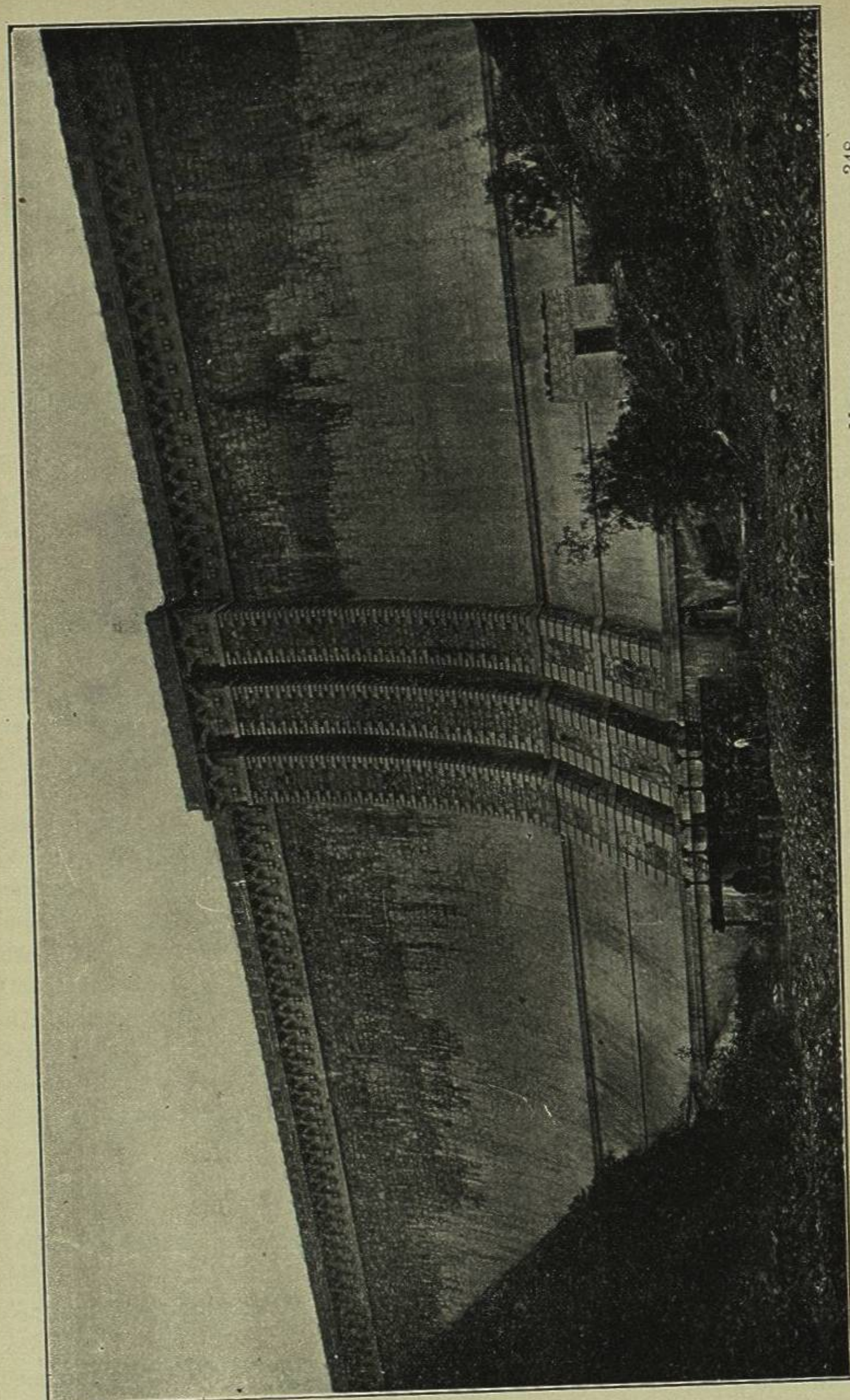

Fig. 254.—Front of Esperanza Dam, at Guanajuato, Mexico.

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

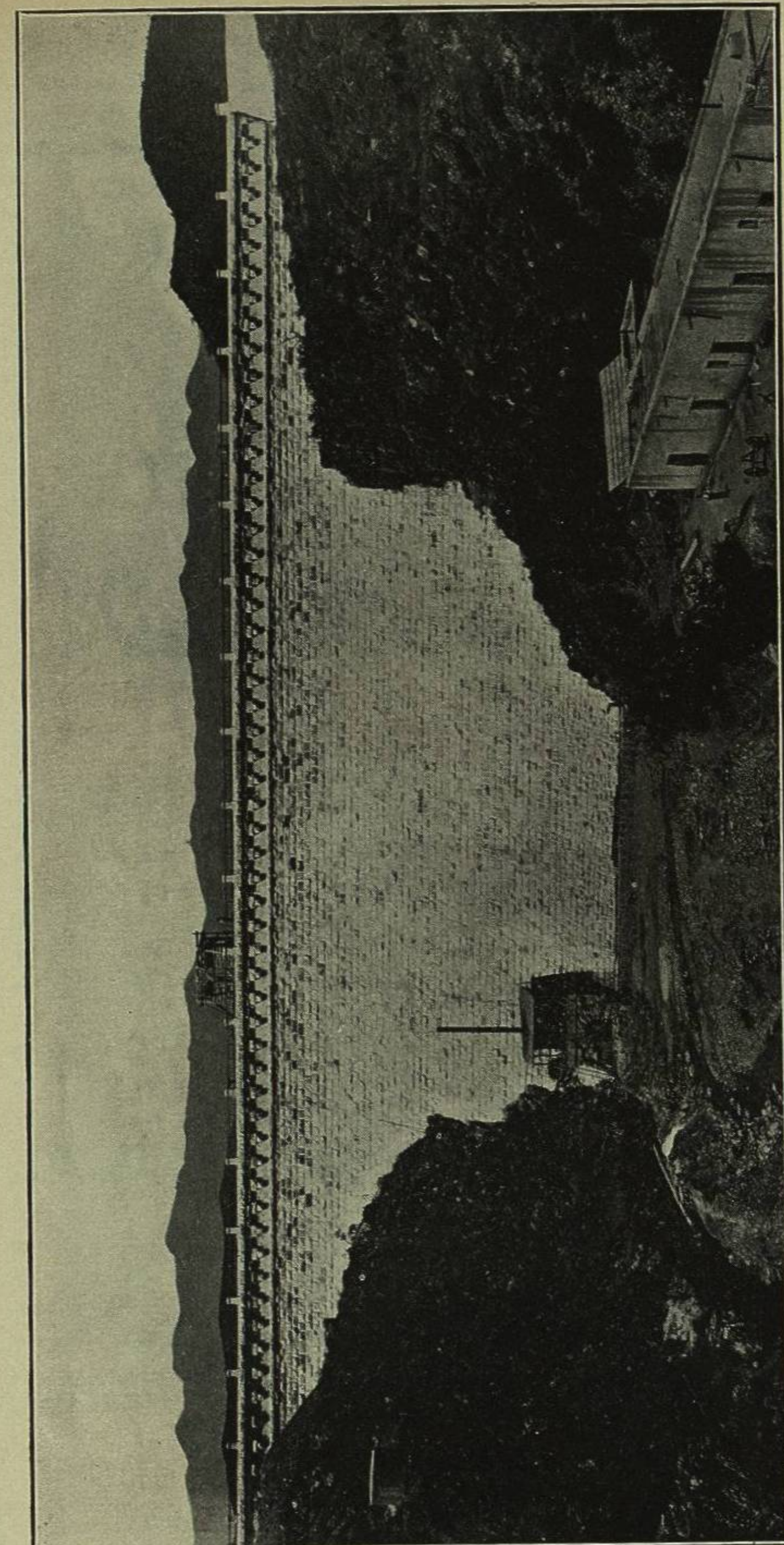

FIG. 256.—MERCEDES DAM, DURANGO, MEXICO. GENERAL VIEW FROM BELOW BEFORE COMPLETION OF GATE TOWER.

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,

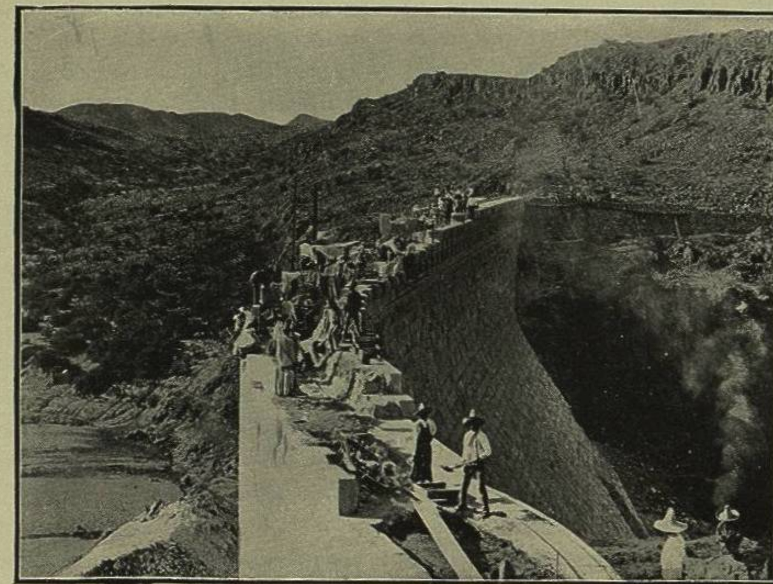

Fig. 257.—Mercedes Dam, Mexico, during Construction.

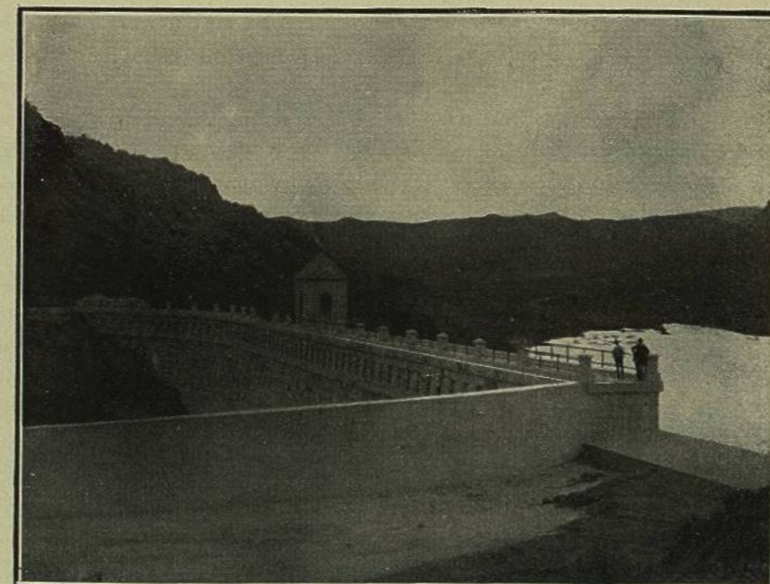

Fig. 258.—Mercedes Dam, Mexico, looking across Spillway Channel, showing Curved Portion at Far End.

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 Carlos Duran, 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

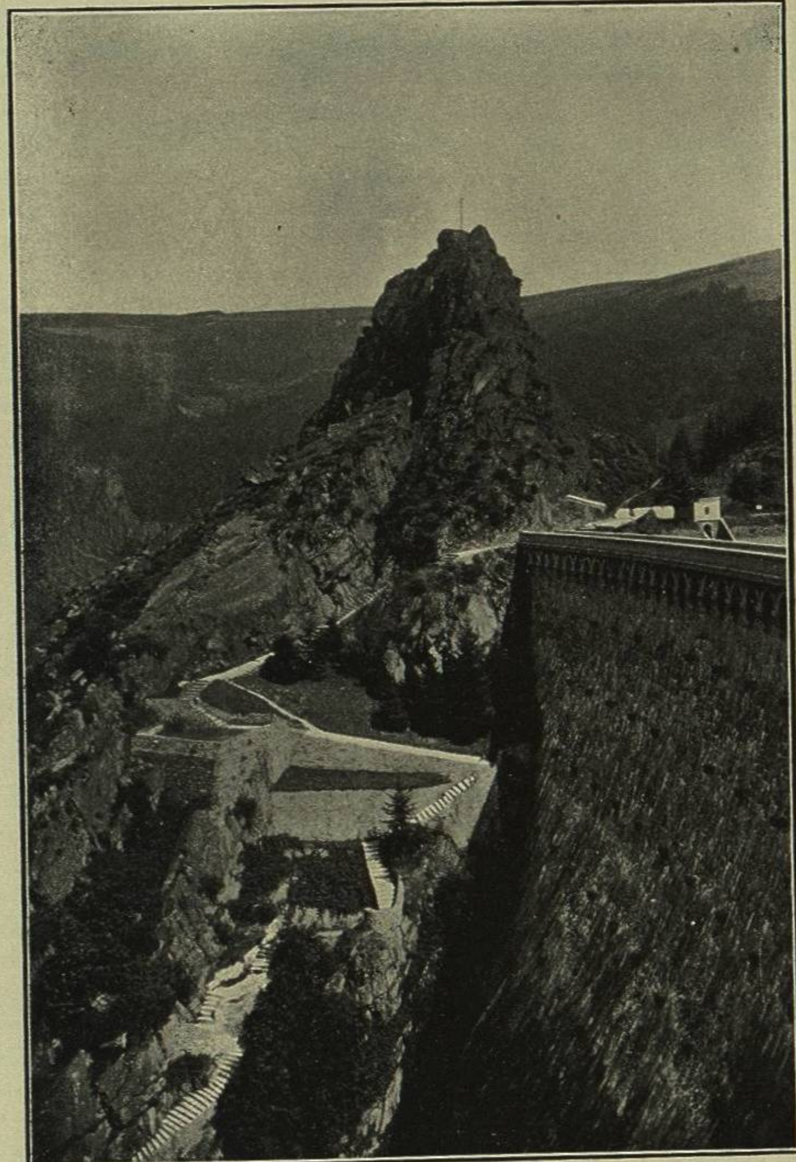

Fig. 259.—Furens Dam, St. Etienne, France, Down-stream Face.

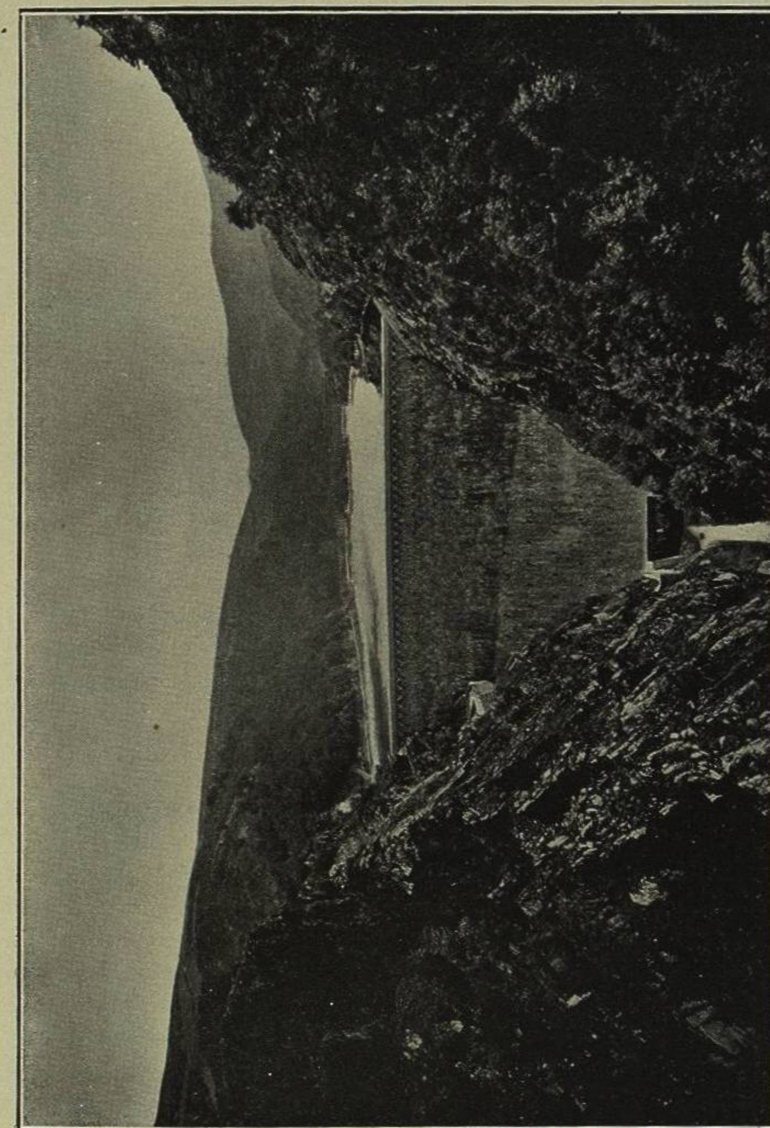

Fig. 260.—General View of Furens Dam, Guoffre d'Enfer, St. Etienne, France, showing Reservoir.