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, ⅜ inch thick, 8′ 10⅝″ wide, and 8 feet long, the concave side being placed towards the water. They thus present the appearance of a series of troughs or channels between the supports. The bent plates do not extend into the concrete at the base, but the bottom course consists of flat plates, and the course next to the bottom is dished in the form of a segment of a sphere, making the transition between the curved and straight form. The edges of the plates are beveled for calking, and riveted together with soft iron rivets. The joint between the steel and masonry structures at the ends is formed by embedding flat plates into the concrete, the face of which has the same slope as the face of the steelwork. The abutments project 8 inches beyond the line of the face-plates. The masonry-work consists of 342.6 cubic yards of rubble and 1087 cubic yards of concrete, and there was used in the work a total of 1751 barrels of Portland cement. The work was begun October 7, 1897, and completed March 5, 1898, under the supervision of R. B. Burns, Chief Engineer, Santa Fé Pacific Railway, Mr. W. D. Nicholson, Assistant Engineer, being directly in charge.

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

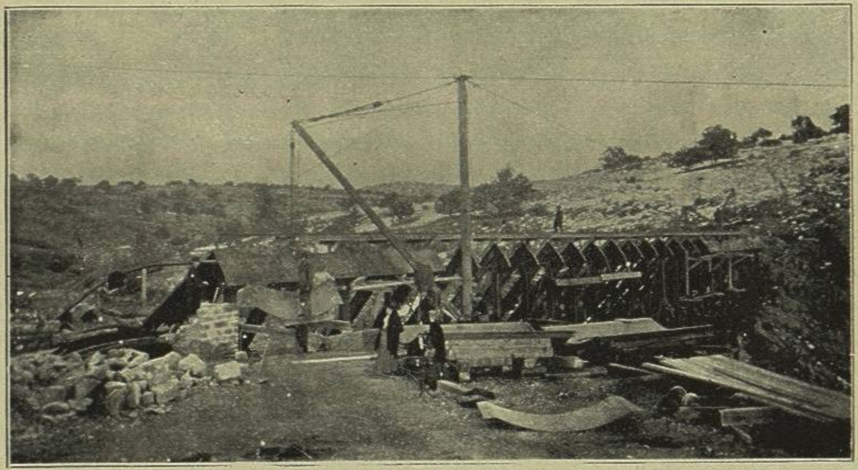

FIG. 294.—ASH FORK, ARIZONA, STEEL DAM, VIEW OF STEEL CONSTRUCTION FROM LOWER SIDE.

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.

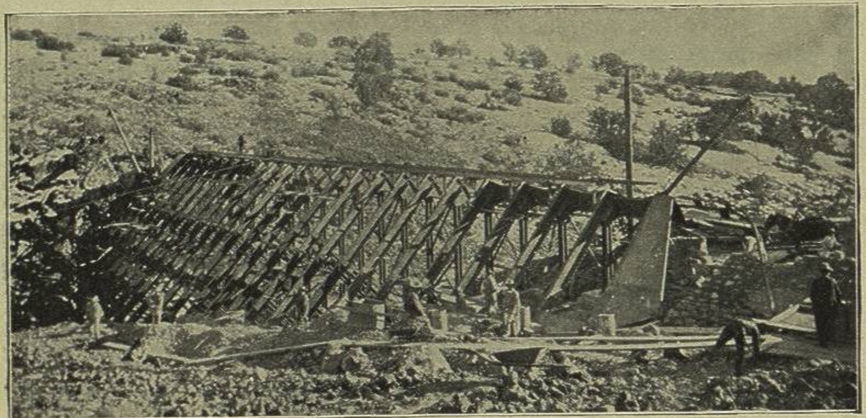

Fig. 295.—Ash Fork, Steel Dam, showing Frame ready to receive Plates.

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 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.

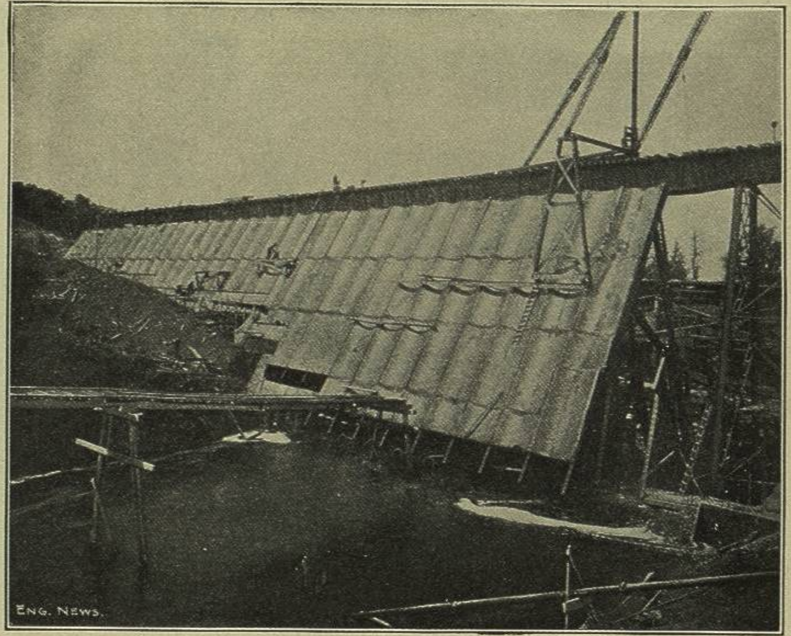

Fig. 297.—Redridge Steel Dam.

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 $\frac{3}{8}$ inch thick, 16 feet high, and having on each side a flat strip of $5\frac{7}{8}$ 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 Co., builders of the Ashfork dam. F. Foster Crowell, M. Am. Soc. C. E., acted as consulting engineer.

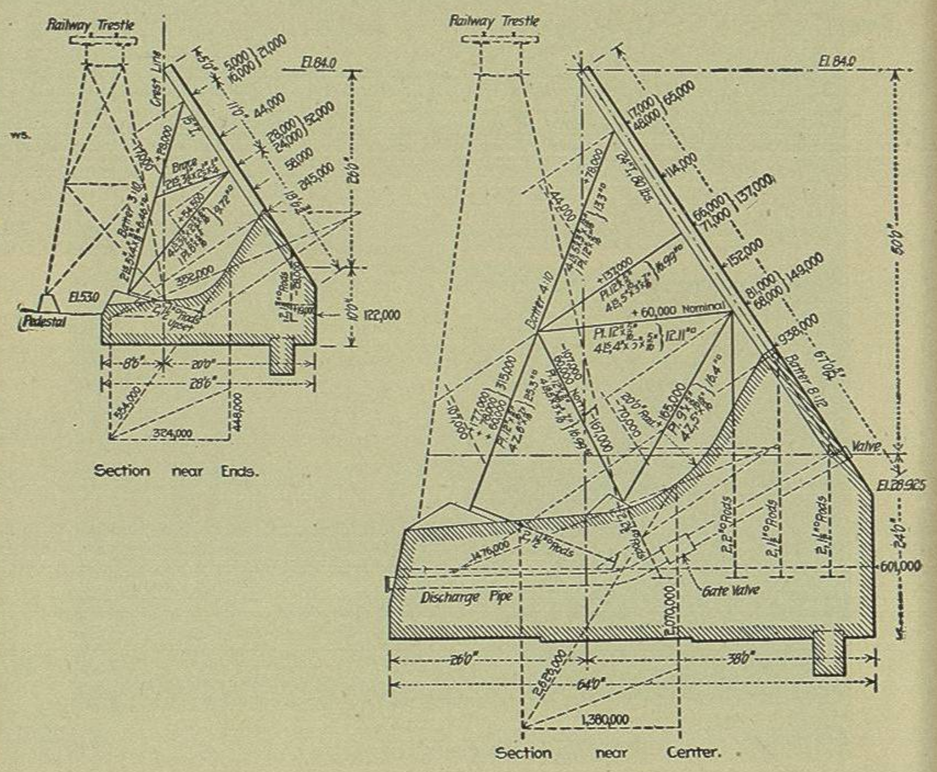

FIG. 298.—REDRIDGE STEEL DAM.

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

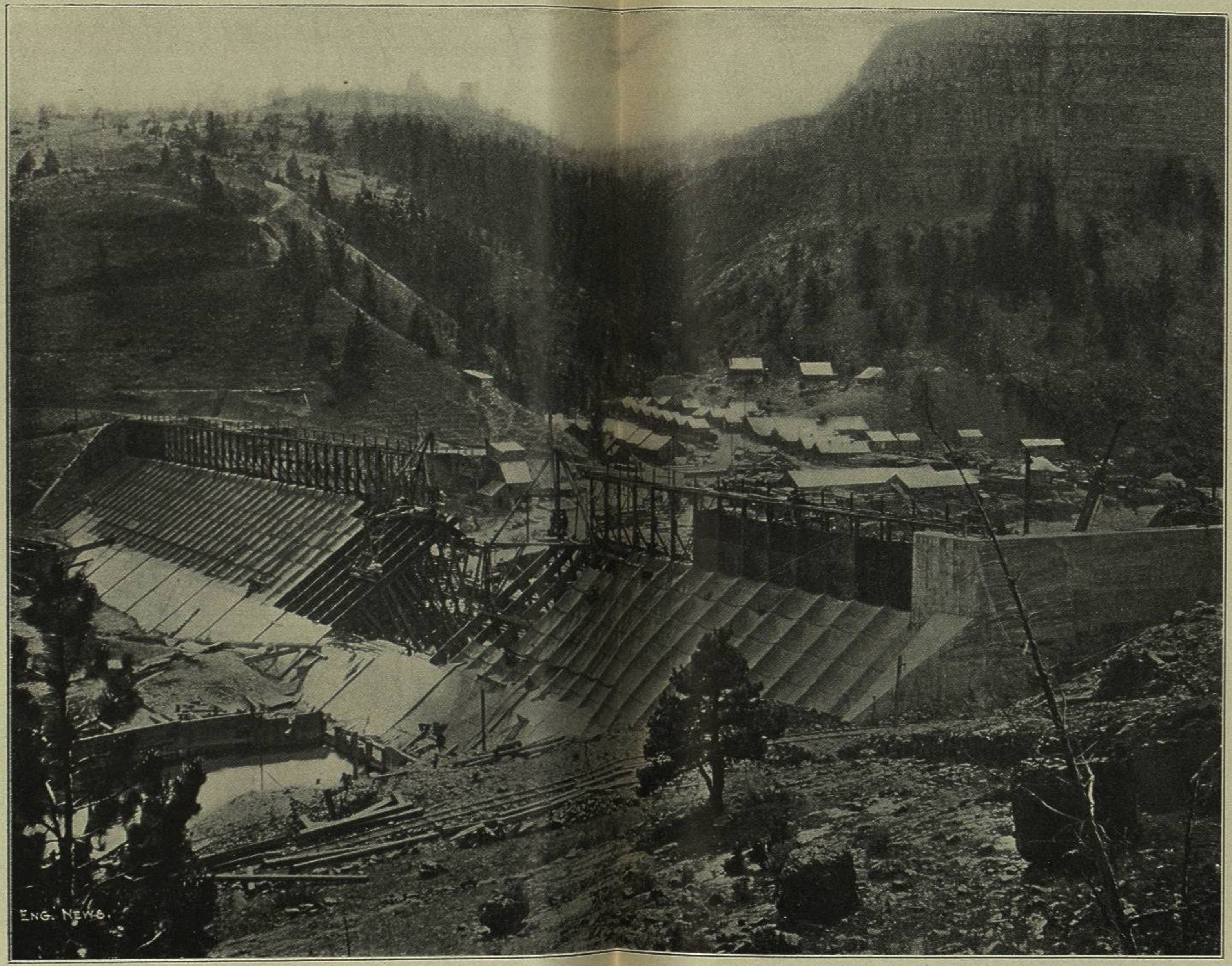

FIG. 299.—HAUSER LAKE DAM, MONTANA.

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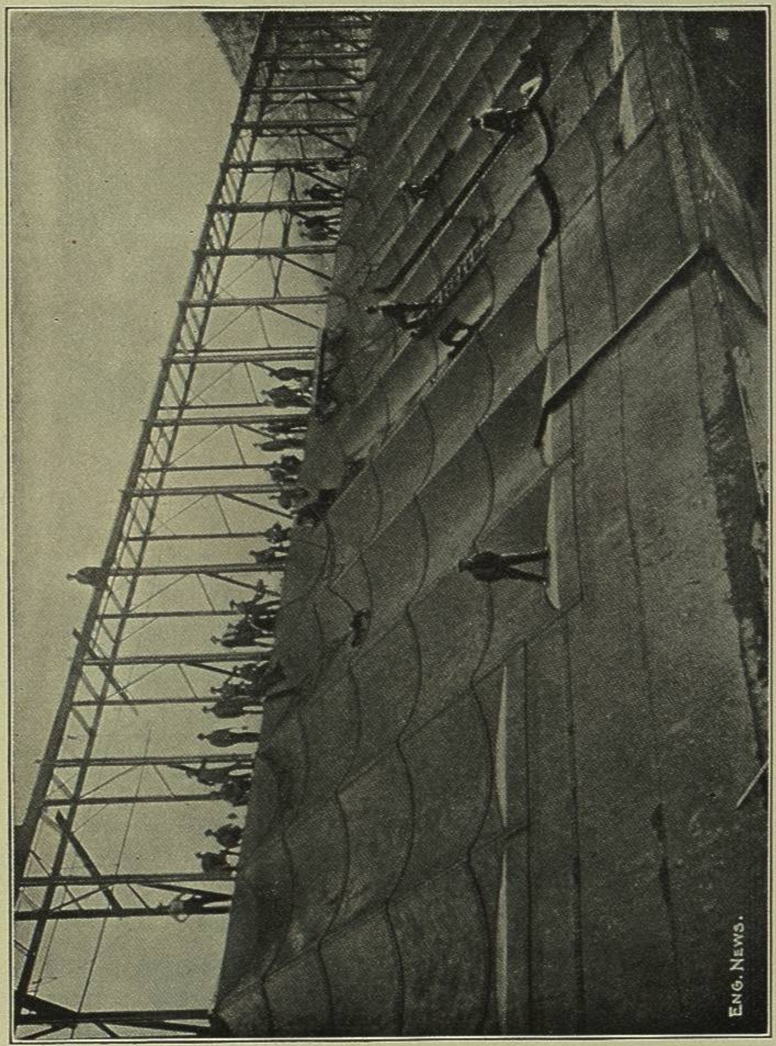
and the dam was then cleared off, covered with a concrete pavement, and that in turn by a bank of puddle clay.

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.



Eng. News.

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