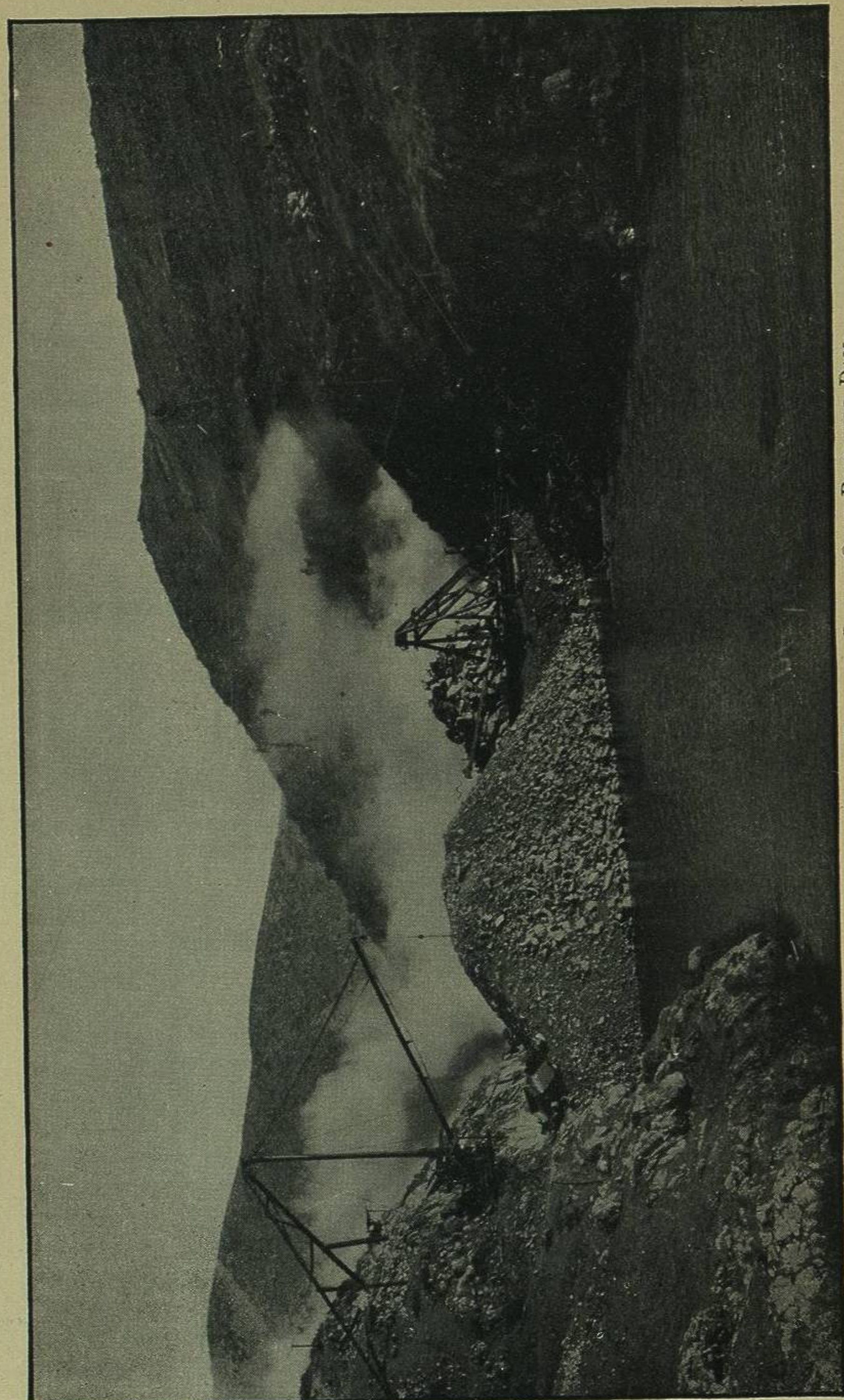

Fig. 19.—Explosion of Great Blast at Lower Otay Rock fill Dam.

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

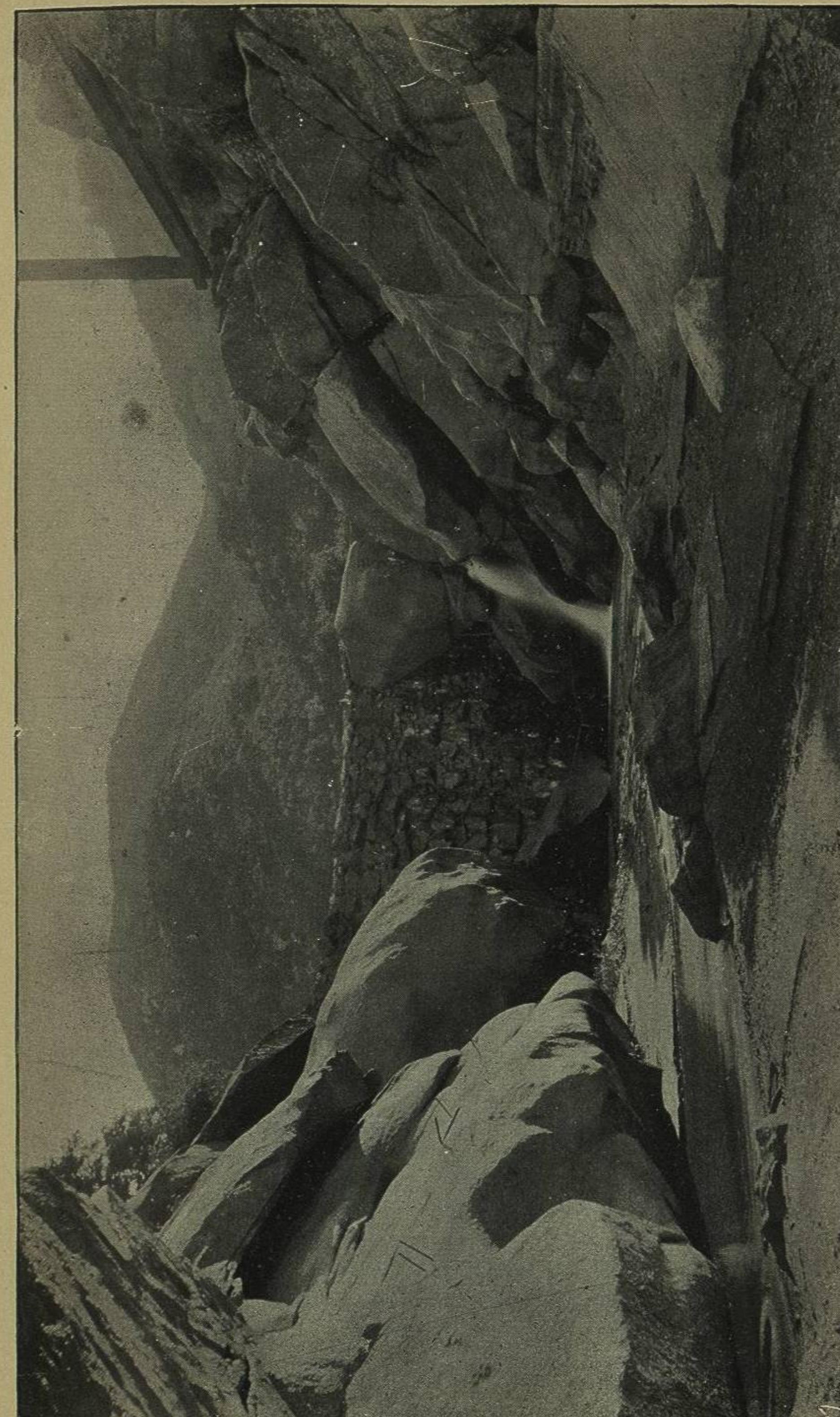

Fig. 20.—The Barrett Dam-site. Showing the Beginning of Masonry Foundations.
The material on left bank above the rock here shown is disintegrated granite to such depth as to require change of plans from original design.

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

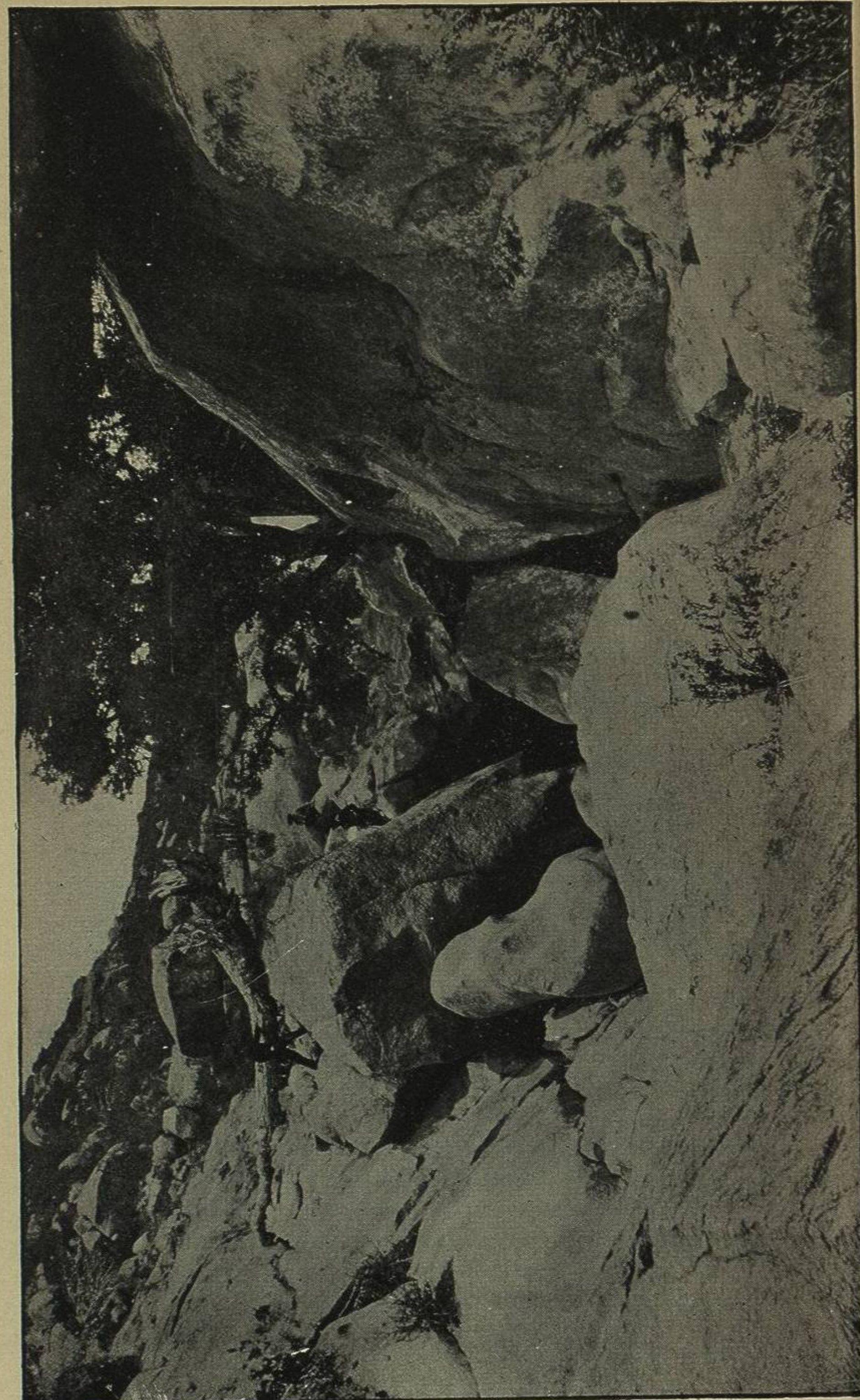

Fig. 21.—Morena Dam-site, Looking East.

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

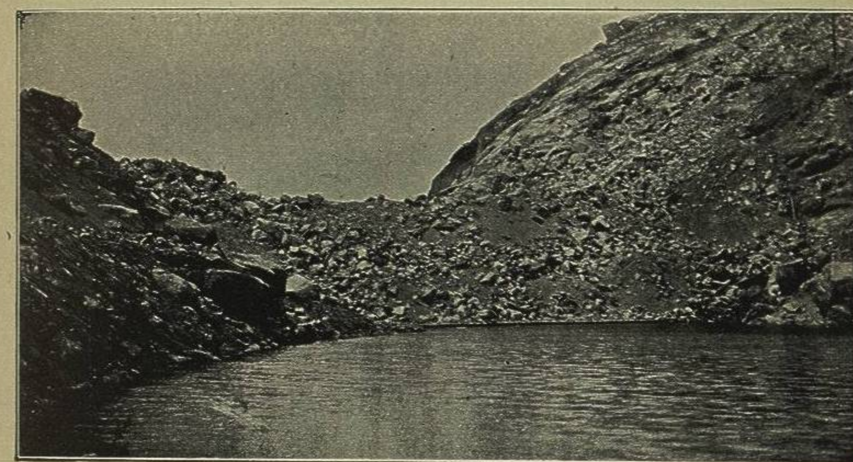

Fig. 22.—Morena Rock fill Dam in Process of Construction. Showing Top of Toe-wall above the Water-line.

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.

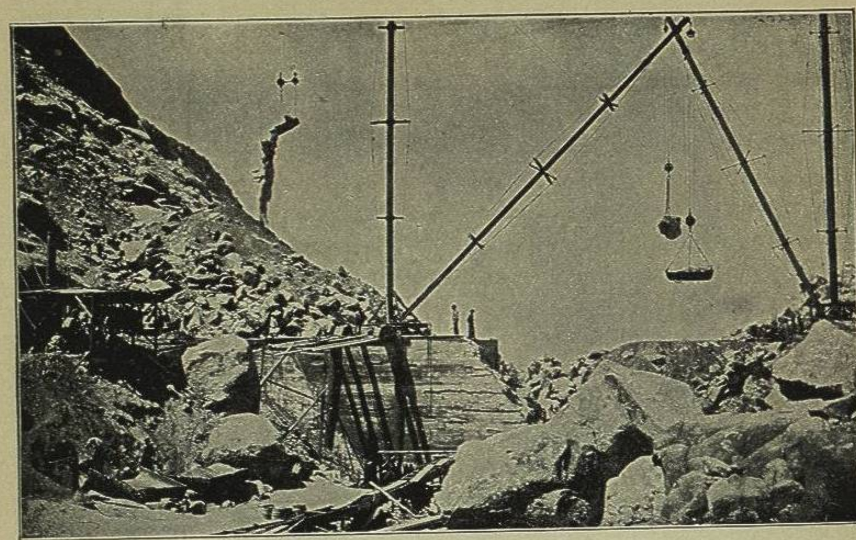

FIG. 23.—MORENA ROCK-FILL DAM, SHOWING A PORTION OF TOE-WALL UNDER CONSTRUCTION.

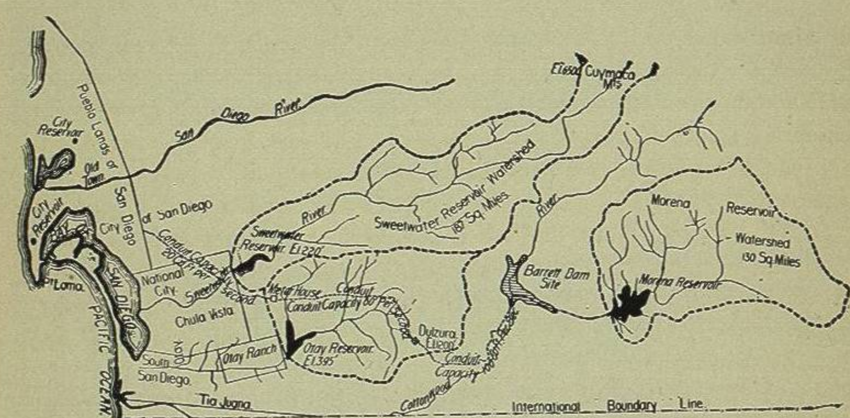

FIG. 24.—RESERVOIRS NEAR SAN DIEGO, CALIFORNIA.

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

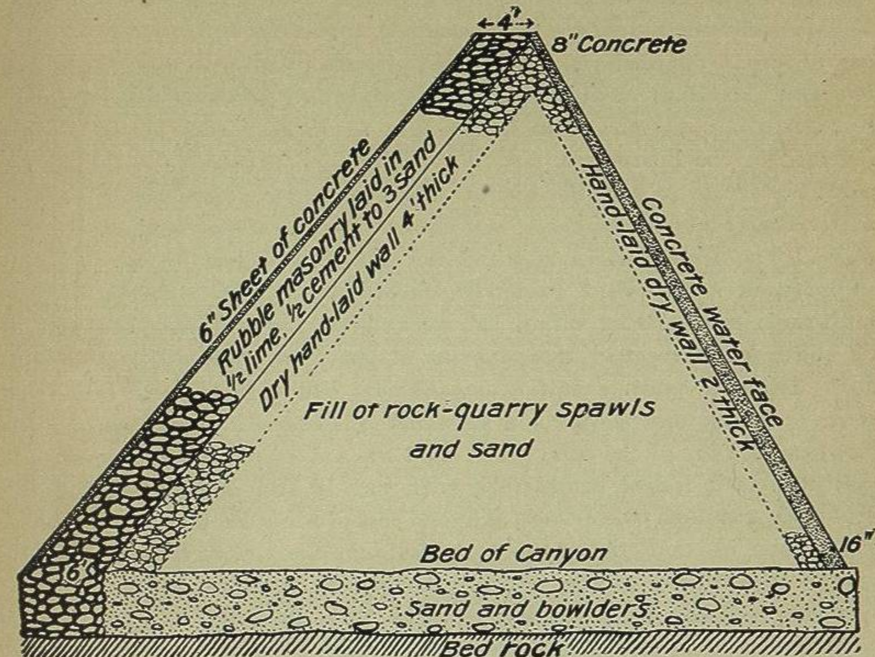

FIG. 25.—SKETCH OF RECONSTRUCTION OF CHATSWORTH PARK ROCK-FILL DAM.

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