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HYDRAULIC LABORATORY REPORT NO. 160

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HYDRAULIC MODEL STUDY OF THE SPILLWAY AND OUTLET WORKS FOR SCOFIELD DAM - SCOFIELD PROJECT, UTAH

By

D. J. HEBERT, ENGINEER

- - -

Denver, Colorado
December 1, 1944

UNITED STATES

DEPARTMENT OF THE INTERIOR

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SUBJECT: HYDRAULIC MODEL STUDY OF THE SPILLWAY AND OUTLET WORKS

FOR

SCOFIELD DAM - SCOFIELD PROJECT, UTAH

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By D. J. HEBERT, ENGINEER

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Under Direction of

J. E. WARNOCK, SENIOR ENGINEER

and

R. F. BLANKS, SENIOR ENGINEER

- - - - -

Denver, Colorado,
Dec. 1, 1944

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
December 1, 1944

Laboratory Report No. 160
Hydraulic Laboratory

Compiled by: D. J. Hebert
Reviewed by: J. E. Warnock

Subject: Hydraulic model studies of the spillway and outlet works for Scofield Dam - Scofield project, Utah.

1. Introduction. Scofield Dam will be an earth-fill dam across the Price River at a point approximately 20 miles north of Price, Utah. It will have a length of 575 feet and will rise to a height of 68 feet above the original river bed. The principal hydraulic features of the dam will be an uncontrolled spillway and an outlet works. The spillway, which is located at the right abutment, will be a reinforced concrete structure consisting of a transition entrance, a crest, a chute, and a stilling pool, as shown in figure 1. The spillway will be required to function only during floods which have been estimated to reach a maximum of 6,200 second-feet by the Bureau and 10,000 second-feet by the Army Engineers. The outlet works will consist of a trashrack structure; a horseshoe-shaped concrete conduit five feet in diameter, intercepted by a gate structure; and a stilling basin. Details of the outlet works are also shown in figure 1. The purpose of the outlet works will be to divert the flow of the river during construction and to release river flow after completion of the dam. These two features were studied in an hydraulic model built to a scale of 1 to 30.

2. Scope of studies. The principal objective of the model studies was to check the designs of the various features of the spillway, such as the entrance, the crest, the chute, and the stilling pool, to ensure that they would perform their required [illegible]otions of passing the predicted flood at the designed reservoir e[illegible]vation wi[illegible] flow conditions and a minimum of scour in the tail[illegible] [illegible]sca[illegible]e ratio which was

selected for this purpose made the outlet works so small that only visual observations were practical. Despite this limitation, the studies led to an improvement in the design of the stilling pool for the outlet works.

3. The model. The various features to be studied were constructed to a geometric scale of 1 to 30 in such a way that revisions could be made quickly and easily. Water was supplied to the model by one of the laboratory pumps through a venturi meter which served as a discharge meter. After passing through the model spillway and the outlet works, the water was returned to the pump sump over an adjustable gate at the end of the tail box. The tailwater was controlled to the desired elevation by manipulation of this gate. Since the outlet studies were considered as more or less incidental, only the stilling pool portion was built to scale. The outlet upstream from the stilling pool was represented in the model by an equivalent circular pipe.

4. Spillway studies. In order to highlight any design deficiencies, the model with the original design of spillway, as shown in figure 1, was operated at discharges corresponding to the two flood predictions of 6,200 and 10,000 second-feet. The performance of the entrance was unsatisfactory because of the very rough flow conditions which occurred at the left side. The velocity of the flow approaching the entrance, in a direction parallel to the face of the dam, was high enough to create a contraction at the beginning of the rectangular section. The dip in the water surface and the rise which followed it, due to recovery of velocity head, are evident in the photograph (figure 2A) and in the water surface profiles in figure 3. The chute operated satisfactorily for a discharge of 6,200 second-feet, but the freeboard decreased to the vanishing point for a discharge of 10,000 second-feet, as shown by the profiles in figure 3. The operation of the stilling pool was satisfactory at even the highest discharge. The discharge capacity of the spillway was more than adequate. The maximum design discharge of 6,200 second-feet was passed with a reservoir elevation 0.5 foot lower than that estimated for the prototype, as shown in figure 4. The scour patterns shown

in figure 3 are exaggerated because no riprap was installed for this preliminary test. From these preliminary tests it was evident that the entrance needed revision which might affect the action of the chute and that the dimensions of the stilling basin were too conservative. In order to facilitate discussion of the revisions in the various features, they will be treated under separate headings.

5. Entrance design. The original entrance was designated as number 1, and subsequent revisions were numbered progressively according to the order in which they were tested. Details of the various revisions are shown in figure 5, and reference to this figure will be implied as each revision is discussed.

With entrance 1 in place, a false crest was inserted at the axis of the dam and the space between the two crests was filled in to the level of the original crest. Conditions at the right side of the entrance which were reasonably good in the first test were improved, but those at the left side were not affected appreciably.

Entrance 2, where a sharp-edged entrance was formed by the intersection of the rectangular spillway channel and the 2:1 slope of the face of the dam, represented the ultimate in simplicity of construction. Flow conditions for this entrance were comparatively little worse than those for entrance 1, but the discharge coefficient was definitely lower. The right side of the entrance was changed by swinging the wall, which originally extended from the cylindrical portion to the 1-1/2:1 slope of the approach channel, from its original position in a plane inclined 45 degrees to the axis to a plane parallel to the axis. This change did not affect the flow, and, since it avoids a certain amount of construction difficulties, it was retained in all subsequent revisions of the entrance.

In entrance 3 the sharp edge was eliminated by installing a portion of a cone between the face of the dam and the side of the rectangular channel. This entrance, with the crest as originally located, did not improve conditions at the left side. It was therefore abandoned.

Entrance 4 represented an adaptation of the design developed by model studies of the spillway for Granby Dam[1] wherein the entrance

[1] Hydraulic model studies of Granby Dam spillway - Colorado-Big Thompson project, Hydraulic Laboratory Report No. 109.

transition is formed by plane surfaces. Flow conditions were considerably improved with this entrance although there was still a roll against the left wall. There was also some disturbance at the sharp edge where the transition plane intersected the face of the dam.

Entrance 5 was a refinement of entrance 4 whereby the vertical face was changed to a slope of 1/2:1 and the sharp edge was replaced by a portion of a cylinder. Flow conditions were somewhat improved by the change, especially at the location of the former sharp edge. The surfaces of all the entrance transitions up to this point had been formed either in cement or sheet metal. Both of these types of surface were too smooth to faithfully represent the riprap surface which would be used to form the prototype entrance. The model was altered to remedy this situation by forming the face of the dam and the 2:1 transition plane in gravel which varied in diameter from 1/4 to 1/2 inch. It was expected that the increased frictional drag offered by the rougher surface would act to decrease the velocity of the flow which approaches the entrance along the face of the dam. The magnitude of this effect was apparently too small to be observed in the model. When the crest was moved upstream to the axis of the dam, instead of merely installing a false crest as was done in connection with the tests of entrance 1, conditions at the right side were improved but there was little change at the left side. With the exception of the small roll at the left side, as shown in figure 3, this last arrangement appeared to be a satisfactory entrance, particularly when a discharge test showed that it would pass the flood of 6,200 second-feet at the required reservoir surface elevation of 7360.

Entrance 6 was a simplification of entrance 5. The 2:1 slope of

the transition plane was made parallel to the axis of the dam, and the toe of the slope was made coincident with the extension of the intersection of the left wall and the floor. This change made flow conditions worse; so it was abandoned.

In the case of entrance 7 an attempt was made to eliminate completely the roll which persisted at the left side by an entirely different type of entrance which would reduce the effects of the cross flow along the face of the dam. A parabola was laid out on the bottom of the approach channel at elevation 7614.5 in the manner used to lay out parabolic curves in grade work. With points A, D, B, and C known (figure 5C), where B is the midpoint of line AC the distance P is half of distance DB. The curve was determined by using the relation $p = P(x/L)^2$ where p is measured parallel to line DB. An apex was located, in plan, at the intersection of the normals at points A and C and at elevation 7635.45. The desired transition shape was then obtained by screeding gravel with a straightedge between the apex and the parabolic curve previously laid out. Certain other changes were required to accommodate this entrance in the model, but, since they were well beyond the effect of the entrance, they are unimportant. A slight change was made in the right approach to the entrance by shifting the center of curvature to a point on the axis. This change eliminated the intersection which had prevailed in all the preceding entrances. The entrance then performed smoothly with only a slight roll at the left side, as shown in figure 6. The progressive improvement in the conditions at the left side had been obtained by extending the left boundary more and more into the forebay, and entrance 7 represented the practical limit of this device. Further reduction in approach velocity could be accomplished only by increasing the depth of flow. In the prototype this would be effected by excavating the approach channel; in the model the same effect was obtained by raising the spillway crest. A false crest was placed on top of the regular crest which approximately doubled the depth of flow for the same

discharge. Although there was a substantial improvement in flow conditions at the left side, it is probable that the necessary excavation would not be justified in the prototype.

6. Crest studies. Detailed measurements of discharge were made in only two cases; first, with the original design, and secondly, with the final design of entrance and crest as described in the preceding section under entrance 5. Any other isolated determinations of spillway capacity have already been discussed in connection with the particular entrance design to which they apply. The spillway capacity for various reservoir surface elevations, with the original design of entrance and original crest location, is shown in figure 4. The capacity exceeded the original estimate by several percent. When the crest was moved upstream to the axis of the dam, as shown in figure 7, the coefficient of discharge of the spillway crest was decreased. The capacity curve for the relocated crest with entrance 5 is shown in figure 4. Whereas the capacity of this arrangement was less than that of the original design, it was only slightly less than the original estimate. Instead of passing 6,200 second-feet at a reservoir surface of elevation 7630.0, the capacity was only 6,100 second-feet. This value of 6,100 second-feet, as well as all other measured values shown in figure 4, has been scaled up from the model measurement and is probably too low because of the disproportionately high boundary drag of the model. It would be expected that with a model scale of 1:30 the actual capacity of the prototype would reach 6,200 second-feet for a reservoir surface of elevation 7630.0.

In an effort to increase the coefficient of discharge and to widen the margin of safety, the upstream face of the crest section was changed to a 45-degree slope. Since the increase in coefficient was within the accuracy of the model measurements, this device was abandoned.

7. Chute studies. The action of the chute in the original design was satisfactory except for the splash against the side walls by the waves generated by the disturbance at the left entrance. Water surface

profiles for discharges of 2,000, 3,000, and 6,200 second-feet, prototype, are shown in figure 3. One point on the water surface profile for 10,000 second-feet is also shown. Except for the splash, which was a problem in entrance design rather than in chute design, the freeboard was adequate for the maximum design flow of 6,200 second-feet.

When the crest was moved upstream to the axis of the dam, the chute was extended upstream and joined to the horizontal portion by means of a vertical curve. The water surface profile for this revised chute, with entrance 5 and with the maximum design discharge of 6,200 second-feet, is shown in figure 7. Due to the improvement in entrance conditions, the flow down the chute was fairly smooth with waves of only nominal height. Some of the waves, which may be seen in figure 2, were of the capillary type which were greatly distorted in the model. The prototype would have smoother flow in the chute because the capillary waves which depend on a physical property of the fluid and not on the scale would be no larger than in the model.

8. Stilling pool studies. In the tests with the original design of stilling basin, the jump stayed in the pool for all discharges, including the Army flood estimate of 10,000 second-feet. Since the pool had been designed for a maximum discharge of only 6,200 second-feet, it was apparent that the pool dimensions were conservatively large.

The amount by which the floor could be raised was determined by tests in which the tailwater was progressively lowered below its normal elevation until the action in the pool started to change. With a model discharge corresponding to 6,200 second-feet, prototype, the tailwater was lowered three feet without any noticeable change in the effectiveness of the pool. Accordingly, the pool floor was raised three feet, and at the same time the length was shortened to 60 feet on the basis of the average dimensions of other stilling pool structures which have stood the test of time. The revised pool handled 6,200 second-feet nicely, even when the tailwater was again lowered below normal elevation. The pool was revised further by raising the floor an additional

one foot to elevation 7564, with the length held to 60 feet as shown in figure 7. In addition, the dentated sill at the downstream end of the pool was raised one foot, as shown in figure 5D, and gravel varying in diameter from 3/4 to 1-1/4 inches was installed to represent the contemplated prototype riprap which will vary from 3/4 to 1 cubic yard. The pool operated effectively at normal tailwater, as shown in figure 8A. To determine the safety factor of this design with respect to possible variation of the tailwater, the model tailwater elevation was lowered in steps corresponding to one foot, prototype. The pool stayed full for a total lowering of three feet and there was no noticeable increase in scour. When the total lowering reached four feet, the sheet of water from the chute impinged directly on the dentated sill at the end of the pool and was thrown into the air as shown in figure 8B, which is a photograph taken with the tailwater lowered 3.7 feet, prototype. A considerable amount of scour occurred where the sheet of water plunged into the tailrace.

9. Dentates and dentated sill. The first revision of the dentated sill at the downstream end of the stilling pool consisted of raising the entire sill one foot after the pool floor had been raised a total of four feet. This additional height of sill aided in maintaining proper pool action when the tailwater was lowered as much as three feet.

A test was made with the dentates removed, and, as in the test with the dentates in place, the pool did not sweep out until the tailwater was lowered four feet. Apparently the dentates had little effect in maintaining the pool; but it was definitely indicated that when the pool was full, the action was steadier and the jump distance was shorter with the dentates in place.

In an attempt to increase the effectiveness of the dentates they were revised so that the upper face had an inclination of 10 degrees rising in the direction of flow with the edges of the top face rounded slightly, as shown in figure 5. As no noticeable improvement could be detected, this approach was abandoned.

Experience has demonstrated that prototype dentates and dentated sills of this type are subject to damage in the form of destructive erosion and pitting of the concrete in the areas near the leading edges of the dentates. In the course of laboratory studies relative to other projects of the Bureau, it has been found that the negative pressures which produce the cavitation that is responsible for the damage may be eliminated by rounding the leading edges of the dentates. When this was done in the earlier studies, however, the effectiveness of the dentates in forming and stabilizing the action of the pool was decreased. The reasons for this decrease in the effectiveness of the dentates were not clear, but there seems to be little doubt that in part the decrease was due to the fact that with the leading edges rounded, the width of the individual jets issuing from any two dentates was increased by virtue of a decrease in the contraction at the entrance to the passage between the two dentates. In an attempt to capitalize on the benefits of rounding the edges without introducing the undesirable increase in width of jet, the dentates were revised as shown in figure 5D. It will be noted that instead of rounding the edges of the original design, the dentates were widened in such a manner that a section parallel to the slope of the chute shows the addition to be a quarter of an ellipse lying entirely outside the limits of the original block. The dimensions of the ellipse were based upon the contraction of a free jet for a large area ratio so that it would be under pressure for the smaller area ratio, as determined by the size and the spacing of the blocks. No tests were made to verify this conclusion because the principal point in question was whether or not the action of the stilling pool would be affected by the change in design of dentate. In the tests, the revised dentates appeared to be the equivalent in every way of the sharp-edged blocks which they replaced.

The dentated sill at the end of the stilling pool was revised in a similar manner, with the additional revision that the top face was shortened to make the jet spring clear, as shown in figure 5D, and the

effect was determined by comparing the scour in the tailrace after the model was operated for one hour with a discharge equivalent to 6,200 second-feet, prototype, with the original sill and then with the final sill. A comparison of the scour patterns, shown in figure 9, indicated that the scour with the final sill was somewhat less than that with the original sill. It was apparent that rounding of the leading edges of the dentates and the dentated sill, when accomplished in the manner described, did not detract from their effectiveness.

It will be noted that most of the scour, as shown in figures 3 and 9, occurred at the left side of the pool. This was due to the eddy which formed in the tailwater bay at the left side where there were no obstructions to inhibit its formation. This was proved by stopping the eddy with a temporary wall which eliminated this localized scour. A few attempts were made to approximate the action of a wall with cones of various shapes that could be constructed from embankment material, but these attempts were abandoned when it became evident that the desired damping of the eddy would require an impractically large extension into the tailrace.

10. Outlet studies. As pointed out previously, the model of the outlet and its stilling pool was included in the investigation more or or less as a matter of course, and it was too small for detailed studies. However, with the design discharge through the model outlet, it was evident from visual inspection that the hump at the end of the outlet was incorrectly designed. Instead of spreading smoothly to fill the transition, under the influence of the hump, the water continued on through the expander with unabated velocity and created high fins of water along the sides. When the outlet pool and the hump were revised, as shown in figure 5E, the action was greatly improved and was satisfactory for all the various tailwater elevations tested. The smoothness of the flow through the pool and the lowness of the residual velocity as the water entered the tailrace are evident in figure 8 A and B which shows conditions for 600 second-feet, prototype, passing

through the outlet for tailwaters of elevations 7583.7 and 7580, respectively.

11. Conclusions. As a result of the tests and the studies on the 1:30 hydraulic model, the following conclusions may be drawn:

(1) The original entrance transition was improved by redesigning it so that the left side conformed to that of entrance 5 and the right side to that of entrance 6. The performance of the left side of entrance 6 was somewhat better than that of entrance 5, but its additional cost would not be justified in this installation.

(2) The right side of the entrance was improved appreciably by moving the crest upstream to the axis of the dam. Although the discharge coefficient was decreased by this change, it was still capable of passing the design flood at the required reservoir water surface elevation.

(3) The chute with the necessary revisions to adapt it to the new location of the crest operated satisfactorily.

(4) Satisfactory operation of the stilling pool was obtained with the floor raised four feet to elevation 7640 and the length shortened from 75 to 60 feet. In conjunction with the decrease in pool dimensions, it was necessary to raise the dentated sill one foot.

(5) The negative pressures which are believed to cause erosion of the dentates can be minimized, without sacrificing their effectiveness, by widening the dentates to form rounded edges as shown in figure 5D.

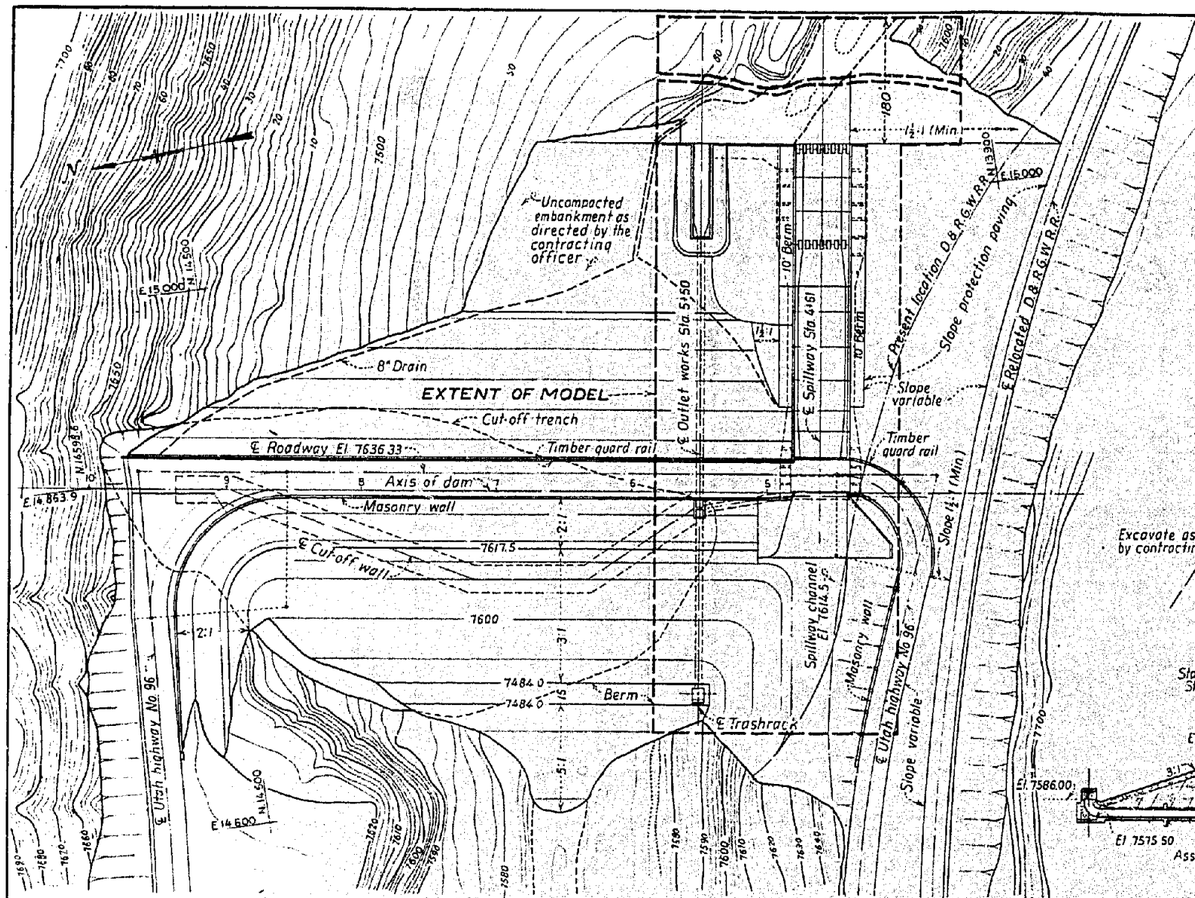
(6) The tendency to scour the tailwater bed, even for flood flows, was not serious. The action of the stilling pool was acceptable for a tailwater elevation more than three feet lower than normal.

(7) The revised stilling pool for the outlet operated smoothly and effectively.

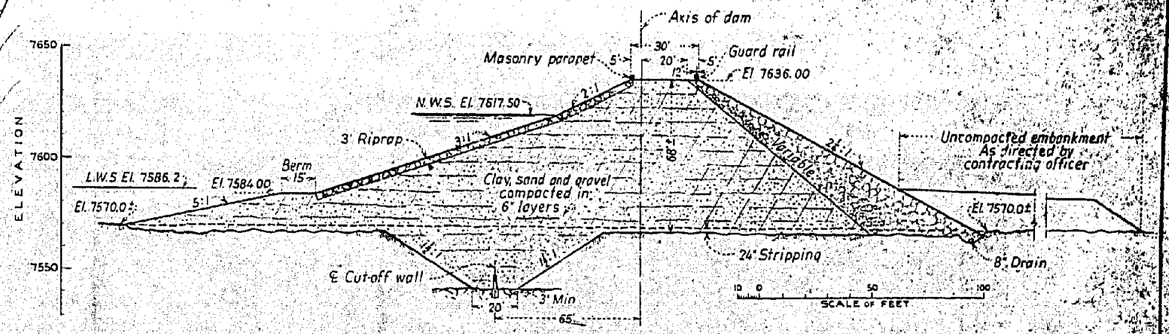
The final design of spillway and outlet works incorporating most of the improvements is shown in figure 10.

- - -

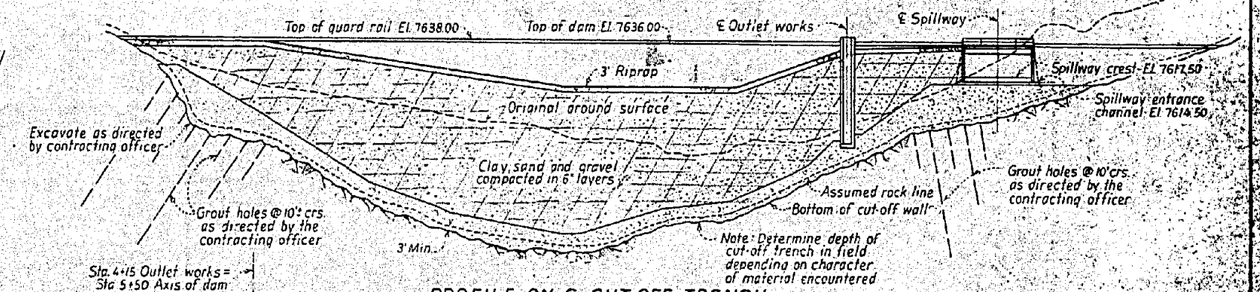
FIGURE 1



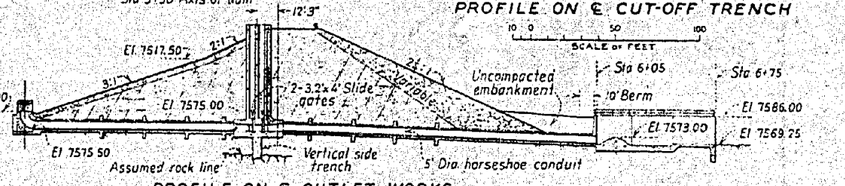
PLAN



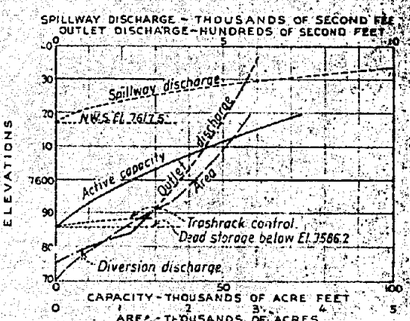
MAXIMUM SECTION



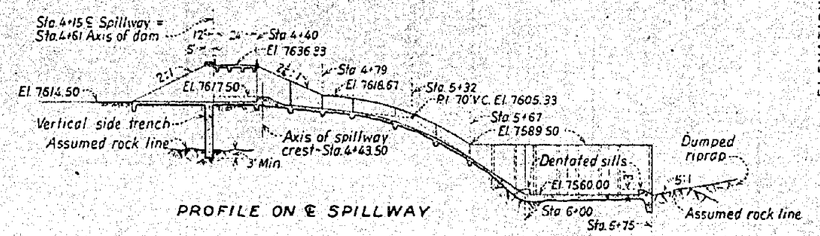
PROFILE ON ℄ CUT-OFF TRENCH



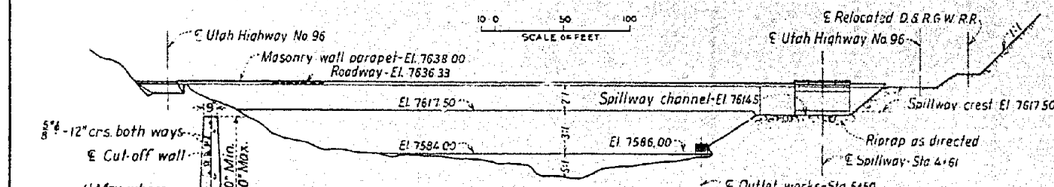
PROFILE ON ℄ OUTLET WORKS



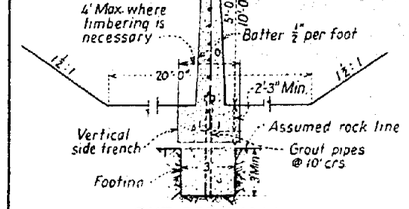
AREA, CAPACITY AND DISCHARGE CURVES



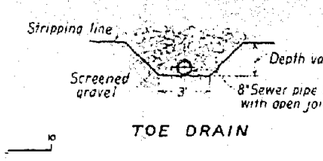
PROFILE ON ℄ SPILLWAY



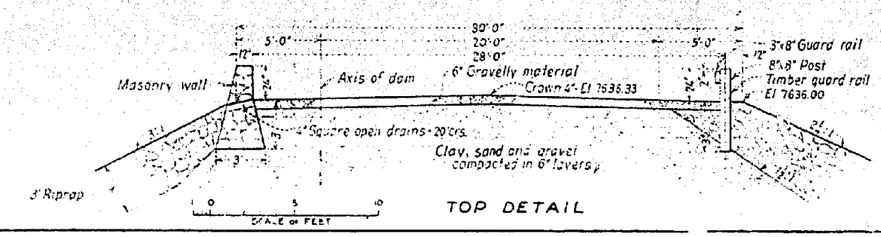
UPSTREAM ELEVATION



CUT-OFF WALL



TOE DRAIN



TOP DETAIL

UNITED STATES
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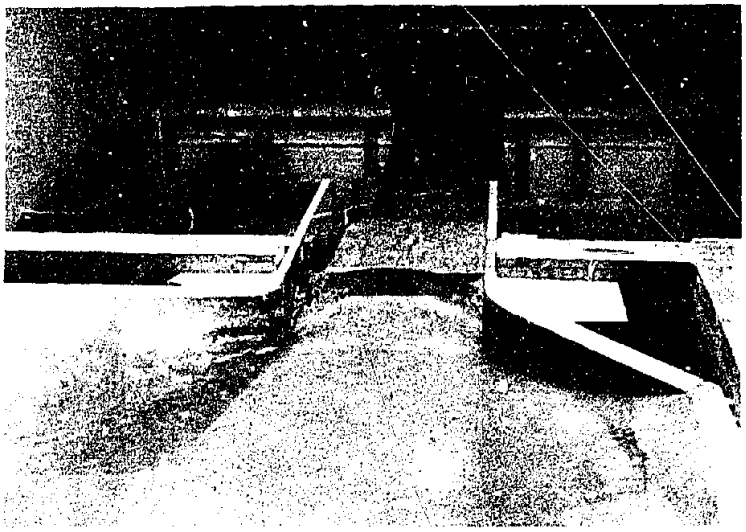
BUREAU OF RECLAMATION
SCOFIELD PROJECT - UTAH

SCOFIELD DAM

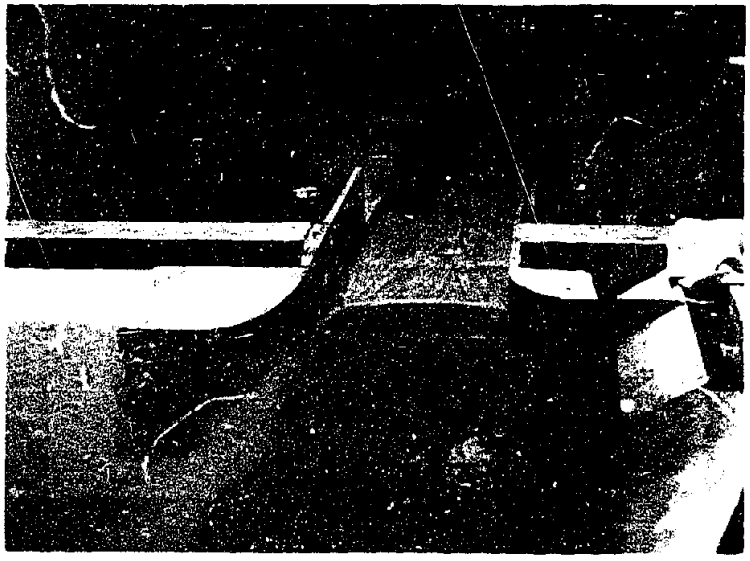
GENERAL PLAN AND SECTIONS

DRAWN C.A.M. SUBMITTED
TRACED M.T. C.J.R. RECOMMENDED
CHECKED APPROVED
DENVER, COLORADO JULY 28, 1943

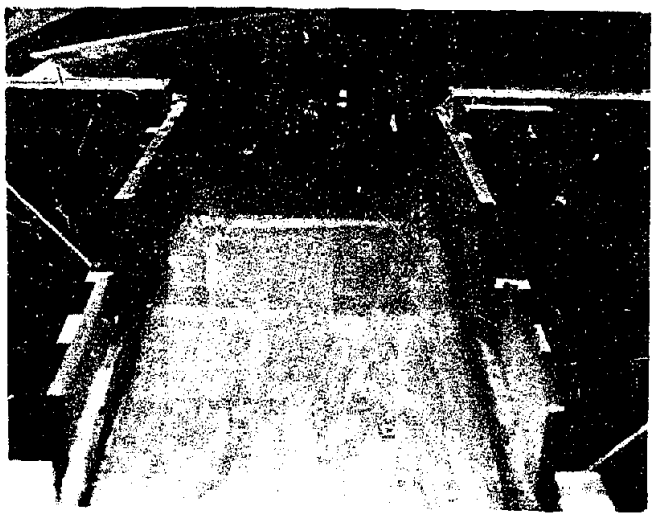
132-D-28



(A) Entrance 1, original design, looking downstream, discharge 6,200 second-feet.

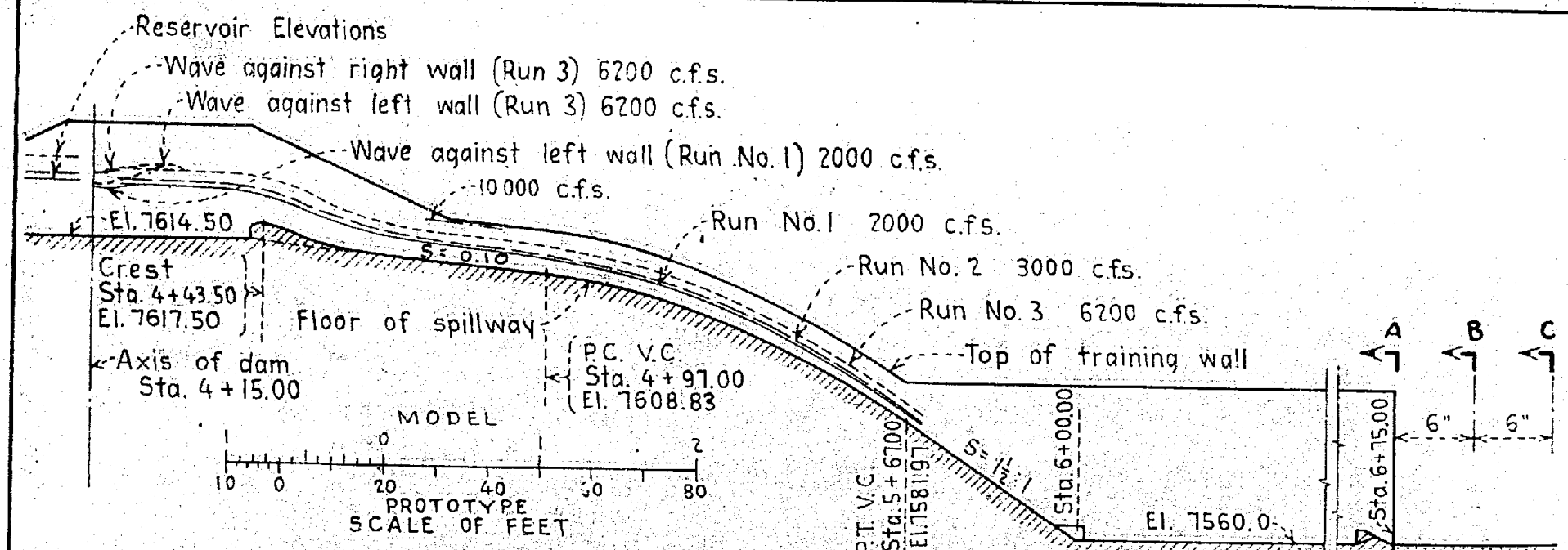


(B) Entrance 5, looking downstream.



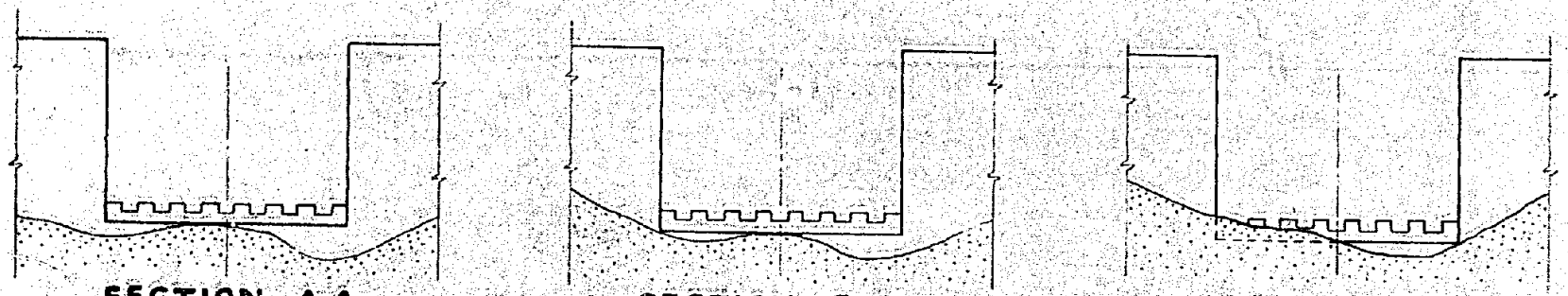
(C) Entrance 5, looking upstream.

FLOW CONDITIONS IN ORIGINAL ENTRANCE AND ENTRANCE 5.



SECTION ALONG ℄ OF SPILLWAY

SHOWING WATER PROFILES — RUNS 1, 2 AND 3



SECTION A-A **SECTION B-B** **SECTION C-C**

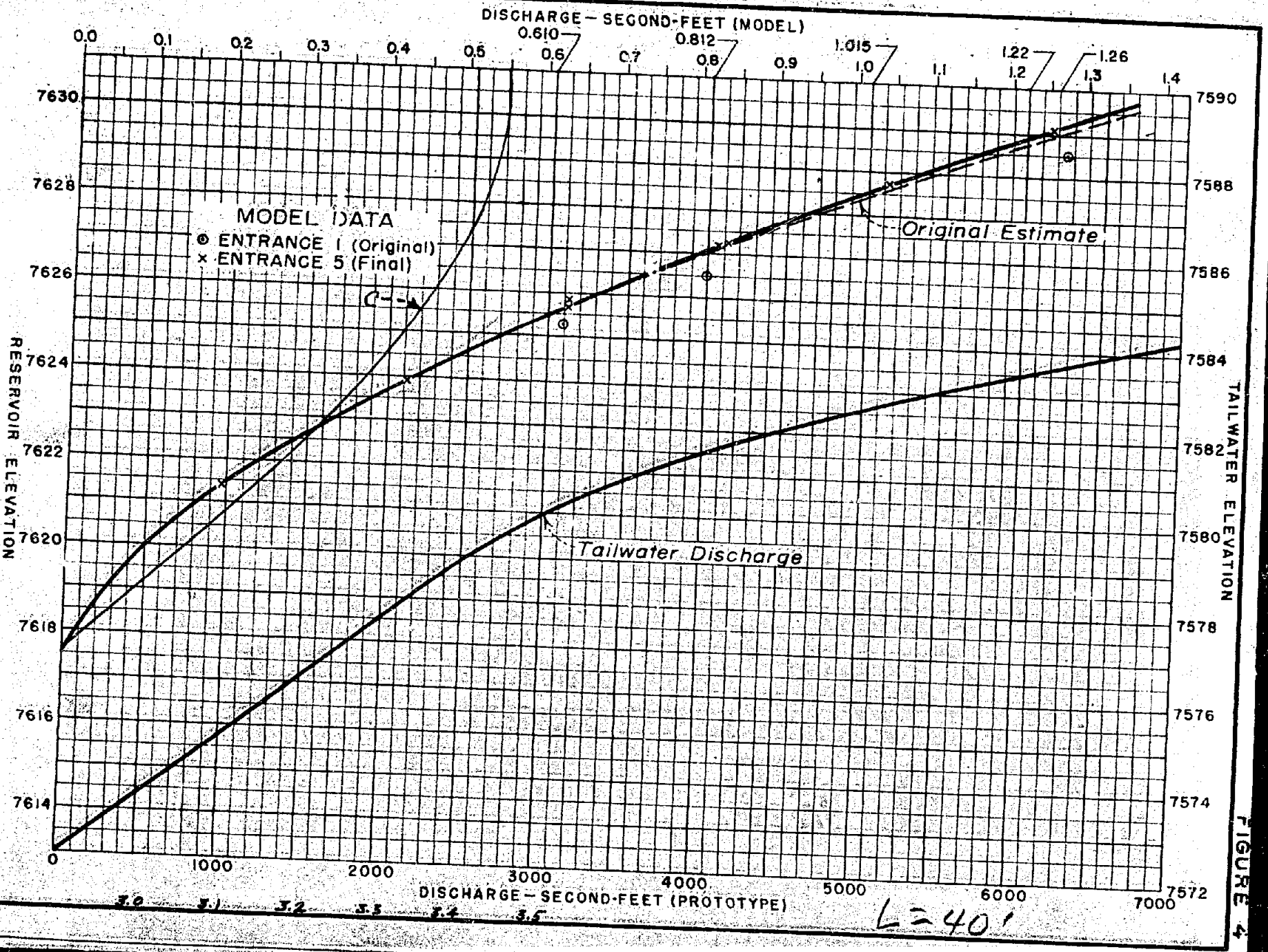
SCOUR BY TAILWATER

After running ½ hr. @ 2000, ½ hr. @ 3000, ½ hr. @ 6200, ¼ hr. @ 7750, ¼ hr. @ 10 000 c.f.s.

SCOFIELD DAM SPILLWAY - MODEL STUDIES

ORIGINAL DESIGN

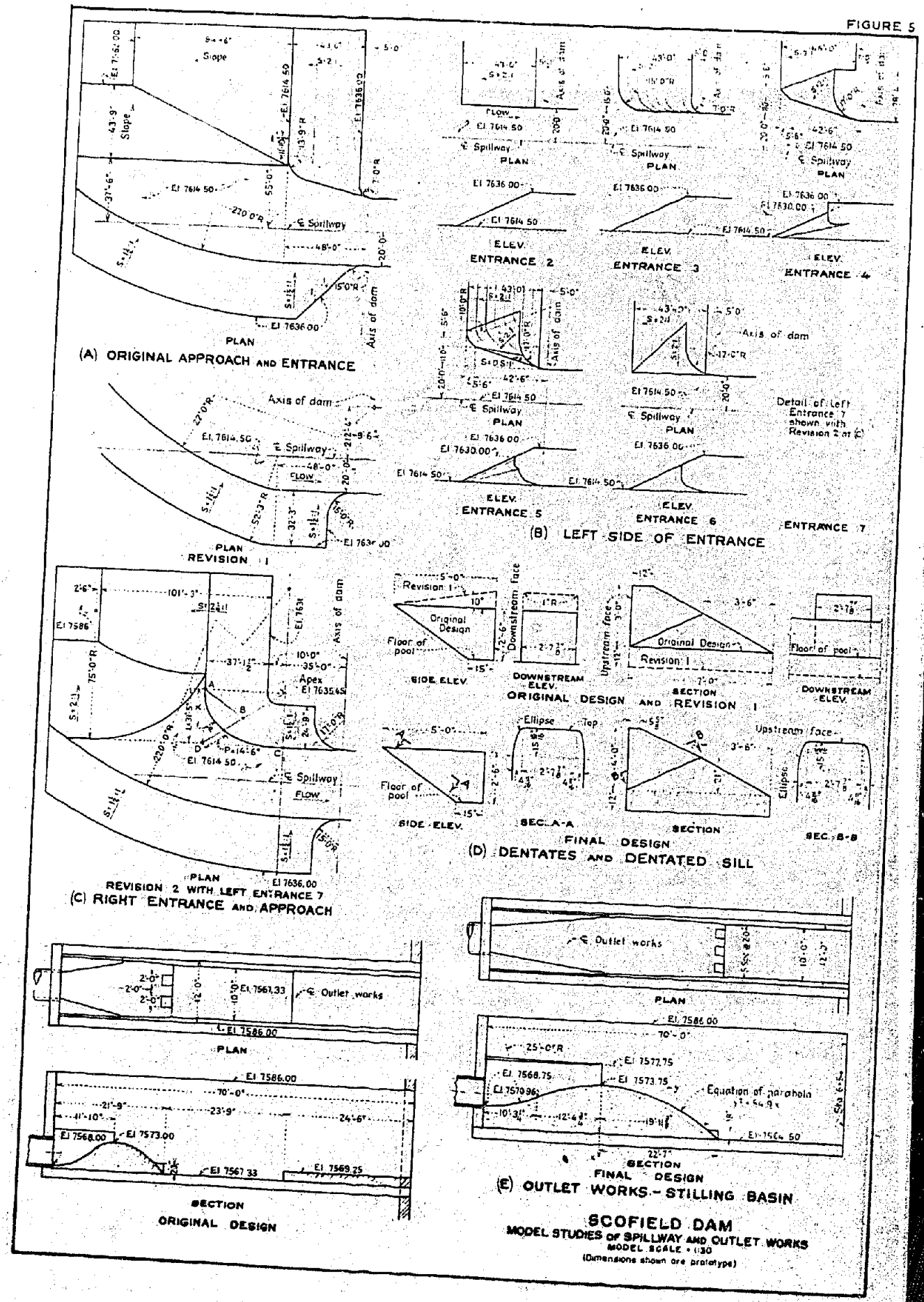
FIGURE 3



SCOFIELD DAM
SPILLWAY CAPACITY

FIGURE 4

FIGURE 5



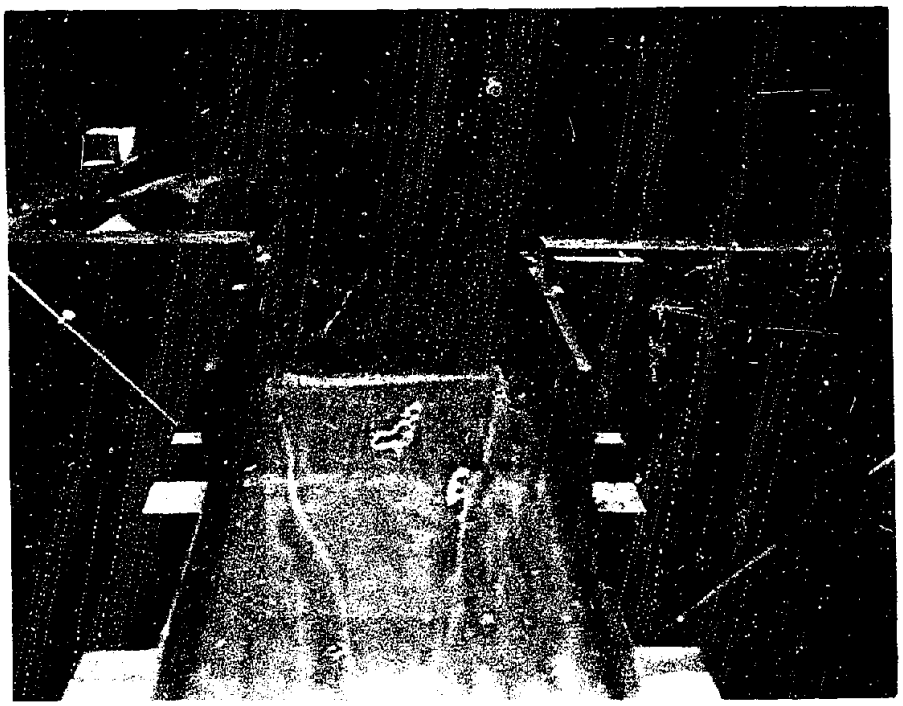
SCOFIELD DAM

MODEL STUDIES OF SPILLWAY AND OUTLET WORKS

MODEL SCALE = 1:30

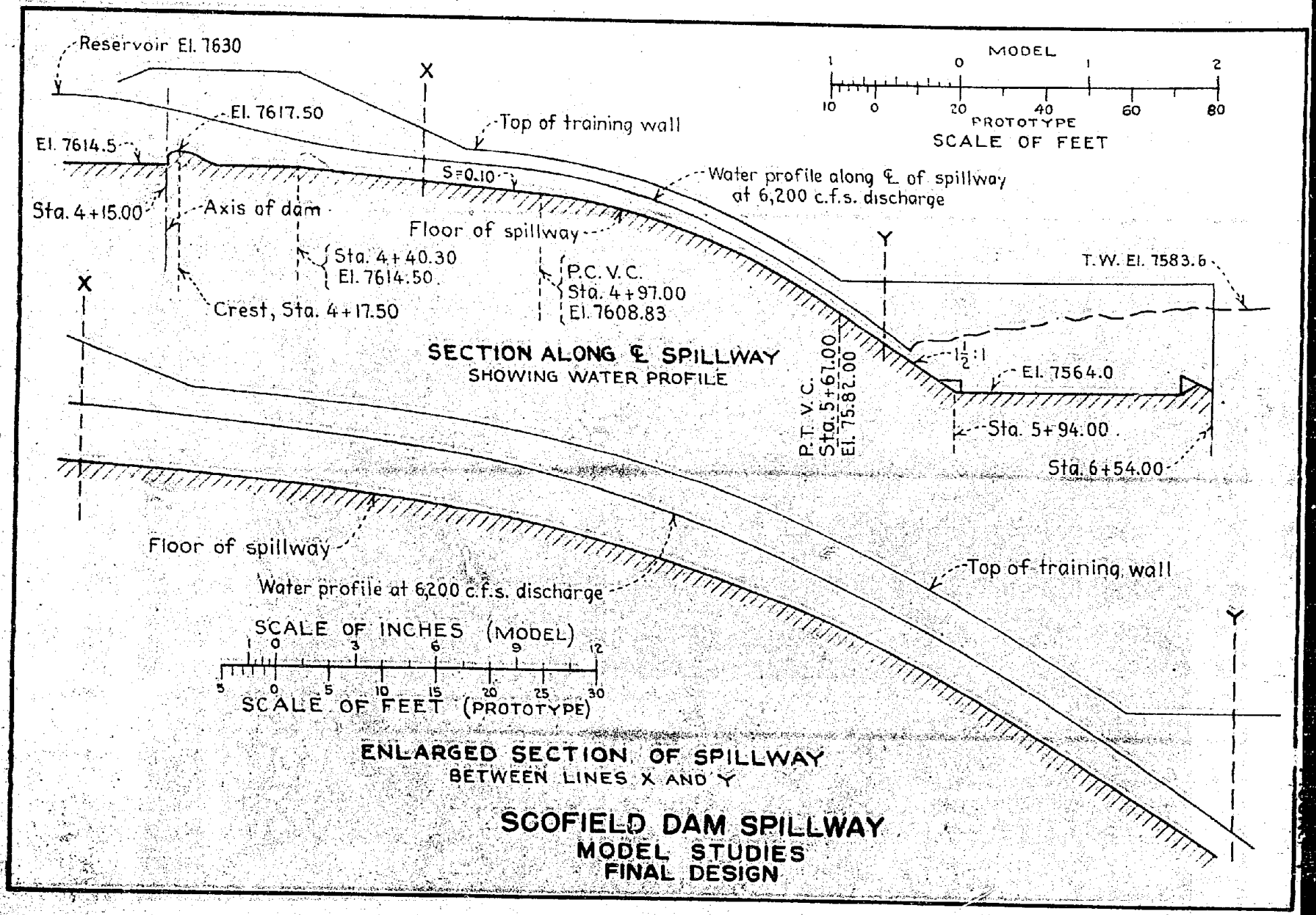
(Dimensions shown are prototype)

(A) Entrance 7, looking downstream.



(B) Entrance 7, looking upstream.

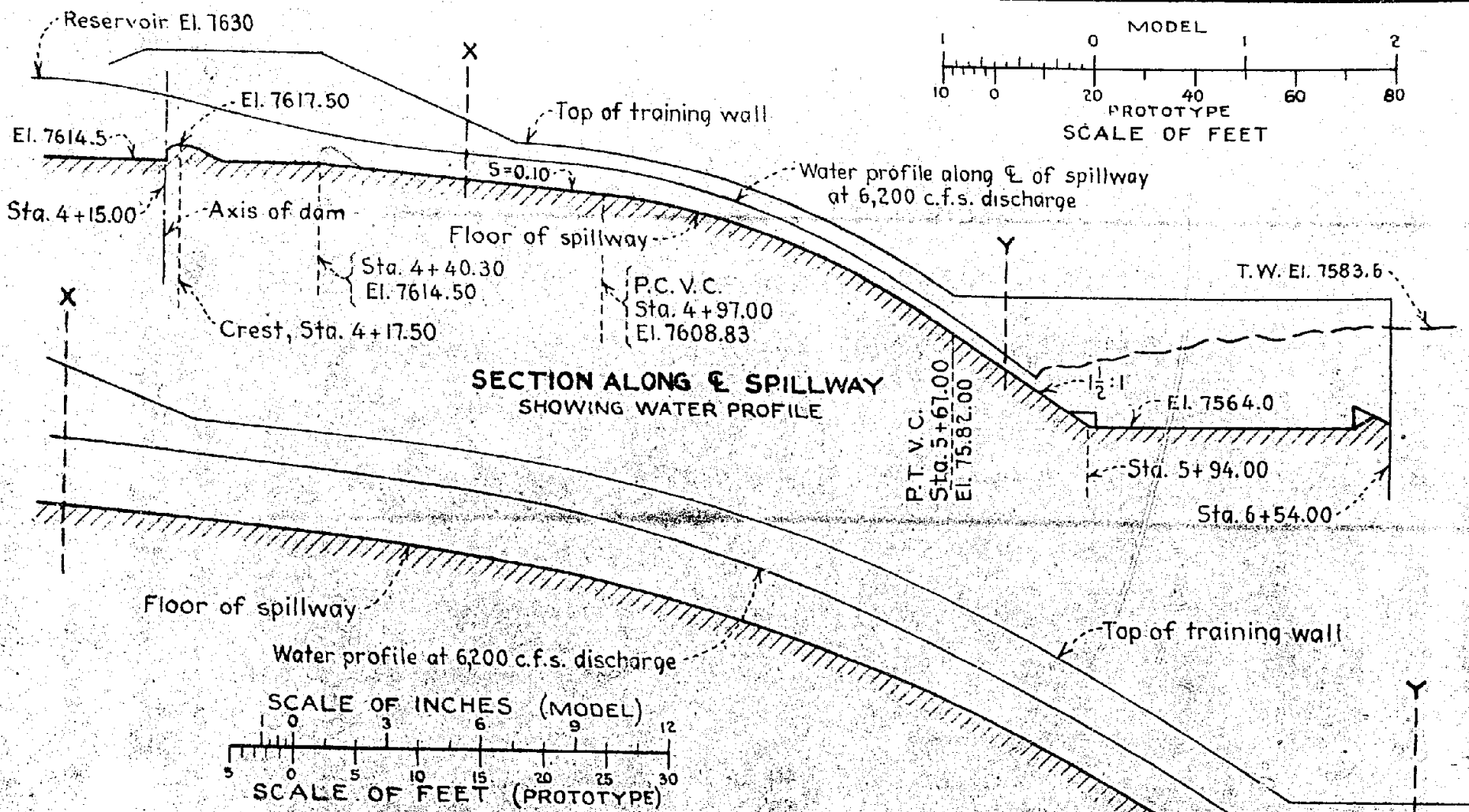
FLOW CONDITIONS IN ENTRANCE 7.



SECTION ALONG ℄ SPILLWAY
SHOWING WATER PROFILE

ENLARGED SECTION OF SPILLWAY
BETWEEN LINES X AND Y

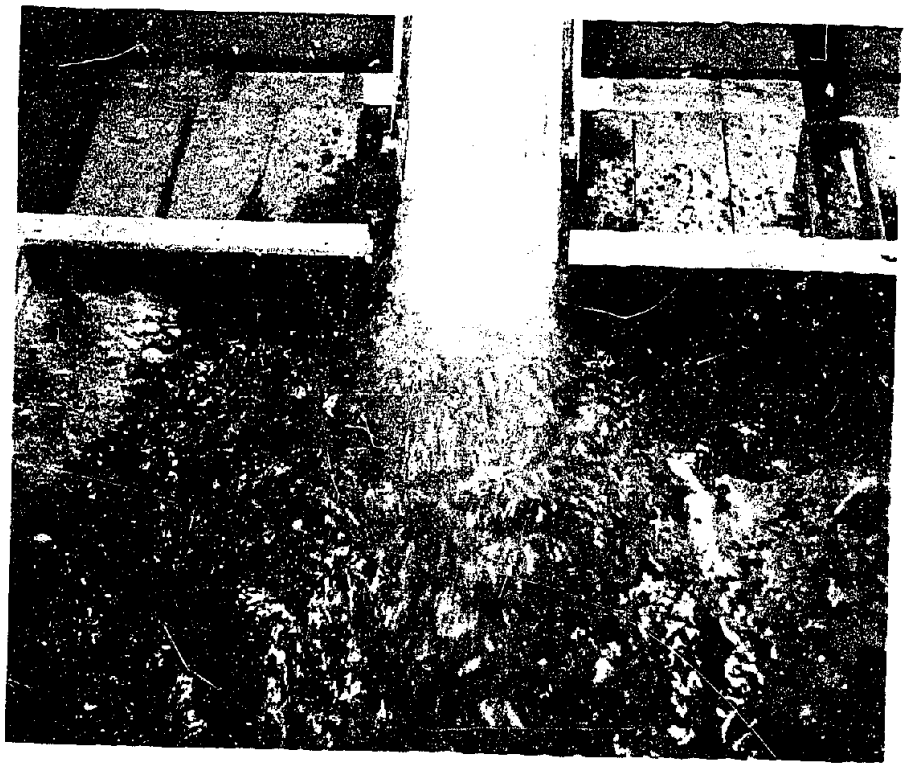
SCOFIELD DAM SPILLWAY
MODEL STUDIES
FINAL DESIGN



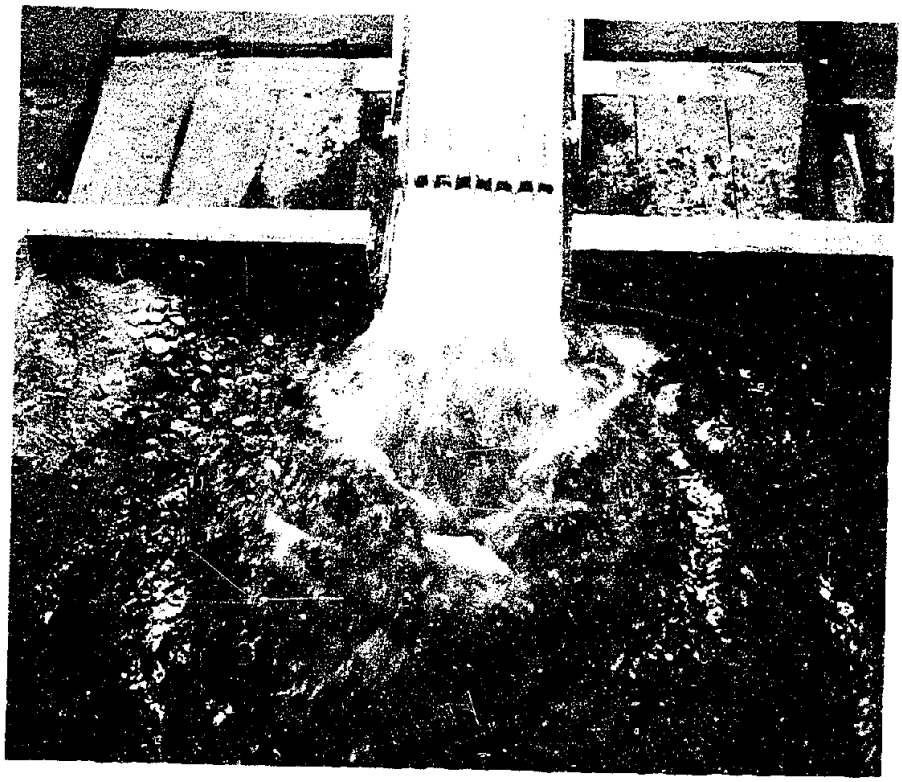
SECTION ALONG ℄ SPILLWAY
SHOWING WATER PROFILE

ENLARGED SECTION OF SPILLWAY
BETWEEN LINES X AND Y

SCOFIELD DAM SPILLWAY
MODEL STUDIES
FINAL DESIGN

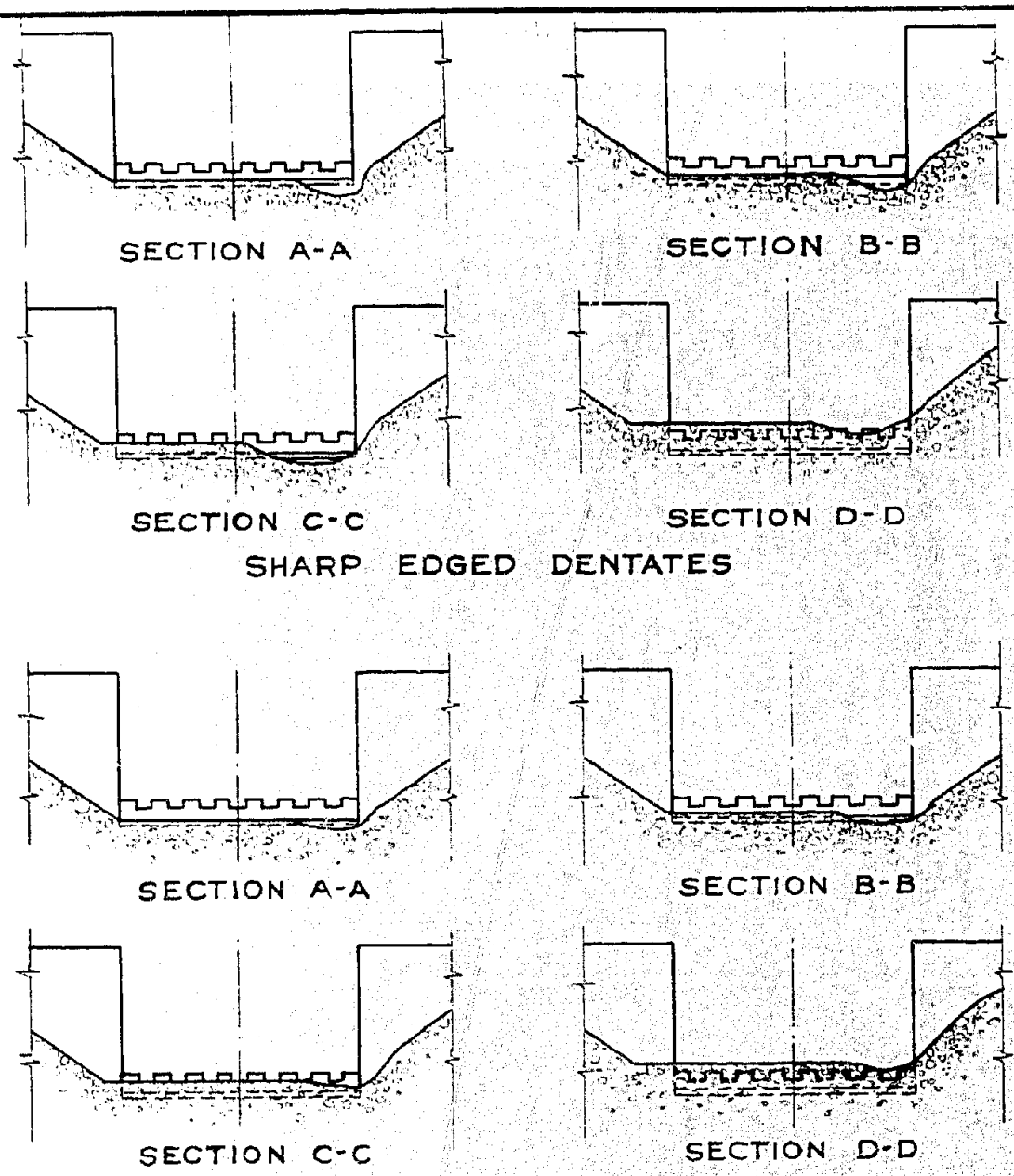


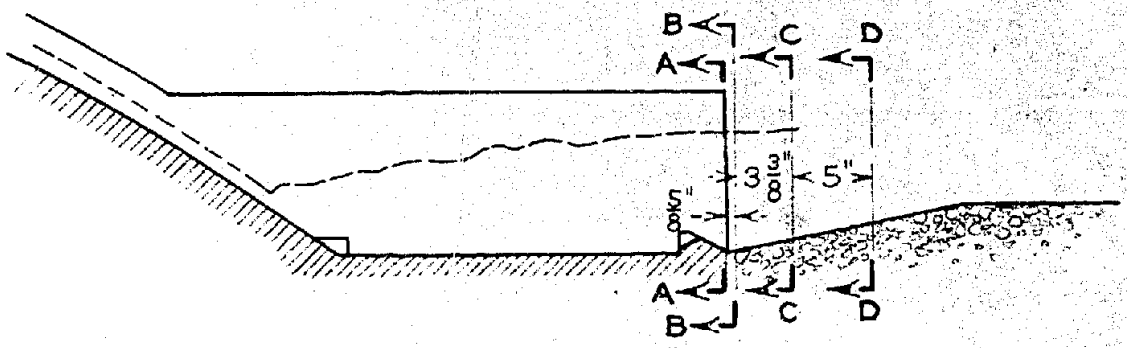
(A) Normal tailwater: Spillway Q=6,200 s.f.; outlet Q=600 s.f



(B) Tailwater 3.7 ft. below normal, same discharges.

POOL ACTION AND TAILWATER CONDITIONS.



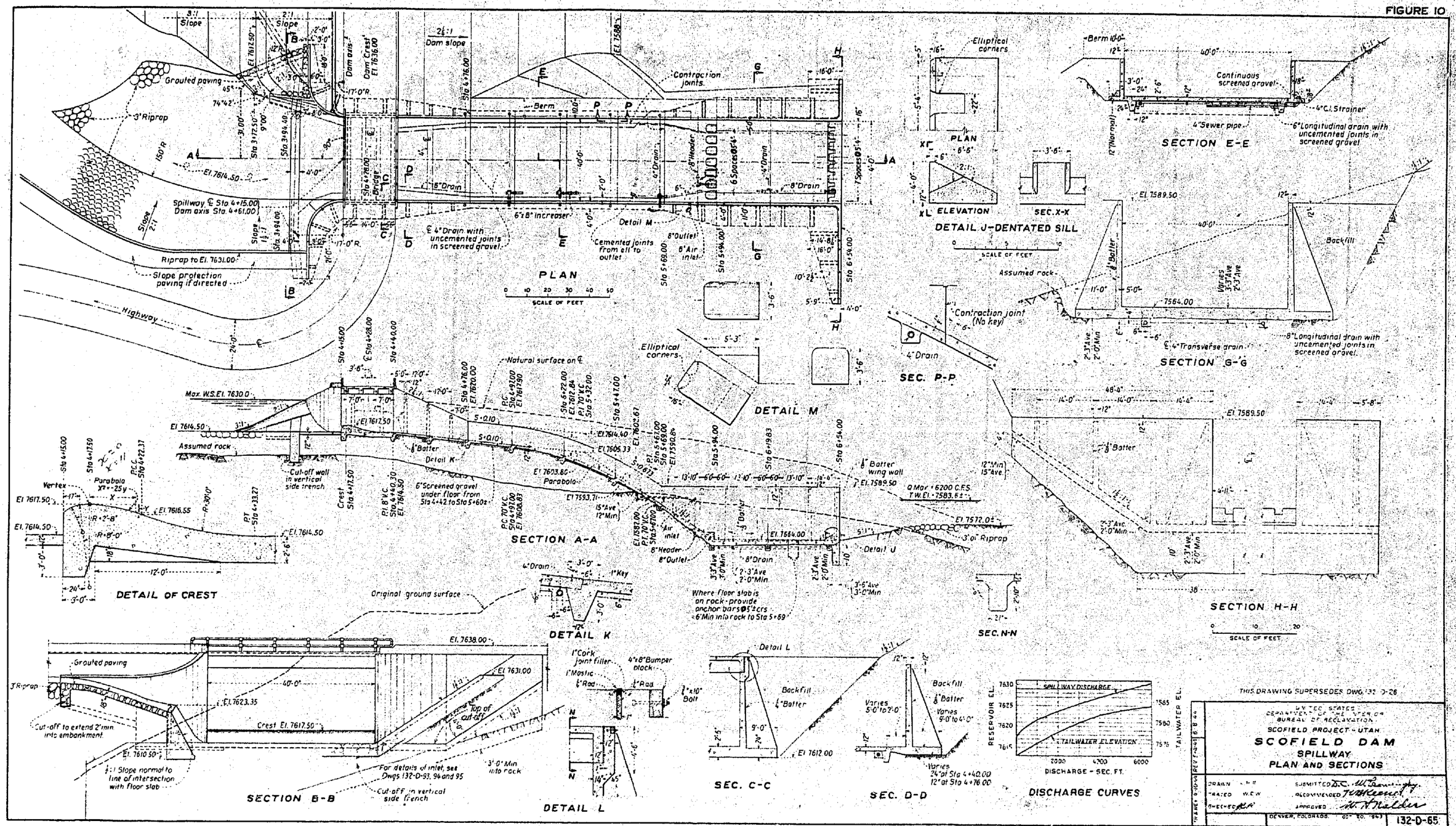


LONGITUDINAL SECTION
SHOWING LOCATIONS OF CROSS SECTIONS A-A TO D-D

SCOFIELD DAM SPILLWAY

COMPARISON OF SCOUR WITH ORIGINAL
AND FINAL DENTATED SILL AFTER RUNNING
ONE HOUR @ 1.26 C.F.S. (6,200 C.F.S. PROTOTYPE)

FIGURE 10


PLAN
SCALE OF FEET
SECTION A-A
DETAIL OF CREST
SECTION B-B
DETAIL K
DETAIL L
DETAIL M
SEC. P-P
SEC. C-C
SEC. D-D
DETAIL J-DENTATED SILL
ELEVATION
SEC. X-X
SECTION E-E
SECTION G-G
SECTION H-H
SEC. N-N
DISCHARGE CURVES
SPILLWAY DISCHARGE
TAILWATER ELEVATION
RESERVOIR EL.
TAILWATER EL.
DISCHARGE - SEC. FT.
THIS DRAWING SUPERSEDES DWG. 132-D-26
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SCOFIELD PROJECT - UTAH
SCOFIELD DAM
SPILLWAY
PLAN AND SECTIONS
DRAWN
TRACED W.E.W.
SHEET-FED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO
132-D-65