UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC LABORATORY REPORT NO. HYD - 26.1

Technical Memorandum No. 556

HYDRAULIC MODEL EXPERIMENTS FOR THE DESIGN OF THE OUTLET WORKS AND SPILLWAY OF THE BULL LAKE DAM

By

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D. C. WEED, JUNIOR ENGINEER

Denver, Colorado
July 15, 1937

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: HYDRAULIC MODEL EXPERIMENTS FOR THE DESIGN OF THE OUTLET WORKS AND SPILLWAY OF THE BULL LAKE DAM

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TECHNICAL MEMORANDUM NO. 556

Denver, Colorado,

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CHAPTER I - INTRODUCTION AND SUMMARY

Introduction

1. Location and description. The Bull Lake Dam will be located on Bull Lake Creek, a tributary of the Wind River, about 40 miles northwest of Riverton, Wyoming (fig. 1). The dam proper consists of an earth-fill structure approximately 1,400 feet in length and 75 feet in height at the deepest part of the creek. In addition, it will be necessary to construct approximately 2,000 feet of earth-fill dike (fig. 2).

The outlet works will consist of an intake and trash-rack structure connected to two 4-foot radius concrete horseshoe tunnels (fig. 3). Each tunnel will diverge into two rectangular control gate sections, having both a control gate and an emergency gate (fig. 4). An air vent located at the downstream end of the piers will supply air to the horseshoe tunnels to prevent the formation of a vacuum which would cause the tunnels to flow full intermittently. The section immediately downstream from the gates will converge into two 4-foot radius concrete horseshoe tunnels which will extend to the stilling pool. In the final design, the stilling pool (fig. 5) will have a hydraulic hump at the downstream end of the tunnels, a dentated step at the lower end of the slope, and a Rehbock sill 35 feet $4\frac{1}{2}$ inches downstream from the dentated step. The stream bed will be riprapped on a slope of 6:1 from elevation 5723.25, at the downstream base of the sill, to elevation 5735.00. Riprap three feet thick will extend from the stream bed, on a 2:1 slope, to elevation 5735.00 on the left side of the stilling pool, and to elevation 5750.00 on the right side. The outlet works will have a capacity of 4,000 second-feet.

A concrete, open-channel spillway (fig. 6) will be provided for bypassing floods. It will have a designed capacity of 10,000 second-feet with an accompanying total drop of 61 feet from the reservoir level to the tailwater level. It will have a constant width of 100 feet and the flow will be controlled at the intake by three radial gates, each 29 feet wide and 11 feet high.

2. Personnel. The hydraulic model experiments for the design of the Bull Lake Dam outlet works and spillway, as described in the report, were made in the United States Bureau of Reclamation Hydraulic Laboratory at Denver, Colorado, and in the Colorado State College Hydraulic Laboratory at Fort Collins, Colorado, under the direction of Jacob E. Warnock, Research Engineer.

The model of the outlet works was begun under the supervision of J. B. Drisko, Assistant Engineer, and completed under the supervision of D. P. Barnes, Associate Engineer, F. L. Panuzio, FIG 1

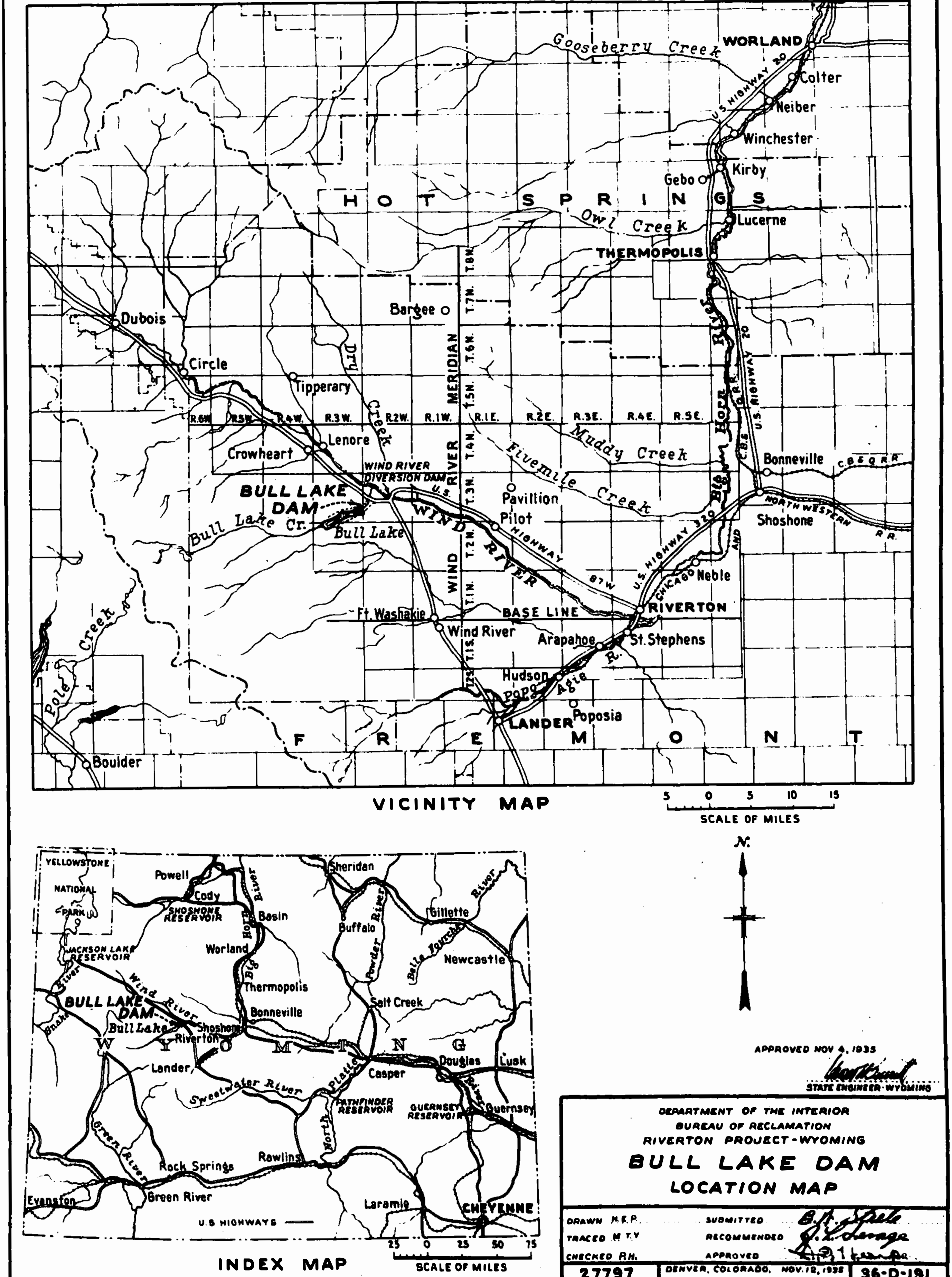

VICINITY MAP
SCALE OF MILES
5 0 5 10 15
HOT SPRINGS
FREMONT
WORLAND
Colter
Neiber
Winchester
Kirby
Gebo
Lucerne
THERMOPOLIS
Gooseberry Creek
Owl Creek
U.S. HIGHWAY 20
Dubois
Circle
Tipperary
Bargee
Lenore
Crowheart
WIND RIVER DIVERSION DAM
BULL LAKE DAM
Bull Lake Cr.
Bull Lake
WIND RIVER
U.S. HIGHWAY 287
Dry Creek
Muddy Creek
Fivemile Creek
Pavillion
Pilot
Big Horn River
C.B.&Q. R.R.
Bonneville
Shoshone
CHICAGO AND NORTH WESTERN R.R.
U.S. HIGHWAY 320
Neble
RIVERTON
BASE LINE
Ft. Washakie
Wind River
Arapahoe
St. Stephens
Hudson
Popo Agie R.
Poposia
LANDER
Boulder
Pole Creek
WIND RIVER MERIDIAN
R.6W. R.5W. R.4W. R.3W. R.2W. R.1W. R.1E. R.2E. R.3E. R.4E. R.5E.
T.8N. T.7N. T.6N. T.5N. T.4N. T.3N. T.2N. T.1N. T.1S. T.2S.
N.
INDEX MAP
YELLOWSTONE NATIONAL PARK
Powell
Cody
SHOSHONE RESERVOIR
Basin
Big Horn River
Sheridan
Buffalo
Powder River
Gillette
Belle Fourche River
Newcastle
Worland
Thermopolis
JACKSON LAKE RESERVOIR
Snake River
Wind River
BULL LAKE DAM
Bull Lake
Shoshone
Riverton
Bonneville
Salt Creek
WYOMING
Lander
Sweetwater River
Casper
North Platte River
Douglas
Lusk
PATHFINDER RESERVOIR
GUERNSEY RESERVOIR
Guernsey
Green River
Rock Springs
Rawlins
Evanston
Green River
Laramie
CHEYENNE
U.S. HIGHWAYS
SCALE OF MILES
25 0 25 50 75
APPROVED NOV 4, 1935
STATE ENGINEER-WYOMING
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIVERTON PROJECT-WYOMING
BULL LAKE DAM
LOCATION MAP
DRAWN M.E.P.
TRACED M.T.Y.
CHECKED R.H.
SUBMITTED
RECOMMENDED
APPROVED
27797
DENVER, COLORADO, NOV. 12, 1935
36-D-191

FIG. 2

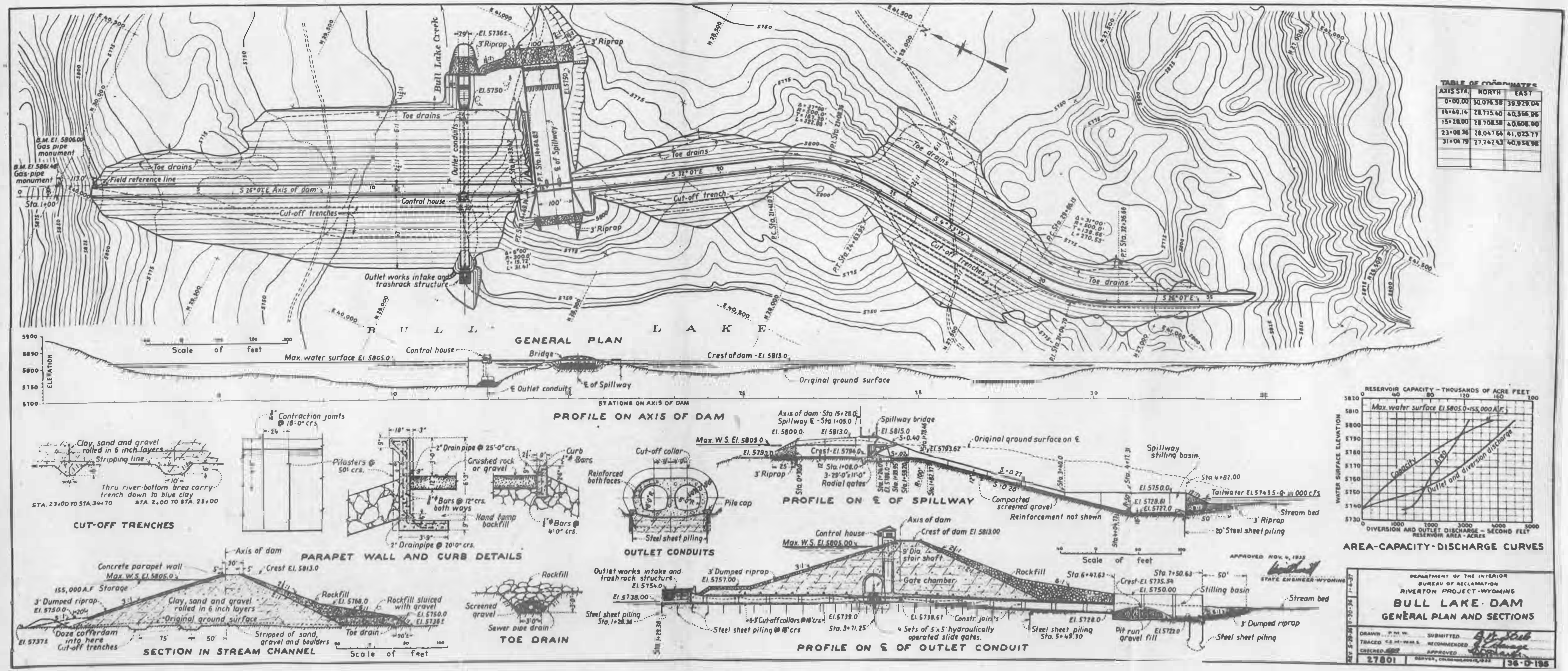
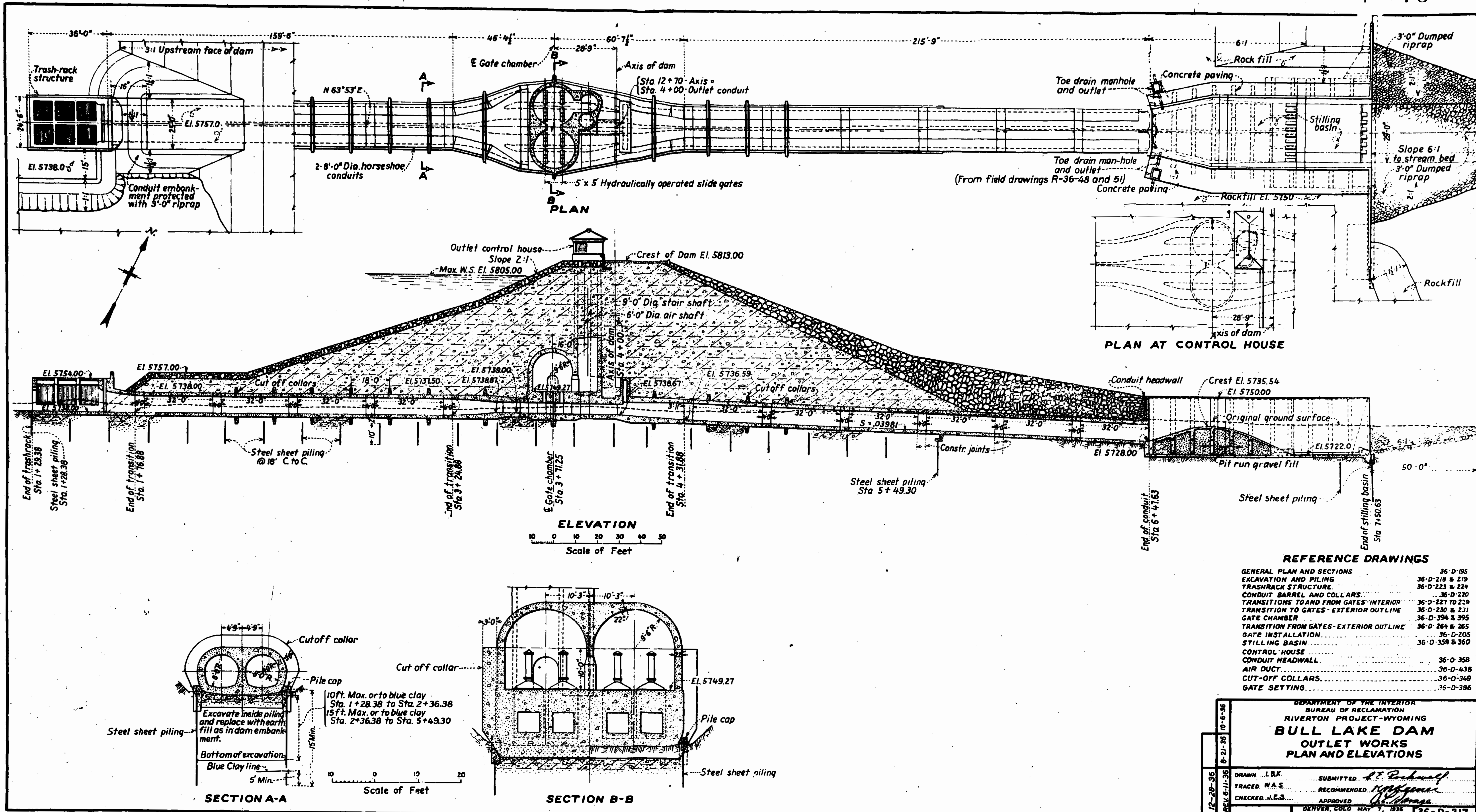


TABLE OF COÖRDINATES

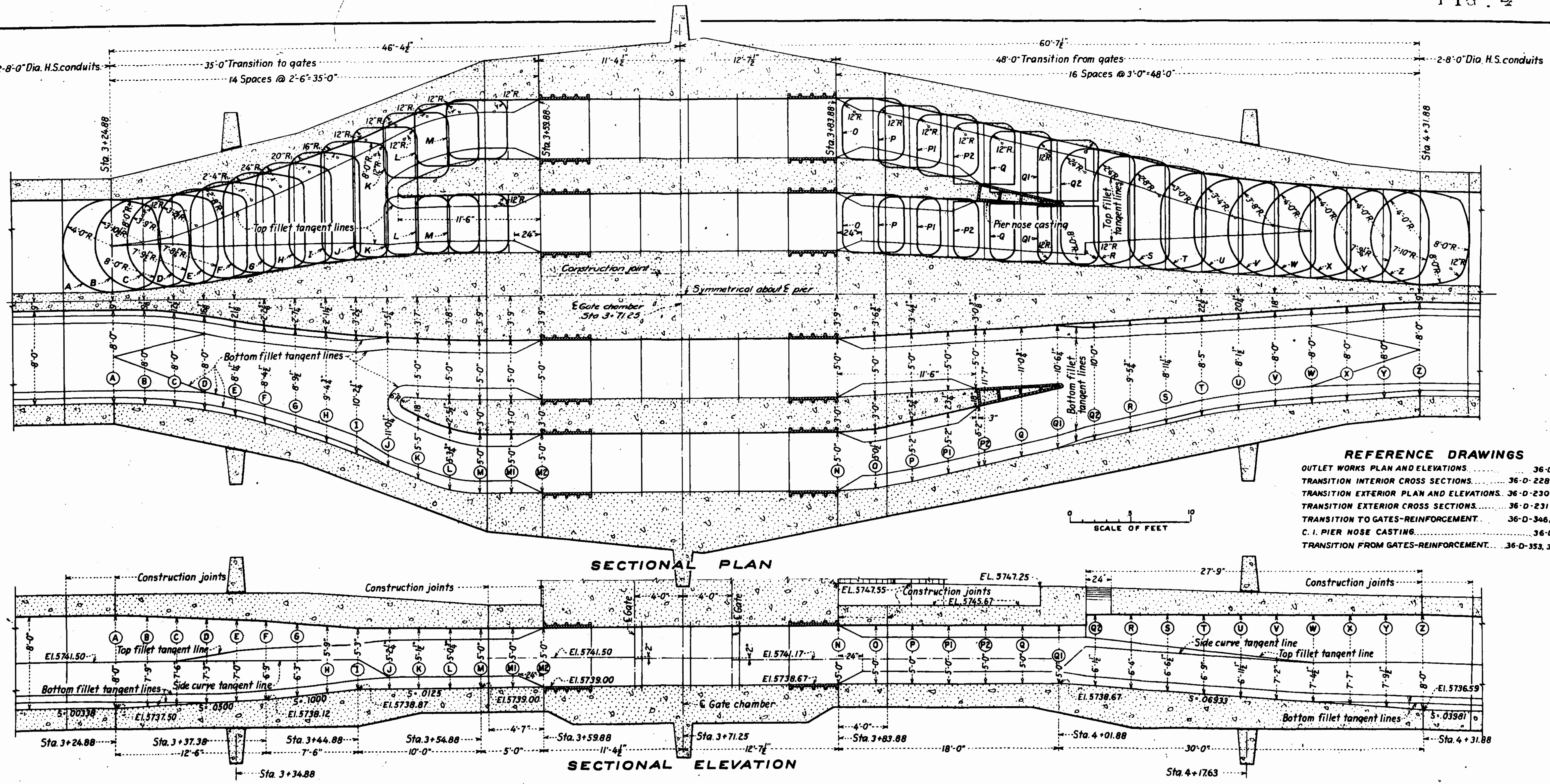
AXIS STA.	NORTH	EAST
0+00.00	30,076.58	39,929.04
14+49.14	28,775.40	40,566.96
15+28.00	28,708.58	40,608.90
23+08.36	28,047.64	41,023.77
31+04.79	27,242.43	40,956.98

FIG. 3



PLAN
Trash-rack structure
3:1 Upstream face of dam
El. 5757.0
El. 5738.0
Conduit embankment protected with 3'-0" riprap
N 63°53' E
2-8'-0" Dia. horseshoe conduits
℄ Gate chamber
Axis of dam
Sta. 12+70 - Axis = Sta. 4+00 - Outlet conduit
5' x 5' Hydraulically operated slide gates
Toe drain manhole and outlet
Concrete paving
Rock fill
3'-0" Dumped riprap
Stilling basin
Slope 6:1 to stream bed
Toe drain man-hole and outlet
(From field drawings R-36-48 and 51)
Rockfill El. 5750
PLAN AT CONTROL HOUSE
Rockfill
Axis of dam
Outlet control house
Slope 2:1
Max. W.S. El. 5805.00
Crest of Dam El. 5813.00
9'-0" Dia. stair shaft
6'-0" Dia. air shaft
El. 5754.00
El. 5757.00
El. 5738.00
Cut off collars
El. 5739.00
El. 5731.50
El. 5738.81
El. 5749.27
El. 5738.67
El. 5736.59
Cutoff collars
S = .03981
Conduit headwall
Crest El. 5735.54
El. 5750.00
Original ground surface
El. 5728.00
El. 5722.0
Pit run gravel fill
Constr. joints
Steel sheet piling @ 18' C. to C.
End of trashrack Sta. 1+29.38
Steel sheet piling Sta. 1+28.38
End of transition Sta. 1+76.88
End of transition Sta. 3+24.88
℄ Gate chamber Sta. 3+71.25
End of transition Sta. 4+31.88
Steel sheet piling Sta. 5+49.30
End of conduit Sta. 6+47.63
Steel sheet piling
End of stilling basin Sta. 7+50.63
ELEVATION
Scale of Feet
SECTION A-A
Cutoff collar
Pile cap
10 ft. Max. or to blue clay Sta. 1+28.38 to Sta. 2+36.38
15 ft. Max. or to blue clay Sta. 2+36.38 to Sta. 5+49.30
Excavate inside piling and replace with earth fill as in dam embankment.
Bottom of excavation
Blue Clay line
Steel sheet piling
Scale of Feet
SECTION B-B
Cut off collar
El. 5749.27
Pile cap
Steel sheet piling
REFERENCE DRAWINGS
GENERAL PLAN AND SECTIONS 36-D-195
EXCAVATION AND PILING 36-D-218 & 219
TRASHRACK STRUCTURE 36-D-223 & 224
CONDUIT BARREL AND COLLARS 36-D-220
TRANSITIONS TO AND FROM GATES-INTERIOR 36-D-221 TO 229
TRANSITION TO GATES-EXTERIOR OUTLINE 36-D-230 & 231
GATE CHAMBER 36-D-394 & 395
TRANSITION FROM GATES-EXTERIOR OUTLINE 36-D-264 & 265
GATE INSTALLATION 36-D-205
STILLING BASIN 36-D-359 & 360
CONTROL HOUSE
CONDUIT HEADWALL 36-D-358
AIR DUCT 36-D-436
CUT-OFF COLLARS 36-D-349
GATE SETTING 36-D-396
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIVERTON PROJECT-WYOMING
BULL LAKE DAM
OUTLET WORKS
PLAN AND ELEVATIONS
DRAWN I.B.K.
TRACED W.A.S.
CHECKED J.E.S.
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLO. MAY 7, 1936
36-D-217

FIG. 4



REFERENCE DRAWINGS

OUTLET WORKS PLAN AND ELEVATIONS	36-D-217
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C. I. PIER NOSE CASTING	36-D-204
TRANSITION FROM GATES-REINFORCEMENT	36-D-353, 354, 355

SECTION NUMBER	STATION	SECTION NUMBER	STATION	SECTION NUMBER	STATION	SECTION NUMBER	STATION
A	3 + 24.88	J	3 + 47.38	N	3 + 83.88	S	4 + 10.88
B	3 + 27.38	K	3 + 49.88	O	3 + 86.88	T	4 + 13.88
C	3 + 29.88	L	3 + 52.38	P	3 + 89.88	U	4 + 16.88
D	3 + 32.38	M	3 + 54.88	P1	3 + 92.88	V	4 + 19.88
E	3 + 34.88	M1	3 + 57.38	P2	3 + 95.88	W	4 + 22.88
F	3 + 37.38	M2	3 + 59.88	Q	3 + 98.88	X	4 + 25.88
G	3 + 39.88			Q1	4 + 01.88	Y	4 + 28.88
H	3 + 42.38			Q2	4 + 04.88	Z	4 + 31.88
I	3 + 44.88			R	4 + 07.88		

COMPANION SHEETS 36-D-228 AND 229.

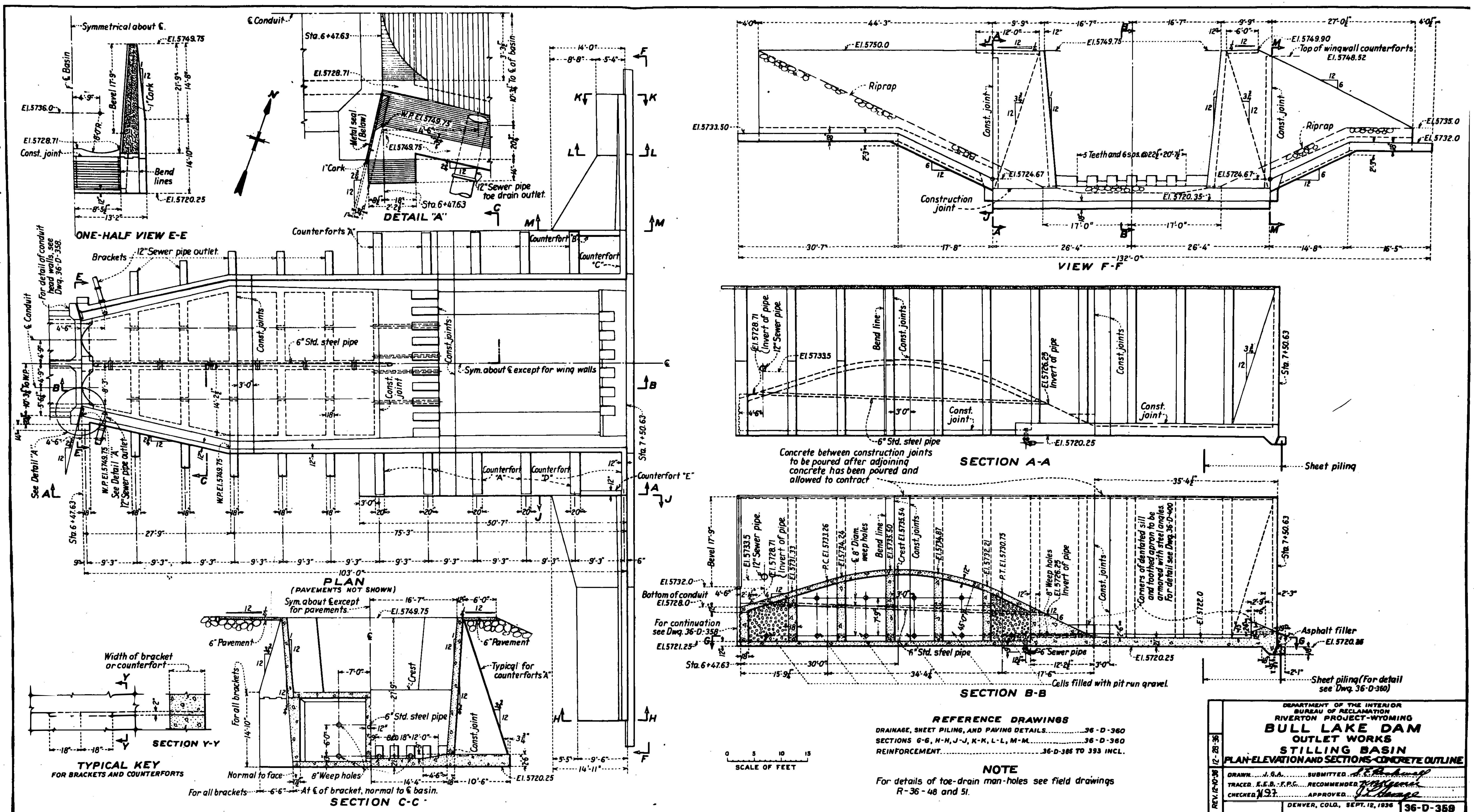
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIVERTON PROJECT-WYOMING

BULL LAKE DAM
OUTLET WORKS
TRANSITIONS TO AND FROM GATES-PLAN-ELEV
INTERIOR CONCRETE OUTLINE

9-21-36 8-7-36 REV. 10-16-36 REV. 6-7-36

DRAWN H.P.E.-I.B.K. SUBMITTED S. E. [signature]
TRACED F.P.C. RECOMMENDED [signature]
CHECKED J.E.S. APPROVED [signature]

DENVER, COLO., MAY 6, 1936 36-D-227


ONE-HALF VIEW E-E
Symmetrical about ℄.
DETAIL "A"
PLAN
(PAVEMENTS NOT SHOWN)
VIEW F-F
SECTION A-A
SECTION B-B
SECTION C-C
TYPICAL KEY
FOR BRACKETS AND COUNTERFORTS
SECTION Y-Y
Sym. about ℄ except for wing walls
Concrete between construction joints to be poured after adjoining concrete has been poured and allowed to contract
Cells filled with pit run gravel.
Sheet piling (For detail see Dwg. 36-D-360)
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DRAINAGE, SHEET PILING, AND PAVING DETAILS.......36-D-360
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REINFORCEMENT.......36-D-386 TO 393 INCL.
SCALE OF FEET
NOTE
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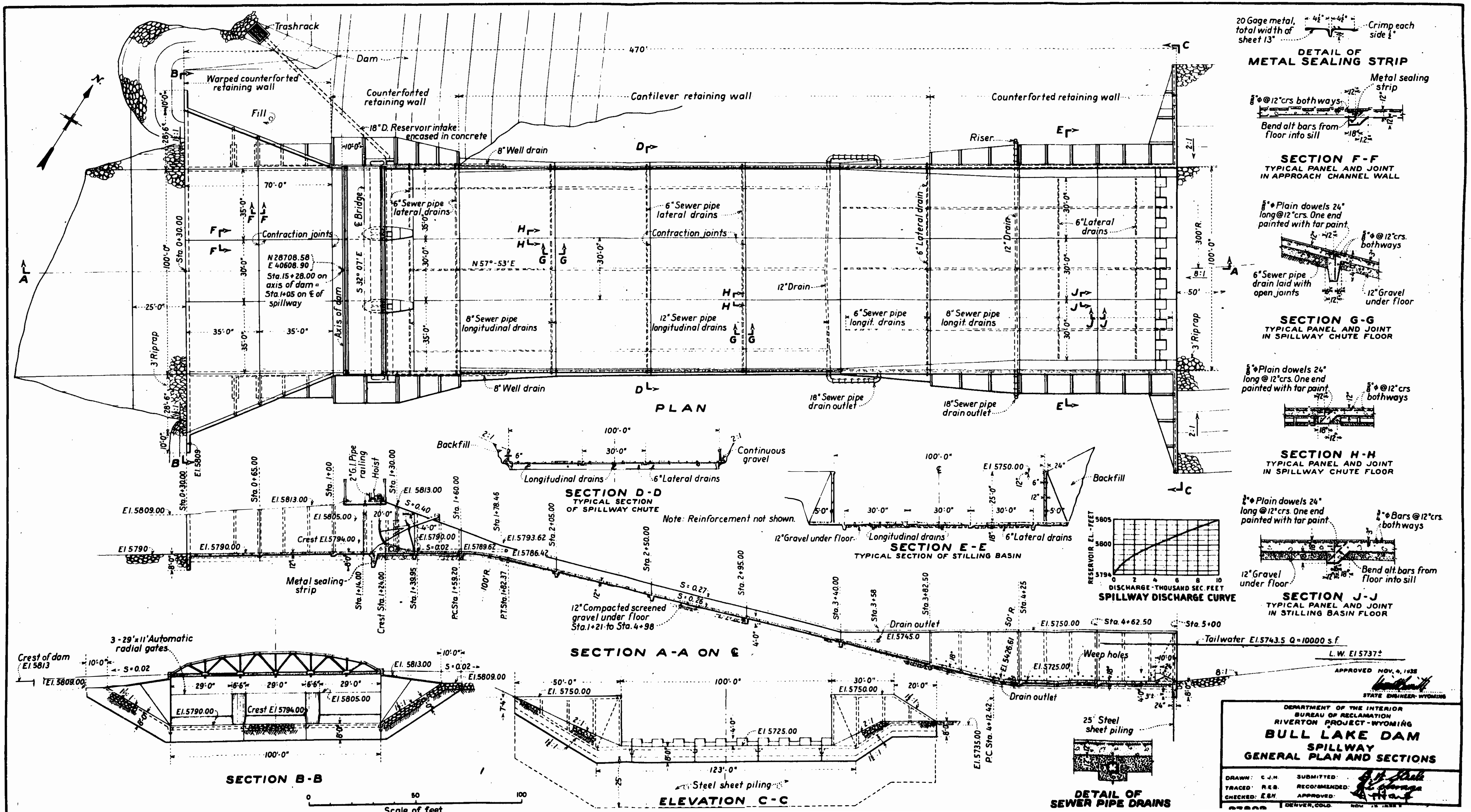
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIVERTON PROJECT-WYOMING
BULL LAKE DAM
OUTLET WORKS
STILLING BASIN
PLAN-ELEVATION AND SECTIONS-CONCRETE OUTLINE
DENVER, COLO., SEPT. 12, 1936
36-D-359



Trashrack
Dam
470'
Warped counterforted retaining wall
Counterforted retaining wall
Cantilever retaining wall
Counterforted retaining wall
Fill
18" D. Reservoir intake encased in concrete
8" Well drain
Riser
N
Contraction joints
℄ Bridge
6" Sewer pipe lateral drains
N 28708.58
E 40608.90
Sta. 15+28.00 on axis of dam = Sta. 1+05 on ℄ of spillway
S 32° 07' E
Axis of dam
N 57°-53' E
8" Sewer pipe longitudinal drains
12" Sewer pipe longitudinal drains
12" Drain
6" Sewer pipe longit. drains
8" Sewer pipe longit. drains
6" Lateral drain
12" Drain
6" Lateral drains
300' R.
3' Riprap
18" Sewer pipe drain outlet
18" Sewer pipe drain outlet
PLAN
Backfill
Continuous gravel
Longitudinal drains
6" Lateral drains
SECTION D-D
TYPICAL SECTION OF SPILLWAY CHUTE
Note: Reinforcement not shown.
12" Gravel under floor
Longitudinal drains
6" Lateral drains
SECTION E-E
TYPICAL SECTION OF STILLING BASIN
2" G.I. Pipe railing
Hoist
Metal sealing strip
Crest El. 5794.00
12" Compacted screened gravel under floor Sta. 1+21 to Sta. 4+98
Drain outlet
Weep holes
Tailwater El. 5743.5 Q = 10000 s.f.
L.W. El. 5737±
SECTION A-A ON ℄
3-29' x 11' Automatic radial gates
Crest of dam El. 5813
SECTION B-B
Steel sheet piling
ELEVATION C-C
Scale of feet
SPILLWAY DISCHARGE CURVE
RESERVOIR EL.-FEET
DISCHARGE-THOUSAND SEC. FEET
25' Steel sheet piling
DETAIL OF SEWER PIPE DRAINS
20 Gage metal, total width of sheet 13"
Crimp each side
DETAIL OF METAL SEALING STRIP
Metal sealing strip
Bend alt bars from floor into sill
SECTION F-F
TYPICAL PANEL AND JOINT IN APPROACH CHANNEL WALL
Plain dowels 24" long @ 12" crs. One end painted with tar paint.
6" Sewer pipe drain laid with open joints
12" Gravel under floor
SECTION G-G
TYPICAL PANEL AND JOINT IN SPILLWAY CHUTE FLOOR
SECTION H-H
TYPICAL PANEL AND JOINT IN SPILLWAY CHUTE FLOOR
Bend alt. bars from floor into sill
SECTION J-J
TYPICAL PANEL AND JOINT IN STILLING BASIN FLOOR
APPROVED NOV. 4, 1935
STATE ENGINEER-WYOMING
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIVERTON PROJECT-WYOMING
BULL LAKE DAM
SPILLWAY
GENERAL PLAN AND SECTIONS
DRAWN: C.J.H.
TRACED: R.E.B.
CHECKED: E.S.H.
SUBMITTED:
RECOMMENDED:
APPROVED:
DENVER, COLO.

Assistant Engineer, was in immediate charge of the testing which was conducted by R. K. Vierck, Junior Engineer. Construction and revisions of the model were directed by H. M. Martin, Assistant Engineer. The section of the report dealing with these studies was prepared by Don C. Weed, Junior Engineer.

The spillway model was initiated under the supervision of Whitney M. Borland, Associate Engineer, and completed under the supervision of James W. Ball, Assistant Engineer. J. M. Buswell, Assistant Engineer, designed the model, supervised the construction and testing, and prepared the pertinent section of the report. The tests were conducted by D. M. Lancaster, Junior Engineer, with the assistance of G. R. Filler, Laboratory Aide.

These studies were made under the general supervision of J. L. Savage, Chief Designing Engineer, and Arthur Ruettgers, Senior Engineer. All engineering work of the Bureau of Reclamation is under the direction of R. F. Walter, Chief Engineer, and all activities of the Bureau are under the direction of J. C. Page, Commissioner.

3. Scope of tests. The model of the outlet works was studied to provide a calibration curve for the gate; to observe and to eliminate any unsatisfactory flow conditions between the gates and the horseshoe tunnels; to determine a satisfactory stilling pool design with consideration for the desirability of a hydraulic hump and sill; and to determine the extent of the riprap required downstream from the stilling pool for the protection of the structure.

The spillway was likewise studied to obtain a calibration curve for the gates; to eliminate any unsatisfactory flow conditions through the gates and down the chute; to develop a satisfactory stilling pool; and to determine the extent of riprap required downstream from the stilling pool.

Summary

4. Results and conclusion. Tests on the outlet works yielded data for the preparation of a calibration curve. An adverse flow condition downstream from the gate section was eliminated by specifying a gate operating program. The latter procedure proved to be more economical than increasing the length of the transition. The hydraulic hump used in the final design in conjunction with the dentated step and Rehbock sill produced satisfactory stilling-pool conditions for all combinations of flow. The riprap proposed in the final design provided ample protection to

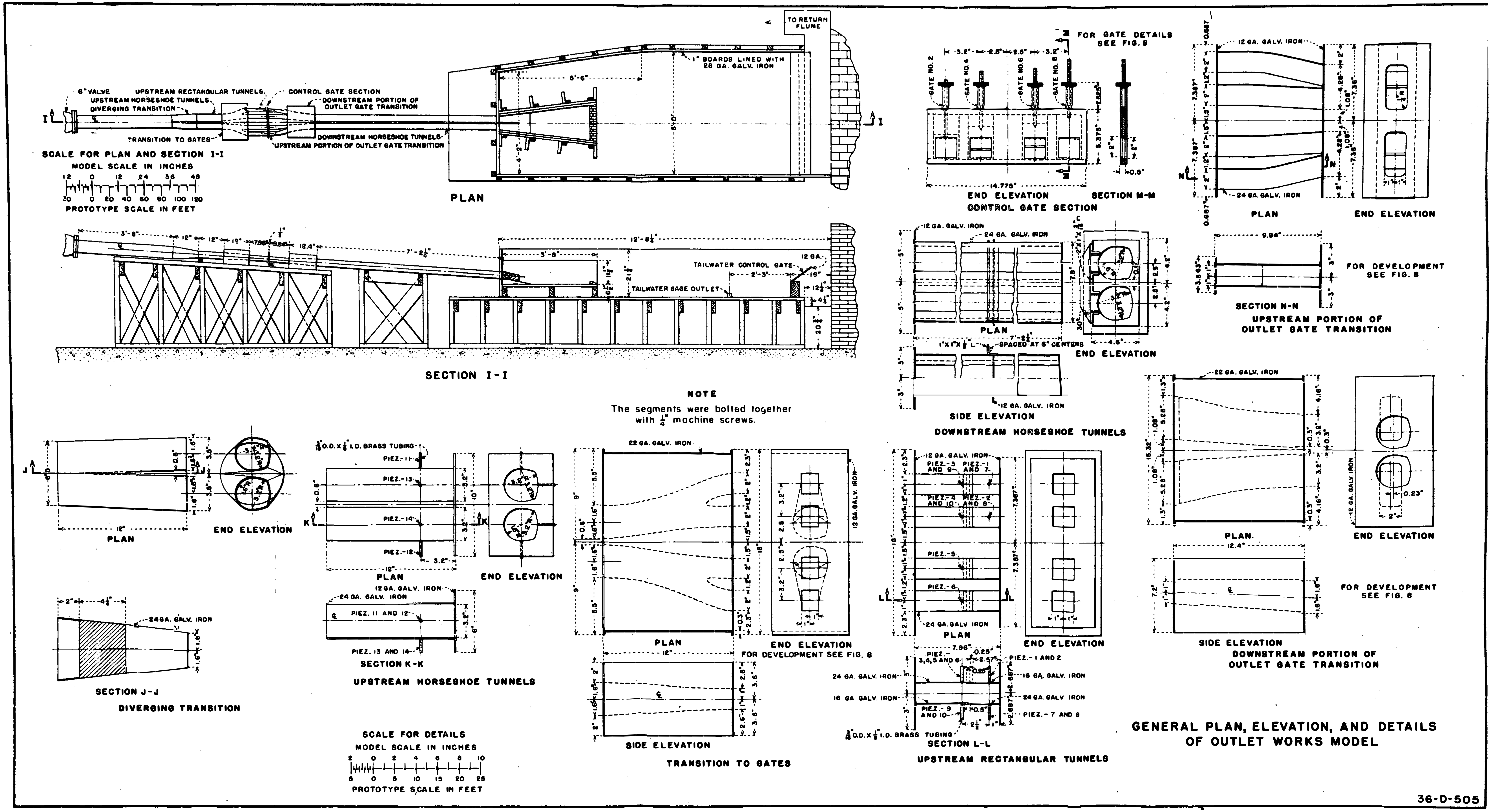
the stilling-pool structure, with very little erosion at maximum discharge.

The approach transition, gate section, and chute of the spillway model had ample capacity for a discharge of 12,000 second-feet, 2,000 second-feet above the design maximum. Even higher discharges may be handled unless interference with the flow by the gate counterbalances is objectionable. The negative pressures on the crest for small gate openings (reservoir elevation 5805.0) were not considered serious because of their small magnitude and because of the remote probability that the gates may be operated under these conditions for more than a short period. The transverse waves in the chute will not affect the action of the stilling pool adversely or increase the erosion of the stream bed. The discharge curves included in this report will be helpful for determining the flow in the stream below the dam in time of flood. The stilling pool was shortened 18 feet and its floor raised 2 feet with an adequate hydraulic jump still forming on the apron. A symmetrical sill with large end teeth was found to be more satisfactory than an unsymmetrical sill with teeth and spaces of equal width throughout. A dentated step placed where the chute enters the pool was found to be very effective in keeping the jump in the pool at abnormally low tailwater elevations and to have practically no effect in preventing erosion downstream from the sill. Riprap placed over an area extending 50 feet downstream from the pool served as a control section and prevented the jump from sweeping out at even the lowest tailwaters.

CHAPTER II - MODEL TESTS OF OUTLET WORKS

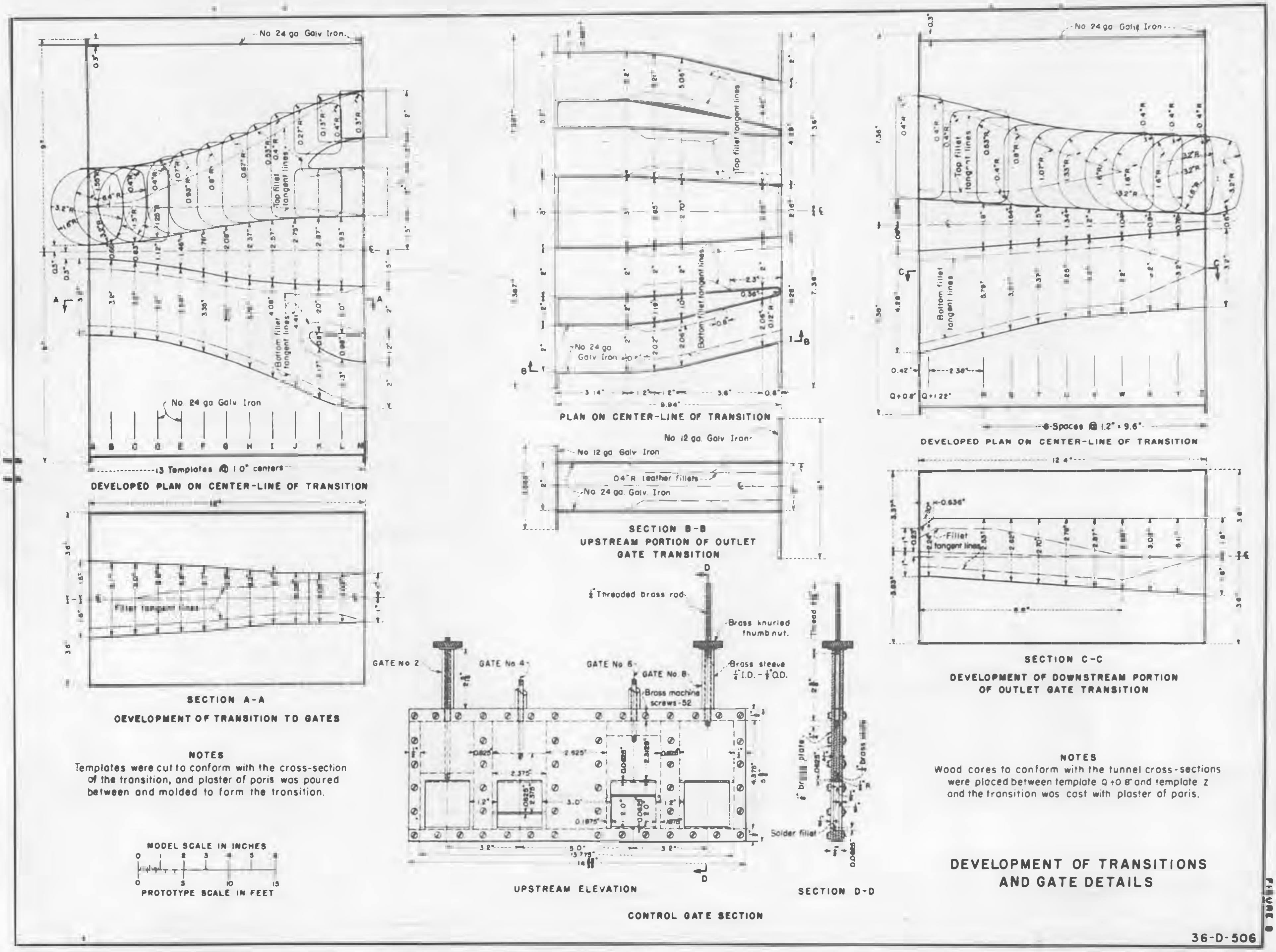
Outlet Works Model

5. Model of outlet works. The model (fig. 7) was built on a scale of 1:30 in the Denver Hydraulic Laboratory. The water was supplied to the head tank by pump through a circulating system. A six-inch gate valve controlled the flow of water from the head tank to the model. The metal diverging transition split the discharge from the six-inch valve equally between the two metal horseshoe tunnels. Piezometers installed in the sides and bottom of the upstream horseshoe tunnels were connected to a manometer board to measure the head on the gates. The transition to the gates (figs. 7 & 8) was formed with plaster of paris between equally spaced templates cut to conform to the inside of the tunnels. The upstream rectangular tunnels were formed to represent the prototype section containing the emergency gates. These will be referred to as gates 1, 3, 5, and 7 numbered from left to right looking downstream. As these gates are not to be operated often, only the



GENERAL PLAN, ELEVATION, AND DETAILS OF OUTLET WORKS MODEL

36-D-505



NOTES

Templates were cut to conform with the cross-section of the transition, and plaster of paris was poured between and molded to form the transition.

NOTES

Wood cores to conform with the tunnel cross-sections were placed between template Q+0.8" and template Z and the transition was cast with plaster of paris.

DEVELOPMENT OF TRANSITIONS AND GATE DETAILS

36-D-506

FIGURE 8

gate sills were constructed (fig. 7). Piezometers were provided to measure the head in the rectangular tunnels immediately upstream from the gates. The operating gates, which will be referred to as gates 2, 4, 6, and 8 numbered from left to right looking downstream, were constructed of brass to simulate the 5-foot by 5-foot slide gates of the prototype (fig. 8).

The transition from the gates was constructed in two parts (fig. 8). The upstream portion consisted of four metal tunnels with $\frac{1}{2}$-inch radius leather fillets; the downstream portion was formed in a split mold with plaster of paris poured around two wooden cores. The mold was contained in a sheet-metal box to which were bolted the adjoining parts. Two metal horseshoe tunnels (fig. 7) were constructed with removable tops to permit observation of the flow. These extended from the transition to the stilling pool box.

The stilling pool box was 5 feet wide by 12 feet, $8\frac{1}{4}$ inches long and 1 foot, $9\frac{1}{4}$ inches deep, and was supported on a wooden framework.. The box was lined with 24-gage galvanized sheet metal. As originally designed, the stilling pool (fig. 7) was constructed of wood supported on 2- by 4-inch joists. The tailwater was controlled with a hinged gate at the downstream end of the stilling box. The tailwater elevation was observed in a manometer mounted on the side of the tank. The water passed over this hinged tailwater gate into a return flume. The discharge was measured over a 90-degree V-notch weir located between the return flume and the pump sump.

The head on the weir was measured with two hook gages located in stilling wells, and the elevation of the water in the head tank was observed in a manometer mounted on the side of the tank. The water surface and erosion in the pool were measured with a point gage mounted on rails parallel to the model.

The hydraulic humps were constructed of 24-gage galvanized sheet metal placed over redwood frames, and the sills were made of sugar pine boiled in linseed oil. Sand was used to represent the excavated river bed in the erosion studies.

6. <u>Slope correction of model.</u> Due to the inability to transfer the value of Kutter's "N" on the prototype to a dynamically similar value on the model, it was necessary to increase the slope in the model to correct for the dissimilarity. Assuming the gates to be the control section, since above this point the water is under pressure, the hydraulic losses in the prototype were computed as follows:

(1) The computed prototype loss in the transition = 1.75

feet.

(2) The computed prototype energy gradient = 0.0374.

(3) The length of tunnel = 215.30 feet.

(4) Head loss in tunnel equals 0.0374 x 215.30 = 8.06 feet, and the total loss is 8.06+1.75 = 9.81.

(5) By similarity, $\frac{\text{Slope (model)}}{\text{Slope (prototype)}} = \left(\frac{\text{N (model)}}{\text{N prototype}}\right)^2 (\text{Scale ratio})^{1/3}$.

Using an N of 0.010 for the model and an N of 0.013 for the prototype, the ratio of slopes is $\frac{Sm}{Sp} = \left(\frac{0.010}{0.013}\right)^2 (30)^{1/3} = 1.84$.

(6) The increase in friction slope = (1.84 - 1.00) = 0.84, and the excess head loss is 9.81 x 0.84 = 8.24 feet.

(7) The prototype difference in elevation between the gate sill and the tunnel outlet = 10.67 feet, and the necessary drop in the model = (10.67+8.24)0.4 = 7.564 inches.

The model of the tunnel was sloped to produce a drop from the gate sill to the tunnel outlets of 7.564 inches. Since the operation of the portion of the model upstream from the gate section was independent of the slope, all of the model was placed on the same slope as the downstream portion to facilitate construction.

Discharge Conditions Through Control Gate Section

7. Calibration of gates. The model was initially assembled down to and including the gate section (fig. 7 and plate 1A). The control gates will be referred to as gates 2, 4, 6, and 8 numbered from left to right looking downstream. A small V-notch weir, placed downstream from the gate section, was used to measure the discharge through each gate. Each gate was calibrated separately with full, three-quarter, one-half, and one-quarter gate openings (plate 1-A, -B, -C, and -D). The calibration curve (fig. 9) shows the discharge for any gate operating alone, and for all gates operating uniformly.

Hydraulic Action in Upstream Portion of Outlet Gate Transition

8. Flow conditions. The upstream portion of the outlet gate transition (figs. 7 and 8) was added to the gate section, and

A. GATES FULL OPEN

B. GATES THREE-FOURTHS OPEN

C. GATES ONE-HALF OPEN

D. GATES ONE-FOURTH OPEN

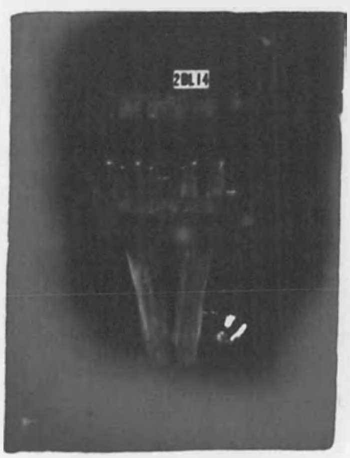
FLOW THROUGH CONTROL GATE SECTION

E. GATES FULL OPEN
ALL TUNNELS FULL

F. GATES THREE-FOURTHS OPEN
LEFT TUNNEL FULL
RIGHT TUNNEL FREE

G. GATES ONE-HALF OPEN
LEFT TUNNEL FREE
RIGHT TUNNEL FULL

H. GATES ONE-FOURTH OPEN
ALL TUNNELS FREE

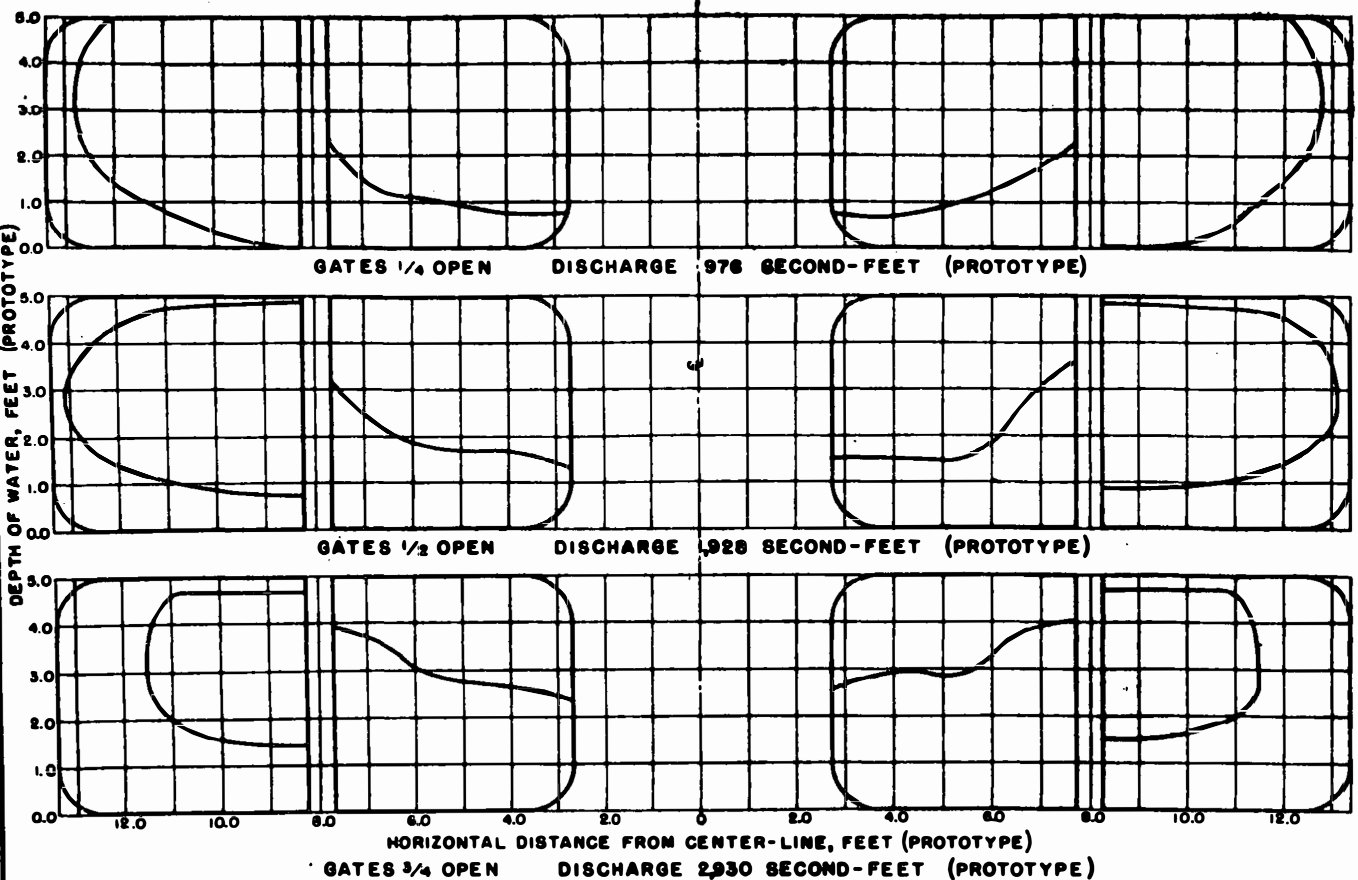


I. AIR VENTS OPEN

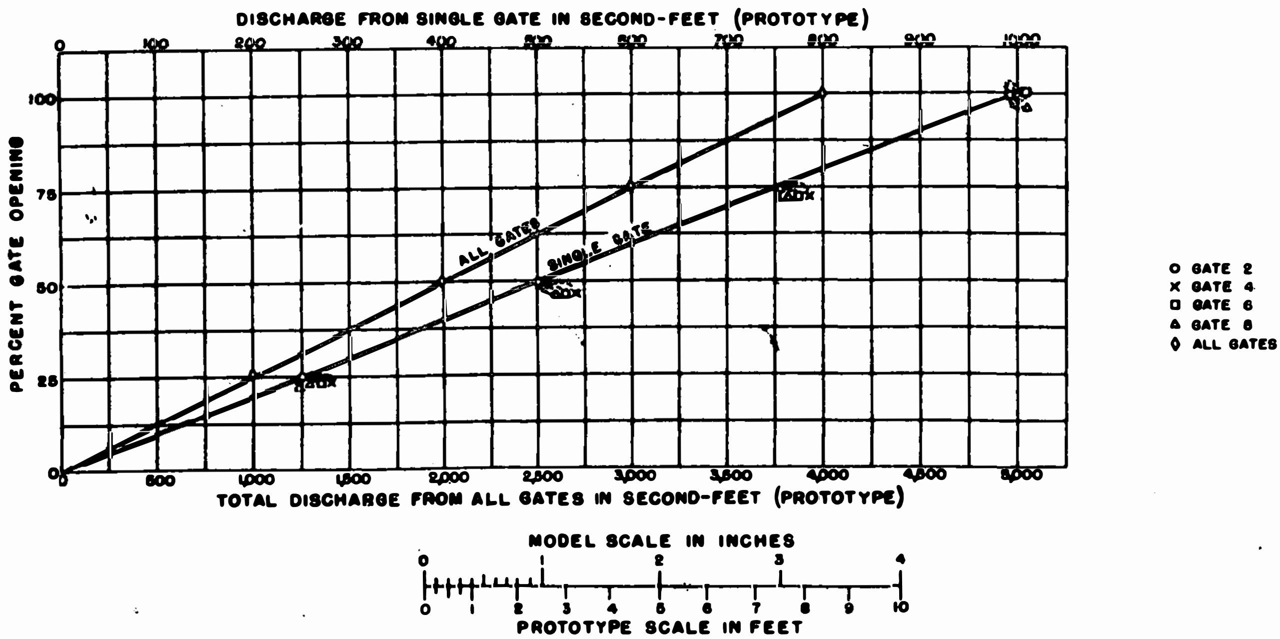
J. AIR VENTS CLOSED

FLOW THROUGH UPSTREAM PORTION OF OUTLET GATE TRANSITION

FLOW THROUGH GATES AND TRANSITION



WATER SURFACE AT DOWNSTREAM END OF PIERS - STA. 3 + 92.0



DISCHARGE FOR GATE OPENINGS

36-D-507

the hydraulic action was observed for different gate openings. As the gate opening was increased, the transition tunnels flowed free until a gate opening of 97 percent was reached. At this point the tunnels flowed full. Figure 9 shows the water surfaces at the downstream end of this portion of the transition for three different gate openings and for the tunnels flowing free. As the gates were closed, the tunnels flowed full until an opening of 36 percent was reached, after which the tunnels flowed free. Plate 1-E, -F, -G, and -H, shows the flow in the tunnels for different conditions of discharge and gate openings.

9. Effect of air vents. Air vents were placed immediately downstream from the gate section to aerate each transition tunnel. The use of several sleeves of telescope tubing provided a convenient method of varying the size of the air vent. It was found that a tube with an inside diameter of 3/16-inch was the smallest air vent that would allow the water in the tunnels to flow free with gates fully open. Plate 1-I and -J shows the effects of the air vents on the flow characteristics.

Hydraulic Action in Downstream Portion of Outlet Gate Transition

10. Flow conditions. The downstream portion of the transition (figs. 7 and 8) was added, and the top of the transition was removed to facilitate observation of the flow. The flow from the two center gate tunnels produced satisfactory flow conditions in the transition tunnels, but the flow from the two outside gate tunnels gave adverse flow conditions. Plate 2-A, -B, -C, and -D shows the flow conditions with all gates open an equal amount. Plate 2-E, -F, -G, and -H shows the flow with one side gate (gate 2) and one center gate (gate 6) set equally at various openings, the remaining two gates being closed.

The adverse flow could have been eliminated by increasing the length of the transition which would have allowed the water to change direction less abruptly. Because of the increased cost of such a change, however, it was considered preferable to establish a gate-operating schedule. As it will not be necessary to discharge 4,000 second-feet continuously, it is, therefore, recommended that the two inside gates (4 and 6) be operated for normal discharges and that the two outside gates (2 and 8) be operated only when additional capacity is needed.

Original Design of Stilling Pool

11. Hydraulic action in tunnels and stilling pool. The model of the original stilling pool design (figs. 7 and 10, and plate 3) exhibited three unfavorable flow characteristics.

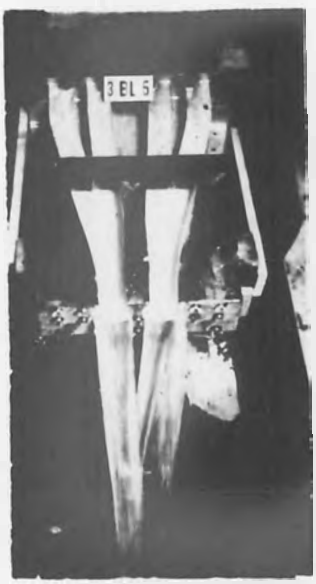
A. GATES ONE-FOURTH OPEN

B. GATES ONE-HALF OPEN

C. GATES THREE-FOURTHS OPEN

D. GATES FULL OPEN

ALL GATES OPEN EQUAL AMOUNTS



E. GATES ONE-FOURTH OPEN

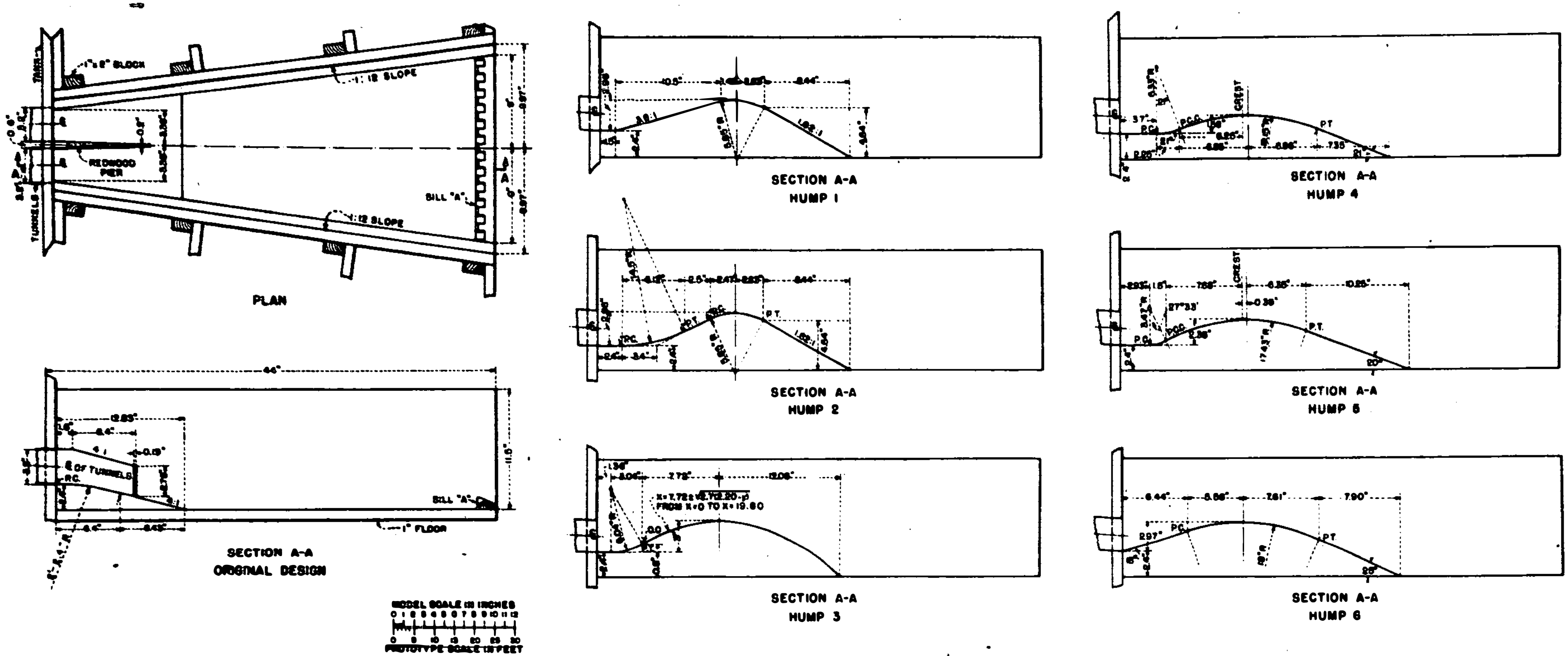
F. GATES ONE-HALF OPEN

G. GATES THREE-FOURTHS OPEN

H. GATES FULL OPEN

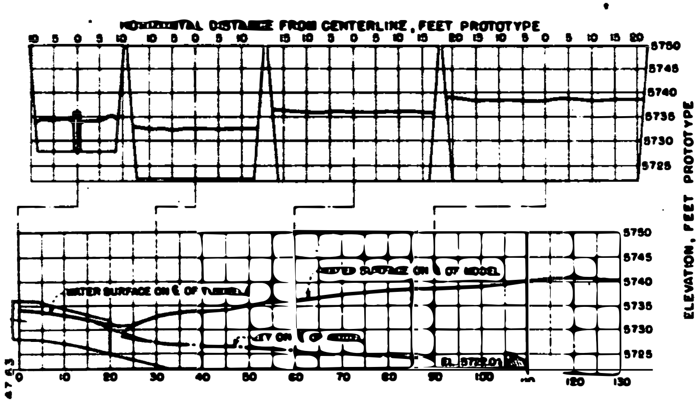
GATES 2 AND 6 ONLY OPERATED

FLOW THROUGH DOWNSTREAM PORTION OF OUTLET GATE TRANSITION



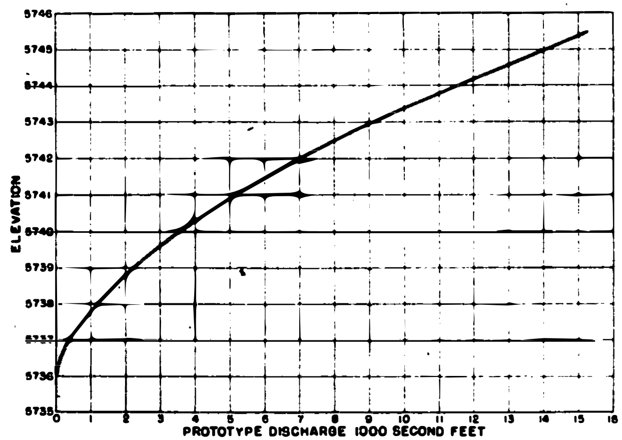
DETAILS OF ORIGINAL DESIGN AND HYDRAULIC HUMPS

NOTES
Humps were made of 26 gage galvanized iron over redwood frames. Floor is supported on 2"x4" stringers



DISCHARGE 4,000 SECOND-FEET – TAILWATER ELEV. 5740.0

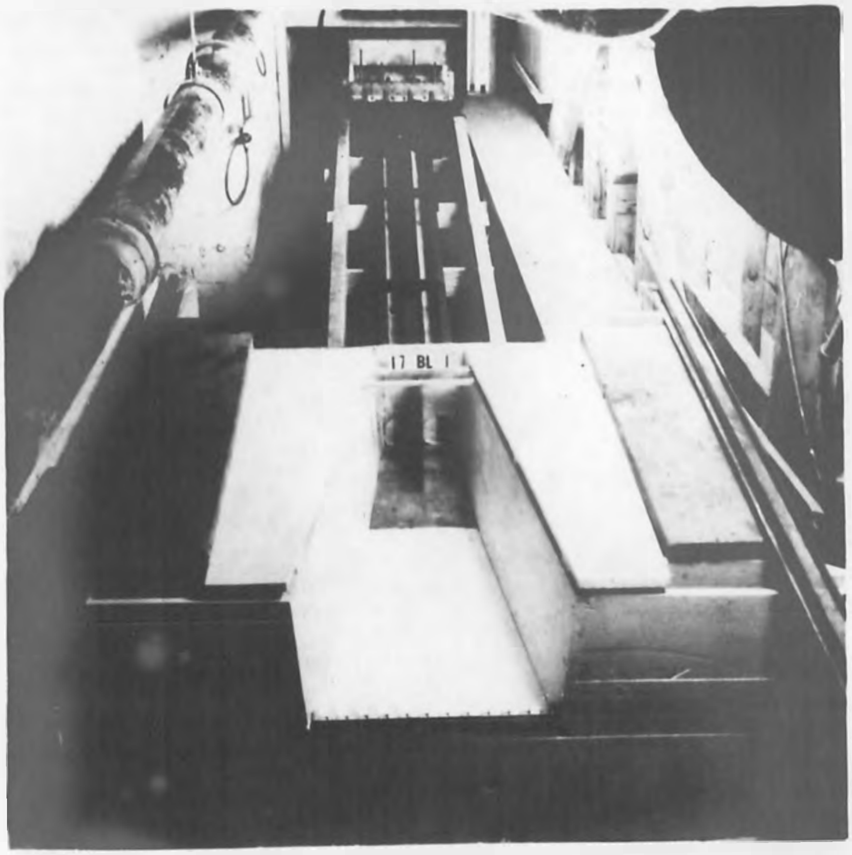
WATER SURFACE IN STILLING POOL



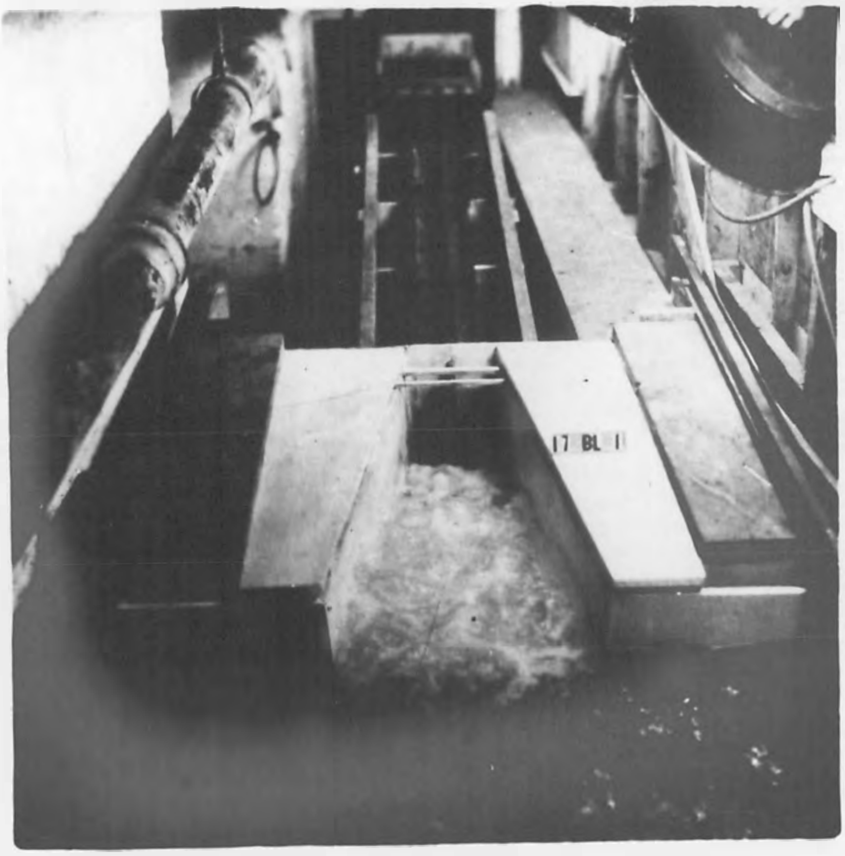
TAILWATER RATING CURVE

FIGURE 10

36-D-508



A. NO FLOW



B. DISCHARGE 4000 SECOND-FEET - NORMAL TAILWATER

ORIGINAL DESIGN OF STILLING POOL

(1) The hydraulic jump formed inside the tunnels at maximum discharge when the tailwater (fig. 10) was five feet above normal (plate 4-A). This would be the tailwater condition for maximum discharge over the spillway. The forming of the jump in the tunnels caused them to flow full, and due to the increase in friction, the tunnels continued to flow full even after the tailwater was decreased. Aeration of the horseshoe tunnels did not remove this unfavorable characteristic.

(2) For maximum discharge with normal tailwater, the jump formed at the downstream end of the splitter pier (plate 3-B). Plate 4-C shows the flow in the pool with no tailwater. Figure 10 shows the water surface profile in the stilling pool for maximum discharge and normal tailwater elevation.

(3) When the flow from the two tunnels was unbalanced, adverse flow conditions were produced in the stilling pool. This caused the hydraulic jump to form in the tunnel carrying the small discharge. Plate 4-B shows a discharge of 2,000 second-feet through the left tunnel. Different types of baffle piers failed to decrease the helical flow in the pool.

To eliminate the unfavorable flow conditions it was necessary to resort to other means of expanding the jets and of forcing the jump to form downstream from the tunnel outlets.

Study of Hydraulic Humps*

12. Action of hydraulic humps. Hydraulic humps of various designs (fig. 10) were studied as a means of spreading the jet from the tunnels and of forcing the jump to form downstream from the tunnels for all combinations of gate opening and discharge with the tailwater 5 feet above normal. Humps 1 and 2 spread the jet satisfactorily and held the jump downstream from the tunnel outlets. The pool however was very rough.

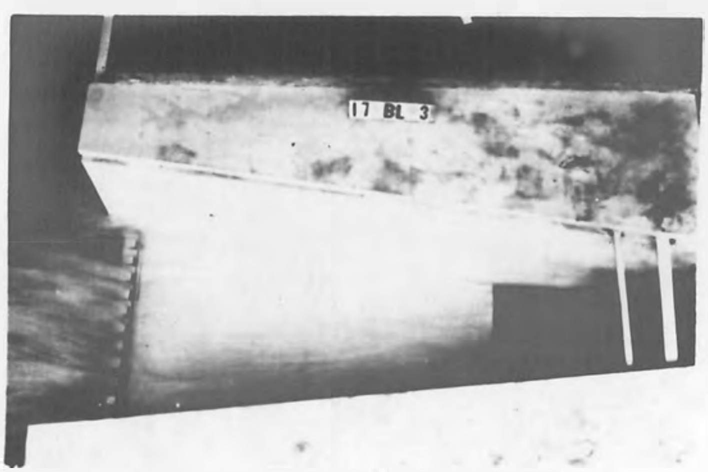
A high fin occurred along the center line of the pool and along each wall with hump 3, but the water surface in the pool (fig. 11) was quiet and the hydraulic jump was well formed and well placed. The hydraulic jump for hump 4 was too far upstream and fluctuated considerably, entailing a very rough water surface in the pool (fig. 11). Hump 5 improved the flow in the pool (fig. 11), but the hydraulic jump formed too far upstream for stability.

13. Action with raised stilling pool floor. Studies were made with hump 5 and the stilling pool floor raised 2 inches

* The first use of the device hereinafter termed the "Hydraulic Hump" appears to be that described in "Hydraulic Model Studies for the Wills Creek Dam" by George E. Barnes, Case School of Applied Science, Cleveland, Dec., 1934. The same device was subsequently used by Mr. Barnes on at least eight other dam models.

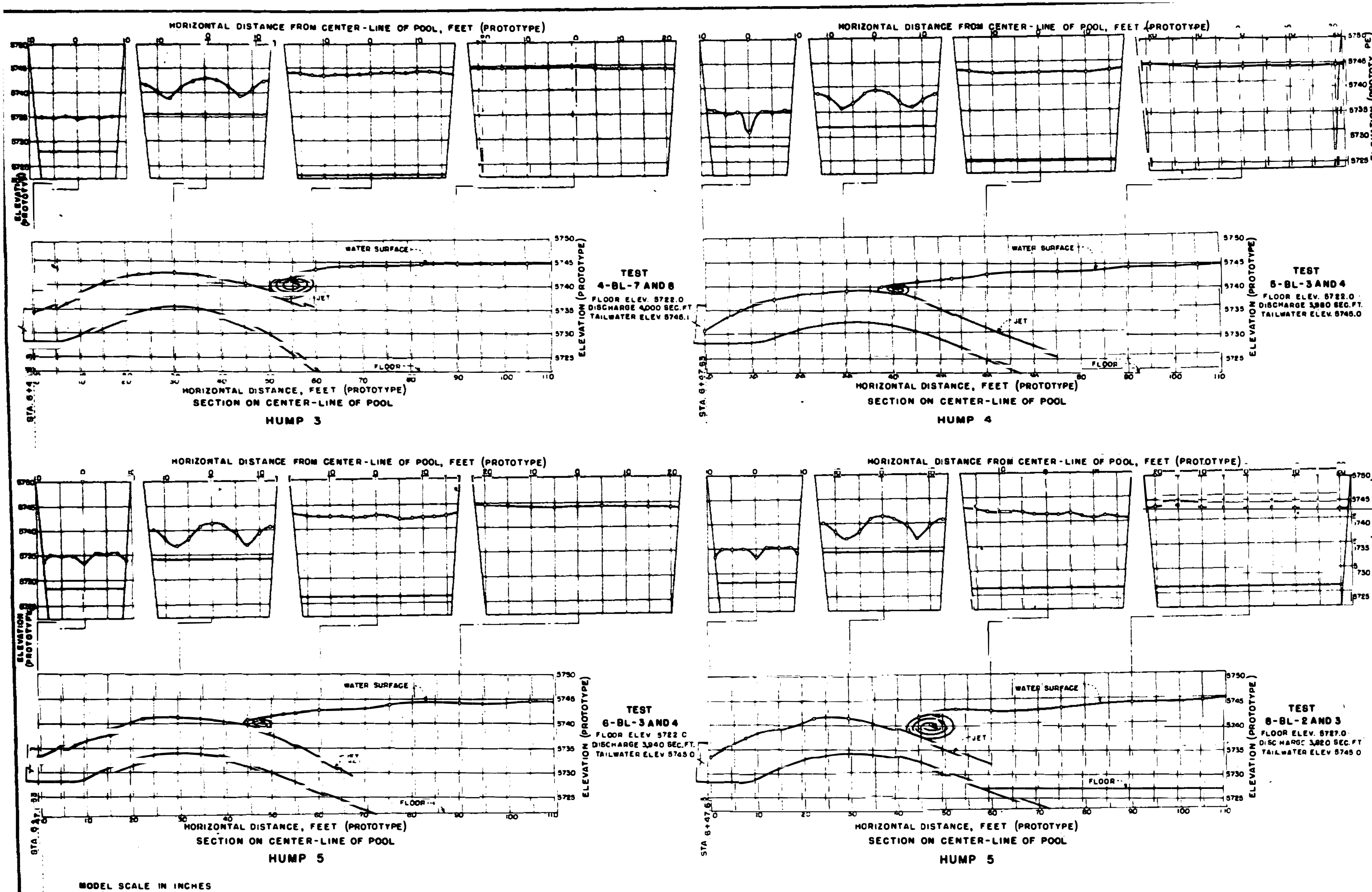
A. DISCHARGE 4000 SECOND-FEET
TAILWATER 5 FEET ABOVE NORMAL

B. DISCHARGE 3000 SECOND-FEET
GATES 4, 6 AND 8 OPEN
NORMAL TAILWATER ELEVATION



C. DISCHARGE 4000 SECOND-FEET - NO TAILWATER

FLOW CHARACTERISTICS - ORIGINAL DESIGN



WATER SURFACE OVER HUMPS 3,4 AND 5

NOTE
All cross-sections are looking downstream.

FIGURE 11

308-D-8

in the model (5 feet in prototype). The pool was rough with the flow concentrated in the center. Return flow occurred along both sides (fig. 11). At certain discharges and gate combinations, undesirable helical flow occurred in the pool. Hump 6, the semifinal design evolved from the foregoing studies (fig. 10), proved satisfactory.

Determination of Stilling Pool Dimensions

14. Width of stilling pool and divergence of side walls. Hump 6 as originally constructed was 30 inches wide in the model (fig. 10 and plate 5-A). With a discharge of 4,000 second-feet (plate 5-B) the jet at the top of the hump spread to about six inches on either side of the center line and continued this width throughout the length of the pool. Pieces of sheet metal placed on either side of the jet proved convenient for determining the correct angle of flare for the side walls. Plate 5-C and figure 12 show the semifinal design with the corrected side-wall flare.

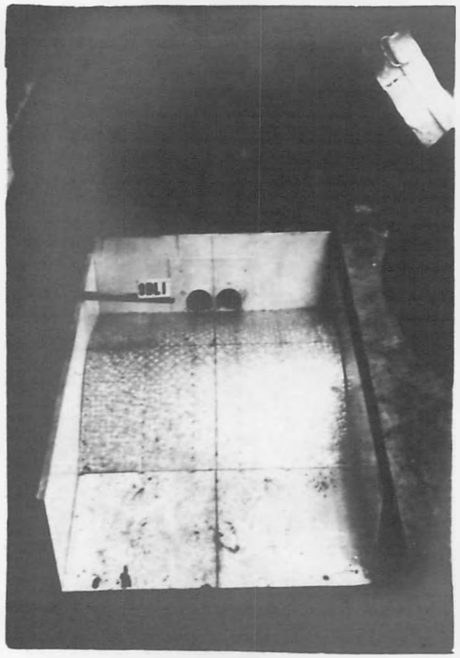
15. Length of stilling pool. Studies for determining the proper length of stilling pool and position of the sill were made on the semifinal design using the flaring sidewalls, hump 6, a dentated step, and various Rehbock sills (fig. 12). The dentated step was placed at the downstream end of the hump, and the distance from the dentated step to the sill was then varied. Plates 6 and 7 show the character of the flow and the scour produced by three different lengths of pool. Figure 13 shows the water surface profiles and scour for four different lengths of pool. It was found that the pool could be shortened without detrimental effect, and this revision was incorporated in the semifinal design. The behavior of this revised design was satisfactory.

Style of Sill and Revetment

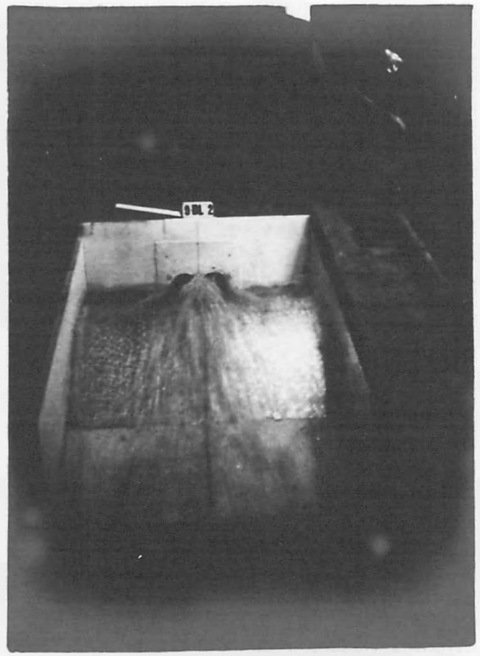
16. Dentated step and Rehbock sill. Different designs of Rehbock sill were tested in combination with a dentated step (fig. 12). Sill G produced satisfactory flow conditions and this pool layout was then used to study schemes for the design of the revetment.

17. Revetment. With sill G and pool 4, different revetment plans (fig. 14) were studied, to determine the extent of riprap necessary to insure stability of the stilling pool structure. Revetment scheme 3 which was constructed of sand (plate 8-A and -B) shows the need of riprap for protection against erosion. Revetment scheme 5 (plate 8-C and -D) was of the same type as 3 except that the river bed was riprapped. Plate 9 shows the erosion and water surfaces with revetment schemes 4 and 8. Figure 15 shows the water surface and erosion of river bed for revetment schemes 3, 4, 5, and 8.

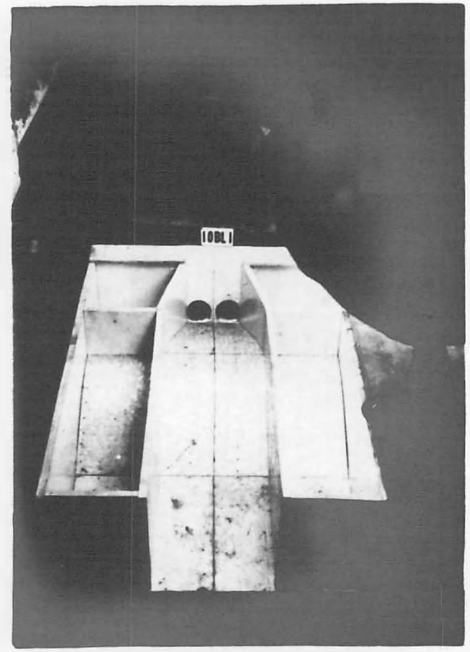
18. Semifinal design. Sill N, a modification of sill



A. NO FLOW

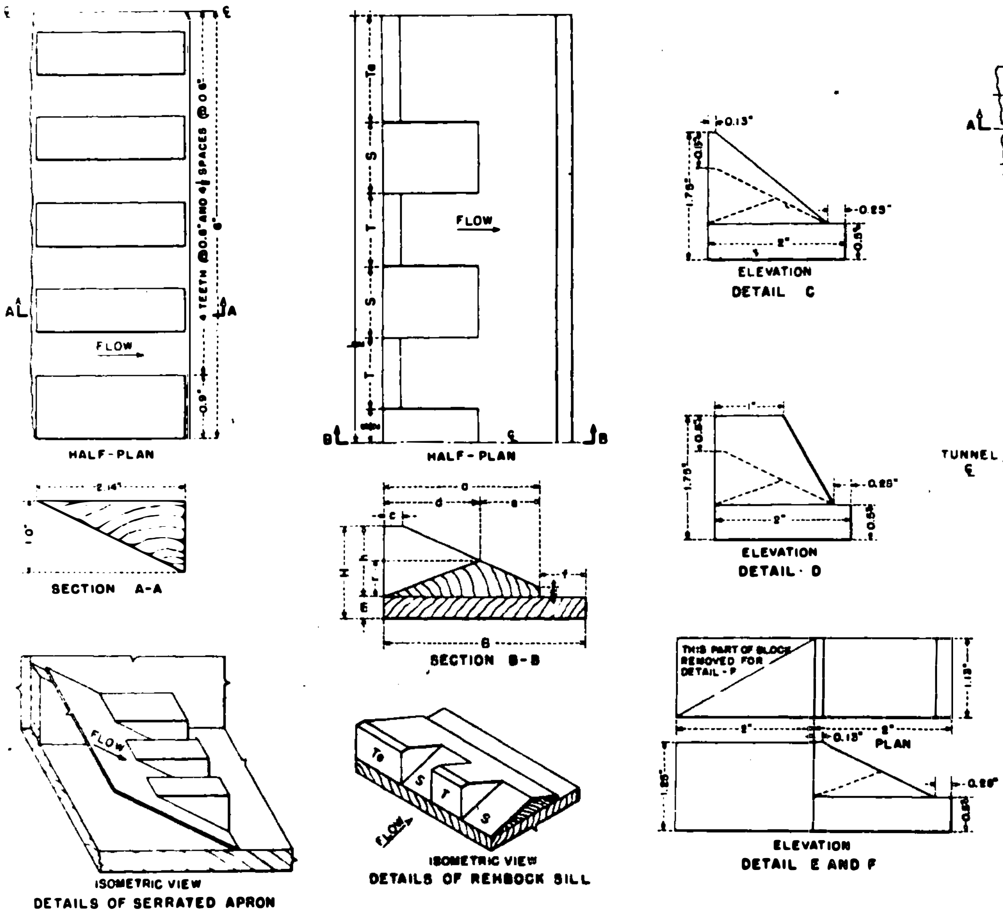


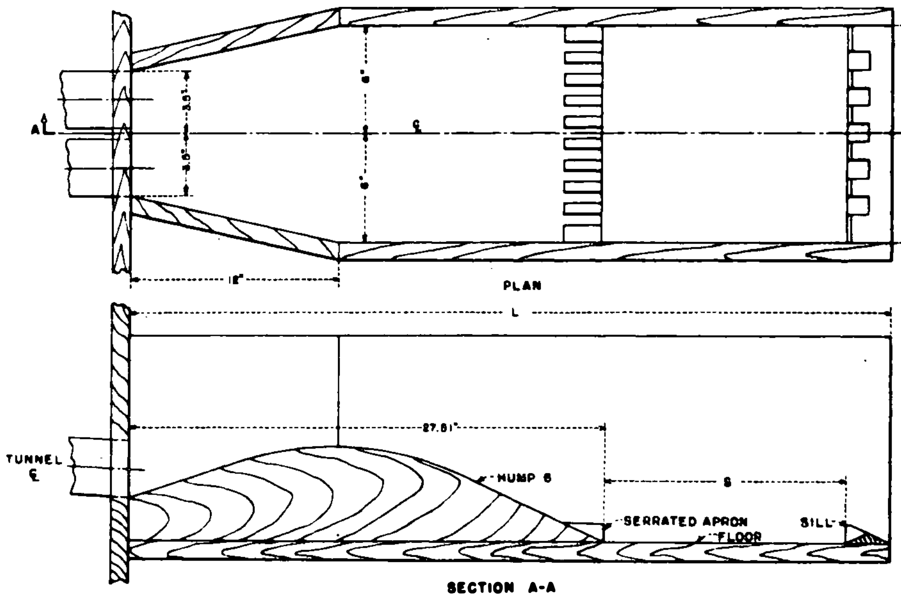
B. DISCHARGE 4000 SECOND-FEET
NO TAILWATER



C. SEMI-FINAL DESIGN OF
SIDE WALLS

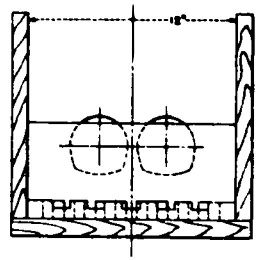
HUMP 6
DETERMINATION OF STILLING POOL DIMENSIONS





POOL	LENGTH OF POOL L, IN.	DISTANCE FROM HUMP TO SILL S, IN.
1	44.00	12
2	44.00	14
3	44.00	16
4	41.75	12

DIMENSIONS FOR POOLS

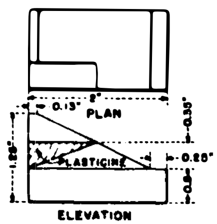


STILLING POOL

DIMENSIONS OF REHBOCK SILLS

SILL	OVER-ALL LENGTH L, IN.	OVER-ALL HEIGHT H, IN.	OVER-ALL WIDTH B, IN.	HEIGHT OF SILL h, IN.	WIDTH OF SILL a, IN.	WIDTH OF END TOOTH T_e, IN.	WIDTH OF TOOTH T, IN.	WIDTH OF SPACE S, IN.	FLAT c, IN.	RISE r, IN.	OFF-SET f, IN.	HEIGHT OF BLOCK m, IN.	HORIZONTAL OF SLOPE d, IN.	HORIZONTAL OF SLOPE e, IN.	VERTICAL OFF-SET, n	NUMBER OF SPACES	NUMBER OF TEETH *	REMARKS
A	18.0	1.16	1.88	0.75	1.88	0.38	0.75	0.75	0.13	0.47	0.00	0.38	0.82	1.06	0.00	12	11	End teeth taper to fit flaring sides
B	12.0	1.00	2.50	1.00	2.50	1.50	1.00	1.00	0.25	0.50	0.00	0.00	1.37	1.13	0.00	5	4	
C	12.0	1.00	2.25	1.00	2.25	1.50	1.00	1.00	0.25	0.50	0.00	0.00	1.37	0.88	0.11	5	4	
D	12.0	1.00	1.25	0.50	1.25	1.13	0.75	0.75	0.13	0.25	0.00	0.50	0.75	0.50	0.00	7	6	
E	12.0	1.25	2.25	1.00	2.25	1.50	1.00	1.00	0.25	0.50	0.00	0.25	1.37	0.88	0.11	5	4	
F	12.0	1.00	2.00	1.00	2.00	1.50	1.00	1.00	0.25	0.50	0.00	0.00	1.37	0.63	0.22	5	4	
G	12.0	1.25	2.00	0.75	1.75	1.13	0.75	0.75	0.13	0.35	0.25	0.50	1.00	0.75	0.00	7	6	
H	12.0	1.25	2.00	1.00	2.00	1.50	1.00	1.00	0.25	0.50	0.00	0.25	1.37	0.63	0.22	5	4	
J	12.0	1.00	2.00	0.75	1.75	1.13	0.75	0.75	0.13	0.35	0.25	0.25	1.00	0.75	0.00	7	6	
K	12.0	1.25	2.00	0.75	1.75	1.13	0.75	0.75	0.13	0.35	0.25	0.50	1.00	0.75	0.00	7	6	End teeth shown on Detail C
L	12.0	1.25	2.00	0.75	1.75	1.13	0.75	0.75	0.13	0.35	0.25	0.50	1.00	0.75	0.00	7	6	End teeth shown on Detail D
M	12.0	1.30	2.00	0.80	2.00	0.75	0.70	0.70	0.20	0.40	0.00	0.50	1.10	0.90	0.00	8	7	
N	12.0	1.30	2.00	0.80	2.00	1.88	0.75	0.75	0.20	0.40	0.00	0.50	1.10	0.90	0.00	6	5	
O	12.0	1.25	2.00	0.75	1.75	2.63	0.75	0.75	0.13	0.35	0.25	0.50	1.00	0.75	0.00	5	4	
P	12.0	1.25	2.00	0.75	1.75	1.13	0.75	0.75	0.13	0.35	0.25	0.50	1.00	0.75	0.00	7	6	End teeth shown on Detail E
Q	12.0	1.25	2.00	0.75	1.75	1.13	0.75	0.75	0.13	0.35	0.25	0.50	1.00	0.75	0.00	7	6	End teeth shown on Detail F
R	12.0	1.25	2.00	0.75	1.75	1.13	0.75	0.75	0.13	0.35	0.25	0.50	1.00	0.75	0.00	7	6	End teeth shown on Detail G

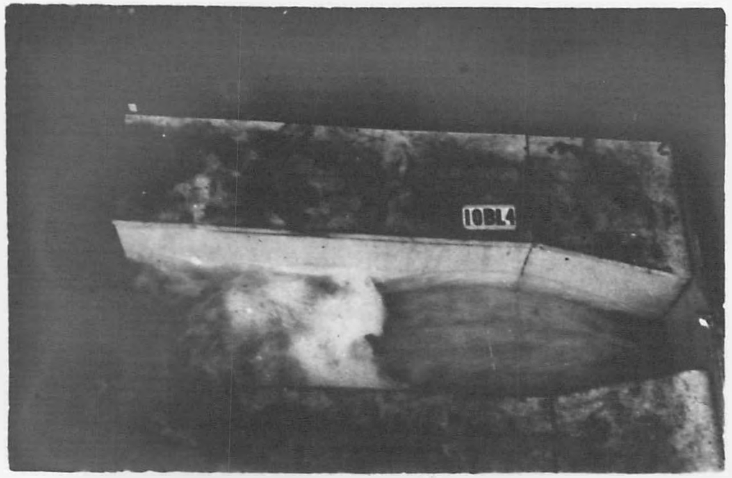
* The "Number of teeth" does not include the two end teeth (T_e).



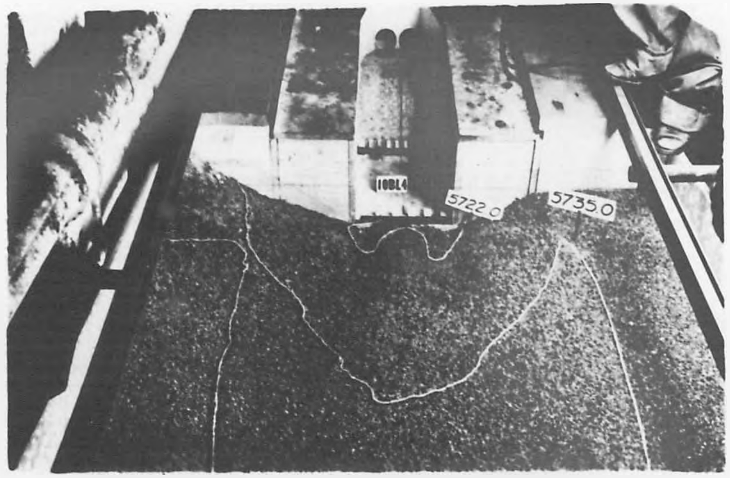
DETAILS OF SILLS AND STILLING POOL

36-D-510

FIGURE 18



A. FLOW IN POOL



B. EROSION OF RIVER BED AFTER ONE HOUR RUN

DISCHARGE 4000 SECOND-FEET

POOL 2 - SILL C

C. FLOW IN POOL

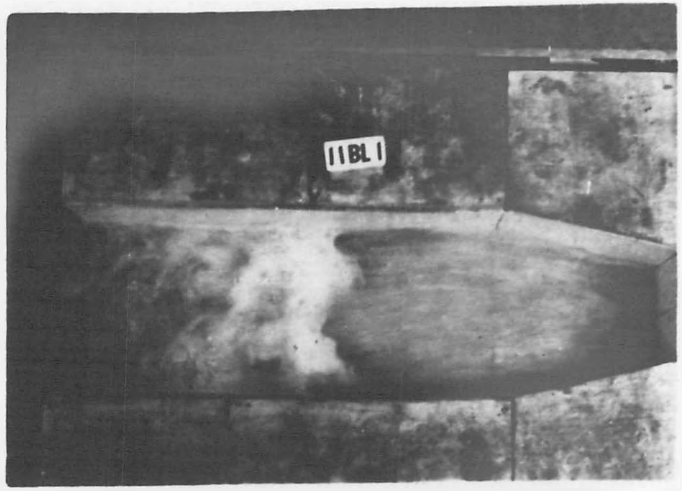
D. EROSION OF RIVER BED AFTER ONE HOUR RUN

DISCHARGE 4000 SECOND-FEET

POOL 3 - SILL D

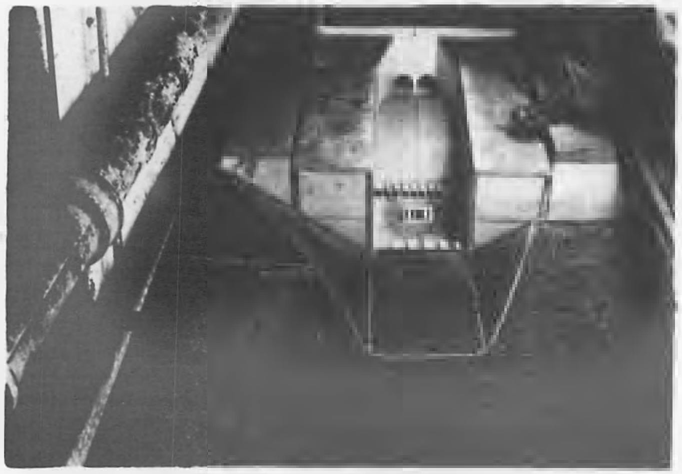
FLOW AND EROSION OF RIVER BED - POOLS 2 AND 3

A. FLOW AT DOWNSTREAM END OF POOL



B. FLOW IN POOL

DISCHARGE 4000 SECOND-FEET - NORMAL TAILWATER



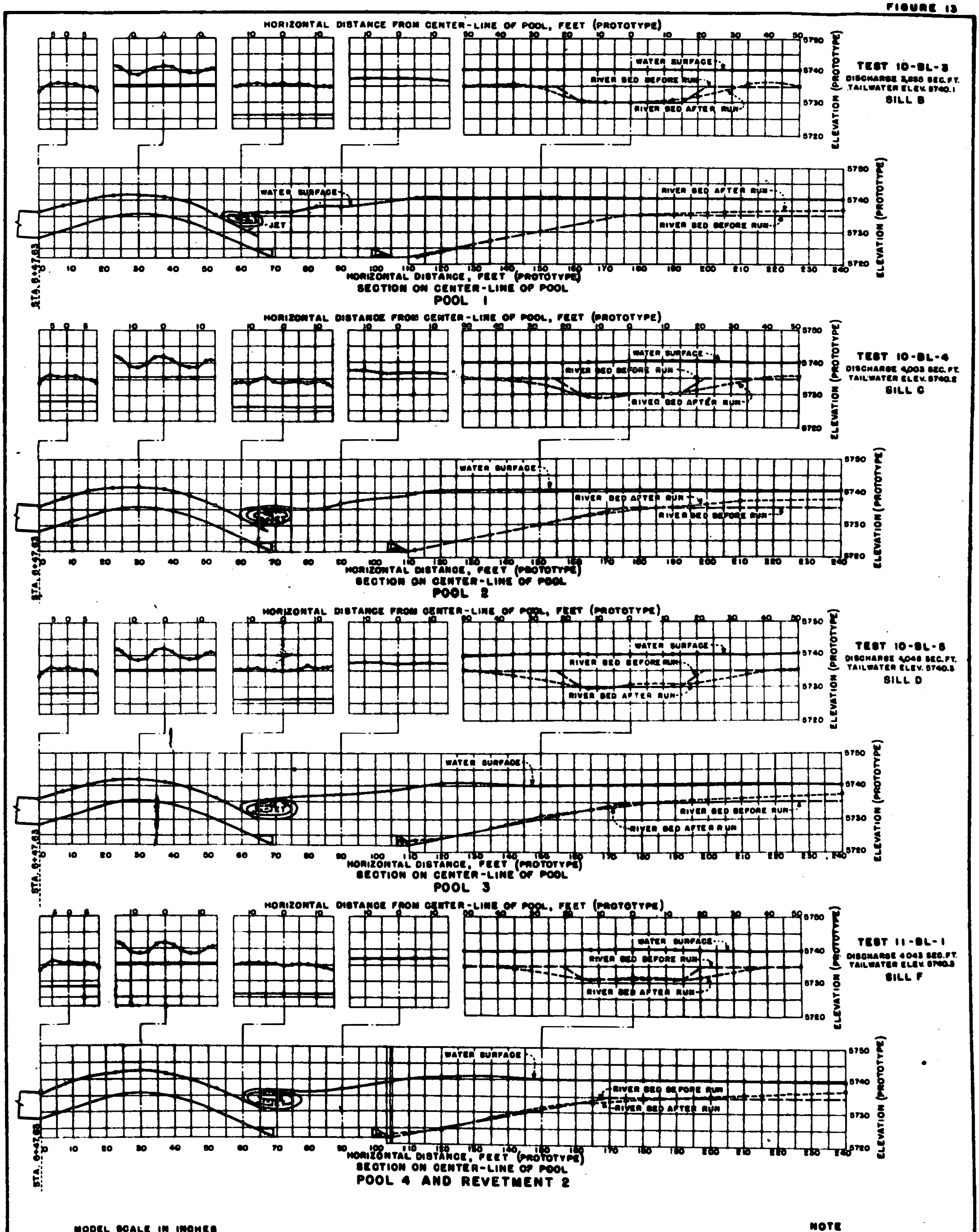
D. RIVER BED BEFORE RUN

E. EROSION OF RIVER BED AFTER ONE HOUR RUN

SILL F - REVETMENT SCHEME 2

FLOW AND EROSION OF RIVER BED - POOL 4

PLATE 7

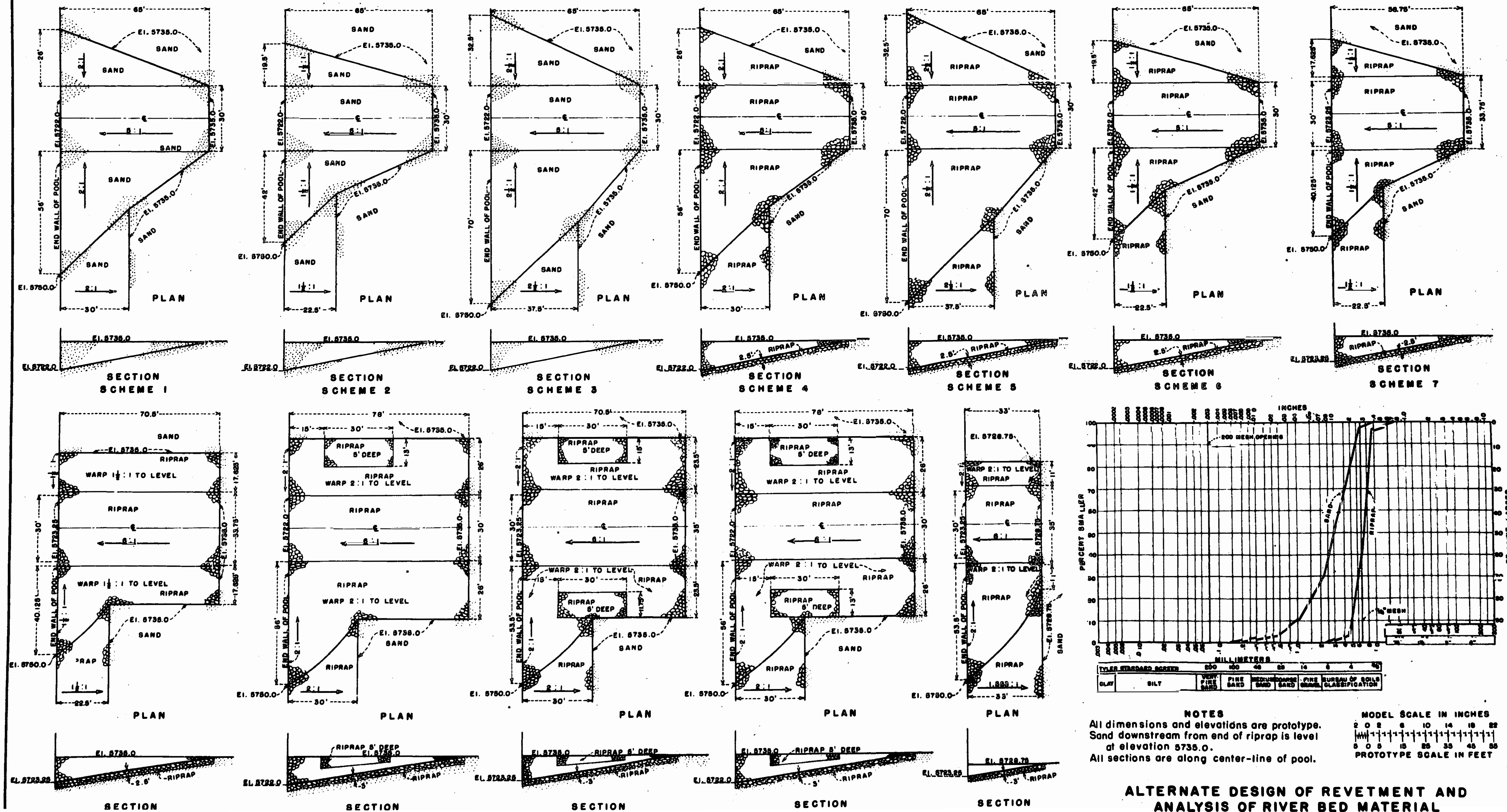


WATER SURFACE PROFILE AND EROSION OF RIVER BED FOR POOLS 1,2,3 AND 4

NOTE

Sections are looking downstream. Erosion of river bed after one hour. (Model).

36-D-511



NOTES

All dimensions and elevations are prototype.
Sand downstream from end of riprap is level at elevation 5735.0.
All sections are along center-line of pool.

ALTERNATE DESIGN OF REVETMENT AND ANALYSIS OF RIVER BED MATERIAL

A. RIVER BED BEFORE RUN

B. EROSION OF RIVER BED AFTER ONE HOUR RUN
DISCHARGE 4000 SECOND-FEET

REVETMENT SCHEME 3

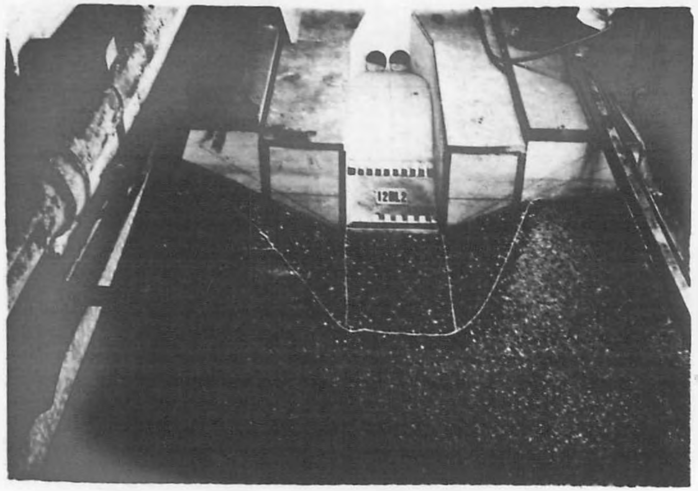
C. RIVER BED BEFORE RUN

D. EROSION OF RIVER BED AFTER ONE HOUR RUN
DISCHARGE 4000 SECOND-FEET

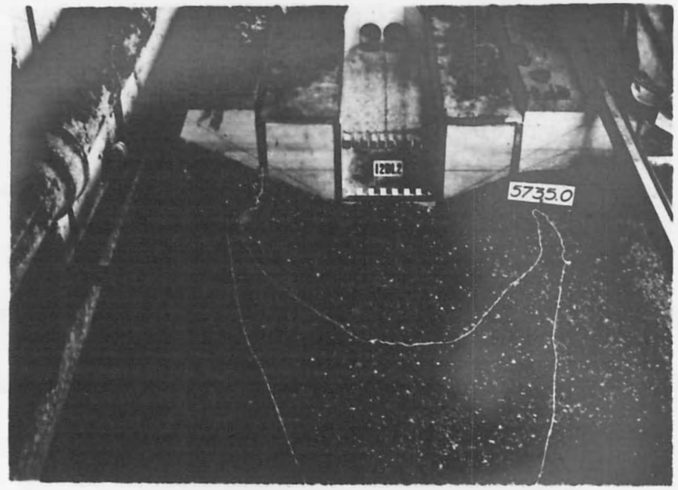
REVETMENT SCHEME 5

POOL 4 - SILL C

EROSION OF RIVER BED - REVETMENT SCHEMES 3 AND 5

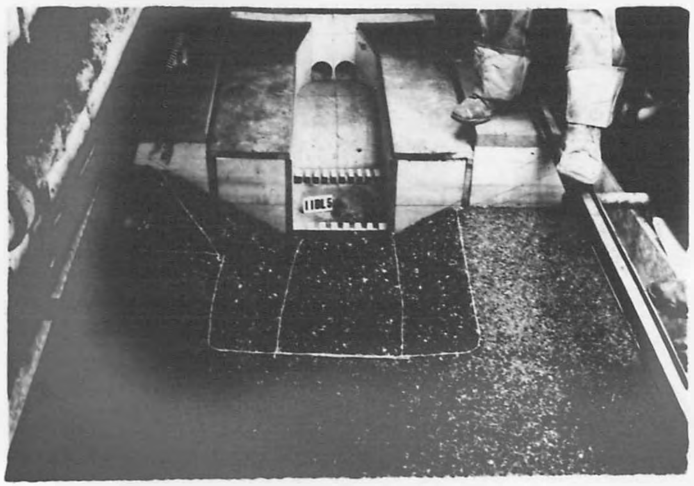


A. RIVER BED BEFORE RUN

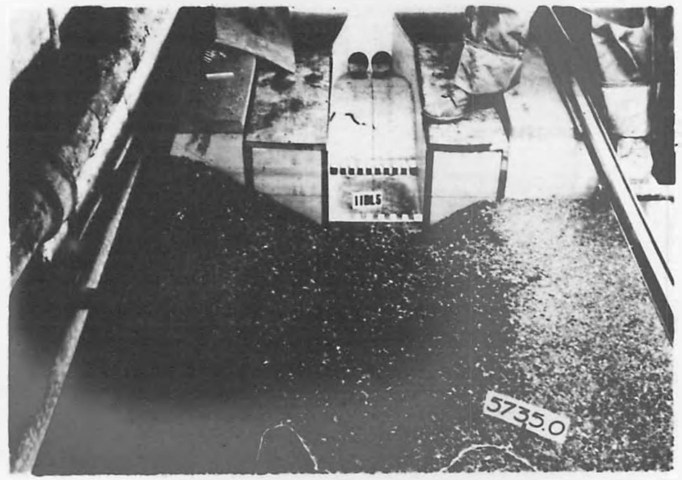


B. EROSION OF RIVER BED AFTER ONE HOUR RUN
DISCHARGE 4000 SECOND-FEET

REVETMENT SCHEME 4



C. RIVER BED BEFORE RUN



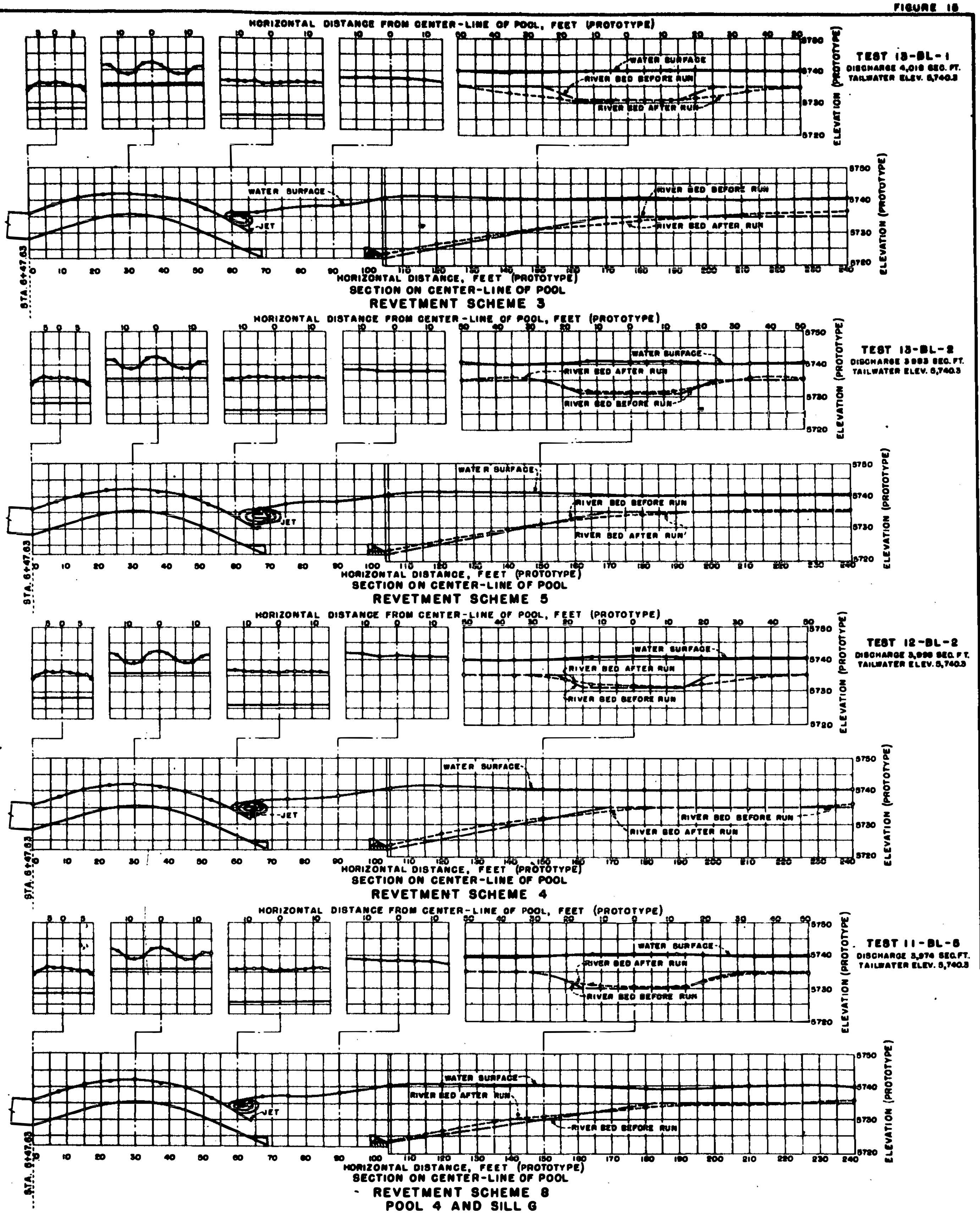
D. EROSION OF RIVER BED AFTER ONE HOUR RUN
DISCHARGE 4000 SECOND-FEET

REVETMENT SCHEME 8

POOL 4 - SILL G

EROSION OF RIVER BED - REVETMENT SCHEMES 4 AND 8

PLATE 9



MODEL SCALE IN INCHES

PROTOTYPE SCALE IN FEET

WATER SURFACE AND EROSION OF RIVER BED FOR REVETMENT SCHEMES No. 3,4,5, AND 8

NOTE

Sections are looking downstream. Erosion of river bed after one hour run (Model).

36-D-513

G, and revetment scheme 10 (plate 10-A) were tested for various gate combinations to determine the final action in the pool. Figure 16 and plate 10-B show the erosion and water surface for maximum discharge and normal tailwater elevation. When the tailwater was 5 feet (prototype) above normal (fig. 16) no erosion of the river bed occurred. With an unbalanced flow of 3,000 second-feet (fig. 16 and plate 10-C) very little erosion occurred and the flow conditions in the pool were satisfactory. With a balanced flow of 2,000 second-feet (fig. 16), no scour occurred and flow conditions were satisfactory.

The semifinal design was used as the final design except for minor changes in the revetment and slope of the hump. Since these changes were made for construction reasons only and could produce no adverse hydraulic action in the model, they were not tested.

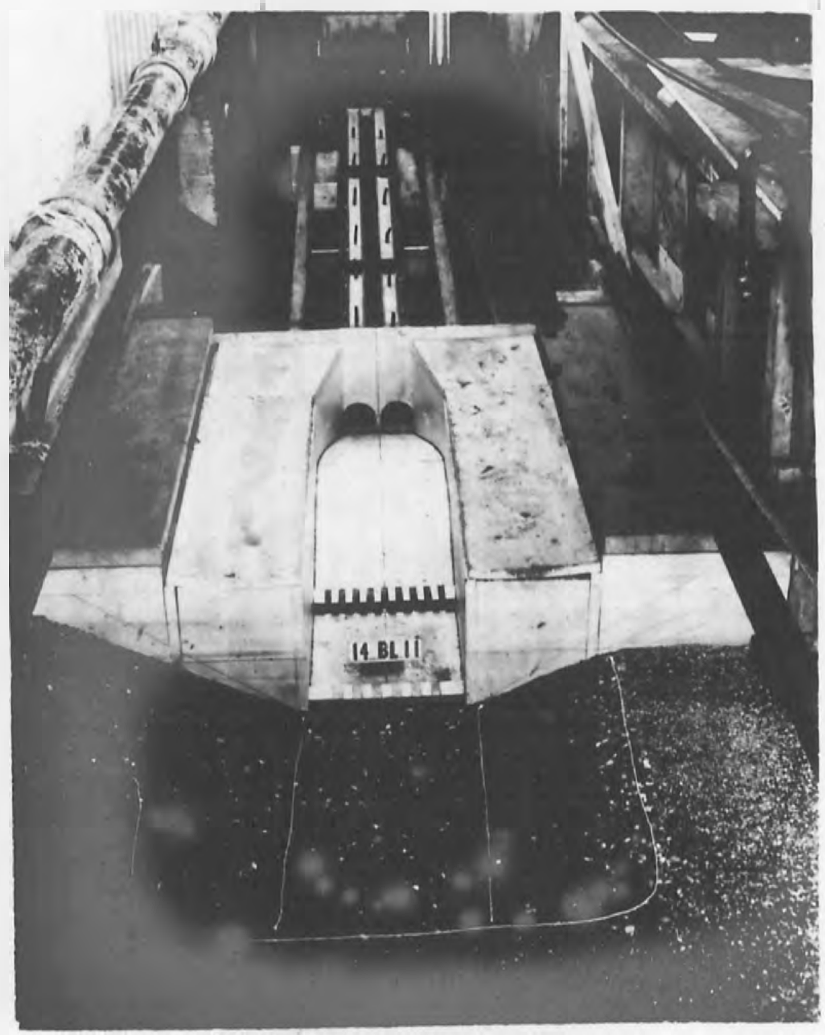
19. Recommended design. The results outlined in the foregoing paragraphs may be briefly recapitulated to indicate precisely the finally recommended design of the outlet works stilling pool. The pool itself, hump 6, proper side walls, and sill N in its adopted position are shown in figure 14 as Pool 4. Revetment scheme 10 is shown in figure 14, and plate 10 is a photograph of the whole as finally tested.

CHAPTER III - TESTS ON SPILLWAY MODEL

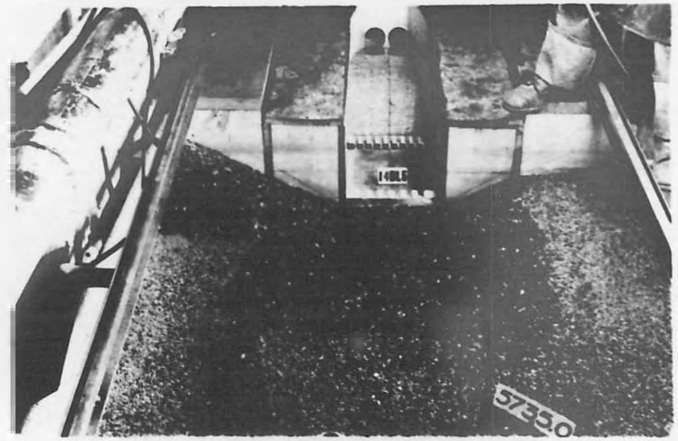
Spillway Model

20. Construction of model. A model of the Bull Lake spillway consisting of a head tank, intake section, gate section, chute, pool and sand box was constructed on a scale of 1:30 (fig. 17) in the Colorado State College Hydraulic Laboratory at Fort Collins, Colorado. The head tank was built of wood and lined with light sheet metal. The warped walls of the intake section were made of concrete. The piers and gate section walls were constructed of redwood, the gates and crest of 20-gage galvanized sheet iron. The chute and pool were made of wood, and lined with 27-gage galvanized iron. A large wooden box lined with light sheet metal was filled with sand to represent the river bed downstream from the pool. An adjustable weir on the end of the sand box was used to regulate the tailwater.

The reservoir elevation was measured with a hook gage in a stilling well attached by hose to a piezometer opening in the head tank. A float gage was used to record the tailwater elevation.



A. RIVER BED BEFORE RUN



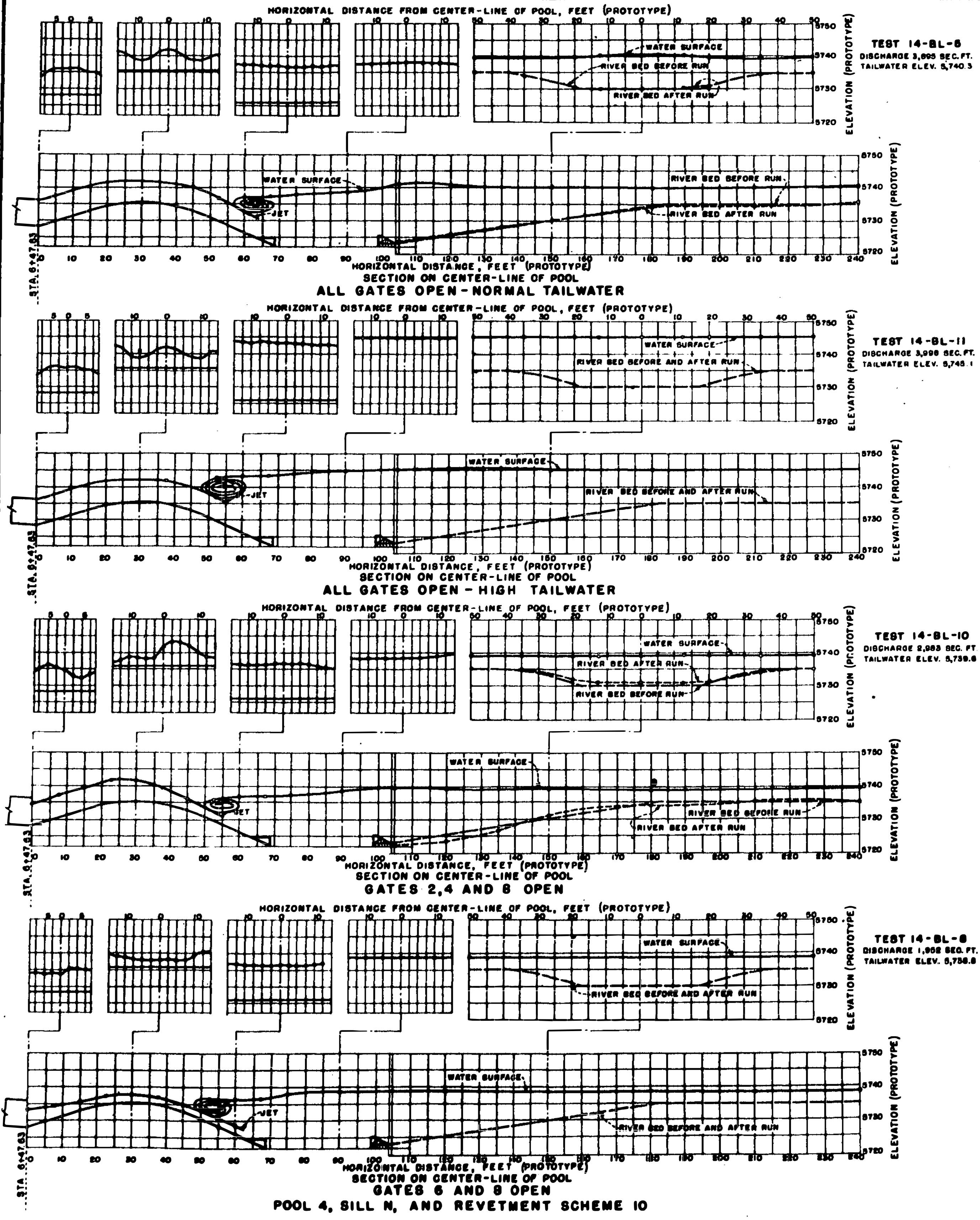
B. RIVER BED AFTER ONE HOUR RUN
DISCHARGE 4000 SECOND-FEET
TAILWATER ELEVATION 5740.3

C. RIVER BED AFTER ONE HOUR RUN
DISCHARGE 4000 SECOND-FEET
TAILWATER ELEVATION [illegible]

POOL 4 - SILL E - REVETMENT SCHEME 10

EROSION OF RIVER BED - SEMI-FINAL DESIGN

PLATE 10



MODEL SCALE IN INCHES

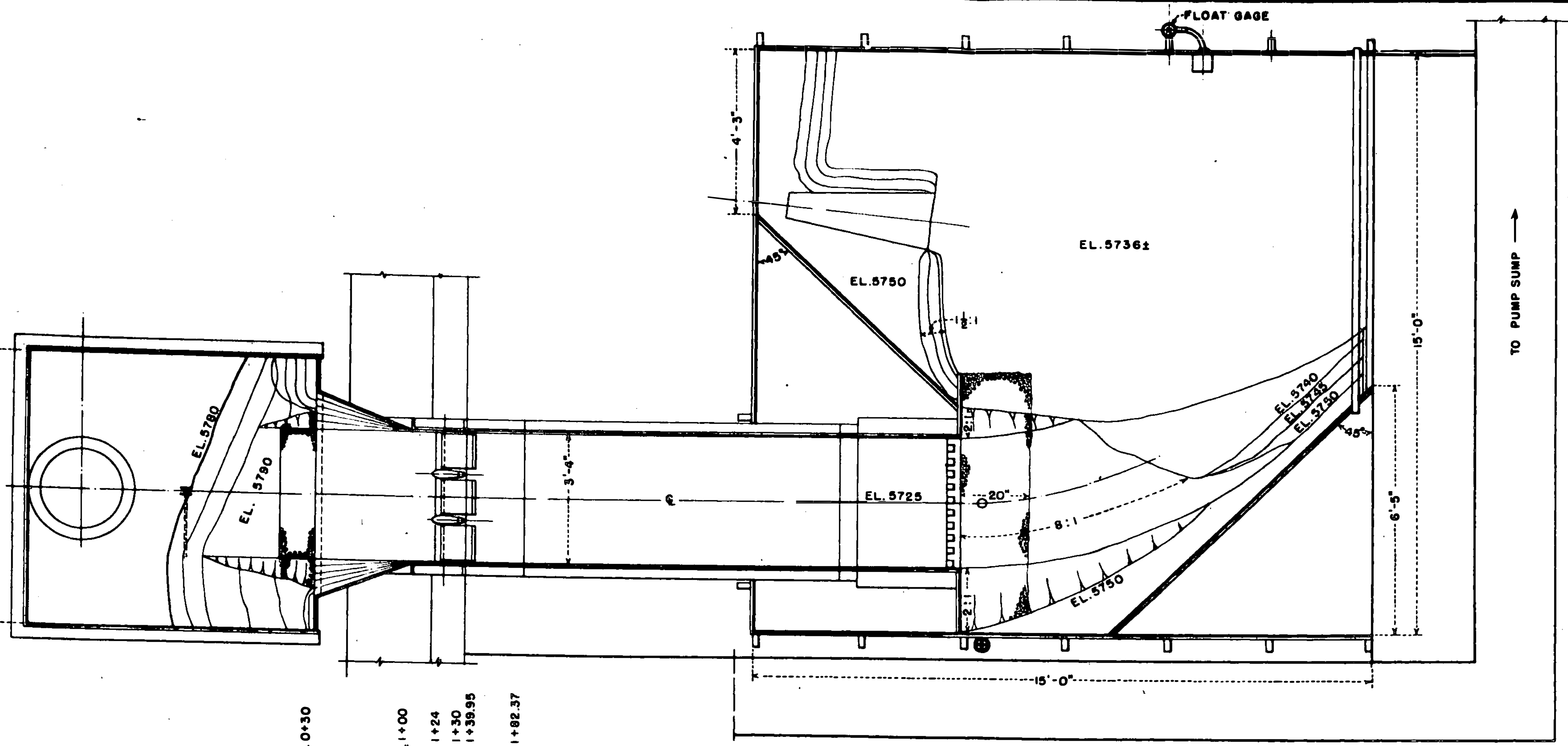
PROTOTYPE SCALE IN FEET

WATER SURFACE AND EROSION FOR VARIOUS FLOW CONDITIONS - SEMI-FINAL DESIGN

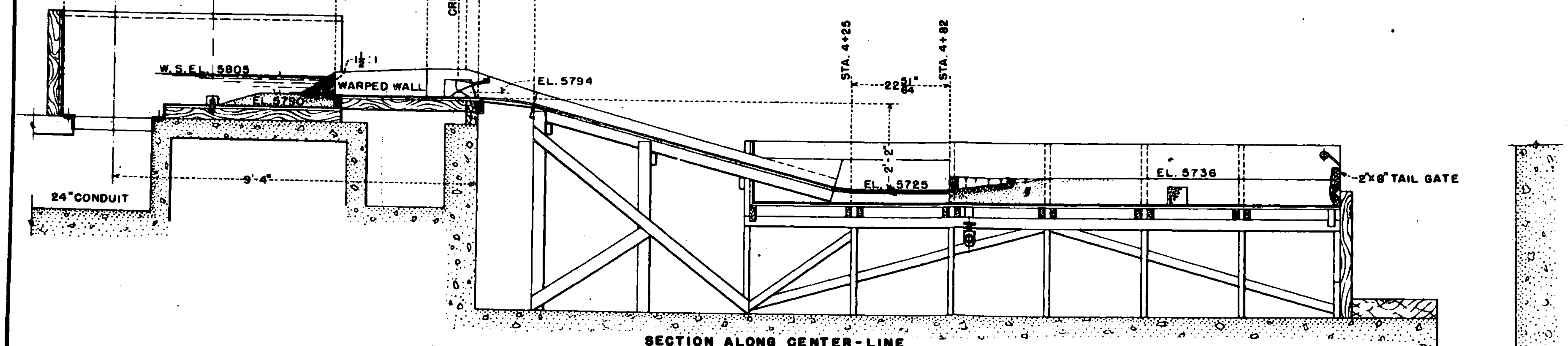
NOTE

Sections are looking downstream. Erosion of river bed after one hour run (Model)

36-D-514

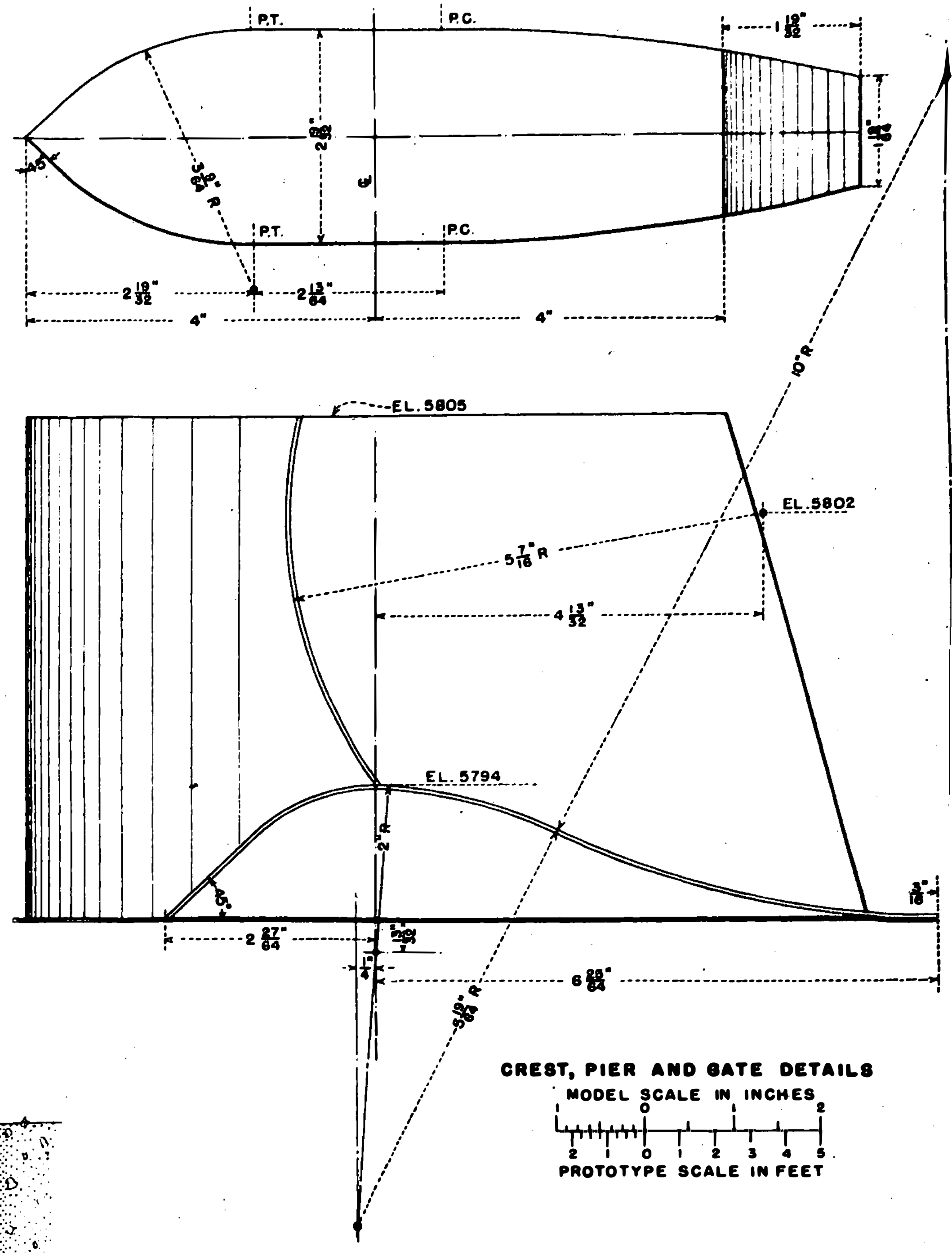


PLAN



SECTION ALONG CENTER-LINE

MODEL SCALE IN INCHES
20 10 0 10 20 30 40
50 25 0 25 50 75 100
PROTOTYPE SCALE IN FEET



CREST, PIER AND GATE DETAILS

MODEL SCALE IN INCHES
0 1 2
2 1 0 1 2 3 4 5
PROTOTYPE SCALE IN FEET

GENERAL PLAN, ELEVATION AND DETAILS OF SPILLWAY MODEL

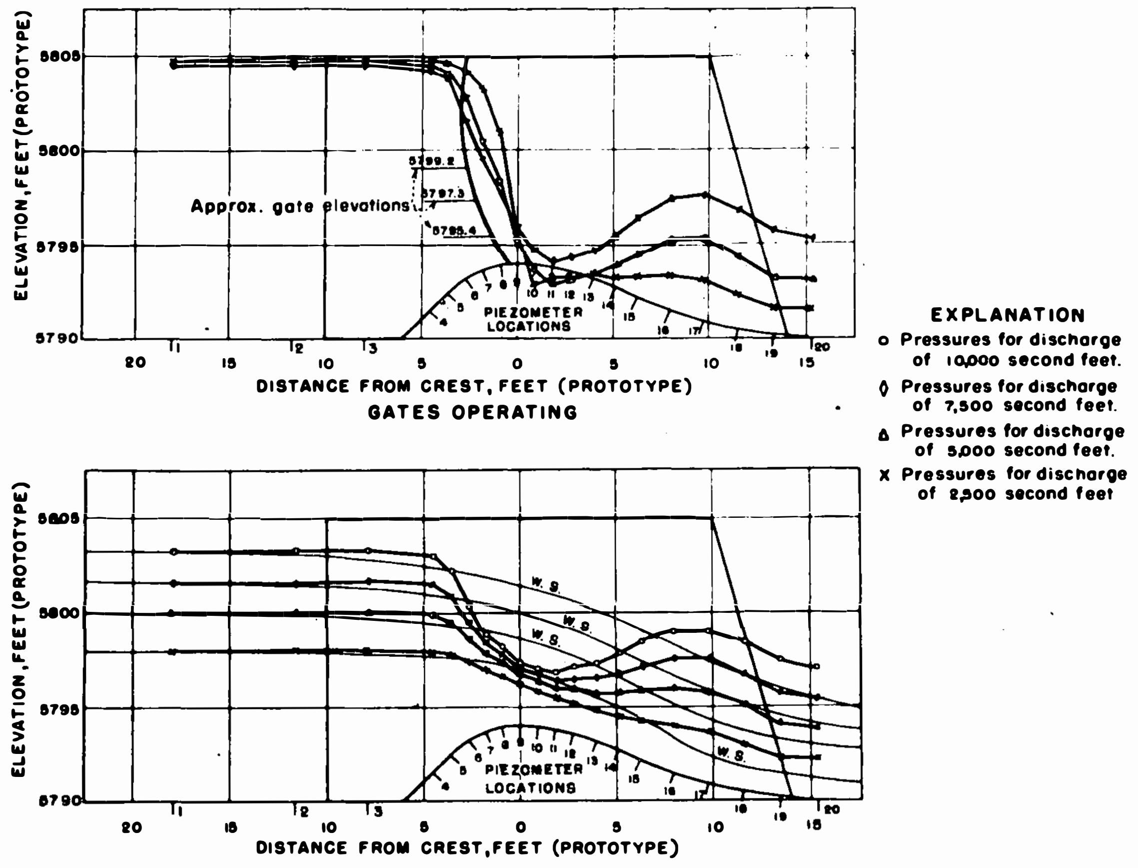
Water was supplied to the model by gravity from a 30,000 cubic-foot reservoir. Flow from the reservoir into a weir box 13.5 feet long, 10 feet wide, and 7 feet deep, was regulated by hand-operated gates. The quantity of water was measured over a volumetrically calibrated 2-foot Cipolletti weir, and was then conducted to the model through a 2-foot concrete conduit. After it had passed through the model, the water was returned to the reservoir through a pump whose maximum capacity is rated at about eight second-feet.

21. Approach transition and gate section. The flow from the reservoir through the approach transition and through the gate section was very satisfactory and no attempt was made to change the original design.

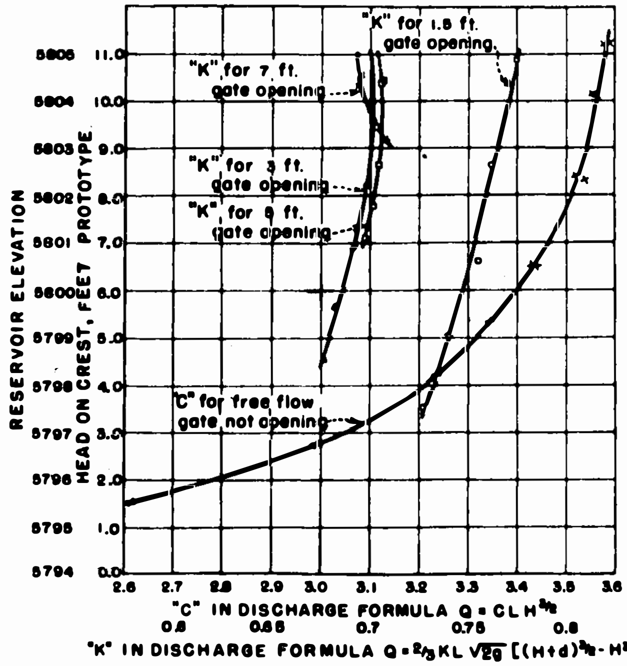
The pressure distribution (fig. 18) on the crest was measured both with and without the gates in operation. Slight negative pressures were noted for discharges of 2,500 and 5,000 second-feet with the reservoir water surface at elevation 5805.0 and with the gates in operation. Free flow over the crest gave positive pressures for all discharges. Water surface profiles (fig. 18) on the center line of the middle gate were also taken for various discharges.

Discharge coefficients (fig. 18) were obtained for free flow as well as for various gate openings, and a discharge diagram was prepared (fig. 18). This diagram shows both the free flow and flow for different gate openings and reservoir elevations. All three gates were operated uniformly.

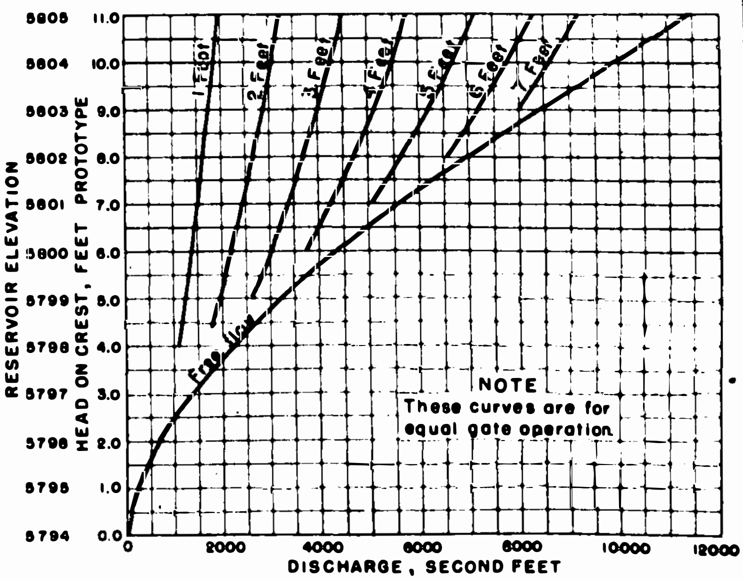
22. The chute. The section was connected to the stilling pool through a chute with parallel sides. The joining of the flows from adjacent gates downstream from the thick piers (fig. 17) caused transverse waves in the chute.(fig. 19). The effects of these waves continue into the stilling pool. Numerous designs of the downstream ends of the piers were tested in an attempt to eliminate these waves. Some improvement was noted for a few of the designs (figs. 20 and 21), but it was not considered sufficient to justify the added expense of pier construction. The water surface across the chute at various stations was measured with the original piers in place (fig. 19), and a reasonably uniform cross section was noted at station 4+25.0.where the jet entered the pool. Velocity measurements were taken for a discharge of 10,000 second-feet at station 4+25.0 with no slope correction applied to the chute floor. The measured mean velocity, found to be 59.4 feet per second (fig. 22) checked the calculated mean velocity of 59.2 feet per second at the same section. For this reason the tests on the stilling pool were made with no slope correction.



WATER SURFACES AND PRESSURES OVER CREST

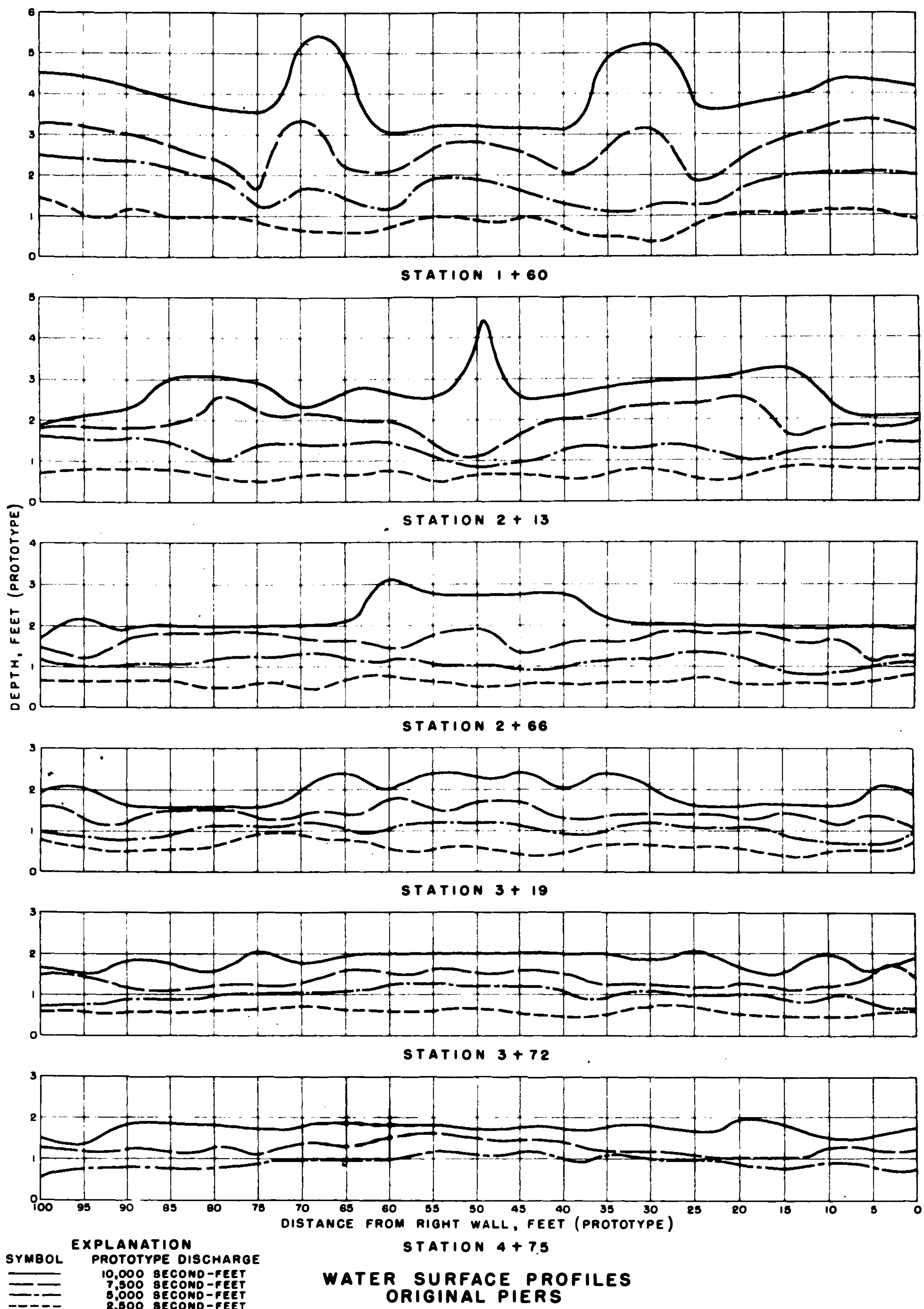


DISCHARGE COEFFICIENTS OF RADIAL GATES



SPILLWAY DISCHARGE CURVES

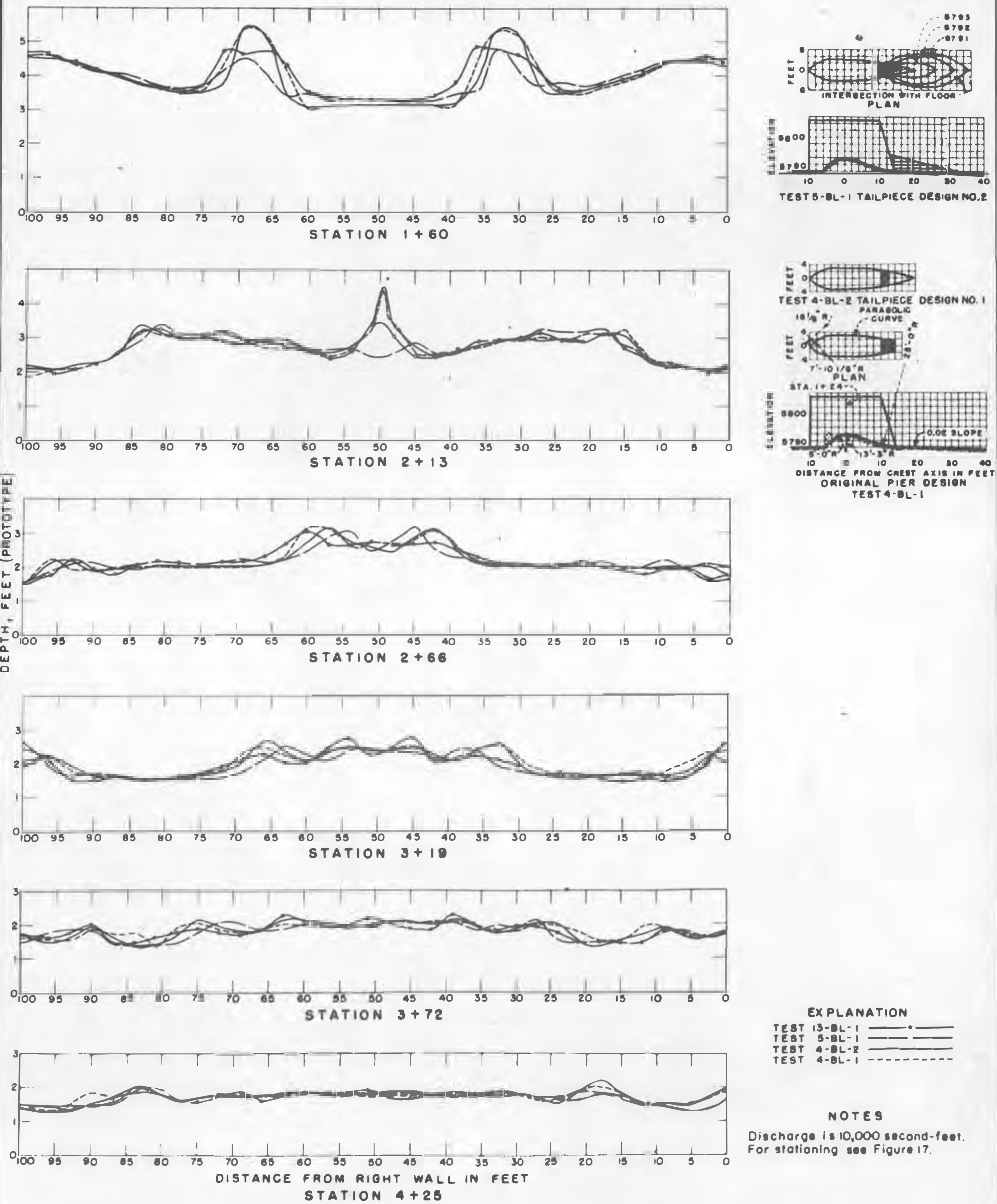
36-D-516



WATER SURFACE PROFILES
ORIGINAL PIERS

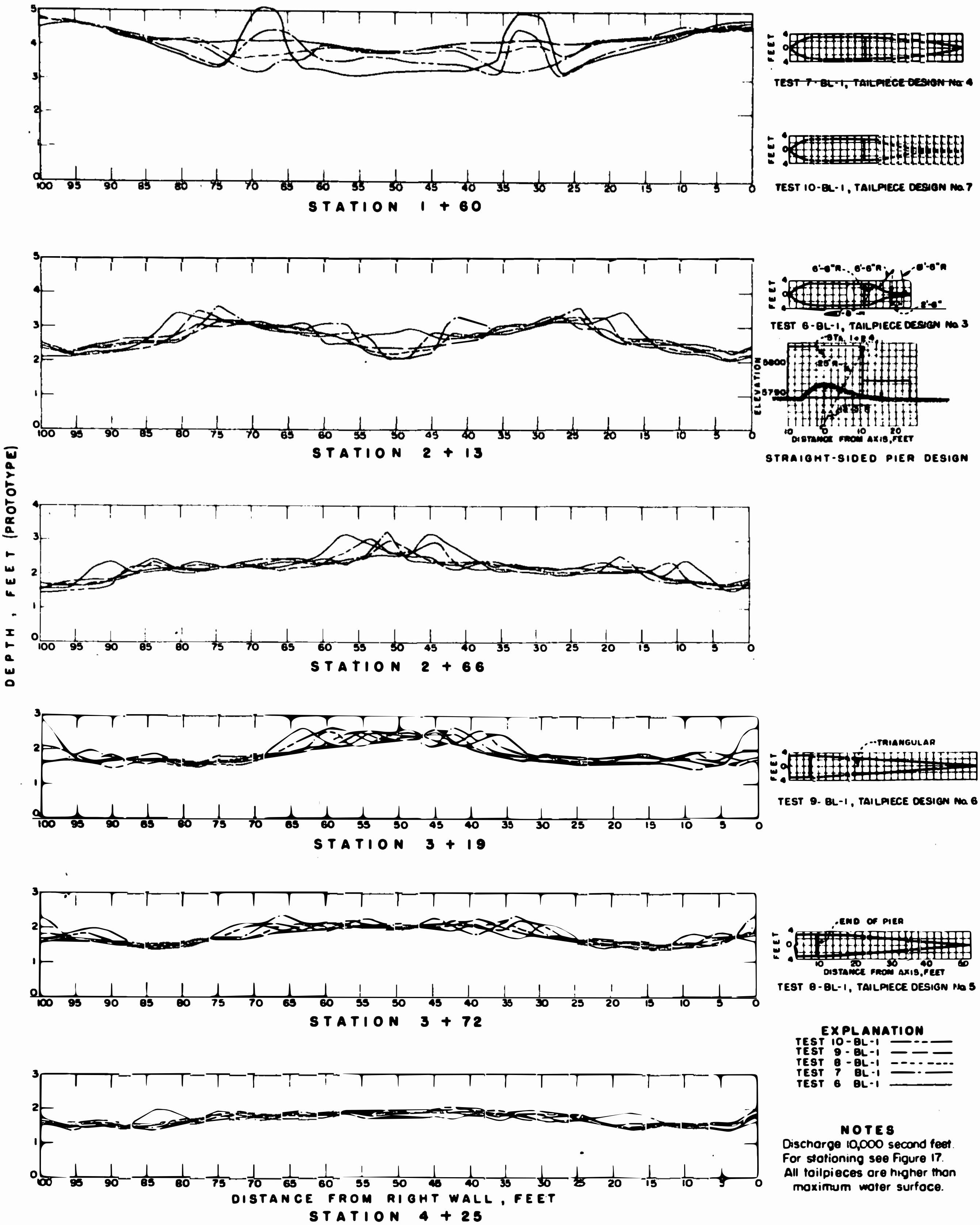
36-D-517

FIGURE 20



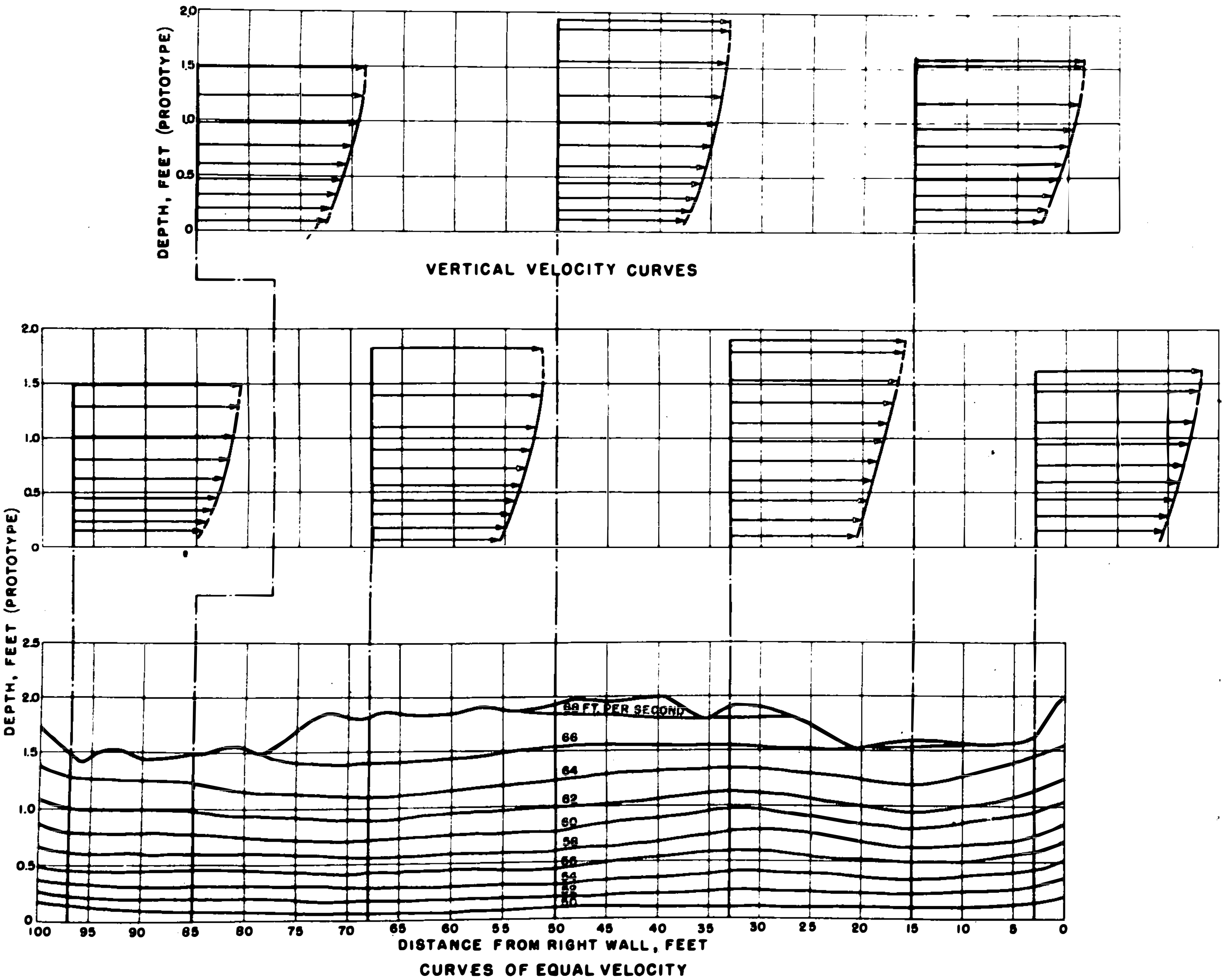
WATER SURFACE PROFILES - COMPARISON OF TAILPIECE DESIGNS USED ON ORIGINAL PIERS

36-D-518



WATER SURFACE PROFILES – COMPARISON OF TAILPIECE DESIGNS USED ON STRAIGHT SIDED PIERS

36-D-519



DISTANCE FROM RIGHT WALL, FEET

CURVES OF EQUAL VELOCITY

Discharge = Σ(Area x ave. velocity over that area) = 10,292 sec.ft.

Area = 173.2 sq.ft. Depth = $\frac{\text{area}}{\text{width}} = \frac{173.20}{100} = 1.73$ ft.

Average velocity = $\frac{\text{discharge}}{\text{area}} = \frac{10292}{1.73} = 59.43$ ft. per sec.

10 0 10 20 30 40 50 60 70

VELOCITY SCALE - FT. PER SEC.

CHECK OF VELOCITY DISTRIBUTION AT STA. 4 + 25

36-D-520

FIGURE 22

23. <u>The stilling pool - Original design.</u> The original pool with the floor at elevation 5725.0 and its downstream end at station 5+00.0 was more than adequate for a discharge of 10,000 second-feet. A satisfactory jump formed in the pool without the use of a step or sill on the apron.

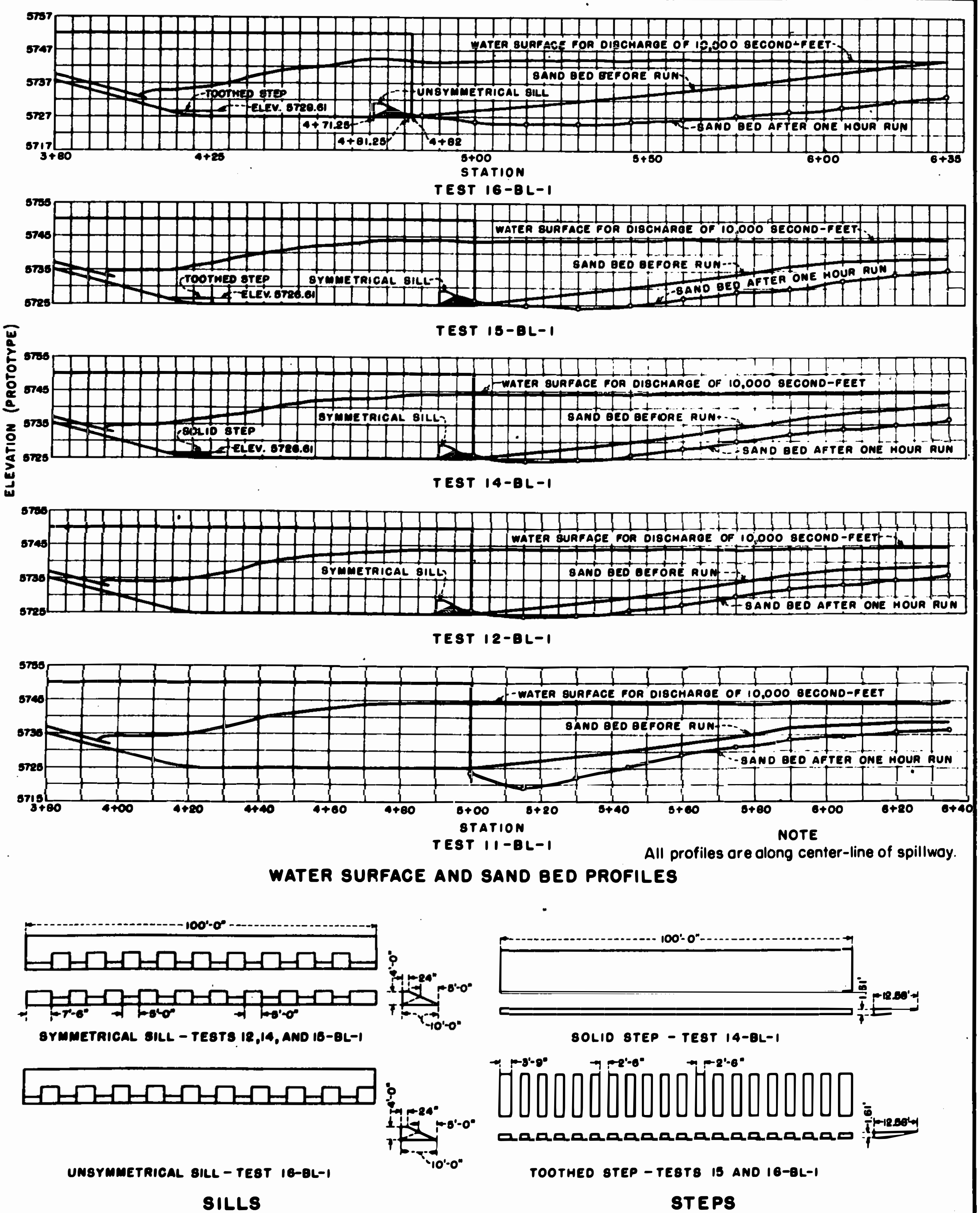
Four tests were made using sand downstream from the apron to study the effectiveness of the symmetrical sill, dentated step, and solid step (fig. 23) in preventing erosion of the stream bed. The results of these tests (fig. 23 and plate 11) showed that the symmetrical sill was very effective in preventing erosion of the river bed, and that neither the dentated step nor the solid step aided in scour prevention downstream from the apron. The tops of the brass rods in the pictures indicate the original sand bed. The steps were effective in holding the jump in the pool at tailwater elevations much lower than normal. As the foregoing test indicated ample tailwater depth as well as more than sufficient pool length, the apron was raised and the pool shortened.

24. <u>Recommended design.</u> The pool floor was raised two feet from elevation 5725.0 to elevation 5727.0 and the structure was shortened 18 feet, from station 5+00.0 to 4+82.0. A tentative recommended design had a dentated step at station 4+25.0 and an unsymmetrical sill (fig. 23) placed with its downstream edge at station 4+81.25. The step was used to keep the jump within the pool at abnormally shallow tailwaters and the unsymmetrical sill was used because it simplified the expansion-joint spacing. Test 16 on this arrangement was comparable to the erosion tests on the original pool, and the scour downstream from the apron was not serious (fig. 23).

In the final recommended design, the dentated step was omitted because it was found that a 50-foot strip of riprap downstream from the apron was equally effective in keeping the jump in the pool at abnormally low tailwater elevations. The unsymmetrical sill was also replaced by the symmetrical sill because the erosion was more severe downstream from the ends of the former.

This design was satisfactory for all discharges (plate 12). No scour occurred when 50 feet of three-foot riprap was placed downstream from the sill. The tailwater could be dropped $4\frac{1}{2}$ feet below normal at a discharge of 10,000 second-feet without causing the jump to sweep off the apron (plate 12). Considerable splash was noted in the pool at the maximum design discharge. Small drops of water frequently attained a height of one foot (model) above the top of the stilling pool wall. Various

FIGURE 23



WATER SURFACE AND SAND BED PROFILES

SILLS

STEPS

36-D-521

NO SILL OR STEP

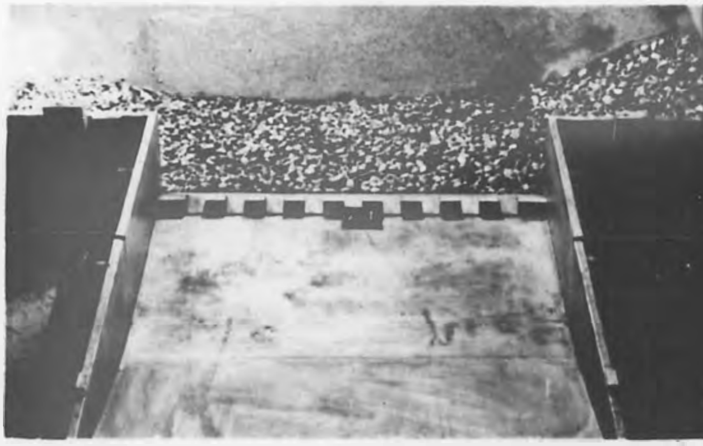
SYMMETRICAL SILL - SOLID STEP

SYMMETRICAL SILL - NO STEP

SYMMETRICAL SILL - TOOTHED STEP

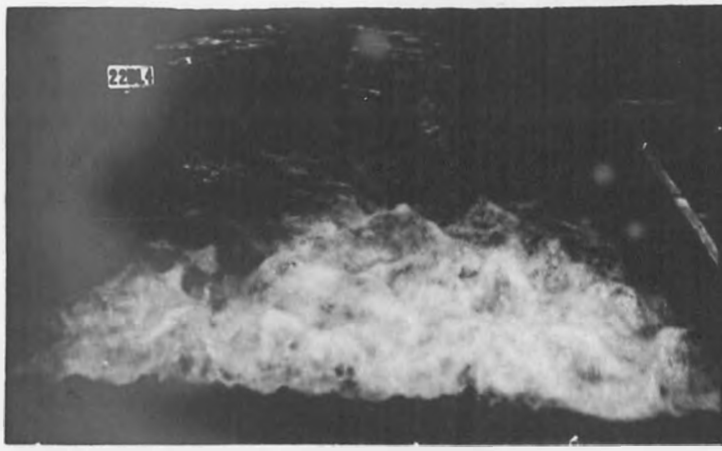
EROSION OF ORIGINAL POOL AFTER 1-HOUR RUN
DISCHARGE 10,000 SECOND-FEET.

PLATE 11



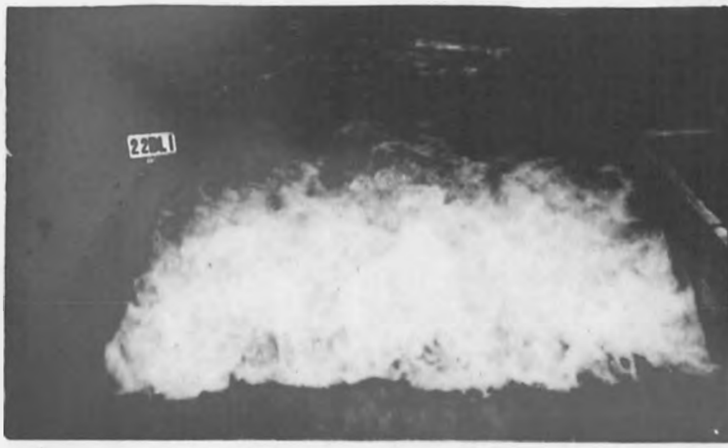
SET-UP

DISCHARGE 2500 SECOND-FEET



DISCHARGE 5000 SECOND-FEET

DISCHARGE 7500 SECOND-FEET



NORMAL TAILWATER

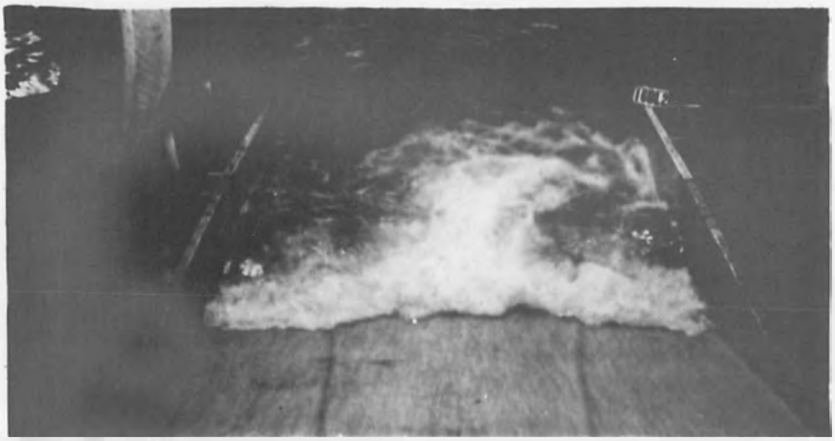
TAILWATER 4½ FEET BELOW NORMAL

DISCHARGE 10,000 SECOND-FEET

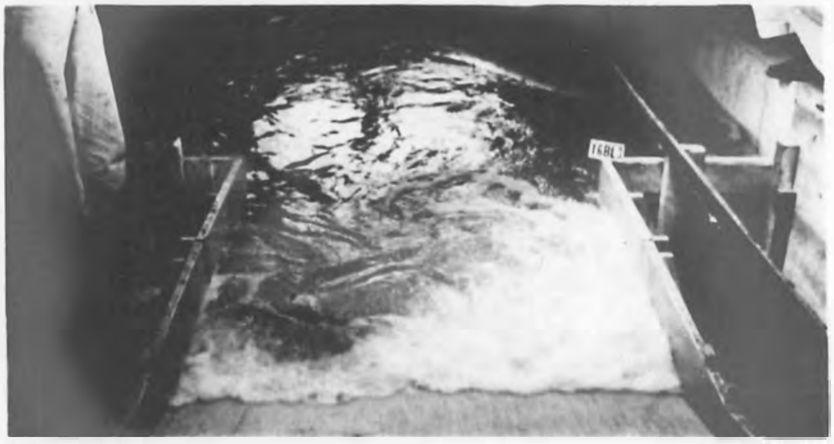
RECOMMENDED STILLING POOL

gate combinations failed to disclose any dangerous flow conditions in the pools, and only the worst conditions are shown on plate 13. Plate 14 shows the recommended design.

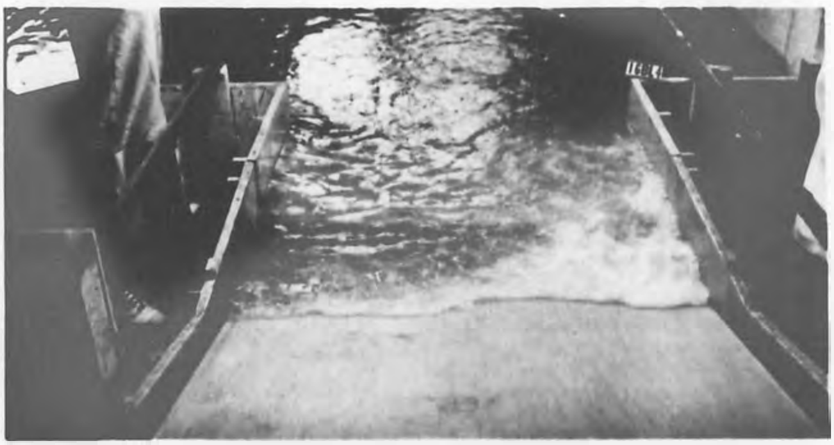
- - -



CENTER GATE CLOSED
DISCHARGE 7500 SECOND-FEET



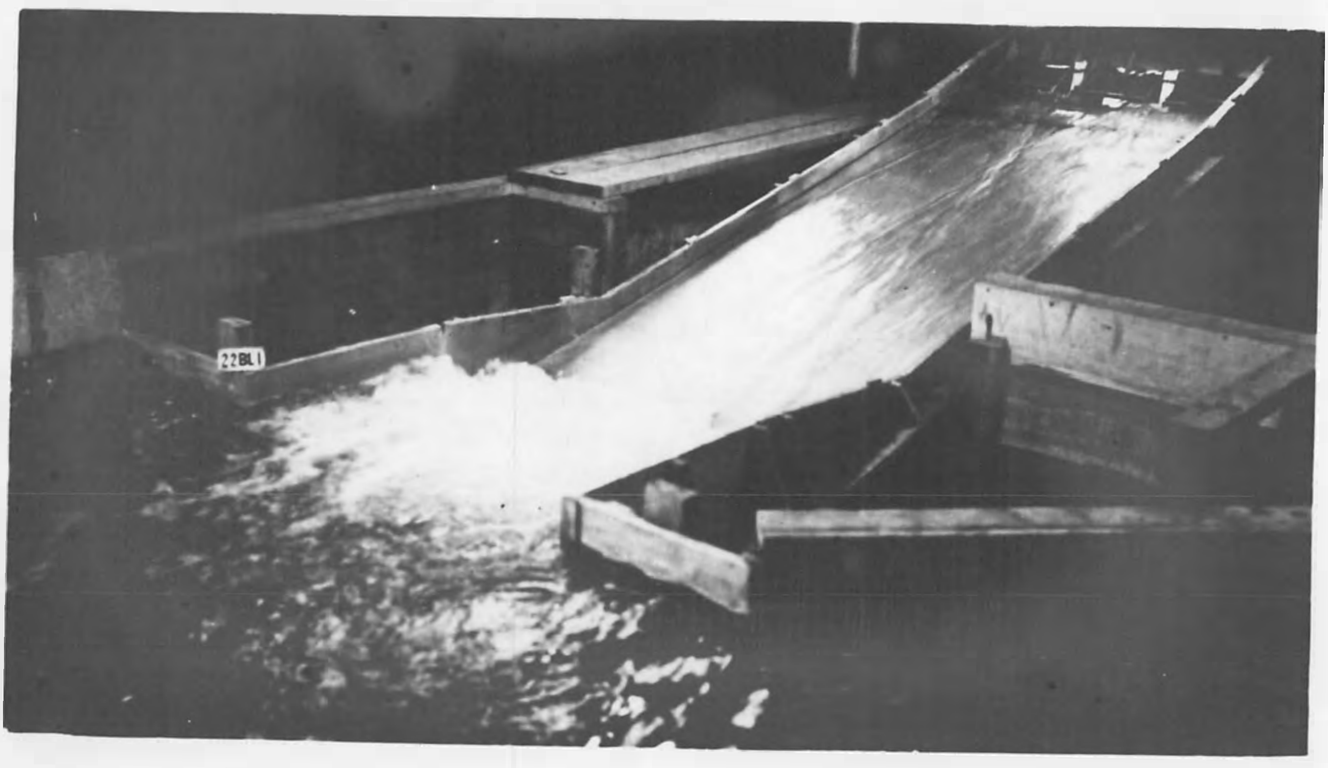
LEFT GATE CLOSED
DISCHARGE 5000 SECOND-FEET



LEFT GATE CLOSED
DISCHARGE 2500 SECOND-FEET

WORST CONDITIONS FOR UNEQUAL GATE OPERATION

NO FLOW



DISCHARGE 10,000 SECOND-FEET

RECOMMENDED SPILLWAY DESIGN