Report on the Dam of the Holyoke Water Power Company
Holyoke, Massachusetts

1945

War Department
United States Engineer Office
Providence, Rhode Island

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1. <u>History</u>. - The following are descriptions of the timber and masonry dams. The first part of the description is an abstract of Clemens Herschel's paper of 1886 as reproduced from "Design and Construction of Dams" by Wegmann, Page 290.

a. "<u>The Holyoke Dam</u> (See Plate No. 1) was built in 1849 across the Connecticut River by the Hadley Falls Company (now the Holyoke Water-Power Co.). Before this structure was begun a temporary dam was built a little further up-stream to serve as a protection during the construction of the permanent dam and to furnish water-power in the meantime. The temporary dam was built somewhat like the permanent dam, constructed subsequently, but was given less strength. The gates of the temporary dam were closed on November 16, 1848. When the water reached within 2 or 3 feet of the top, the whole dam, except 75 feet on one end and 150 feet on the other, was rolled over and floated down-stream on the crest of a wave about 8 feet high. The loss to the company on account of this failure is stated to have been $40,000 to $50,000.

"The permanent dam shown in Fig. 1, Plate No. 1, was begun the following year and finished in the summer. This dam is still standing, but will soon be replaced by a masonry dam below it. It is 1017 feet long and has a maximum height of about 30 feet. The down-stream face of the dam was originally made vertical, but in 1870 a sloping apron was built in front of the dam, as shown in Plate No. 1.

"The dam was founded on a ledge of red slate and sandstone, which dips down-stream about 30° from a horizontal plane. The whole dam was built of heavy timbers, nothing less than 12 by 12 inches being used. The bottom timbers (15 by 15 inches in section) were placed parallel with the current and were bolted to the bed-rock with iron bolts 1-1/4 inches in diameter, about 3000 of these bolts being used in the dam. The bottom timbers and those directly over them were placed 6 feet apart and divided the dam into 170 sections. The upstream slope, which makes an angle of 20° 45' with a horizontal plane, was covered with three courses of 6-inch timber. This planking was strongly fastened together with spikes and treenails. The rolling top or combing was covered across the whole length of the dam with sheets of boiler-iron. Four million feet, board measure, of wood was placed in the dam.

"As the dam was built up the pockets between the timbers were filled with stone to a height of 10 feet. Above this the dam was originally left hollow. The foot of the dam was protected by concrete. A bank of gravel was filled in against the upstream face of the dam, beginning 70 feet above the dam and covering over 30 feet of the slope. Strong abutments of masonry were built on both sides of the timber dam. The total cost of the dam amounted to $150,000.

"During the construction of the dam the river-water was passed through 46 gates, each having an opening of 16 by 18 feet! These gates were closed for the first time on October 22, 1849, the water being thus forced to pass over the dam. The work stood this test very successfully. The leakage through the dam was very trifling, not more than was thought necessary to keep the timbers from decay.

"In November, 1849, 6 feet of water passed over the top of the dam. It caused the windows in Springfield, 8 miles away, to rattle, as no provision had been made to allow the air to pass freely from abutment to abutment under the sheet of water. In April, 1862, 12-1/2 feet of water passed over the dam, which is the maximum height the water has reached.

"The water, ice, logs, etc., passing over it rapidly wore away the rock in front of it. By 1868 the ledge had been eroded to a depth of 20 to 25 feet, and the dam had become undermined in some places. Besides the wearing out of the rock, the front timbers had become injured by logs and ice which, after passing over the dam, were forced against the front face by the eddies caused by the falling water. In some cases logs having become wedged among the front timbers and being struck by the falling water forced the timbers apart, acting like large levers. In order to protect the dam against such injuries and to reduce the fall of the water, a large inclined apron of cribwork was built in front of the dam during the years 1868, 1869, and 1870 (Plate No. 1.). This crib, which exceeds the original dam in volume, was built of round logs laid so as to form pockets 6 by 6 feet, which were filled with stone to the top before the covering, consisting of 6-inch planks of hard wood, was put on. The cost of the apron is given variously as $263,000 to $350,000--about double the cost of the original dam.

"The construction of the apron merely transferred the erosive action of the water further down-stream. The slope of the apron being nearly parallel with the dip of the rock, the circumstances for washing out the ledge were very favorable. By 1886 the rock in front of the apron had been eroded in places to a depth of 20 to 25 feet.

"While the apron was being constructed a considerable amount of stone was also filled into the old dam. This work was done carelessly, stones weighing 4 to 5 tons and even whole scow-loads of stone being occasionally dropped on the upstream slope of the dam. The leakage through the dam, which in after years entailed much expense, was probably partly due to the injuries thus sustained.

"From 1849 to 1879 only trifling repairs were required on the dam with the exception of the construction of the apron. In the latter year a break occurred in the plank covering of the upstream slope. Many similar breaks taking place in the next few years, the whole up-stream slope was replanked in 1885. At the same time sheet-piling was driven longitudinally through the dam, about three bents back from the face, and gravel dumped and puddled on both sides of the sheet-piling. The cause of the breaks was the rotting of the planking (which, as already stated, had been injured by stones being dropped on it) and also of some of the timbers. For a full account of how the dam was repaired we must refer the reader to Mr. Clemens Herschel's Paper C(Trans. Am. Soc. C. E., for 1886).

"As the repairs appeared to have no permanent effect in stopping the leakage, it was finally decided to build a masonry dam 112 feet at one end and 132 feet at the other downstream from the old timber structure. Surveys for the new dam were made in 1891. The construction of the masonry dam was begun in 1895, and the work was completed during the season of 1899.

"Figs 2 and 3, Plate No. 1, show the profile adopted for the masonry dam. The upper part of the down-stream face is the parabola, which a sheet of water 4 feet in depth over the crest would describe in falling freely. The parabola continues to the point of reversing below which a cycloid (the curve of "quickest descent") is adopted for the face. At the extreme toe the face is turned somewhat upwards to break the force of the water and to prevent it from cutting the ledge beyond. The back slope forms a series of steps, 5 feet high, equivalent to a batter of 1 foot in 5 feet. The length of the rollway of the new dam will be 1020 feet. The plans for the masonry dam were prepared by Mr. E. S. Waters, Chief Engineer of the Holyoke Water Power Company."

b. The following are excerpts of an Article by Sanford E. Thompson in the Engineering News May 13, 1897.

"The Present Wooden Dam. As far as can be learned by the writer no careful examination has been made of the timbers or of the condition of the gravel filling since the work in 1885. From the fact that an immense amount of gravel has been found in the river bed below the dam, and as the leakage through the dam has been rapidly increasing from year to year, it appears that the repairs were not so permanent as it was hoped they would be. In 1891 it was decided to build a stone dam below the present wooden dam, and as near to it as would be consistent with the condition of the river bed.

"Since 1885 two breaks have occurred in the surface, but these were probably due to the decay of the timbers rather than to the rotting of the plank, since the latter had only been in a few years. The first of these two breaks occurred in 1893. The hole was about 4 feet by 6 feet and its depth measured vertically below the top of the dam was about 11 feet.

"The stopping of these two leaks constitute all of the repairs bestowed upon the main dam during the last 12 years. Occasionally planks have had to be replaced on the apron and last year after the spring freshet a hole about 20 feet long by 6 feet high was found in the face of the cribwork of the apron, extending back under the apron, the length of one crib or about 6 feet. The logs were cleanly broken off and a sufficient number were left directly under the planking to prevent any sagging and it was not even thought necessary to replace them. The leakage had been gradually increasing until in 1895 there was a loss of 118 cubic feet per second which under a head of 60 feet is equivalent to a loss of 800 theoretical horse-power.

"The New Stone Dam. - Surveys for a new dam were begun in 1891. The total length of the rollway between abutments is 1,020 feet. The bed of the river on a part of the distance across is of blue slate, and, for the remainder of the way, red sandstone, so that no difficulty was encountered in obtaining a suitable foundation.

"An outline section of the main dam is shown on Plate No. 2. The upper part of the curve on the downstream face of the dam is that of a parabola. The parabola selected being the curve of freely falling water flowing 4 feet in depth over the crest of a dam. The parabola extends down the slope as far as the point of reversing, and below this the curve is a cycloid. Selected as the "curve of quickest descent," the up-curve at the extreme toe is designed to break the force of the water and prevent its cutting into the ledge beyond. The slope of the back or upstream face is equivalent to a batter of 1-foot in 5-foot. It is stepped off every 5 feet in height in order to afford a footing for the coffers as will be described further on.

"The stones of each of the first 8 courses are dogged together horizontally with galvanized iron dogs countersunk into the surface. To tie together the stones of the coping galvanized iron dowels are used instead of dogs, except in two cases, where the tie has to be put in after the stones are in place.

"Materials. - The stone for the concrete is broken stone and is brought from the crusher at Westfield, Massachusetts. The stones for the rubble filling is taken from the bed of the river below the dam. All of the granite for the dam is being furnished under subcontract by the National Granite Company of New York whose quarry is situated on Leadbetter's Island, near Vinal Haven, Maine. The cement is furnished by the Alpha Cement Company, The Bourse, Philadelphia. The selection of the Alpha brand of cement was the result of competitive tests. Seventeen bidders presented samples. Of these, five were American, four English, five German, two Belgian and 1 Turkish. The tests were conducted in accordance with the standards of the American Society of Civil Engineers.

"The sand used in the mortar is obtained from a bank in Holyoke about a mile and a half from the dam. It is screened once to remove the stones. A sample of this sand if put in a glass of water and shaken up hardly clouds it. The high tests obtained with the mortar are probably due to the absence in this sand of clay and loam.

"Contract Work. - Every stone is laid to line, grade and batter, and extreme care is exercised to see that the work is accurately done. The stones are leveled and lined by instruments. The batter is obtained from templets furnished by the company. The joints of the face stone are only 1/4 inch and they are so nearly vertical at and near the toe that it is necessary to grout them there. The mortar is poured in and a sword is run through the joint to make sure that the mortar reaches every crevice. The rubble for the bed which is directly under the stone is laid up to within two or three inches of the granite several hours in advance of the latter in order to set sufficiently to bear the weight. The rubble is laid with full joints and under close inspection. Joints which are difficult to fill by spreading the mortar are left open and grouted. The mortar is all 2 parts sand to 1 of cement.

"Each cubic yard of rubble masonry requires 7/8 barrels of cement. The weight of the granite is 163 lbs. per cubic foot; of the slate from the river bed 170 lbs. per cubic foot; and of the sand from the river bed 180 per cubic foot.

"The engineers of the Holyoke Water Power Company who have this work in charge and through whose courtesy the facts for this article were obtained are Messrs. Edward S. Waters, Treasurer and Hydraulic Engineer; James M. Sickman, Engineer in charge of Construction; Robert Ramlet and W. E. Sawin, Assistant Engineers. Mr. Sawin drew the plans for the work."

c. Damage to the Masonry Dam in 1936 - The 1936 floods resulted in the displacement of the capstones at the crest of the dam to a depth of 5 feet. The exact time of the accident is not known but is believed to have occurred during a minor crest, accompanied by ice passage, which occurred about one week in advance of the record-breaking March 21, 1936 flood. It has been reported that the amount of material which it was necessary to replace is as shown on Plate No. 3. Concrete was used to replace the lost capstones. The section shown is typical for the full length of the dam with the exception of 28 feet at the left abutment and 6 feet at the right abutment, where no damage occurred, and also with the exception of 213 feet where the stone indicated in dotted lines on Plate No. 3 withstood the water pressure. Those capstones which did not carry away were permitted to remain in place. The structural members indicated on Plate No. 3 were for the purpose of supporting the concrete forms and the coffer dam, and were left in place in the concrete.

2. Crest Elevations. - The elevation of the crest of the old dam is given in a testimony by a Holyoke Dam engineer, Clemens Herschel, at El. 97.975. Numerous articles give the same crest elevation for the new dam. The datum plane is Hartford zero (approximate low water at Hartford as determined by Ellis 1872-78). To refer elevations to the Holyoke Power Company base, 2.025 feet is added giving the crest elevation of the dams at 100. The Holyoke Power Company base is referred to a permanent stone bench at elevation 107.975 Hartford zero, or 110 Holyoke Base. Hartford zero is 0.55 feet below zero mean sea level. Holyoke Power Company base is 2.53 feet below mean sea level.

Elevations of March 4, 1937, by Mr. Whitcomb of this office, give 97.42 m.s.l. for the new dam and 97.35 for the old dam. These were taken at the west end of the dam. Although no reference is made in individual articles to both dam crests being constructed at the same elevation, scaling of sketches included in the writings, substantiate this fact.

Flashboard operation is recorded on both dams. Flashboards are held in place on the masonry dam by iron rods inserted into castings set in the concrete below crest surface; these rods are made of soft iron which bends, releasing the flashboards when pressure is too great. The same method was used on old dam. Height of flashboards presently used is 2.1 feet. The height of flashboards was limited to a maximum of 2 feet.

As previously mentioned, records show that 4-foot flashboards were used on the crib dam in 1862.

3. Discharge Characteristics of Crest. - Although discharge characteristics for the two types of crests may vary for low heads, study shows that like quantities of discharge may be expected under high heads. There is but three feet variation in the length, the length of the old crest being 1017 feet and that of the new 1020 feet. Both crests under high heads are capable of having free discharge, that is, the overfalling jet will spring free from the downstream surface of the spillway. The downstream surface of the masonry spillway was designed to follow the lower nappe of the jet profile discharging under a four-foot head. Wegmann and Creager both record a flow of six feet over the old dam where vibrations caused by the rapid breaking of the overfalling sheet so as to let air into the vacuum space between the sheet and dam caused the windows to rattle in Springfield eight miles away. Theoretical analysis of flow over the masonry structure suggests the possibility of the presence of vacuum for surcharges of ten feet or over.

Discharge under free overfall is that of critical flow where the depth of water at the crest is two-thirds of the head, and the discharge per foot of spillway crest is $5.67D^{3/2}$.

Such flow accelerates with decreasing depth over the downstream face of the dam to that section where impact of the stream against backwater or tailwater causes the hydraulic jump to take place. Should the tailwater at the toe of the dam be greater than that necessary for good jump action, undulation action will take place with much boiling effect and eddy currents. This boiling action is amplified should the tailwater be high enough to almost submerge the contraction of the overfalling sheet on the crest of the dam. This is the condition between the two dams as found by Mr. Davis and is suggested by aerial photographs taken in March 1936. Study shows that for any possible flood in the Connecticut River Watershed, backwater from the new dam will for all heads create more tailwater than necessary for jump action below the old dam. Also, due to the fact that the crests of both dams are at the same elevation, the control of flow past Holyoke for high heads is at the masonry dam by the amount of backwater created between the two dams, that is to say, the stage at the crest of the old dam at present approximates that at the crest of the old dam prior to 1901.

4. <u>Foundation of the Masonry Dam</u> - A description of the bed rock which forms the foundation of the masonry dam taken from contemporary sources at time of construction of the dam states:-

<u>a</u>. Type - red and gray shale. Very sound red shale occurs at left abutment.

<u>b</u>. Hardness - the rock is hard and sound.

<u>c</u>. Bedding - The bedding planes of the rock dip in the downstream direction generally between 10° and 20° from the horizontal. Local dips

occur ranging from zero to 30° from the horizontal. The strike of the bedding plans is approximately parallel to the dam.

d. Porosity - The bed rock is dense. No soft or porous layers were observed.

e. Soundness - No shattered zones were observed. Joints were found to be tight and occur at right angles to the bedding. The steps in the natural weathered surfaces conform to the bedding and joint plans.

At the present time, shallow pool varying from 50 to 100 feet in width occurs immediately downstream of the spillway apron and extends the full width of the river bed. Progressive scouring is prevented from approaching the toe of the dam by the presence of a concrete apron having a minimum width of about 50 feet.

5. Stability of the Masonry Dam. - The face of the spillway has been left rough. The body of the dam is constructed of heavy rubble masonry laid in rich Portland cement mortar, with beds inclined somewhat from the horizontal, the downstream side being the highest. The trench for the toe of the dam was excavated to an average depth of 8 feet, and from 15 to 18 feet in width, the bottom being leveled off by a bed of concrete for the reception of masonry. Back of this, the rock was roughly stepped to afford a good bearing for the rubble masonry.

The section investigated was a simplified equivalent section trapezoidal in shape having a top width of 10 feet, a base width of 35 feet and a height of 30 feet. This section is a little lighter than the actual effective section of the dam. The following forces were considered:-

a. The weight of the masonry structure assumed at 150 lbs. per cubic foot.

b. Full hydrostatic water pressure against the upstream face.

c. Impact of the approaching water against the upstream face acting at 1/2 the height of the dam above the base. This force is generally considered for low dams having large discharges. The stone dam is now protected from this force somewhat by the old crib dam upstream which may disintegrate in time. This force does not exceed 2700 lbs. per linear foot of dam as computed for maximum flood condition.

d. Effective force of tail water equal to 1/2 the actual hydrostatic pressure of the tail water against the downstream face. Under flood conditions the tailwater is characterized by considerable turbulence and white water indicating air entrainment, and full hydrostatic pressure is not considered effective as a stabilizing factor for the dam.

e. Weight of water on the inclined upstream face of the equivalent section.

f. Uplift assumed equal to 50% of the hydrostatic pressures at heel and toe of the section.

g. The water pressure on the crest and downstream face of the dam due to the spilling water is neglected as the jet approaches very nearly spouting velocity.

The following tabulation gives the analytical results based on the forces considered:

Flood Condition	Discharge c.f.s.	Depth of water-ft. above crest	Depth of water-ft. above toe	S.F.	F.S.O.T.
Design flood	356,000	22	18	0.90	1.45
March 1936	244,000	17	10	0.75	1.67
Design flood modified by reservoirs	213,000	16	7	0.72	1.74

S.F. = sliding factor.
F.S.O.T. = factor of safety against overturning.

The resultant of all forces including uplift falls inside the middle third of the base by 0.8 foot and 0.4 foot, respectively for the two smaller floods considered; it falls outside the middle third of the base by 1.4 feet for the largest flood considered. The above analytical results appear satisfactory for all but the maximum flood.

In order to make the analytical results appear as satisfactory for the maximum flood condition as for the March 1936 flood condition, it was necessary to revise two items of the schedule of forces shown above as follows:

a. The weight of the masonry structure assumed at 165 lbs. per cubic foot.

b. Uplift assumed equal to 40% of the hydrostatic pressure at heel and toe of the section.

Applying the revised schedule of forces to the maximum flood condition of 356,000 c.f.s. the sliding factor becomes 0.73, the factor of safety against overturning becomes 1.72, and the resultant of all forces was computed to fall inside the middle third of the base by 0.6 foot.

Silt deposits have not been considered as a factor in analyzing the stability of the dam. It is established that waterborne detritus reaching the lower part of the reservoir consists only of finer sands and silts. Silt does accumulate in the space between the two dams and against the upstream face of the masonry dam. Owing to turbulence in this zone, caused by the presence of the old timber dam, it is believed that the velocity of the water during major floods is such that this silt will be swept away. The conclusion is that silt pressures will not occur simultaneously with the maximum application of water pressures against the dam.

6. Summary. -

a. The first dam built across the Connecticut River at Holyoke was a timber structure and was constructed in 1849. The length was 1017 feet and the maximum height about 30 feet. In 1870 a sloping apron was built in front of the dam, as shown in Plate No. 1.

b. Apparently when the timber dam had reached the end of its useful life and was no longer safe, it was decided to construct a new masonry dam below it. The new dam, constructed between 1895 and 1899, is located approximately 125 feet downstream of the timber structure and has a length of 1020 feet. The masonry dam is an o-gee gravity, free overflow weir for its full length. The construction is rubble masonry set in Portland cement mortar, surfaced with cut granite blocks.

c. The observed crest elevation of the new dam is Elevation 97.42 mean sea level, and for the old timber dam Elevation 97.35. Flashboards having a height of 3.1 feet are used on the masonry dam. The height of flashboards for the timber dam was a maximum of 2 feet. Records show that 4-foot flashboards were used on the crib dam in 1862.

d. Although discharge characteristics of the two types of crests as used on the two dams may vary for low heads, study shows that like quantities of discharge may be expected under high heads.

e. The bedrock forming the foundation of the masonry dam is sound and well-preserved. A concrete apron protects the rock at the toe of the dam from scouring.

f. By the application of favorable assumptions under the maximum flood condition of 356,000 c.f.s., the sliding factor becomes 0.73, the factor of safety against overturning becomes 1.72, and the resultant of all forces was computed to fall inside the middle third of the base by 0.6 foot.

g. Although it is questionable whether the existing masonry dam is safe under an extreme surcharge head such as could be caused by a maximum flood in the Connecticut River, the construction of the flood control reservoirs in the approved project for the Connecticut River would reduce flood flows (and consequently the maximum surcharge head on the dam) thereby increasing the safety of the dam against failure considerably.

W. J. Truss
Colonel, Corps of Engineers
District Engineer

U. S. Engineer Office
Providence, R. I.

HOLYOKE DAM.

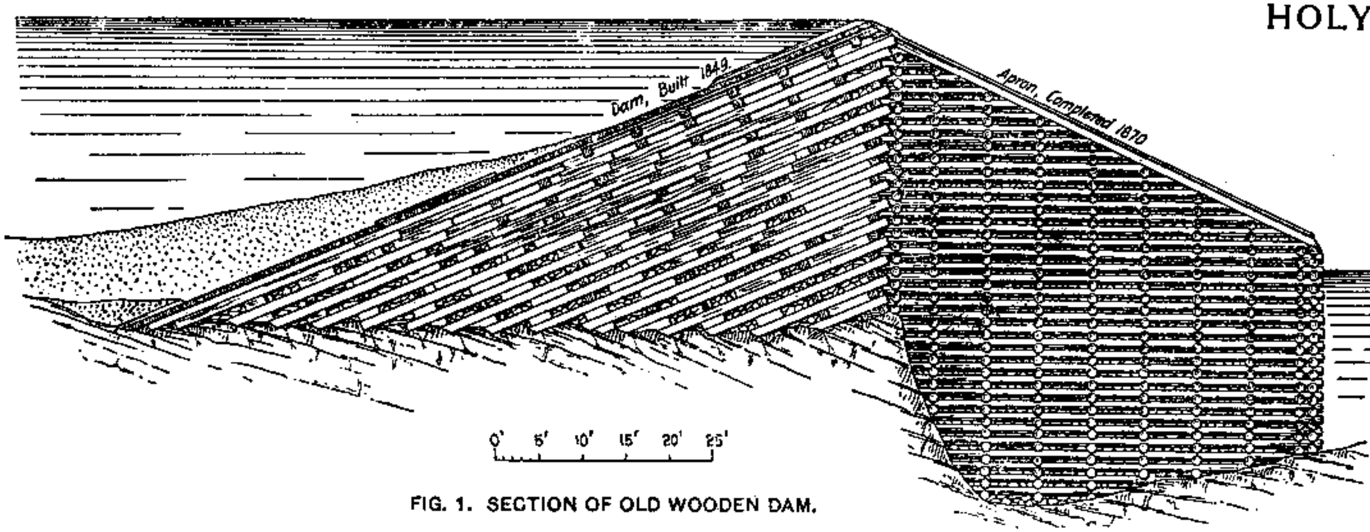


FIG. 1. SECTION OF OLD WOODEN DAM.

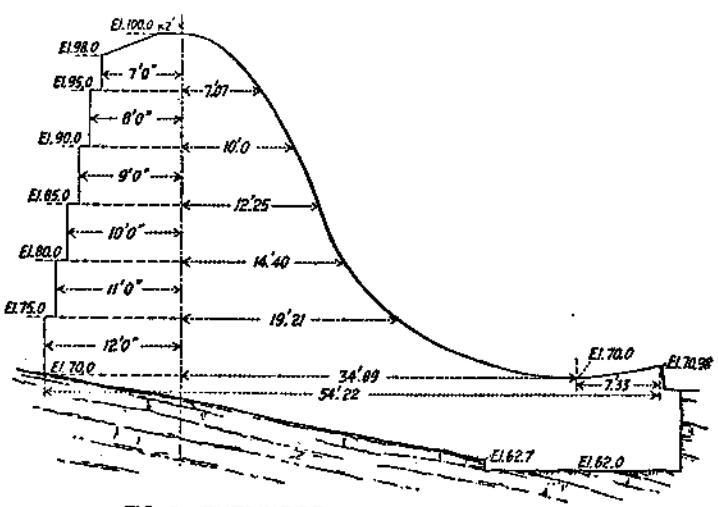


FIG. 2. OUTLINE SECTION OF DAM.

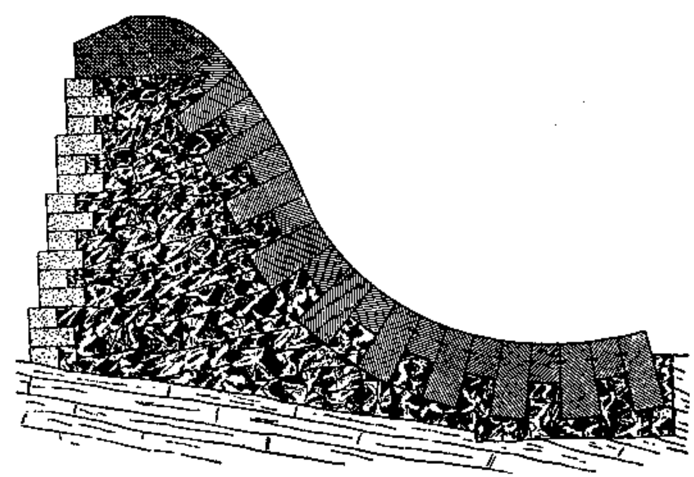
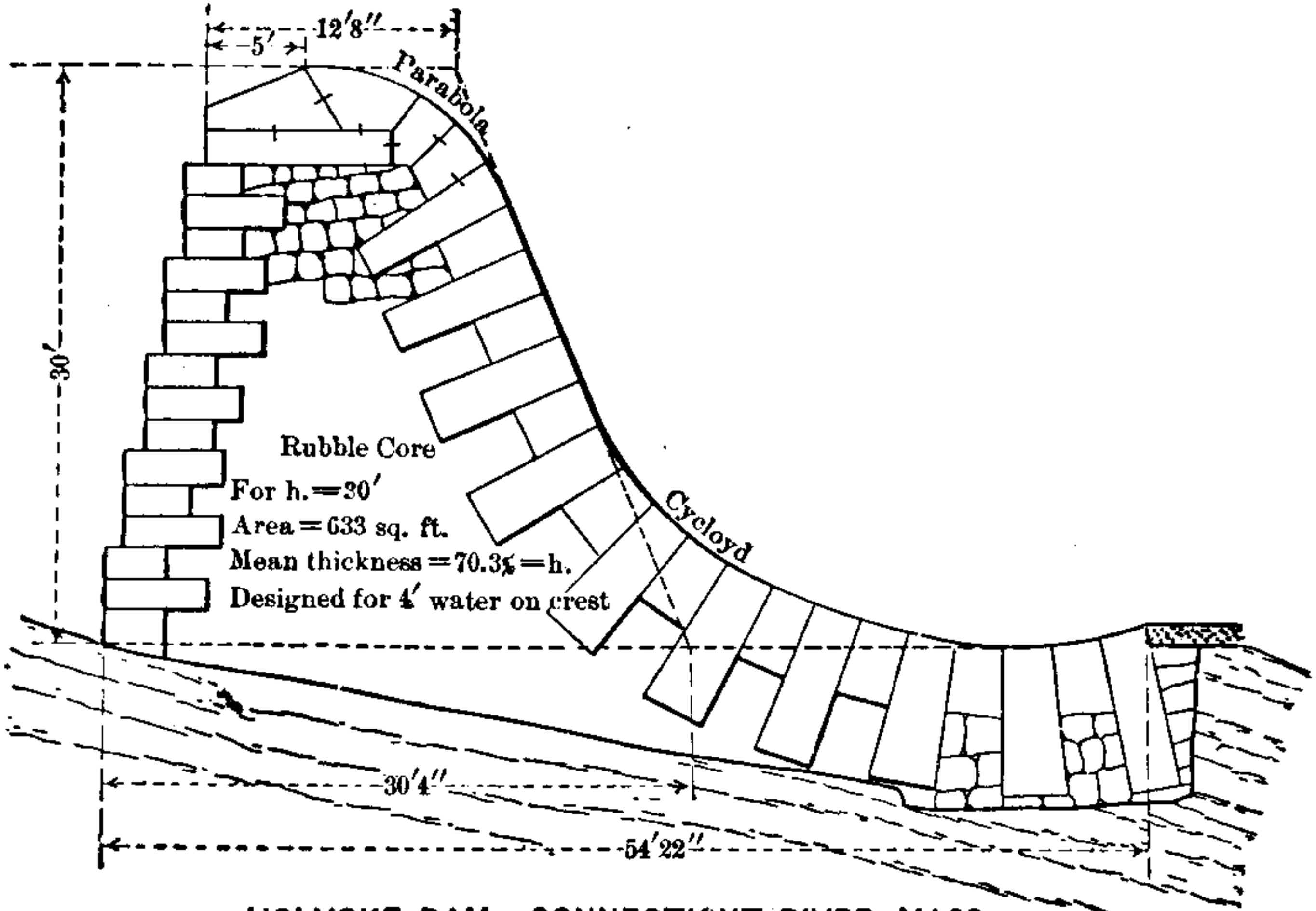


FIG. 3 CROSS SECTION OF DAM.

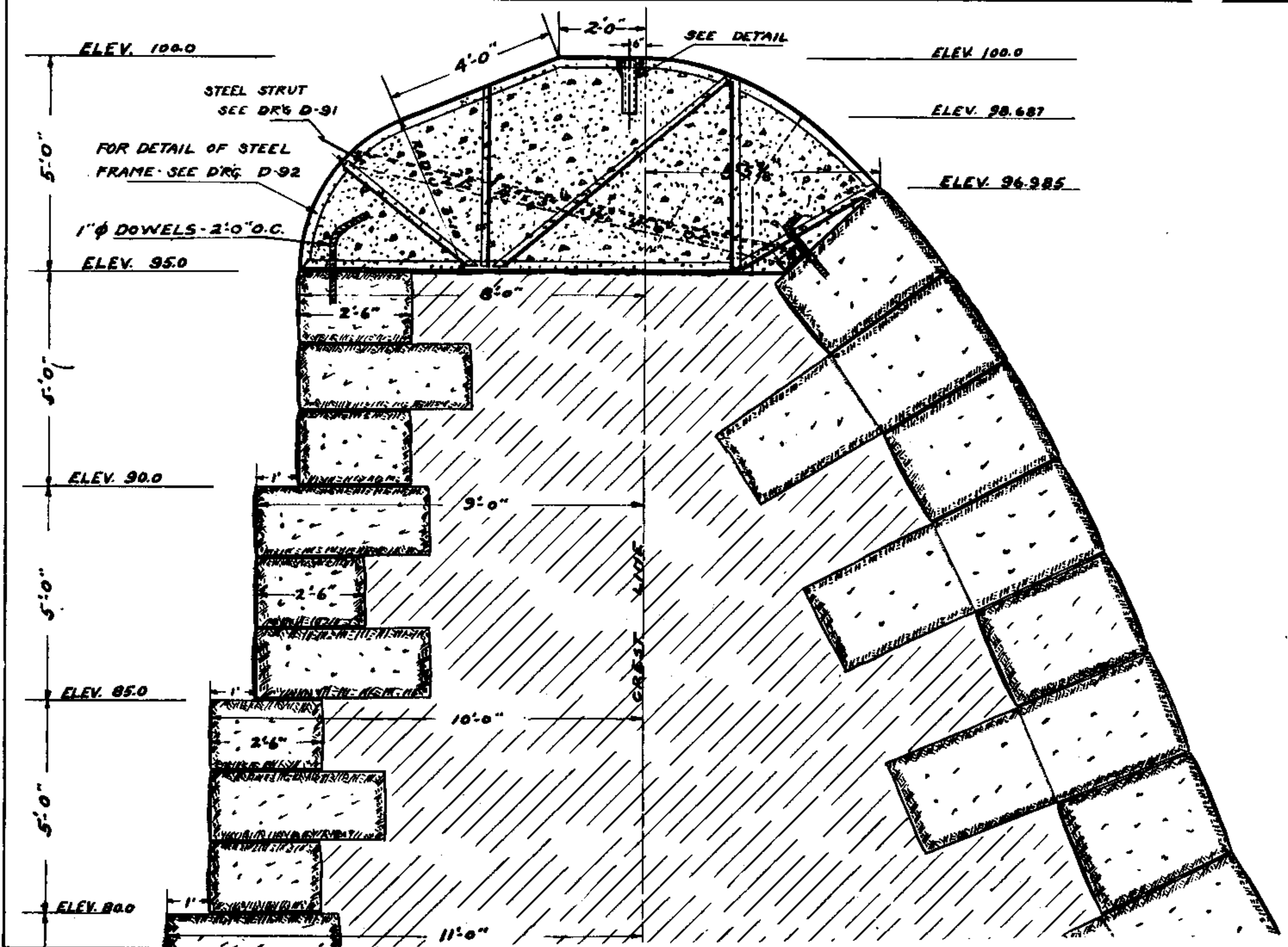
Plate No. 1.



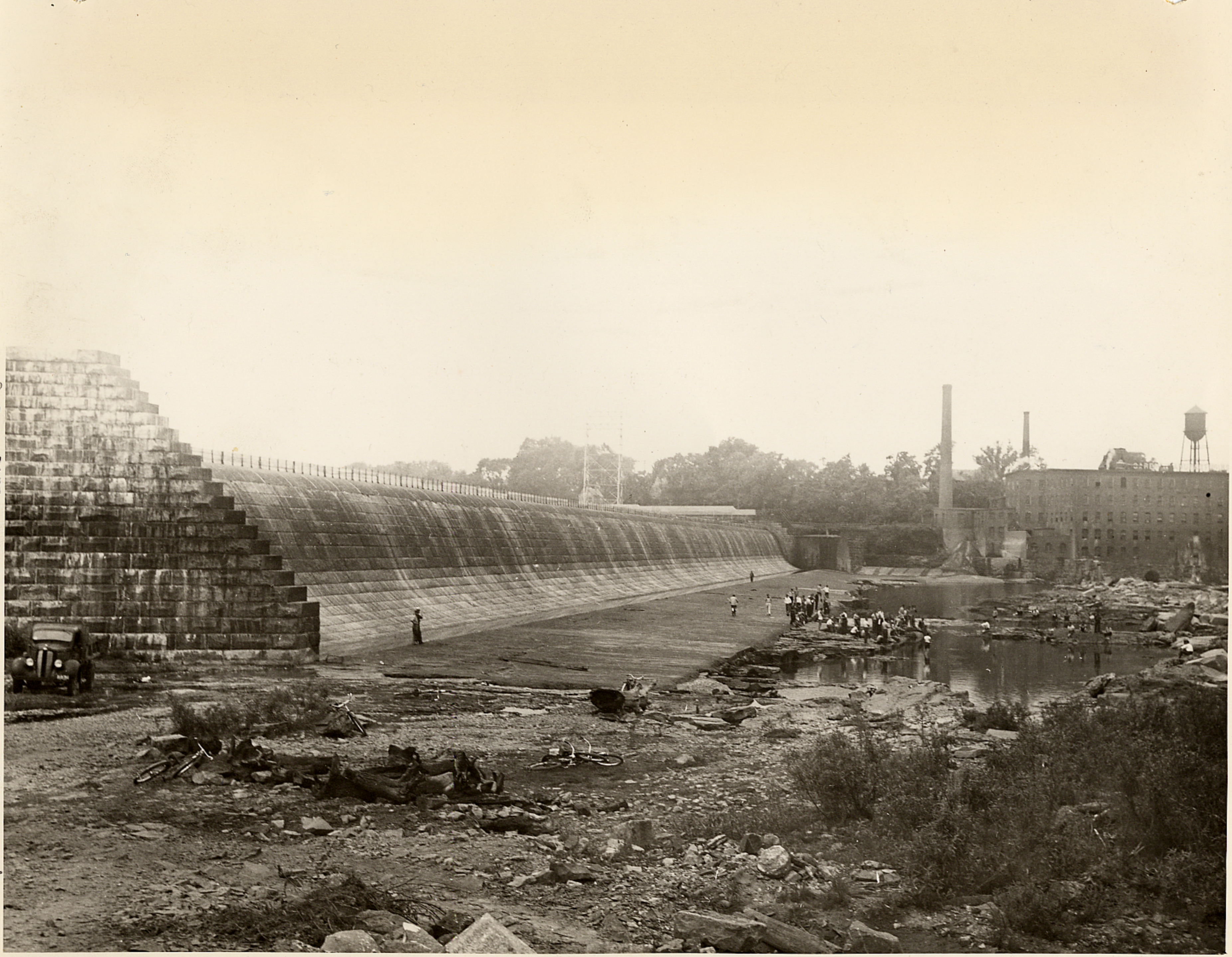
HOLYOKE DAM – CONNECTICUT RIVER, MASS.

(The Design and Construction of Dams - Wegmann Eng.-News 5-13-97)

Plate No. 2.



ELEV. 100.0
2'-0"
6"
SEE DETAIL
ELEV. 100.0
4'-0"
STEEL STRUT
SEE DR'G D-91
ELEV. 98.687
FOR DETAIL OF STEEL
FRAME - SEE DR'G D-92
ELEV. 96.985
1"φ DOWELS - 2'-0" O.C.
ELEV. 95.0
8'-0"
2'-6"
5'-0"
ELEV. 90.0
1'
9'-0"
2'-6"
5'-0"
CREST LINE
ELEV. 85.0
1'
10'-0"
2'-6"
5'-0"
ELEV. 80.0
1'
11'-0"



8 June 1939

Plate No. 4

26 April 1939 8.8 Ft. Over Spillway Plate No. 5

25 May 1939

Plate No. 6

1 August 1938

Plate No. 7

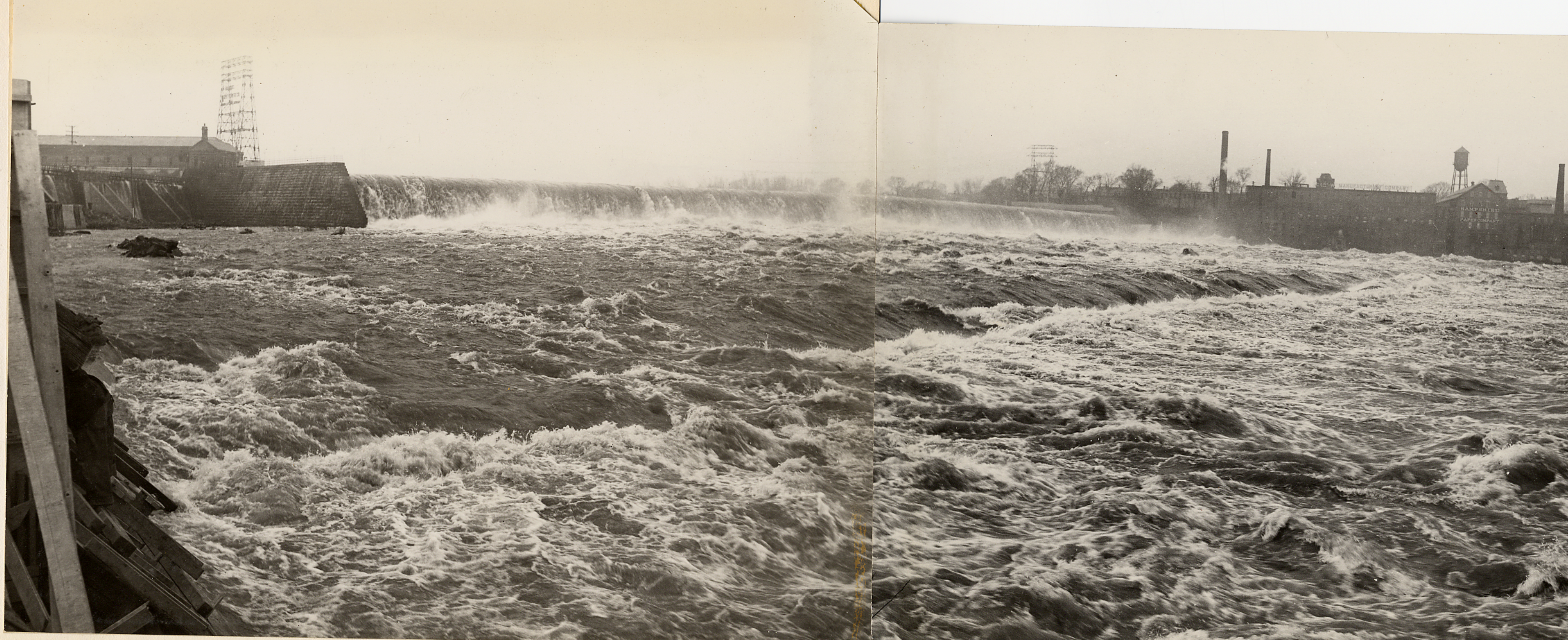
1 August 1938

Plate No. 6

26 April 1939

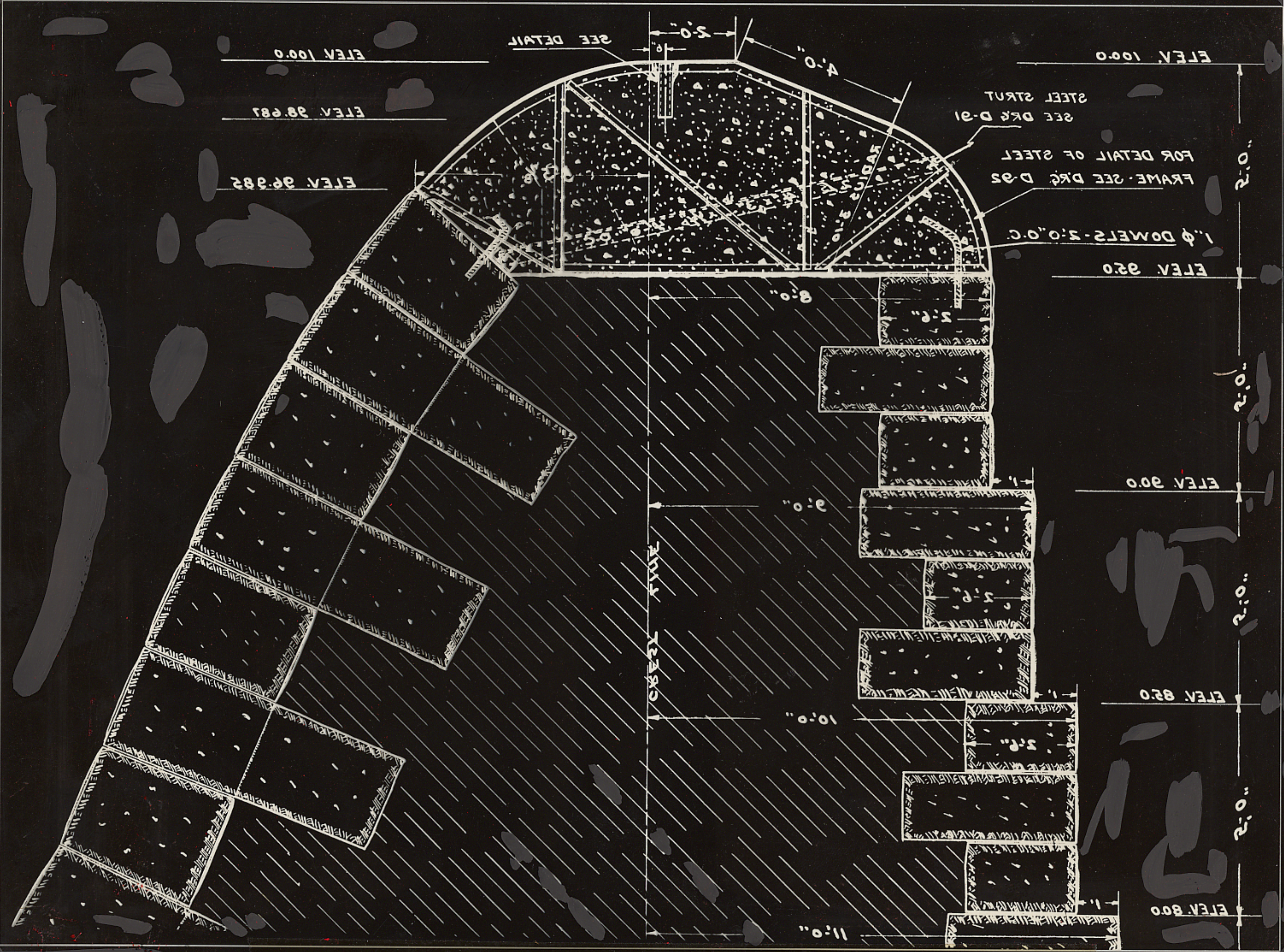
8.8 Ft. Over Spillway

Plate No. 8



3 November 1939

Plate No. 10


ELEV. 100.0
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HOLYOKE DAM - CONNECTICUT RIVER, MASS.

(The Design and Construction of Dams - Wegmann Eng.-News 5-13-97)

HOLYOKE DAM.

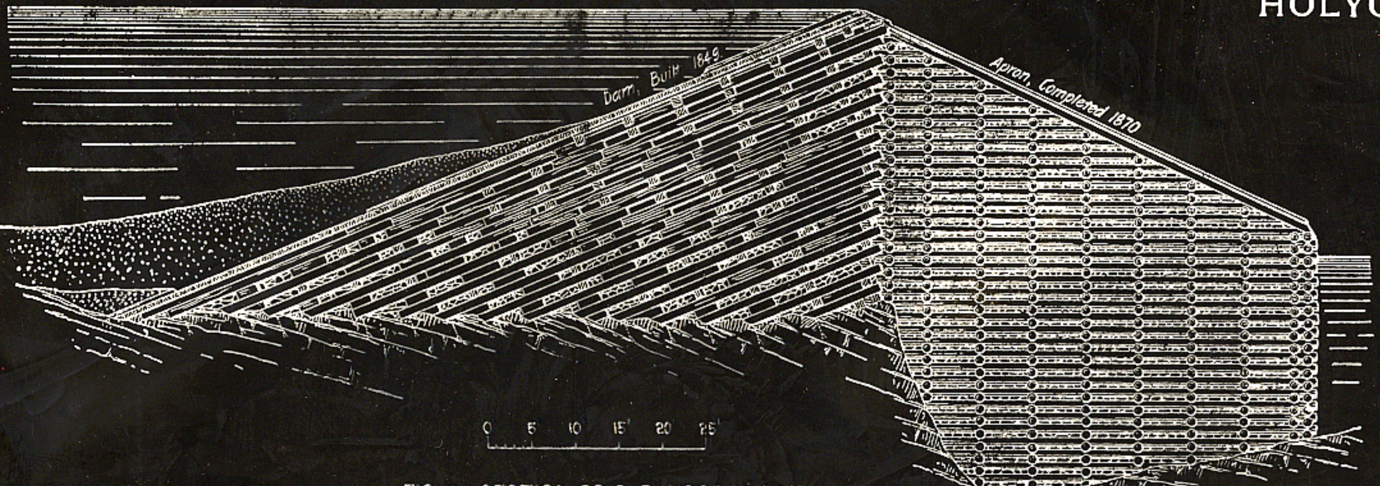


FIG. 1. SECTION OF OLD WOODEN DAM.

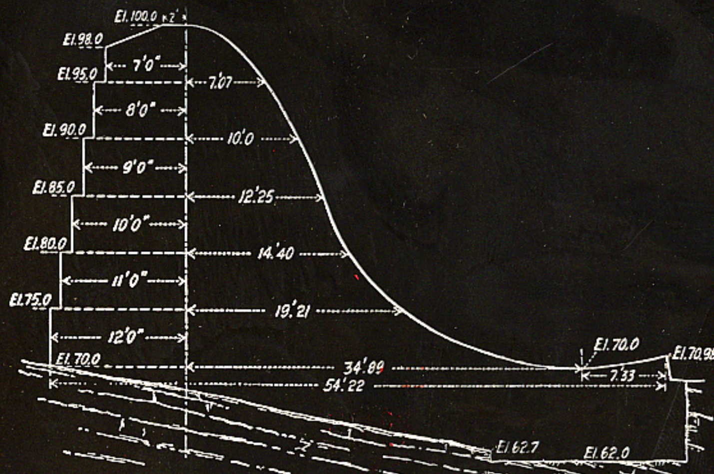
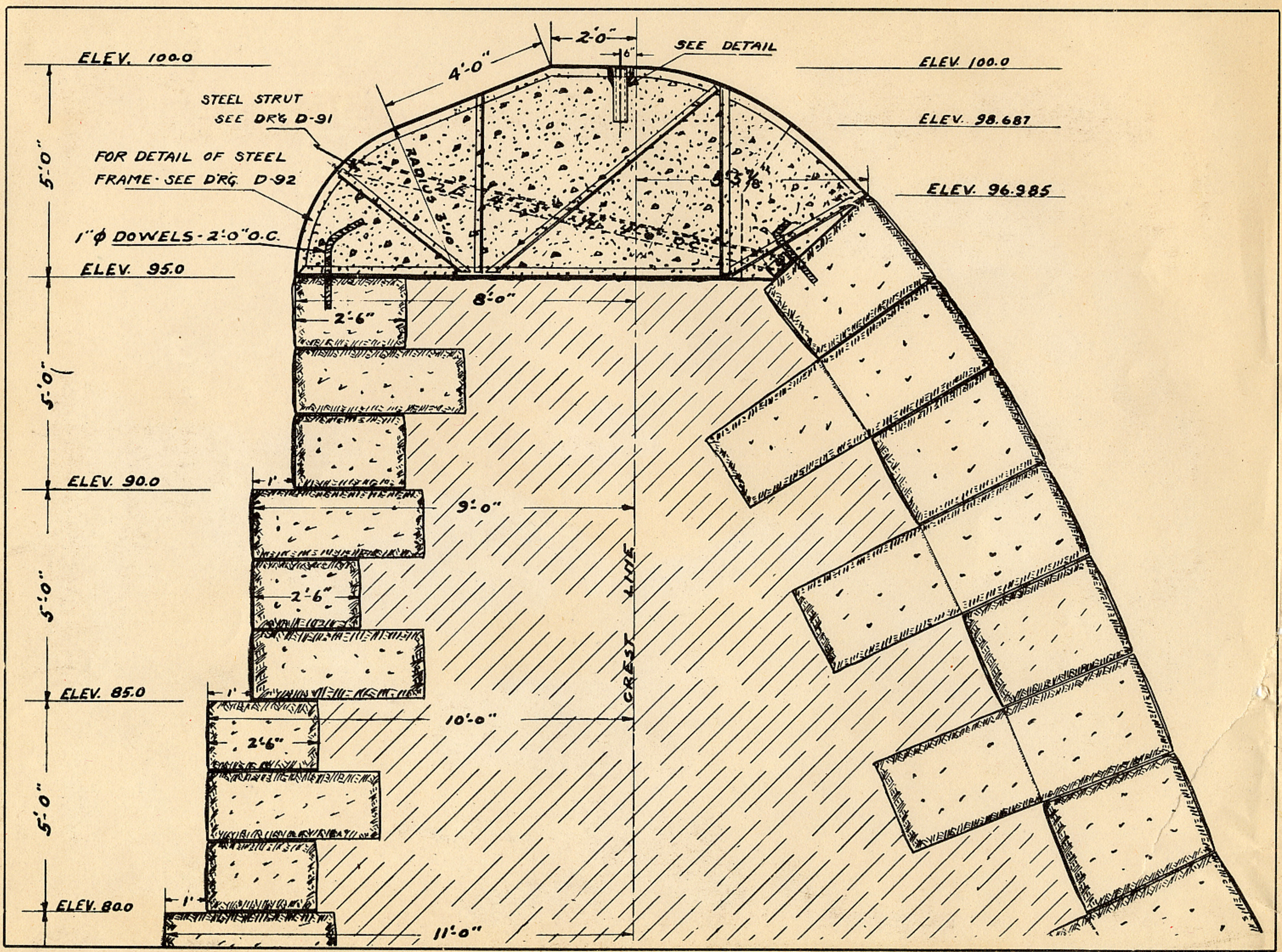


FIG. 2. OUTLINE SECTION OF DAM.

FIG. 3 CROSS SECTION OF DAM.



ELEV. 100.0
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CREST LINE
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1'
11'-0"

HOLYOKE DAM.

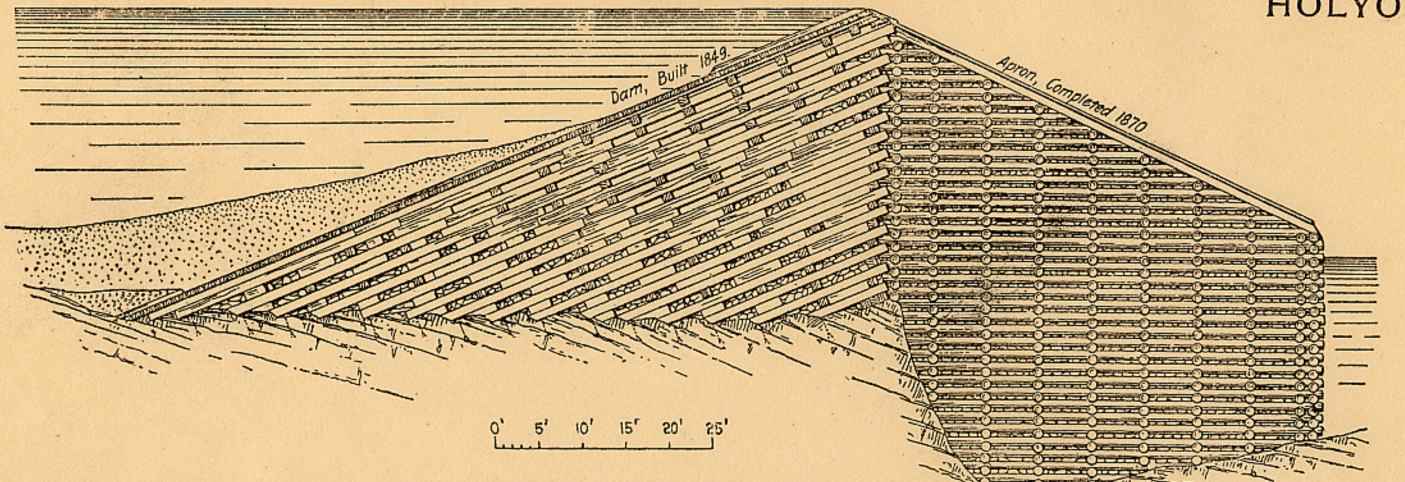


FIG. 1. SECTION OF OLD WOODEN DAM.

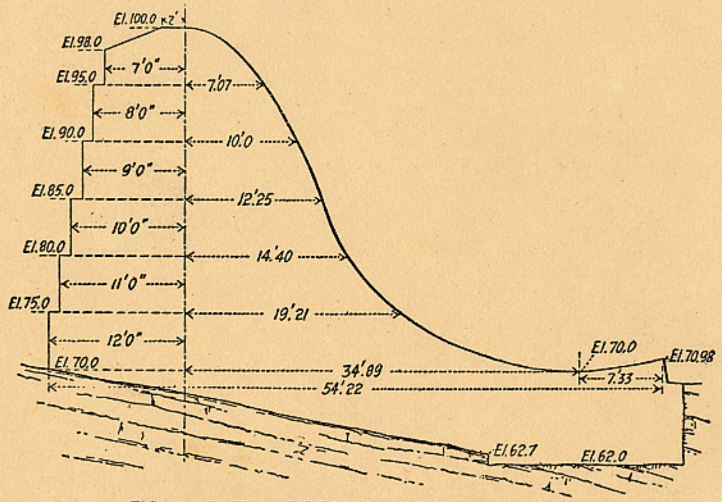


FIG. 2. OUTLINE SECTION OF DAM.

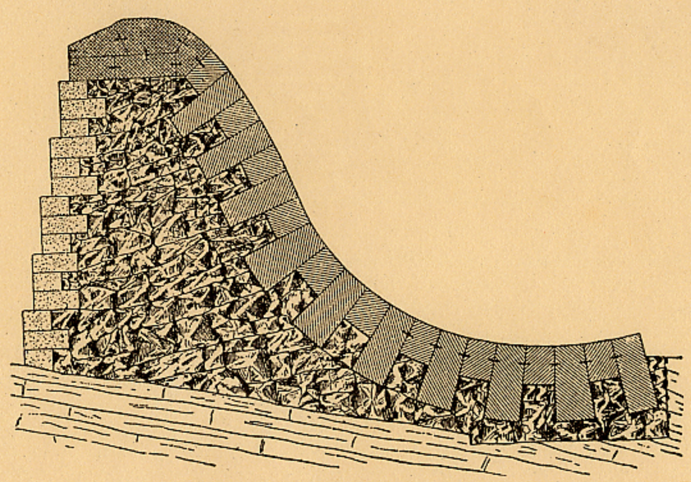
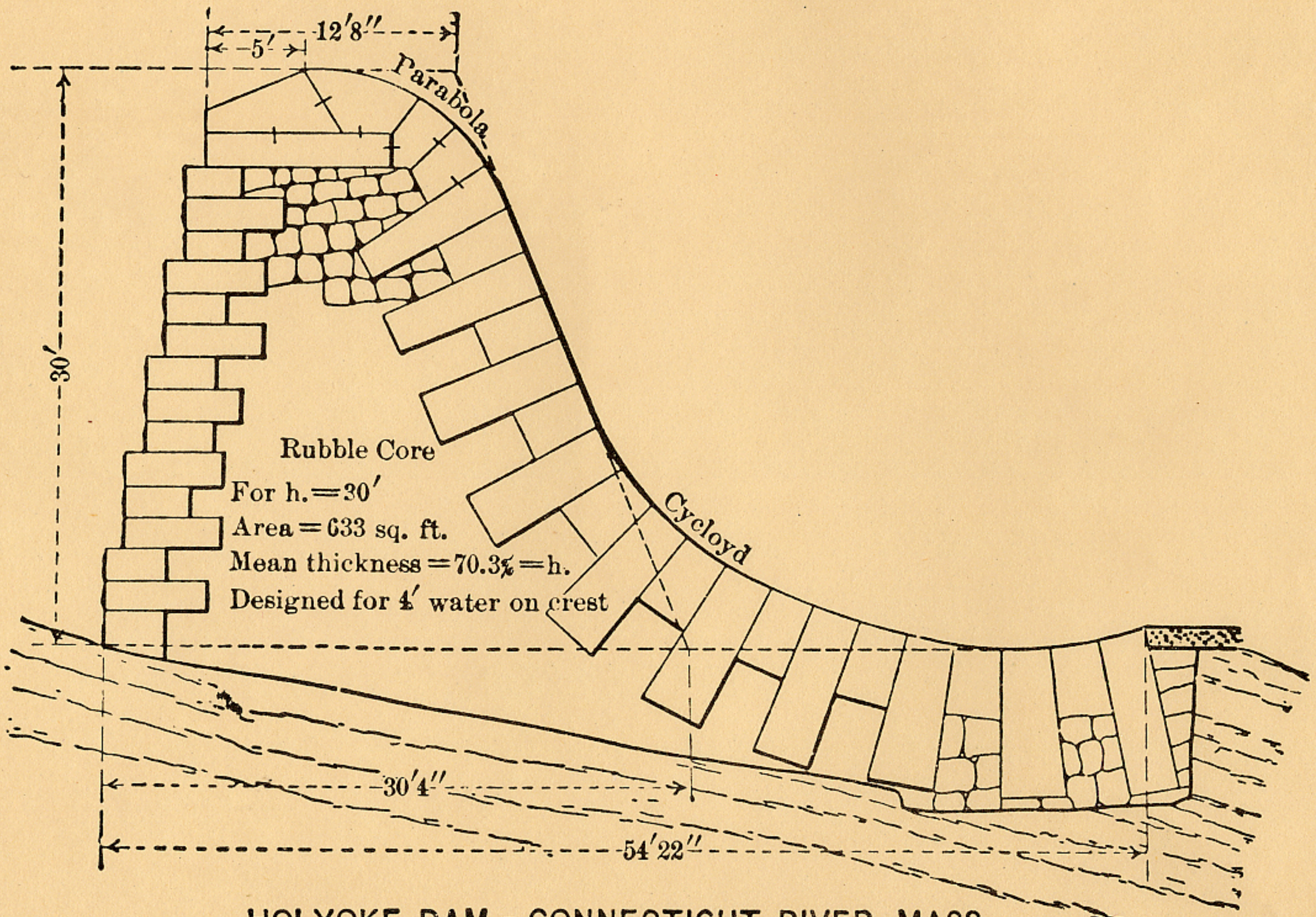


FIG. 3 CROSS SECTION OF DAM.



HOLYOKE DAM - CONNECTICUT RIVER, MASS.

(The Design and Construction of Dams - Wegmann Eng.-News 5-13-97)