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 stability 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 water-tight 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.

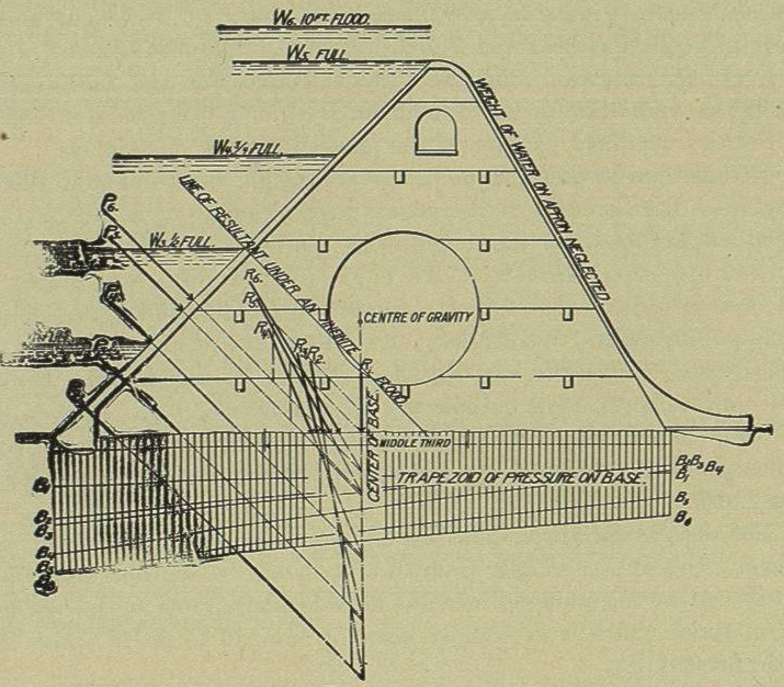

FIG. 306.

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 the edges and around the openings which are usually made through them, either for convenient passages or for the saving of material.

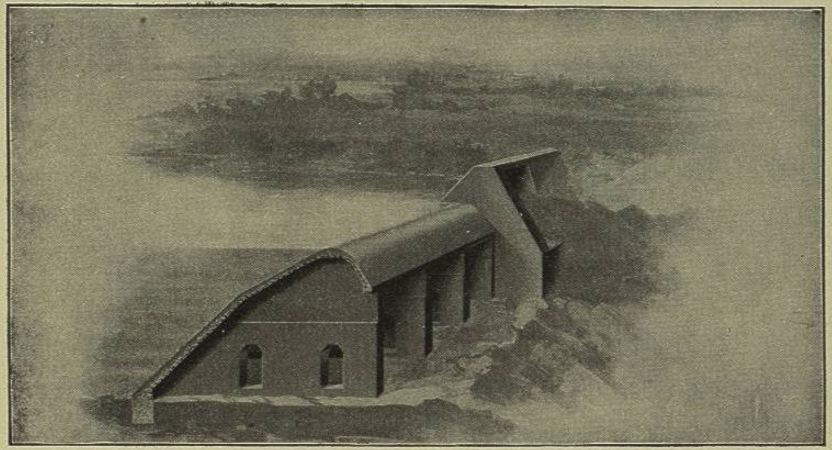

FIG. 307.

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 foundation 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-

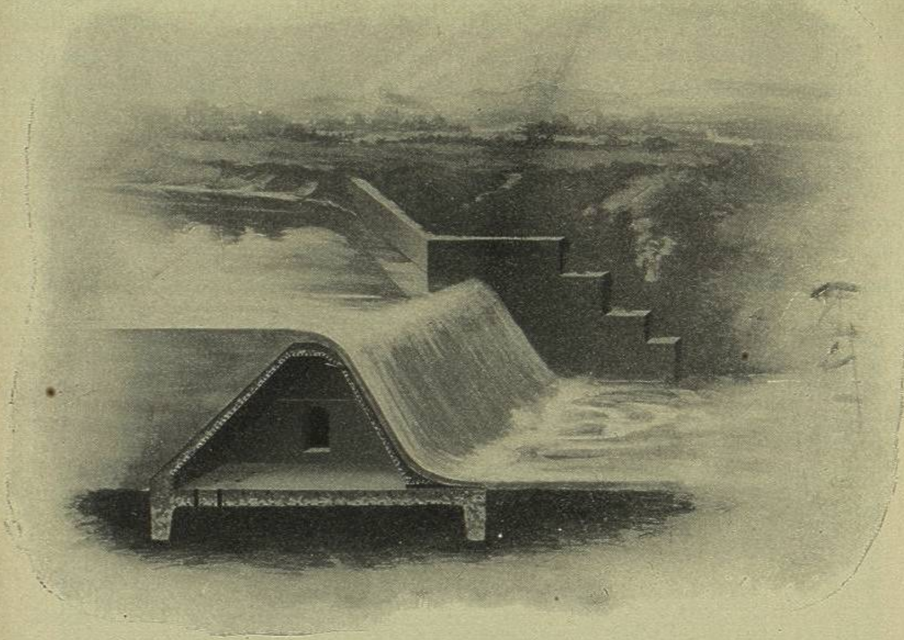

Fig. 308.

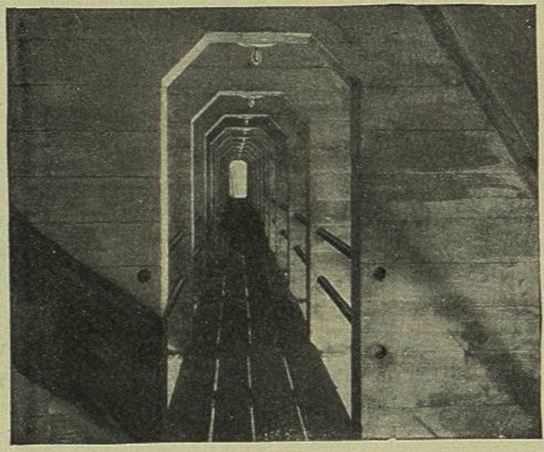

Fig. 309.

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 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

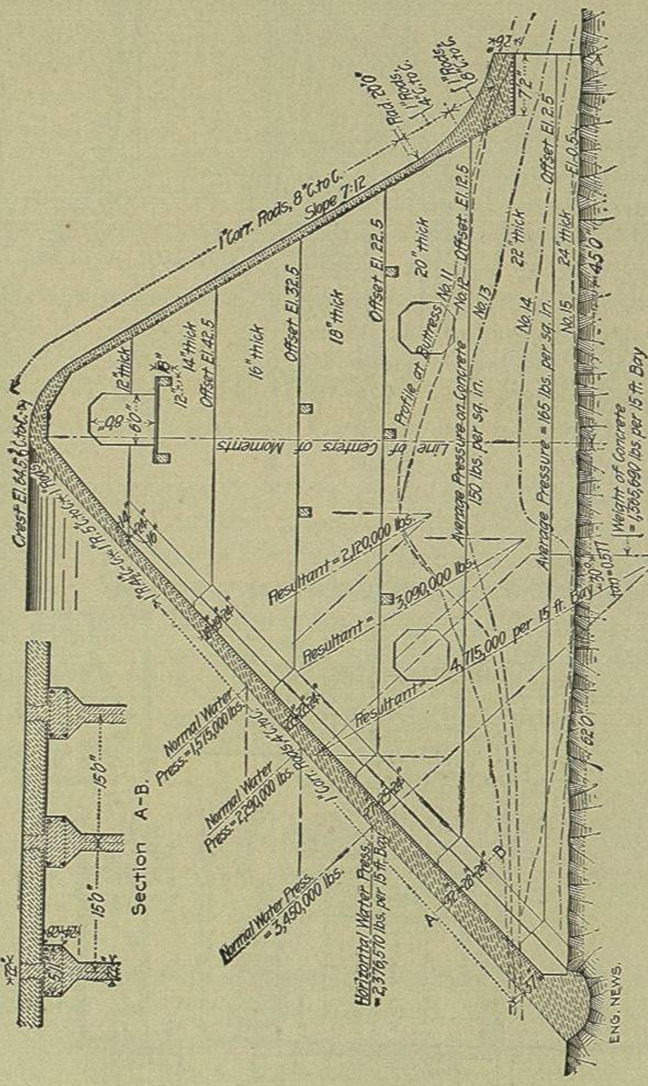

Fig. 310.

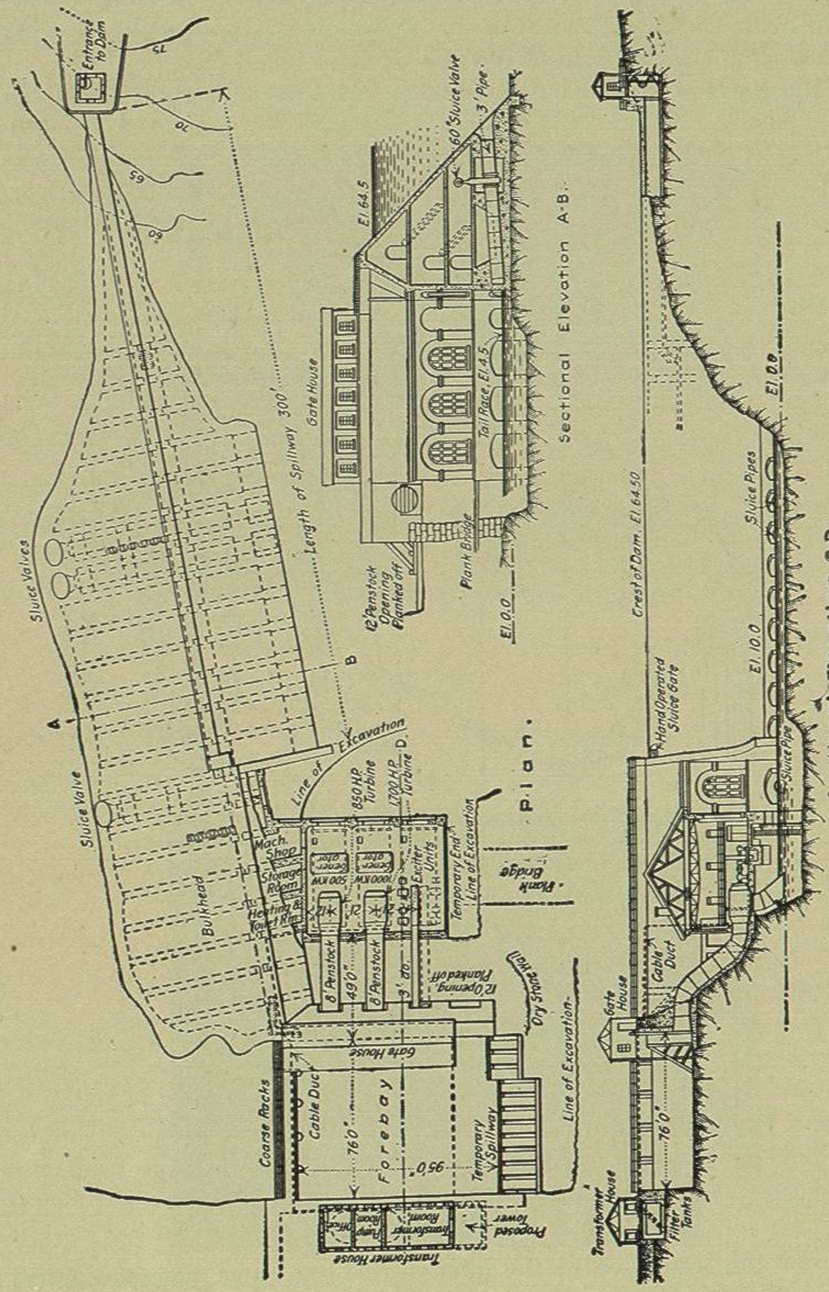

FIG. 311.—PLAN AND ELEVATION OF ELLSWORTH DAM.

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

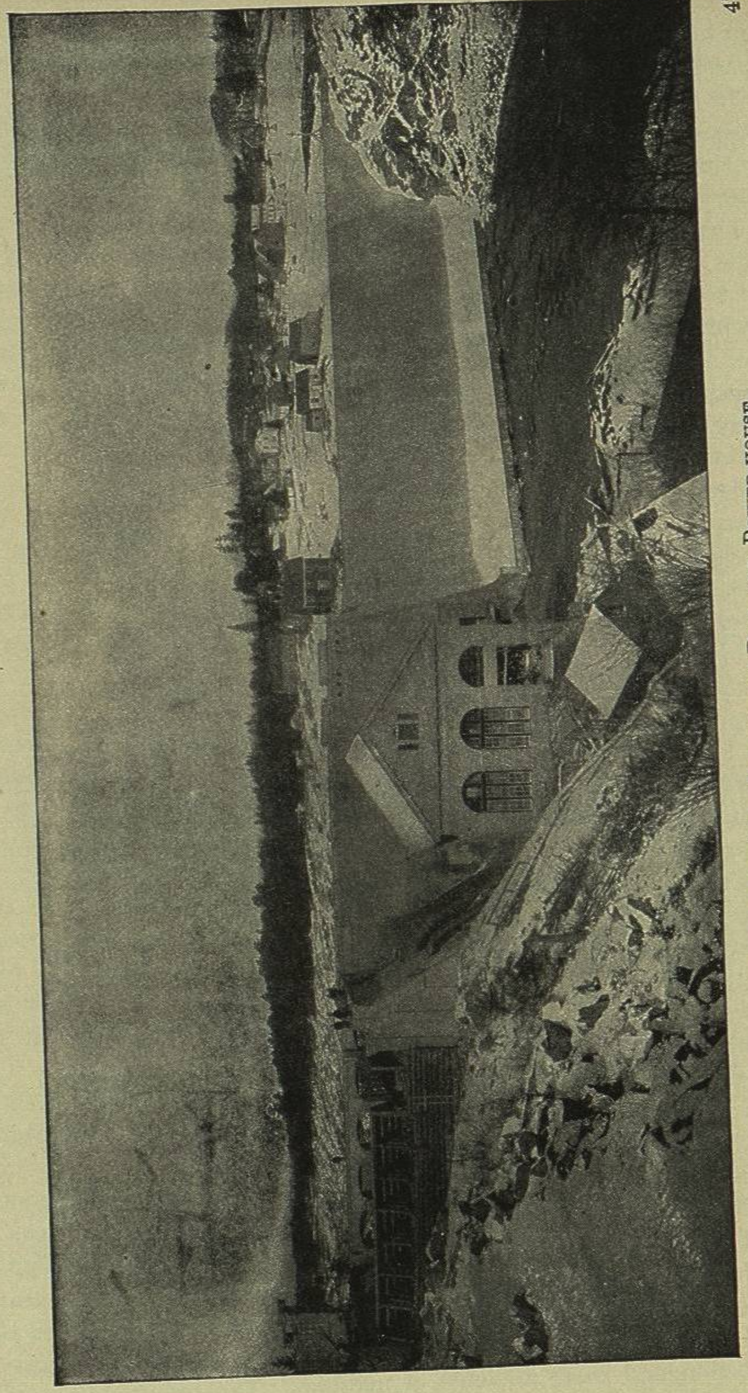

Fig. 312.—The Ellsworth Dam and Power-house.

with the cost of dams of any other material and of other types, as must result from the smaller quantities required.

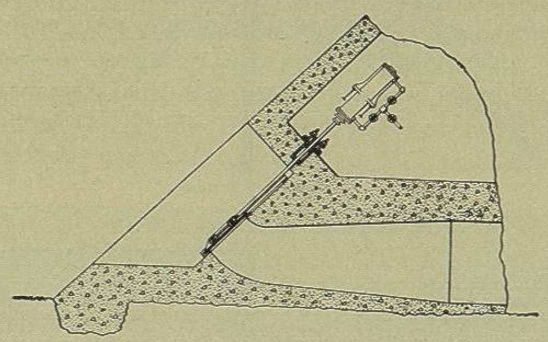

Fig. 313.

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 steel, to act as seats for the deck-slabs. This construction is illustrated on the margin of Fig. 310.

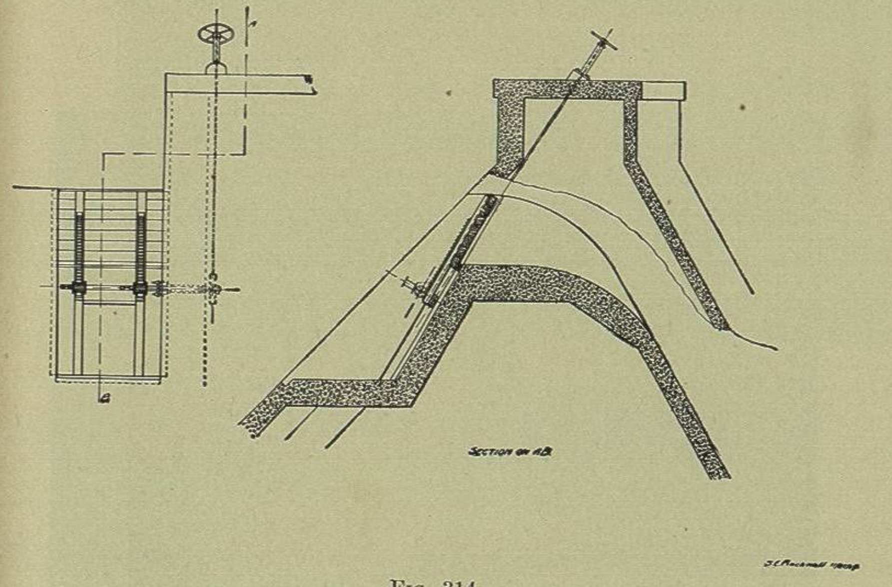

Fig. 314.

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.

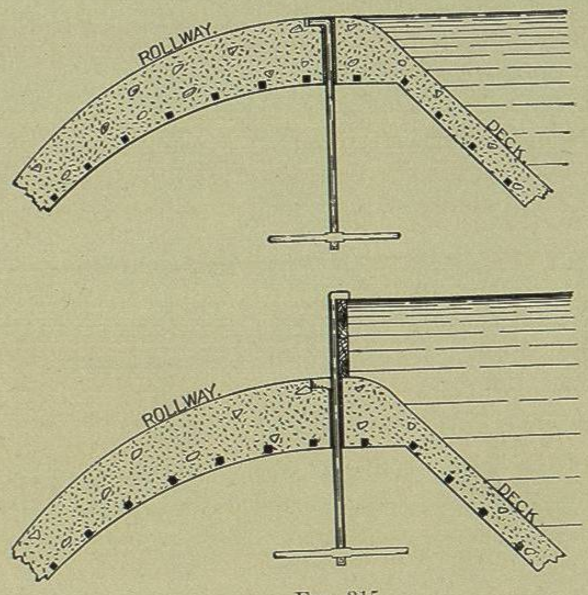

Fig. 315.

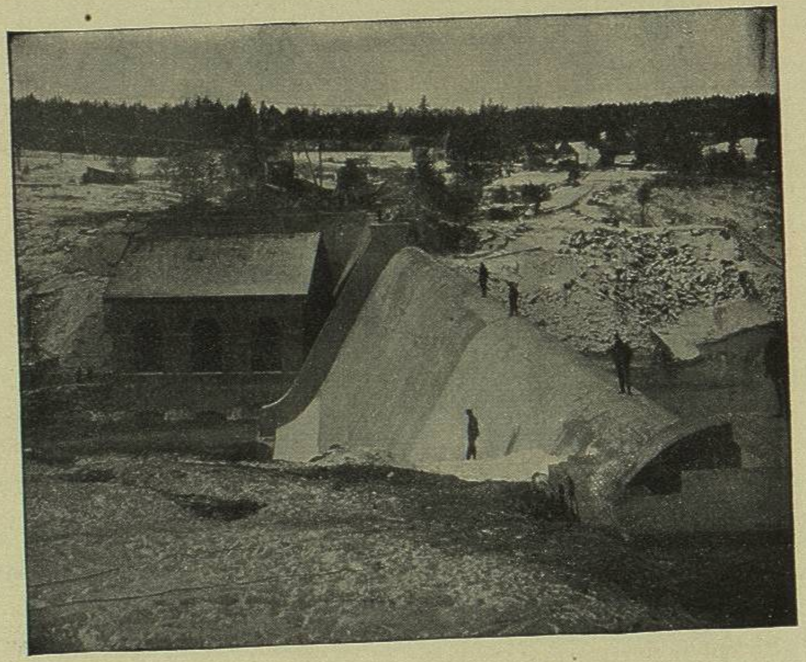

Fig. 316.—Ellsworth Dam, Maine.

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 became necessary to utilize the room in the hollow interior for the power-house, 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.

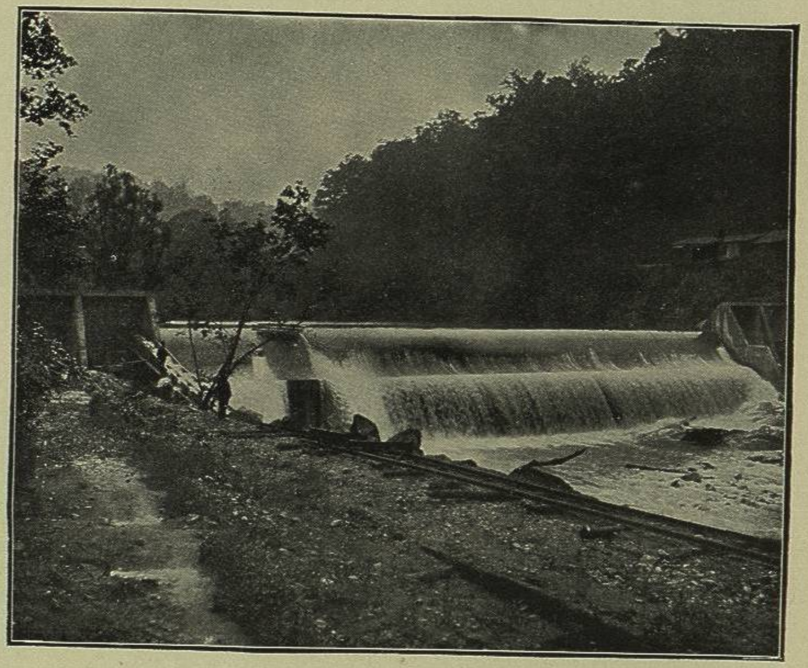

Fig. 317.—Patapsco Dam, Ilchester, Maryland.

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 power-house. 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.