the new reservoir will be 35,000,000 cubic meters (28,370 acre-feet).

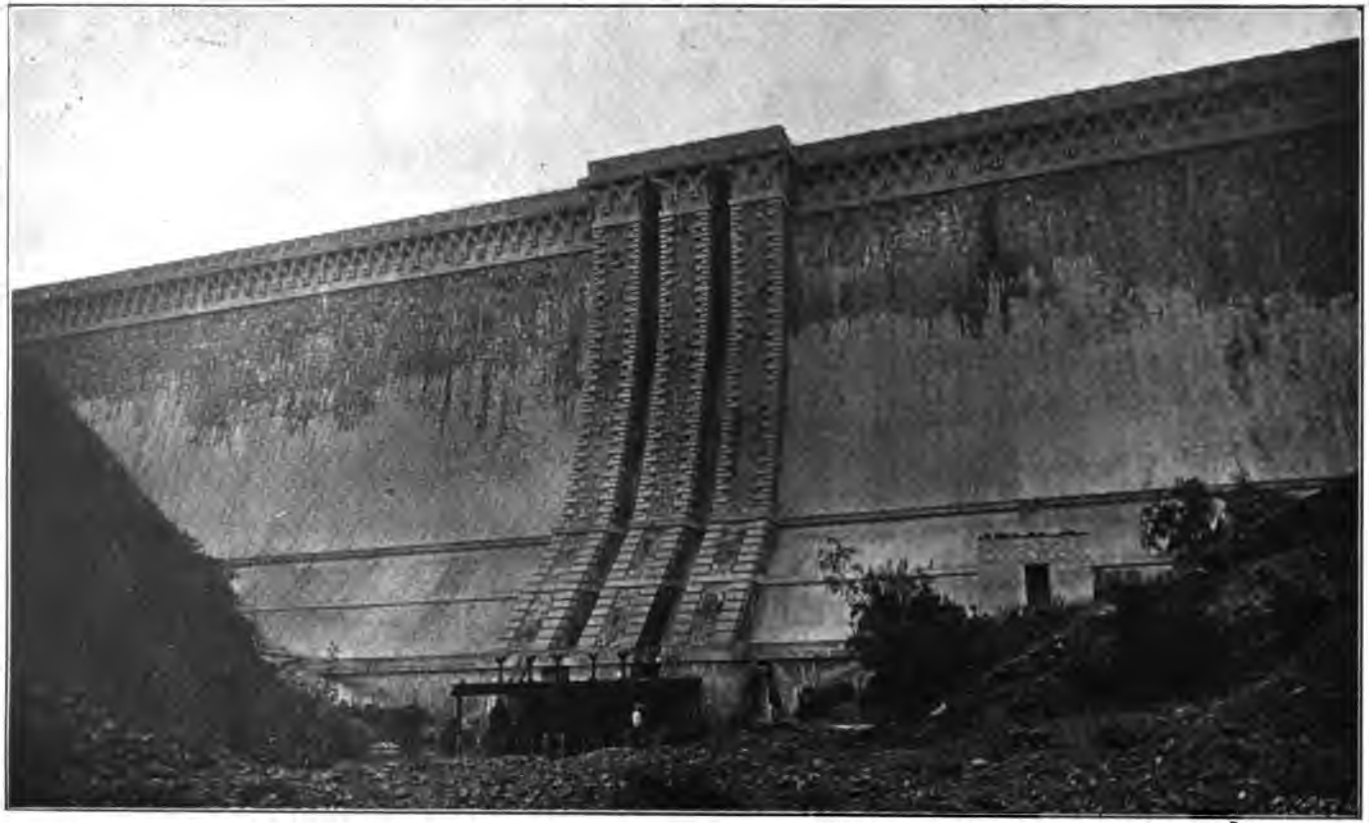

Fig. 254.—Front of Esperanza Dam, at Guanajuato, Mexico.

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. 254 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. 255 (frontispiece).

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 to 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.

Mercedes Dam, Mexico.—One of the large landed estates of Mexico, in the State of Durango, is the Hacienda de Santa Catalina del Alamo y Anexas, which includes five minor haciendas, or centers of administration, embracing more than one million acres, and belongs to Señor Pablo Martinez del Rio, of Mexico City. While a large part of the estate consists of rugged grazing lands, there are extensive valleys of fertile soil where cotton can be profitably grown. The Nazas river is the source of irrigation supply or a large and extremely fertile territory known as the Laguna District, stretching eastward from the line of the Mexican Central railway for 50 miles or more. A large part of the cotton crop of Mexico is produced in this district. It has developed into such a profitable industry as to give a high value to all the water supply available for irrigation.

The property of Mr. del Rio adjoins the Laguna District on the west, from which a number of small tributaries of the Nazas river drain the mountainous portion of the hacienda in a northeasterly direction from the region broadly known as the Yerbanis Sierra. One of these tributaries, called Zorrillo creek, drains an area of 120 square miles before passing through a narrow box canyon known as the Boquillo del Zorrillo. Below this canyon, there are many thousands of acres of fine land, in a large valley of a stream called La Vieja, which only require sufficient water supply, applied artificially at the right time, to produce cotton or any other crops in abundance. Immediately above the canyon is a small valley of a few hundred acres, surrounded by hills and adaptable for the formation of a capacious reservoir.

The canyon is not more than 1,800 feet in length, in the form of a letter S, and at its upper end the width between the rocky walls is but 102 feet at the creek bed. These walls are nearly vertical for 60 to 70 feet in height and then slope back at an angle of about 2 to 1 on one side and 3 or 4 to 1 on the other.

This site was selected for the construction of a masonry dam, which was begun May 14, 1901, and completed May 8, 1905, forming one of the most notable dams in Mexico and comparing favorably with many of the best known structures in the world. It is easily accessible by good road, eight miles from the station of Pasaje, on the Mexican International Railway, which is about midway between Torreon and Durango.

The dam has an extreme height from the lowest foundations to the crest of 40.5 meters (132.8 feet) of which 8.5 meters (27.88 feet) is below the original creek bed. The thickness of the wall at the top is 3.5 meters (11.48 feet), at the level of the creek bed 22.2 meters (72.8 feet), and at extreme base it is 25.75 meters (84.5 feet). The profile is of the well known Wegmann gravity type, based on a specific gravity of 2 for the masonry. Its cubic contents are 21,416 cubic meters (about 28,000 cubic yards), and its cost complete was approximately $200,000, Mexican currency. The wall is straight for little more than half its length, the remainder being curved with a radius of 60 meters, measured from the central axis at the crest, its convex side being up-stream. Its length at base is but 13 feet; at the creek bed, it is 103 feet long; 66 feet above the creek bed it is 256 feet long, and at the crest its total length is 535 feet, not including the spillway, which is 98 feet in length and 6½ feet deep.

A tunnel 77.6 feet long, 6 feet by 6 feet 5 inches, was cut out through the rock at the level of the stream bed at the end of the dam, through which the flow of the stream was diverted during construction. This diversion was effected by means of a slender wall, built as a portion of the upper face of the dam, which was founded on bedrock in a trench cut for the purpose. This tunnel was temporarily closed with a wooden bulkhead, but was to be provided with a 24-inch outlet pipe and gate, surrounded by concrete.

To cut off seepage through bedrock underneath the dam, a trench, 1 meter wide, 2.5 meters deep, was excavated in the solid rock above the footing of this wall, the rock being plastered with cement and the trench refilled with puddled clay. The remaining excavation for the base of the dam was then made, without molestation from water, and the foundations of the dam were laid with cement mortar for a thickness of 2 meters. On

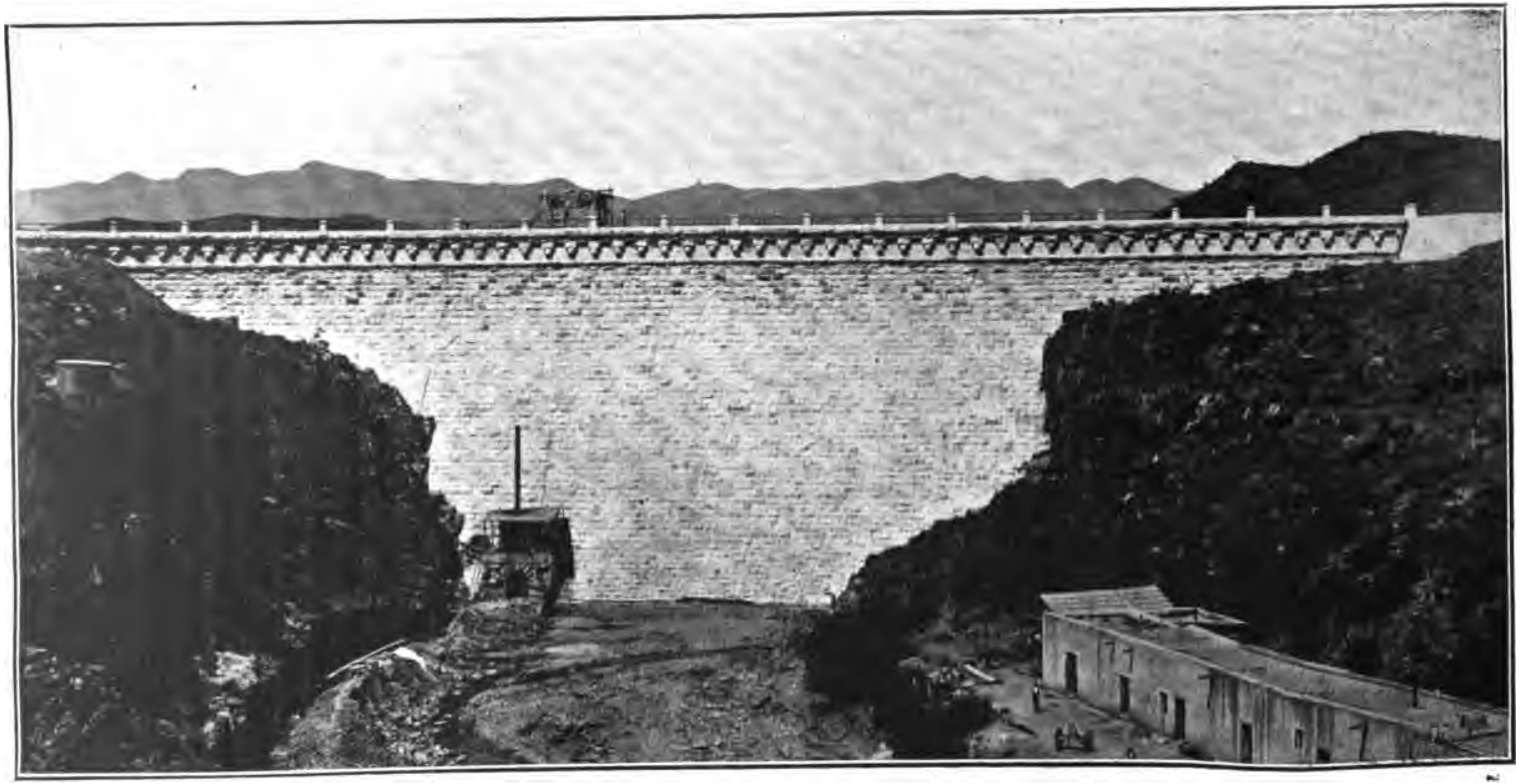

Fig. 256.—Mercedes Dam, Durango, Mexico. General View from below before Completion of Gate Tower.

the sides this thickness diminished from 2.0 meters next to the bottom to 0.75 meters at the top. In the body of the dam hydraulic lime mortar was used, made near the site from an excellent quality of limestone there existing. The sand used was a clean, sharp quartz sand, found in the bed of a tributary stream some distance above the dam. The Portland cement used amounted in all to 1800 barrels. It was mixed in the proportion of 1 to 4 of sand, and hence only about 10% of the entire volume of masonry is laid in cement, the remainder being laid with hydraulic lime mortar.

The character of masonry in the body of the dam was an uncoursed rough rubble, but the two faces were built of cut stone, in uniform courses of 0.6 meters (2 feet) on the lower face and 0.45 to 0.70 meters on the up-stream face. It was estimated that 37% of the mass of masonry consists of mortar.

The stone at the dam is of volcanic origin, classified as rheolite, which was so brittle and of such irregular cleavage as to be considered unfit for use in the masonry. The stone used in the work was taken from a quarry opened 2 kilometers above the dam. It is an *andesite* or sandstone formation of a reddish color, which appeared to fill all requirements, as it could be quarried in large blocks and was easily dressed to dimensions required. When tested at the National School of Engineering in Mexico, it was found to have a compressive strength equal to 521 tons per square foot.

The main outlet of the dam consists of a cut-stone culvert, 6 feet wide, 7.87 feet high, having vertical sides and a semi-circular arched roof. This connects with a rectangular shaft or tower built against the dam on the up-stream side, extending from the base to and above the top, the interior dimensions being 5.1 feet thick. At the base of the tower on the outside is a 6-foot circular sluice gate of cast iron, operated by a steel gate stem, 1.75 inches diameter, a ball-bearing geared hoisting device, resting on a platform projecting from the tower at the level of the crest of the dam.

On the inside of the tower, against the face of the dam proper, is a similar sluce gate, 5 feet in diameter, also operated from the top. The method of operating these gates is to fill the tower with water through other smaller openings, while both gates are closed. The outer gate, being relieved of pressure, can then be raised. The inner gate, which can be kept well oiled, as it will be easily accessible, can presumably be easily raised under full pressure as much as desired. If it were opened wide the discharging capacity with the reservoir but half full would be approximately 900 cubic feet per second. As it is never intended to draw out more than 40 to 50 sec.-feet for irrigation at any time, the evident purpose of these huge gates is to provide for a very large discharge at times, to be used in the attempt to wash out silt accumulations from the reservoir,

FIG. 257.—MERCEDES DAM, MEXICO, DURING CONSTRUCTION.

FIG. 258.—MERCEDES DAM, MEXICO, LOOKING ACROSS SPILLWAY CHANNEL, SHOWING CURVED PORTION AT FAR END.

although they are of doubtful value for this purpose. They will probably never be used except when the reservoir is nearly empty.

The main service outlets consist of two flange-joint 12-inch cast iron pipes, placed vertically inside the walls of the tower and opening out into the reservoir with six upturned elbows, which are closed with cast iron covers, lifted from the top by cables. These pipes pass through the masonry of the dam underneath the culvert, and discharge into the cement-lined canal which starts at the base of the dam and is carried through the canyon to fields below. Gate valves at the lower end control the discharge. The covers on the inlet elbows have hinged one-inch flap valves, which are raised to admit water for filling the pipes, before the covers are raised, and thus act as by-pass valves. The intake elbows are placed in pairs at depths of 34.4 feet, 62.8 feet and 91.3 feet from the top. The four upper ones are in the front wall of the tower and the lower two on the sides. They connect with the vertical standpipes by means of flanged crosses, the free ends of which are closed with cast-iron caps bolted to the flanges.

The six-inch by-pass connections, controlled by gate valves, open into the tower at the base of each vertical standpipe, through which the tower may be filled behind the 5-foot sluice gate.

As a precaution against percolation through the dam, the upper face was treated with alternate washes of alum dissolved in water, and potash soap, five coats of each on the lower third, four coats on the middle third and three coats on the upper section. Application was made by spraying with a hand pump.

The dam was entirely built by native labor, with but few mechanical appliances. The materials were hauled to the site on small cars drawn by mules on a two-foot gage tramway, hoisted by animal power up an incline of 24% grade, and distributed over the dam by portable tracks and cars pushed by hand. The mortar was mixed in a vat operated by mule power and located about a mile above the dam, where water was obtained from wells. It was delivered on the same track by which stone was brought from the quarry. During the first year of construction the work was over-topped by freshets several times without injury. During the second year the run-off was very small and the work was interrupted by floods; in fact, a shortage of water for construction was experienced for a brief period. The dam reached a height of 10 meters during that season.

At the close of the rainy season in the fall of 1905, the water in the reservoir had reached a height of only 13.5 meters (44 feet) above the floor of the outlet culvert. With the water standing at this height in the reservoir dampness and sweating was observed on the down-stream face of the dam, but this completely disappeared a few days later. Leakage through the bedrock at the sides of the dam and into the tunnel continued as long as water remained in the reservoir, although in finely distributed filtrations, through minute seams and not in a manner threatening the least danger to the dam.

By the end of August, 1906, the reservoir was filled to the height of 46 feet, but without the reappearance of moisture on the face of the dam, although the leakage through bedrock seams was renewed in the same amount as before. As the stream carries a large quantity of silt at times, it is expected that the seams in the rock may ultimately be closed by the fine particles of silt drawn into them and finally shut off all further leakage.

Water Supply.—The discharge of the stream was measured during the time of construction of the dam, as follows: 1901, 4306 acre-feet; 1902, 26,000 acre-feet; 1903, 2830 acre-feet; 1904, 8590 acre-feet; 1905, 5463 acre-feet; average 9438 acre-feet. This is a run-off of 24 to 217 acre-feet per square mile per annum, averaging 78.6 acre-feet per square mile. The rainfall at the dam has been recorded as follows: 1901, 11.65 inches; 1902, 24.84 inches; 1903, 16.38 inches; 1904, 14.80 inches; 1905, 16.36 inches. The rainy season begins in June and ends in November, the heaviest rains occurring in the month of September, before and after the equinox.

Owing to the precipitous and impermeable nature of the watershed and the lack of the retarding influences of forests and gravel-filled valleys, the run-off is torrential in character and at times reaches a rate of 7000 cubic feet per second. The watershed is about 42 miles in extreme length and the summit elevations more than 3000 feet higher than the dam. Owing to the irregularity in rainfall the water supply is correspondingly fluctuating, amounting to considerably less than the reservoir capacity during four of the five years in which it was measured.

The reservoir floods an area of 416.4 acres and has a capacity of 12,000 acre-feet.

The spillway of the reservoir was excavated from the solid rock at the north end of the dam to a width of 30 meters (98.4 feet). The crest is well paved with masonry laid in cement. It is two meters in depth below the crest of the dam. Its capacity is said to be double the amount deduced as essential by observation of the volume and duration of maximum floods, and considering the equalizing action of the reservoir capacity in the two meters of depth over the sill of the spillway.

Irrigation.—The area of land which may be irrigated from the reservoir has yet to be determined from the observation of catchment during a period of years. If the reservoir could be filled once each year, it would suffice for the irrigation of 5000 acres. A single crop of cotton produced on this area, with the normal yield of one bale per acre, valued at $50 per bale, would more than repay the cost of the dam. The investment is therefore to be regarded as a profitable one.

Silt.—Observations on the volume of silt brought to the reservoir indicated that at times it might reach as high as three per cent. Upon the advice of the author a partial precipitation of the silt will be made by the building of some small dams above the main reservoir, as any attempt to sluice it out of the reservoir could only result in a loss of valuable water, without moving more than an inappreciable quantity of the silt which had precipitated over the floor of the reservoir.

Canal System.—The main canal is 2100 meters in length, mostly lined with masonry. It has a section of 2.75 square meters and a grade of 5 feet in 10,000 (2.64 feet per mile). From the end of the main canal a smaller ditch with a section of one square meter and having the same slope or grade as the main canal, is carried to the south a total distance of 6500 meters (4.4 miles), while toward the north extends a ditch with a section of 1.8 square meters and a fall of 1 per 1000 for a distance of 1560 meters. This ditch has several drops of 2 to 3 meters, built in masonry. These ditches have a combined length of 8600 meters (5.8 miles) as far as completed, and command an area of 5000 acres, on a portion of which a satisfactory crop of cotton was produced in 1906.

The dam was designed by Carlos Patoni, C. E., of Durango, and the construction was carried out under direction of Nicolás Durán, C. E., of Mexico City, to whom the author is indebted for the facts embodied in the foregoing description, as well as to P. Barnetche, the intelligent foreman in more immediate charge of the work.

Figs. 256, 257, and 258 are excellent photographs, taken during construction and after completion of the dam.

Masonry Dams in Various Parts of the World.

The data for the following condensed descriptions of the principal masonry dams of the world have been gleaned from many sources, including the Minutes of Proceedings of the Institution of Civil Engineers, the Transactions of the American Society of Civil Engineers, *Engineering News*, *Engineering Record*, and other journals, but chiefly from the exhaustive and valuable work on "The Design and Construction of Dams," by Edward Wegmann, M. Am. Soc. C. E.

Dams in Spain.

The Del Gasco Dam, Spain.—To the engineer the history of the failure of a structure is quite as interesting and valuable as that of a successful construction, and the case of the old dam started on the Guadarrana River, in 1788, is an excellent example of the fact that Spanish engineers of the

18th century were not as scientific as their descendants of the present day. The dam was a pretentious structure, and was to have been 305 feet in height, 823 feet long, with a base thickness of 236 feet, and a crest width of 13 feet. It was straight in plan, consisting of two parallel walls, each 9.2 feet thick, connected by cross-walls, leaving compartments to be filled with stones laid in a mortar of clay. When the dam reached a height of 187 feet a severe storm filled the reservoir, overtopped the dam, and so saturated the clay that its swelling forced out a part of the front wall. After this discouraging experience the dam was abandoned.

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 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.

Dams in France.

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

Fig. 259.—Furens Dam, St. Etienne, France, Down-stream Face.

FIG. 260.—GENERAL VIEW OF FURENS DAM, GUOFFRE D'ENFER, ST. ETIENNE, FRANCE, SHOWING RESERVOIR.

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 France, 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-Feugerolles. This also is of the Furens type, curved in plan, and has a maximum height of 144.3 feet, with maximum depth of water of 121.4 feet. It is curved on a radius of 1148 feet, and is 508 feet in length on top. It was built in 1900–04 on the Cotatay river by M. Reuss, Engineer of Bridges and Roads.

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.

Settons Dam, France.—This structure was built originally with the view to improving navigation on the Yonne River, in 1855-58. It had an extreme length of 889 feet, a maximum height of 69 feet, and was 14 feet wide on the crest. In 1899 the dam was reinforced by the addition of a "guard wall" on the up-stream face for its entire height, the wall having a thickness of 17.3 feet, with a number of vertical wells constructed in the wall to intercept and drain off the leakage through the wall.

Avignonet Dam, France.—This dam is remarkable for the fact that it has been built to the height of 75.5 feet as an overfall weir in the river Drac, which in flood carries as much as 35,000 sec.-feet, without having been founded on bedrock. It was located in a narrow gorge whose sides rise nearly 1000 feet, and the stream being torrential in character the canyon had been filled to a great depth with boulders and gravel, the excavation in which to reach bedrock would have been exceedingly deep. Therefore the engineers decided to build it on the detritus of the canyon, merely sinking two cut-off trenches about 13 feet deep, 8 feet thick, and giving the dam a base of 78.4 feet, which is greater than its height.

The dam is curved in plan, on a radius of 656 feet, is 196.8 feet long on the crest, and is 15.6 feet thick on top, with a roll-way form on the down-stream slope. (See plate I.) The toe of the dam is extended down-stream by an apron of reinforced concrete. The entire dam is built of concrete, was completed in 1902, and is used for the development of power for the city of Grenoble, whose population in 1896 was 64,000.

The Sioule Dam, France.—This structure, erected in 1902-04, across the Sioule River, is utilized for water storage and power, the power-house being located immediately below the dam. It is curved in plan, with a radius of 984 feet, and is 393.7 feet long on the crest, has a maximum height of 98.4 feet, is 79 feet wide at base, and 16.4 feet wide on top. At each end of the dam an overflow weir is provided, extending parallel with the valley, and nearly at right angles with the direction of the dam.

The Miodeix Dam, France.—The storage of water and the development of power from the Miodeix river, for the city of Auvergne, was the purpose of the erection of this dam in 1903. The maximum height is 80 feet, the crest width 10 feet, and the base 69 feet, The up-stream batter is 9% and that of the down-stream face is 80%, with a vertical curve near the top, having a radius of 26.4 feet, above which it is vertical for 8.4 feet to the top.

The Turdine Dam, France.—A reservoir of 28,840,000 cubic feet capacity (661 acre-feet) was formed in 1902-04 for the water-supply of the city of Tarare (population in 1896, 14,500) by the erection of a masonry dam of triangular profile, having a height of 82 feet, a base width of 65 feet, and a crest width of 13 feet. The dam is curved in plan, with a total length of 394 feet on top. The up-stream batter from the base up for 15 meters is 8.33%, thence to the top 5%, while on the down-stream face the batter from foundation up to a height of 11.12 meters is 80%, thence by a vertical curve of 49.5 feet radius to within 5.4 feet of the top. The spillway level is but 2.3 feet below the crest of the dam. This dam is about 20 miles northwest from the city of Lyon, and about 35 miles north of St. Etienne, the location of the Furens dam.

The Echapre Dam, France.—One of the high modern dams of France was that erected in 1894-98 for the water-supply of the city of Firminy, Department of the Loire (population in 1891, 14,500). The maximum height above lowest foundations is 160 feet, the width at base 88.6 feet and on top 17 feet. It carries a maximum depth of water of 121.4 feet. It is curved in plan on a radius of 1148.2 feet, and is 541 feet long on the crest. A pleasing architectural effect is given to the down-stream face by a series of arches, with spans of 13 feet, which support the side of the roadway on top of the dam, which has been corbelled out over the arches to give the desired width of roadway and sidewalks. The arches rest on pilasters 4 feet wide. The arches have a total height of 33 feet. The up-stream face of the dam is vertical for 99 feet from the top down, while the lower face batters about 76%. The spillway of the dam at one side is 101.7 feet long. The dam was designed and built by M. G. Reuss, Ingénieuer des Ponts et Chaussées. The reservoir for so high a dam is comparatively small in capacity, containing but 33,535,000 cubic feet, or 770 acre-feet. The dam is but a few miles west of the Furens dam.

The Ondenon Dam, France.—Quite similar in design to the Echapre and Cotatay dams is the structure erected in 1900-04 by the same engineer, to store water for the supply of the town of La Ricamarie. It is 123 feet in height, carrying a maximum depth of 107 feet of water. It is also curved in plan, with a radius of 984 feet, is 420 feet long and 15.4 feet wide on top, with a base width of 94 feet. It also carries a roadway on top, supported by corbeling out the normal width on 10 foot arches resting on pilasters. The reservoir capacity is extremely small, being but 14,120,000 cubic feet (324 acre-feet) and is indicative of the scarcity of good reservoir sites in that region.

The Cher Dam, France.—One of the highest of the modern French dams is now under construction to create a storage reservoir for the supply of the City of Montlucon, in Central France (population in 1896, 31,600) and for power development, the capacity being about 20,000 acre-feet. The height will reach 158 feet; crest width 15.4 feet; base thickness 141 feet. It is to be curved in plan, with a radius of 656 feet. The Cher River, on which the dam is located, is one of the tributaries of the Loire.

DAMS IN ITALY.

The Lagolungo Dam, Italy.—This structure was built in 1883 to a height of 131 feet, and 20 years later, in 1903, it was decided to increase its height by ten feet. The dam is immediately above the Gorzente dam, near Genoa, and creates a reservoir for the supply of that city, with a capacity of 130,000,000 cubic feet, or 2950 acre-feet. As originally constructed it was given a thickness of 140 feet at the base, 16.4 feet at the crest, with a parapet 8.4 feet higher than the top of the dam. The addition to the height was made by replacing the old parapet by a new one, 14 feet high, 16 feet wide at the base, 8.2 feet wide on top—in other words, the dam was simply added to on the top from the original crest width of 16.4 feet to the new width of 8.2 feet, while the spillway, which was 72 feet long, was built up 10 feet higher with masonry. A second spillway, 59 feet long, was added. Both weirs have flash boards on their crest to give additional reservoir capacity, which now amounts to 156,700,000 cubic feet (3600 acre-feet) with possible increase of 5.5% by the flashboards.

The dam is provided with cast-iron outlet pipes at four different levels, by means of which the water may either be turned into the aqueduct leading to the city or into the next reservoir below, formed by the Gorzente dam.

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.

French Dams in Algeria.

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 3½ 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.

Dams in India.

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

* 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.

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.

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

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

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 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.

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

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 × 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,

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

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 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.

Meer Allum Dam, India.—Sometime prior to the year 1800, an extraordinary dam was built to form a reservoir for the supply of the city of

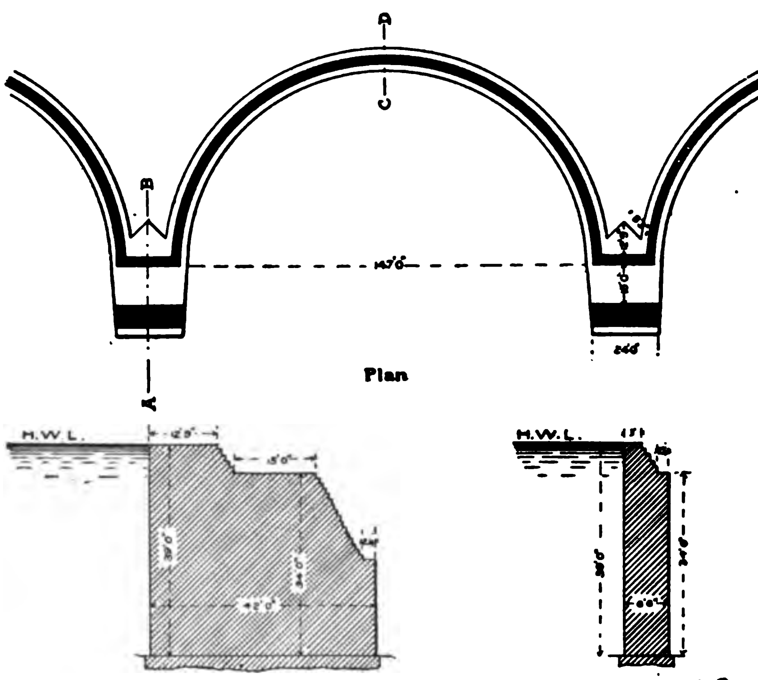


FIG. 261.—MEER ALLUM LAKE DAM, HYDERABAD, INDIA.

Hyderabad, in the form of a large arch, about half a mile in length, composed of 21 smaller arches, of semi-circular form, resembling scallops, with massive buttresses or piers between them. Fig. 261 shows the longest of the arches.

The spans between piers are of varying length, from 70 to 147 feet in the clear. The masonry of the arches, which is vertical on both faces, is 8.5 feet in thickness, and they transmit the pressure to the piers, which are 24 feet in thickness.

The reservoir formed by the dam is known as the Meer Allum lake, having an area of 900 acres, a maximum depth of 50 feet, and a capacity of 355,500,000 cubic feet (8168 acre-feet).

A spillway is provided at one end, but the water at times flows a few inches deep over the entire crest of the dam.*

Dams in Australia.

Burraga Dam, N. S. W.—One of the slenderest concrete dams constructed in recent years in Australia, where several structures of extremely light type have been erected, was that built for the supply of the Lloyd Copper Company's mine, on Thompson's creek, New South Wales, forming a reservoir of 31 acres area, with a capacity of 13,500,000 cubic feet (310 acre-feet). The greatest height of the dam is 41 feet, the width at the crest being but 2 feet, and at the base 25.3 feet. Its length on top is 425.6 feet, of which 140 feet is used as an overflow waste-weir.

The work is described by John Hayden Cardew, Assoc. M. Inst. C. E., in a paper published June, 1903, in the Minutes of Proceedings of the Institute of Civil Engineers, from which the following quotation is taken:

"Although the greatest care was observed in the mixing of the concrete to secure a water-tight wall, it was recognized that the coarseness of the same would greatly militate against success in spite of the inner face of richer concrete, and it was found as the dam progressed and the water rose in the reservoir that a considerable leakage occurred, which appeared on the down-stream face of the dam like water coming from a very fine rose. To render the inner face with cement mortar made from such coarse sand would not improve matters; it was therefore decided to paint the inner face with neat cement mixed to a slurry, applied with stiff brushes, and well rubbed into the pores in three successive coats; this proved most effective, for when the water rose again in the reservoir the wall was found to be perfectly water-tight.

"The expansion and contraction in concrete dams when the reservoir is low is very great, and when the reservoir is full it is very unequal in different parts of the cross-section; this is especially the case in some parts of Australia, where hot days and cold nights are of frequent occurrence, giving a range of temperature of about 90° F., and on that account many of the concrete dams in this country are badly cracked. In order to

* *Engineering Record*, January 10, 1903.

obviate this tendency to some extent, and to assist in closing the cracks as the reservoir filled, the curved form was adopted.

"It has been observed that the curved form does not render the structure altogether immune from cracking, and the cracks occur generally at about one-third of the length of the dam from the wings, commencing at the crest, first as a very fine crack and afterwards opening out and extending down the wall a distance of one-third to one-half of its height, and opening and closing as the reservoir empties or fills. It was thought that the introduction of an iron tie-bar in the crest of the dam to take the tensile stress due to contraction, would completely preserve the work from cracking. It has been proved in other works that the temperature in the heart of the dam, say 3 feet from the surface, is constant, from which it may be argued that in order to ensure safety from cracking it is only necessary to protect from tensile stress the upper or thinner part of the dam where the cracks invariably originate."

As a result of this reasoning three lines of 70-pound "T" rails were laid six inches below the level of the weir overflow, jointed with fish-plates and embedded in the concrete. The cost of the dam was £9566 ($44,500). The inner face for a thickness of 18 inches consisted of 1 of cement, 2.5 of sand and 3.5 of crushed stone to pass through a ring of ½ inch diameter, and the outer face for a thickness of 6 inches was made of concrete composed of 1 of cement, 3 of sand and 5 of crushed stone, passing a ring of 1½ inch diameter. The heart of the dam was built of blocks of stone, set in concrete, making what is locally known as "plum concrete," each stone having 6 inches of concrete all around, and no stone being laid nearer than 18 inches to the inner face, nor 6 inches to the outer face, nor 2 feet to the foundations. The stones were not larger than 16 cubic feet nor smaller than 2.5 cubic feet, roughly squared and placed with their longest dimensions normal to the axis of the dam. The proportion of "plums" was 33% of the whole.

Barossa Dam, South Australia.—One of the most remarkable of the recently constructed dams in Australia is that completed in February, 1903, by the South Australian Government at Barossa, for the domestic supply of the town of Gawler and surrounding farming district, including a small amount of irrigation, the total annual supply available being about 1,000,000,000 imperial gallons, or 3675 acre-feet. The dam is built entirely of concrete, as an arch, curved up-stream with a radius of 200 feet on the up-stream face (Fig. 262), the total length of the crest being 472 feet, the chord subtending the segment of a circle being 370 feet and the versed sine about 133 feet. The dam has a thickness at top of but 4.5 feet, and a maximum thickness at base of 45 feet, the extreme height being 113 feet, or 95 feet above the stream bed. The up-stream face is vertical, while the down-stream face has a batter of 37.14% from a point 27.34 feet below the

Fig. 262.—Barossa Dam.

top to the base. It contains 17,975 cubic yards of rubble concrete, of which 2215 yards, or 12.3%, are large stones or "plums." The average cost of the concrete was $9.30 per cubic yard, and the total cost £169,947 ($827,000). It was estimated that a saving of $217,000 was effected by the substitution of an arched concrete dam for a structure of gravity type as originally proposed.

The dam is built in a subsidiary basin of 3675 acre-feet capacity, supplied by a tunnel 7400 feet long from the Para River. By this arrangement only clear water is taken into the river after the muddy floods have passed.

The main outlet pipe is 22 to 18 inches diameter, 7 miles long to the

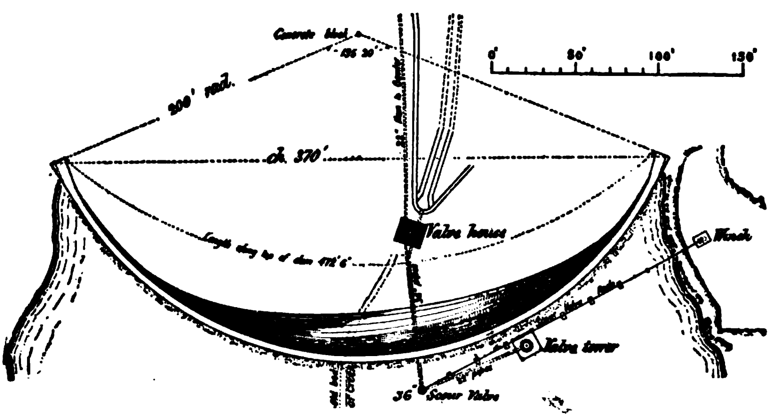


Fig. 263.—Barossa Dam.

town of Gawler, and is constructed of steel by the locking bar principle first used on the famous Coolgardie pipe line.

The top of the dam for the upper 20 feet is reinforced with 18 lines of 40-pound steel rails, joined with fish-plates, and imbedded in the concrete. The range of temperature during construction was from 30° to 163° F. Observations taken after completion during six days upon which equal extremes of 50° prevailed, the top of the dam was found to have moved up-stream to the extent of ⅞-inch, showing an expansion of about 1.5 inch in the total length during the interval of the observation. This backward and forward movement of the dam appears to produce no cracking of the structure, which remains in an entirely satisfactory condition.

Coolgardie Dam, Helena River, Australia.—The daring and costly project for the supply of the desert mining region of Coolgardie, by pumping 5,000,000 imperial gallons daily through a pipe line 153.5 miles long, is

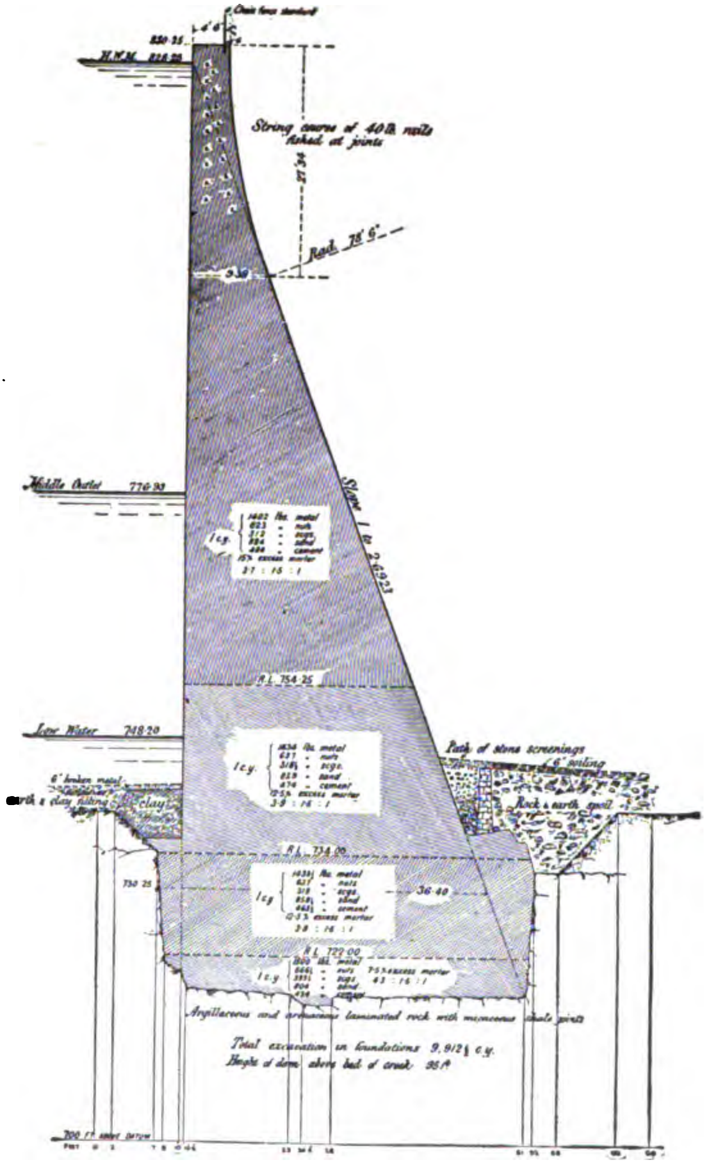


FIG. 264.—BAROSSA DAM.

better known to the engineering world than the fact that in connection with this project, and for the purpose of impounding water for it, a dam of large dimensions was built across the Helena river. The works were described with great minuteness in an able paper by Chas. Stuart Russell Palmer, M. Inst. C. E., and published in the Minutes of the Institution of Civil Engineers, in March, 1905.

The dam is a rubble concrete structure, straight in plan, 755 feet long on top, 100.5 feet high above the stream bed, and 197 feet in extreme height above lowest foundations. The width on top is 10 feet, and at 100 feet below 90 feet. The spillway is made over the crest of the dam for a length of 440 feet, spanned by a footbridge resting on seven piers. A water cushion has been provided at the base of the dam by an auxiliary weir below 100 ft. long.

The crest of the dam is 426.75 feet above sea level, 6.75 feet above the lip of the spillway. The maximum depth of water is 97 feet.

The volume of concrete is not given, but there were used 76,418 barrels of cement, the mixture being in the proportion of 1 of cement, 2 of sand to 5 of crushed granite rock, passing a 2½-inch ring.

The construction of the dam began in January, 1900, and was completed in June, 1902.

The reservoir covers an area of 800 acres, and has a capacity of 4,600,000,000 imperial gallons (16,900 acre-feet).

The pipe line to Coolgardie is 30 inches diameter, 351.5 miles long, and has a capacity of 5,600,000 gallons in 24 hours. It is of the lock-bar type. The total natural lift overcome by the eight pumps installed along the line is 1290 feet, but the total head pumped against including friction is 2700 feet, requiring an effective power of 3129 H. P. The power provided was 3642 H. P. The selling price fixed for the water to cover interest, depreciation and operating cost was 82 cents per 1000 gallons, equivalent to $5.10 per 1000 cubic feet, or $222 per acre-foot.

Cataract Dam, Australia.—The highest and most pretentious dam construction in Australia has been in progress of erection since 1902, to form a reservoir of 25,700,000,000 gallons (78,860 acre-feet) for the domestic supply of the city of Sydney, N. S. W. The dam is straight in plan, 811 feet long on top, 192 feet maximum height (35 feet below and 157 feet above the river-bed), 158 feet thick at the base, and 16½ feet at the crest, at a height of 7 feet above the spillway level. The dam is provided with a spillway at one end, 715 feet in length.

It is formed of cyclopean rubble masonry of blocks of sandstone weighing 2 to 5 tons, set in cement mortar, and packed in with concrete, the blocks forming about 65% of the mass. (See Fig. 265.) The up-stream face consists of concrete blocks, 5×2.5×2 feet, set in place with cement mortar, and backed with 3 feet of concrete, made of crushed basaltic stone and cement. The down-stream face is made of 6 feet of concrete, moulded in place. The total volume of the masonry and concrete is 146,242 cubic yards, and the entire cost of the structure is estimated at $1,599,600 including the clearing of the reservoir, which covers an area of 2400 acres. It is supplied by the run-off from fifty-three square miles of watershed area. The reservoir is underlaid with coal, whose value is estimated at approximately 500,000,000 pounds sterling.

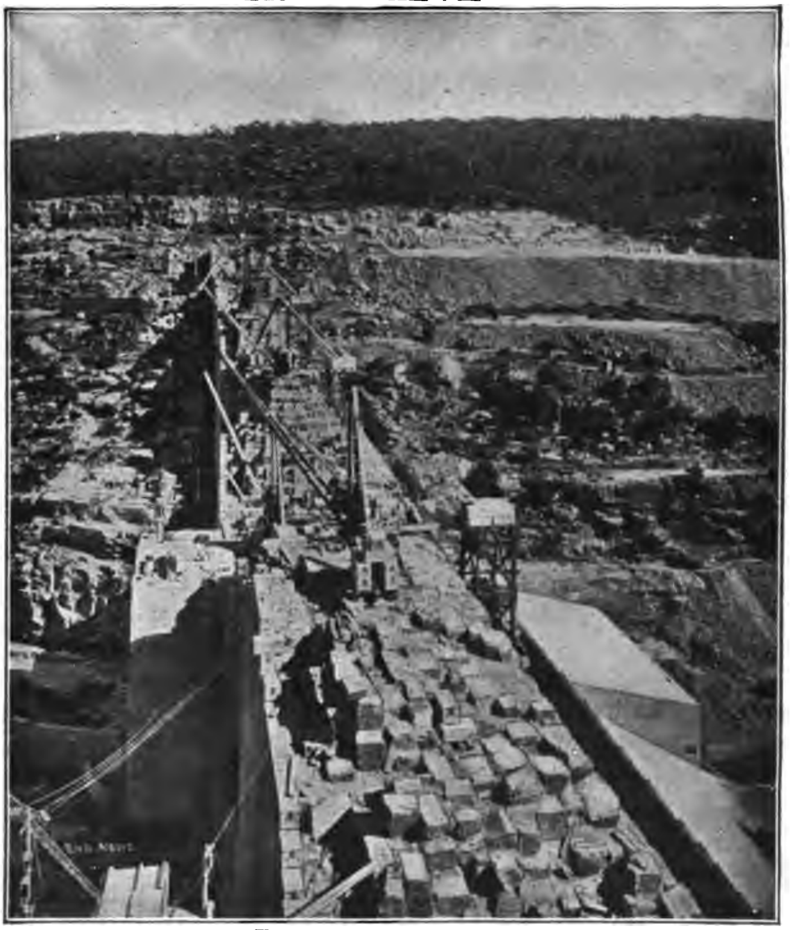


FIG. 265.—CATARACT DAM.

The outlets of the dam consist of two 48-inch pipes, placed 147 feet below the spillway level. Two additional pipes of same size were also built through the dam for carrying the low-water flow during construction. When the dam was 76 feet high at its lowest part, a flood occurred during which water flowed 16 feet deep through a gap in the center of the work, 65 feet wide, without causing injury.

The dam was designed and built by L. A. B. Wade, M. Inst. C. E. It occupied four years and eleven months in construction.

Belubula Dam, Australia (Fig. 266).—A dam consisting of a series of buttresses, or piers, with elliptical arches between them, was built on the Belubula river, N. S. W., for the Lyndhurst Goldfield Co., by Mr. Oscar Schulze, C. E., of Sydney, for the storage of water for power. The dam is of unusual design and construction, the base, or foundation, up to a height of 23 feet, consisting of concrete, above which the dam was built of brick a further height of 36.75 feet, in the form of six buttresses, 28 feet apart, center to center, each 40 feet long, 12 feet wide at the up-stream side and 5 feet thick at the outer end. These buttresses form piers for five brick arches, inclined at an angle of 30° from the vertical, and made 4 feet thick at bottom, 1 foot 7 inches thick at top. The spandrels between the arches were filled with concrete, which covered the crown of the arches to a depth of 12 inches, and joined the side walls of the dam, which are also of concrete. The total length of the dam, including the spillway section of 65 feet, is 431 feet. The dam contains almost 6000 cubic yards of concrete, and 500,000 bricks (1000 cubic yards) and the total cost was less than $45,000.

The storage in the upper 16 feet of the reservoir amounts to 87,120,000 cubic feet, and gives a head of 200 feet on the turbines located one-half mile below the dam.

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.

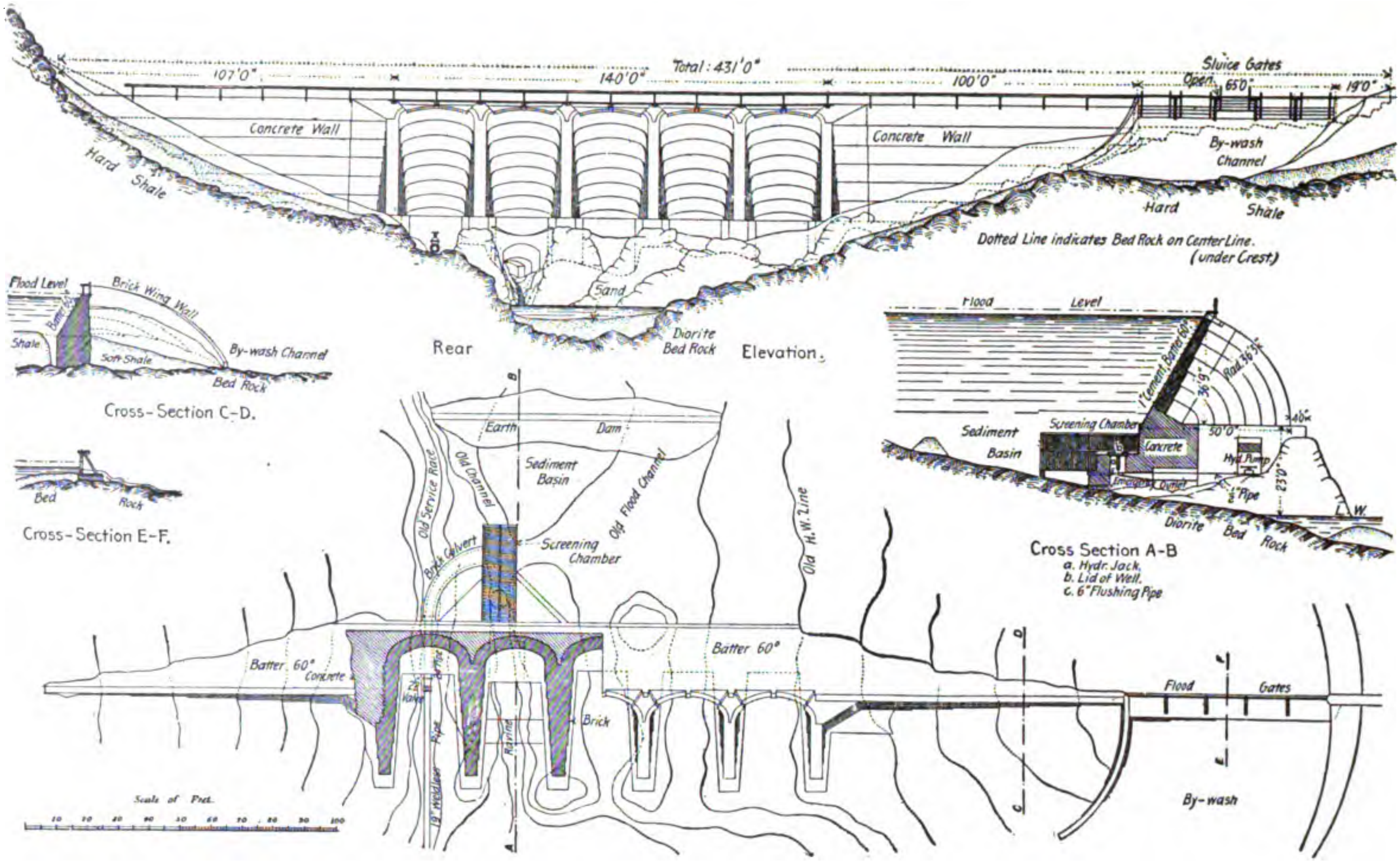
Water is distributed entirely by pipes under pressure, some 255 miles of pipe from 2 to 18 inches diameter being required.

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



Sectional Plan.

Fig. 266.—Belubula Dam.

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.

Dams in China.

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.

Dams in Africa.

Assouan Dam, Egypt (Fig. 267).—No irrigation works of modern times are more notable and far-reaching in their beneficial results upon the industrial welfare of the people than the great storage dam erected by the Egyptian Government at Assouan, on the river Nile, 700 miles above its mouth. It creates a reservoir with a capacity of 863,000 acre-feet, its effect extending back up the river a distance of 140 miles, estimating its surface slope at 1:32,000. It will thus cover an area of over 40,000 acres, a large portion of which is not over 1000 feet wide. The dam which was begun in 1898 and completed in June, 1902, is of vast proportions, being 6400 feet in length, with a maximum height of 130 feet above the lowest foundations and containing 704,000 cubic yards of masonry. The maximum depth of water in the reservoir available for draft is about 60.8 feet at the dam. The elevation of high-water level in the reservoir is 348 feet above mean tide. The dam is divided into two sections, one of which extends from the east bank for 1800 feet as a solid masonry wall without openings, while the remaining portion of 4600 feet, containing 180 sluice-ways, reaches to the west bank, and includes a navigation lock on that side. The sluice-ways are designed to carry the entire volume of the river at flood, without permitting the water to reach higher than within 9.8 feet of the top of the dam. The width of crest of the eastern solid section is 17.8 feet, while the portion in which the sluice-ways are built is 23 feet wide on top, carrying a roadway entirely across the dam. The sluice-ways are in four levels, 140 of them on the two lower levels, each being 7 meters high by 2 meters wide, while the upper banks of 40 sluices are each 2 meters wide by 3.5 meters high. The total discharging area thus provided, with all sluice-gates open, is 24,100 square feet. The maximum recorded discharge of the river was 494,500 second-feet (1878-79).

The sluices mostly are in groups of ten, with spaces of 5 meters of solid masonry between individual sluices, and 10 meters between two adjoining groups, where buttresses 26 feet wide, 3.8 feet thick, are built on each face at intervals of 240 feet. The openings or outlets being arranged at varying heights the reservoir may be drawn from near the top, without excessive head or friction to resist the opening of the gates. Sixty-five of them are placed near the bottom of the dam, with sills 70.7 feet below the floor of the roadway on top, of which forty are lined with plates of

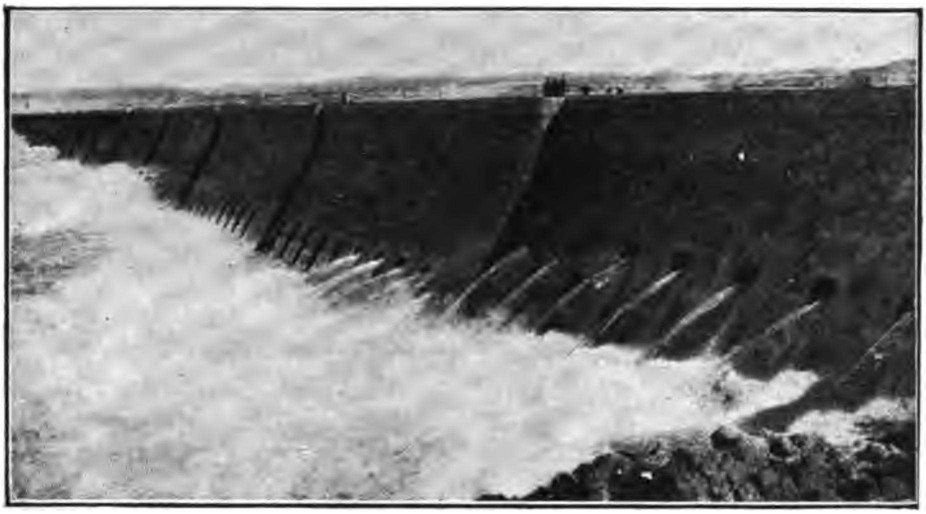


FIG. 267.—THE ASSOUAN DAM, EGYPT. SHOWING DISCHARGE THROUGH A NUMBER OF SLUICES.

cast-iron, 1½ inches thick, having flanges or ribs embedded in the masonry, 12 inches deep, by which the plates are bolted together. Seventy-five sluices are placed at the next higher level, 55.8 feet below the crest, and of these one-third are provided with balanced gates of the Stoney roller type, easily operated under full pressure, if desired. Of the remaining sluices 18 are placed with sills 42.7 feet below the top of the dam, and 22 are 29.7 feet below the roadway level. The navigation pass around the dam consists of a canal, partly excavated in rock and partly in embankment witb 4 locks, making a total descent of 68.9 feet. The canal is 654 feet long, 49.2 feet wide on the base.

The dam is founded on a ledge of granite of very irregular surface, one narrow channel requiring a maximum height of 130 feet, but the average height is about 82 feet. The base width is about 85 feet. The down-stream batter is 1: 1.5, while that on the up-stream face is 1: 18.

The dam consists of rubble masonry laid in 1.4 cement mortar. It was said to be entirely water-tight when completed. The total excavation required was 824,000 cubic yards or double the estimate. This increased the masonry by 45% over what was anticipated, so that the final cost of the dam reached the sum of £2,450,000 ($11,907,000) or $13.80 per acre-foot of storage capacity. The plans for the dam were prepared originally by Sir Wm. Wilcocks, M. Inst. C. E., and executed by Frederick W. S. Stokes, M. Inst. C. E., and his successor, C. R. May, M. Inst. C. E. Sir Benjamin Baker, M. Inst. C. E., acted as consulting engineer for the Egyptian Government. The contractors were Sir John Aird & Co.

The original plans first proposed would have raised the water to such a height as would have inundated the ancient temple of Philæ, situated a mile above the dam on an island. Out of deference to public protest against the destruction of this archæological monument, the plans were modified so as to limit the flood level to the floor of the temple. In order to protect the portions of the temple resting on silt a great deal of work in underpinning was performed. Quite recently it has been decided that the temple must be sacrificed, as the importance of raising the dam to give increased storage has become paramount to all sentimental considerations. The capacity of the reservoir will be nearly doubled by the higher construction which has begun, and which will make it the largest reservoir in the world. It is reported that the increase of storage will add 1,000,000 acres to the irrigable area. Work has already begun on raising the dam, which will require three to four years to complete.

The Assiout Dam, Egypt.—In connection with the utilization of the water stored in the great Assouan reservoir, a diverting dam was constructed at the same time across the Nile, 339 miles below, to supply water to the Ibrahimia irrigation canals. The work is fully described in a paper prepared by George Henry Stephens, C. M. G., M. Inst. C. E., and published in Volume 153 of the Proceedings of the Institution of Civil Engineers, for March, 1904. Mr. Stephens had charge of the work from its commencement until its completion in 1902.

The dam is a masonry structure, 2691 feet long, built on a quicksand foundation and carrying a roadway on arches above the flood level. It consists of a series of 111 arched openings, each 16.5 feet wide, formed by masonry piers, each 6.56 feet thick, 51 feet wide, resting on a platform or base of concrete and rubble masonry, 87 feet wide, 9.8 feet thick having a row of cast-iron sheet piles, with tongued and grooved joints, driven 13 feet into the sand, on the upper and lower edges of the platform, as a cut-off against seepage under the dam. The roadway level on top is 41 feet above the floor of the structure. The maximum head of water against the dam is 34.5 feet.

The river bed is protected from erosion by a stone pavement, laid parallel with the dam entirely across the channel, 67 feet wide, placed on a bed of clay puddle, 4.6 feet deep, 46 feet wide on the up-stream side, with a similar pavement on the lower side, covering an inverted sand and gravel filter beneath to clarify percolating water and prevent wash.

One of the interesting special features of this work is the use of cast-iron sheet-piles in the foundations. These were each 16 feet long, 2 feet 3.5 inches wide, 1⅛ inch thick, and weighed about 2180 pounds. The tongues were 2½ inches deep, and the grooves enough deeper to admit of a ¾ inch O. D. pipe for carrying a water jet to facilitate driving, and subsequently to carry cement grout with which the grooves were filled and made water-tight. The work required 210,222 cubic yards rubble masonry and concrete, 11,472 cubic yards ashlar masonry, 1,626,660 cubic yards earthwork in excavation and embankment, and 642,370 cubic yards in temporary cofferdams. The navigation lock around the dam is 262 feet long, 52.5 feet wide, and capable of passing the largest steamers that ply on the Nile. The cost of the dam and locks was about $4,200,000, including the canal headworks, which cost about $660,000.

The irrigation under these extensive works is chiefly devoted to the production of cotton and sugar cane, and it was stated that the value of the crops produced the first year after their completion was in excess of the entire cost of the works constructed.

Sand River Dam, South Africa (Fig. 268).—A dam of rubble concrete was built in 1906 to store water for the supply of Port Elizabeth, Cape of Good Hope, South Africa, having a height of 55 feet, a length of 398 feet, and a base width of 38 feet. The overflow portion, 5 feet below the crest, is 151 feet long. The total cubic contents of the dam are about 9000 cubic yards. It is composed of concrete mixed in the proportion of 1 cement, 1.33 sand, and 5.5 stone, broken to pass a 1½ inch ring, with "plums" of large quartzite rock and iron rods and rails embedded. The materials were conveyed to place by means of an aerial wire tramway. The dam is straight in plan. The cost was about $140,000. The works were planned and constructed by Mr. W. Ingham, Assoc. M. Inst. C. E.

The reservoir formed by the dam has a capacity of about 220,000,000 gallons (660 acre-feet).

Johannesburg Dam, South Africa.*—To supply the Rand mines with water for mining and domestic purposes, the Vierfontein Water Syndicate, in 1898, undertook the erection of a rubble masonry and concrete storage dam 120 feet in extreme height, located six miles south of Johannesburg. The dam was planned as a combination arch and tangent, the arched por-

* *Engineering Record*, January 7, 1899.

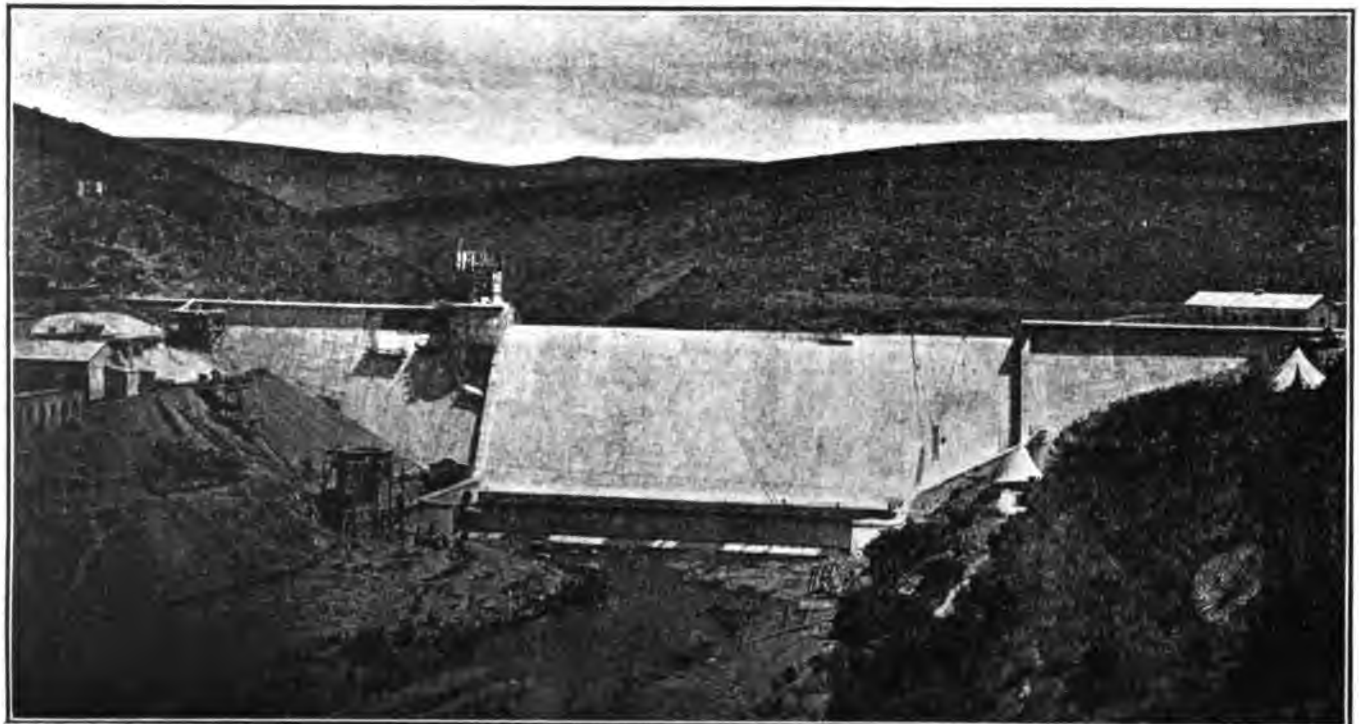


FIG. 268.—SAND RIVER DAM, CAPE OF GOOD HOPE, SOUTH AFRICA.

tion being 340 feet long and the length over all 585 feet. The radius at the crest of the arch was 275 feet, decreasing to 206 feet 75 feet below, to meet the lines of the gravity dam on tangent. After stripping a depth of 12 to 14 feet, a base of concrete 40 feet wide, 15 feet thick, was laid, in which railway rails were embedded in two layers, one longitudinally near bedrock and the other transversely about two feet below the top. On this foundation the masonry work of uncoursed rubble was laid with a base width of 36.5 feet, decreasing to 33 feet at a height of 20 feet, and to 7 feet at the crest. The total volume of masonry in the dam was estimated at 30,000 cubic yards. The materials were handled by a Lidgerwood cableway, suspended across the gorge. The rock used was a hard blue quartzite, quarried half a mile away. The water was to be pumped from the dam to a service reservoir 1¾ miles distant, at an elevation of 575 feet above the dam.

The reservoir covered an area of 104 acres, and had a capacity of about 3900 acre-feet. The works were planned by Wm. Ham. Hall, M. Am. Soc. C. E., as consulting engineer, with Mr. J. B. Rogers as resident engineer.

Construction was well advanced at the time of the breaking out of the Boer war, which caused a suspension of operations.

Dams in Germany.

The Remscheid Dam, Germany (Fig. 269).—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

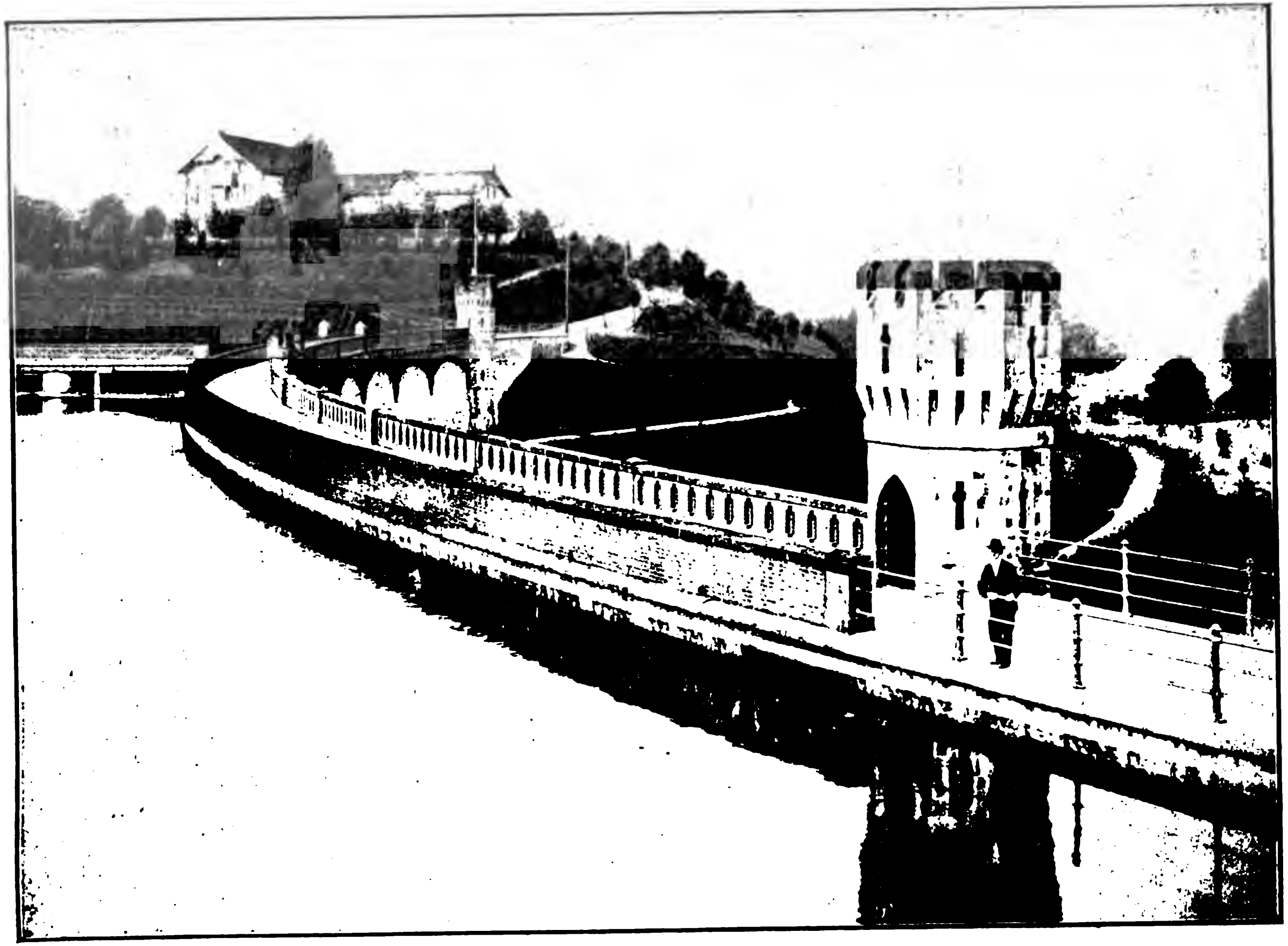


FIG. 269.—THE REMSCHEID DAM, GERMANY.

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 Urft Dam, Germany.—The highest dam in Europe is that built in 1901 to 1904 across the river Urft, near the city of Aachen, Germany (population in 1895, 110,500), the seat of the great Polytechnic School, one of whose Professors, Otto Intze, designed the structure, which is but an hour's journey from the famous Gileppe dam, in Brussels. The dam is curved in plan, on a radius of 656 feet, and has a crest length of 741 feet. Its maximum height is 190.3 feet. Its thickness at base is 165.7 feet, and at top 18 feet, at a height of 4.9 feet above the spillway level. The base is exactly equal to the maximum depth of water. On the up-stream face of the dam an earth embankment is built to within 77 feet of the top, having slope of 2 on 1, paved with rock. The body of the dam is built of slate masonry laid in courses inclined against the lines of pressure, after the plan of the Remscheid dam, while on the up-stream face is laid a separate wall of traprock masonry, 3 feet thick, the stones of which are stepped on the battered portion of the face. Previous to laying this face wall the masonry was covered with a plaster coat of cement, one inch thick, and a coat of asphaltum, to insure water-tightness. As an additional precaution for the same purpose, the earth embankment was built as described. To provide for the drainage of any water that might penetrate the body of the masonry in spite of these extraordinary measures, two rows of 2½ inch clay pipes were placed vertically in the heart of the dam, from top to bottom, the pipes being 8 feet apart in each row. The pipes of each row are connected to a 6-inch header pipe that leads to the drainage tunnels built through the dam near the center at the lowest level. In each drainage tunnel, which extends through the earth embankment to the reservoir, a 23-inch steel washout pipe is laid.

The main outlet of the reservoir is a tunnel, 9200 feet long, about a mile north of the dam. Water carried through this tunnel supplies power under a head of 360 feet, from which 10,000 H. P. is generated in 8 units and transmitted to neighboring manufacturing towns. (See Fig. 270.)

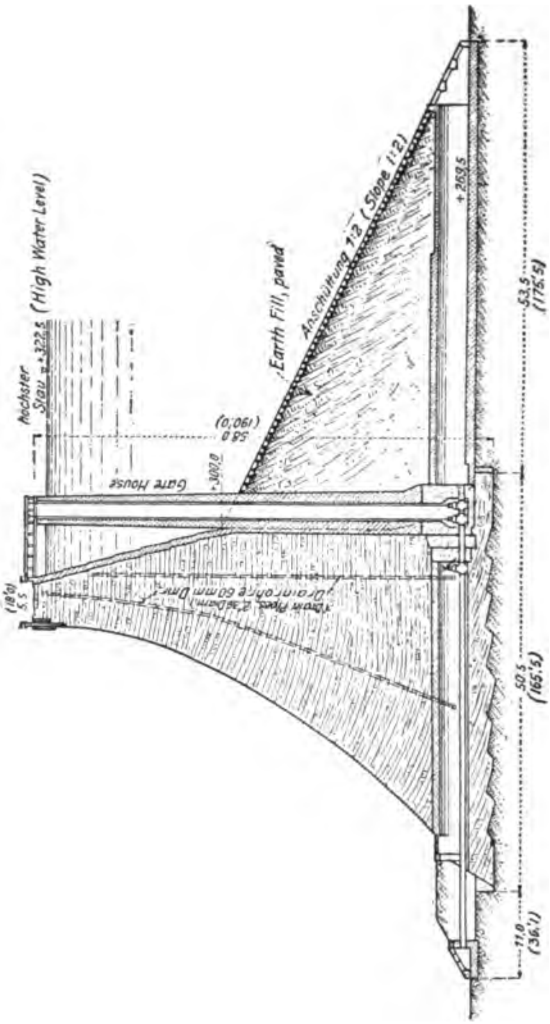


FIG. 270.—URFT RIVER DAM, GERMANY.

The Solingen Dam, Germany.—The water supply of the city of Solingen (population in 1895, 40,800) is in part derived from a reservoir formed by a stone masonry dam, arched in plan, on a radius of 492 feet, having a crest length of 585 feet. Its length at base is 125 feet; the thickness at top is 14.7 feet, and at the foundation level the masonry is 120 feet thick, while the maximum height is 141 feet. The location of this dam is but a short distance from Remscheid.

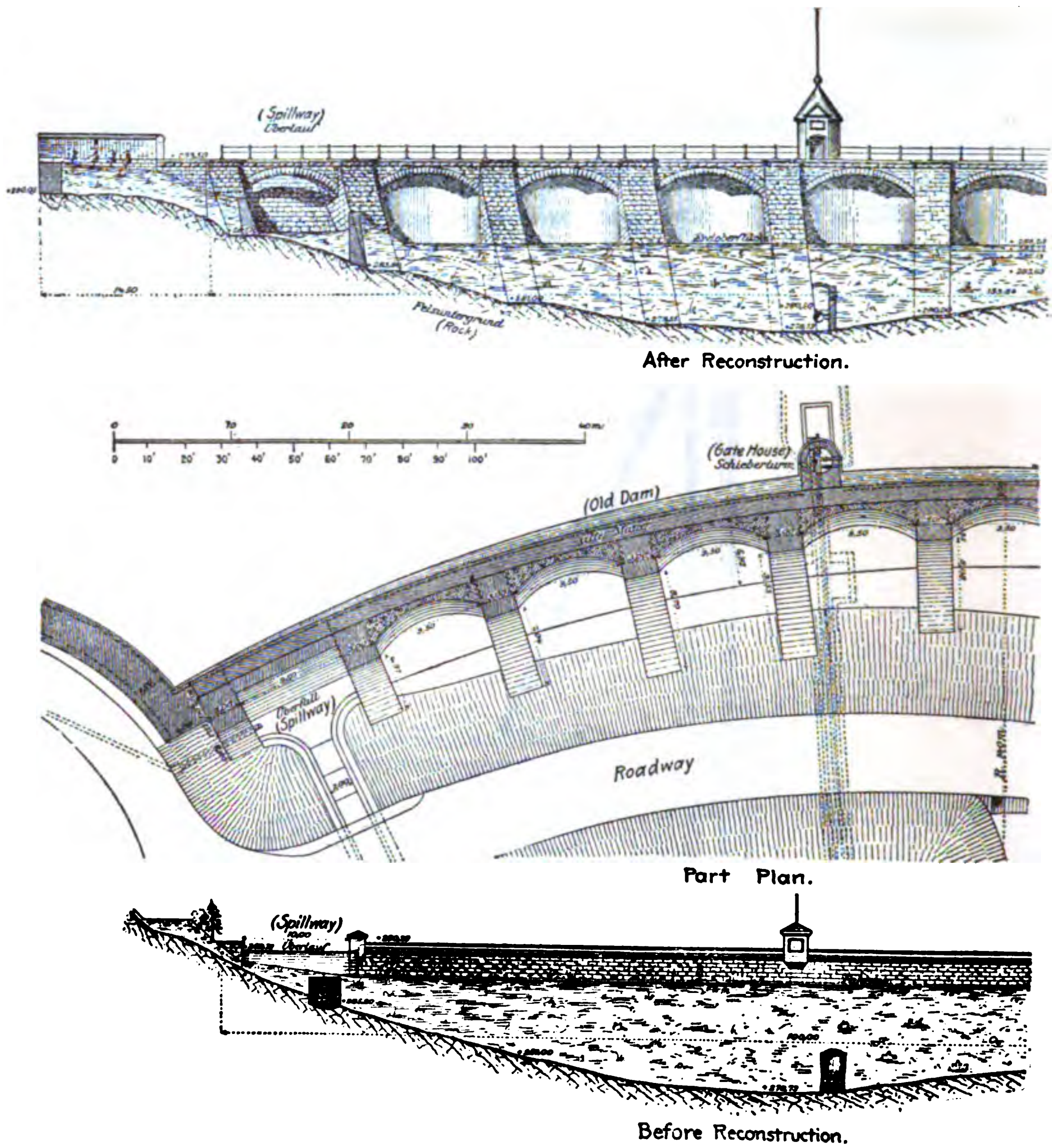


FIG. 271.—LENNEP DAM, GERMANY.

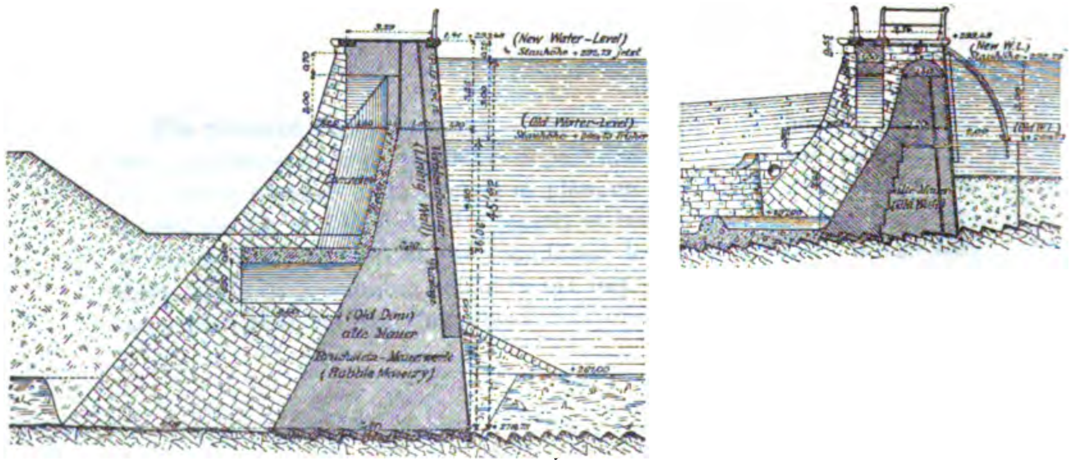


FIG. 272.—LENNEP DAM, GERMANY.

The Lauchensee Dam, Germany.—This structure is one of four built by the German Government in 1892-95, for the purpose of increasing the low water flow of the streams of the Vosges mountains, and has many interesting features. It has a maximum height of 98.4 feet, is about 840 feet long on top, and is curved up-stream with a radius of 2950 feet. The crest width is 13 feet, base 65 feet, designed as a gravity structure, with all lines of pressure falling within the center third. It is composed of cyclopean rubble, laid in concrete of trass mortar, mixed in the proportion of 1 part lime, 1 part trass and 2½ parts sand, produced by crushing sandstone, which is the foundation rock of the dam.

The dam contains 37,400 cubic yards of masonry, of which 65% is stone and 35% mortar. The masonry cost $5.38 per cubic yard, the total cost of the dam being $243,750, including $23,750 for an earth embankment placed against the down-stream side of the dam four years after the masonry was completed, when it had been demonstrated that there were no defects in the masonry structure. The purpose of this embankment, which reaches nearly to the top of the dam, is to protect the masonry from the sun, it having been noted during many years' observation on the elastic movements of the dams of that region that the water pressure exerted a much smaller influence than the expansion due to warm weather. The embankment is paved on the surface, and is provided with two berms.

The reservoir has a capacity of but 27,200,000 cubic feet (624 acre-feet). The average cost was therefore about $390 per acre-foot of storage capacity provided. The chief engineer of the work was Mr. H. Fecht, who contributed an article in the "Zeitschrift für Bauwesen," quoted by *Engineering Record*, August 30, 1902.

Lennep Dam, Germany (Figs. 271, 272).—This dam was originallly built in 1893 to a maximum height of 37.7 feet, with a width on bottom of 24.6 feet, and a crest width of 5.25 feet, forming a small reservoir of 32,000,000 gallons capacity, supplying the city of Lennep. The dam was curved up-stream with a radius of 460 feet, and its crest length was 416 feet. To increase the storage capacity to about double, it was decided to add 10 feet to the height of the dam, and this addition was recently completed in a somewhat remarkable manner by building a series of buttresses or counterfort walls on the down-stream side, 41 feet apart from center to center, each buttress being uniformly 9.84 feet thick. At the section of maximum height the buttresses extended down a distance of 26.24 feet from the original toe of the dam, and at the level of the crest of the old dam the buttress is 10.66 feet wide. An addition to the top of the dam, 10.7 feet high, was built in trapezoidal section, starting with the crest width of the old dam and narrowing slightly to the top. A series of horizontal arches were sprung between the buttresses at the crown level and at mid height to transmit the pressure to the buttresses, and at the same time vertical arches of concrete were made between the upper and lower horizontal arches. The masonry of the buttresses was laid in courses so inclined as to be normal to the lines of pressure, as in the Remscheid, Urft and other German dams. The mortar used in the concrete and in laying the masonry consisted of 1 part Portland cement, 1 part slaked lime, 1½ parts trass, and 4¾ parts washed sand. Lennep is a small city of 14,000 inhabitants, in the neighborhood of Remscheid.*

Other German Dams.—The following list of masonry dams, designed after what may be termed the Intze type, with earth embankments on the up-stream face, is quoted by Mr. Edward Wegmann in his work, from an article on masonry dams by H. Bellet, Civil Engineer.

Name.	Location.	Height in Feet.
Salbach	Ronsdorf	78.5
Lingese	Marienheide	80.5
Eschbach	Remscheid	82.0
Bever	Hükeswagen	82.0
Fuelbecker	Altena	88.7
Jubach	Meinerzhagen	91.3
Glörbach	Breckerfeld	105.4
Hasperbach	Haspe	111.0
Herbringhauser	Lüdringhausen	112.0
Oester	Plettenberg	119.0
Henner	Meschede	125.0
Ennepe	Altenvörde	135.0
Sengbach	Solingen	142.0
Queis	Silesia	148.0

Dams in Austria.

The Komotau Dam, Austria.—The highest dam in the Austrian Empire was built near the city of Komotau, Northern Bohemia, near the German frontier, on a tributary of the river Elbe, in 1901-1904, for the water supply of that little city, whose population in 1900 was 13,050. The dam forms a reservoir of 24,710,000 cubic feet capacity, or 568 acre-feet. It has a maximum height of 139.4 feet, or 116.5 feet above the stream bed, and carries a maximum depth of 111.5 feet of water. It is 508.5 feet in

* *Engineering News*, August 29, 1907, with illustrations from the "Zeitschrift für Bauwesen."

length on top, 170.6 feet long at bottom, is 98.4 feet thick at the base, and 13 feet on the crest. It is curved in plan, on a radius of 820 feet. The total volume of masonry is 53,600 cubic yards, consisting chiefly of cyclopean rubble. made of large blocks of gneiss embedded in Portland cement concrete. The crest of the dam is ornamented with dimension stone of granite, cut and laid in mortar.

In this dam, as in many of the newer German dams, a facing of asphaltum and tar was applied in two layers, held in place against the up-stream slope by a layer of concrete, dovetailed into the main body of the dam. A drainage system in the body of the masonry was also provided to carry off possible seepage, by means of 3-inch vertical pipes with open joints, placed in small shafts, built 6.5 feet apart, 3.3 feet in from the water-face. These connect at the bottom with larger pipes discharging any water so collected into a drainage gallery leading to the down-stream side. In this manner it is intended to prevent the possibility of the existence of upward pressure in the interior of the masonry. This treatment of masonry dams is becoming quite universal among European engineers and is being adopted in the United States.

The dam, though known to the outside world by the name of the city it supplies, is locally named for the Austrian Emperor, Franz Joseph.

Dams In Belgium.

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

FIG. 273.—GILEPPE DAM, VERVIERS, BELGIUM.

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.

Dams in Great Britain.

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 Blackbrook Dam, England.—A dam of considerable importance was built in 1900 to 1905 across the valley of the Blackburn, to form a reservoir of 80,960,000 cubic feet capacity (1860 acre-feet) as storage for the domestic supply of the city of Loughborough (population in 1891, 18,200). The dam is 108 feet in maximum height, 525 feet long on the crest, 65 feet thick at base, and 14 feet at top, carrying a maximum depth of 65 feet of water. The foundations extend down 30 feet below the original stream level, and a cut-off trench goes down 25 feet still deeper. The dam has a spillway over the crest for a length of 150 feet, which is spanned with six arches of 25 feet each, carrying a 9-foot roadway over the top of the dam. A water-cushion or tail pond is provided at the downstream toe of the structure to prevent scouring during heavy floods. Water is drawn from the reservoir through valves placed at various levels in a valve tower above the dam.

The work was carried out under direction of Messrs. George and F. W. Hodson, M. M. Inst. C. E.

The Swansea Dam, Wales.—The waterworks of Swansea, Wales (population in 1891, 90,400), were supplemented in 1905 by a storage reservoir formed by a dam of cyclopean rubble masonry, faced with brick, having a maximum height of 144 feet, and a crest length of 1250 feet. The structure was carried down into the rock a depth of 37 feet below the river bed, and is 7 feet higher than the overflow level, leaving an available depth of 100 feet of water in the reservoir.

The up-stream face is vertical from the top down for 70 feet, then batters 1:20 to the bottom. The thickness at the river bed level, 107 feet below the crest, is 75 feet. For the heart of the dam the large stones were bedded in 1:2:5 concrete, but in the lower part of the base and the upper six feet of the water face a richer mixture was used, consisting of 1 of cement, 2 of sand and 3.4 of fine crushed rock.

The brick facing on both up-stream and down-stream sides of the dam is uniformly 18 inches thick, tied into the body of the masonry, and laid in 1.3 cement mortar. The brick used were blue Staffordshire brick, hard burned, with hard pressed brick for the exterior facing courses.

The dam was designed and constructed by Mr. R. H. Wyrill, M. Inst. C. E., Borough and waterworks engineer for the city of Swansea.

The use of brick for the facing of a masonry dam is confined to three principal structures in the world, as far as recorded in technical literature: the Renscheid dam, with one face so covered, and the Ithaca dam, with both faces of brick, being the other two examples, aside from the Swansea dam.

The Burrator Dam, England.—The city of Plymouth (population in 1891, 84,200), a port in the south of England, began the construction of the Burrator reservoir, on the river Meavy, 10.5 miles from the city, in 1893, by the erection of a masonry structure called the Burrator dam, and an earth embankment called the Sheepstor dam, both notable structures. The works were described by Edward Sandeman, M. Inst. C. E., in a paper contributed to the Institution of Civil Engineers, and published in October, 1901, from which the following description has been compiled. Mr. Sandeman was hydraulic engineer for the city, and constructed the works under the advice of James Mansergh, F.R.S., President Inst. C. E., acting throughout as consulting engineer.

The Burrator dam has a total height of 145.5 feet from base of foundation to the coping of the parapet wall, is straight in plan, 361 feet in length, with a thickness of 62.8 feet at the level of the river bed, 77 feet below the overflow level, and is battered on the up-stream face 7.5%, and on the lower face 61%. It carries a roadway 18 feet wide on top, supported over a central spillway of 125 feet total length by five segmental arches of 28 feet span. The maximum depth of excavation to granite bedrock was 40 feet.

FIG. 274.—THIRLMERE DAM, ENGLAND.

Blocks of granite, roughly dressed on the bed and weighing from a few hundred pounds to 7 tons, were embedded in rich concrete, while the facings were composed of large stones having an average thickness of 30 inches, with beds and joints carefully dressed, but left rough on the exterior, and laid in cement mortar, the joints being pointed and calked with neat cement mortar.

The cost of the masonry dam was $495,700, while the cost of the earth dam was $106,600, a total of $602,300. The reservoir has a capacity of 105,120,000 cubic feet, or 2410 acre-feet. The average cost, therefore was $250 per acre-foot of reservoir capacity.

The earth dam is a remarkable structure on account of the extraordinary depth of excavation required to reach bedrock with the concrete core-wall, whose lowest level is 91 feet below the surface. This was built up to within 22 feet of the water-line throughout, 5 to 6 feet thick, on top of which clay puddle 8.5 feet thick at bottom, 6 feet at top, was extended nearly to the crest of the embankment. The maximum depth of water against this embankment is but 17 feet. Its length is 470 feet, crest width 12 feet, slopes 3 on 1 and 2 on 1.

Thirlmere Dam, England (Fig. 272).—A part of the water supply of Manchester is furnished from a reservoir at Thirlmere lake, formed by a masonry dam, built in 1886-1893. The dam has a maximum height of 62 feet, and is 18.5 feet wide on top, forming a roadway with masonry parapets on each side. The width of the dam at the base is 51.8 feet. The up-stream face has a batter of 12.5%, while on the down-stream side is a vertical curve with a radius of 100 feet.

The dam has a gravity section, and is built on a reverse curve, in order to follow the alinement of highest bedrock across the valley. The crest of the roadway of the dam is 6.2 feet higher than the high water level of the reservoir.

The dam was built by Mr. George H. Hill, engineer in charge.

Craig Goch Dam, Wales.—The city of Birmingham, England, has been engaged for many years past in extensive works of water storage to obtain an additional supply from the mountains of Wales, to be brought to the city by an aqueduct 74 miles long, 8 feet high inside, by 7.5 feet wide, with a capacity of 129 cubic feet per second. A total storage capacity of 66,000 acre-feet is being created by the erection of five high masonry dams, one of which, the Craig Goch dam, is illustrated by two photographs, Figs. 275 and 276, taken from *Engineering Record*, January 30, 1904. Other dams on the same stream are the Caban Goch and Pen-y-Gareg dams, which are straight in plan. The Careg-Dhu dam and one other masonry structure are located on the Clarewen river.

The total cost of the dams and aqueduct are estimated at over

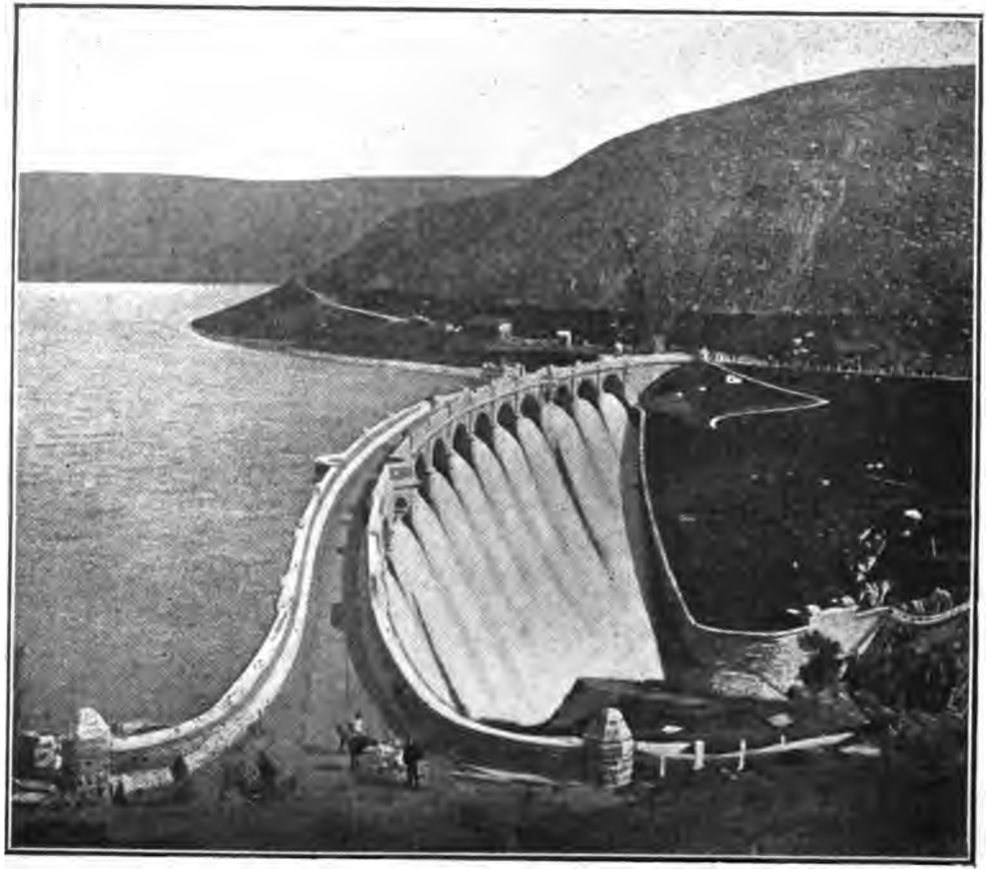


Fig. 275.—Showing Overpour on the Craig Goch Dam, Wales.

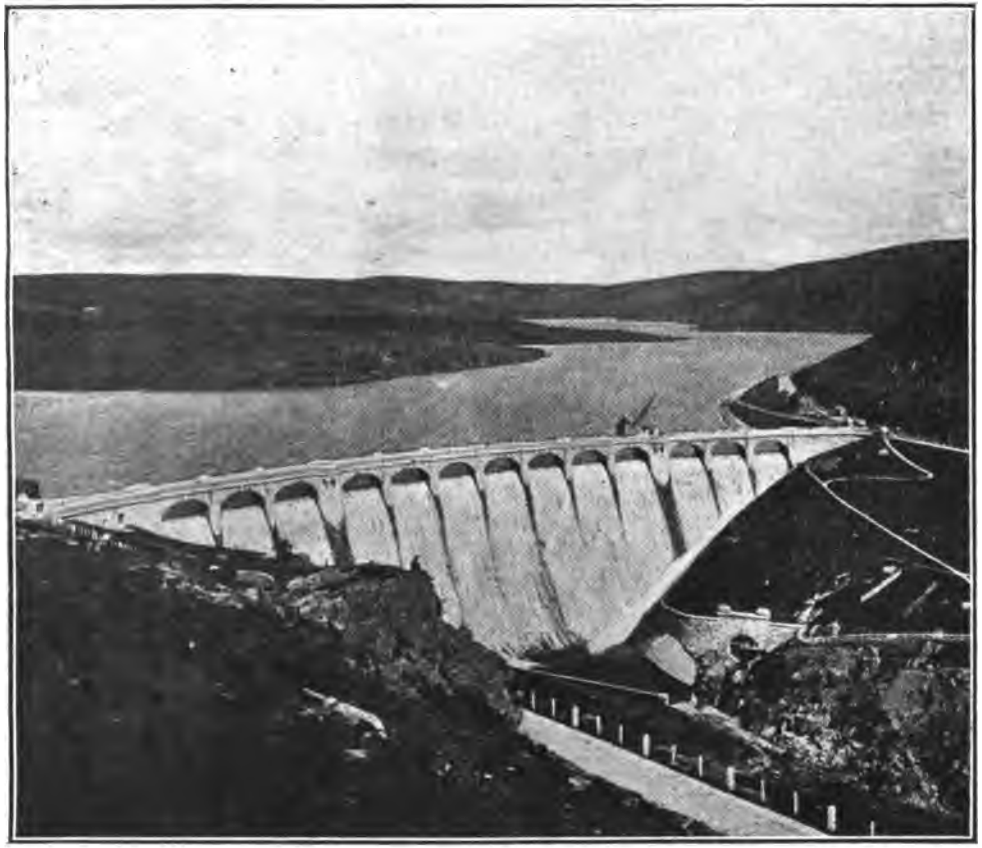


Fig. 276.—Craig Goch Dam and Reservoir, Radnorshire, Wales, for Birmingham Water-supply.

$29,000,000. All dams are built of cyclopean rubble laid in a matrix of high class Portland cement. The dams were designed and built under the direction of James Mansergh, F.R.S., M. Inst. C. E.

Derwent Valley Dams, England.—Five large masonry dams for the storage of water to supply the cities of Leicester, Derby, Sheffield, and Nottingham have been under construction since 1904, under one combined project controlled by an organization called the Derwent Valley Water Board. These dams are of the following general dimensions:

Name	Length. Feet.	Maximum Height above Valley Level.
Howden dam	1080	118
Derwent dam	1070	115
Haglee dam	980	136
Ashop dam	840	103
Bamford dam	2500	95

In excavating for the Howden dam it has been necessary to sink to a depth of 67 feet below the river bed to reach bedrock, and a trench 20 feet deeper has to be cut into the rock to reach water-tight strata. In making the excavations a cableway for carrying away the spoil has been used.

The dam is to be 160 feet thick at the base, 9 feet at crest, and be built of cyclopean rubble masonry. It will have a long spillway over the crest.

It is estimated that the works will cost entire about $35,000,000, and serve about 2,000,000 people. The work will occupy twenty years in construction before the entire system is completed, although they will be in partial service at a much earlier date. The main aqueduct will be 55 miles long.

Dams in South America.

The Rio das Lages Dam, Brazil.—The Rio de Janeiro Tramway, Light and Power Co., in 1905-07, built a rubble masonry dam 135 feet in height, on the Rio das Lages, 50 miles from the city of Rio de Janeiro, to form a regulating reservoir for the development of power. The dam is of gravity type, with all lines of pressure well within the middle third, the main portion of which is curved on an arc of short radius, best fitting the bedrock, with tangential extensions into the banks at either end. Five hundred feet below the dam the river plunges over a vertical fall of 200 feet over a hard ledge of granite, in a gorge filled with rank tropical foliage, forming a scene of great beauty and grandeur.

The dam creates an enormous reservoir, 16 miles long, with many tortuous windings and arms, giving a total capacity of 7,780,000,000 cubic feet, or 178,000 acre-feet.

The writer examined and reported upon the site before the plans were definitely decided upon, at which time the quantity of masonry required was estimated at about 63,000 cubic yards.

From the dam to the power house a total fall of 1030 feet is utilized for the development of over 50,000 H. P. in the primary installation, transmitted to Rio de Janeiro at 80,000 volts.

The works have been designed and built by Mr. Chas. H. Kearney, chief engineer, under direction of F. S. Pearson, M. Am. Soc. C. E., as consulting engineer, and vice-president of the company.

Parnahyba Dam, Brazil.—In 1900 the Sao Paulo Tramway, Light and Power Co. built a masonry dam across the Tieté river, 22 miles below the city of Sao Paulo, near the village of Parnahyba, for the development of power. The dam is 850 feet long on the crest, straight in plan, 37 feet in height, with a base width of 30 feet. A rollway section for overflow is located in the central portion of the dam, 325 feet in length, the end sections being 5 feet higher. The dam rests throughout on solid granite, and is formed of rough rubble masonry, with cut-stone facings on the down-stream portion of the rollway and crest.

The water from the dam is conveyed to a small penstock reservoir, 200 feet from the power-house, through two ⅜-inch steel feeder pipes, 12 feet diameter, 2223 feet long, resting on steel saddles, placed 10 feet apart, on masonry piers. The secondary dam is constructed of concrete, resting on rock, is about 45 feet high, 255 feet long, 24 feet thick at the base, with a batter of 35% on the down-stream side. The crest width is about 8 feet at a height of about 10 feet above the water line.

The constructing engineer was Mr. Hugh L. Cooper, with F. S. Pearson, Dr. Sc., M. Am. Soc. C. E., acting as consulting engineer.

Reservoirs in Peru.

The only storage reservoir dams of importance in Peru are situated on the headwaters of the Santa Eulalia river, the main tributary of the Rimac river, and are probably the highest in altitude of any dams in the world, as well as possessing many other unique conditons.

In the years 1874-75 the Peruvian Government undertook the work of developing a water supply for irrigation in the Rimac valley by the building of masonry dams and outlet cuts in a group of lakes known as the "Lagunas Huarochiri," situated at elevations of 14,000 to 16,000 feet above sea level in the Andes mountains at the head of the Rimac river. There are some 65 or 70 of these lakes, nine of which were converted into storage reservoirs, having an aggregate capacity of 37,212 acre-feet, although the maximum quantity ever stored since they were put in service has been but 28,100 acre-feet. The lakes are about 80 miles away from the land irrigated; the loss by evaporation and seepage in transit by the natural stream channels in this distance is estimated at 50%, and the net results accomplished by the water of these reservoirs is stated to be the reclamation of only 1940 acres, at an average cost of $506.70 per acre! The works are nevertheless of an interesting and instructive character, and the writer is indebted to Mr. W. T. Turner, chief of the Hydrographic Commission, Department of Lima, for the accompanying photographs, illustrating their construction and the data concerning them, from which the following description has been compiled.

Lake Carpa Dam.—Lake Carpa is situated near the head of the Huasca river, a small tributary of the Santa Eulalia, having a limited drainage

FIG. 277.—CARPA DAM, PERU, SHOWING TYPICAL OUTLET CUT, FILLED WITH STEEL BULKHEAD, GLACIER IN BACKGROUND.

area and principally fed by the melting of a glacier. A cut through gravel and solid rock, about two meters wide, was first made to a depth of 11.7 meters (38.4 feet) to drain the lake, and a masonry dam was built about the top of the cut to a total height of 4.30 meters (14.1 feet) making a total depth of reservoir of 16 meters (53.5 feet). The dam is vertical on the up-stream face, has a crest width of 1.5 meters, and is vertical on the lower face for a depth of two meters below the top, thence slopes 0.5:1 to the bottom. The length of the dam on the crest is 58 meters (190 feet) and it is curved with a radius of 60 meters. It contains a total of 907 cubic meters (1190 cubic yards) of masonry, the contract cost of which was $65.00 per cubic meter. Excavation in rock, 2978 cubic meters at $20.00 per cubic meter, and in gravel 1857 cubic meters at $12.00 per cubic meter, brought up the total cost of the work, exclusive of gates, to $140,800. The storage capacity when filled is 16,921 acre-feet, but as the lake has never filled above the foot of the masonry in this dam, the maximum storage has been but 10,190 acre-feet.

Fig. 277 shows the dam from the down-stream side and the outlet cut from near the bottom to the top of the masonry, which is divided by the cut in two halves, the space being filled with a bulkhead composed of I-beams and steel plates. Water is released at the bottom of the cut through gates in the bulkhead that are raised by screw-stems reaching to the top.

Lake Quisha Dam.—About a mile above lake Carpa reservoir and 300 feet higher in elevation, is lake Quisha which has been converted into a storage reservoir by a dam quite similar in construction to the works at lake Carpa. The cut to drain the lake is 10.6 meters deep and the dam 6 meters high, a total of 16.6 meters (54.5 feet). The dam has the same section as the Carpa dam with a crest length of 48 meters and a volume of 887 cubic meters of masonry. It is also curved up-stream, with a radius of 66 meters. The water-shed tributary to the lake is but 3 square miles, and the annual run-off is so much less than the reservoir capacity that the water has never reached within 5 meters of the top of the dam. The capacity of the lake is 8035 acre-feet, while the maximum amount stored has been 5654 acre-feet. As this dam is on the same water-shed as the Carpa dam, and the total annual run-off of the tributaries of both is less than the capacity of Carpa lake reservoir, it is evident that the Quisha dam was not required, and its cost—over $125,000—was a useless expenditure. The elevation of the lake is 15,400 feet above sea level. Fig. 278 shows the entire dam and a portion of the lake. Incidentally it conveys an idea of the scenic grandeur with which the lake is surrounded.

The Sacsa Dam.—Sacsa lake is 1000 feet lower in elevation than Quisha lake, and is located near the head of the Sacsa river, but, unlike the two reservoirs just described, has a water supply greatly in excess of its capacity, which is but 4172 acre-feet. The outlet cut was made to a depth of 5 meters, and gates were erected with the evident purpose of building a dam 7.5 meters in height above the bottom of the cut. This dam, however, was never completed, although it would have added 50%

Fig. 278.—Quisha Dam, Peru.

Fig. 279.—Sacsa Dam, Peru, Designed to be Increased in Height 8 Feet, showing Gates.

to the storage capacity of the lake. The excavation of the cut required the removal of nearly 18,000 cubic meters of clay, gravel and rock, the cost of which, with the 173 cubic meters of masonry around the gates, and including the latter, was over $250,000. The photograph (Fig. 279)

FIG. 280.—HUASCA DAM, PERU, ILLUSTRATING TYPE OF IRON BULKHEADS USED IN OUTLET CUTS OF ALL NINE LAKES USED AS RESERVOIRS.

clearly shows the typical plan of outlet gates used on all the reservoirs. The other six reservoirs, Huasca, Bucro, Mischa, Huachua, Manca, and Pichua, are natural lakes, converted to use by merely making outlet cuts and erecting controlling gates. Fig. 280 is typical of all of these, and shows the iron work of the bulkhead in the cut, in which the gates are placed at Huasca lake reservoir—the largest of the six, having a capacity of 4228 acre-feet. The total expenditure on these works by the Government was $983,000. The enormous unit prices paid for the works is suggestive of official graft on an extensive scale.

The coastal plain of Peru, extending from 30 to 50 miles inland, is extremely arid, and rain falls at rare intervals of many years. The valleys of the streams intersecting this plain and draining from the precipitious Andes mountains, are generally small and have an inadequate water supply during eight months of the year. The rainy season in the Western Cordillera, one of three parallel ranges which make up the Andes chain of mountains, occurs during the summer months from December to March, when the precipitation is very heavy, and the run-off is so great that if one-fourth

Fig. 281.—Autisha Dam Site, Santa Eulalia River, Peru—a most remarkable Gorge.

of it could be stored, the entire arable area of the Peruvian coast could be abundantly irrigated. The rivers, however, are very short and precipitous, and possess few flat basins suitable for the storage of flood waters. The soil of the valleys is extremely fertile, and the incentive for the development of irrigation is large, as it is said that Peru produces a greater quantity of sugar per acre than any other cane growing country in the world. Other crops yield with equal luxuriance. In the course of the investigation which is being conducted by the Hydrographic Commission under Mr. Turner, a remarkable dam site has been surveyed which is without parallel. It is located on the Santa Eulalia river, 20 miles above Chosica. For 400 feet in height above the stream bed, this wonderful canyon is nowhere more than 35 feet in width and presents a most tempting opportunity for daring hydraulic engineering in the erection of a dam

FIG. 282—RESERVOIR SITE ABOVE PROPOSED AUTISHA DAM, PERU.

of unprecedented height. Fig. 281 is a view of this phenomenal canyon, and Fig. 282 is a photograph of the reservoir basin above the dam. The opportunity for water power development is also remarkable on these rivers, which fall so very precipitously toward the west. One branch of the Rimac river falls 7300 feet in a distance of 35 miles, with a minimum flow of 250 sec.-feet, capable of developing 200,000 H. P. This is a fair illustration of nearly all the rivers of Peru flowing into the Pacific Ocean.

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 Panduwaasa 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-

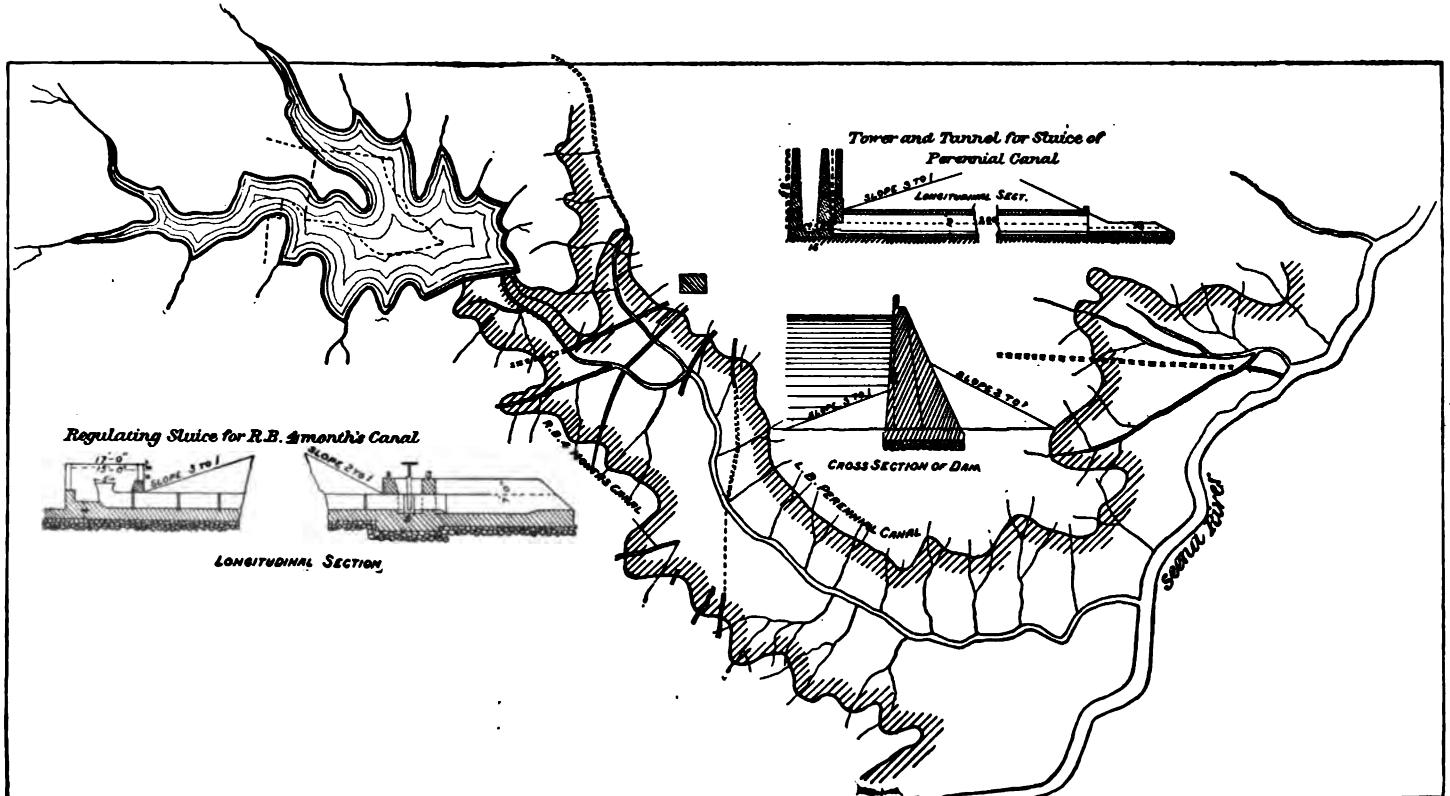


FIG. 283.—THE EKRUK TANK, BOMBAY. PLAN AND DETAILS OF DAM, ALSO SHOWING LANDS IRRIGATED

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. 283) impounds 76,500 acre-feet, and has a dam whose maximum height is 75.6 feet. The total length is 6940 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. 284) is formed by an earth dam 12,709 feet long,

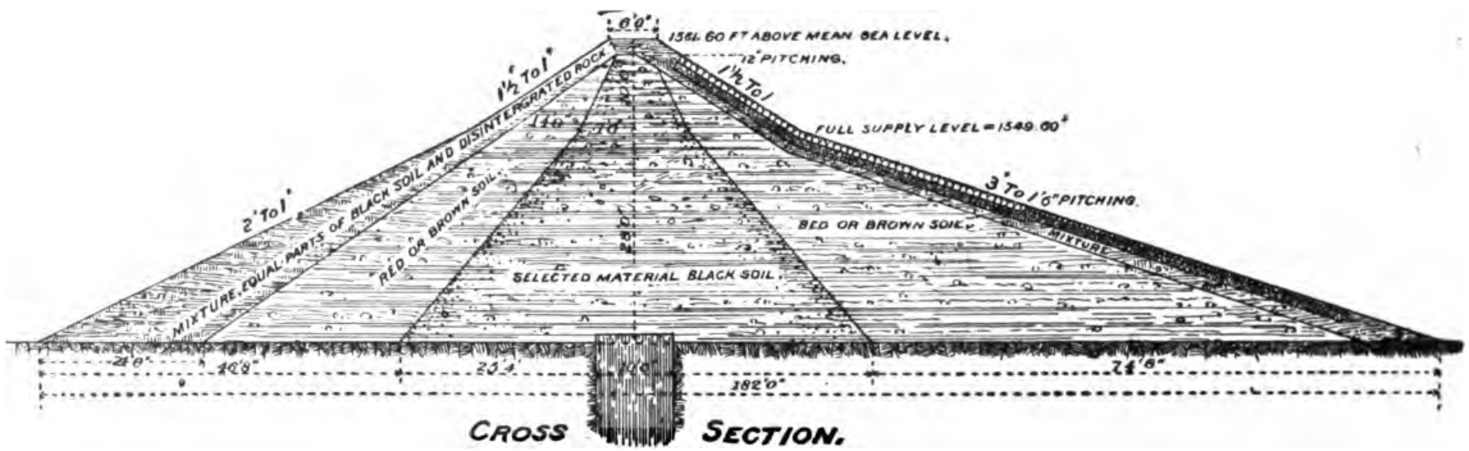


FIG. 284—CROSS-SECTION OF THE ASHTI DAM, INDIA.

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 35,700 acre-feet, of which 9200 acre-feet, or 26%, is lost by evaporation. The reservoir has a surface area of 2870 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 ot 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. 285.—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. 285 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. 286.—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	8,076	21.75	0.885	3	9.50	0.316	
1889	52.83	5,568	17.91	0.697	4	5.00	0.250	2,853
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. 286 and 287.)

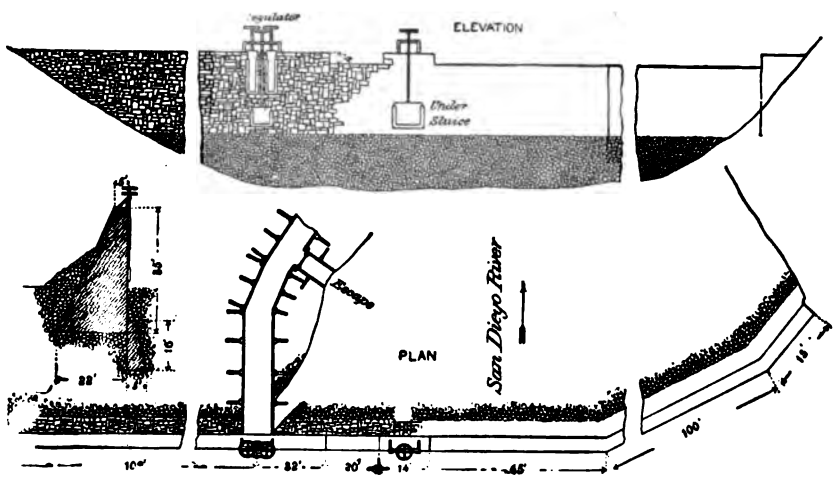


FIG. 287.—PLAN AND ELEVATION OF DIVERTING-DAM OF SAN DIEGO FLUME CO., CALIFORNIA.

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. 288, 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

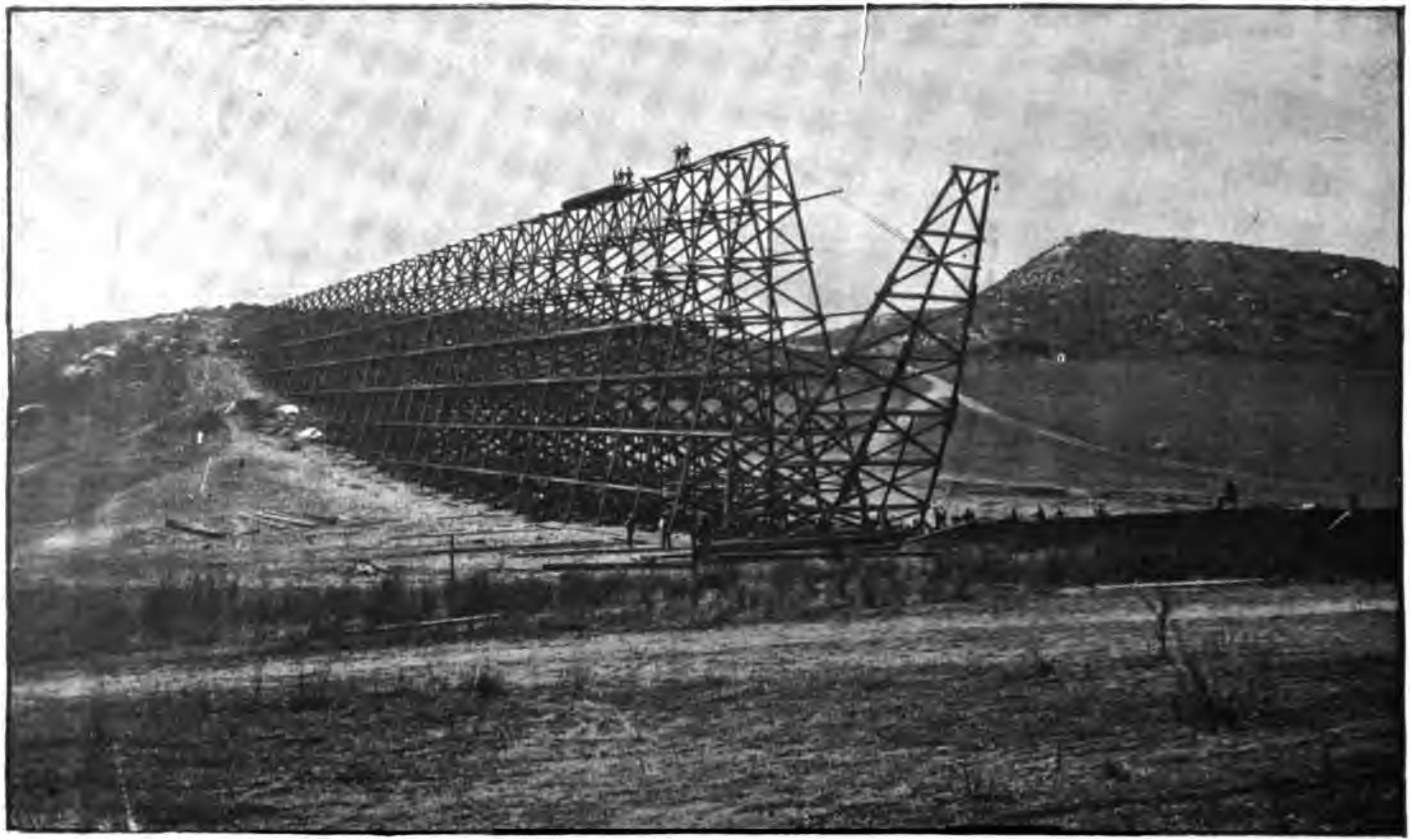


Fig. 288.—Sample of High-trestle Construction on San Diego Flume, California.

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. 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-

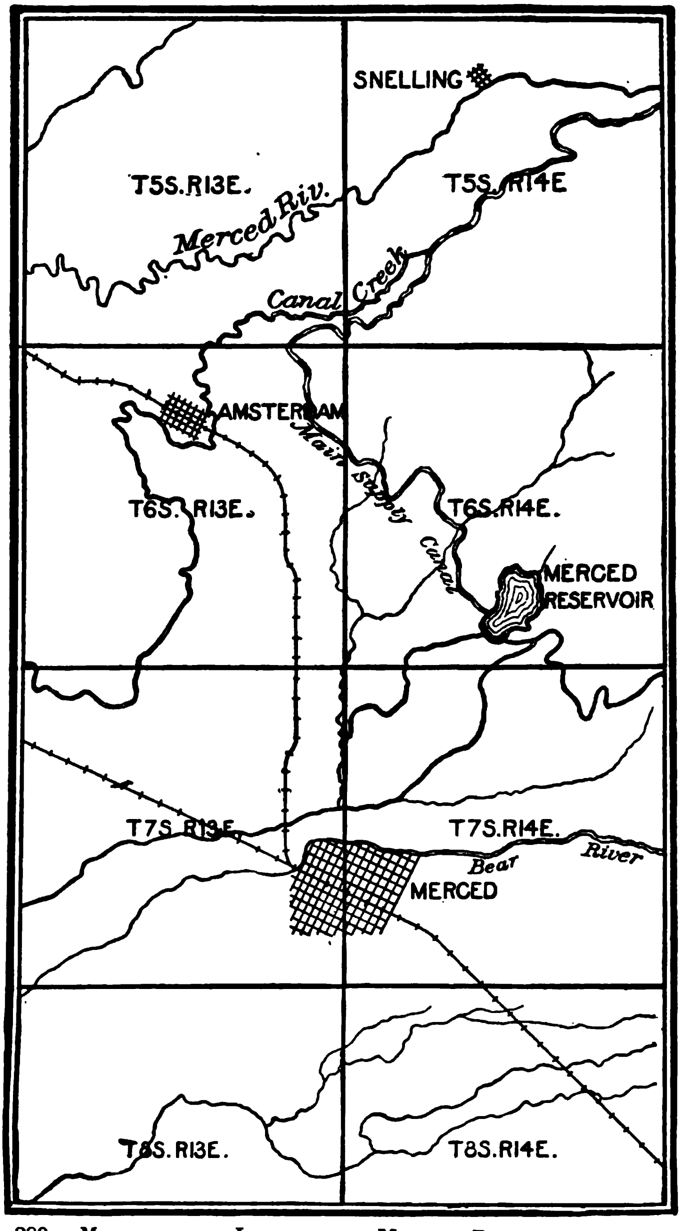


FIG. 289.—MAP SHOWING LOCATION OF MERCED RESERVOIR, CALIFORNIA.

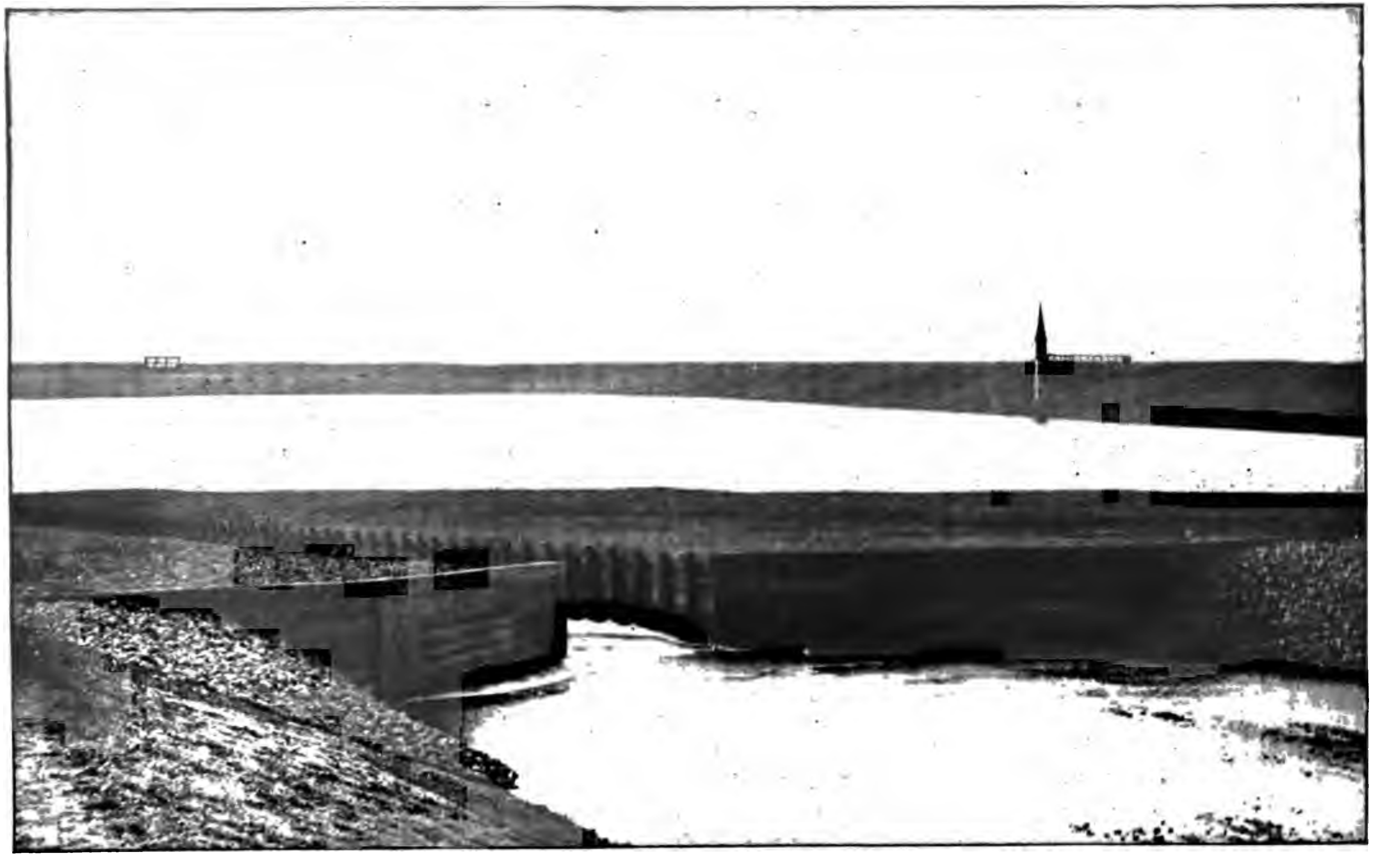


Fig. 290.—View of Yosemite Reservoir, Merced, Cal., showing Feeder-canal and Outlet-tower.

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. 290.

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.

Tabeaud Dam, California.—For the purpose of creating a penstock reservoir at the head of the pressure pipes of the Electra Power-house, the Standard Electric Co., in 1900-01, built a high earthen dam across a small tributary of the South Fork of Jackson creek, 8 miles from the town of Jackson, Amador Co., Cal. The reservoir receives the drainage from a catchment area of but two square miles. It is fed by a long flume from the Mokelumne river. The reservoir area is 36.75 acres, with a capacity above the outlet tunnel of 1070 acre-feet. The crest of the dam is 1258 feet above sea level, the flow line of the reservoir is 8 feet lower, while the level of the outlet tunnel is 70 feet below the flow line.

The dam ranks among the highest earth dams of the world, and has the following dimensions: Height at center above bedrock 120 feet; height above lower toe 123 feet, height above up-stream toe 100 feet; length on crest 636 feet, length at bottom 50 to 100 feet; width at base 620 feet; width on top 20 feet.

The side-slopes of earth are 2.5 on 1, on both sides, with a rock-fill on the up-stream slope, from the base up two-thirds of the height, laid on a slope of 3 on 1, and overlying a heavy layer of clay puddle.

The dam has a total volume of 370,350 cubic yards, all of which except 40,000 cubic yards, was put in by contract at 40 cents per cubic yard. It was all of choice material, consisting of a red gravelly soil, containing about 70% clay, obtained from nearby borrow-pits within the reservoir basin and near the ends of the dam. It was hauled in carts and four-horse dumping wagons, loaded by scrapers through traps, or loading platforms, and spread in layers of 6 to 8 inches, thoroughly sprinkled, and harrowed and rolled by 5 and 8 ton rollers. The center of the dam was maintained lower than the two sides by about 10% of the height at all levels.

The dam was so carefully built and so thoroughly supervised that one year after its completion a maximum settlement of but 2½ inches was found to have occurred, with 90 feet of water in the reservoir. It has shown no sign of leakage.

The dam was planned and built by Mr. Burr Bassell, M. Am. Soc. C. E., since deceased, author of a useful little book entitled "Earth Dams."

On September 1, 1901, when the dam was nearing completion, the author was employed to make a report upon its construction and stability. His findings were entirely favorable. During the course of this investigation it was found that the weight of earth material taken from test pits on the dam was 133 pounds per cubic foot, showing that it had been condensed and compacted 40% from its weight in a loose condition. The dam has no core-wall or puddle core, but is a homogeneous earth structure of such high-class material and such superior workmanship that, although nearly the highest of all earth dams, it is tight and stable without these features that are usually regarded by the profession as indispensable.

Chollas Heights Dam, California.—An earthen dam built by the Southern California Mountain Water Co. in 1901, four miles east of San Diego City reservoir, at an elevation of 428 feet on the crest, is worthy of note as the first dam of that material to be built with a core-wall of steel plates, riveted together to form a water-tight diaphragm in the center. The dam is 526 feet long, 56 feet high, and 20 feet wide on the crest, with slopes of 3 on 1 and 2 on 1, up-stream and down-stream respectively. It is an embankment of earth taken from the reservoir bottom, consisting of sand, clay and gravel. It was deposited in layers and rolled, after the natural soil under the up-stream half had been stripped to a depth of one foot.

The steel diaphragm is embedded at the bottom and ends in a concrete wall, built in a trench 30 inches wide, extending across the valley. This wall has a maximum height in the center of the valley of about 17 feet, and is stepped up the slopes to correspond with the courses of steel plates. It was made up of 1:2:4 concrete and is carried up to within 13 feet of the crest of the dam, or 8 feet below the flow line of the reservoir. The steel diaphragm reaches to the same height, and consists of four courses of plates, each 6 feet high, 20 feet long, ¼ inch thick. These are riveted and calked and coated with hot asphaltum. A layer of burlap dipped in hot asphaltum was then applied to both sides of the plate, and the whole surface treated to a second coat of the bitumen.

Water is drawn from the reservoir through a 24-inch cast-iron pipe, laid in a trench excavated in the natural earth beneath one end of the dam

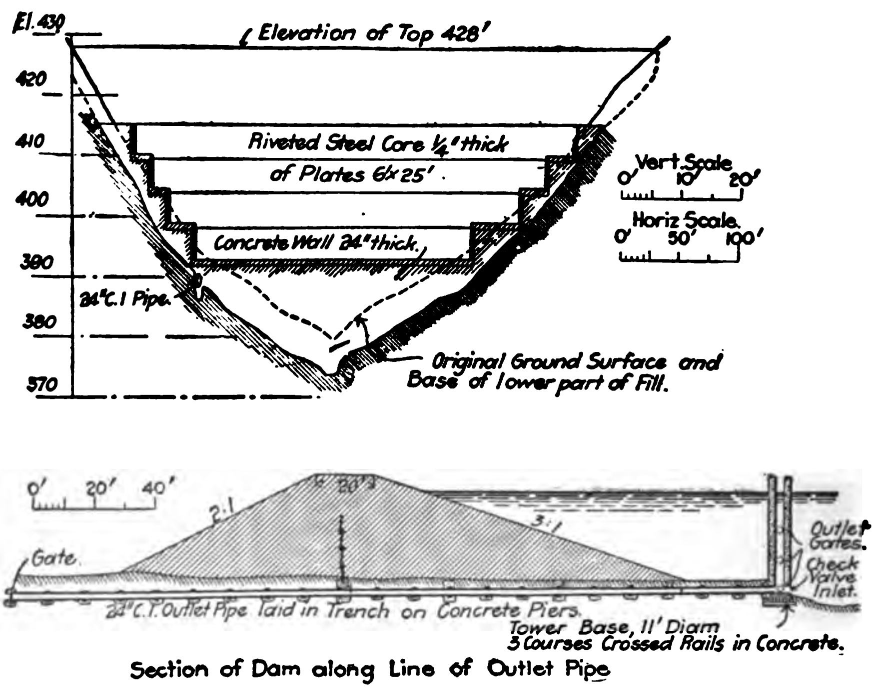


FIG. 291.—CHOLLAS HEIGHTS DAM, CALIFORNIA.

about 38 feet below the top. The pipe is supported on concrete piers every six feet, several being extended as cut-off collars. At the head of the pipe is a circular tower of concrete, with gates at three levels for admitting water to the pipe.

The reservoir is used as a receiver at the end of a pipe line of wood stave construction, 20 miles long, leading the water from the Lower Otay reservoir. Mr. E. F. Tabor, now in charge of the construction of the Shoshone dam for the U. S. Reclamation Service, was engineer on the building of this dam, under the direction of H. N. Savage, M. Am. Soc. C. E., acting as consulting engineer.

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.

Canistear Dam, New Jersey.—The main earth dam of the Canistear reservoir of the East Jersey Water Co. was built in 1896, to form a reservoir of 323 acres, with a capacity of 2,407,000,000 gallons (7390 acre-feet) at a cost of $341,000, including a masonry overflow weir and two auxiliary dikes. It is worthy of note for the rapidity with which it was completed, less than five months' time having been required to construct it. The main dam contains 98,000 cubic yards and the two auxiliaries 3850 cubic yards. All three have concrete core-walls, amounting to 9050 cubic yards, while the overflow weir has 4500 cubic yards of masonry. It was a rush job, in which work was done by night as well as by day. The main dam was about 57 feet high, 672 feet long on top. The wasteway was made 275 feet long to provide for floods from a watershed of 10.5 square miles.

The dam was planned and built by Clemens Herschel, M. Am. Soc. C. E., of New York, one of the distinguished American engineers who are apparently firmly committed to the concrete or masonry core-wall as an essential element in the building of earth dams.

The Glenwild Dam, Amsterdam, New York.—The city of Amsterdam, New York, in 1902, built an earth dam 63.5 feet high, 450 feet long, 13 feet wide on top, with up-stream slope of 2 on 1, down-stream slope 2.5 on 1, to form a reservoir of 180 acres area, and having a capacity of 1,200,000,000 gallons (3675 acre-feet). The dam is curved up-stream with a radius of 708.6 feet, and has a core-wall of cement masonry in the center, reaching to a height of 1 foot above the flow line of the reservoir. The core-wall is 14.5 feet thick at the ground line, and extends 7 feet below the surface with a uniform thickness of 6 feet. Above the wide part of the base at the stripped surface it has a batter on one side of 3 inches to the foot. The wall is composed of broken bowlders, none of which exceed ½ cubic foot in size, laid by hand, and grouted with 1:3 cement mortar, in 16-inch courses.

The outlets consist of two 18-inch and one 12-inch cast-iron pipes laid side by side and bedded in rubble masonry, through the body of the dam. Where they passed through the core-wall, an arch was sprung over them, and the space between pipes and arch subsequently filled with cement grout poured in through three 1½-inch pipes reaching to the top in the interior of the wall, after all settlement had ceased.

The dam was designed by Mr. Stephen E. Babcock, of Utica, as consulting engineer. Its cost by contract was $47,360.

The Laramie River Dam, Wyoming.—The Wyoming Development Co., in 1900-01, constructed a dam across the Laramie river to form a storage reservoir covering an area of 6588 acres and having a storage capacity of 120,000 acre-feet, for the irrigation of 60,000 acres in the neighborhood of Wheatland, 90 miles north of Cheyenne, at an altitude of 4700 feet above sea level. The dam is 8000 feet in length, 34.5 feet maximum height, and contains 344,000 cubic yards. The up-stream slope is 3 on 1, outer slope 2 on 1, crest-width 15 feet at a height of 5 feet above the flow line of the reservoir. The dam is built as a homogeneous earth structure, the material being placed by horse-scrapers and carts. It has no core-wall, but for a distance of 1200 feet in the center, crossing the river channel, a row of wooden triple-lap sheet piles was driven to a depth of 10 to 12 feet below the surface.

The embankment is rip-rapped with large bowlders on the water-face, extended by an apron of the same material, 30 feet wide above the upper toe of the dam, requiring a total of 16,000 cubic yards of rock.

The dam was built by George Frederick Vollmer, Assoc. M. Inst. C.E.*

Cedar Grove Dams, Newark, N.J.—The city of Newark, New Jersey, in 1901-04, created a storage reservoir near Cedar Grove, seven miles from

* *Vide* Minutes of Proceedings, Institution of Civil Engineers, vol. 162, Nov., 1905.

the city, having a capacity of 700,000,000 gallons (2150 acre-feet) by building an earth dam 2700 feet long, across the main outlet of the basin, with dikes at each end of the reservoir, 650 feet and 825 feet in length respectively. All three dams have concrete core-walls, which extend up 2.5 feet higher than the full reservoir level, are 4 feet thick at top, and have a uniform batter of ½ inch to the foot on both sides, down to the original ground surface, below which the thickness is uniform to the bottom of the trenches in which they are built. The walls are plastered with ½ inch of 1:1 cement mortar on the water side, applied in the forms as the concrete was placed. The maximum height of the core-wall in the main dam is 102 feet, and the total volume of concrete in all the core-walls was 36,000 cubic yards. It was mixed in the proportion of 1 part of Rosendale cement, 2 of sand and 5 of crushed rock. The posts of the forms on each side of the wall were made to support a light railway the entire length of the dam, on which cars operated by a cable and winding engine were run, conveying concrete from the mixing plant at one end. This trestle was carried up in three bents or levels of 20 feet each on the main dam.

The maximum heights of the north and south dikes above the original surface are 26 and 25 feet respectively, the core-walls being 40 and 42 feet high. They are 12 feet wide on top, 6 feet above reservoir level, and have 2 on 1 slopes each side. The main, or west dam, is 18 feet wide on top, 5 feet above the water line, and has an 8-foot berm in each slope 20 feet below the top.

The core-wall trenches were refilled on the water side of the walls to the original ground surface, with clay puddle, and on the other side with selected material shoveled into water or well rammed.

The earth, a red clayey loam, was excavated by steam shovels and hauled to the dam in trains of 3½ yard cars by numbers of small saddle-tank locomotives. It was spread in 5-inch layers by scrapers, and compacted by steam rollers and traction engines.

This dam is to be noted as having one of the highest concrete core-walls in America, and the whole construction is typical of modern earth-dam work. The total amount of material borrowed, representing the approximate volume of the dams, was 400,000 cubic yards.

The total cost of the dams complete was $660,000. This includes cost of stripping of the reservoir to a depth of six inches, but does not include pipes or outlet tunnel. The outlet of the reservoir is through a tunnel, 300 feet long, on the opposite side of the reservoir from the main dam.

The works were designed and constructed by M. R. Sherrerd, M. Am. Soc. C. E.

Belle Fourche Dam, South Dakota.—The largest earth dam under construction by the United States Reclamation Service is to form a res-

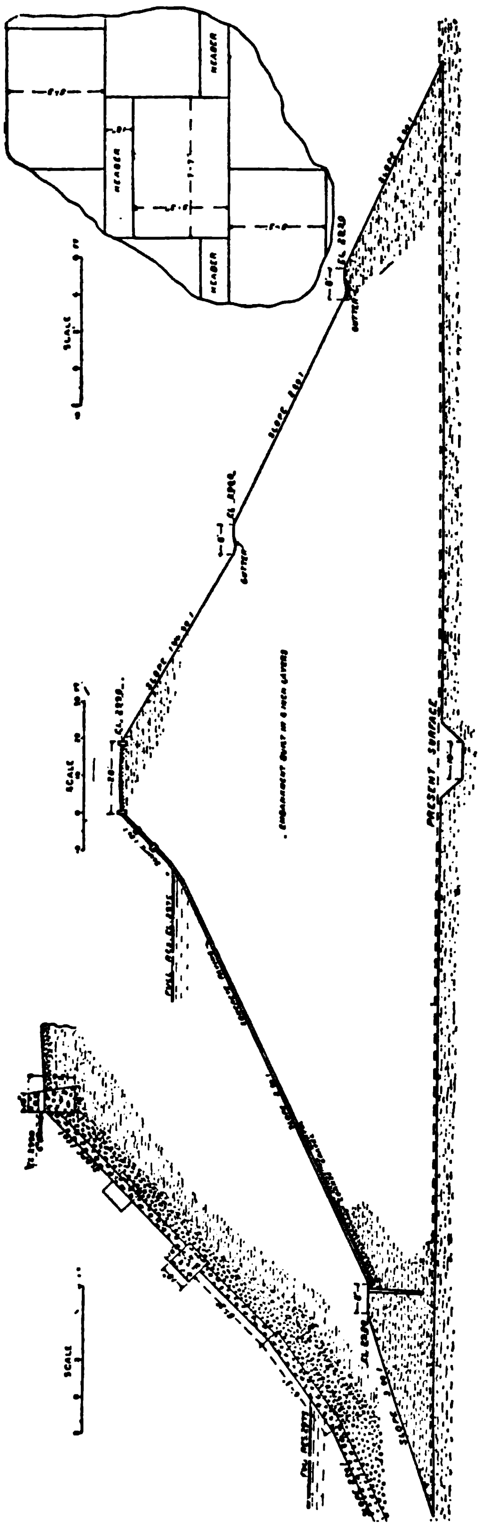


FIG. 292.—SECTION OF BELLE FOURCHE EARTH DAM, SOUTH DAKOTA.

ervoir of 215,000 acre-feet capacity, for the irrigation of about 90,000 acres of arid land, largely public, situated south east of the Black Hills, South Dakota, by the diversion of the waters of the Belle Fourche and Redwater rivers, into a large basin east of the town of Belle Fourche, on Owl creek. The reservoir will be filled by a large feeder canal 6½ miles long, 40 feet wide on the bottom, carrying 10 feet depth of water.

The dam is to be 115 feet high, 6500 feet long and will contain 1,600,000 cubic yards. Its crest width will be 20 feet, at a height of 15 feet above the flow line or crest of spillway. The latter is 300 feet long, semi-circular in form.

A section of the dam is shown in Fig. 292.

The inside slope is 3 on 1 from the base up to near the water line, with an 8-foot berm near the bottom, 10 feet below low-water line at the foot of the pavement. Above the water the slope is 1 on 1. The facing of the dam is of concrete, made in large slabs, laid on 12 inches of screened gravel, overlying 12 inches of unscreened gravel. The slabs will be laid in the form of headers and stretchers, breaking joints, the largest being 5 feet 3 inches × 7 feet 7 inches in size and 8 inches thick. The lower slope is 2 on 1, with two 8-feet berms. The dam contains no core-wall but consists of a heavy adobe clay, placed in 6 inch layers, sprinkled and rolled. The bulk of the earth was contracted for at a cost of 28 cents per cubic yard.

The contract was let to Orman & Crook, of Pueblo, Colorado, for a total of $879,164.25 or $4.09 per acre-foot of reservoir capacity. This does not include preliminary expenses, engineering, supervision, etc., amounting to perhaps 20% more.

The total volume of concrete in the work was estimated at 31,930 cubic yards, ranging in price from $6.50 to $7.00 per yard. It is understood that the financial embarrassments of the contractors were chiefly due to the losses on this work.

North Dike, Wachusett Dam, Mass.—One of the most difficult earth dam constructions and one of the largest reservoir embankments in the world, is the North Dike of the Wachusett reservoir, referred to in the account of the Wachusett dam. The dike is two miles long, 65 feet high at the deepest place to the water line, or 80 feet high to the top, with a maximum width on the base of 1930 feet. It covers an area of 135 acres, and contains 5,300,750 cubic yards. The down-stream slope of the dike varies from 3% to 6%, averaging less than one-tenth the usual slope given to reservoir banks.

To cut off percolation through porous substrata under the dike, a cut-off trench was excavated for a distance of 9505 feet, to a maximum depth of 60 feet, with a bottom width of 30 feet. For 3130 feet the excavation reached to bedrock. Over a distance of 5239 feet wooden sheet-piles 4 to 6 inches thick were driven in the bottom of the trench, to great depths, with the aid of the water jet, reaching at bottom to extremely fine sand. The cost of this work was about $125,000. Over 540,000 cubic yards were removed in the excavation of this trench, which was carefully replaced by selected soil from the reservoir stripping, placed in layers, sprinkled and rolled. The shrinkage of soil from the borrow pit to the finished dike after rolling was found to be 37.5%.

On April 11, 1907, a section of this dike in the highest place slid off into the reservoir over a length of 675 feet at a time when the water was 40 feet below the top of the dike. About 65,000 cubic yards moved bodily from 250 to 300 feet laterally. The dike was heavily riprapped with stone on the water-face, with 5 feet of coarse gravel and small stones, and overlying this was a layer of rock 10 feet thick, taken from the excavation and dumped on the slope. The embankment broke away to the crest, but caused no serious injury, and it is thought the safety of the dike was in no way affected. The slope was 1 on 2 on the water-face, and the embankment has a wide berm 30 feet below the top. The cause of the slide is not definitely known, but it seems evident that the angle of the slope was greater than the natural angle of repose of the materials used when saturated with water.

Druid Lake Dam, Baltimore, Md.—One of the highest earth dams in America was built in 1864 to 1870, with a maximum height of 119 feet, a crest width of 60 feet, at an elevation of 5 feet above the flow line, and with inner slope of 4 on 1, outer slope 2 on 1. The dam has a puddle clay core-wall in the center, having a base width of 36 feet, and a crown width of 17 feet, a little above the water line. In the construction of the dam, narrow embankments were first built up on each side of the core-wall to a height of 25 feet, the material being placed in layers well rolled. Then embankments of dumped material were built to the same height at the slopes, leaving basins between them and the center. These basins being filled with water the earth to fill the basins was dumped from the fill-banks over the edges into the water until the two basins were filled to the uniform height of the banks either side. Then the process was repeated by building up the core-wall, with supporting banks of rolled material, followed by dump-fills and the formation of pools of water or basins on either side into which the earth was subsequently dumped to fill them. This was a crude form of hydraulic fill, but it was an early recognition of the principle that earth settled under water is more cheaply compacted than would be possible of attainment by other means, while the proven stability of the dam after 37 years of service attests the efficiency of the process.

Cold Springs Dam, Oregon.—The Umatilla project of the United States Reclamation Service in Oregon is designed to irrigate about 20,000 acres from the Umatilla river. In connection with it the Cold Springs dam is being built in a small valley to form a storage reservoir of 50,000 acre-feet capacity. It is to be 3200 feet long, about 82 feet maximum height above the original surface, and will contain 620,000 cubic yards. Its width on the crest, 7 feet above the water line, will be 20 feet. The down-stream slope 2 on 1, up-stream slope 3 on 1. The diagram, Fig. 293, is a section of the dam showing the proposed arrangement of materials. The material immediately available for the construction of the dam consists of basalt rock, an extensive deposit of gravel on the northerly hillside below the dam, and fine surface soil, covering the entire country about. These were the most abundant, but in addition there is also available a deposit of pure volcanic ash, at infrequent intervals and scanty in quantity, an indurated clay at one end of the dam and sand and gravel underlying the surface soil, somewhat indurated and stratified. Prior to determining the choice of materials to be selected a series of interesting experiments were conducted under the direction of D. C. Henny, M. Am. Soc. C. E., supervising engineer, assisted by E. G. Hopson* the purpose of which

* *Engineering News*, March 7, 1907.

was to ascertain the permeability of the materials and the rates of percolation of water through them. These rates were determined by placing the materials in tanks similar to those used by the Massachusetts State Board of Health and by the Massachusetts Metropolitan Water Board in experimenting on the permeability of soils to be used in constructing the North Dike of Wachusett reservoir. The tanks were of galvanized iron, 18 inches in diameter, 5 feet deep. Two perforated pipes passed through the tanks horizontally, 3 feet apart, connected on the outside with glass gage tubes. The material to be tested was carefully rammed in a wet condition into the tanks between and around the perforated pipes. To prevent seepage of water following along the sides the interiors of the tanks were painted and sanded. Water was then put in on top of the material and maintained at a constant level. At regular intervals the outflow from the tubes was measured by weight. As the result of these it was found that the rate of percolation through surface soil was about 18,000 gallons per acre per day; through fine subsoil, 350,000; through gravel, 155,000,000; through volcanic ash, 400,000, and through coarse subsoil 650,000 gallons per acre per day. A mixture of 50% of fine subsoil with an equal amount of gravel showed a rate of but 20,000 gallons per acre per day. The experiments resulted in a material change in arrangement of materials in the dam from what had been the original design, and the selection and disposition have been made as shown in the diagram. This is such an intelligent and rational design of earth dam construction that the author considers it worthy of special commendation and study. The placing of coarse gravel on the downstream side where it gives stability and drainage is directly in line with

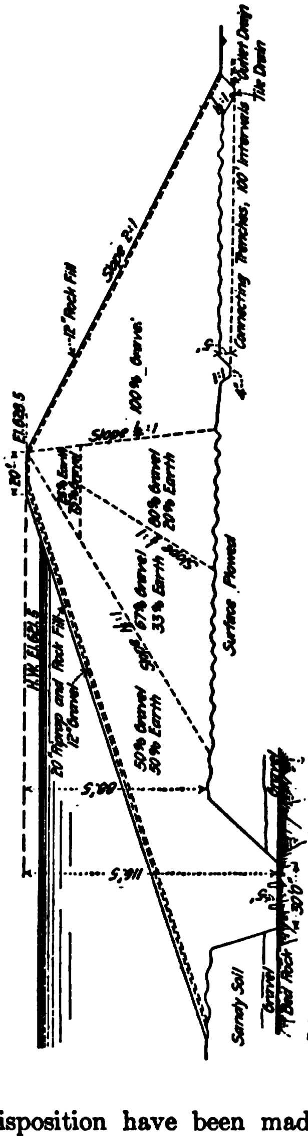


Fig. 293.—Section of Cold Springs Dam, Umatilla Project, Oregon.

the principles employed in hydraulic-fill dam construction. The position shown for the drain-pipes, considerably below the center, is more nearly correct than to carry them as far as the center. The absence of a core-wall will also be noted.

As the result of the experiments the engineers computed the possible loss by percolation through the dam when completed under this design with full reservoir, at about 20,000 gallons per day, or less than one-thirtieth of a cubic foot per second.

Slips in Earth Dams.—This experience with the Wachusett dike appears to be a very common one in the building of reservoirs in India, where many such slides have occurred, although almost invariably on the down-stream slope of the reservoir. These are doubtless largely due to the peculiarly unctious, black soils of that country, which lack in the elements to produce friction and stability, as well as drainage. In building the Waghad dam, which was to have been 95 feet high, an extensive slip occurred when it was completed to a height of 87 feet. The outside slope in this case was 2 on 1. The slope assumed by the slide from the bottom up for nearly half the height was about 3 on 1. It was repaired by first digging three drains at right angles to the axis of the dam. Then a few feet of soil was built up in the work of restoration, when a further motion was observed. This was only stopped after a large trench had been dug about 250 feet long, with base width of 30 feet and side slopes of 1 on 1, to a maximum depth of 40 feet down to rock. This was refilled with dry stone, and a wide berm added. The repair was effective, doubtless due to the drainage provided by the stone filling of the trench.

Mr. William L. Strange, Assoc. M. Inst. C. E., in a paper on "Reservoirs in Western India"* says:

"Low dams can be constructed with much steeper slopes than high ones. The water-faces of dams require a flatter slope than the rear ones. From these considerations it may be deduced that in an originally homogeneous dam with plane slopes, the resistance to slipping decreases with the height from the top, and that the proper section is one having the slopes continually flattened toward the base." On these principles he proposes an empirical section with the following slopes: Inner slope, base to 25 feet, 7 on 1; 25 to 40 feet, 6 on 1; 40 to 55 feet, 5 on 1; 55 to 70 feet, 4 on 1; 70 to 85 feet, 3 on 1; 85 to 100 feet, 2½ on 1. The down-stream slope of his ideal section starts with 5 on 1 to 25 feet, then 4½, 3½, 3, 2½ and 2 on 1, respectively, for each change of 15 feet of height. The crest width of this section he shows as 10 feet at a height of 7 feet above the flow line, with a retaining wall nearly vertical on the water side for the 7 feet of superelevation.

* Minutes of Proceedings Institution of Civil Engineers, vol. 132.

For high earth dams in narrow gorges, where rock or "some non-viscous material is obtainable, he suggests a "compound dam," in which the two toe embankments for about one-third of the height are built up of rock, or presumably gravel if rock is not to be had, having the usual slopes of 3 on 1 on the water face and 2 on 1 outside, the inner batter of these toe walls to be steep; the space between these toe walls to be filled with earth, and the embankment to be continued above the top of the toe walls after the ordinary method of earth construction.

This "compound dam" is virtually based upon the same principles which have been set forth in the chapter on Hydraulic-fill Dams, as the leading advantage of the hydraulic-fill process of dam construction, which employs natural forces to segregate the coarse, "non-viscous material" from the soil, and deposit it in the form of massive toe walls on the slopes, confining the fine, unctuous, impervious materials in the center where they cannot escape or cause slips.

Soluble Salts as a Cause of Earth Slips.—As noted elsewhere in the foregoing pages, the slips which occurred in the Ashti and Ekruk dams were attributed to the fact that the black soil from which the dams were made, and which prevails over a large portion of India, contains impure lime and alkali in small nodules, which dissolve readily. In California, Colorado, and the Western States generally, these soils are of frequent occurrence, and cause great trouble in canal banks because of the seepage through the banks, which do not become firm and impervious until the soluble salts have been leached out of the soil in the course of years.

This class of soil when placed in a dam is subject to saturation not only from the rains but from percolation of water through the embankment from the reservoir. When so saturated the salts form a lubricant on which the embankment is apt to slide. Where the materials can be sluiced into the dam and deposited by the hydraulic process the water in transit must separate the insoluble materials, take up the salts in solution to a large degree, and finally carry them away as it drains off after leaving the earth. This is one of the advantages of the hydraulic process, which have not been dwelt upon in the chapter on Hydraulic-fill Dams, for the reason that this class of soil is the most undesirable, unfavorable and difficult to handle by this process, and therefore to be avoided. But where it has to be used for lack of better, it can certainly be made more stable by washing out its soluble contents by hydraulic sluicing, thus permitting of stable construction from otherwise unstable materials.

Various Modern Indian Dams.—In the paper referred to above, Mr. Strange gives a list of twelve earth dams built by English engineers in the Bombay Presidency, India, for irrigation storage, with the following data of dimensions and capacity:

Name of Dam.	Length, Feet.	Height, Feet.	Top Width, Feet.	Reservoir Area, Acres.	Reservoir Capacity, Acre-feet.
Ashti	12,700	58	6	2600	35,700
Ekruk	6,940	75.7	6	4550	76,500
Kas	718	56.4	10	75	
Maini	3,370	57.3	5	180	4,500
Medleri	2,250	41	6	169	1,430
Mhaswad	7,950	79.8	8	4020	71,000
Makti	3,000	65	10	505	7,850
Nehr	4,820	74	8	675	12,000
Parsul	2,770	62.3	6 to 8	152	2,870
Waghad	4,162	95	6	778	14,300
Malavedi	4,445	114	10	3550	118,000
Tarla	3,120	94	10	815	19,600

Talla Dam, Edinburgh, Scotland.—In 1897-1904, the city of Edinburgh, Scotland, built a storage reservoir dam on the Talla, a branch of the river Tweed, from which a conduit 32 miles long conveys water to the city. As an example of the latest type of earth dam as built in Great Britain, this dam is particularly interesting. It is 78 feet high above the original surface, and 1030 feet long on top. The crest width is 20 feet at a height of 7 feet above the flow line of the reservoir. The puddle trench was 50 feet or more in depth, excavated into slaty rock a maximum depth of 30 feet. The width at bottom was about 12 feet, with nearly vertical sides for 15 feet, above which it widened to 30 feet in the next 20 feet of height. From this point up the puddle core was given a batter of 1 in 8 on each side to the top, where it is 20 feet wide. On either side of the core-wall the middle third of the dam, or a little less, was made of "clayey or adhesive material in layers 9 inches thick." Outside of this zone, the construction was of "stony or open material in layers 18 inches thick." The inner slope was 4 on 1, the outer 3 on 1. The total volume of the dam is about 500,000 cubic yards.

From the description of the materials given* the dam is as perfect an imitation of the modern hydraulic-fill dam as could be made with the old and more expensive methods necessarily employed for handling the materials, although it may be doubted if the construction is any more satisfactory or has any higher factor of safety than if it had been built by the hydraulic process. The leading idea of the design is practically identical, viz.: a body of clay forming the heart of the dam to the extent of nearly one-third, with porous, rocky materials on the two slopes giving drainage. The so-called "compound dam" suggested by Mr. Strange is on the same general design, or aims at the same result.

* Paper by Wm. A. P. Tait, M. Inst. C E., in vol. 167, Proceedings Institution of Civil Engineers.

Illustrations of Typical Earth Dams.—Plates 4, 5, and 6 have been taken from the valuable work of Wm. Ham Hall, Am. Soc. C. E., published in 1888, entitled "Irrigation in California," to illustrate a few standard types of high earth dams with clay puddle core-wall. Plate 4 shows longitudinal and cross-sections of the Pilarcitos and San Andrés dams, and a longitudinal section of the Old or Upper Crystal Springs dam, all pertaining to the waterworks of San Francisco.

On Plate 5 are similar sections of the Llannefydd dam, Wales, in which the maximum depth of excavation for the core-wall was 122 feet; of the Dodder river dam, Ireland, where the excavation was comparatively small; of the Yarrow dam, Liverpool, England, 90 feet high, with a puddle core reaching down to 175 feet below the crest; and of the Vehar dam, Bombay, India, having a height of 84 feet.

On Plate 6 are sections of the Stubden, Leeming and Loch Island Reavy dams in Ireland, the Rotten Park dam, the Ulley dam, and the Vale House dam in England, and two dams in France, built without puddle cores. The Vale House dam is a part of the waterworks of Manchester, and has a puddle extending to a depth of 50 feet below the surface, with a base of concrete on the bottom of the puddle, filling the core-trench on bedrock —a common practice with English engineers.

Core-walls for Earth Dams.—The recent invention of steel sheet-piling which can be made practically water-tight, as a substitute for wooden sheet-piles, which are never entirely satisfactory, has greatly simplified the matter of securing a foundation for core-walls of earth dams. The construction of a satisfactory cut-off in quick-sand, gravel, soft rock or alternating strata of porous material, can now be made in many locations by the driving of steel piles without the necessity for excavating, bracing, pumping, etc., all of which is slow and difficult. Unless large bowlders are encountered, steel piles can be driven to as great a depth as is generally necessary to go down for a foundation. Time is often of vital consideration, and the use of piles of this class will frequently be the means of rapidly completing a job which would otherwise be delayed indefinitely waiting for the completion of the final excavation of foundations.

This use of steel piles as a cut-off and for foundation of the concrete core-wall may be cited in the building of the Big Rapids dam, Mich., in 1907, by William G. Fargo, hydraulic engineer, of Jackson, Mich., where sheet-piles were driven as deep as 56 feet through sand and gravel into hardpan. On top of this row of piles a thin reinforced concrete core-wall was built up through the dam, to the top, so located that the line of the wall coincided with the water line of the reservoir. In this way the continuation of the core-wall was made to act as a retaining wall, and the finishing of the riprap on the face of the dam.

The notable feature of this construction and that of the Lyons dam, built by the same engineer, is not alone the use of steel piling, but the extreme thinness of the core-wall, which is but 10 inches thick throughout. The wall is therefore merely a curtain, or diaphragm, of no stability unsupported, but having a certain amount of flexibility. It will therefore accommodate itself to unevenness of settlement in the embankment on either side with less danger of serious rupture than a rigid wall would undergo.

This use of a flexible, reinforced concrete core-wall or diaphragm for earth dams was first suggested by Mr. H. M. Wilson, M. Am. Soc. C. E.,* who wrote that in his opinion "such a diaphragm would be impervious, tough and flexible if not too thick," and suggested a thickness of 4 to 6 inches throughout, "firmly anchored in cement masonry at the foundation and up the abutment."

The only example of the use of cast-iron sheet piles as a foundation for a dam on record is that of the Assiout dam, Egypt, described in Chapter III on Masonry Dams.

The steel-plate diaphragm of the Chollas Heights dam of San Diego, Cal., heretofore described, is another notable instance of the use of a flexible diaphragm as a core-wall.

These are in striking contrast to the heavy masonry and concrete core-walls built in earth dams in the Eastern States, to which British engineers so seriously object. Mr. Reginald E. Middleton, M. Inst. C. E., says on this subject: †

"Where masonry alone is used, should there be any movement in the bank, the wall will be fractured, serious leakage may take place and the dam may be so much weakened thereby that its unforeseen destruction may result, and it is exceedingly difficult to make a thin or even a thick masonry wall perfectly water-tight."

British engineers adhere to clay puddle core-walls, and are not to be convinced that it can be considered good practice to attempt to support a rigid material such as masonry with a plastic material such as earthwork. The introduction of a thin, strong diaphgram, having a certain amount of flexibility and capable of yielding to pressure without injury, would seem to solve the objections raised toward the standard American type of core-wall as hitherto established, although as yet not sufficiently tested to establish their reliability.

The recognition of the desirability of building core-walls with flexibility combined with water-tightness, led to a suggestion by the editor of *Engineering News* ‡ that the core-walls of earth dams be built of brick, 16 inches thick, laid in hot asphaltum, in such a way as to hold a center diaphragm of pure bitumen between walls of brick. In this situation,

* *Engineering News*, July 16, 1903.

† *Engineering Record*, vol. 54, page 304.

‡ *Engineering News*, February 20, 1902.

in the heart of the dam, the asphaltum would be forever protected from oxidation or volatilization, and its water-tight properties preserved indefinitely. At the same time it could yield to uneven settlement without injury. The suggestion does not appear to have been adopted as yet, as far as the author is aware.

The editor of that journal * also suggests the use of stone macadam as a substitute for more expensive concrete in core-walls for earth dams. By this plan the macadam would consist of crushed rock, with an extra quantity of fine rock dust, to be spread in layers, thoroughly wetted and rolled or tamped in position, the finer dust to be obtained by recrushing and rebolting and passing through rolls a portion of the medium product of the rock crusher, in order to fill the voids in the rock. The editor calls attention to the high cementation value possessed by the dust of limestone, felsite, and even quartzite when saturated and pressed together under heavy rollers.

This suggestion would appear to be quite as applicable to the building of a core or facing for a rock-fill dam, in localities where cement is costly and difficult to obtain.

Special attention of engineers throughout the world was called to the discoveries made by a board of engineers called in 1901 to report upon the safety of the proposed earth extension of the New Croton dam. This board consisted of three prominent members of the American Society of Civil Engineers, Messrs. J. J. R. Croes, Edwin F. Smith, and Elnathan Sweet. Under their direction borings were made in a number of high earthen dams with masonry and concrete core-walls, at right angles to the axis, and at such intervals as to determine that in almost every case there was a continuous water-plane extending from the water surface of the reservoir to the core-wall, and on the down-stream side to the lower toe, having an inclination of 17% to 20% and indicating that the dams were saturated below this plane. The inference was plain that the core-walls were not water-tight and not effective in preventing water from passing through the dam. Their stability therefore depends in little or no degree upon the core-wall, but rather upon the compactness of the earth and the fineness of the particles composing the embankment, through the medium of which the movement of water on the plane of saturation is so exceedingly slow as to have no power to remove any particles from the dam.

The result of the investigation by the board was to recommend that the proposed earth section of the dam, which required a masonry core-wall of over 180 feet maximum height, be substituted by a solid masonry dam. These findings were generally approved by the engineering profession and the change was made.

* *Engineering News*, June 25, 1903.

If a concrete core-wall is not water-tight its only function in a dam must be as a stop against the ravages of burrowing animals. For this purpose it is customary with English engineers to spread a layer of broken stone over the outer slope, and then put six inches of soil above it. This simple treatment is found quite effective.

As noted in Chapter I on Rock-fill Dams, a core-wall of reinforced concrete but six inches thick at the top, 12 inches at bottom, 24 feet high, was built into the Avalon dam, New Mexico, in the reconstruction of the dam by B. M. Hall, engineer for the United States Reclamation Service. In an article written on this subject * Mr. Hall says:

"It is a well recognized fact that a durable core-wall or diaphragm of some kind should be placed in every earth dam to prevent burrowing animals from making tunnels through the dam that will enlarge rapidly as soon as a stream of water begins running through, and to prevent definite water channels through the dam from any other cause. So far as the writer is informed, no advocate of core-walls has ever claimed that even the heaviest walls in use are intended to add anything to the strength of the earth dam, or that the section of an earth dam could be safely reduced on account of having a masonry or concrete core-wall in it. This being the case, it is evident that a diaphragm made of imperishable materials, and having a certain amount of flexibility, will fulfill all the requirements of the ordinary core-wall, and will have the additional advantage of being able to accommodate itself to slight inequalities of settlement in the dam."

He states that he has designed an earth dam for the proposed Carite reservoir in the island of Porto Rico, in which it is planned to use a vertical diaphragm of concrete 6 inches thick, reinforced with ½-inch steel rods spaced one foot apart both vertically and horizontally. The dam will be 92 feet high and the diaphragm will extend from the bedrock to the crest of the dam, 12 feet above the high water level of the reservoir. The earth will be puddled against the wall on each side as it is built up.

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* *Engineering News*, February 6, 1908, "Reinforced Concrete Diaphragm for Earth Dams," by B. M. Hall, M. Am. Soc. C. E.

CHAPTER V.

STEEL DAMS.

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, 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, $\frac{3}{8}$ 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

FIG. 294.—ASH FORK, ARIZONA, STEEL DAM, VIEW OF STEEL CONSTRUCTION FROM LOWER SIDE.

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.

Considerable difficulty was experienced after the reservoir was just filled in making a water-tight connection between the steel structure and the concrete on bottom and sides, although no leakage occurred through the joints in the steel portion of the dam. This was apparently due to the expansion and contraction of the steel exposed to the sun. Even after adding several feet of concrete to either side of the base of the steel structure the leakage was still annoying. Finally in 1900 a heavy coating of asphalt mastic was applied, and the dam has made water-tight.

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. 294 and 295 give an excellent general idea of the construction. Fig. 296 shows a portion of the reservoir, and represents clearly the igneous rock formation of the canyon in which it is located.

FIG. 295.—ASH FORK, STEEL DAM, SHOWING FRAME READY TO RECEIVE PLATES.

FIG. 296.—ASH FORK RESERVOIR.

The Redridge Dam, Michigan.—Four years after the erection of the first steel dam in Arizona, a second was constructed across the Salmon Trout river at Redridge, Mich., for the development of power in the copper regions for mining purposes, by the Atlantic Mining Co. and the Baltic Mining Co., and furnishes water to stamp mills. It is located only a few hundred feet from Lake Superior, and its crest is but 84 feet above the normal lake level. The dam is of much larger dimensions than the Ash Fork dam, although designed on the same general plan, with the important difference that it has a concrete base throughout, to which the steel structure is anchored. The proportions are such that at any section of the dam the resultant of all pressures with full reservoir falls within the middle third of the concrete base. This base is built in a trench in bed-rock, two to four feet deep.

The dam is 1006 feet long, the steel portion being 464 feet long between the abutments, in the center of the structure, which is continued at the ends by earth embankments with masonry core-walls. The maximum height is 74 feet. There are 8000 cubic yards of concrete in the main

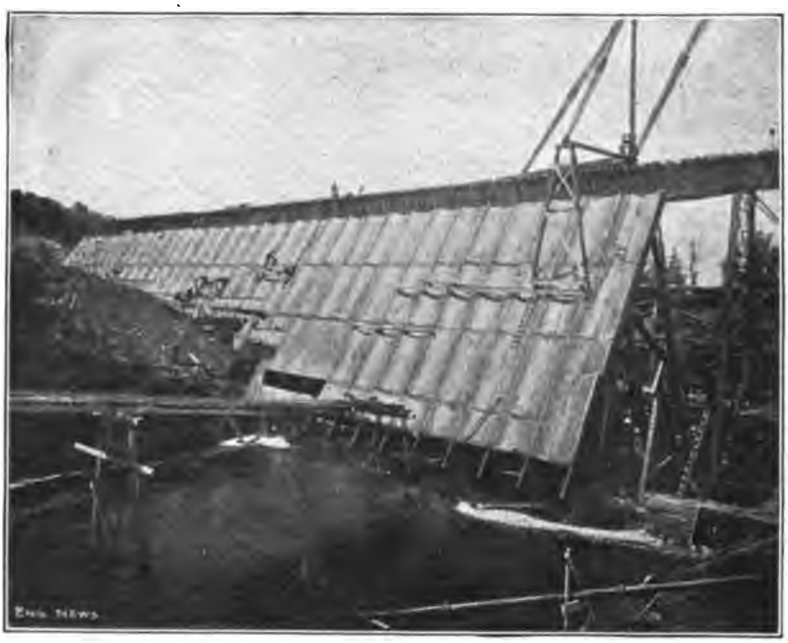


FIG. 297.—REDRIDGE STEEL DAM.

dam, and 2000 cubic yards in the abutments and core-walls. The concrete base is 64 feet thick, and has somewhat of an ogee form, with a depth of 14 feet at the lower toe, and 38 feet maximum height. The up-stream side is inclined to conform to the batter of the steel frame and plates.

The steel portion of the dam consists of a series of steel bents of A-frames 8 feet apart, to which is riveted a facing of steel plates, curved with the concave side up-stream. The face is inclined at an angle of 55° 58′, while the apex angle between the face and the inclined columns or struts is 56° 10′. The plates are ⅜ inch thick, 16 feet high, and having on each side a flat strip of 5⅞ inch wide, which is riveted to the flange of the I-beams. These beams, forming the face members are 15 to 24 inches in depth. Below the bottom course of curved plates is a course of flat plates, the space between being closed by a segmental inclined diaphragm. The joining with the concrete base is made with the flat plates.

The dam forms a reservoir of 150 acres, having a capacity of 600,000,000 gallons (1830 acre-feet).

The dam was designed by J. F. Jackson, M. Am. Soc. C. E., engineer of the contracting firm that built the dam, the Wisconsin Bridge and Iron

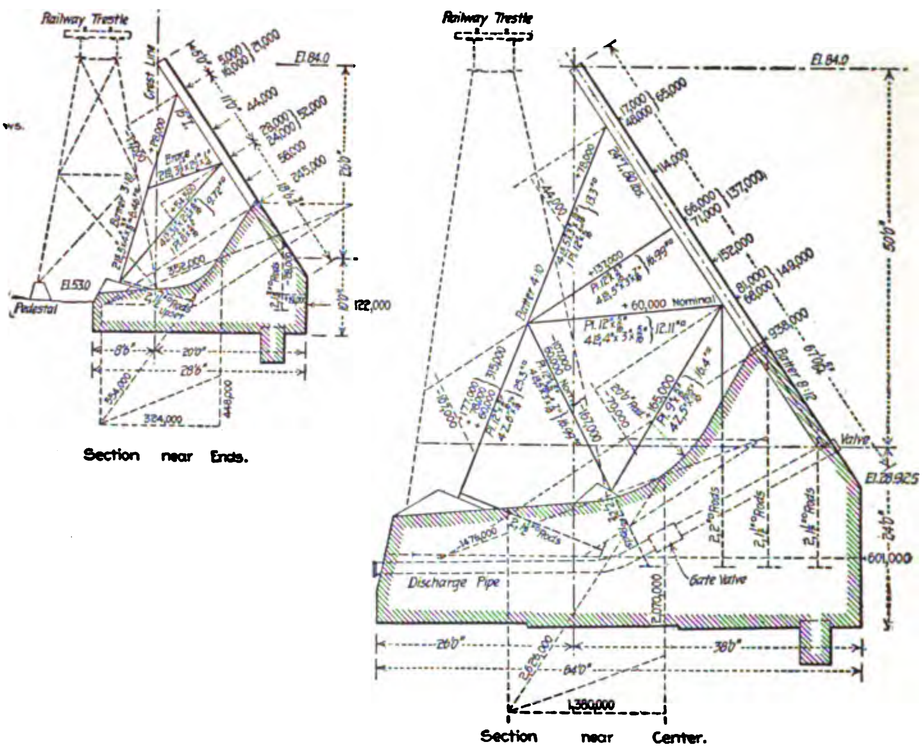


FIG. 298.—REDRIDGE STEEL DAM.

Co., builders of the Ashfork dam. F. Foster Crowell, M. Am. Soc. C. E., acted as consulting engineer.

An interesting feature of the construction was the method employed to fortify the bedrock in front of the dam and cut off percolation underneath it.

A line of drill holes, 2 inches diameter, 10 feet deep, and spaced 7 inches apart, was put down into the rock on a line 20 feet above the toe of the dam. Cement grout was forced into these holes under an air pressure of 90 pounds per square inch. The rock floor between the line of holes

Fig. 299.—Hause

—Hauser Lake Dam, Montana. [To face page 459.]

and the dam was then cleared off, covered with a concrete pavement, and that in turn by a bank of puddle clay.

The work is fully described in *Engineering News*, August 15, 1901. The dam was begun in June, 1900, and put into service October 28, 1901.

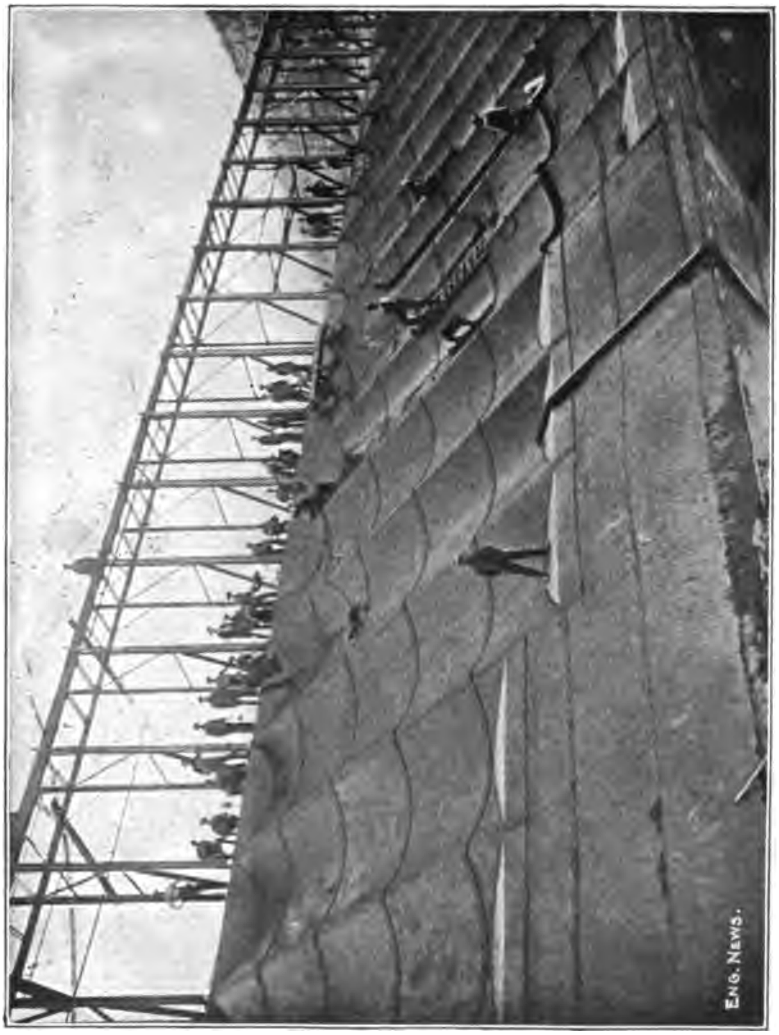


FIG. 300.—HAUSER LAKE DAM, MONTANA.

Hauser Lake Dam, Helena, Mont.—The third and highest steel dam yet erected was completed in March, 1907, by the Wisconsin Bridge and Iron Co., for the Helena Power and Transmission Co. The dam is located across the Missouri River, about 15 miles from Helena, and 16 miles below the Canyon Ferry timber crib dam belonging to the same company. It

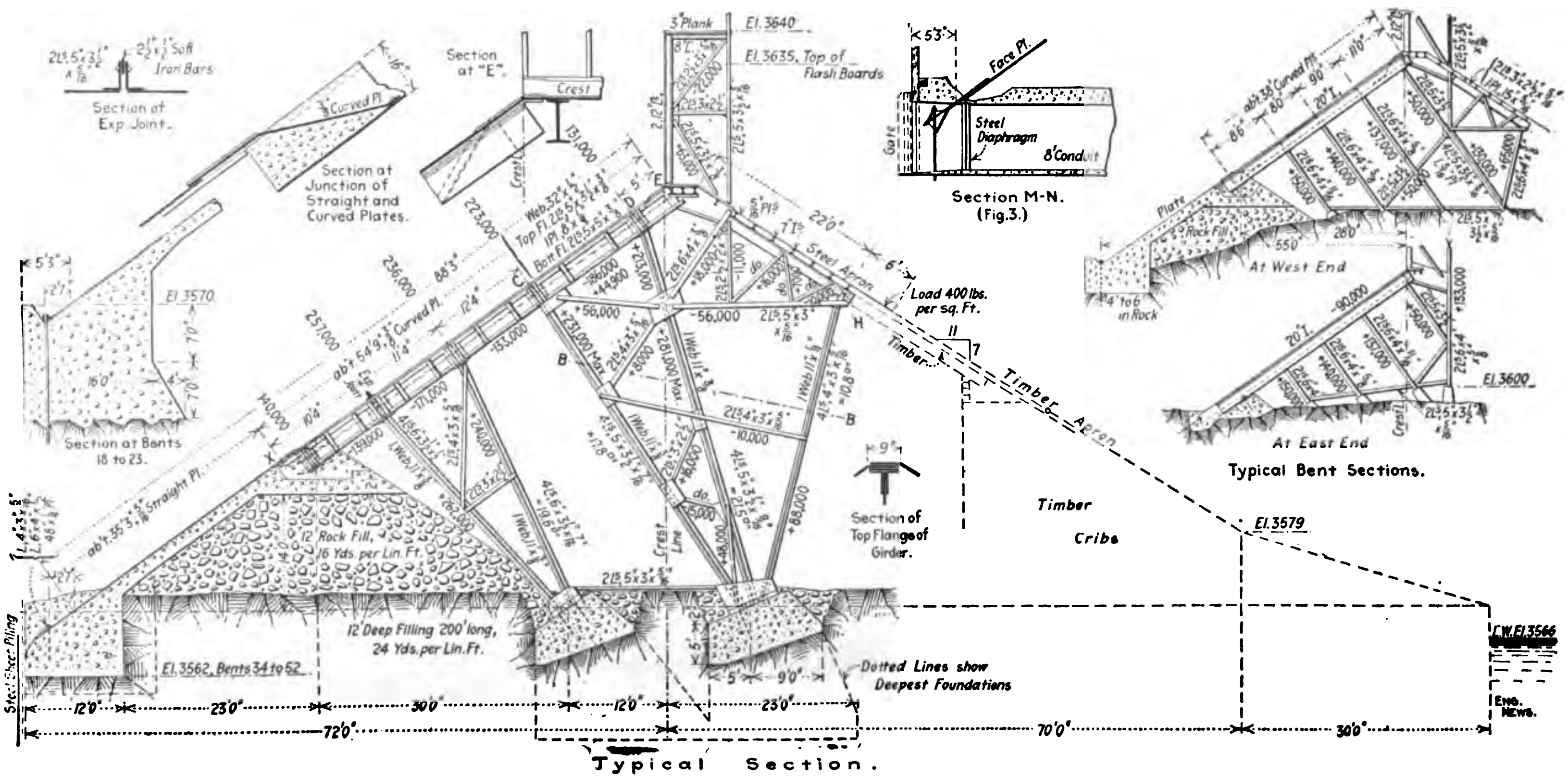


FIG. 301.—HAUSER LAKE DAM, MONTANA.

FIG. 302.—COMPLETED HAUSER LAKE DAM NEAR HELENA, MONT.

FIG. 303.—HAUSER LAKE DAM, MONTANA, NEARING COMPLETION.

is 630 feet long and has a maximum height of 81 feet. The dam has an inclination of 1.5 on 1. It was designed by Mr. J. F. Jackson, Assoc. M. Am. Soc. C. E., and built of steel in a similar manner to the Ash Fork and Redridge steel dams. A portion of the dam was founded on solid rock.

FIG. 304.—VIEW OF THE WRECKED HAUSER LAKE DAM, IN APRIL, 1908.

The remaining portion for 300 feet, where gravel was found to an unknown depth, was founded on steel sheet-piles of the Friestedt pattern, 35 feet long, driven at the up-stream toe of the dam. The steel plates covering the dam were connected with the top of the sheet piles, and an upper layer of concrete covers the toe plate and the tops of the sheet piling. The dam

is required to pass floods that may reach 60,000 sec.-feet, and for this purpose a spillway, 500 feet long, 13 feet deep, is placed in the center, with a timber apron, founded on stone filled cribs on the down-stream side to receive the over-pour. Wooden flash boards are arranged to be

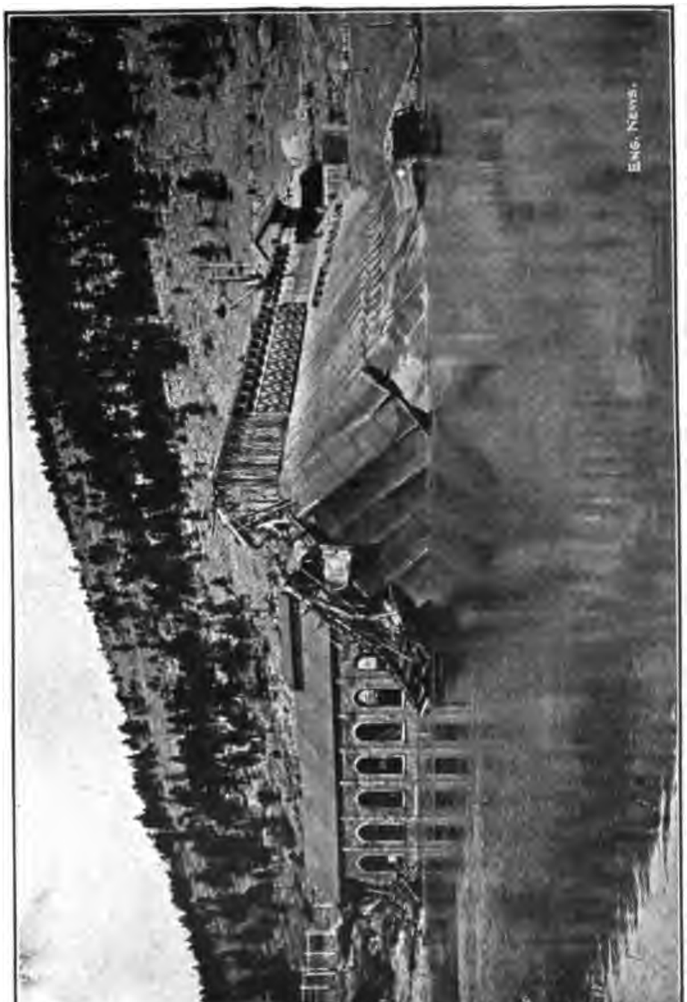


FIG. 305.—HAUSER LAKE DAM AS IT APPEARED APRIL 15, 1908.

placed in this spillway section after the high-water season is past. The low-water flow, amounting to 3000 sec.-feet, was carried during construction by six lines of 8-foot steel pipes, about 100 feet long, embedded in concrete. The steel work was mostly erected between July and November, 1906.

The reservoir above the dam, called Hauser Lake, is 16 miles long, extending to the foot of the Canyon Ferry dam. Mr. Wm. De la Barre, M. Am. Soc. C. E., acted as consulting engineer.

Failure of the Hauser Lake Dam, Montana.—The new steel dam built on the Missouri river, about 18 miles from Helena, Mont., described on page 499, and but recently completed, was partially destroyed on April 14, 1908, subsequent to the preparation of the description, and a section about 300 feet wide in the center of the dam was washed out. The failure, as described in *Engineering News*, April 30, 1908, with photographs of the ruined structure, was caused by water undermining the rubble masonry fill and the steel sheet-piling at the up-stream toe of the dam. This piling had been used over a portion of the channel where bed-rock could not be reached and where the gravel of the river-bed is of great depth. The maximum depth reached by the piling driven in this gravel was 35 feet. The concrete placed over the top of the piling, which formed the junction between the expansion joint of the steel work and the sheet piling, is said to have been placed in a depth of 10 feet or more of water, so that its quality may have been very poor. The total damage caused by the break is estimated at $250,000 to $300,000, requiring six months time to make the necessary repairs. Figs. 302 and 303 illustrate the dam as completed, and just prior to completion. The wreck of the dam is clearly shown by Figs. 304 and 305. These interesting cuts have been kindly loaned by *Engineering News*.

A contract for the reconstruction of the dam has been let to the Stone & Webster Engineering Corporation, by whom borings have been made to bedrock, which was located at a depth of 55 feet below normal water level. The plan to be adopted for the restoration of the dam has not been announced.

CHAPTER VI.

REINFORCED CONCRETE DAMS.

The design of the structural steel dams described in the preceding chapter is that of a triangle with the up-stream face so flatly inclined that the water-pressure is made to give increased stabilitv by its weight, and this basic principle has been the leading feature in the development of dams of reinforced concrete, which were first introduced in the Eastern States about the year 1902 by the Ambursen Hydraulic Construction Company of Boston, who hold patents on the plans and methods employed.

No less than 39 dams, from 10 to 80 feet high, and from 60 to 1200 feet long, have been erected in this short interval, many of which have been described in detail in the engineering periodicals and have attracted marked attention throughout the engineering world. No failures have yet been recorded. The list of structures erected includes the following: Sheldon Springs and Woodstock, Vt.; Wilton and Goffston, N. H.; Newton, Russell, Gloucester and Pittsfield, Mass.; Ellsworth, Me.; Huntingdon and Ricketts, Penn.; Ilchester, Md.; Danville, Ky.; Fenelon Falls, Ontario; Woonsocket, R. I.; Theresa, Schuylerville, Ramapo, Grays, Colliers, and Horseshoe, N. Y., Dellwood, Illinois; Douglas, Wyoming and many others.

The designs for these dams are highly specialized and exhibit an intelligent conception of the problems involved. They also illustrate in a striking way the manifold uses and flexible adaptability of the new building material which is so rapidly entering into all forms of construction at the present day.

The basic design is that of the original type of timber crib dam of triangular form and long low back slope, the old so-called "horse dam," from which it differs mainly in the substitution of imperishable and watertight concrete for the wood used by our forefathers.

The valuable principle adhered to throughout is that the vertical component of the static pressure shall be made to pin the dam more firmly down to its foundation, whereas with the usual type of gravity masonry or concrete dam, where the up-stream face is generally vertical, or but slightly inclined, the pressure is exerted horizontally to overturn the dam, which must therefore be made sufficiently massive to resist this force by its weight alone.

A properly designed gravity dam exerts a pressure on its foundation ranging theoretically from zero at the up-stream edge to a maximum at its down-stream toe, which maximum is kept at or just within the safe limit of crushing for masonry, usually on a safety factor of 2 or 2.5. The diagram of foundation pressure is therefore a triangle.

In the reinforced concrete dam, the slope of the "deck" or water-face may be so related to the weight and base width of the dam that the pressure on the foundation is controlled at the will of the designer, and it is said that the factor of safety in all its relations is never made less than 5.

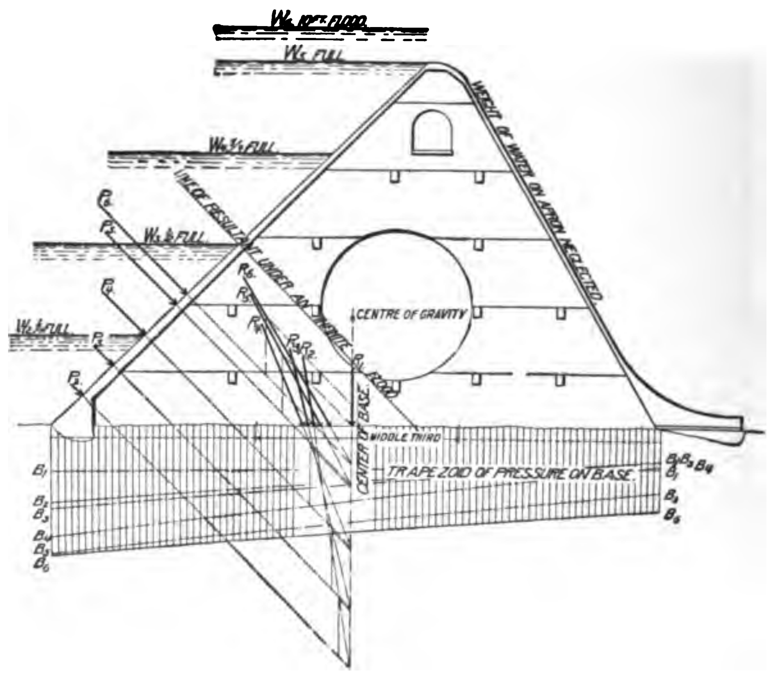


Fig. 306.

Usually the proportions are such that the diagram of pressure is nearly a rectangle. In other words, the pressure is uniformly distributed over the whole foundation, with any excess pressure thrown slightly towards the up-stream angle instead of being concentrated at the down-stream toe. This arises from the fact that the resultant of the water pressure and weight of the dam can be held at or a little above the center of the base instead of passing down to the lower edge of the middle third.

In diagram, Fig. 306, the movements of this resultant and the pressures on the base may be traced. As the water rises back of the dam, the resultant advances slightly up-stream from the center, until it reaches to about three-fourths full height, when it returns again nearly to the center with the dam under its calculated flood load. The angle of the resultant also is always kept within the limit of the angle of friction, thus preventing any tendency of the dam to move on its base.

Fig. 307 shows in perspective and section the form adapted to low heads and hard foundations. It consists of a series of piers or buttresses, spaced 12 to 18 feet apart on centers, and covered with a deck of concrete, reinforced between the different bays as a beam, in which the tension members of steel are placed near to the under side, leaving from ten inches to several feet of concrete between the steel bars and the water. The thickness of the concrete sheet necessarily increased from top to bottom with the increase of head. But little reinforcement is used in the piers, except at

Fig. 307.

the edges and around the openings which are usually made through them, either for convenient passages or for the saving of material.

The concrete in the deck is mixed as rich as 1:2:4, usually with fine aggregates, and is poured into the forms in sloppy condition, which ensures a thorough coating of the steel with cement. Experience seems to show that water-tightness can best be insured by mixing the concrete very wet, which is becoming generally recognized and adopted on all modern concrete work.

One apparent advantage of this design is that the dam when founded on rock has no continuous base, and therefore cannot be threatened by upward lifting pressure of water that may find its way through seams in the rock.

Several of the dams have been built on gravel or other porous foundat on with a continous base of concrete over the gravel, protected by a curtain wall, or sheet-piling above and an apron below. The floor is pro-

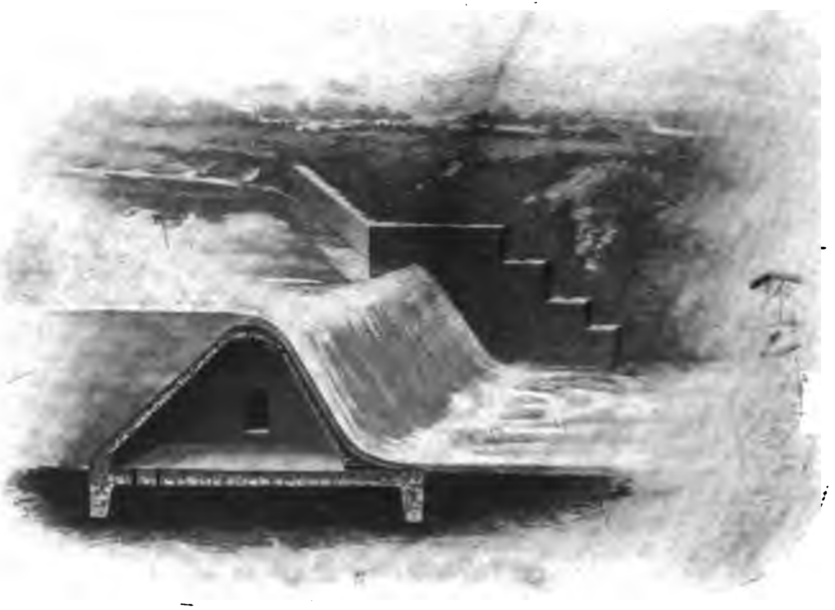


FIG. 308.

FIG. 309.

tected from the uplift of water pressure underneath by leaving numerous "weep-holes." These holes are shown in the perspective drawing of that type of construction, Fig. 308.

The design of these dams leaves them hollow, which has the advantage

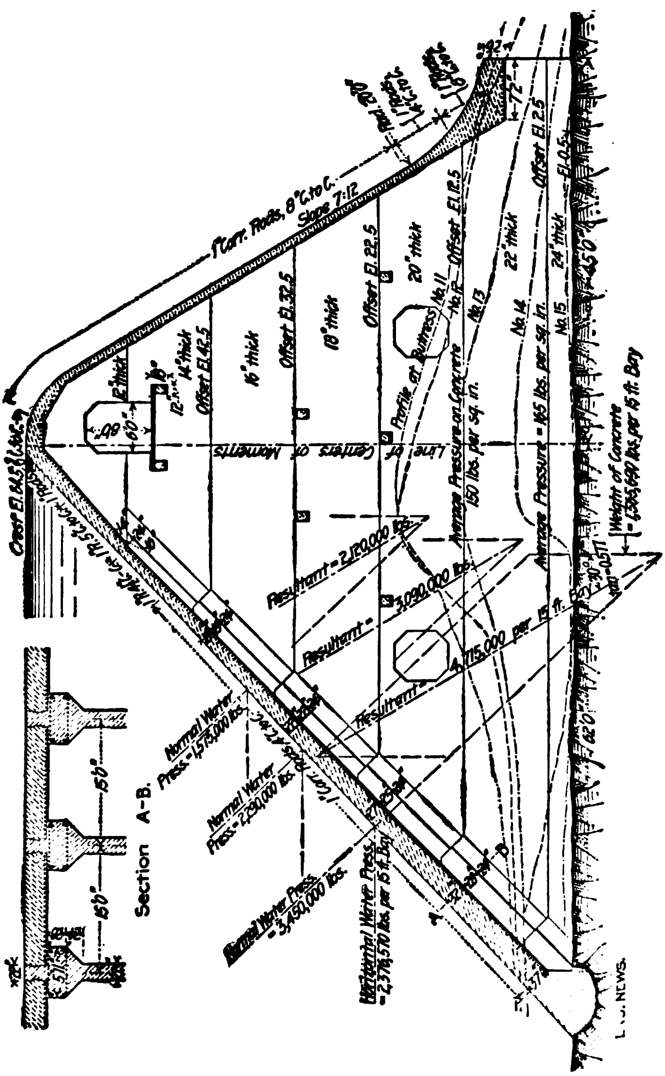


FIG. 310.

of permitting inspection of the interior. At the same time, the space can be utilized for handling flashboards, waste gates, log sluices, or movable crests from beneath safely and conveniently, and a passageway can be maintained through the interior of the structure from one side of the

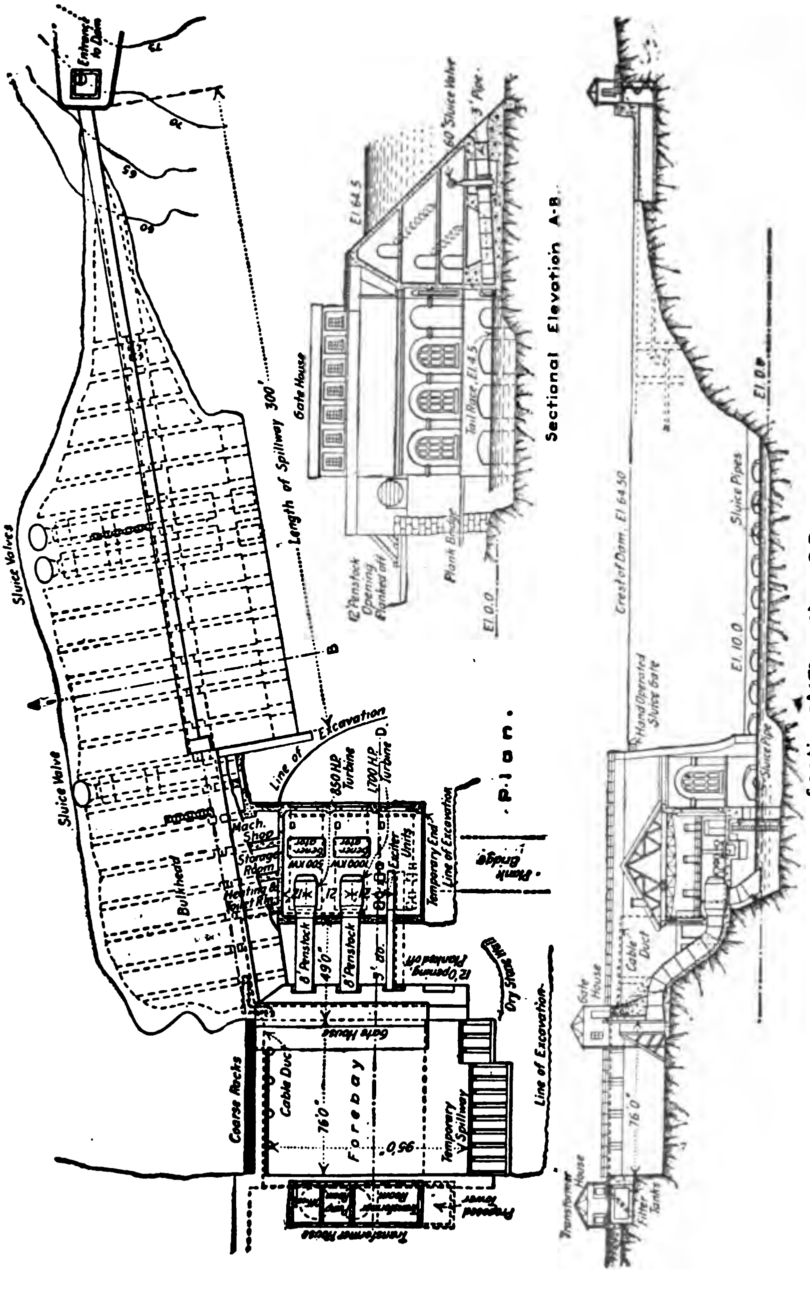


FIG. 311.—PLAN AND ELEVATION OF ELLSWORTH DAM.

river to the other, as a substitute for a foot-bridge over the stream. Such a passage is illustrated in Fig. 309.

In some of the later designs the interior passageway has even been increased to accommodate a highway, and in other cases it has been used as a runway for a traveling crane for picking up the machinery of a power house located in the interior of the structure.

The part of the dam first constructed in the bed of a flowing stream is the piers, and these can be built independently inside of caissons, so that the use of expensive cofferdams for the diversion of the entire stream may often be avoided. This is done by completing the structure above the water line, allowing the stream to flow uninterrupted between the piers. Subsequently the closure of the separate bays is made with concrete as simply as the process of putting in stop logs in a large canal headgate.

The Ellsworth Dam, Maine.—As an example of the latest form of this new type of construction, the dam built across the Union river at Ellsworth, Me., during 1907, completed in January, 1908, may be cited. This dam was built for the Bar Harbor and Union River Power Co., to form a reservoir of 71,000 acre-feet capacity, but chiefly to give head to a power-house located against the dam, where the first installation was for 4250 wheel H. P.

It is founded on granite, and the transverse profiles are very irregular, as shown in Fig. 305, which is a section through the rollway. The maximum height of the dam is 71.5 feet, in the bulkhead portion, back of the power-house. The rollway is 65 feet high. The total length of the dam is about 500 feet. The general plan, elevation and section of the structure are shown in Fig. 306. The space underneath the bulkhead and immediately in the rear of the power-house is utilized as a transformer-house, store-house, machine-shop, etc., while the power-house is approached from the town on the opposite side of the river by a tunnel beneath the low part of the crest and a passage at different levels entirely through the body of the dam. The structure is shown in Figs. 312 and 316.

The high tension wires for the power house pass through portholes shown in the picture just underneath the top of the dam to the right of the power-house.

Considering the height and length of the dam, the fact that it contains but 8000 cubic yards of concrete is striking. The work was begun the last of February, 1907, on the excavations of foundations and building of cofferdam. As there were 3000 cubic yards of hard rock to excavate the first concrete was not laid before June 9th, and the last put in place Nov. 14th. Evidently the design permits of remarkable rapidity of construction, and small amounts of material. The cost is not available for any of these structures, although they are said to compare favorably

Fig. 312.—The Ellsworth Dam and Power-house.

with the cost of dams of any other material and of other types, as must result from the smaller quantities required.

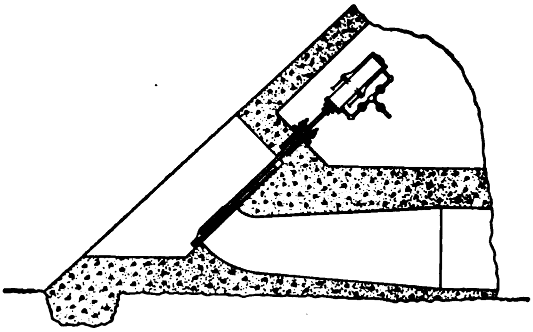


FIG. 313.

On dams of the height of the Ellsworth dam, the piers are expanded on their up-stream edges to form haunches or corbels reinforced with

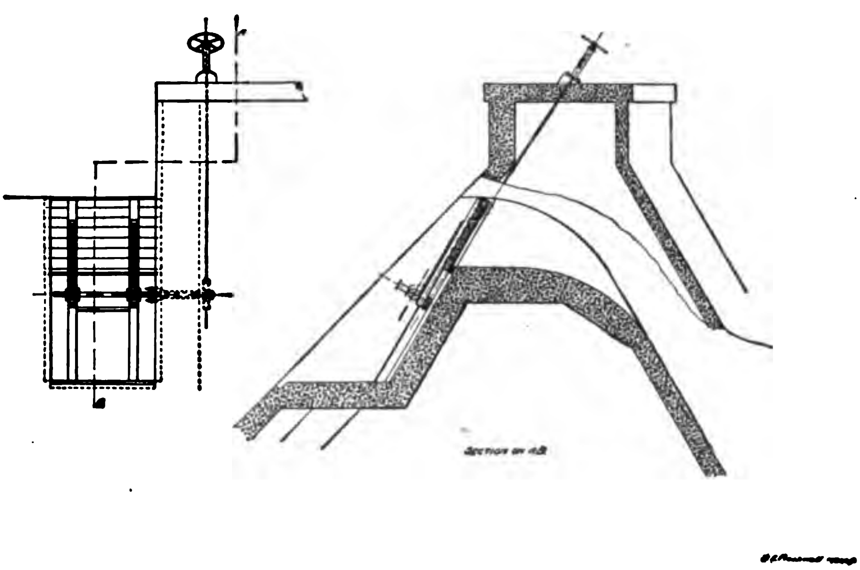


FIG. 314.

steel, to act as seats for the deck-slabs. This construction is illustrated on the margin of Fig. 310.

A detail of the waste gate adapted for movement by hydraulic power is shown in Fig. 313.

Fig. 314 shows a section of a log sluiceway, and its closing mechanism.

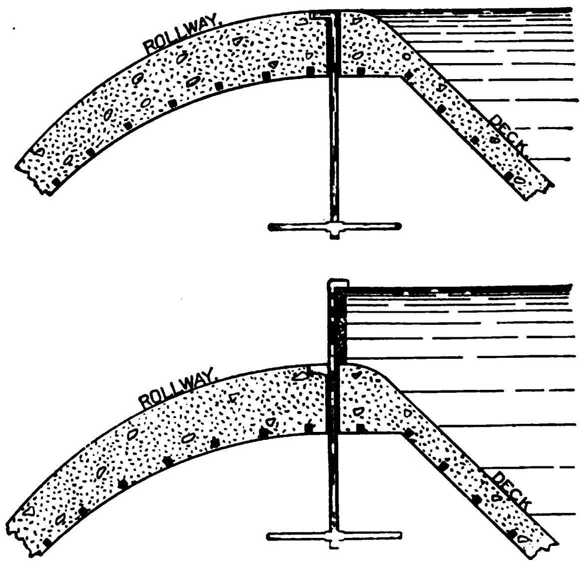


Fig. 315.

Fig. 316.—Ellsworth Dam, Maine.

Flashboards to increase the storage in low water are set and released by the device indicated in Fig. 315.

As will be observed the standards which clamp the boards in position may be withdrawn entirely into the interior, leaving the crest of the rollway entirely unobstructed for passage of floods.

The Patapsco Dam, Maryland.—This structure is 30 feet high, 200 feet long, built across the Patapsco river near Ilchester, Maryland. The entire width of the river was required for the overflow weir, so that it

FIG. 317.—PATAPSCO DAM, ILCHESTER, MARYLAND.

became necessary to utilize the room in the hollow interior for the powerhouse, in which three units of 500 H. P. were snugly installed. The dam is of the half-apron type, affording ample daylight on the downstream side. The cubic contents of this dam are but 2200 cubic yards. A general view is shown on Fig. 317.

Fig. 318 is a cross-section of the dam with its enclosed power-house, and Fig. 319 shows an interior view of the power house after completion.

This dam is of the lowest height admissible for a submerged powerhouse. Two dams of this submerged power-house type are being built, 70 feet high, affording ample room for installations of 5000 H. P. each, accommodating traveling cranes, transformer-rooms, switch-boards, etc.

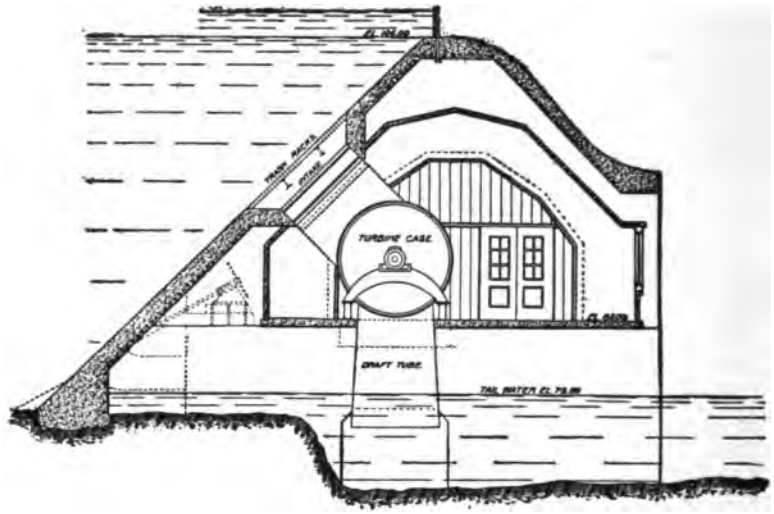


FIG. 318.—CROSS-SECTION OF PATAPSCO DAM AND POWER-HOUSE INSIDE.

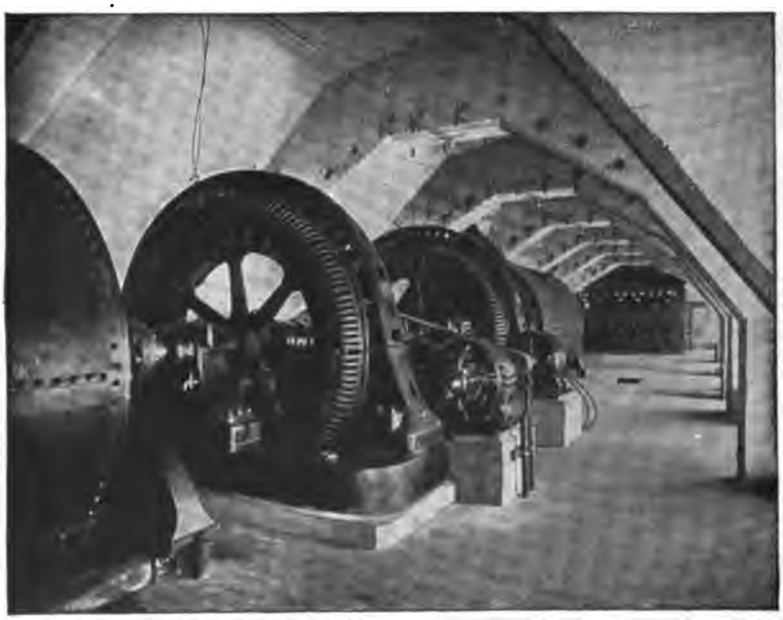


FIG. 319.—INTERIOR OF PATAPSCO SUBMERGED POWER-HOUSE.

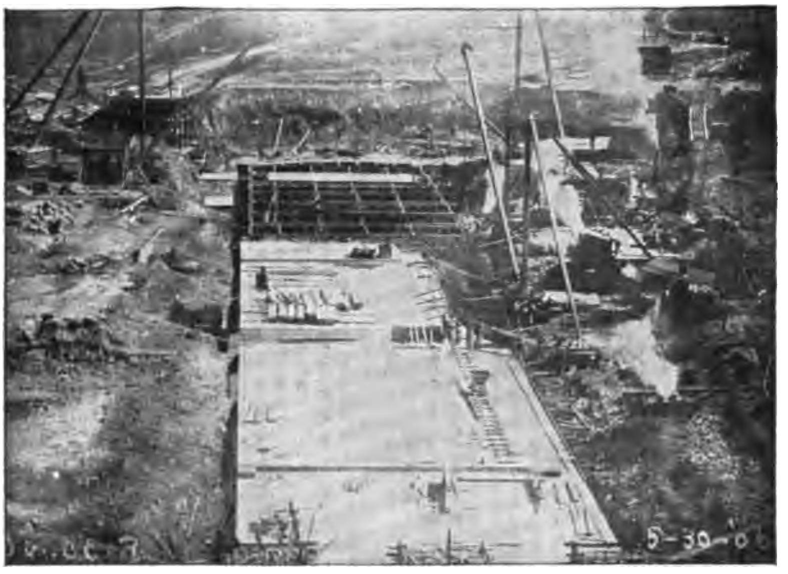


FIG. 320.—FLOOR CONSTRUCTION, JUNIATA DAM.

FIG. 321.—JUNIATA DAM, AND POWER-HOUSE PARTIALLY COMPLETED.

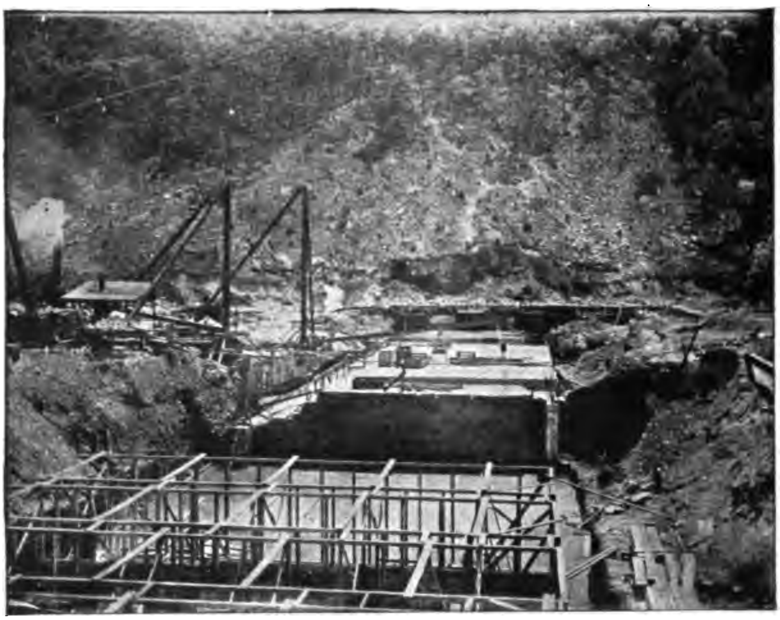


FIG. 322. —WHEEL PIT AND CUT-OFF WALLS, JUNIATA DAM.

FIG. 323.—VIEW OF COMPLETED JUNIATA DAM.

The Juniata Dam, Huntingdon, Pa.—This interesting dam is built on a foundation of porous gravel, underlaid by hardpan at a depth of about 18 feet. A trench was first sunk to the hardpan at each edge of the dam, and a reinforced concrete cut-off wall molded therein, intercepting the underflow. (See Fig. 322.)

The completed floor forming the base for the superstructure of the rollway is illustrated by the photograph, Fig. 320, on page 480.

The reinforcement of this floor is proportioned to distribute the pressure to an average of 1.3 tons per square foot.

Fig. 321 gives a clear view of the work at an advanced stage, with the river flowing through openings beyond the cofferdam, and Fig. 323 shows the completed dam and power-house. The dam in the rollway section is 28 feet high and 460 feet long. It contains 6400 cubic yards of concrete, including abutments and bulkheads.

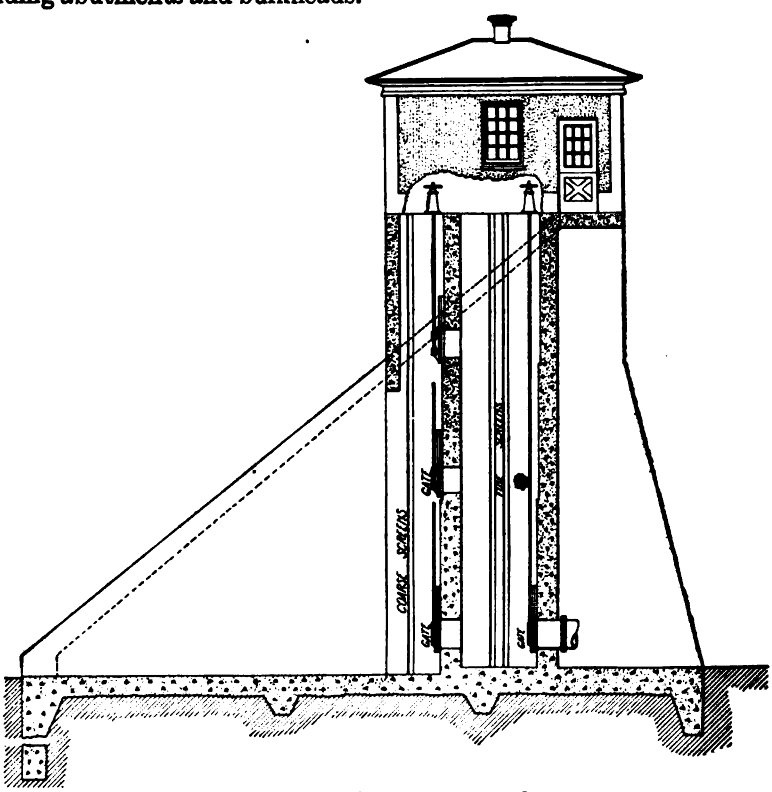


FIG. 324.—SECTION OF PITTSFIELD DAM, SHOWING GATE-HOUSE CONTAINED.

The Pittsfield Dam, Mass.—This structure, 42 feet high, 465 feet long, containing 3950 cubic yards of concrete, was begun Sept. 1, 1907, and completed March 1, 1908, a total of six months. It is founded on gravel, underlaid at a depth of 12 feet with dense yellow clay. Cut-off walls at each edge extend down 3 feet into the clay at bottom and sides. The gate-house is incorporated with the dam, utilizing the space between two piers for that purpose. Fig. 324 is a cross-section through the gate-house.

The longitudinal section, Fig. 325, shows the footings adapted to the hillside, and soft foundation. The completed dam is shown in Fig. 326.

The work was carried on continuously throughout freezing weather, when the thermoneter reached a minimum of 12 degrees below zero, by heating the materials, and by using "salamanders" in the bays beneath the deck, for which the hollow dam construction was favorable. There is said to be no discernable difference in the quality of the concrete laid in the winter months and that which was placed in moderate weather.

A dam of this type has been designed for construction during 1908, which is to be 115 feet high, 1,300 feet long, and contains about 85,000 cubic

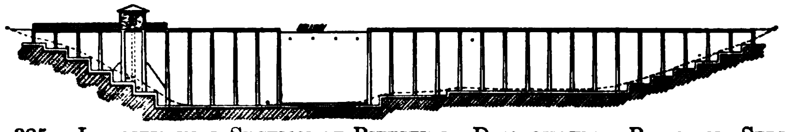


FIG. 325.—LONGITUDINAL SECTION OF PITTSFIELD DAM, SHOWING PIERS AND STEPPED FOOTINGS ON SLOPES.

yards including the power-house. Floods approximating 40,000 second-feet are to be cared for without variation of the working level of the water by a series of waste gates between the several bays, operated by hydraulic lifts, and by a movable crest on the rollway.

A section through the bulkhead and power-house is shown in Fig. 328, representing all essential details clearly. Fig. 327 is a longitudinal section of the dam.

Another dam planned for construction in 1908, is shown in section in Fig. 329.

This dam is to have an ultimate height of 120 feet, will be 520 feet long and contain 54,000 cubic yards of concrete, as shown by dotted lines in the section. The first construction will be limited to 80 feet, with a temporary wooden apron supported on steel beams on the down-stream side.

La Prele Dam.—This dam for irrigation purposes is now under construction near Douglas, Wyoming. It is 135 feet high and 250 feet long, and will contain about 15,000 cubic yards of concrete.

The limit of height to which dams of reinforced concrete may be safely built is as yet to be determined. Preliminary designs for a structure 315 feet high were computed by request of engineers in Government service, and it is stated that no insuperable difficulties were encountered, the unit stresses being kept the same as on smaller dams, and the ratio of material and costs holding about as in other cases.

Fig. 326.—The Pittsfield Dam as Completed.

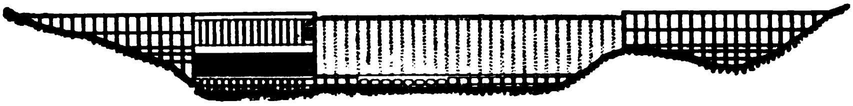


FIG. 327.

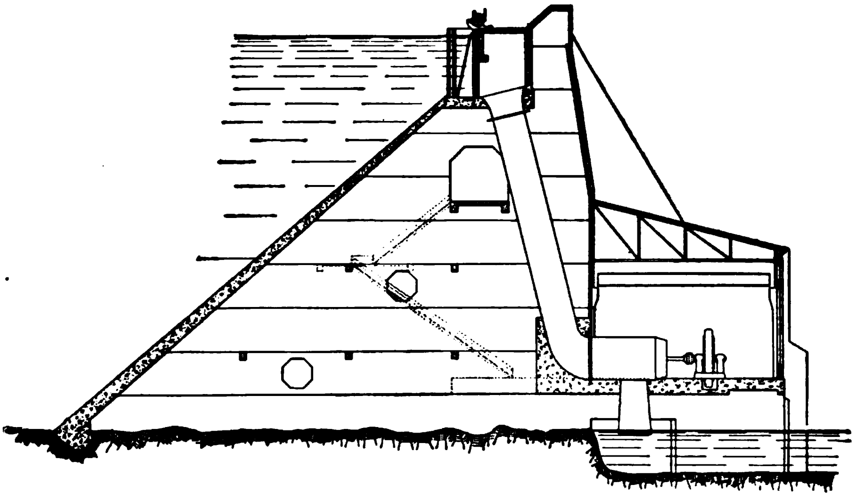


FIG. 328.—SECTION OF DAM 115 FEET HIGH, WITH POWER-HOUSE.

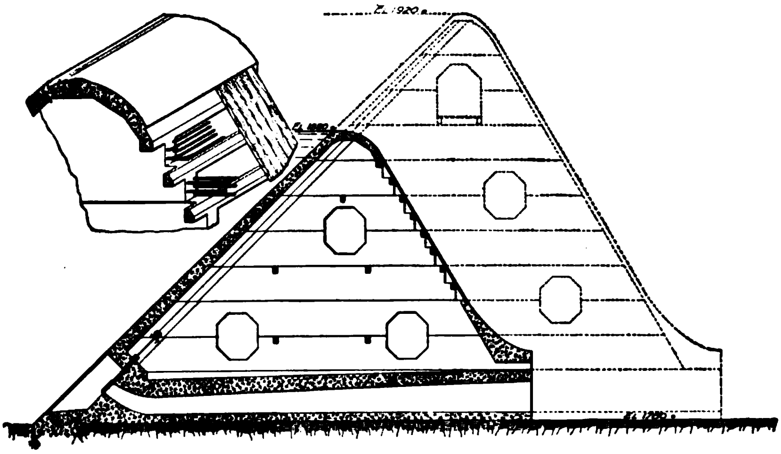


FIG. 329.—SECTION OF HIGH DAM, PLANNED FOR INCREASE OF HEIGHT IN FUTURE

CHAPTER VII.

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.

In the mountains, too, many natural basins are to be found, which have been formed by land slides, but more frequently by glacial moraine deposit, often of great depth and width, forming natural dikes of enormous magnitude. These basins are usually occupied by lakes, which can be converted into storage-reservoirs, either by restoring a portion of the originally higher dike which has been worn down by the channel of the outlet of the lake, and thus increase the capacity of the lake basin, or by the deepening of this channel by artificial cut, or by both these methods. Frequently these lakes are of very great depth, held back by dams built by Nature's hydraulic-fill methods, and suggesting the limitless heights to which such dams can be built, provided they be made of adequate dimensions. The author has seen a natural dam on a branch of the Umpqua river in Oregon, over 300 feet high, formed by a landslide from the adjacent sandstone cliff. The base of this dam was not over 3000 to 4000 feet. Floods of several thousand second-feet pass over the top of it every year, and it is practically water-tight, as it holds back a good sized lake. This is a natural rock-fill dam, composed of enormous blocks of stone, whose voids are filled with smaller stone and rock dust ground up in the process of falling.

Lake Como, in the Bitter Root valley, Montana, is an instance of a very deep natural lake basin formed by a terminal moraine of fine and coarse gravel, sand and glacial flour. This lake is to be converted into a reservoir for irrigation storage by the building of a hydraulic-fill dam across the outlet channel.

Twin Lakes Reservoir, Colorado.—Almost identical in geographical formation and glacial origin to that of Lake Como, Montana, are the Twin Lakes on the fork of the Arkansas river which heads in Mt. Massive, near Leadville. This was one of the reservoir-sites segregated and surveyed by the United States Government in 1892, as shown by the map (Fig. 330).

FIG. 331.—TWIN LAKES, COLORADO, MASONRY DAM OVER OUTLET, WITH EARTH BACKING, GATE-HOUSE, AND OUTLET CULVERTS.

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

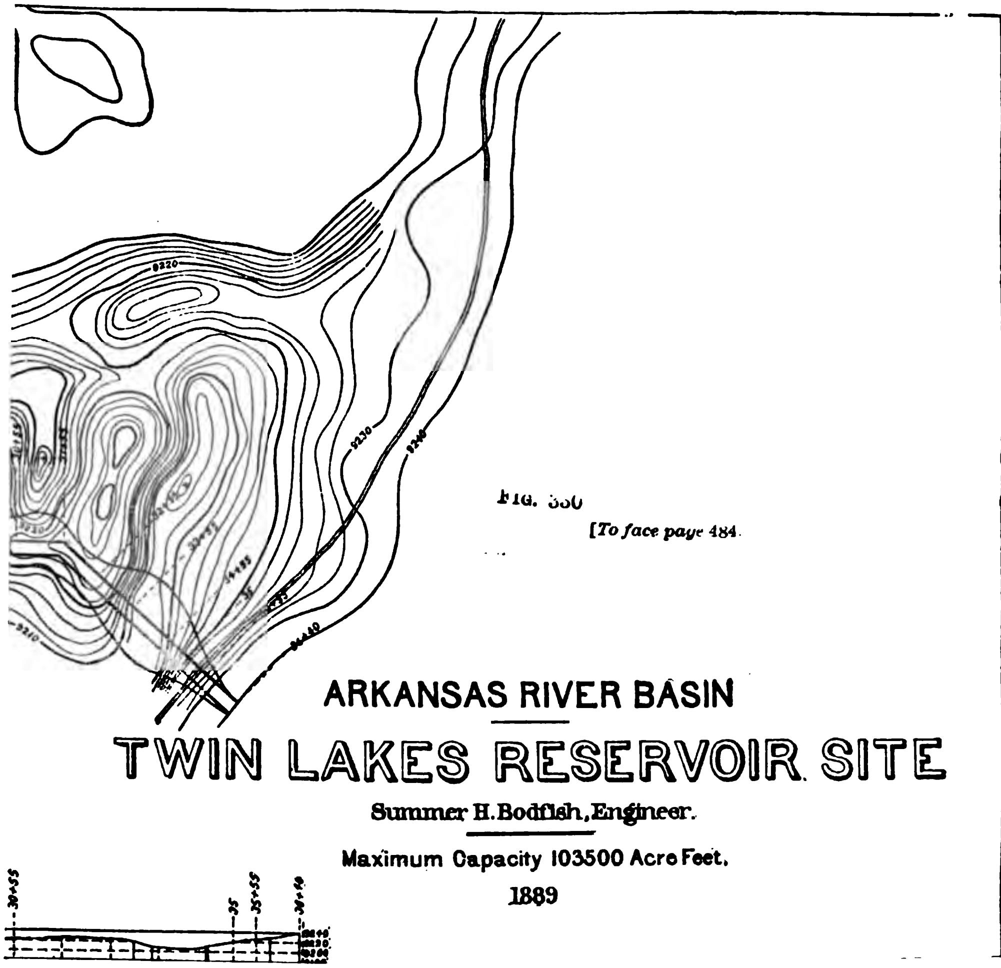


Fig. 330

[To face page 484.

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 comtemplated 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 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. 332.)

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.

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. 332, and the work has since been completed in complianc

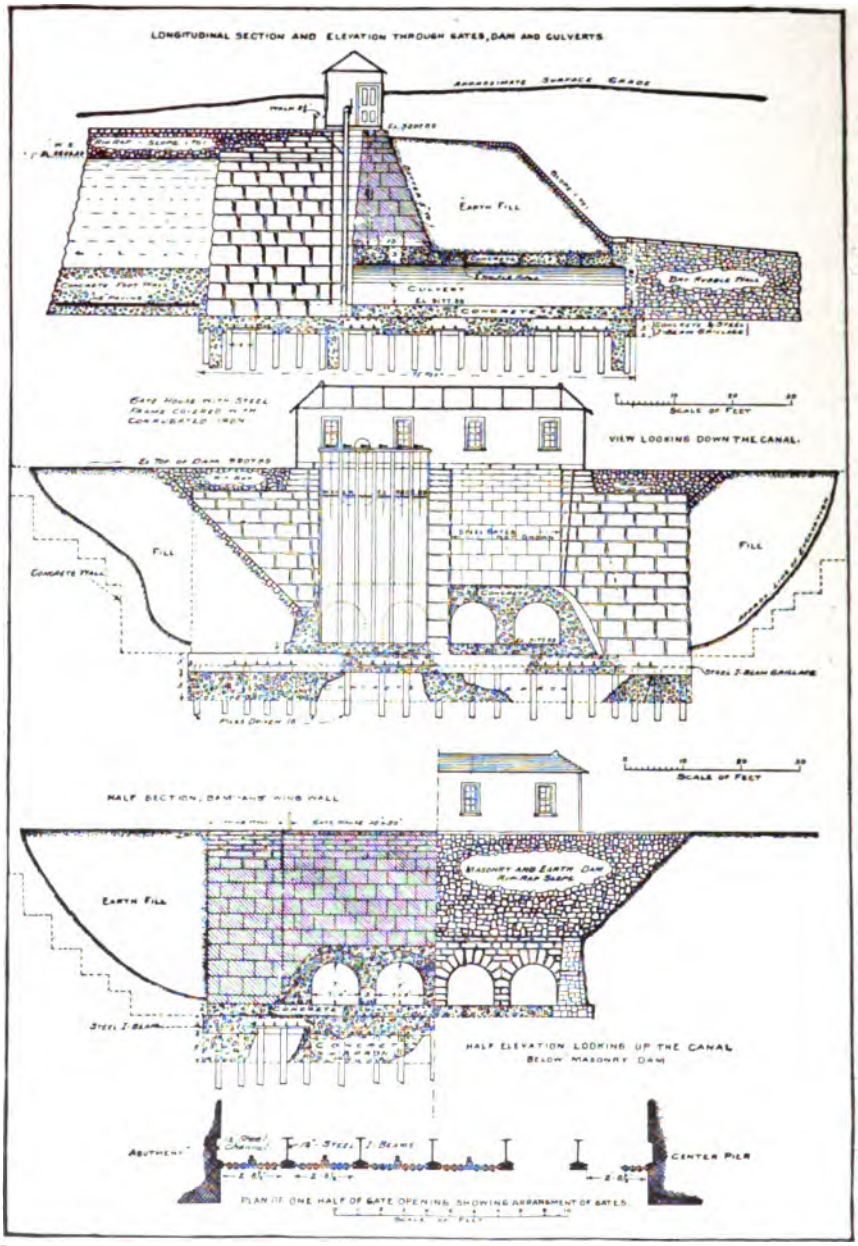


Fig. 332.—Details of Outlets for Twin Lakes, Colo. Designed for the Twin Lakes Reservoir Co. by J. D. Schuyler, Cons. Engr., and built by O. O. McReynolds, Chief Engineer.

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 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 overflowed into the Arkansas river was 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 Larimer 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.—Another one 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 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.

* 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 8, 1896. House Document No. 141, 55th Congress, 2d Session.

† *Ibid.*

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, whose name has been changed to that of The Arkansas Valley Sugar Beet and Irrigated Land 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.

Oregon Basin Reservoir, Wyoming.—One of the most capacious natural basin reservoirs in the West is that created by the Big Horn Basin Development Company near the town of Wiley, Wyo., for the irrigation of lands lying between the Shoshone and Grey Bull rivers. The reservoir is to be fed by a canal taking water from the south fork of the Shoshone river, about 15 miles above the Shoshone dam.

The reservoir has an area of 5106 acres, at an elevation of 5213 feet above the level of the sea. It is nearly circular, is 4 miles long, nearly 12 miles in circumference, and 100 feet in depth. Its capacity is 400,000 acre-feet.

The outlet is through a tunnel 4000 feet long between approaches, the water being controlled by gates at the bottom of a shaft 60 feet deep, located 250 feet below the head of the tunnel. A dike is required at the outlet gap over the tunnel 150 feet long, with 15 feet maximum depth of water against it. Mr. G. W. Zorn is chief engineer of the company, to whom the author is indebted for the information.

The Douglas Lake Reservoir, Colorado.—An earth dam across a natural depression on Dry Creek, five miles northwest of Fort Collins, Col., was built in 1902, an illustration of which is shown in Fig. 333.

The great cracks in the dam are the conspicuous feature of the picture, and are evidence of the lack of proper care and supervision in important works of this character. The dam contains about 150,000 cubic yards of earth, and forms a reservoir of 10,600 acre-feet capacity, sufficient to create great havoc in the country below it if it were suddenly released. The reservoir is filled by a ditch from the North Poudre river.

The Fossil Creek Reservoir, Colorado.—A part of the same system of reservoirs for irrigation storage is one built the same year, requiring an earth dam, 60 feet high, half a mile long, and containing 300,000 cubic yards. It forms a reservoir covering 750 acres, with a capacity of 12,600 acre-feet. Its estimated cost was $170,000. The feeder ditch from Cache la Poudre river is 4.5 miles long, with a capacity of 400 second-feet.

FIG. 333.—DOUGLAS LAKE DAM, COLORADO, SHOWING DANGEROUS SETTLEMENT CRACKS, DUE TO IMPROPER METHOD OF CONSTRUCTION.

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.

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

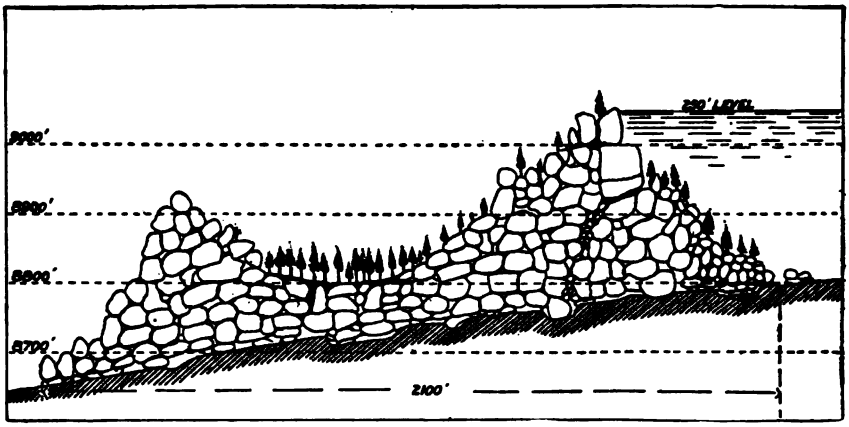


FIG. 334.—SKETCH OF LONGITUDINAL SECTION OF LOST CANYON NATURAL DAM

2100 feet in length, and is fairly well represented in a general way by the longitudinal and cross sections shown in Figs. 334 and 335. 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

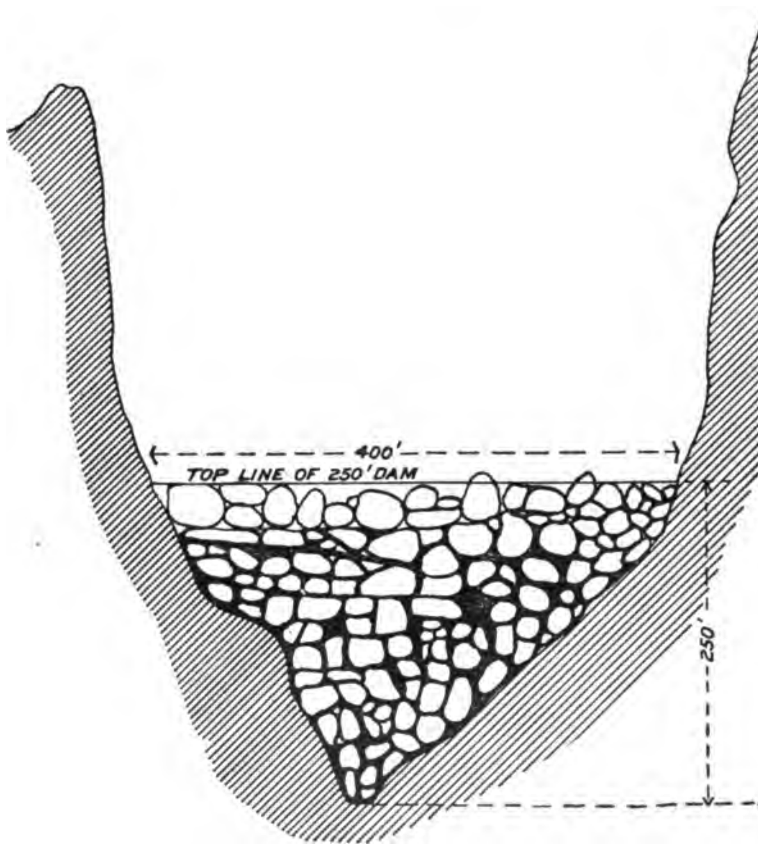


FIG. 335.—SKETCH OF CROSS-SECTION AT UPPER END OF LOST CANYON NATURAL DAM.

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.

ACKNOWLEDGMENTS.

Throughout the text of this work the author has endeavored to make due acknowledgment for information furnished and courtesies extended, in connection with each of the subjects treated. If any omissions have been made, their subsequent discovery will cause him sincere regret and mortification. To cover any such omissions in the first edition he begs to make a broad and general expression of gratitude for all aid extended in making the work more complete.

Special acknowledgments are due the Director of the U. S. Geological Survey, for the use of many of the cuts and illustrations which embellish the foregoing pages, and are indispensable to the proper understanding of the text.

CHAPTER VIII.

MISCELLANEOUS.

After completing the proof-reading of the revised edition presented in the foregoing chapters, a number of photographs were received which had been intended to be incorporated in the body of the work had they been available. As these illustrations, mostly of new or little known types, are particularly valuable and instructive, adding much to the illumination of the subject, they have been assembled in a concluding chapter of miscellany.

The author takes pleasure in acknowledging his indebtedness for these photographs and notes descriptive of them, as follows:

To Mr. Samuel Storrow, M. Am. Soc. C. E., for thirteen recent photographs of the Bowman Lake, the English, the Weaver Lake, and the Eureka Lake rock-fill dams in the mining regions of Northern California, referred to in the text; also a view of the Faucherie timber frame, triangular dam—a very old structure still in service—and a late picture of the Lake Frances hydraulic-fill dam, as it appears after completion. Many of these dams are remotely situated in the Sierra Nevada mountains and not readily visited or photographed. The views supplied by Mr. Storrow have been taken in the course of his professional work, and his notes upon the construction of these curious old dams of the mining-day type of temporary structure, have been kindly placed at the author's disposal. The obligation is still further increased by the fourteen pictures of four Mexican masonry dams, most of which are quite new to the world at large, but one of them having been illustrated in the first edition. These fourteen pictures were taken by Mr. Storrow on a tour of Mexico with a party of mining engineers in November, 1901.

The author is under obligations to Messrs. Wiley & Lewis, contractors, for the interesting pictures of the hydraulic-sluicing operations which are transforming the topography of the city of Seattle, Washington, by deep excavations and high embankments.

Fig. 336.—General View of the Bowman Lake Rock-fill Dam, California, showing character of Surrounding Country.

To the kindness of Mr. P. S. A. Bickel, civil engineer, of Twin Falls, Idaho, the author is indebted for the panoramic picture of the three dams at Milner, Idaho, and to Mr. James W. Martin for the photograph taken just after the completion of the Granite Reef dam, Arizona.

Mr. C. E. Curtis, M. Am. Soc. C. E., has contributed the photographs

FIG. 337.—NEAR VIEW OF CREST OF BOWMAN LAKE DAM, SHOWING ANGLE IN DAM.

and drawing illustrating the cinder-fill dam built on Hinckston Run by the Cambria Steel Works of Johnstown, Penn.

The pictures of the Santo Amaro dam, Brazil, are kindly supplied by Mr. Thomas Berry, chief engineer, while the latest view of the Necaxa dam is contributed by Mr. R. F. Hayward, M. Am. Soc. C. E., general manager of the Mexican Light and Power Company. The plan and sections of the high hydraulic-fill dam projected in Japan are from the office of J. M. Howells, M. Am. Soc. C. E., chief engineer.

The Bowman Rock-fill Dam.—Renewed interest is being taken in the old rock-fill dams of the Sierra Nevada Mountains, in Northern California, built originally to store water for hydraulic mining, because they are becoming valuable for the double uses of generating power and affording domestic and irrigation supply to the valley below. The Bowman dam, described on page 65, and outlined by cross-sections, Fig. 44, is more clearly illustrated in its situation and construction by Figs. 336, 337, 338, 339, and 340.

The dam was first built as a timber structure, prior to 1869, as shown by the cross-section, Fig. 44. In that year work began by which it was raised to a total height of 63 feet, and when finished it contained

FIG. 338.—DOWN-STREAM FACE OF BOWMAN LAKE DAM, CALIFORNIA, ILLUSTRATING THE QUALITY OF THE DRY MASONRY.

17,000 cubic yards of stone filling, 33,000 lineal feet of heavy timber, and 63,000 feet, B. M., of three-inch plank. It was actually designed to carry flood water over its crest to a depth of 3 feet for a length of 300 feet in emergency. The main spill-way, however, is an entirely separate structure, as described later. Before this work was finally completed it was destroyed by fire, October 12, 1871, and again damaged, or practically destroyed, by flood at the end of the same year. In 1872 it was rebuilt to a height of 65 feet, after the same plan as before, with flash-boards on the crest, raising its height to a total of 72 feet. The final increase in height was made, and the dam completed as it now stands, December 10, 1876. Its height has always been called 100 feet in round numbers, but its actual measure is 96 feet at the highest point.

The present dam contains a great deal of the old timber structure at the bottom unburned in the fire. The upper part of the timber facing differs from the old design in that the inclined posts on which the plank skin is spiked are not parts of timber bents, but are merely embedded into the face of the rock-fill and anchored back into the rock, so that

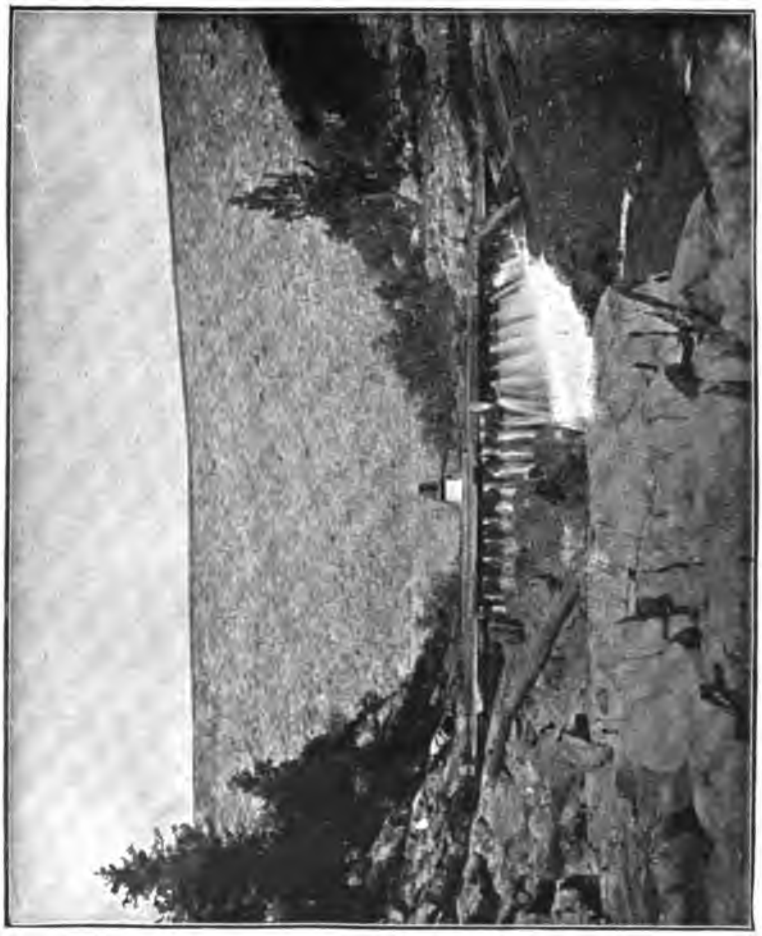


FIG. 339.—FRONT VIEW OF BOWMAN LAKE DAM, FROM BELOW MEASURING WEIR.

the first layer of plank is placed horizontally and not vertically as before. At the base the 3-inch plank are in three layers; at the top is but one layer. The plank facing of the lower half of the dam, laid in 1876, is still serviceable after thirty-two years of wear. The upper half of the planking has been replaced once. Since the dam was built, in 1876, there has been a sag in its center amounting to about 12 inches, due to the decay of the timber in the cribs and the settlement of the rock.

The engineer of the company now owning this dam proposes to increase its height to 150 feet by the addition of a structure of reinforced concrete.

Spillway.—While the main dam was intended to act as an emergency overflow, or spillway, the principal spillway is a separate structure (Fig. 340), 52 feet high, built of round logs fastened together by 1-inch drift bolts, forming a crib, filled with small stone. This structure is also covered with a skin of 3-inch plank on the water side, and has a slight angle pointing up stream. The crest is 12 feet lower than the crest of the main dam. It is arranged with A-frame bents so that flash-boards may be added to raise the water 8 feet. There are thirty-one openings

Fig. 340.—Timber Crib Spillway of Bowman Lake Dam. This Structure is 52 Feet High.

between bents, each 4 feet wide. During the flood season the flash-boards are removed, but when all danger of floods is supposed to be past these wasteways are closed with 2-inch loose planks. This structure, built in 1876, has had little or no repair since that date, and has sagged very perceptibly. The ends of the main timbers are torn from the walls of the canyon, and the header logs have rotted to a soft pulp at their extremities, where exposed to the weather. The water passing through or over this spillway leaps clear of the log face on the down-stream side, otherwise it would not have lasted as long as it has.

The Faucherie Dam.—The Faucherie Dam is a good example of a timber-frame dam, with all rock-filling omitted. Its original height was 35 feet, but after its destruction in the early winter of 1875, it was rebuilt with a reduced maximum height of 21 feet (see Figs. 341 and 342). The frame supporting the inclined face is triangular in form, leaning

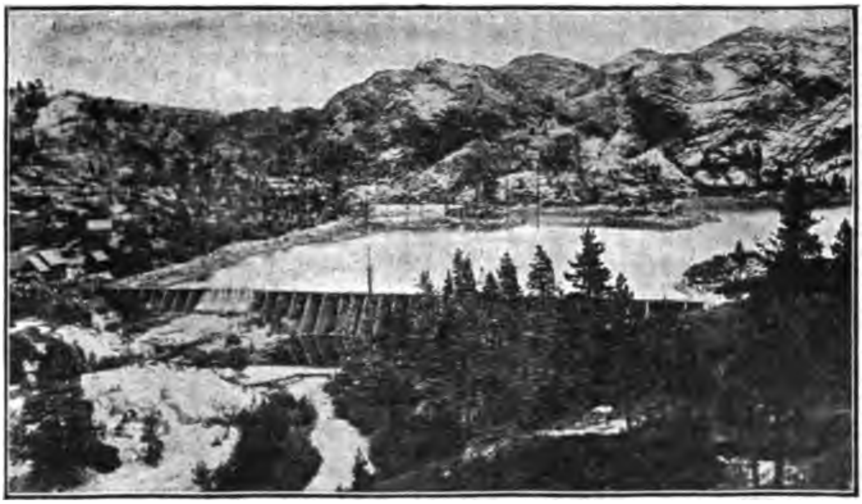


FIG. 341.—THE FAUCHERIE DAM, CALIFORNIA. A GENERAL VIEW OF DAM AND RESERVOIR.

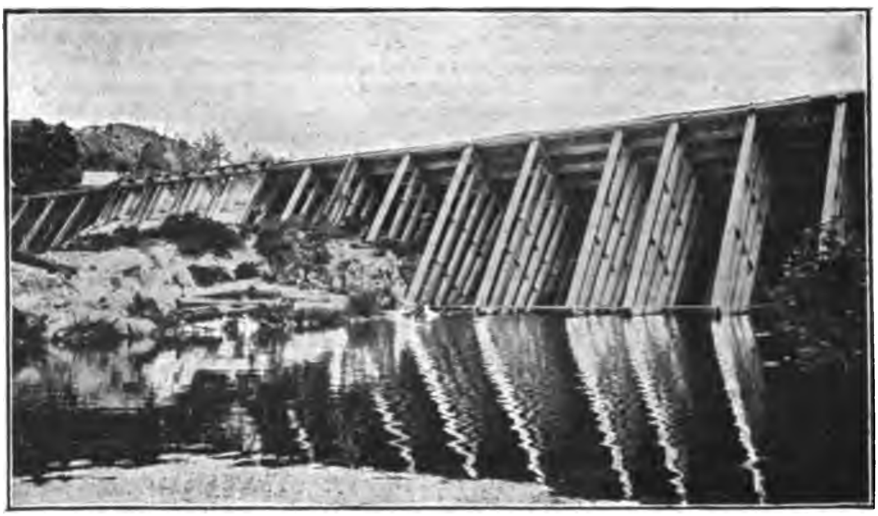


FIG. 342.—THE TIMBER WORK OF THE FAUCHERIE DAM AS SEEN FROM BELOW.

down stream at an angle of 55°. The struts supporting the frame have angles varying from 45° to 60° from the horizontal, the latter being the inclination of the longer outer posts.

On the up-stream side the facing planks make vertical joints and are supported by and spiked to square timbers lying horizontally and bolted to the frame. There is no diagonal or horizontal bracing. The posts and struts rest upon wood sills that are bolted to the bed-rock. Thus the entire structure depends upon the strength of the timber for its stability, and not in any manner upon its weight. The top length of the dam is 550 feet, forming a reservoir of 90 acres with a capacity of 1344 acre-feet. It is the simplest possible type of dam, a mere fence leaning down stream, supported by a series of props. The face of the fence is composed of several thicknesses of boards which break joints to render the structure more water-tight.

The Eureka Lake Dam.—The two dams just described are located on Canyon creek, a tributary of the South Fork of Yuba river, Bowman dam being the lowest, at an elevation of about 5400 feet, and Faucherie dam at an altitude of 6100 feet. Higher up on the same stream, at an elevation of about 6500 feet, is French lake, or Eureka lake, formed by a rock-fill dam built in 1859.

The dam has an extreme height of 68 feet, is 250 feet long on top, and forms a reservoir of 337 acres, the capacity of which is 15,150 acre-feet.

The offset shown in the photographs (Figs. 343 and 344) was the result of an enforced economy during construction when money became scarce. The dam is built entirely of rock (without timber cribs), rather loosely placed, and with the larger stones in the down-stream face laid up in the form of a dry wall. The up-stream face is made water-tight with two layers of a 3-inch pine planking, laid with broken joints, spiked to inclined posts sunk flush with the stone work, which is also laid up with care as a dry wall, to receive the pressure of the water transmitted through the planks. On the crest is a timber structure about 6 feet high, made by extending the inclined posts and timber facing above the stonework.

The spillway consists of two sluices or wooden flumes, having a combined width of 20 feet and a depth of 30 inches. These are built into the end of the dam on the right bank.

The water is drawn out through an arched sluiceway under the center of the dam, the gates of which are only accessible in winter through the box-like structure, or manway, shown in the photographs, which protects the ladder resting on the face of the dam from the deep snow. The gates are situated near the water face of the dam, at the end of the arched sluiceway.

The Weaver Lake Dam.—A new dam has recently been constructed at Weaver lake, within a mile of Bowman dam, which is typical of the class of rock-fill wood-faced dams. The method of construction is well shown by the photograph, Fig. 345.

FIG. 343.—THE EUREKA LAKE ROCK-FILL DAM, CALIFORNIA, SHOWING COVERED MAN-WAY TO REACH GATES FROM CREST IN WINTER.

FIG. 344.—SHOWING THE CREST OF THE EUREKA LAKE ROCK-FILL DAM, AND A PORTION OF THE LAKE.

Inclined posts, placed at an angle of 45°, are first set up and held in position by struts that are subsequently removed. These posts are long enough to reach from bed-rock to the crest of the dam. The rock-fill is carefully laid by hand between the posts, forming a face flush with the exterior face of the posts. They are spaced 4 feet apart, center to center. At intervals of 6 feet, from bottom to top, an iron rod, $\frac{3}{4}$ of an inch in diameter, passes through each of the posts to an anchorage back in the rock-fill. This anchorage is made by winding the rods around the largest stones that are selected for that purpose. These posts are of varying size, but the smallest are 9 inches across at top.

The plank face is made with but one layer of well-seasoned 3″×8″ pine plank, laid horizontally, and driven tightly together. The bottom

FIG. 345.—THE WEAVER LAKE DAM, CALIFORNIA, SHOWING RECENT CONSTRUCTION.

edge of each plank is cut with a caulking bevel of one-half inch in the thickness of 3 inches, but no caulking is done by hand, reliance being placed upon the sediment and floating organic matter in the water to make the joints tight. The planks are held by two 6-inch spikes at each post.

Especial care has been taken to keep all earth out of the structure. The down-stream face is laid up carefully as a dry wall.

The dam is 22 feet high at present, but is finished off with a crest width of 18 feet, with the intention of making a subsequent addition to the top. The up-stream slope is 45°, but the down-stream slope is unusually steep, being 77°, or but 13° off the vertical. The reservoir formed by the dam is 81.7 acres in area, and it can be drawn off to a maximum depth of 62.5 feet by a tunnel, at which level the lake is 26.7 acres in area. The capacity is therefore about 3400 acre-feet.

The geological formation at the dam-site is very unusual and interesting. There had been a stream whose bed was filled to a considerable depth with auriferous gravel. A subsequent lava flow crossed the stream forming a natural dam and creating a lake the outlet to which wore down a channel into the lava, but not cutting entirely through it to the gravel. It is in this basaltic formation that the dam is built. The reservoir outlet is through a tunnel, some 500 feet long, excavated chiefly through the gravel beneath the lava flow. This tunnel tapped the lake at a depth of 62.5 feet below the spillway level of the present dam. At its extreme end, before entering the lake, the tunnel reached the granite bed-rock.

The new dam was built to replace an all-timber dam of the same height, the main posts of which inclined at an angle of 29° from the horizontal, and were each supported by five struts, equally spaced against the posts, at angles of 44°, 47°, 52°, 57°, and 60°. The posts have bolted to them six horizontal stringers, each 12″×16″, spaced about 4 feet apart, over which a single layer of 3-inch plank is spiked in a vertical direction.

The English Dam.—On pp. 63–64 the high rock-fill structure known as the English Dam is described, with an account of the bursting and destruction of the main dam, the central one of three which formed the reservoir. Figs. 346, 347, and 348 illustrate the style of construction and present condition of the principal one of the two remaining dams.

These dams were first built for mining purposes in 1856, enlarged in 1876 to their present height, and destroyed by flood in 1883. The reservoir has since been out of service, as the missing dam has not since been rebuilt, although the other two are capable of being restored to usefulness at moderate expense. The middle dam, which failed, was a rock-fill with up-stream slope of 60° and down-stream slope of 40°. In making the addition in 1876 the new work consisted of a dry rock wall on the down-stream side, surfaced on the exterior with large blocks of split granite well laid in a wall of substantial construction. Unfortunately the funds gave out before completion of this work as planned, and the rock work was stopped 16 feet below the proposed crest. The top was then formed by the extension of the plank facing, the inclined posts of the face being supported by struts resting on top of the uncompleted dry-stone embankment. As there was a splice in these inclined posts at the point where the rock-fill stopped a line of weakness was thus made at the toe of the rafter dam. When the dam failed the water was within a foot or two of the top, and the real cause of the failure is now

FIG. 346.—UP-STREAM FACE OF ONE OF THE TWO REMAINING ROCK-FILL STRUCTURES WHICH, WITH THE THIRD STRUCTURE DESTROYED IN 1883, ORIGINALLY FORMED THE ENGLISH LAKE DAM.

FIG. 347.—GENERAL VIEW OF THE TIMBER SKIN ON UP-STREAM SIDE OF THE ENGLISH LAKE DAM. NOW IN RUIN.

attributed to the lack of strength in the top structure of wood, rather than in the rock-fill, or to the use of dynamite. It is not to be wondered at that a fence of that slender character should collapse under water pressure.

The existing dams both have a crest extension of wood, 6 feet high, of similar construction. (See Figs. 346 and 347.) This is also well illustrated by Fig. 348, showing the dry wall laid up on the down-stream face.

FIG. 348.—THE DOWN-STREAM FACING OF THE ENGLISH LAKE DAM, CONSISTING OF A HAND-LAID DRY WALL IS WELL ILLUSTRATED BY THIS PHOTOGRAPH.

The Lake Frances Dam.—All of the photographs accompanying the description of the Lake Frances hydraulic-fill dam on pp. 115 to 125 were taken during construction and before its final completion. Fig. 349, however, is a recent view taken in 1907, showing the finished dam in service. In the foreground is seen a secondary spillway and controlling-gates, added since the dam was completed. This is a wooden flume, 16 feet wide, 6 feet deep below the water-line, the apparent object of which was to allow them to begin wasting water before the lake filled to its full depth at the main spillway level.

Hydraulic Sluicing in Seattle, Wash.—The precipitous character of the topography of Seattle is unfavorable to the creation of practicable grades for streets without heroic reconstruction and modification. As the geological formation of the peninsula is entirely alluvial in character, consisting of clay or moraine gravel, left by glacial action, it is feasible to accomplish extensive excavations and embankments by hydraulic sluicing at a more moderate cost than by any other method. As the

FIG. 349.—THE LAKE FRANCES HYDRAULIC-FILL DAM AS COMPLETED AND IN SERVICE, SHOWING NEW SPILLWAY AND GATES IN FOREGROUND.

FIG. 350.—THE HOPKIRK WOOD PIPE, FOR CARRYING GRITTY MATERIAL, THE WEAR BEING UPON THE END GRAIN OF THE WOOD.

appliances that have been used on this work, which has been in progress several years, and the methods that have been evolved have a direct bearing upon the construction of hydraulic-fill dams by the same agency, they are of very positive interest, and the illustrations in Figs. 350, 351, 352, 353, and 354 are most acceptable additions to this book.

FIG. 351.—THE HOPKIRK PIPE, AFTER SIX AND ONE HALF MONTHS WEAR ON 20% GRADE, IN SEATTLE.

Cuts more than 150 feet deep, and embankments 40 to 50 feet high, have been made and are still being planned.

The general plans for the regrading of the city are comprehensive and of broad scope. They are quite fully set forth in the *Engineering Record* for May 9 and 16, 1908. Contracts for the removal of 5,000,000 cubic yards have already been completed, while contracts for the removal of 11,000,000 cubic yards additional have been awarded and are to be completed before the spring of 1910. A further quantity of 11,000,000 cubic yards will be removed by contracts shortly to be let. Practically all of this work has been or is to be done by hydraulic sluicing.

The Lewis Construction Company of Seattle, Washington, has had a work that was unique in that it was applied to the grading of a hill close to the heart of the City of Seattle and to the filling in of the tide lands, of which there is a great area at the foot of the city. The methods used in this work were very much the same as in other hydraulic excavations previously mentioned.

Their pit was 120 feet above the level of the tide lands, which at high tide were covered with 10 or 12 feet of water, and was situated at a distance of 3000 to 5500 feet from the fill. While the surface of the

FIG. 352.—THE REGRADING OF JACKSON STREET, SEATTLE, LOOKING NORTH ON MAYNARD STREET. THE HOUSES ARE REMOVED JUST BEFORE THEY ARE UNDERMINED.

hill consisted mostly of sand and gravel, some few feet from the top a difficult bank of hard blue clay was encountered. In spite of this complication from 500 to 2000 cubic yards of earth were sluiced out each twenty-four hours, using from 2,000,000 to 8,000,000 gallons of water. The water was carried from a reservoir situated more than half a mile from the work. The grade was such, however, that it gave 60 to 80 pounds pressure. The spoil was carried by the Hopkirk Patent Pipe. This is a stave wooden pipe with a reinforced bottom which can be renewed when worn out. The reinforced bottom is made of fir with the end grain of the wood faced so as to withstand the wear of the spoil.

Fig. 353.—The Jackson Street Regrade by Hydraulic Sluicing, with Water Pumped.

Eighteen, twenty, and twenty-two-inch pipe were used. It has been estimated that the life of this pipe is many times that of cast iron or any other pipe. The patent is owned by the Hopkirk Patent Pipe Company of Seattle, Washington. The Lewis Construction Company are heavy shareholders in the company. No. 2 giants with tips varying from 3 inches to 4 inches were used. The average ratio of solids to water used on the entire job was about 5%. The total number of cubic yards of this work was 868,454.

This work was accomplished so successfully and so inexpensively as compared with any other method that similar regrade projects have been undertaken by the City of Seattle. The first of these, the Jackson Regrade Project, involved the moving of 3,400,000 cubic yards of earth. It was let to Lewis & Wiley, Inc., successors to the Lewis Construction Company, at a contract price of 25 cents per yard. This contract involved the cutting down in one section and the filling in another of a district comprising sixty-eight city blocks.

The second project, known as the Denny Hill Regrade, involves the cutting of 5,600,000 yards from Denny Hill and wasting it in deep water in the harbor. This contract was let at a price of 27 cents per cubic yard to the Rainier Development Company, in which Messrs. Lewis & Wiley have the controlling interest.

The third project is known as the Dearborn Street Regrade and contemplates the moving of about 3,000,000 yards, but the contract has not yet been let.

In carrying out the later contracts the Lewis Construction Company have changed their water-supply from fresh to salt water, and are pumping salt water from the bay for sluicing purposes to the extent of 12,000,000 gallons in twenty-four hours, or 18.6 cubic feet per second. The pumps consist of two pairs of 10-inch, five-stage Worthington turbine-pumps, delivering the water against a head of 375 feet. Each pair of pumps is driven by a 650 horse-power electric motor.

On the Denny Hill work a second pumping-station was installed for delivering salt water to the hydraulic giants to the extent of 8500 gallons per minute (18.8 second-feet), delivered against a maximum head of 400 feet.

The Milner Dam, Idaho.—The photograph shown in Fig. 355 gives a more comprehensive picture of the three combination dams described on page 60 than any of the other illustrations accompanying the article (see Figs. 47 to 53), and will therefore add to the interest in these important and successful dams.

The Walnut Grove Dam, Arizona.—The ill-fated rock-fill dam on the Hassayampa river in Arizona, described on page 53, et seq., has never been depicted by photographic illustration in any of the published accounts of it that have yet appeared. The author accidentally found

Fig. 354.—The delivery of Sluiced Material to fill low Ground in the Regrading of Seattle, Wash.

FIG. 355.—THE MILNER DAM, SNAKE RIVER, IDAHO, ON THE TWIN FALLS CANAL PROJECT.

Arrows: 1 indicates the main channel dam; 2, the North Island spillway; 3, the middle dam; 4, the South Island regulating-gates; 5, the south dam; 6, the head-gates of Twin Falls Canal.

Fig. 356.—The ill-fated Walnut Grove Dam, Hassayampa River, Arizona, before its Destruction by Flood.

the accompanying picture in Phœnix and is glad to add it to the collection.

The dark spot under the center of the dam is evidently a deep hole excavated in the sandy bed of the canyon by water that has passed through the wooden outlet culvert, whose unsupported end overhangs the vertical bank of the pit. The picture shows no spillway—a fatal defect—which was only partially remedied when the flood came which overtopped the dam and caused its rupture.

The reservoir-site is such an excellent one, and the watershed area above it so extensive that the restoration of the dam will surely become necessary and profitable as a factor in the development of Arizona in the course of time.

The Granite Reef Dam, Arizona.—Quite as important to the irrigators of Salt River Valley, Arizona, as the Roosevelt Storage dam under construction in the mountains, is the smaller structure recently completed by the U. S. Reclamation Service for the diversion of the waters of Salt river into the canals on either side of the river by which all stored water will be controlled and turned into the channels of service. The Granite Reef dam was built by force account by authority given July 26, 1906, and was begun in October of the same year. It was finally completed and put into service in May, 1908. It is a concrete structure of ogee form, 1000 feet long, 20 feet high, resting for the most part on reinforced concrete piers, spaced 20 feet apart, center to center, parallel with the stream, with thin concrete curtain walls, also reinforced, at the upstream and down-stream toes of the dam. These walls, as well as the piers, rest on bed-rock. They form cells about 32′×20′ in size, solidly filled with sand beneath the dam. Bedrock was found throughout the entire length of the dam except about 320 feet south of the center of the channel, where the dam rests on gravel, with sheet piling carried down a considerable depth, sufficient to be considered by the engineers quite safe from the danger of undermining. Over the distance where bedrock was not reached an apron of concrete 75 feet wide, 18 inches thick, resting on dry rock filling, 4½ feet thick, was built, with a curtain wall 12 feet deep at outer edge.

The picture, kindly supplied by James Wm. Martin, C. E., engineer in charge of construction, under Lewis C. Hill, Supervising Engineer, Fig. 357, shows clearly the arrangement of the intake gates and canal headworks on either side of the river. Sluiceways have been provided through the dam at each end for the purpose of washing out accumulated sand and maintaining a channel in front of the canal headgates.

The Hinckston Run Dam, Pennsylvania.—This dam, located three miles east of Johnstown, Penn., on Hinckston Run, was built in 1904 as a part of the water-supply of the Cambria Steel Company.

FIG. 357.—THE GRANITE REEF DAM, SALT RIVER, ARIZONA.

Fig. 358.—The Hinckston Run Dam, Cambria Steel Works, Johnstown, Pa.

Fig. 359.—Illustrating the Steel Outlet Tower and Methods of Construction of the Hinckston Run Cinder-fill Dam, Johnstown, Pa.

It is essentially an earth embankment with concrete core-wall extending from bed-rock up to about one-third the height, or 45 feet below the water-line. The unique feature of the dam is the heavy reinforcement given to it by a backing of cinders, the waste product of the blast-furnaces of the Cambria Steel Works. This cinder-fill is to eventually give the dam a minimum crest width of 500 feet. It is now 300 feet wide at the minimum, and 1000 feet at the widest place. The illustration, Fig. 360, gives a clear idea of the plan of construction. The dimensions are as follows:

Top length	900 feet
Top width of earth portion	20 "
Up-stream slope	2.25:1 and 1.75:1
Height above stream-bed	80 feet
Maximum height of core-wall	58 "
Maximum height from bottom of core-wall to crest of dam	121.7 "
Top of core-wall below crest	53.7 "

The cut-off wall of concrete is carried down deeply into the bed-rock, in a trench, in the bottom of which 2-inch drill holes were bored 10 to 16 feet deep and filled with cement grout under 60 pounds pressure, to close all porous layers or cavities of the rock. At the ground-line the wall is 20 feet thick; at the top it is 6 feet thick, and at the elevation of 1348 it is finished off level across the valley, and is not carried further up the slopes. It is enveloped in puddle clay which is carried up as a core-wall through the earth embankment, carrying the concrete in its center part way. Outside of the puddle wall the up-stream portion of the embankment is all made of selected earth, while the down-stream side is chiefly formed of cinder.

This cinder material was transported from the furnaces to the dam, a distance of three miles, in dump-cars, by rail. The road is standard gauge, owned and operated by the steel company. The cars are of 50-tons capacity, of the hopper-bottom type. The cinder was dumped freely without effort to compact it, and when dumped from the cars it takes the natural slope of gravel, about 1.5 on 1. The earth and cinder embankments were built up from the base simultaneously.

The cinder weighs about 70 pounds per cubic foot, and is chiefly composed of lime, silica, and alumina. It is grayish white in color, hard, somewhat brittle, and air-slakes when containing an excess of lime. On its delivery to the cars it naturally breaks into pieces a little smaller than the usual run of crusher stone, and with a larger percentage of fines.

On the up-stream slope below the berm where cinder is used in place of rip-rap, it was placed with narrow-gauge dump-cars and locomotives. It was spread on the slope by four men with a team and plank-scraper.

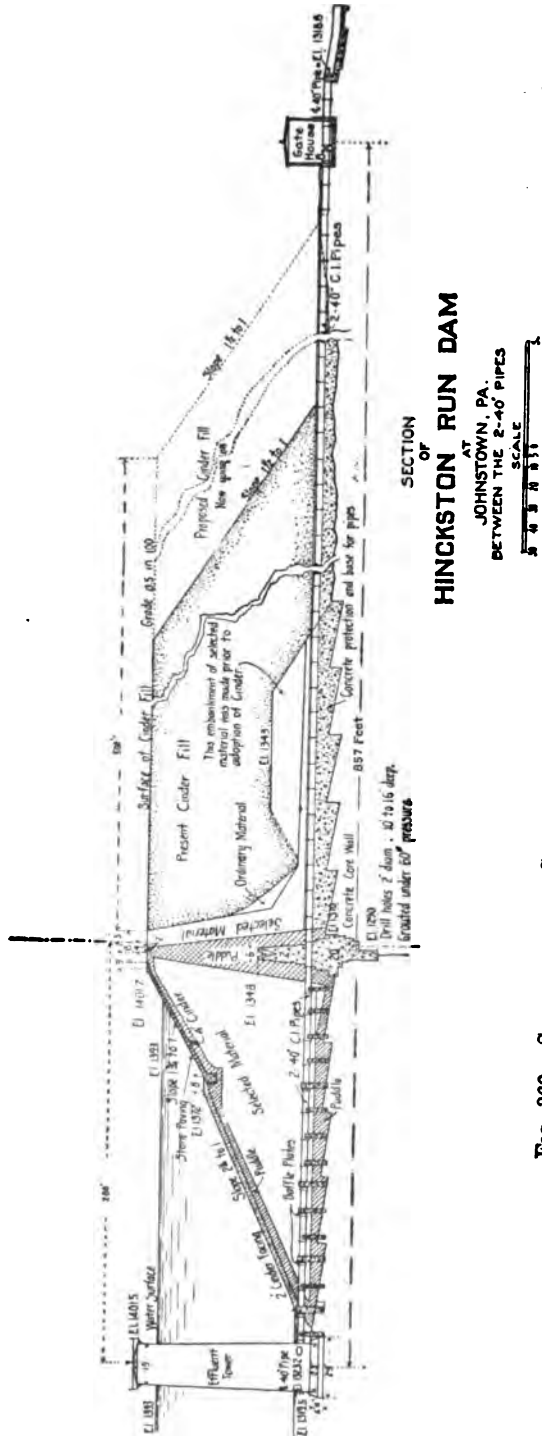


FIG. 360.—SECTION OF THE CINDER-FILL DAM ON HINCKSTON RUN, JOHNSTOWN, PA.

A cinder-fill of 500 feet width was considered as an essential part of the dam, but all excess of width beyond 500 feet was made merely as a convenient waste dump.

The cost of the dam, including highways, watchman's house, bridges, etc., was about $500,000. The reservoir has a capacity of 3130 acre-feet, and is supplied by the drainage from an area of 10.75 square miles. The annual rainfall is about 40 inches.

Outlets.—The outlets consist of two 40-inch cast-iron pipes, laid side by side on a concrete base, resting on bed-rock. These pipes extend entirely through the dam from the intake tower in the reservoir to the outlet gate-house, 900 feet down stream.

The intake tower is of novel design and is made of riveted steel plates. It is 23 feet in diameter at the base, 19 feet at the top, and is lined with concrete. It is provided with square outlets from the reservoir, at three different levels, each being closed by sluice-valves. The gate-house below the dam contains two 40-inch valves, one for each pipe, with by-pass connection from each to the 24-inch cast-iron service pipe leading to the steel works.

Spillway.—The spillway is excavated in rock, 8 feet deep, 90 feet wide, and extends for 100 feet down stream from the dam.

The Necaxa Dam.—Fig. 361 is a photograph taken July 1, 1908, of the hydraulic-fill dam at Necaxa, Mexico, and is inserted in this chapter of Miscellany because it is the latest and best picture yet obtained of the work. It conveys a better idea than all others of the magnitude of the work. The pond in the picture is a miniature lake on top of the dam, the width of which at the height here shown is not less than 500 feet. The dam at that time was about 100 feet high.

The Esperanza Dam, Mexico.—The Esperanza dam is a modern structure designed and built by a Mexican engineer named Ponciano Aguilar, for impounding a domestic water-supply for the city of Guanajuato. The dam is built of rubble masonry, straight in plan, and of the following dimensions:

Length on crest	580 feet
Thickness at crest	19.7 "
Thickness at base	75.7 "
Maximum height	137.5 "
Cubic contents	55,000 cu. yds.

An excellent general view of the dam and its reservoir of 462 acres is given by the accompanying cut, Fig. 362, which shows the three buttresses, each 9.87 feet square, which extend from bottom to top. These were designed as an ornamental feature, primarily, but serve to

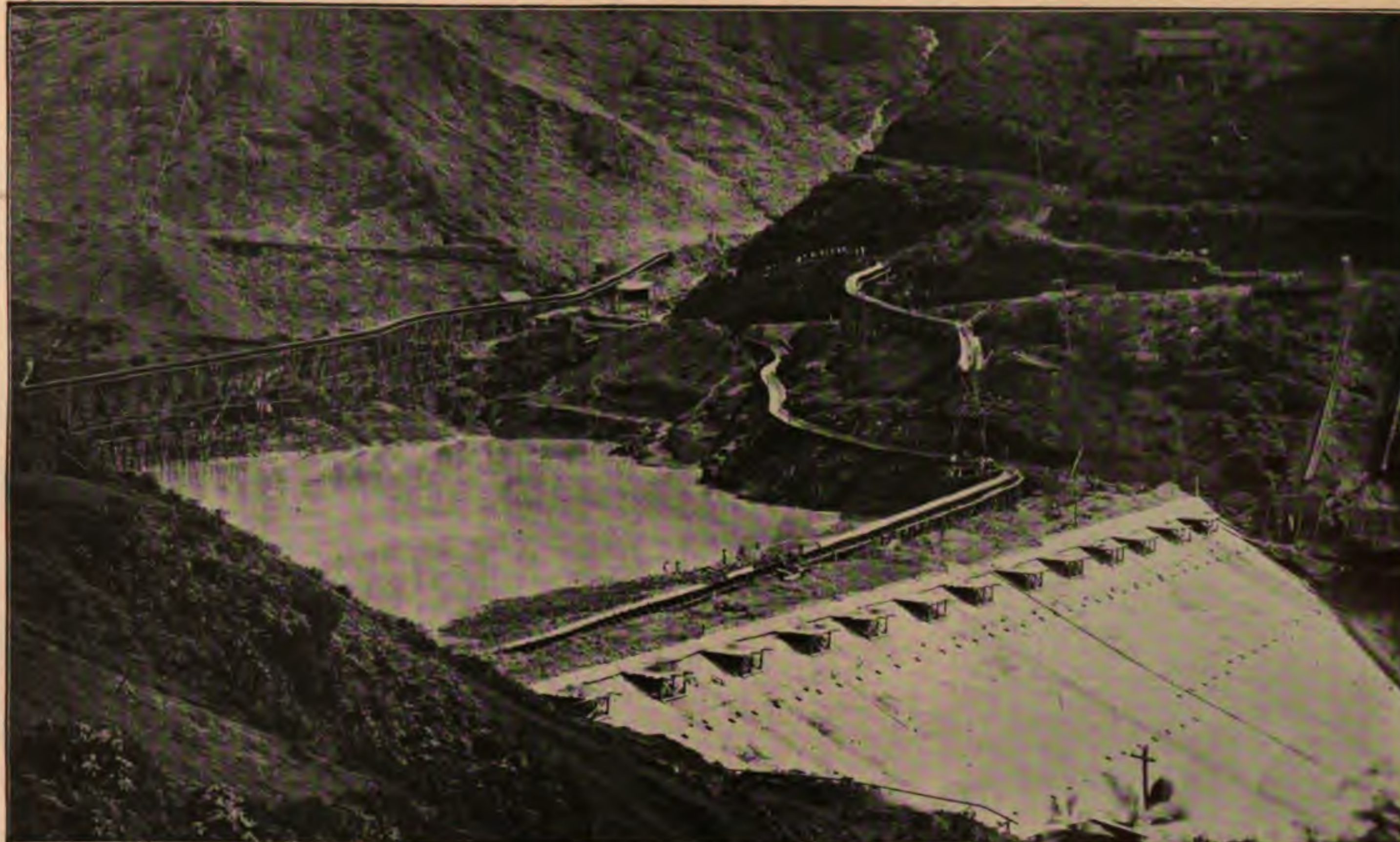


FIG. 361.—THE NECAXA DAM, MEXICO, AS IT APPEARED JULY 1, 1908.

FIG. 362.—GENERAL VIEW OF THE ESPERANZA DAM AND RESERVOIR, NEAR GUANAJUATO, MEXICO.

FIG. 363.—THE ESPERANZA DAM, MEXICO, LOOKING ALONG THE EXTERIOR FACE.

add somewhat to the stability of the structure. They certainly are effective from an architectural point of view. Fig. 363 conveys a still better idea of the details of the ornamentation given to the dam by the trimmings of these buttresses, and the decorative cornice in cut stone.

The cementing material exclusively used in building the dam was lime burned in the vicinity and having some hydraulic properties. The

FIG. 364.—DISCHARGE END OF SPILLWAY, ESPERANZA DAM, GUANAJUATO, MEXICO.

dam shows considerable leakage, estimated at 0.4 cubic feet per second, which has precipitated white hydrate of lime on the exterior face.

The dam is supposed to have cost but 160,000 pesos ($80,000 U. S. gold), which appears a ridiculously inadequate figure when it is known that its cubic contents are 55,000 cubic yards. The reservoir has a capacity of 16,200 acre-feet, covering 462 acres.

Spillway.—The spillway is located at the south end, or left bank, and is stated to have a capacity of 1765 second-feet. Its discharge end is shown by Fig. 364. It passes through the dam by a channel which is

FIG. 365.—THE SPILLWAY CHANNEL OF THE ESPERANZA DAM, AT ITS UPPER END, SHOWING OBSTRUCTIONS TO FREE DISCHARGE BY PIERS SUPPORTING ROADWAY.

FIG. 366.—THE SIX OUTLET PIPES AND GATE-VALVES OF THE ESPERANZA DAM, BEFORE CONNECTION WITH WATER MAINS OF CITY.

somewhat obstructed by the masonry piers supporting the roadway on the top of the dam, as seen in Fig. 365.

The watershed above the dam has an area of 95 square miles. The normal annual rainfall is 23.5 inches, falling during the rainy season of three months. In computing the capacity of the spillway a maximum rainfall of 2.35 inches per hour for one and one-half hours was assumed.

The outlet-gates of the reservoir are six in number, located under the buttresses. They each have a clear diameter of 28½ inches, and are controlled by gate-valves operated by hand windlasses, as shown by Fig. 366. They are in sets of three, each set being attached to one of two wrought-iron pipes, 4 feet 6 inches in diameter, which pass through the masonry of the dam.

The gates are wholly unprotected, except by a light wooden-platform which serves merely as a means of access to the operating mechanism. Any injury to the gates would have disastrous consequences, as they cannot be repaired or adjusted except by wholly emptying the reservoir.

The small pipe shown in the angle between the buttress and the dam is a cast-iron pipe 15½ inches outside diameter, which passes through a tunnel in the dam to a standpipe in the reservoir. This standpipe has seven openings from the reservoir, at varying levels, each controlled by a separate valve which is operated by mechanism mounted on a tower reached by a bridge from the center of the dam. This appears to be the main supply-pipe to the city, and its exposed condition is a matter of remark.

The Olla Reservoirs.—The two dams of masonry forming what are known as the Olla Reservoirs, in the neighborhood of Guanajuato, are but half a mile apart on the same stream, in a canyon with precipitous sides, and limited catchment area. The reservoirs are used chiefly for sewer flushing in the city and irrigation below. The banks of the reservoir are parked and ornamented, and serve as the pleasure ground of the people of the city. (See frontispiece.)

Fig. 367 is a distant view of the Upper Olla dam, while Fig. 368 shows the Lower dam, both of which combine many architectural effects with their utility as storage dams. The crest of each serves as a promenade as well as a flood-discharge spillway. A small volume of water wasting passes under the footway without flooding the crest, while a larger discharge passes over the footway. In either event the waste waters pass into a pit close to the down-stream toe of the dam, and out through a tunnel under the park to a lower point of discharge into the stream-bed.

The arched and aqueduct-like appearance of the face of the dam is

FIG. 367.—THE UPPER OLLA DAM, GUANAJUATO, MEXICO.

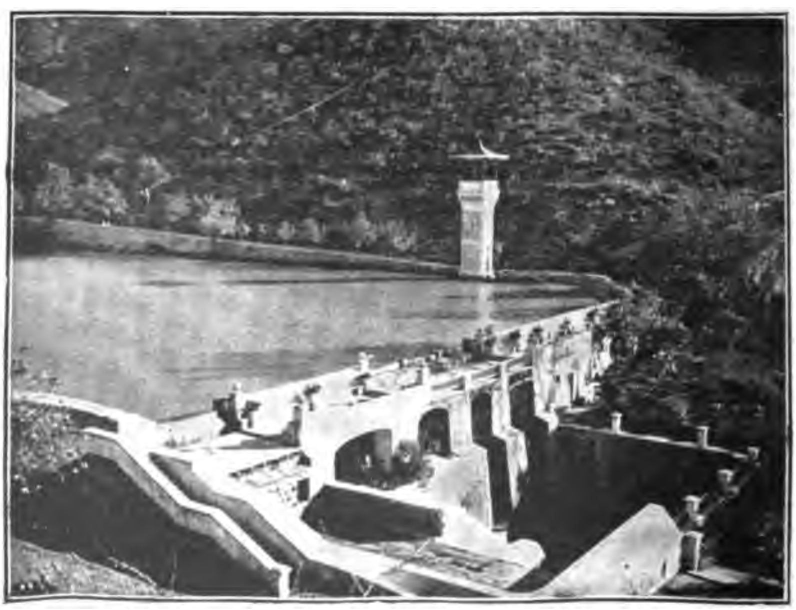


FIG. 368.—THE LOWER OLLA DAM, GUANAJUATO, MEXICO. (See also frontispiece.)

due to the fact that the up-stream face is a wooden barrier of flash-boards, removable in times of extreme flood.

The width of the lower dam at the crest is 19 feet, and its length about 300 feet. An angle of 45° down stream exists in the alignment of the lower dam.

FIG. 369.—SPILLWAY CHANNEL OF THE LOWER OLLA DAM, GUANAJUATO, MEXICO.

The San José Dam, San Luis Potosi, Mexico.—In 1901, at the time the photographs shown in Figs. 371, 372, 373, 374, and 375 were taken, a private company was engaged in building a high masonry dam for the storage of water to supply the city of San Luis Potosi and to irrigate land in its vicinity. The city is a stockholder in this corporation. The dam as subsequently completed has an extreme length on the crest of 592 feet, and a maximum height of 151 feet from the lowest foundation to the crest, or 110 feet from the stream-bed to the top. Its thickness at the base is 128 feet, and at the crest about 15 feet.

The profile is that of the Crugnola type, with a vertical curve near the base on the up-stream side, and near the top on the down-stream face. In plan the dam is slightly curved up stream with a radius of 2000 metres (6560 feet). It is built of uncoursed rubble masonry, with no stone larger than two men can conveniently carry and mostly of one-man-stone. The bonding of this rubble with long vertical headers is clearly shown in Fig. 375. The two faces are laid in well-cut stone.

FIG. 370.—A DETAIL OF THE DOWN-STREAM FACE OF THE LOWER OLLA DAM, GUANAJUATO. These openings are closed by a form of movable flash-board.

Practically all of the great masonry work of Mexico has been laid in lime mortar in the absence of cement, the manufacture of which is still an infant industry in that country, almost unknown. This dam is not an exception to this rule: the lime was burned on the ground and put into the work immediately without curing. It has slight hydraulicity in common with most Mexican lime.

The volume of the dam is not given, but its cost was estimated at $400,000 Mexican silver. Spillways have been provided at each end of the dam, and consist of channels formed in part by excavation into the rock of the mountain side and in part by building up masonry walls parallel to the course of the valley. These channels carry the water far enough down stream to avoid interference with the toe of the dam. These spillways are tapered in width from the dam down stream. The one on the left bank is 95 feet wide at the dam and tapers to 52 feet in a distance of 120 feet from the face of the dam. The spillway on the right

FIG. 371.—GENERAL END VIEW OF THE PRESA DE SAN JOSÉ AT SAN LUIS POTOSI, WHILE UNDER CONSTRUCTION.

bank has a maximum width of 86 feet, tapering to 36 feet in a length of 65 feet. The supporting side wall of the larger spillway is shown in Fig. 373.

The depth of these channels is about 2 metres. The area of watershed drained above the reservoir is 67.5 square miles. The capacity of the reservoir is 7,526,000 cubic metres, or 6100 acre-feet. Its surface area at the spillway level is 185 acres, and its mean depth 32.8 feet.

The dam is provided with two gate towers, or buttresses, on the downstream face, which are of a peculiarly elaborate and ornate character, adding to the architectural effect. The lower part of one of these is shown in Fig. 372. They are massive and of generous dimensions. One of them was designed to be surmounted by a statue of a lion on a pedestal.

The dam was designed and started in 1896, and was completed since 1902, as it is reported to have been in service for several years. The engineer of this notable structure was Señor Sebastian Reyes.

FIG. 372.—ONE OF THE TWO GATE-HOUSES OF THE SAN JOSÉ DAM, SAN LUIS POTOSI, MEXICO.

The reservoir has been filled several times, but as the distributing-pipe system in the city of San Luis Potosi is still under construction, the water is not yet utilized for domestic supply except in very small quantities, but is used for irrigation. In a report submitted to the Government by the engineer it was estimated that the supply from this source would not only furnish the city with domestic water but would also irrigate 2642 hectares (6525 acres) of valley land.

Señor Luis S. Cuevas, an engineer of San Luis Potosi, has kindly supplied the data as to the present condition of the dam, from which it is learned that the masonry has proven to be absolutely water-tight, and the dam withstands the strains of water pressure without evidence of weakness.

FIG. 373.—LOOKING ALONG THE FACE OF THE SAN JOSÉ DAM, AT SAN LUIS POTOSI, SHOWING FACE OF WALL SUPPORTING SIDE OF PRINCIPAL SPILLWAY.

The Santo Amaro Dam, Brazil.—At the end of May, 1908, there remained but 18,600 cubic yards of this great dam to complete it, out of a total of 737,539 cubic yards. The photograph, Fig. 376, was taken March 3d, from practically the same point of view as Fig. 105, page 146, and shows the dam well along toward completion. The progress made in the construction of this dam as summarized in the semi-monthly reports, constitutes a most interesting record of that class of work, which is here presented in tabulated form, as the most complete and continuous record of the work accomplished by a given quantity of water in hydraulic sluicing that has even been published:

FIG. 374.—MASONS AT WORK ON THE SAN JOSÉ DAM, MEXICO.

FIG. 375.—ILLUSTRATING THE BONDING OF THE MASONRY OF THE SAN JOSÉ DAM MEXICO.

Fig. 376.—The Santo Amaro Dam, Brazil, approaching completion, March 3, 1908.

PROGRESS TABLE, SANTA AMARO DAM.

Month.	No. Days.	Actual Running Time. Hrs. Min	Daily Average Running Time. Hrs. Min.	Monitor Discharge. Cu. Yds.	Material in Dam. Cu. Yds.	Ratio Material to Water.	Material in Dam Daily Average. Cu. Yds.	Material in Dam, Hourly Average Actual Work. Cu. Yds.
June		15 00		10,265				
July	6	23 50	6 28	32,051	7,586	17.9%	1264	195
Aug.	15	61 21	4 05	71,183	8,756	12.3	584	143
"	16	193 42	12 06	158,309	32,996	20.8	2062	170
Sep.	15	142 01	9 28	123,343	18,625	15.1	1241	131
"	15	327 39	21 50	343,221	77,392	22.5	5159	236
Oct.	15	355 50	23 44	390,670	80,923	20.7	5395	227
"	16	370 05	23 08	419,717	75,169	17.9	4698	203
Nov.	15	118 25	7 54	127,173	24,246	19.0	1616	205
"	15	261 21	17 25	308,411	55,230	17.9	3682	211
Dec.	15	305 12	20 21	356,398	58,468	16.4	3898	191
"	16	289 45	18 03	333,973	21,010	6.3	1313	72
Jan.	15	125 54	8 24	159,796	12,500	7.8	833	99
"	16	303 27	18 58	380,631	45,408	11.9	2838	149
Feb.	14	275 54	19 42	327,214	34,078	10.4	2434	125
"	15	315 32	21 02	331,925	30,907	9.3	2060	98
Mar.	15	243 43	16 15	241,727	35,889	14.8	2392	147
"	16	261 49	16 22	256,646	21,756	8.5	1359	83
Apr.	15	235 25	15 42	132,709	26,700	20.1	1780	113
"	15	126 28	8 26	66,808	14,000	20.9	933	111
May	15	176 08	11 44	98,477	16,000	16.2	1067	91
"	15	197 10	13 08	117,053	20,391	17.4	1359	
	310	4725 41	15 25	4,787,700	718,030	14.9	2316	152

The average volume of water used in all this period of time, covering a little more than ten months, was 7.6 cubic feet per second. The maximum was 10.0 second-feet, and the minimum 3.8 second-feet.

After the end of March, 1908, when practically all the material was delivered to the extreme eastern end of the dam, or east of the center, it was necessary to handle it a second time with a "booster" pump, of smaller capacity than the main pump. The volume was thenceforward reduced to about 4 second-feet, but the percentage of solids carried was maintained or increased.

The material was excavated to the spillway level out of the high hill at the west end of the dam. A spillway was there made with a minimum width of 250 feet, and a maximum discharge capacity of 10,000 second-feet. The floor of the spillway reached down into a fairly hard quality of granite. At one stage of the work a hydraulic elevator was used to lift the sluiced material to the height of the west end of the main flume, after it had been excavated by the monitor and flowed by gravity across the spillway area. An isolated section of the hill was left between the spillway channel and the dam, and up the steep face of this island the elevator pipe was placed with a jet of water added from the main pump, which raised the stream carrying earth in suspension and deposited it into the flume, some 25 feet higher.

The remarkable picture shown in Fig. 377 is the best possible demonstration of the effect of hydraulic sluicing in the segregation of pure clay from a mass of coarser materials, and its deposit in a condition of stable solidity within a short time. It is a picture of the clay core of the Santo Amaro dam accidentally exposed to view by a break in one of the lateral levees, the effect of which was to empty the pond on the dam and wash

FIG. 377.—ILLUSTRATING THE COMPACT CHARACTER OF THE CLAY CORE OF THE SANTO AMARO DAM, ACCIDENTALLY EXPOSED TO VIEW BY A BREAK FROM THE POND ON TOP OF THE DAM.

away the levee and its supporting base of coarser material for a distance of about 50 feet. The break, which occurred in the up-stream slope, caused the loss of 400 cubic yards of material, but the demonstration of the stability of the clay core, none of which had been deposited three months, and some of it but a few days, was worth far more than the loss. The clay as exposed was left standing almost vertically, and it had successfully withstood the wash of water pouring over it from the emptying of a pond several hundred feet long, 50 to 60 feet wide, and 2 to 4 feet deep, with comparatively slight erosion. The break was caused by the saturation of the levee, built of material brought in by cars, which, not being sluiced and assorted, the finer particles from the coarser, there was no gradation from fine to coarse, and consequently a comparative lack of drainage. The break occurred on the line of contact between the sluiced clay and the material deposited by cars. This method of building the levee was employed only east of the center of the dam.

The conditions of solidity and maturity in the clay core shown in this case is a most reassuring endorsement of the superiority of the hydraulic sluicing method of dam construction.

A similar demonstration was made in very much the same manner of the stable and satisfactory condition of the clay core of the Necaxa dam a few months ago. The pond on top of the dam was accidentally emptied by a cutting down of the overflow channel, causing a loss of a quantity of soft, immature material, but showing a bank of firm clay formed a few feet beneath the surface. It is somewhat difficult to conceive of percolation through such a mass of clay as is usually segregated and assembled in the center of hydraulic-fill dams after it has matured. It must be even superior in impermeability to such a puddle core as was built in the north and south dikes of the Wachusett dam, which consisted of 6-inch layers of fine loam soil, well sprinkled and rolled. Recent experiments to determine the permeability of this type of earth or loam core in an earth dam have been made by means of a series of pipes driven into the embankments of the Wachusett dikes. The results as reported by the *Engineering Record*, July 18, 1908, indicate that while the plane of saturation on the reservoir side of the loam core was level with the water in the reservoir, it dropped immediately below this core to a level slightly above the base of the dam. Weekly measurements proved that the amount of water draining out of the dike was not in excess of what might be expected, as the natural drainage from precipitation on the area of the dike itself. No masonry or concrete core-wall ever built in an earth dam can show better results than these, and few can compare with them in the absence of percolation from the reservoir. The dike type of dam is undoubtedly a reliable type, when properly made with suitable materials, especially where the core can be sluiced out of the available material and deposited under water.

A High Japanese Dam.—Fig. 378 is a contour plan of a dam of unusual height projected as a hydraulic-fill structure, to impound water for power purposes on the Oigawa river, in Japan. The dam has been planned by J. M. Howells, chief engineer of the Anglo-Japanese Hydro-Electric Company, and is to be 300 feet in height above the river-bed at its up-stream toe, or 325 feet in maximum height. It will occupy a narrow gorge, whose width at the low-water line of the river is 200 feet, and at the crest of the dam but 700 feet.

The volume of water to be cared for during construction in by-pass tunnels may reach 80,000 to 100,000 cubic feet per second in time of extreme flood. Three tunnels, each 30'×24', are planned for this purpose.

A section of the dam as proposed by the board of consulting engineers, of which the author was a member, who were called upon to review the

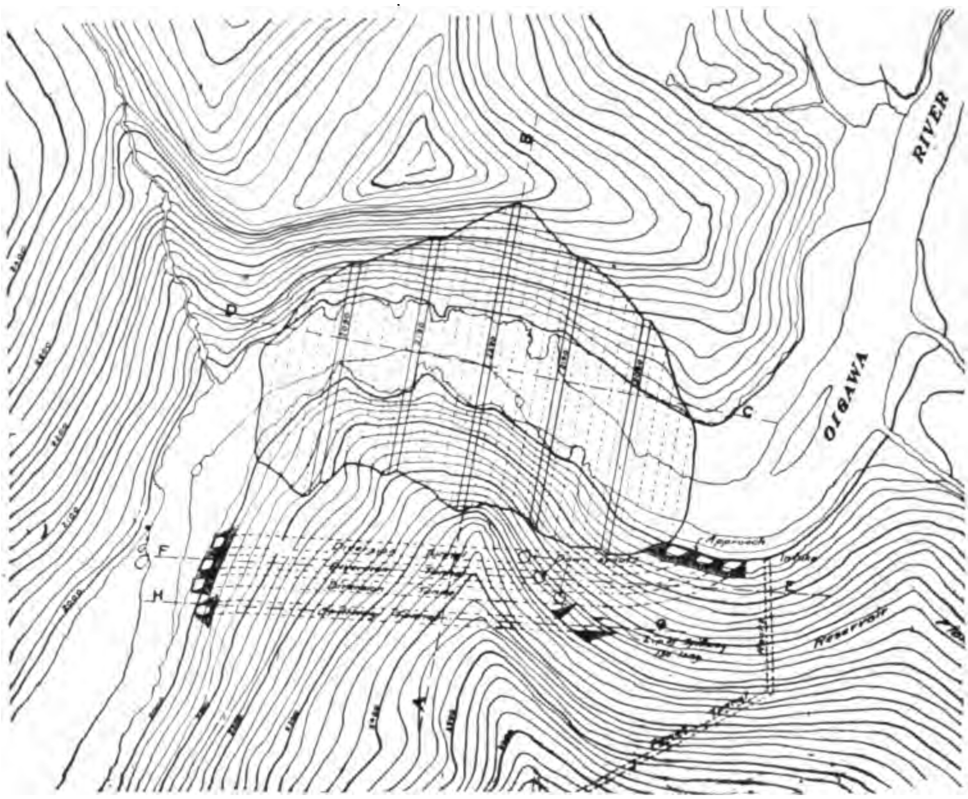


FIG. 378.—CONTOUR PLAN OF HYDRAULIC-FILL DAM PROJECTED FOR POWER STORAGE AT IKAWA ON THE OIGAWA RIVER, JAPAN.

general plans of the project for power development, is shown in Fig. 379. From this section it will be seen that two concrete cut-off walls are proposed to be carried down to bed-rock through the gravel deposit of the channel, both above the center line. The upper wall is to be at the down-stream toe of the temporary coffer-dam of loose rock, faced with plank, which will form the up-stream toe of the large dam.

On top of the concrete wall a diaphragm of sheet steel plates is to be built to the height of 100 feet, reaching to the face of the dam on the

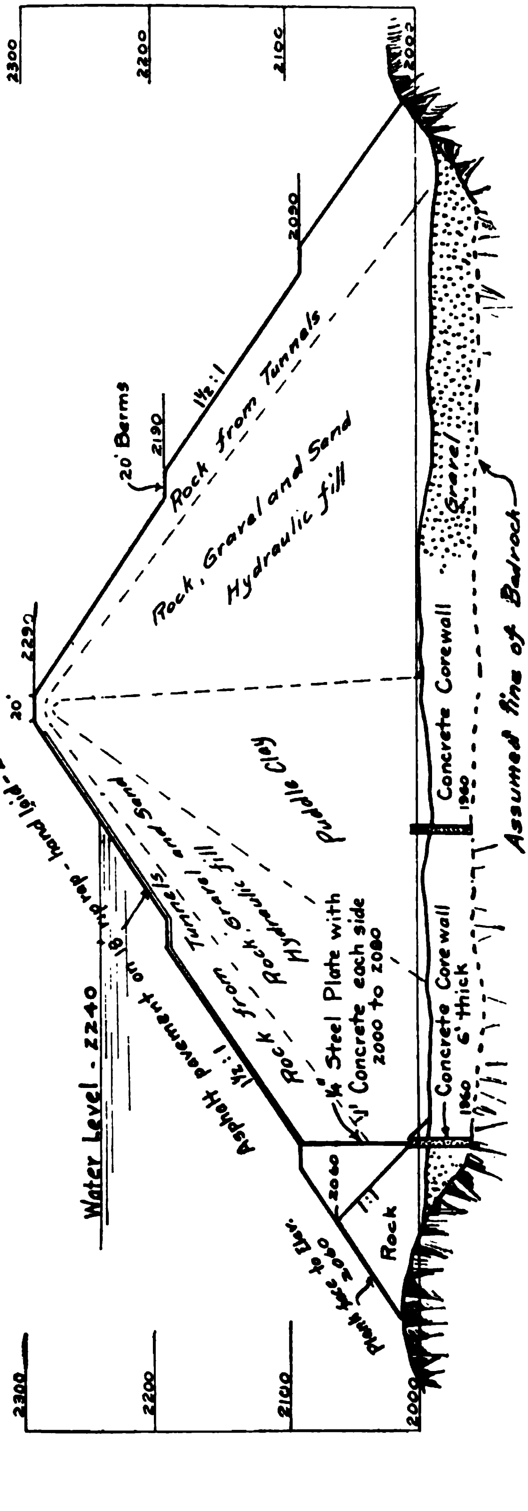


FIG. 379.—SECTION OF PROJECTED DAM, 320 FEET HIGH, ON THE OIGAWA RIVER, JAPAN.

reservoir side. This diaphragm is to be continued in the form of a water-tight asphalt pavement up the slope to the crest of the dam. The core of the dam will consist of clay, while the outer thirds will be formed of rock, slaty gravel, and sand, to be sluiced from an extensive deposit of loose material of most favorable character, lying in a high plateau or valley, some 200 feet higher than the top of the dam. The contracted situation of the dam compelled the adoption of side slopes of 1.5 on 1 on each side. The crest, however, will be 50 feet higher than the lip of the spillways. Fig. 380 is a longitudinal section through the dam-site.

The dam will contain 2,450,000 cubic yards, all of which, except the spoil from the tunnels, will be sluiced into position. The site is a remarkably favorable one for hydraulic-fill construction, because of the heavy gradients which can be given to the sluices, the superior quality of all the materials, and the abundance of water. The annual rainfall recorded at the dam-site for eight years averages 11.7 feet, with a maximum of nearly 16 feet.

Dixville, N. H., Earth Dam.—A dam of novel type is under construction to be completed in the current year of 1908, at Dixville, New Hampshire. It is built of earth with reinforced concrete core-wall resting on steel sheet piling. The dimensions given in *Engineering Record*, April 25, 1908, are as follows:

Maximum height	76 feet
Top width	25 "
Length on crest	500 "
Up-stream slope	2 on 1
Down-stream slope	1½ on 1

The structure when completed will contain 80,000 cubic yards, and about 3500 cubic yards of reinforced concrete. The sheet piling was driven to depths of 10 to 32 feet in the bottom of a 6-foot trench. The tops of the piles were incorporated into the bottom of the concrete core-wall, which was made 3 feet thick at base, 10 inches thick at top. It is located 3 feet down stream from the top of the up-stream slope. The concrete cost about $4.50 per cubic yard in place.

On the up-stream side of the core-wall is a puddled earth core, 20 feet thick at the base battering to 8 feet at the top, composed of a mixture of clay and gravel, puddled and rolled. All earth on the upper slope was put in in layers 6 inches thick, thoroughly rolled and compacted. This work showed a cost of 25 cents per cubic yard by force account. The dam was built on the plans of Arthur W. Dudley, C.E., of Manchester, N. H., approved by Prof. Robert Fletcher, of Dartmouth College, consulting engineer.

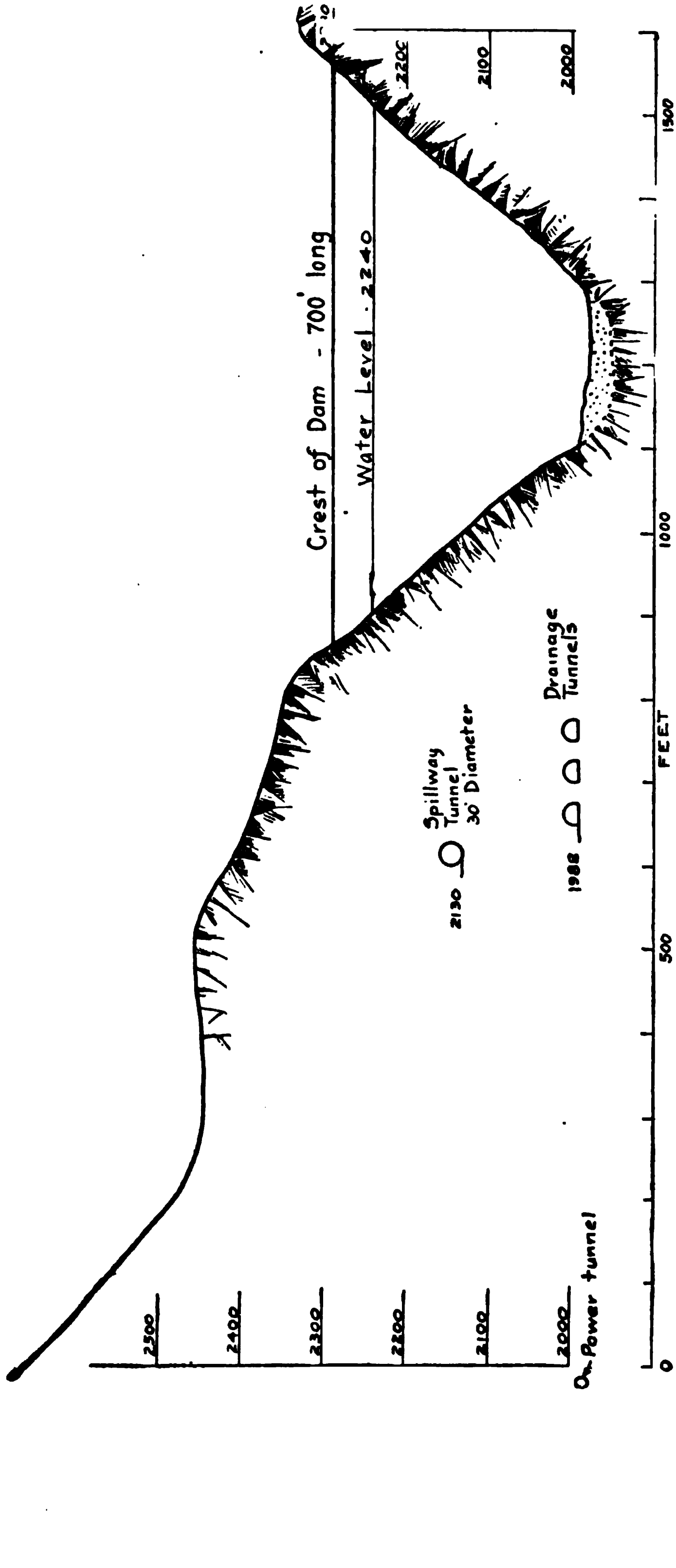


FIG. 380.—LONGITUDINAL SECTION OF THE IKAWA DAM, JAPAN, LOOKING DOWN STREAM

Arrowhead Reservoir Company's Dam, Little Bear Valley, California.—On page 180 a brief description is given of the combination dam with concrete core-wall and earth which has long been under construction in the San Bernardino mountains. An illustrated account of the general project appears in *Engineering Record,* April 4, 1908. In the following month of August the local press recorded the signing of a contract to add 12 inches of concrete to the up-stream face of the core-wall to stop the leakage taking place and remedy defects in the wall.

Leakage through Concrete Core-walls.—An earth dam built at Lynn, Mass., in 1903, with a concrete core-wall, has been found to leak from about 239,000 to about 448,000 gallons per day, depending on the water-level of the basin. As described in *Engineering Record* of March 7, 1908, the dam is 2200 feet long, 45 feet high, 52 feet wide at the crest, and has a core-wall of concrete 4 feet 8 inches thick at the top, 9 feet 6 inches thick at the bottom. The core-wall contains 22,000 cubic yards of concrete. It extends to a depth of 25 feet below the base of the dam. The front face of the wall was plastered with a 1:1 mortar. The core-wall was built between two rows of 6-inch sheet piling, driven by steam-hammer in the bottom of the trench to a depth of 26 feet, or about 18 feet below the bottom of the concrete wall, where the piles brought up against hard material. The earth in the dam "was deposited in layers and puddled or rolled where necessary." The slopes of the dam are $1\frac{3}{4}$ on 1 each side.

The fact that a dam with a core-wall of the thickness described and plastered as it was, should leak is significant of the untrustworthiness of concrete or masonry core-walls in general.

The John Day's Dam, California.—This is a concrete and earth structure completed on the South Fork of Eel river, in Mendocino county, California, in the summer of 1907. The concrete portion of the dam is an overfall spillway section 350 feet long, with an extreme height of 73 feet. The remaining 280 feet is an earth embankment having a thin concrete core-wall, resting partly on rock and partly on a sandy earth foundation. The earth embankment is 10 feet wide on top, and has slopes of 3 on 1 up stream and $2\frac{1}{2}$ on 1 down stream. Where the core-wall is on the rock it is 4 feet thick at top, battering 1:12 on each side. Where it is on earth foundation it is reduced to 8 inches thickness, reinforced with a diaphragm of expanded metal, and resting on a base of concrete 3 feet wide, 2 feet thick.

The concrete portion of the dam is designed to withstand floods of 100,000 second-feet, or more, passing over its crest, giving a depth of overflow of 20 feet and upwards. The down-stream face of the dam has been built in vertical and horizontal steps, most of which are 5 feet in height and the same in width. Eel river has a watershed of 324 square miles area above the dam.

The dam was designed by Edwin Duryea, Jr., M. Am. Soc. C. E., of San Francisco.

Roland Park Hydraulic-fill Dam, Baltimore, Md.—An interesting application of the hydraulic-sluicing method to the grading of a hill

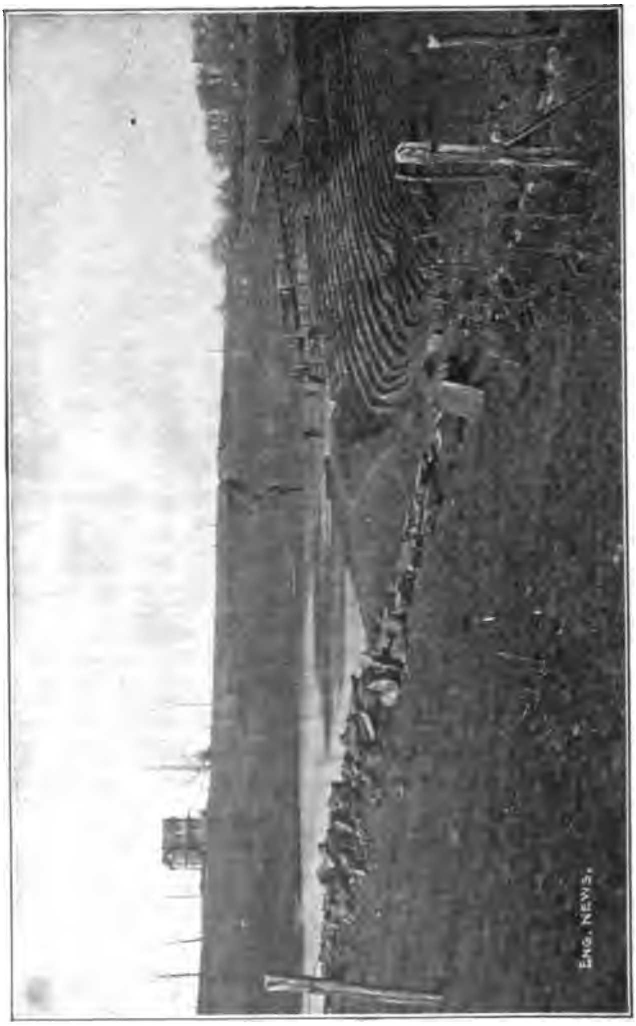


FIG. 381.—Roland Park Hydraulic-fill Dam, Baltimore, Md.

and the building of a small dam is described in *Engineering News*, June 11, 1908. The grading of the hill required the removal of 50,000 cubic yards of earth. This was placed in a dam 400 feet long, 24 feet high, all of which was constructed by the hydraulic process, the earth being deposited along the face of the dam by means of flumes, and held in place by the use of 1″×12″ boards, 16 feet long. These boards, set on edge, were held in position by stakes driven into the earth composing the fill. Each tier of boards was set so that they lapped, vertically, over the next lower tier by 2 inches, thus forming a backing for the earth and water to fill against. The earth thus held was built up on a slope of 2 on 1. The engineer who designed the plant and built the dam was Mr. John H. Walzl. This method of holding the slopes is known as the "shear-board method," and is successfully and extensively used in controlling the fills made of sluiced clay and sand in the regrading of Seattle, Wash., described and illustrated on pages 509 to 514 inclusive. Bulkheads are thus formed on average slopes as steep as 1.5 on 1.

APPENDIX

CONTAINING TABULATED DATA OF THE COST OF RESERVOIR CONSTRUCTION PER ACRE-FOOT IN THE UNITED STATES AND IN FOREIGN COUNTRIES.

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, "	Rockfill	3,500	100,059	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
Faucherie 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
Yorba dam, California..........	Hydraulic-fill	1,171	38,000	32.50
New Croton dam, New York....	Masonry	180,000	7,631,000	42.00
Wachusett dam, Massachusetts..	"	193,300	2,270,116	11.74
Round Hill dam, Pennsylvania..	Masonry and earth	4,050	240,548	59.39
Pedlar River dam, Virginia......	Concrete	1,115	103,708	93.00
Canistear dam, New Jersey......	Earth	7,390	341,000	46.15
Glenwild dam, New York.......	"	3,675	47,360	12.90
Laramie river dam, Wyoming...	"	120,000	117,200	0.98
Cedar Groove Res. dam, N. J.....	"	2,150	660,000	307.00
Belle Fourche dam, South Dakota	"	215,000	879,164	4.09

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.
Cousin, France	Masonry	1,297	$247,600	$190.00
Furens, "	"	1,297	318,000	245.00
Ternay, "	"	2,433	204,372	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
Mouche, "	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
Burrator dam, England	Masonry and earth	2,410	602,300	250.00
Assoun dam, Egypt	Masonry	863,000	11,907,000	13.80
Belubula dam, Australia	Brick and concrete	2,000	45,000	22.50
Burraga dam, "	Masonry	310	46,500	150.00
Cataract, Australia	"	78,860	1,599,600	20.28
Sand river dam, South Africa	Concrete	660	140,000	212.10
Lauchensee dam, Germany	Masonry	624	243,750	390.00
Talla reservoir dam, Edinburgh	Earth	10,280	1,220,000	118.66

TABLES OF RESERVOIR CAPACITIES AND AREAS.

Escondido 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	....	8,698	
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 80-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	

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	103.0	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	

PAUBA RESERVOIR-SITE, SAN DIEGO COUNTY, CALIFORNIA.

[Area of tributary watershed, 372 square miles; elevation of base of dam, 1850 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	62.8	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	

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	428	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	662	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.]

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	15,342

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	3,847	65	2,532	52,428
40	1,060	7,166	70	2,812	65,065
45	1,425	13,357	80	3,800	95,500
50	1,691	21,139			

Roosevelt Dam 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 Outlet 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	220	......	1,284,000

PLATE NO. 1.—PROFILES OF FOREIGN DAMS

9 in SPAIN.—Alicante.
Almanza.
Elche.
Hijar.
Lozoya.
Nijar.
Puentes.
Val de Infierno.
Villar.

22 in FRANCE.—
Avignonet.
Ban.
Bouzey.
Bosmolea.
Chartrain.
Chazilly.
Cher.
Echapré.
Furens.
Glomel.
Gros Bois.
Lampy.
Miodeix.
Mouche.
Pont.
Settons.
Sioule.
Ternay.
Turdine.
Vioreu.
Verdon.
Zola

PLATE NO. 2.—PROFILES OF FOREIGN DAMS.

5 in ALGERIA.—Gran Cheurfas.
Djidionia.
Habra.
Hamiz.
Tlelat.

3 in ITALY.—Lagolungo.
Cagliari.
Gorzente.

3 in ENGLAND and WALES.—Burrator.
Thirlmere
Vyrnwy.

1 in CHINA.—Tytam, Hongkong.

1 in AUSTRIA.—Komotau.

2 in EGYPT.—Assouan.
Assiout.

5 in INDIA.—Betwa.
Bhatgur.
Periyar.
Poona.
Tansa.

6 in AUSTRALIA.—Barossa.
Beetaloo.
Burraga.
Cataract.
Coolgardie.
Geelong.

1 in NEW ZEALAND.—Idaburn

2 in MEXICO.—La Jalpa.
Mercedes.

5 in GERMANY.—Einseidel.
Eschbach.
Lauchensee.
Remscheid.
Urft.

1 in BELGIUM.—Gileppe.

PLATE NO. 3.

29 Profiles of American Masonry Dams.

- Ashokan, N. Y.
- Boonton, N. J.
- Boyds Corners, N. Y.
- Bear Valley, Cal.
- Colorado, Texas.
- Cheesman Lake, Colo.
- Cross River, N. Y.
- Croton Falls, N. Y.
- Granite Springs, Wyo.
- Hemet, Cal.
- Indian River, N. Y.
- Ithaca, N. Y.
- La Grange, Cal.
- Manila, P. I.
- McCall's Ferry, Penn.
- New Croton, N. Y.
- Pathfinder, Wyo.
- Roosevelt, Ariz.
- Sodom, N. Y.
- Spier's Falls, N. Y.
- San Mateo, Cal.
- Sudbury, Mass.
- Shoshone, Wyo.
- Sweetwater, Cal.
- Titicus, N. Y.
- Upper Otay, Cal.
- Wachusett, Mass.
- Wigwam, Conn.

PLATE NO. 4.—SECTIONS OF CALIFORNIA

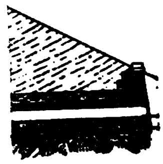
Pilarcitos Dam.
San Andrés Dam.
Old Crystal Springs Dam.

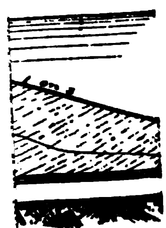
PLATE NO. 5.—SECTIONS OF TYPI
EARTH DAMS.

Llannefydd Dam, Wales.
Dodder Dam, Ireland.
Yarrow Dam, England.
Vehar Dam, India.

PLATE NO. 6.—SECTIONS OF T
EARTH DAMS

Stubden Dam, Ireland.
Leeming Dam, Ireland.
Loch Island Reavy Da
Rotten Park Dam, En
Ulley Dam, England.
Vale House Dam, Engl
De Torcy Dam, France
Montaubry Dam, Franc





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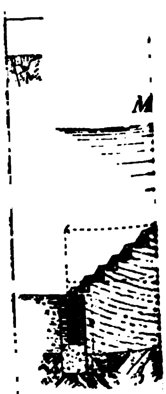

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