UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 162

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HYDRAULIC MODEL STUDY OF THE SPILLWAY AND OUTLET WORKS FOR SHADOW MOUNTAIN DAM COLORADO-BIG THOMPSON PROJECT, COLORADO

By

D. J. HEBERT, ENGINEER

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Denver, Colorado
January 4, 1945

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FOR
SHADOW MOUNTAIN DAM
COLORADO-BIG THOMPSON PROJECT, COLORADO

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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

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Denver, Colorado,
Jan. 4, 1945

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
January 4, 1945

Laboratory Report No. 162
Hydraulic Laboratory

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

Subject: Hydraulic model studies of the spillway and outlet for Shadow Mountain Dam - Colorado-Big Thompson Project, Colorado.

1. Introduction. Shadow Mountain Dam will be an earth-fill dam across the Colorado River at a site about three miles south of the town of Grand Lake, Colorado. The principal hydraulic feature of this dam will be the concrete-lined, open-channel spillway at the right abutment whose discharge will be controlled by two 18- by 18.5-foot radial gates. Details of the spillway are shown in figure 1. Incorporated within the spillway will be an outlet which will function to pass small flows when the radial gates are closed.

A hydraulic model study was made, using a model constructed to a geometric scale of 1 to 30, model to prototype, to verify the adequacy of the spillway design.

2. Summary. The model tests indicated that the entrance transition functioned smoothly both with and without the outlet operating. It was found that the crest had to be lowered one-half foot, prototype, to achieve the required discharge capacity. The stilling pool was raised and shortened, and the dentates were revised. The lower part of the outlet was relocated so that it discharged into the chute instead of into the stilling pool, and a design was developed which did not affect flow conditions in the chute. Special tests were made to study the possibilities of dissipating the energy of the water spilling down the chute by means of sills placed transverse to the direction of flow.

3. Model details. The extent of the model, which was constructed

to a geometric scale of 1 to 30, is indicated in figure 1. Water was supplied to the model by a laboratory pump through a venturi meter which served as a means for measuring the model discharge. After passing through the model, the water was returned to the pump sump over an adjustable tail gate which provided the means for controlling the tailwater level. Some of the details of the model construction appear in figure 3.

4. *Test of original design.* In order to highlight any possible defects in the original design, a test was made with a discharge corresponding to 10,000 second-feet, prototype, which represents the maximum prototype flood. Entrance conditions were satisfactory, as shown in figure 3. There was some disturbance on the surface of the water, particularly in the vicinity of the pier nose, but it was minor in magnitude.

In order to pass the 10,000 second-feet, it was necessary to increase the elevation of the reservoir water surface above the designed maximum.

Flow down the chute was quite smooth, as shown in figure 3, and the freeboard was ample, as shown by the water surface profile in figure 4.

The stilling pool proved to be more than adequate. The tailwater was lowered 4 feet from its normal elevation without materially affecting the action of the pool.

More detailed studies of each component part were made, and they will be discussed under separate headings.

5. *Entrance studies.* The pertinent details of the original entrance are shown in figure 1, and an enlarged detail of the left side is shown in figure 2. In the model the transition section was constructed by screeding medium gravel with a straightedge between the apex at elevation 8370.08 and a parabolic curve laid out at elevation 8345.0 according to the dimensions shown in figure 2. This entrance

was satisfactory in the high-discharge test, and, for smaller discharges, with the radial gates lowered to maintain the reservoir level at elevation 8367.0 which corresponds to the proposed prototype operation, entrance conditions were even better. With the gates completely closed and the outlet opened, the disturbance at the entrance of the outlet conduit which is located in the nose of the pier, was hardly noticeable.

6. Crest capacity studies. The capacity and the characteristics of the crest were studied by varying the discharge; first, with the spillway uncontrolled, and secondly, with the reservoir water surface maintained at its designed maximum by lowering the gates. The discharge of the uncontrolled spillway scaled up from the model measurements is shown in figure 5, with the spillway crest at elevation 8348.5. It is apparent that the crest coefficient was lower than assumed in the design studies, since the reservoir water surface required to pass 10,000 second-feet was elevation 8367.5 instead of the designed value of elevation 8367.0. Based on the calipered net length of model crest, the coefficient of discharge was 3.34 for a discharge of 10,000 second-feet. The coefficient of the same crest without piers as determined by other model experiments was 3.50, which was the value used in designing the crest. This decrease in coefficient was undoubtedly due to the changes in flow pattern caused by the presence of the pier. The required capacity of the spillway was restored in the final design by lowering the crest one-half foot, prototype, to elevation 8348.0, as shown in figure 6. Other revisions necessitated by this change are also shown in figure 6.

Although the model was not designed for a calibration test of the radial gates in that no provision was made for holding the water level in the head box at a given constant level, some data which might be useful for operation of the prototype were obtained. For any given discharge the two gates were adjusted to the same opening such that the reservoir water surface stabilized at an elevation 19 feet, prototype, above the elevation of the spillway crest. The data are shown in graphical form in figure 5. Since the model crest was located at elevation 8348.5, the maximum water surface is shown as 8367.5. With the prototype crest lowered to elevation 8348.0, the 19-foot head would correspond to the required maximum water surface of elevation 8367.0. There was a range of operation in the model corresponding to discharges greater than 8,000 second-feet wherein the gate position could not be determined accurately because of the lack of refinement in the gate-adjusting device and the restricted forebay area. For example, with a discharge of 9,000 second-feet, prototype, the gates were lowered until the bottom edge just touched the water surface. Water piled against the gate intermittently until, finally, enough water accumulated against the gate to change the coefficient of discharge, and the gate assumed control of the flow with an attendant rise of about 1 foot, prototype, in the reservoir level. When the gates were then raised 0.006 foot, model, or 0.2 foot, prototype, the reservoir level gradually lowered until the gate bottom was clear of the water surface. Because of this difficulty no data were obtained for discharges greater than 8,000 second-feet, prototype, and the curve is shown as approximate in this region.

7. Stilling-pool studies. During the test of the original design it was demonstrated that the tailwater level could be lowered 4 feet without affecting appreciably the action of the pool. Accordingly, the floor of the pool basin was raised 3 feet to elevation 8313.0, and the length was shortened from 64 to 56 feet. The change in the floor moved its intersection with the chute upstream a distance of 6 feet. As a result of both changes, the vertical walls were cut back a total of 14 feet, as shown in figure 4. The performance of the revised stilling pool was equal to that of the original design. When the tailwater level was lowered 4 feet, the pool stayed full, as shown in figure 3.

Dentates and a dentated sill, of a new type, developed in the studies of the spillway for Scofield Dam* were installed, and a test

*"Hydraulic Model Studies of the Spillway and Outlet Works for Scofield Dam - Scofield Project, Utah," Hydraulic Laboratory Report No. 160.

with 10,000 second-feet showed no adverse effect on the pool action. The new type of block which is shown in figure 6, details U and H, was developed to eliminate cavitation erosion without changing its effectiveness in the stilling-pool action. Since the stilling-pool action was not affected by the change, the revised blocks were adopted for the final design.

8. Studies of scour. The tendency of the water to scour the bed of the tailbay was not pronounced, and was limited for the most part to a small area on each side of the stilling pool at the point where the water entered the tailbay. This localized scouring action was caused by an eddy which formed as the jet of water from the stilling pool plunged into the tailbay, and may be offset in the prototype by increasing the size of the riprap in these two areas.

In an effort to eliminate the cause of the erosion, the dentates next to each vertical wall were removed, but the scouring action appeared to have been increased by the change. Attempts to eliminate the rollers by extending the vertical side walls into the tailbay were equally fruitless from a practical standpoint. In order to have an appreciable effect, the wall extensions had to be 15 feet high and 15 feet long. With extensions of this height and length the erosion was eliminated at the end of the dentated sill, but a new scour pocket of reduced size was created at the end of each extension.

9. Outlet studies. In the original design of outlet the discharge end was located in the center dentate at the toe of the chute, as shown in figure 1. Before any tests were made for this location, the outlet was changed from a 30-inch diameter pipe to a 2-foot square, reinforced-concrete conduit, and its discharge end was shifted to a new location on the chute with an opening 24 by 43 inches at elevation 8323.0. In the first design the opening had sharp edges which created a disturbance at low spillway discharges. When the downstream edge was rounded as shown in figure 6, detail K, the disturbance was eliminated for all flows. It was also established by the tests that the outlet

would be under pressure for all spillway discharges, and therefore air relief would not be required. In the final design the outlet size and width of opening were increased to 30 inches and its location was shifted to elevation 8326.0, as shown in figure 6.

10. Special tests of energy dissipation by sills. The chute of this model was used, in connection with another study, to investigate the drop in pressure downstream from a sill when placed in a stream of water flowing down an inclined plane. It was noted while measuring velocities upstream and downstream from the sill that an appreciable decrease in energy occurred. To exploit the possibilities of such dissipation, a series of tests was made in which the number and the size of the sills were varied. These sills were triangular in cross section and were placed so that they extended from wall to wall normal to the center line of the chute, with the upper faces horizontal and the downstream faces vertical. In the two sizes which were used, the height of the vertical face was 1/4 inch and 3/8 inch, respectively. The length of the horizontal face varied with the slope of the chute where the sill was located. The dissipating effect was determined by measuring the energy head at a point just upstream from the toe of the chute both with and without sills. The measurements were made with a small pitot tube placed parallel to the slope. Since this tube had a single impact opening, only the total energy head was indicated. The sills were installed, starting at station 3+71.75, with the locations shown in figure 4. The energy heads and the velocities for different numbers and combinations of sills, where the count began at station 3+71.75, are shown in the following tabulation for an uncontrolled spillway with a discharge corresponding to 9,000 second-feet, prototype.

Condition	Model energy head, inches	Energy in percent	Model velocity, ft./sec.
No sills	17.69	100.0	9.75
2 sills at 1/4 inch	15.25	86.2	9.10
4 sills at 1/4 inch	14.06	79.5	8.68
5 sills at 1/4 inch	13.75	77.7	8.60
6 sills at 1/4 inch	13.25	74.9	8.42
7 sills at 1/4 inch	13.69	77.4	8.60
7-) (3 sills at 3/8 inch (4 sills at 1/4 inch	13.50	76.3	8.55

The velocity in the last column was obtained by assuming that by comparison with the total energy head, the depth of flow was negligible and the measured energy head was equal to the velocity head. Although the flow in the chute was rough, with the sills in place, it was acceptable for all discharges. When the flow was controlled by the gates so that the water entered the chute with a small depth and a high velocity, the sill made the flow very rough, with considerable spray. Although it was evident that the use of sills was not applicable for a gate-controlled crest, the possibilities of dissipating some of the energy of an uncontrolled spillway by sills placed on the chute, with the resultant saving in stilling pool cost by virtue of a reduction of its size, would bear further investigation.

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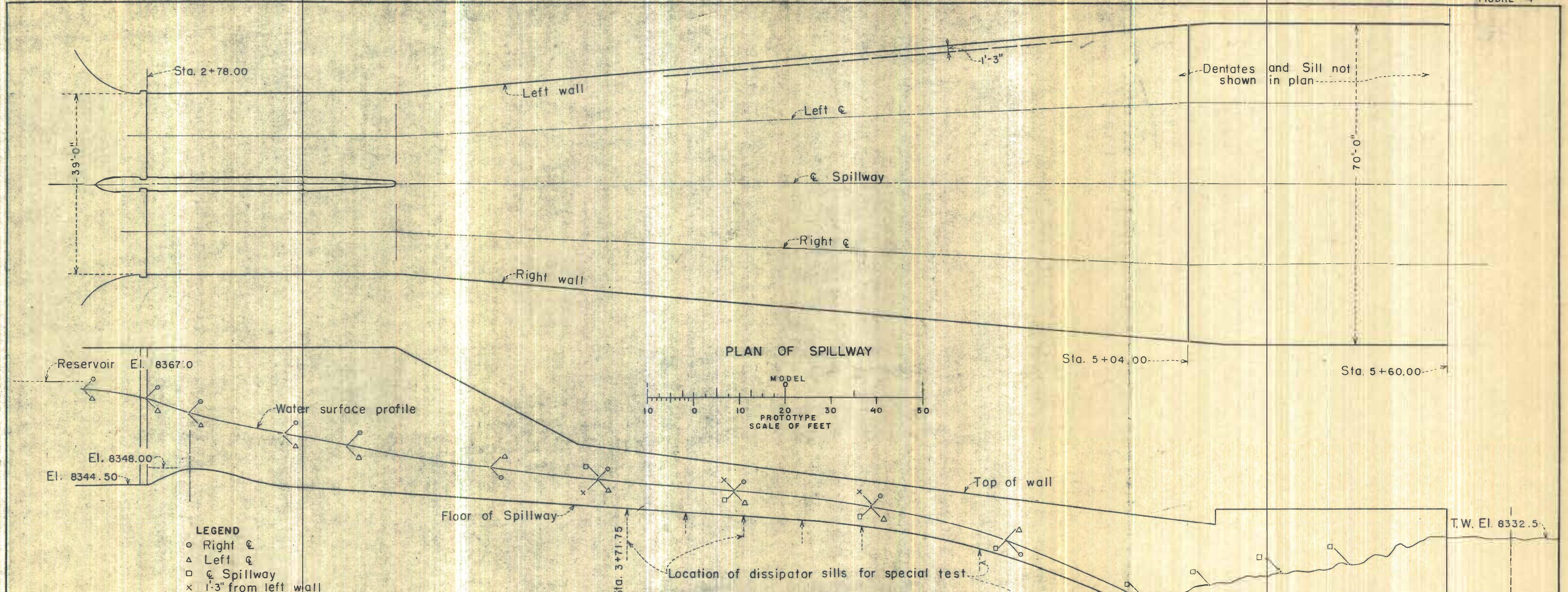


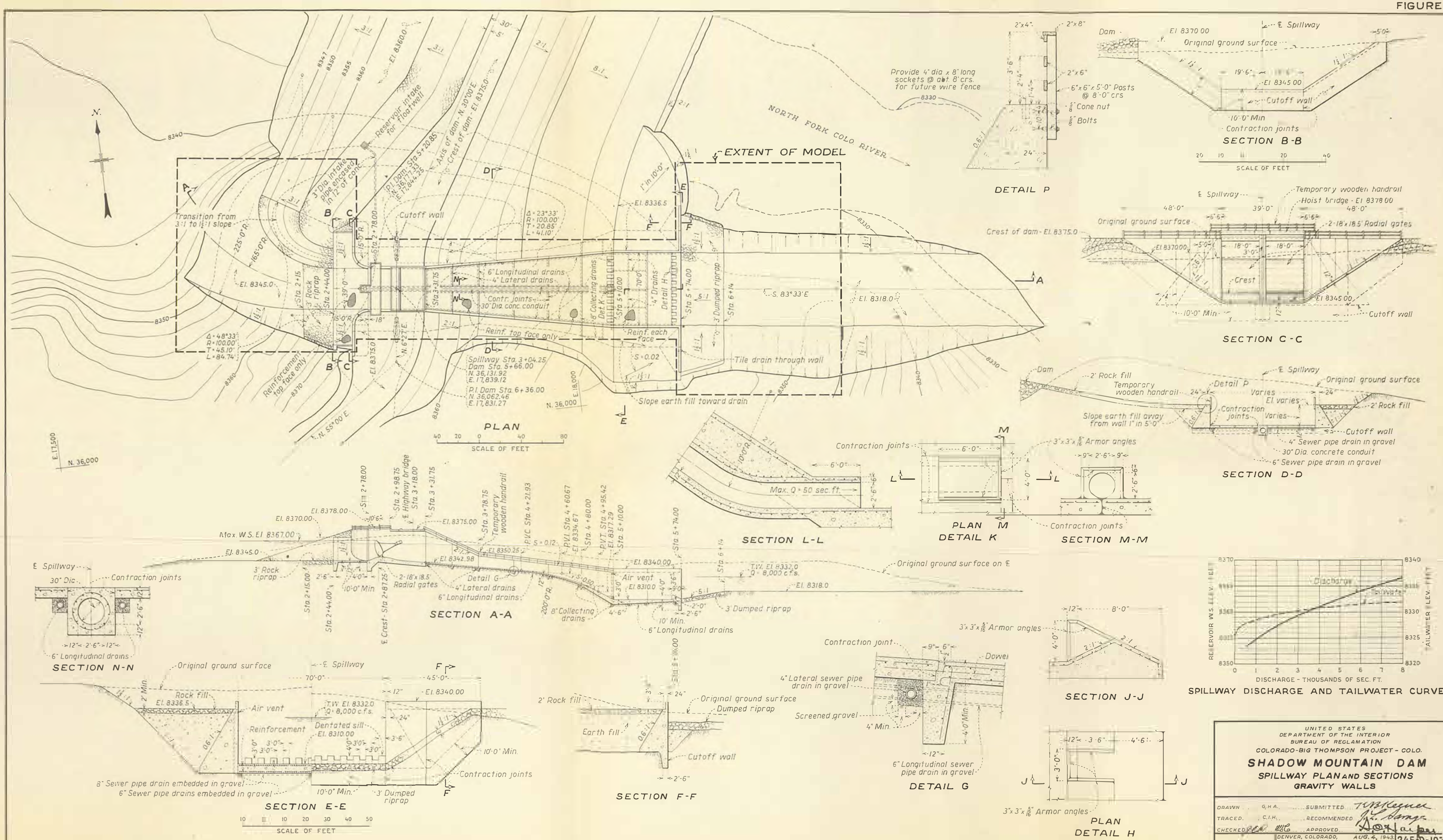
SECTION THRU SPILLWAY

SHADOW MOUNTAIN DAM

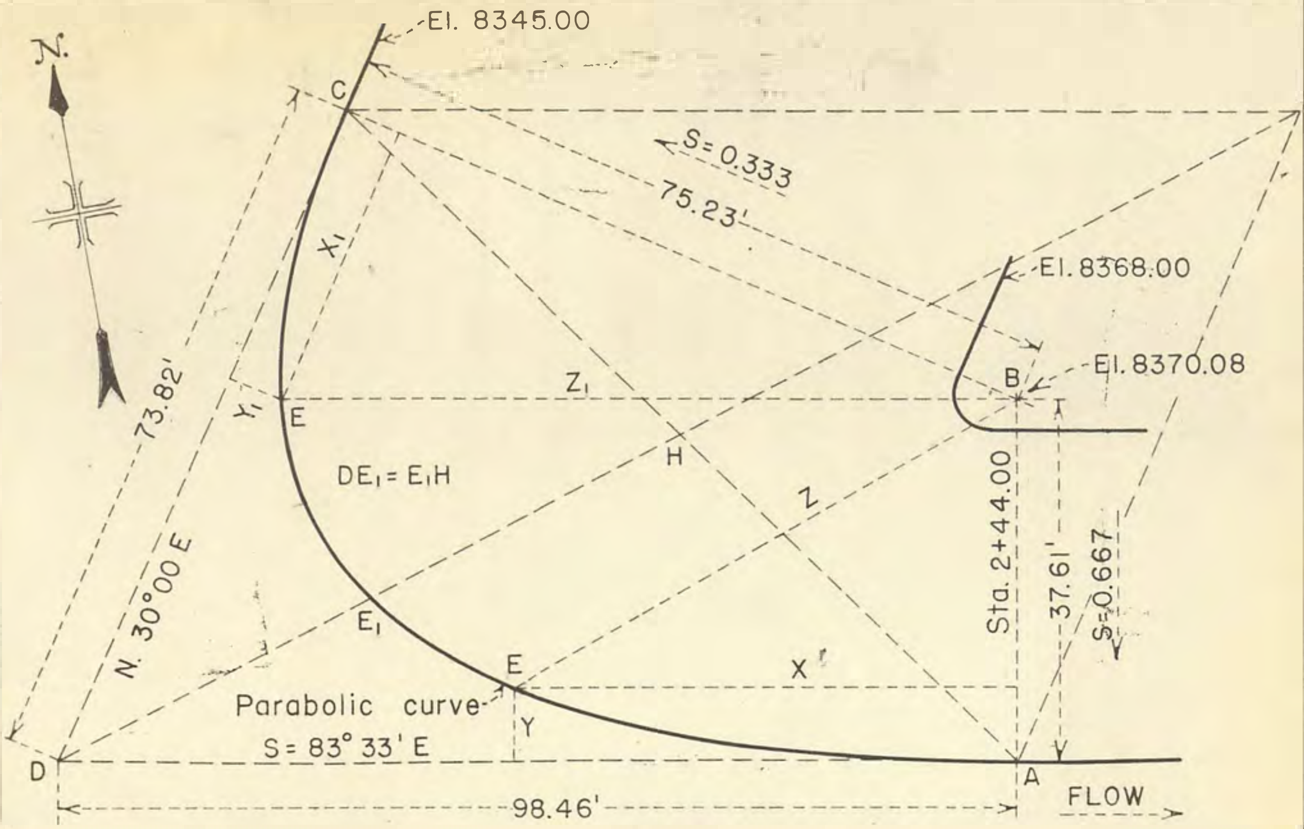
FINAL DESIGN OF SPILLWAY

WATER SURFACE PROFILE FOR 10,000 C.F.S. DISCHARGE

FIGURE 1



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT - COLO.
SHADOW MOUNTAIN DAM
SPILLWAY PLAN AND SECTIONS
GRAVITY WALLS
DRAWN G.H.A.
TRACED C.I.H.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO, AUG. 4, 1943
PLAN
SCALE OF FEET
EXTENT OF MODEL
NORTH FORK COLO RIVER
Reservoir intake for floatwell
Axis of dam - N. 30°00' E.
Crest of dam - El. 8375.0
Cutoff wall
Transition from 3:1 to 1½:1 slope
6" Longitudinal drains
4" Lateral drains
Contr. joints
30" Dia. conc. conduit
Reinf. top face only
Tile drain through wall
Slope earth fill toward drain
Provide 4" dia x 8" long sockets @ abt. 8' crs. for future wire fence
DETAIL P
SECTION B-B
SECTION C-C
SECTION D-D
SECTION A-A
SECTION N-N
SECTION L-L
PLAN DETAIL K
SECTION M-M
SECTION E-E
SECTION F-F
DETAIL G
SECTION J-J
PLAN DETAIL H
Max. W.S. El. 8367.00
2-18'x18.5' Radial gates
T.W. El. 8332.0
Q = 8,000 c.f.s.
3' Dumped riprap
Original ground surface on ℄
Original ground surface
Dentated sill El. 8310.00
8" Sewer pipe drain embedded in gravel
6" Sewer pipe drains embedded in gravel
Contraction joints
Temporary wooden handrail
Hoist bridge - El. 8378.00
2-18'x18.5' Radial gates
Max. Q = 50 sec. ft.
3"x3"x⅜" Armor angles
SPILLWAY DISCHARGE AND TAILWATER CURVES
DISCHARGE - THOUSANDS OF SEC. FT.
RESERVOIR W.S. ELEV. FEET
TAILWATER ELEV. FEET
Discharge



PLAN

OFFSETS FROM LINE AD

X	Y	Z	S*
5.00	0.05	37.90	0.662
10.00	0.19	38.74	0.647
15.00	0.44	40.09	0.626
20.00	0.81	41.89	0.599
25.00	1.32	44.07	0.569
30.00	1.99	46.57	0.538
35.00	2.85	49.33	0.508
40.00	3.92	52.30	0.479
45.00	5.27	55.42	0.453
50.00	6.96	58.65	0.428
55.00	9.10	61.95	0.405
60.00	11.85	65.30	0.384
65.00	15.56	68.64	0.365
66.47	16.92	69.62	0.360

* Slope of straight line element from E to B

OFFSETS FROM LINE CD

X_1	Y_1	Z_1	S*
5.00	0.11	75.28	0.333
10.00	0.46	75.43	0.332
15.00	1.11	75.62	0.332
20.00	2.13	75.79	0.331
25.00	3.61	75.86	0.331
30.00	5.72	75.70	0.331
35.00	8.75	75.13	0.334
40.00	13.30	73.72	0.340
45.53	22.56	69.62	0.360

Equation for offsets from line AD:

$$Y = 0.52888 \frac{K - \sqrt{K(K-4X)}}{2}; \quad K = 303.0401$$

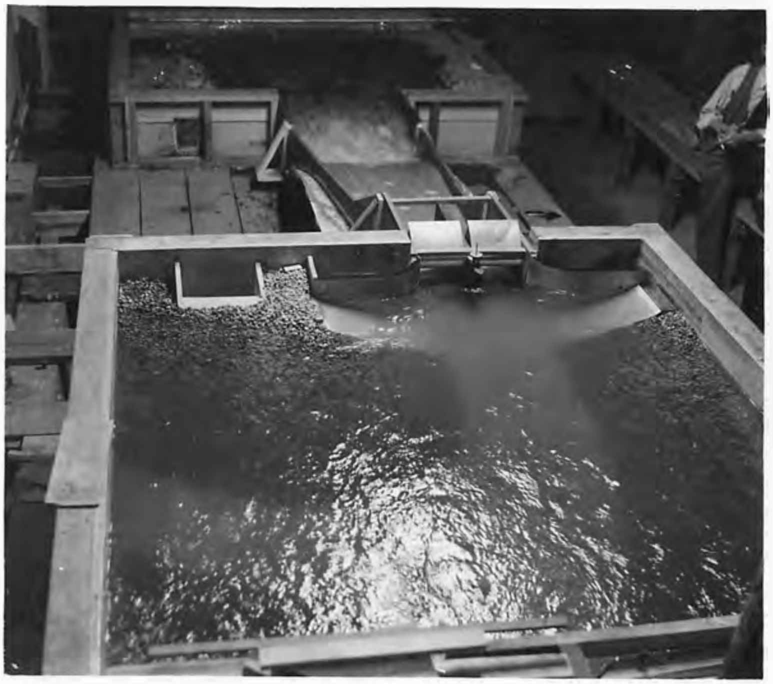
Equation for offsets from line CD:

$$Y_1 = 0.79763 \frac{K - \sqrt{K(K-4X_1)}}{2}; \quad K = 192.6264$$

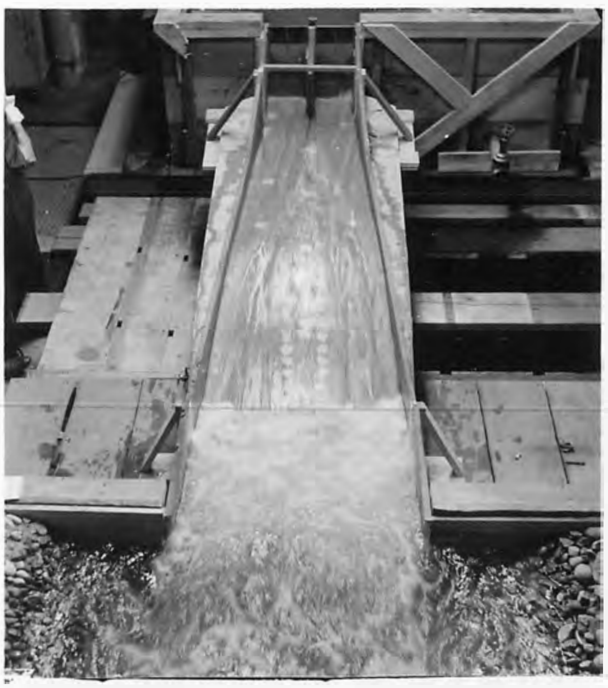
SHADOW MOUNTAIN DAM

ORIGINAL DESIGN OF SPILLWAY
DETAIL OF LEFT ENTRANCE TRANSITION

FIGURE 3



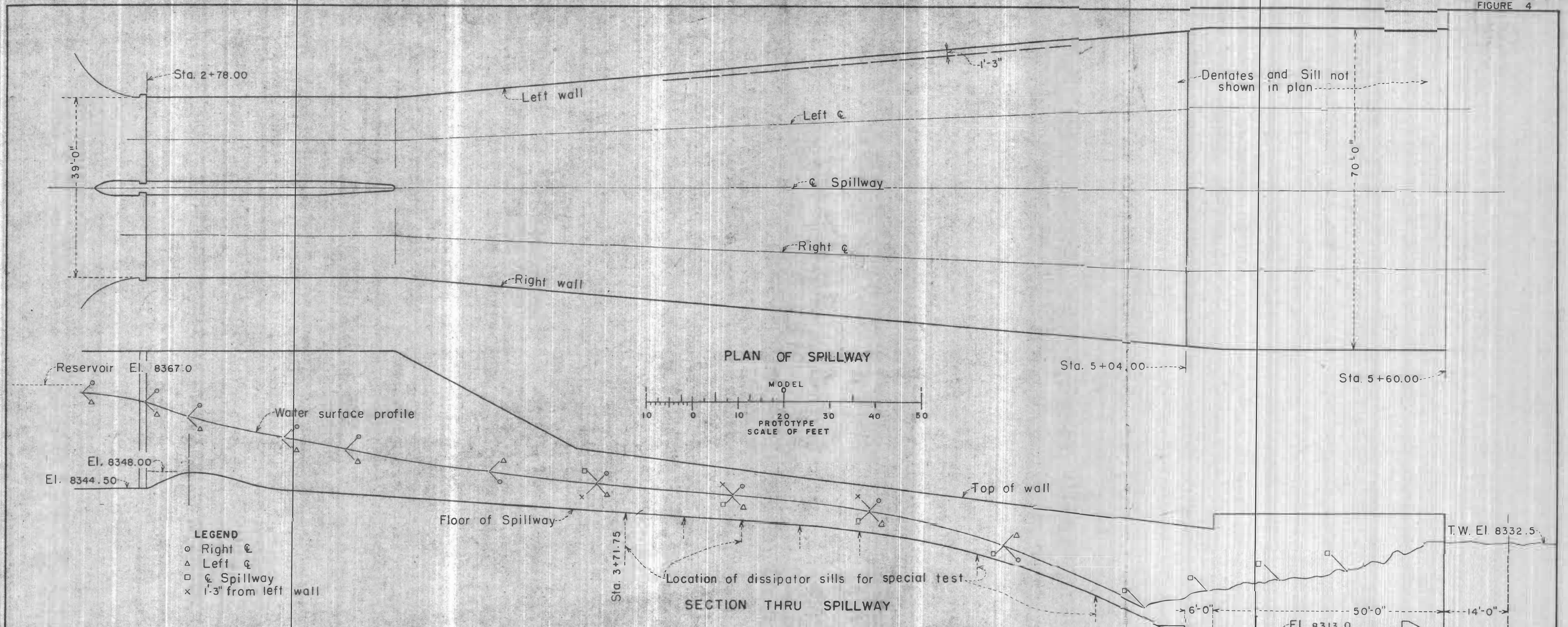
(A) Flow conditions at spillway entrance.



(B) Stilling pool - tailwater El. 8332.50

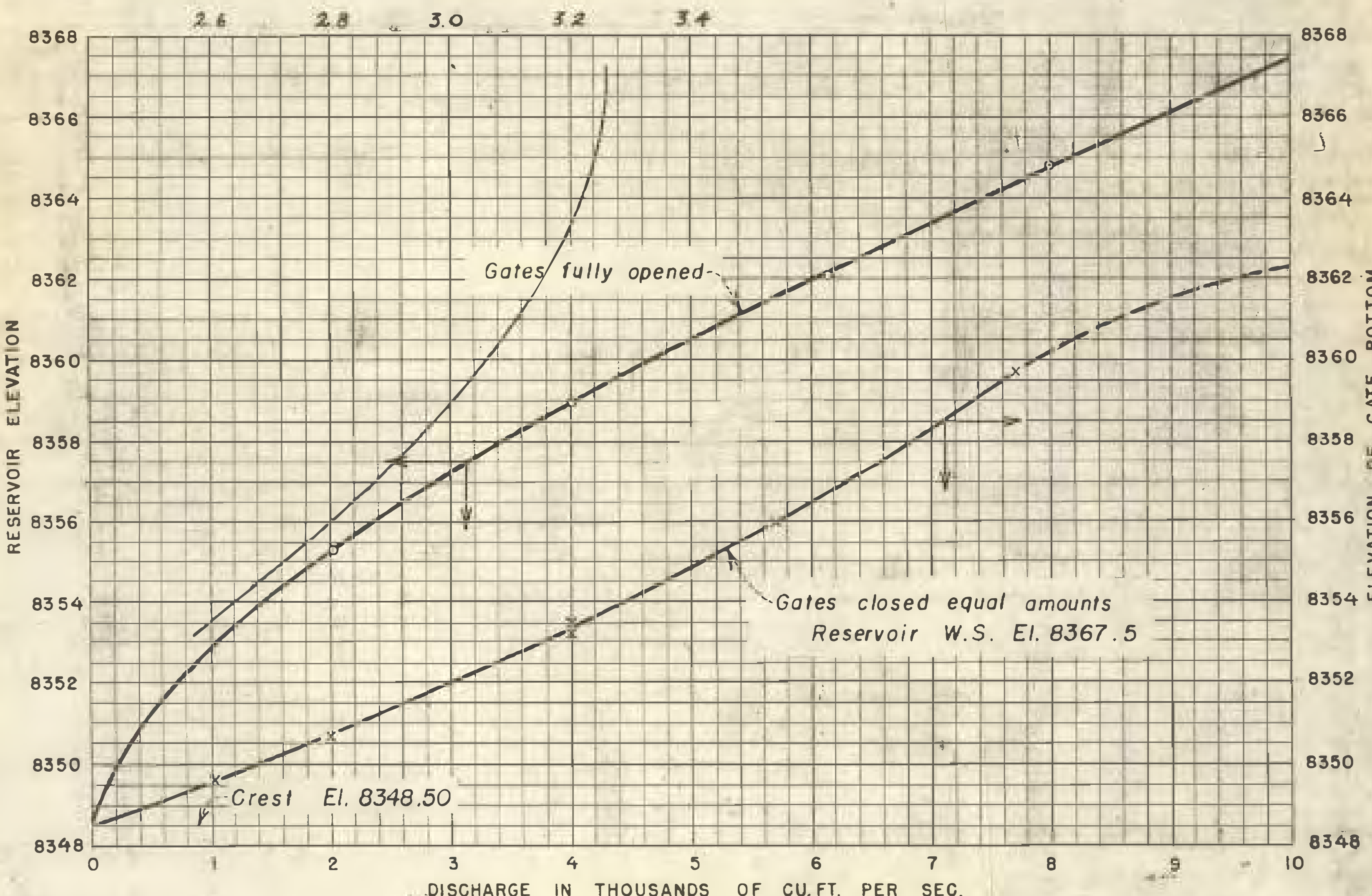
(C) Stilling pool - tailwater El. 8328.50

MODEL STUDY - SHADOW MOUNTAIN DAM SPILLWAY



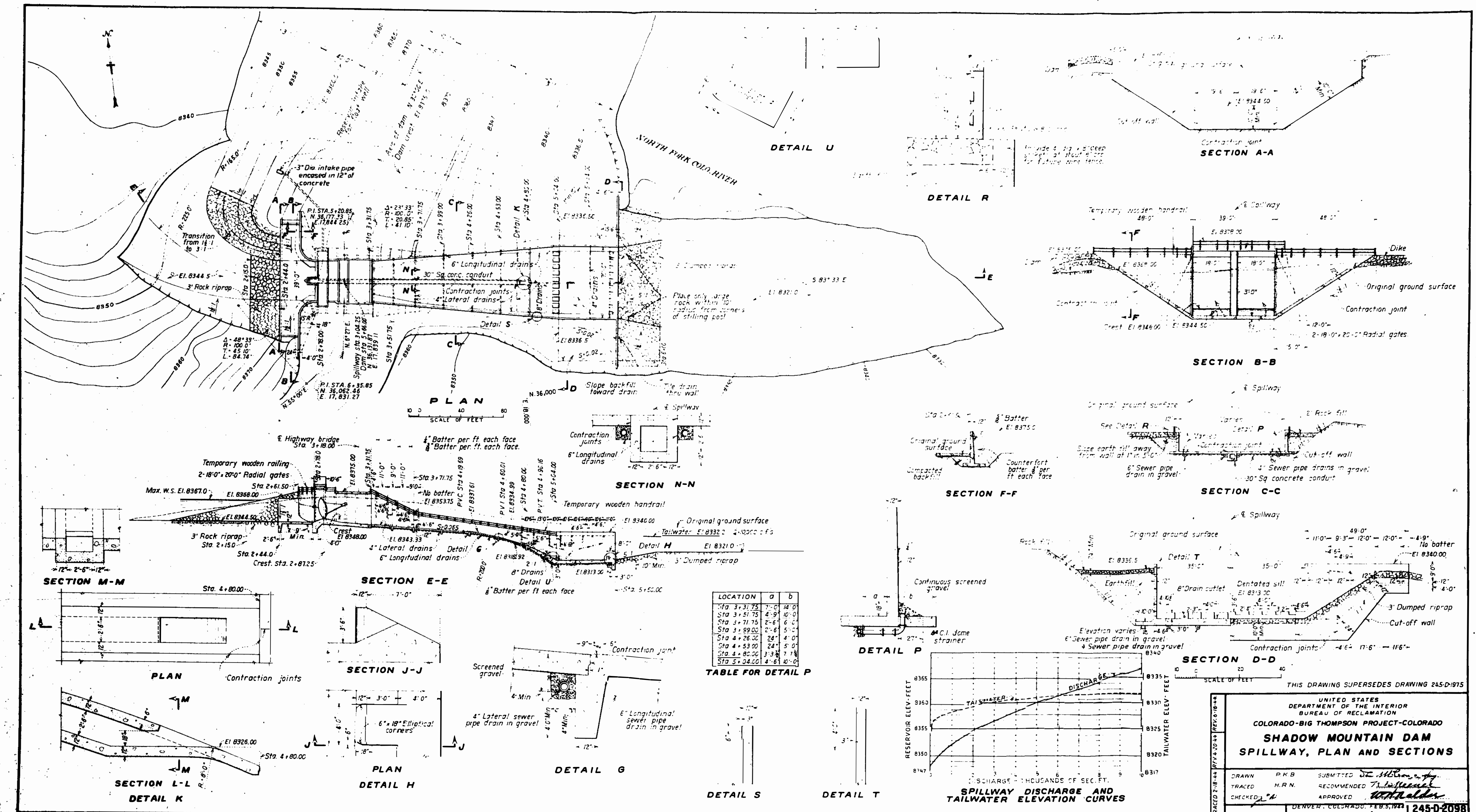
SHADOW MOUNTAIN DAM
FINAL DESIGN OF SPILLWAY
WATER SURFACE PROFILE FOR 10,000 C.F.S. DISCHARGE

HYD-162



SHADOW MOUNTAIN DAM
SPILLWAY CAPACITY CURVES

FIGURE 5



LOCATION	a	b
Sta. 3+31.75	7'-0"	14'-0"
Sta 3+51.75	4'-9"	10'-0"
Sta. 3+71.75	2'-6"	6'-0"
Sta 3+99.00	2'-6"	5'-0"
Sta 4+26.00	24"	4'-0"
Sta 4+53.00	24"	5'-0"
Sta. 4+80.00	3'-3⅞"	7'-1⅞"
Sta. 5+04.00	4'-6"	10'-0"

TABLE FOR DETAIL P

THIS DRAWING SUPERSEDES DRAWING 245-D-1975

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

COLORADO-BIG THOMPSON PROJECT-COLORADO

SHADOW MOUNTAIN DAM
SPILLWAY, PLAN AND SECTIONS

REV. 6-16-44
REV. 4-20-44
TRACED 2-18-44

DRAWN P.K.B. SUBMITTED
TRACED H.R.N. RECOMMENDED
CHECKED APPROVED

DENVER, COLORADO. FEB. 5, 1944

245-D-2098

Job No. 245-4-2