HYD 159

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 159

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HYDRAULIC MODEL STUDIES FOR THE GLORY-HOLE SPILLWAYS AT OWYHEE DAM - OWYHEE PROJECT, OREGON-IDAHO AND GIBSON DAM - SUN RIVER PROJECT, MONTANA

By

F. C. LOWE, ASSISTANT ENGINEER

- - -

Denver, Colorado,
Nov. 15, 1944

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SUBJECT: HYDRAULIC MODEL STUDIES FOR THE GLORY-HOLE SPILLWAYS
AT
OWYHEE DAM - OWYHEE PROJECT, OREGON-IDAHO

AND

GIBSON DAM - SUN RIVER PROJECT, MONTANA

- - - - -

By F. C. LOWE, ASSISTANT ENGINEER

- - - - -

Under Direction of

J. E. WARNOCK, SENIOR ENGINEER

and

R. F. BLANKS, SENIOR ENGINEER

- - - - -

Denver, Colorado,
Nov. 15, 1944

F O R E W O R D

Studies on the model of the glory-hole spillway for Owyhee Dam were made by the Bureau of Reclamation personnel under the direction of E. W. Lane, Hydraulic Research Engineer, in the hydraulic laboratory on the campus of the Colorado State College of Agriculture and Mechanic Arts, at Fort Collins, Colorado.

Model tests in connection with spillway alterations at Gibson Dam were made by T. G. Owen, Assistant Engineer, under the direction of J. E. Warnock, Senior Engineer, at the Bureau of Reclamation hydraulic laboratory, now abandoned, which was located in the basement of the Old Customhouse at 16th and Arapahoe Streets, in Denver, Colorado.

CONTENTS

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
November 15, 1944

Laboratory Report No. 159
Hydraulic Laboratory
Compiled by: F. C. Lowe
Reviewed by: J. E. Warnock and
J. N. Bradley

Subject: Hydraulic model studies for the glory-hole spillways at Owyhee Dam - Owyhee project, Oregon-Idaho, and Gibson Dam - Sun River project, Montana.

1. Introduction. A series of tests on a model of the glory-hole spillway at Owyhee Dam were made in 1930-31. In 1936, model studies were made in connection with alterations to the glory-hole spillway at Gibson Dam. As no formal reports on these studies have been prepared, the purpose of this memorandum is to describe these studies and the results obtained, and to present a review and bibliography of available literature upon the subject.

OWYHEE DAM

2. The floating-ring gate and glory-hole spillway at Owyhee Dam. The Owyhee Dam (figure 1) is located in the Owyhee River 21 miles southwest of Nyssa, Oregon. The spillway is a vertical shaft, 309 feet deep, connecting with the former diversion tunnel at a point 240 feet downstream from the tunnel inlet (figure 2). This vertical shaft is bell-mouthed, or trumpet-shaped, at the entrance, having a circular crest 60 feet in diameter at elev. 2658.0 flaring inward, to a diameter of 30.75 feet at elev. 2633.0 and to a diameter of 22.6 feet below elev. 2513.0. To control the flow into this shaft a 60-foot diameter ring gate, 12 feet high, was installed in the crest. The ring gate is a hollow annular drum, seated within an hydraulic chamber located in the crest. The ring gate is thus a floating type of crest similar in operation to a drum gate, such as is used at Shasta Dam, but designed for flow into a vertical, circular, spillway shaft.

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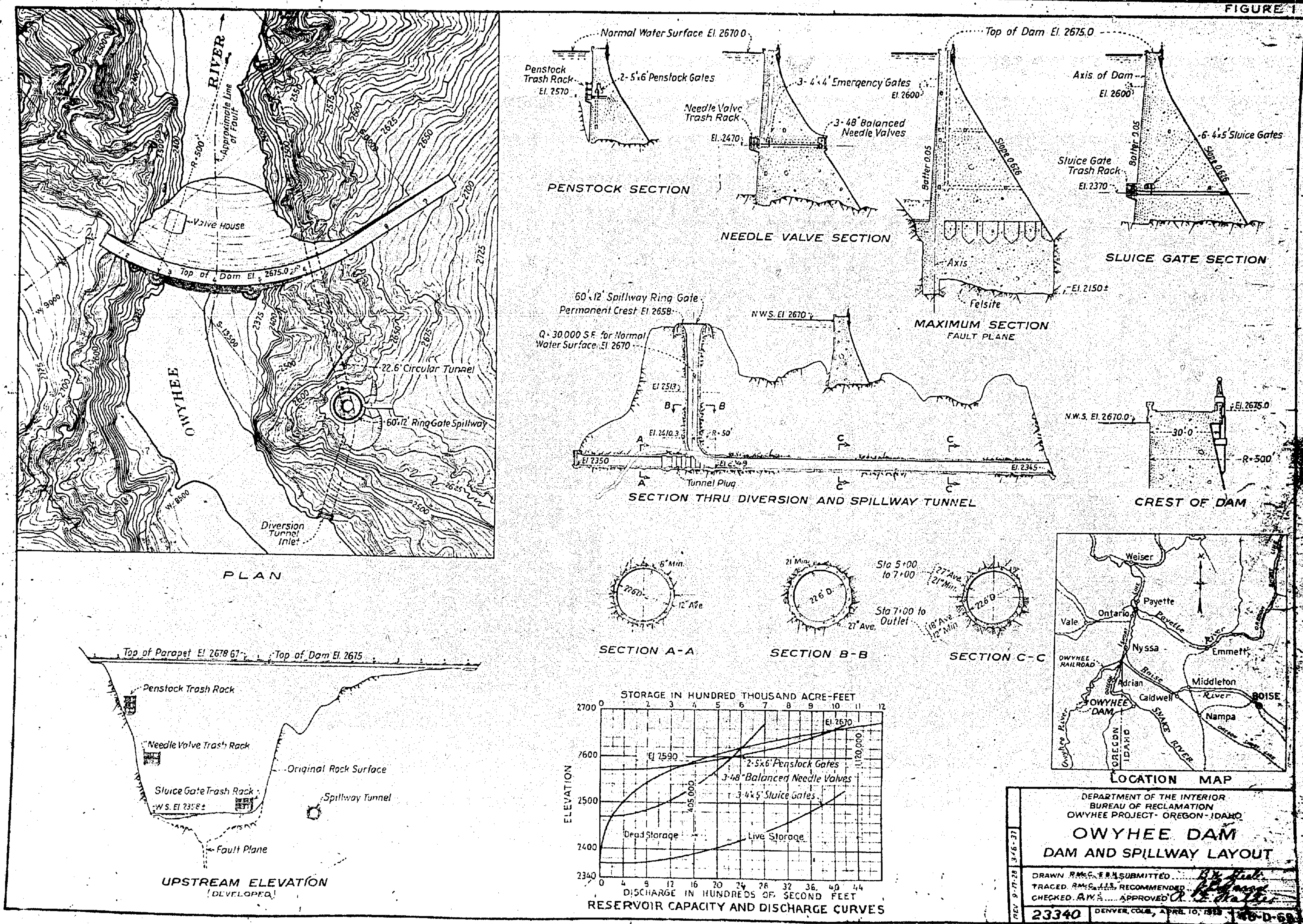


FIGURE 1
PLAN
RIVER
OWYHEE
Approximate Line of Fault
R=500'
Valve House
Top of Dam El. 2675.0
22.6' Circular Tunnel
60'x12' Ring Gate Spillway
Diversion Tunnel Inlet
Normal Water Surface El. 2670.0
Penstock Trash Rack
El. 2570
2-5'x6' Penstock Gates
PENSTOCK SECTION
3-4'x4' Emergency Gates
El. 2600
Needle Valve Trash Rack
El. 2470
3-48" Balanced Needle Valves
NEEDLE VALVE SECTION
Top of Dam El. 2675.0
Batter 0.05
Slope 0.626
Axis
Felsite
El. 2150±
MAXIMUM SECTION
FAULT PLANE
Axis of Dam
El. 2600
6-4'x5' Sluice Gates
Sluice Gate Trash Rack
El. 2370
SLUICE GATE SECTION
60'x12' Spillway Ring Gate
Permanent Crest El. 2658
Q=30,000 S.F. for Normal Water Surface El. 2670
N.W.S. El. 2670
El. 2513
El. 2410.3
R=50'
El. 2350
El. 2345
Tunnel Plug
SECTION THRU DIVERSION AND SPILLWAY TUNNEL
N.W.S. El. 2670.0
El. 2675.0
30'-0"
R=500'
CREST OF DAM
SECTION A-A
SECTION B-B
Sta 5+00 to 7+00
Sta 7+00 to Outlet
SECTION C-C
Top of Parapet El. 2678.67
Top of Dam El. 2675
Penstock Trash Rack
Needle Valve Trash Rack
Original Rock Surface
Sluice Gate Trash Rack
W.S. El. 2358±
Spillway Tunnel
Fault Plane
UPSTREAM ELEVATION
(DEVELOPED)
STORAGE IN HUNDRED THOUSAND ACRE-FEET
ELEVATION
El. 2670
El. 2590
2-5x6' Penstock Gates
3-48" Balanced Needle Valves
3-4x5' Sluice Gates
Dead Storage
Live Storage
405,000
1,120,000
DISCHARGE IN HUNDREDS OF SECOND FEET
RESERVOIR CAPACITY AND DISCHARGE CURVES
Weiser
Payette
Ontario
Vale
Payette River
Nyssa
Emmett
OWYHEE RAILROAD
Adrian
Caldwell
Middleton
Boise River
BOISE
OWYHEE DAM
Nampa
SNAKE RIVER
OREGON
IDAHO
Owyhee River
LOCATION MAP
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OWYHEE PROJECT - OREGON - IDAHO
OWYHEE DAM
DAM AND SPILLWAY LAYOUT
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
23340
DENVER, COLO.
148-D-69

HYD-154

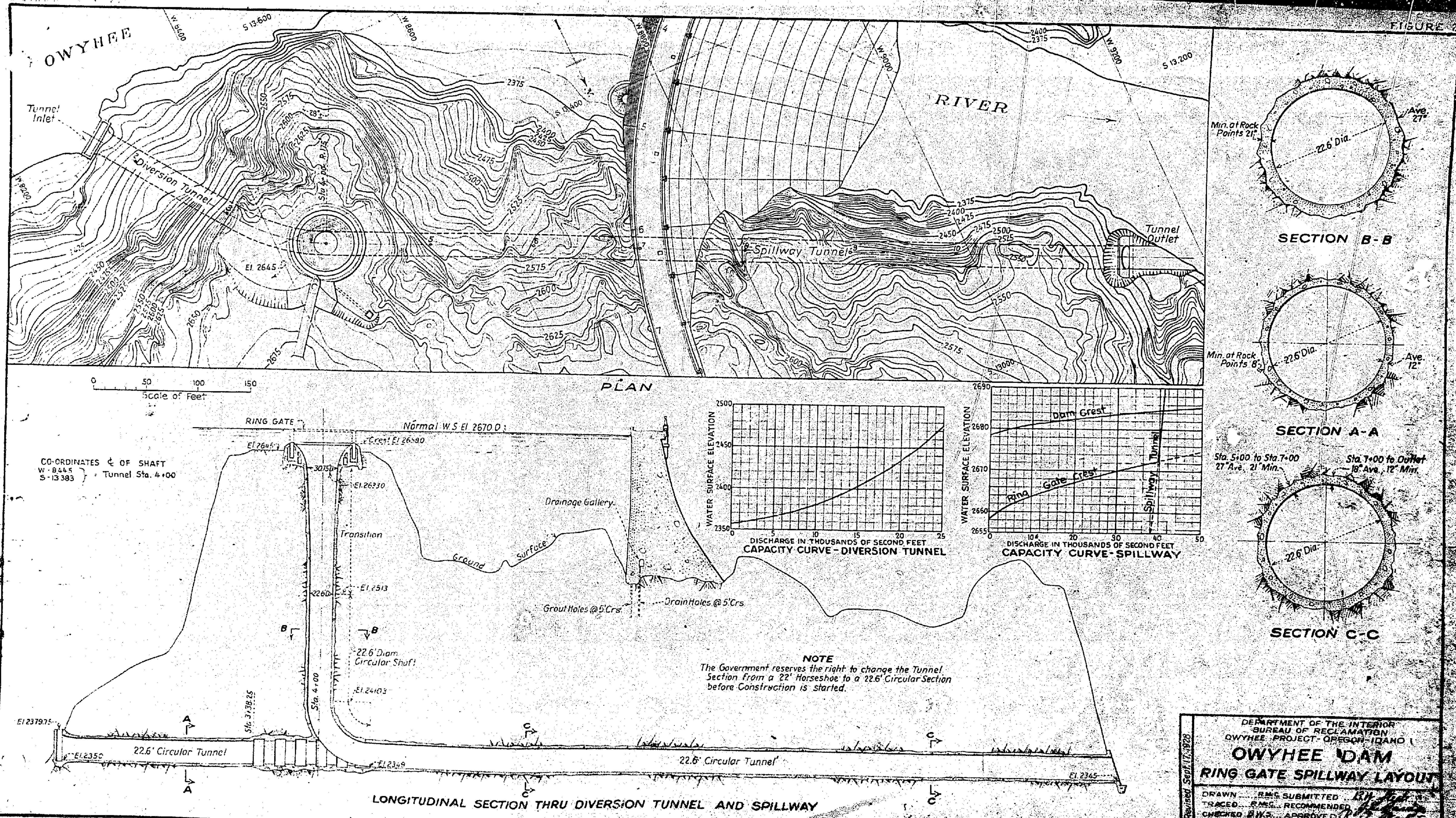
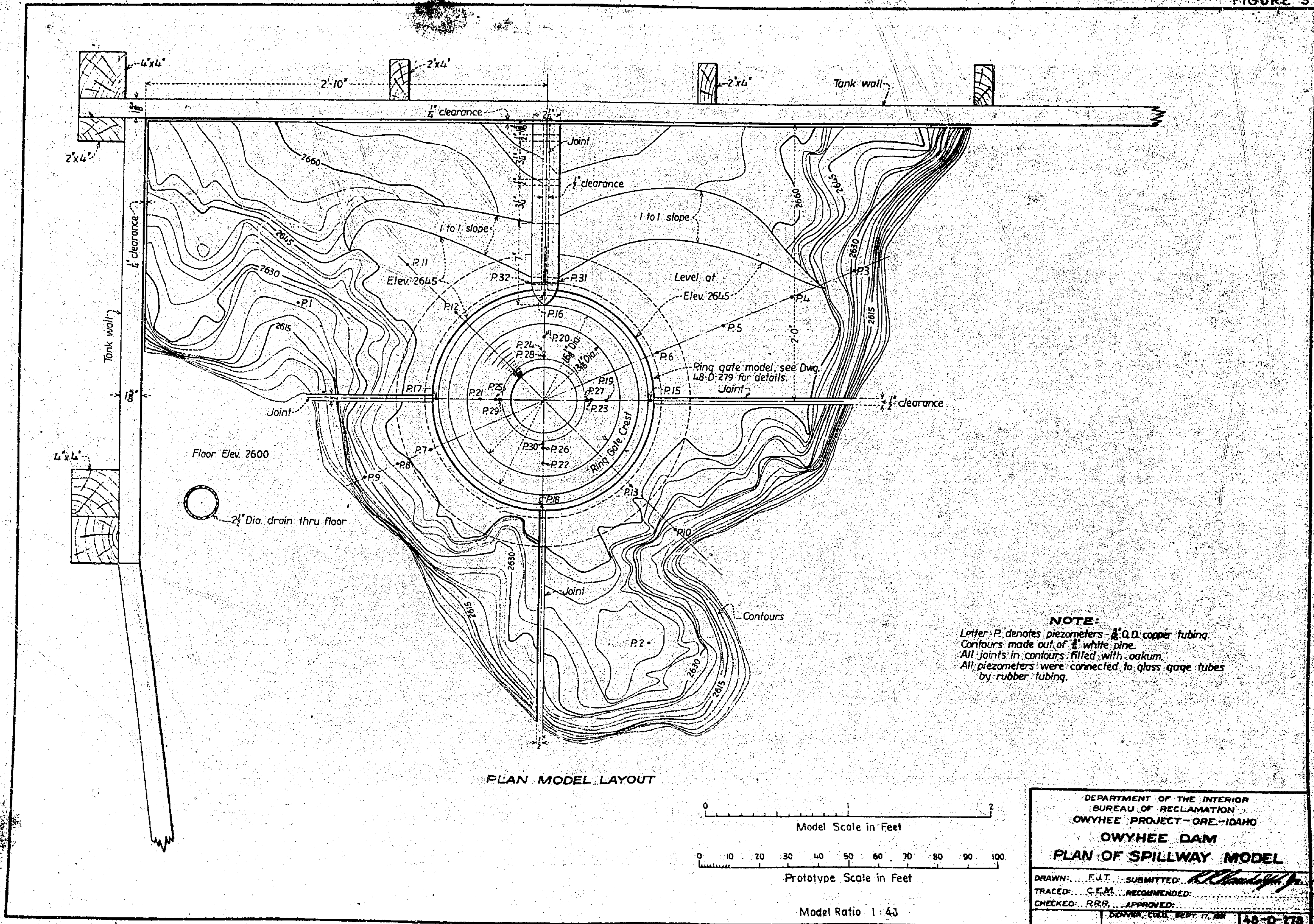


FIGURE 2
OWYHEE
RIVER
Tunnel Inlet
Diversion Tunnel
Spillway Tunnel
Tunnel Outlet
El. 2645
PLAN
0 50 100 150
Scale of Feet
SECTION B-B
Min. at Rock Points 21"
Ave. 27"
22.6' Dia.
SECTION A-A
Min. at Rock Points 8"
Ave. 12"
22.6' Dia.
Sta. 5+00 to Sta. 7+00
27" Ave., 21" Min.
Sta. 7+00 to Outlet
18" Ave., 12" Min.
SECTION C-C
22.6' Dia.
WATER SURFACE ELEVATION
DISCHARGE IN THOUSANDS OF SECOND FEET
CAPACITY CURVE - DIVERSION TUNNEL
WATER SURFACE ELEVATION
Dam Crest
Ring Gate Crest
Spillway Tunnel
DISCHARGE IN THOUSANDS OF SECOND FEET
CAPACITY CURVE - SPILLWAY
RING GATE
Normal W.S. El. 2670.0
El. 2645
Crest El. 2658.0
CO-ORDINATES ℄ OF SHAFT
W - 8445
S - 13383
= Tunnel Sta. 4+00
El. 2623.0
Transition
Drainage Gallery
Ground Surface
El. 2513
Grout Holes @ 5' Crs.
Drain Holes @ 5' Crs.
22.6' Diam. Circular Shaft
Sta. 4+00
El. 2410.3
El. 2379.75
El. 2350
Sta. 3+38.25
22.6' Circular Tunnel
El. 2349
22.6' Circular Tunnel
El. 2345
NOTE
The Government reserves the right to change the Tunnel Section from a 22' Horseshoe to a 22.6' Circular Section before Construction is started.
LONGITUDINAL SECTION THRU DIVERSION TUNNEL AND SPILLWAY
Revised Sept. 17, 1928
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OWYHEE PROJECT - OREGON - IDAHO
OWYHEE DAM
RING GATE SPILLWAY LAYOUT
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
23355
DENVER, COLO.

In 1928, when designs for the Owyhee Dam were under way, there were few installations of vertical shaft or glory-hole spillways, and, aside from studies by Ford Kurtz in connection with the design of the shaft spillway at Davis Bridge Dam, there was little information available which would assist in the design of the Owyhee Dam spillway. The ring gate had no precedent whatsoever. Therefore, hydraulic model studies were made in connection with the design of the glory-hole spillway at Owyhee Dam to check pressures, discharges, and to ascertain, in so far as possible, that no adverse events would occur in the operation of the prototype.

3. The Owyhee Dam spillway model. A 1:48 scale model was built which included the topography surrounding the spillway, the spillway and ring-gate control, and the discharge tunnel below the spillway (figures 3, 4, and 5). The topography was made from 3/4-inch layers of treated lumber, as shown on figure 4. The spillway inlet between elevations 2600 and 2658 was made of laminated wood - 3/4-inch segments of white pine cut radially, treated with clear lacquer, and assembled so that the segmental joints overlapped alternately. After assembly the inlet was machined to size, with a slot at the crest to accommodate the ring gate. The ring gate consisted of a crest of cast type metal and a galvanized-iron cylinder or ring attached to the crest at the outer circumference of the gate proper. Two crest designs were studied. The original design of the crest was symmetrical, with overhanging lips at both the upstream and the downstream edges. In the final design the lip at the upstream edge was removed so that the crest was flush with the outer circumference of the cylinder. This gate, which fits snugly in the slot on the crest of the spillway inlet, was operated manually. Three push rods, equally spaced, were fastened to the bottom of the cylinders and protruded below the floor of the model. The gate was positioned from below by raising or lowering these push rods and fastening them in place with adjusting screws. Forty-eight 1/16-inch holes equally spaced around the circumference of the lower crest served as air vents to aerate the crest

FIGURE 3



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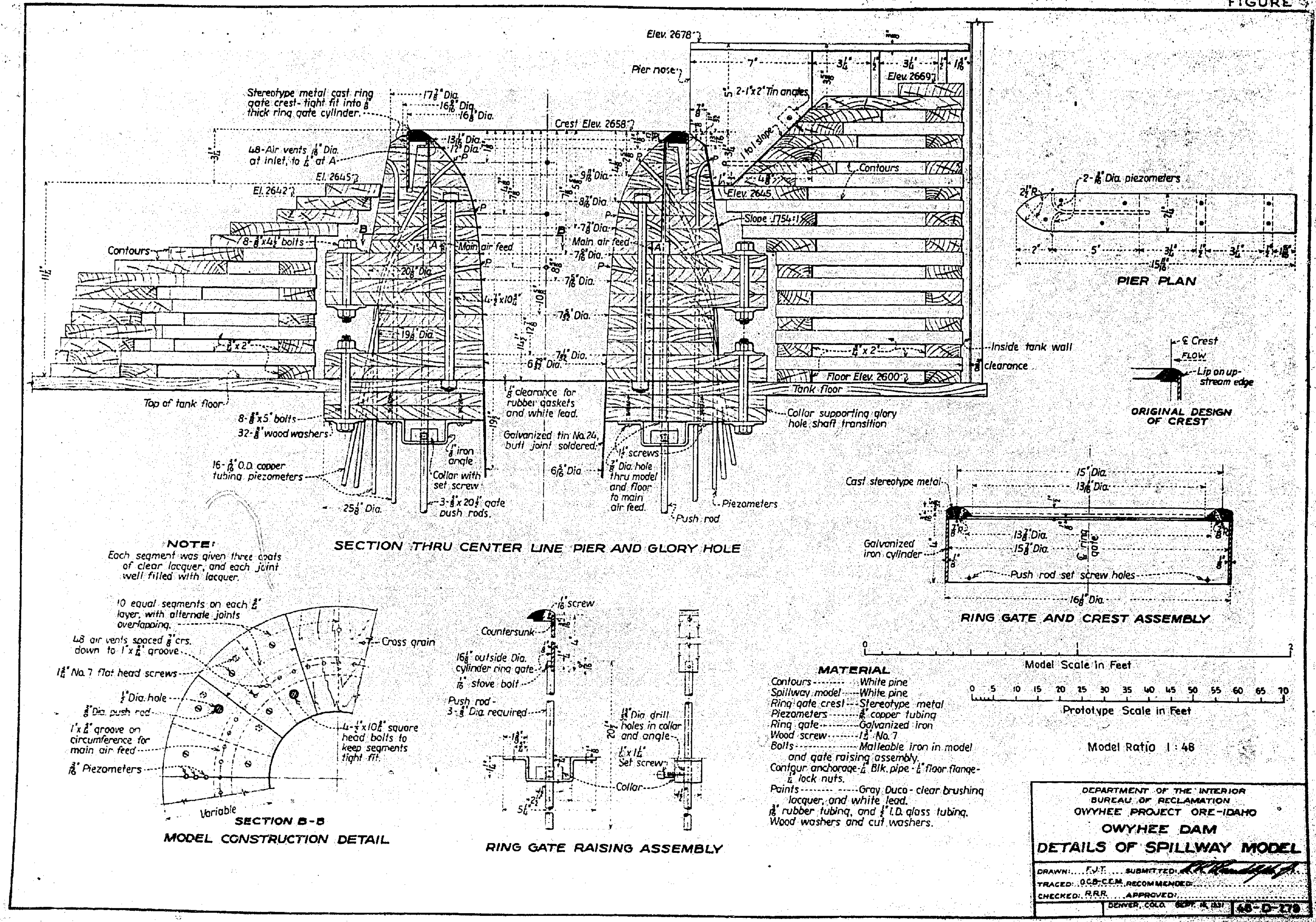
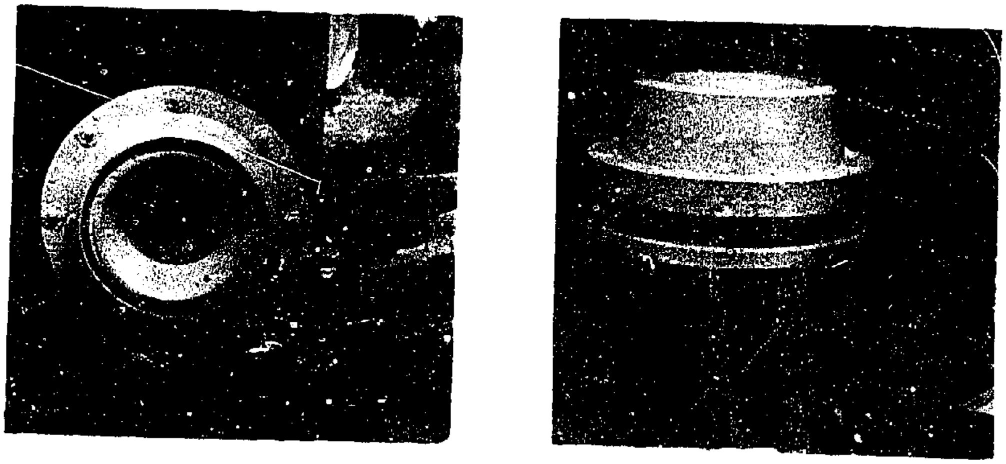
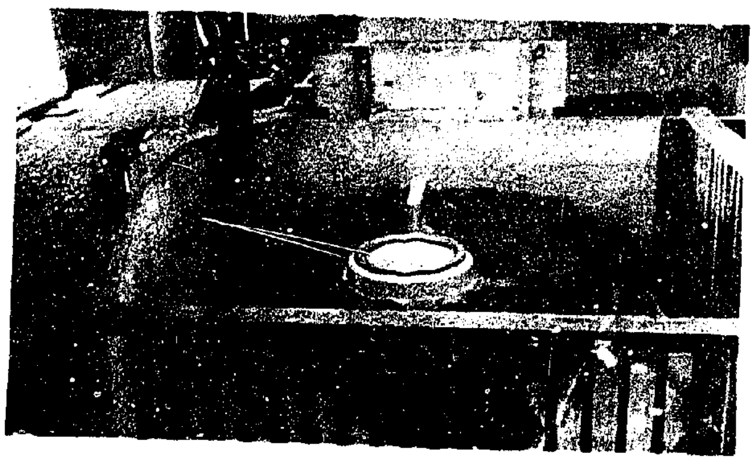


FIGURE
SECTION THRU CENTER LINE PIER AND GLORY HOLE
Stereotype metal cast ring gate crest- tight fit into 1/8" thick ring gate cylinder.
48-Air vents 1/16" Dia. at inlet, to 1/4" at A
El. 2645
El. 2642
Contours
8-3/8"x4 1/2" bolts
Top of tank floor
8-3/8"x5" bolts
32-3/8" wood washers
16-1/8" O.D. copper tubing piezometers
25 5/8" Dia.
Collar with set screw
3-3/8"x20 1/2" gate push rods.
1/8" iron angle
Main air feed
Crest Elev. 2658
1/8" clearance for rubber gaskets and white lead.
Galvanized tin No. 24, butt joint soldered.
1/4" screws
3/8" Dia. hole thru model and floor to main air feed.
Push rod
Piezometers
Elev. 2678
Pier nose
2-1"x2" Tin angles
Elev. 2669
1 to 1 slope
Elev. 2645
Slope .1754:1
Inside tank wall
1/8" clearance
Floor Elev. 2600
Tank floor
Collar supporting glory hole shaft transition
2-1/8" Dia. piezometers
PIER PLAN
℄ Crest
FLOW
Lip on upstream edge
ORIGINAL DESIGN OF CREST
Cast stereotype metal
15" Dia.
13 7/8" Dia.
Galvanized iron cylinder
Push rod set screw holes
16 5/8" Dia.
RING GATE AND CREST ASSEMBLY
NOTE:
Each segment was given three coats of clear lacquer, and each joint well filled with lacquer.
10 equal segments on each 3/4" layer, with alternate joints overlapping.
48 air vents spaced 3/8" crs. down to 1"x1/4" groove.
1 1/4" No. 7 flat head screws
1/2" Dia. hole
3/8" Dia. push rod
1"x1/4" groove on circumference for main air feed
1/8" Piezometers
Cross grain
4-1/2"x10 1/4" square head bolts to keep segments tight fit.
Variable
SECTION B-B
MODEL CONSTRUCTION DETAIL
1/16" screw
Countersunk
16 5/8" outside Dia. cylinder ring gate
1/8" stove bolt
Push rod - 3-3/8" Dia. required
13/32" Dia. drill holes in collar and angle
1/4"x1 1/2" Set screw
Collar
RING GATE RAISING ASSEMBLY
MATERIAL
Contours ---- White pine
Spillway model ---- White pine
Ring gate crest ---- Stereotype metal
Piezometers ---- 1/8" copper tubing
Ring gate ---- Galvanized iron
Wood screw ---- 1 1/4" No. 7
Bolts ---- Malleable iron in model and gate raising assembly.
Contour anchorage - 1/4" Blk. pipe - 1/4" floor flange - 1/4" lock nuts.
Paints ---- Gray Duco - clear brushing lacquer, and white lead.
1/8" rubber tubing, and 1/4" I.D. glass tubing.
Wood washers and cut washers.
Model Scale in Feet
Prototype Scale in Feet
Model Ratio 1 : 48
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OWYHEE PROJECT ORE-IDAHO
OWYHEE DAM
DETAILS OF SPILLWAY MODEL
DRAWN: F.J.T. SUBMITTED:
TRACED: O.C.B.-C.E.M. RECOMMENDED:
CHECKED: R.R.R. APPROVED:
DENVER, COLO.
48-D-278

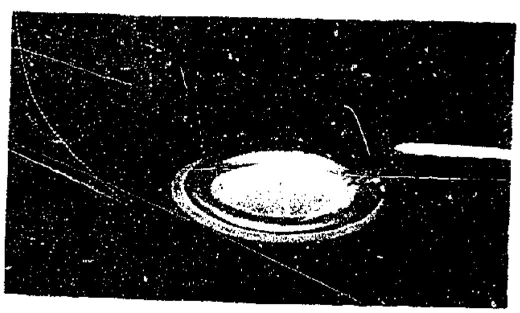
Figure 5



A. SPILLWAY CREST WITHOUT RING GATE



B. MODEL COMPLETE WITH TOPOGRAPHY,
PIER AND RING GATE IN PLACE.



C. GATE AT ELEV. 2658.0
POND ELEV. 2670.0
DISCHARGE = 31,100 C.F.S.

D. GATE AT ELEV. 2667.0
POND ELEV. 2679.0
DISCHARGE = 32,500 C.F.S.

THE 1:48 HYDRAULIC MODEL OF
THE OWYHEE DAM SPILLWAY

when the gate was raised. The vertical shaft of the spillway below the inlet section was made of 24-gage galvanized iron, formed as the frustrum of a cone for the transition section and as a cylinder for the circular shaft. The tunnel proper and the 90-degree elbow connecting the shaft to the tunnel were made of transparent pyralin tubing.

To measure pressures in the model, 14 piezometers were placed in the topography at various points. Four piezometers were also placed on the outside walls of the spillway and twelve inside the spillway - four at elev. 2650.5, four at elev. 2638.5, and four at elev. 2626.5 (figures 3 and 4). Two piezometers were located on the pier at elev. 2658.0, the normal crest elevation with the ring gate seated. Pressure measurements were made on a manometer board, and the head or water surface was measured with a hook gage. Discharge was measured over a calibrated weir which was part of the permanent equipment of the Fort Collins laboratory.

4. Summary of tests on Owyhee spillway. Thirteen tests were made on the model. In tests 1 to 6, inclusive, the original design was studied. In test 7 the upstream lip of the crest and the access pier were removed. Tests 8 to 12, inclusive, were studies of the final design; and test 13 was made by removing all topography to study the flow into the entrance with a perfectly symmetrical approach. The procedure for each test was similar. The gate was set at a definite elevation, and four or five runs were then made by varying the head and the discharge. Tests 8, 9, and 10 were run twice, once with the air vents closed and once with them open. In each test one run was made at maximum capacity when the inlet was submerged, that is, with the vertical shaft flowing full of water. The other runs were made with the spillway in normal operation - the water falling over the circular weir into the shaft without filling the shaft. In each run the discharge, the water surface elevations, and the piezometric pressures were measured; the flow into the outlet was studied, and photographs were taken.

An analysis of the results included the conversion of pressure and discharge measurements to prototype by the laws of hydraulic similitude and computation of coefficients of discharge. From pressure measurements it was possible to ascertain whether severe vacuums or other unreasonable pressure conditions would occur. The coefficient of discharge C was obtained from the expression

$$Q = CL (H)^{3/2}$$

where

Q = discharge in second-feet,

H = head over the spillway crest, in feet, and

L = the circumference of the crest.

It is well to emphasize that the coefficient of discharge is not an index of the capacity of the spillway but only the rating for the circular weir at the crest. Moreover, caution should be used when comparing the coefficient of one spillway with that of another because the values of H and L may not be based on the crest but on some other point; so it could be possible that two spillways would have different coefficients but exactly the same discharge capacity. Coefficients for the Owyhee spillway, as originally computed, were based on a head H measured above the crest but upon the length L equal to the outside circumference of the ring-gate crest section, which was 208.1 feet, prototype, in tests 1 to 6, inclusive, and 203 feet in tests 8 to 12, inclusive. This would make the coefficients in the final design appear slightly larger than those in the original design. To avoid such confusion and to have a better basis for comparison with other studies, the coefficient of discharge in this memorandum is based on values of H and L referred to the 60-foot diameter crest (188.5 feet). These coefficients will be slightly larger than the values originally computed.

5. Summary of results on Owyhee spillway. The results of the model studies of the spillway are given in table 1. Rating and discharge-coefficient curves for the final design are shown in figure 6, and photographs of the model in action are shown in figure 5.

In table 1 the pressure data has been condensed by eliminating piezometers 1 to 18, inclusive, and 31 and 32. These piezometers are located upstream from the control at the crest, in regions of low velocity; consequently, in every instance pressures were equal or nearly equal to the head above the crest. Originally they were located to determine different velocities of approach due to the configuration of the topography, but the resulting difference in head was too small to measure accurately. Pressures in the spillway inlet, piezometers 19 to 30, inclusive, were generally slightly negative; but no negative pressures were recorded which would indicate the presence of cavitation in the prototype. In general, pressures for the original and the final designs were the same, indicating that there was little basic difference in the two designs.

The final crest design, tests 8 to 12, inclusive, was made by removing the lip at the upstream edge of the crest of the original design, tests 1 to 6, inclusive, and by opening the air vents under the lower nappe of the overfall. The removal of the lip at the upstream edge of the crest was to simplify construction in the prototype.

A comparison of pressures for tests 1 to 6, inclusive, with those for tests 8, 9, and 10 indicated that removal of the lip had no appreciable effect upon the performance of the spillway. A comparison of tests 8, 9, and 10 with tests 8A, 9A, and 10A revealed that the action of the air vents had little effect upon the spillway performance. In the model the sheet of water flowing over the spillway was usually not symmetrical, with fins and troughs near the pier; so it was possible to provide aeration to the lower nappe of the overfall without vents. Such a condition may not occur in the prototype. There the flow would be much smoother, and with a jet several feet thick it would be difficult to provide aeration without vents. In test 6, run 2, such a condition actually occurred; the under nappe failed to aerate, producing undesirable flow conditions. Therefore, air vents were included in the final design.

As may be seen by the rating curves (figure 6), the flow over the spillway increased with head until a discharge of about 40,000 second-feet was reached under a 14-foot head. The vertical shaft of the spillway then

TABLE 1

SUMMARY OF MODEL TESTS ON OWYHEE DAM SPILLWAY

DATA IN PROTOTYPE

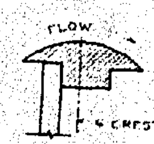
Test No.	Run No.	Gate crest elev.	Head above crest H-ft.	Flow Q sec.-ft.	Discharge coefficient C(1)	Pressures in spillway entrance: Piezometers at El. 2650.5: 19	20	21	22	Piezometers at El. 2644.5: 23	24	25	26	Piezometers at El. 2620.5: 27	28	29	30
1 Gate seated	1	2650.0	5.82	10,200	3.83	- 0.4	- 0.1	- 0.6	- 0.5	- 2.3	- 1.7	- 2.1	- 2.3	+ 0.9	+ 1.0	+ 1.3	+ 0.6
	2		9.18	21,000	3.99	- 1.7	- 0.1	- 1.8	- 1.9	- 5.4	- 3.7	- 5.0	- 5.6	+ 0.8	+ 2.6	+ 1.0	+ 0.8
	3		11.72	30,500	4.03	- 3.2	+ 0.8	- 2.6	- 3.5	- 7.2	- 2.8	- 5.5	- 1.7	+ 1.0	+ 5.9	+ 1.8	+ 7.6
	4		15.35	40,100	3.94	+ 1.8	+ 6.9	+ 2.7	+ 3.7	-12.5	- 7.8	-10.8	- 8.4	- 0.5	+ 5.0	- 8.1	- 4.7
	5A		20.10	41,500	2.44	+11.2	+14.4	+11.7	+ 9.4	- 6.3	- 3.3	- 4.5	- 6.4	- 2.4	- 1.1	- 1.8	- 2.3
2 Gate raised 2 feet	1	2652.0	5.81	10,000	3.77	+ 1.5	+ 1.3	+ 1.1	+ 1.4	- 2.5	- 2.1	- 2.0	- 2.2	- 1.0	+ 1.6	+ 1.3	+ 1.3
	2		8.78	20,000	4.10	+ 1.5	+ 1.9	+ 1.2	+ 1.4	- 5.4	- 4.5	- 4.8	- 5.1	+ 6.5	+ 2.7	+ 0.8	+ 0.8
	3		11.59	30,000	4.15	+ 0.8	+ 3.2	+ 0.9	- 0.1	- 7.9	- 4.5	- 7.0	- 7.3	- 0.3	+ 5.4	+ 0.6	+ 5.7
	4		15.36	40,100	3.82	+ 4.8	+10.6	+ 4.6	- 4.7	-10.4	- 7.9	- 8.8	- 4.6	- 8.1	- 4.0	- 7.6	- 4.3
	5		17.65	41,500	3.00	+12.2	+14.5	+12.5	+ 9.9	- 6.8	- 3.9	- 4.9	- 6.3	- 2.8	- 1.6	- 1.9	- 2.4
3 Gate raised 4 feet	1	2654.0	[illegible]	10,300	4.52	+ 2.3	+ 5.8	+ 2.5	+ 2.1	- 2.7	- 2.1	- 2.2	- 2.4	+ 0.8	+ 1.7	+ 1.4	+ 1.0
	2		8.31	20,100	4.31	+ 3.9	+ 4.9	+ 4.6	+ 3.4	- 5.4	- 4.6	- 4.6	- 5.3	+ 0.2	+ 2.4	+ 0.9	+ 0.5
	3		11.00	27,900	4.30	- 0.1	+ 8.0	+ 2.1	- 2.5	- 7.2	- 4.8	- 6.5	- 6.0	- 0.7	+ 2.5	+ 0.3	+ 2.9
	4		14.39	40,100	[illegible]	+ 5.1	+13.3	+ 6.5	+10.4	-10.3	- 6.5	- 8.4	- 5.6	- 8.6	- 5.7	- 0.7	- 3.3
4 Gate raised 6 feet	1	2656.0	5.31	10,200	4.42	+ 5.3	+ 6.2	+ 5.5	+ 5.2	- 2.6	- 2.1	- 1.9	- 2.2	+ 0.9	+ 1.9	+ 1.5	+ 0.8
	2		8.21	17,900	4.37	+ 5.8	+ 9.5	+ 6.9	+ 5.2	- 5.3	- 4.9	- 4.7	- 5.2	- 0.5	+ 2.2	+ 1.0	+ 0.3
	3		8.16	17,000	4.42	- 0.7	- 0.6	- 0.9	- 0.9	- 1.9	- 4.3	- 1.7	- 1.2	- 1.0	- 2.3	- 0.5	- 0.7
	4		10.92	29,000	4.36	+ 0.5	- 0.4	- 0.7	- 3.2	- 6.6	- 5.3	- 6.1	- 6.7	- 0.1	+ 3.0	+ 0.5	+ 0.6
	5		13.11	39,100	4.38	+ 1.9	+14.0	+ 5.5	+12.7	- 9.4	- 6.1	- 7.6	- 4.2	- 0.2	- 2.3	- 4.7	- 2.2
5 Gate raised 8 feet	1	2658.0	5.25	10,200	4.50	- 0.2	- 0.2	- 0.2	- 0.2	- 2.6	- 2.1	- 1.8	- 2.3	+ 0.7	+ 2.3	+ 1.5	+ 0.6
	2		5.65	10,400	4.11	- 0.5	- 0.2	- 0.6	- 1.0	- 3.8	- 3.1	- 2.7	- 3.1	- 0.4	+ 0.4	- 0.5	- 0.2
	3		8.65	20,900	4.1[illegible]	- 3.1	- 1.9	- 2.5	- 2.6	- 4.0	- 4.6	- 1.7	- 2.3	- 1.8	+ 2.8	+ 0.3	- 2.2
	4		11.15	30,000	4.28	- 3.0	- 2.7	- 2.8	- 2.6	- 4.1	- 3.7	- 2.7	- 2.4	- 2.6	- 2.6	- 2.4	- 2.8
6 Gate raised 10 feet	1	2660.0	5.70	10,400	4.05	+ 0.1	+ 0.1	+ 0.1	+ 0.1	- 0.1	- 0.1	- 0.1	- 0.1	- 0.2	- 0.4	+ 0.1	- 0.1
	2		8.63	20,000	4.15	+ 1.5	-	+ 0.7	+ 0.2	- 4.6	- 5.3	- 4.7	- 4.2	+ 0.2	+ 2.3	+ 0.9	+ 0.1
	3		8.60	20,100	4.20	- 0.7	- 1.1	- 1.0	- 1.1	- 1.2	- 1.4	- 1.1	- 1.0	- 1.4	- 2.6	- 1.5	- 1.1
	4		7.32	15,100	4.05	- 0.6	- 0.2	+ 0.0	- 0.1	- 0.4	- 0.6	- 0.2	- 0.3	- 0.8	+ 0.1	- 0.7	- 0.3
7 Gate seated	1	2650.0	3.15	4,200	3.77	- 0.1	- 0.5	- 0.1	- 0.4	- 0.9	- 1.2	- 1.1	- 0.8	- 0.1	- 0.1	- 0.1	0
	2		6.11	11,700	4.0[illegible]	+ 0.4	- 0.3	- 0.4	- 0.1	- 2.7	- 3.0	- 2.9	- 2.9	- 0.1	+ 1.0	- 0.4	- 1.0
	3		9.00	20,600	4.07	- 0.7	- 0.6	- 1.1	- 1.7	- 5.3	- 4.4	- 5.4	- 5.5	- 0.5	+ 1.8	- 1.0	- 0.6
	4		11.55	31,700	4.12	- 0.8	+ 0.5	- 2.2	- 2.6	- 7.8	- 4.8	- 6.6	- 4.2	- 0.6	+ 2.8	- 0.5	+ 6.6
	5		17.58	41,[illegible]00	2.95	+ 7.4	+14.2	+10.2	+ 8.1	- 4.6	- 2.8	- 3.9	- 4.7	- 2.5	- 0.3	- 0.3	- 0.2
8 Gate seated	1	2658.0	2.87	3,000	3.71	- 0.1	- 0.5	- 0.1	- 0.5	- 0.9	- 1.3	- 1.0	- 0.7	- 0.3	- 0.3	- 0.3	- 0.1
	2		6.01	11,000	3.95	+ 0.7	- 0.2	- 0.2	- 0.3	- 2.4	- 2.2	- 2.5	- 2.5	- 0.5	+ 1.0	- 0.5	- 0.2
	3		8.97	20,200	3.96	- 0.7	- 0.1	- 1.6	- 1.7	- 4.7	- 4.0	- 5.0	- 5.3	- 0.4	+ 1.5	- 1.0	- 0.7
	4		12.02	32,300	4.11	- 6.4	+ 1.6	- 2.0	- 3.3	- 7.1	- 3.3	- 6.9	- 4.2	- 0.4	+ 3.8	- 0.3	+ 4.4
	5		15.97	41,100	3.44	+ 7.4	+11.2	+ 7.5	+ 6.8	- 6.0	- 3.4	- 5.0	- 4.4	- 4.0	- 1.0	- 4.7	- 2.5
8A Gate seated	1	2658.0	2.67	3,000	3.92	- 0.4	- 0.5	- 2.9	- 0.1	- 2.1	- 0.7	- 0.6	- 0.5	- 0.9	+ 0.4	+ 0.7	- 1.3
	2		5.96	11,300	4.12	+ 0.3	- 0.1	- 2.9	- 0.1	- 2.7	- 2.1	- 2.0	- 1.9	- 1.0	+ 1.3	+ 1.4	- 1.5
	3		8.89	20,400	4.12	- 1.3	+ 1.0	- 0.6	- 1.3	- 5.0	- 3.8	- 4.2	- 4.8	- 1.1	+ 1.7	+ 0.6	- 1.6
	4		11.66	31,100	4.13	- 2.7	+ 0.6	- 2.4	- 3.0	- 7.5	- 3.7	- 6.1	- 4.7	- 1.5	+ 2.7	+ 1.0	- 1.3
	5		14.73	41,100	3.55	+ 3.1	+ 7.6	+ 3.1	+ 3.1	- 7.5	- 3.2	- 5.9	- 4.0	- 6.3	- 0.1	- 3.5	- 3.7
9 Gate raised 3 feet	1	2661.0	2.99	3,900	4.07	- 0.5	- 0.3	- 0.8	- 0.7	- 0.8	- 1.3	- 0.7	- 0.6	+ 0.2	+ 1.1	+ 0.1	- 0.3
	2		6.07	11,000	4.14	- 1.2	- 1.1	- 1.2	- 1.1	- 4.8	- 2.9	- 2.7	- 2.6	- 0.1	+ 1.1	- 0.5	- 0.5
	3		9.01	21,000	4.25	- 2.5	+10.3	- 2.1	- 2.6	- 5.0	- 5.0	- 0.4	- 4.6	- 0.6	+ 1.8	- 1.1	- 1.4
	4		11.90	32,[illegible]00	4.26	- 3.7	- 9.1	+ 1.6	- 4.1	- 6.8	- 4.9	- 7.1	- 4.5	- 1.3	+ 2.7	- 1.3	+ 0.5
	5		15.20	41,300	3.70	+12.6	+14.6	+13.2	+11.1	- 3.8	- 1.7	- 4.1	- 2.5	- 1.9	+ 0.2	- 3.3	- 2.7
	6		16.44	41,800	2.80	+17.8	+15.0	+17.3	+13.1	- 1.0	+ 0.5	- 0.8	+ 1.0	+ 1.3	+ 2.7	+ 0.5	+ 0.1
9A Gate raised 3 feet	1	2661.0	3.11	4,200	4.10	- 0.4	- 0.6	- 0.7	- 0.1	- 1.0	- 5.6	- 4.9	- 0.1	- 0.1	+ 1.5	+ 0.5	- 0.4
	2		6.06	11,700	4.13	- 0.3	- 1.0	- 1.0	- 0.5	- 1.5	- 2.4	- 1.9	- 0.8	- 0.8	+ 1.7	- 0.1	- 0.8
	3		9.00	21,400	4.20	- 1.7	+ 1.1	- 2.2	- 1.4	- 2.0	- 4.2	- 1.8	- 1.4	- 1.8	+ 2.1	- 1.5	- 1.6
	4		11.97	32,000	4.22	- 3.6	+13.5	- 3.7	- 3.2	- 3.4	- 3.7	- 4.5	- 3.2	- 3.1	+ 3.7	- 2.6	- 3.4
	5		15.24	41,000	3.70	+12.1	+14.3	+15.0	+11.8	- 2.6	+ 0.1	- 1.6	- 0.6	- 2.0	+ 0.6	- 1.4	- 1.6
	6		17.01	41,700	2.95	+16.8	+17.2	+16.1	+13.0	- 0.3	+ 1.8	+ 0.8	+ 1.0	+ 1.2	+ 3.2	+ 1.6	+ 1.3
10 Gate raised 6 feet	1	2664.0	2.73	3,600	4.22	- 2.0	- 2.5	- 1.3	- 2.0	- 1.6	- 1.0	- 1.3	- 1.0	- 0.2	- 1.3	- 1.4	- 1.3
	2		6.23	12,200	4.24	- 2.0	- 2.5	- 1.3	- 2.0	- 2.0	- 2.1	- 2.0	- 1.6	- 0.4	+ 0.3	- 2.0	- 1.3
	3		9.03	22,100	4.32	- 1.6	- 2.7	- 2.2	- 1.5	- 2.3	- 2.1	- 2.2	- 2.0	- 2.1	+ 1.0	- 2.3	- 1.9
	4		12.03	33,700	4.29	- 3.4	- 2.0	- 3.5	- 4.2	- 3.2	- 2.9	- 3.6	- 3.9	- 3.4	+ 2.1	- 3.3	- 3.7
10A Gate raised 6 feet	1	2664.0	12.36	34,100	4.24	- 3.6	-	- 3.8	- 4.0	- 3.8	- 2.3	- 3.6	- 3.9	- 3.4	+ 1.4	- 3.1	- 1.4
	2		8.99	21,000	4.26	- 2.5	- 0.6	- 3.4	- 3.0	- 2.5	- 1.4	- 2.0	- 3.5	- 1.7	- 0.5	- 1.6	- 2.5
	3		6.06	11,600	4.16	- 0.7	- 0.9	- 0.7	- 0.8	- 0.6	- 2.1	- 0.9	- 0.6	- 0.5	+ 1.1	- 0.7	- 0.5
	4		2.89	4,000	4.18	- 0.6	- 0.6	- 0.6	- 0.5	- 0.8	- 0.7	- 0.5	- 0.5	+ 0.1	+ 1.2	- 0.1	- 0.5
11 Gate raised 9 feet	1	2667.0	3.01	3,900	3.98	+ 0.7	+ 0.4	- 1.0	- 0.5	- 0.6	- 0.5	- 0.3	- 0.2	- 0.8	+ 1.1	+ 1.8	- 0.7
	2		5.99	11,500	4.09	+ 0.3	- 0.1	- 1.1	- 0.7	- 0.6	- 0.7	- 0.7	- 0.5	- 1.1	- 0.6	- 1.0	- 0.7
	3		9.00	21,200	4.17	- 0.6	- 1.1	- 1.6	- 1.9	- 1.7	- 1.8	- 1.7	- 1.8	- 2.2	- 1.7	- 2.1	- 2.0
	4		11.61	32,500	4.23	- 3.3	- 3.6	- 4.4	- 3.5	- 3.5	- 2.2	- 3.5	- 3.8	- 3.2	- 2.3	+ 3.4	- 3.9
12 Gate raised 12 feet	1	2670.0	3.15	4,200	3.96	+ 0.7	+ 0.0	- 1.3	- 0.3	- 0.4	- 0.4	- 5.3	- 5.0	- 0.5	- 0.3	- 0.7	- 0.6
	2		6.14	11,900	4.11	+ 0.3	- 0.6	- 0.5	- 0.6	- 0.4	- 0.7	- 0.8	- 0.6	+ 1.0	- 0.7	- 0.9	- 0.9
	3		8.94	21,400	4.25	- 1.2	- 1.7	- 3.0	- 2.1	- 2.4	- 2.3	- 2.1	- 2.1	- 2.3	- 1.8	- 2.3	- 2.3
13 Gate seated	1	2658.0	3.02	3,900	3.95	- 0.1	- 0.2	- 0.1	+ 0.1	- 1.1	- 0.2	- 0.1	+ 0.3	- 0.2	+ 0.7	+ 0.5	- 0.1
	2		6.27	12,000	4.06	- 1.7	- 0.1	+ 0.6	+ 0.1	- 3.1	- 2.8	- 2.0	- 1.4	- 0.8	+ 1.0	- 0.1	- 0.7
	3		8.77	20,400	4.19	- 1.5	- 0.0	+ 1.1	- 0.0	- 3.8	- 4.7	- 3.9	- 1.6	- 1.8	+ 1.1	- 0.8	- 1.8
	4		11.94	32,700	4.19	- 1.3	+ 1.1	- 0.5	- 2.7	- 7.5	- 6.6	- 6.7	- 5.7	- 2.2	+ 1.9	- 1.5	- 8.8
	5		15.30	41,500	4.18	+ 8.9	+10.2	+ 8.1	+ 5.6	- 4.3	- 2.3	- 2.5	- 6.1	- 2.0	+ 0.3	- 2.5	-
	6		19.97	42,900	2.55	+15.8	+15.8	+14.0	+12.3	+ 0.1	- 2.1	+ 1.5	+ 0.8	- 2.8	+ 5.6	- 3.4	+ 3.4

Remarks and conditions

In all tests the vertical shaft fills and the inlet submerges at discharges greater than 40,000 second-feet.

Tests 1 to 6 incl. Original Design

a. Lip on upstream edge of crest
b. Pier in position.
c. Lower nappe of overfall not aerated - vents plugged.

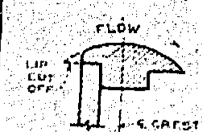


In test 8, run 2, the under nappe failed to aerate. In other runs the under nappe was self-aerated.

In test 7, the pier was removed, and lip on upstream edge of crest cut off, lower nappe of overfall not aerated. (Air vents closed.)

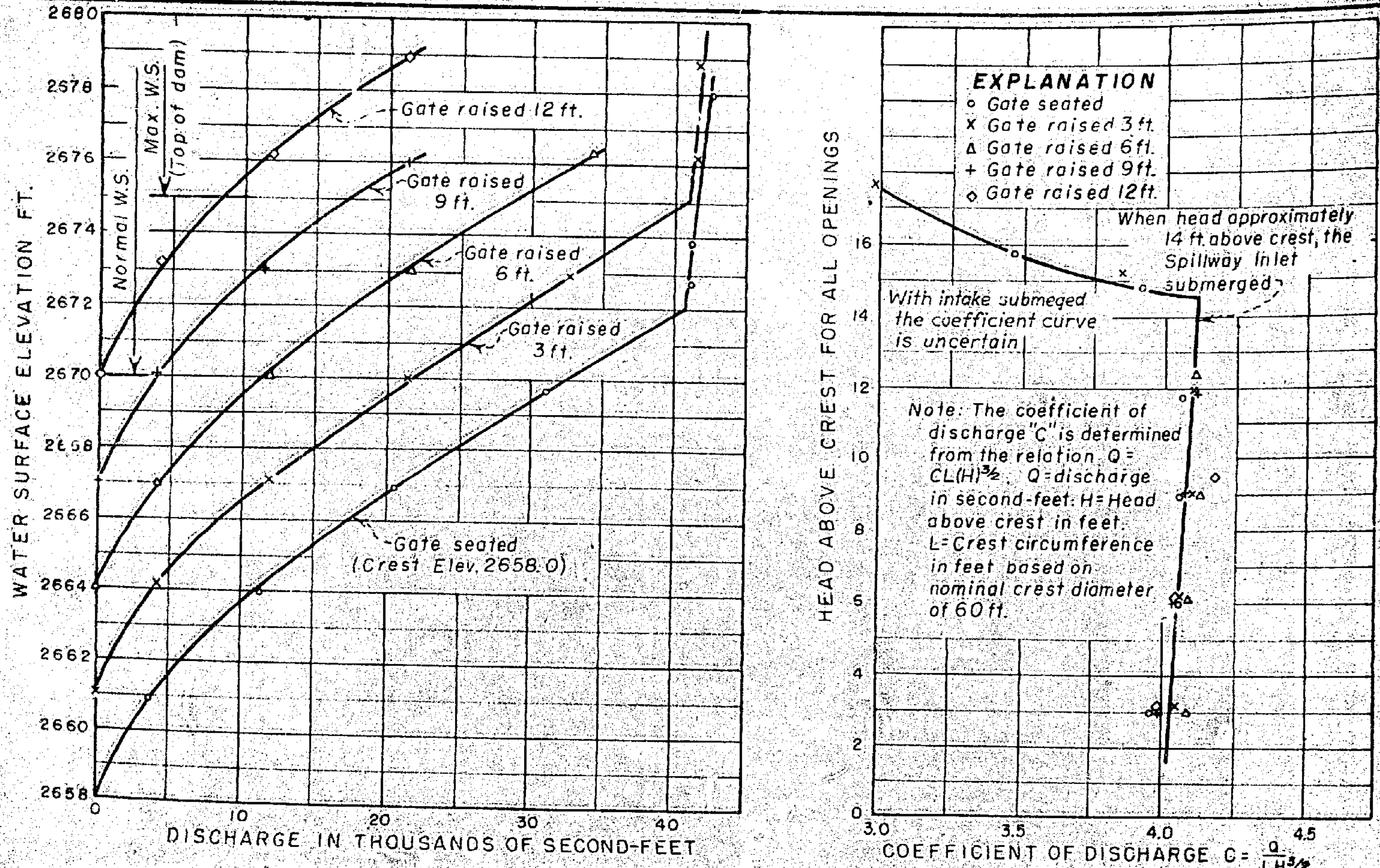
Tests 8 to 12 incl. Final Design

a. Crest as above
b. Pier replaced
c. In tests 8, 9, and 10 air vents closed. In tests 8A, 9A, 10A, 11 and 12, air vents open.



Test 13, topography and pier removed, baffles to give symmetrical approach conditions

Note:
(1) The coefficient of discharge C is based upon the relation $C = \frac{Q}{LH^{3/2}}$
where Q = discharge, H = head above crest and L = circumference of 60-foot diameter crest = (188.5 feet.)



OWYHEE DAM-GLORY HOLE SPILLWAY

RELATION OF DISCHARGE TO WATER SURFACE ELEVATION FOR VARIOUS RING-GATE POSITIONS AND COEFFICIENT OF DISCHARGE OF RING GATE.

FIGURE 6

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filled, and the inlet was submerged and choked. A further increase in head increased the discharge only slightly. This condition was reflected in the discharge-coefficient curves. The coefficient remained nearly constant to a head of 14 feet but rapidly decreased with an increase of head.

As the head increased to the point where the shaft filled, an unstable condition was observed. The vertical shaft would fill, then empty, followed by a refilling and a repetition of the cycle. This surging action would be undesirable in the prototype, but no practical remedy was suggested. However, the spillway would fill in such manner only during a maximum flood, which would be a rare occurrence of short duration; so this surging should have little opportunity to inflict too severe damage on the spillway.

The object of tests 7 and 13 was primarily to see whether removal of the pier (test 7) or all of the surrounding topography (test 13) would change flow conditions to produce effects other than those observed in tests 1 to 6 and 8 to 12, inclusive, especially the formation of a vortex in the spillway inlet. A vortex was recognized as undesirable because the discharge rating would be reduced. No appreciable differences from the other tests were observed, and, in test 13, when attempts were made to induce a vortex, the flow quickly returned to its normal radial pattern. This did not preclude the possibility of a vortex forming at greater heads than tested; and during an abnormal flood, should a vortex form in the prototype and result in an appreciable drop of spillway capacity, the ring gate should be raised to a point where the flow again becomes radial, for by doing so it will be possible to increase the capacity of the spillway.

6. <u>The prototype spillway at Owyhee Dam.</u> The operation of the prototype spillway has been described in an article, "Floating-Ring Gate and Glory-Hole Spillway at Owyhee Dam," by Lewis G. Smith, Assistant Engineer, Reclamation Era, August 1940, and also in an hydraulic laboratory report, HYD-37, "Report on Inspection Trip to Correlate Present Hydraulic Design

Practice and the Operation of Structures in the Field," by J. E. Warnock, Senior Engineer. In describing the flow over the spillway, Lewis G. Smith quotes the Owyhee monthly report dated May 5, 1936, which states that the ring gate worked perfectly after a few minor adjustments to the controls. After passing approximately 55,000 acre-feet of water with a maximum flow of 9,300 second-feet, inspection of the spillway shaft and diversion tunnel revealed no indications of erosion. The flow over the spillway was described in the Smith report as follows:

"During flow around 1-1/2 feet in depth over the crest, the water falls in a solid sheet toward the center of the spillway shaft and apparently entrains air faster than it can be released at the outlet end of the spillway tunnel, causing the air pressure to build up until great enough to 'regurgitate' or break through the sheet of overflowing water. This air comes through with enough force to carry spray 50 or 60 feet above the level of the gate crest, as may be seen in figure 8 [Smith report]. This phenomenon occurs sometimes as often as once every 15 seconds and sometimes only once in 5 minutes, depending upon the tail-water elevations, which are influenced, also by the water released through needle-valve outlets at the dam. For flow less than above-stated, excess entrained air is apparently able to work back unhampered. For flows greater than the 1-1/2 feet over the crest, such as shown in figure 9 [Smith report], the air pressure is not sufficient to break back and is forced out through the outlet end. It is believed that a supplemental air duct could be readily provided for air escape near the bottom of the shaft, which should prevent this regurgitation."

Warnock also observed the flow into the spillway, and, in addition, he described a condition at the exit which was not anticipated.

"With the 1,000 second-foot discharge, the flow into the stilling pool below was undisturbed, but as the flow increased an unexpected disturbance occurred which, so far as is known, was not detected in the model. The stream of water from the spillway tunnel created waves on the surface of the stilling pool. These waves traveled across the canyon, reflected, and returned. As they struck the oncoming high-velocity stream from the tunnel an incident occurred which, for lack of a better term, is called an 'explosion.' With this particular flow (3,000 second-feet) the spray from the explosion was thrown two-thirds the distance up the adjacent cliff. The caretaker said that with larger discharges this spray was thrown to the top of the cliff."

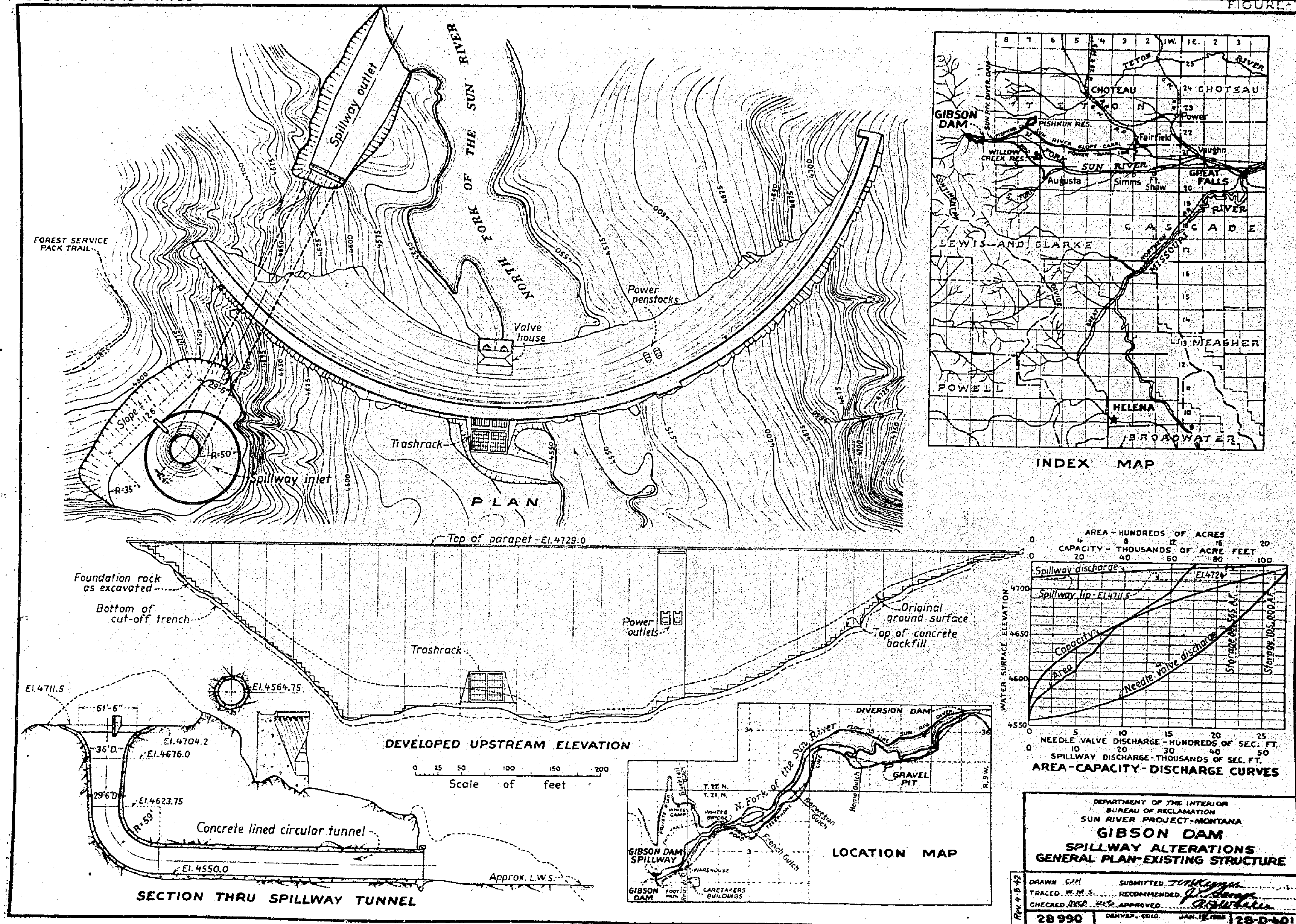
Evidently the air drawn into the spillway entrance was ejected as a strong wind. This has been observed at other spillways of this time; but when the reflected waves reach the tunnel portal, they are great enough to seal the exit for a short time and the air is quickly compressed to the extent that an explosion results from the release of the air.

GIBSON DAM

7. The spillway alterations at Gibson Dam. Gibson Dam, completed in the fall of 1926, is located on the north fork of the Sun River about 60 miles west of Great Falls, Montana. The spillway was of the vertical-shaft or glory-hole type, having an eccentric crest 100 feet in diameter at elev. 4711.5 (figure 7). This shaft flared inward to a diameter of 61.6 feet at elev. 4704.2, 36.0 feet at elev. 4676.0, and 29.5 feet below elev. 4623.75. At elev. 4623.75 the shaft turned through 90 degrees on a 59-foot radius to a circular tunnel 29.5 feet in diameter with the floor at elev. 4550.0. There being no gates on this spillway to hold the water level above elev. 4711.5, the storage capacity above the crest could not be utilized. After several years of operation it became apparent that the extra storage which might be realized by holding the water above elev. 4711.5 would become necessary as the water use in the valley increased; therefore, in 1935, designs for spillway alterations were begun which involved placing piers and gates around the spillway to make possible storage up to elev. 4724.0 (figure 8).

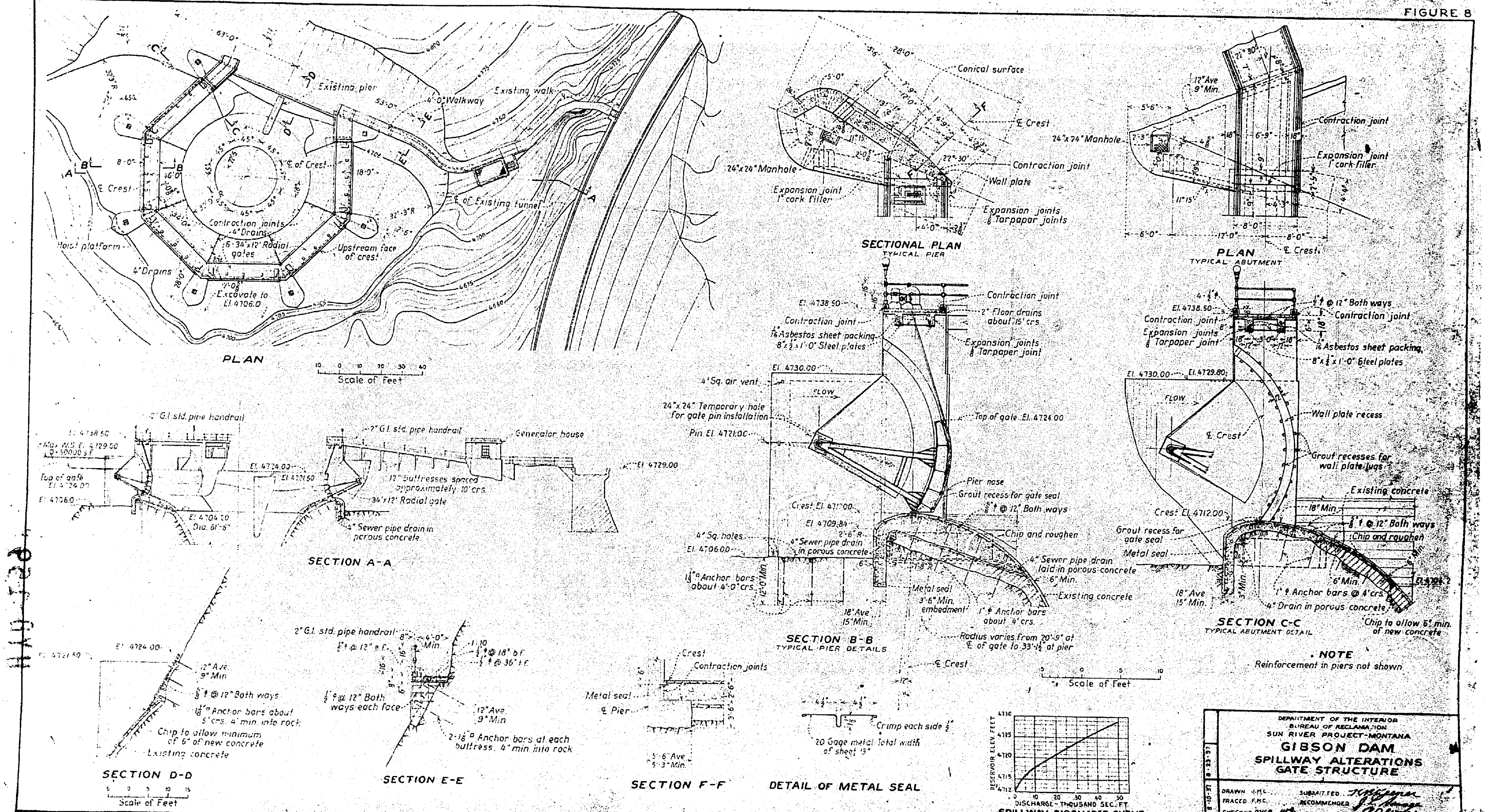
An hydraulic model was used, in connection with these alterations, to study the flow into the spillway with the gates in operation and to compare different designs and arrangements of the gates and the piers.

8. The Gibson Dam model spillway. A 1:63.6 scale model was built which included the topography surrounding the spillway, the proposed piers and the gates, and the spillway and the discharge tunnel below (figures 9 and 10). The topography was made of wire lath and plaster. The spillway entrance, between elev. 4712.0 and elev. 4676.0, was made of concrete, poured with bases on which to set the piers, and with piezometers in place. The transition section between elev. 4676.0 and 4623.75 was made of 1/10-inch pyralin in the form of a frustrum of a cone to permit observation of the flow in that region. A pyralin elbow below this transition connected the vertical shaft to the discharge tunnel. Having been used in the previous Owyhee model, this elbow was not entirely to scale in the Gibson model in that the radius of the bend


PLAN
Spillway outlet
NORTH FORK OF THE SUN RIVER
FOREST SERVICE PACK TRAIL
Power penstocks
Valve house
Trashrack
Spillway inlet
Slope 1:1
R=50'
R=35'
29'-6"
INDEX MAP
GIBSON DAM
CHOTEAU
TETON RIVER
PISHKUN RES.
WILLOW CREEK RES.
Power
Fairfield
Vaughn
SUN RIVER
Augusta
Simms
Ft. Shaw
GREAT FALLS
LEWIS AND CLARKE
CASCADE
MISSOURI
MEAGHER
POWELL
HELENA
BROADWATER
Top of parapet - El. 4729.0
Foundation rock as excavated
Bottom of cut-off trench
Power outlets
Original ground surface
Top of concrete backfill
Trashrack
DEVELOPED UPSTREAM ELEVATION
Scale of feet
0 25 50 100 150 200
El. 4711.5
61'-6"
El. 4564.75
36' D.
El. 4704.2
El. 4676.0
29'6 D.
El. 4623.75
R=59'
Concrete lined circular tunnel
El. 4550.0
Approx. L.W.S.
SECTION THRU SPILLWAY TUNNEL
DIVERSION DAM
N. Fork of the Sun River
GRAVEL PIT
Home Gulch
Norwegian Gulch
French Gulch
WHITES CAMP
WHITES BRIDGE
WAREHOUSE
CARETAKERS BUILDINGS
GIBSON DAM SPILLWAY
GIBSON DAM
T. 22 N.
T. 21 N.
R. 9 W.
LOCATION MAP
AREA - HUNDREDS OF ACRES
CAPACITY - THOUSANDS OF ACRE FEET
Spillway discharge
El. 4724
Spillway lip - El. 4711.5
Capacity
Area
Needle valve discharge
Storage 88,000 A.F.
Storage 105,000 A.F.
WATER SURFACE ELEVATION
NEEDLE VALVE DISCHARGE - HUNDREDS OF SEC. FT.
SPILLWAY DISCHARGE - THOUSANDS OF SEC. FT.
AREA-CAPACITY-DISCHARGE CURVES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SUN RIVER PROJECT - MONTANA
GIBSON DAM
SPILLWAY ALTERATIONS
GENERAL PLAN - EXISTING STRUCTURE
DRAWN C.J.H.
TRACED W.M.S.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLO.
28990
28-D-401

HYD-159

FIGURE 8



PLAN
Scale of Feet
Existing pier
4'-0" Walkway
Existing walk
€ of Existing tunnel
Contraction joints
4" Drains
6-34'x12' Radial gates
Upstream face of crest
Hoist platform
Excavate to El. 4706.0
SECTIONAL PLAN
TYPICAL PIER
Conical surface
€ Crest
24"x24" Manhole
Contraction joint
Wall plate
Expansion joint 1" cork filler
Expansion joints 1/8 Tarpaper joints
PLAN
TYPICAL ABUTMENT
SECTION A-A
2" G.I. std. pipe handrail
Generator house
12" buttresses spaced approximately 10' crs.
34'x12' Radial gate
4" Sewer pipe drain in porous concrete
SECTION B-B
TYPICAL PIER DETAILS
4' Sq. air vent
24"x24" Temporary hole for gate pin installation
Pin El. 4721.00
Top of gate El. 4724.00
Pier nose
Grout recess for gate seal
Crest El. 4712.00
Chip and roughen
4" Sewer pipe drain laid in porous concrete
Existing concrete
Metal seal
Radius varies from 20'-9" at € of gate to 33'-1 1/2" at pier
SECTION C-C
TYPICAL ABUTMENT DETAIL
Wall plate recess
Grout recesses for wall plate lugs
Chip to allow 6" min. of new concrete
NOTE
Reinforcement in piers not shown
Scale of Feet
SECTION D-D
Scale of Feet
SECTION E-E
SECTION F-F
DETAIL OF METAL SEAL
20 Gage metal total width of sheet 13"
Crimp each side 1/8"
SPILLWAY DISCHARGE CURVE
RESERVOIR ELEV. FEET
DISCHARGE - THOUSAND SEC. FT.
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SUN RIVER PROJECT-MONTANA
GIBSON DAM
SPILLWAY ALTERATIONS
GATE STRUCTURE
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO
28991

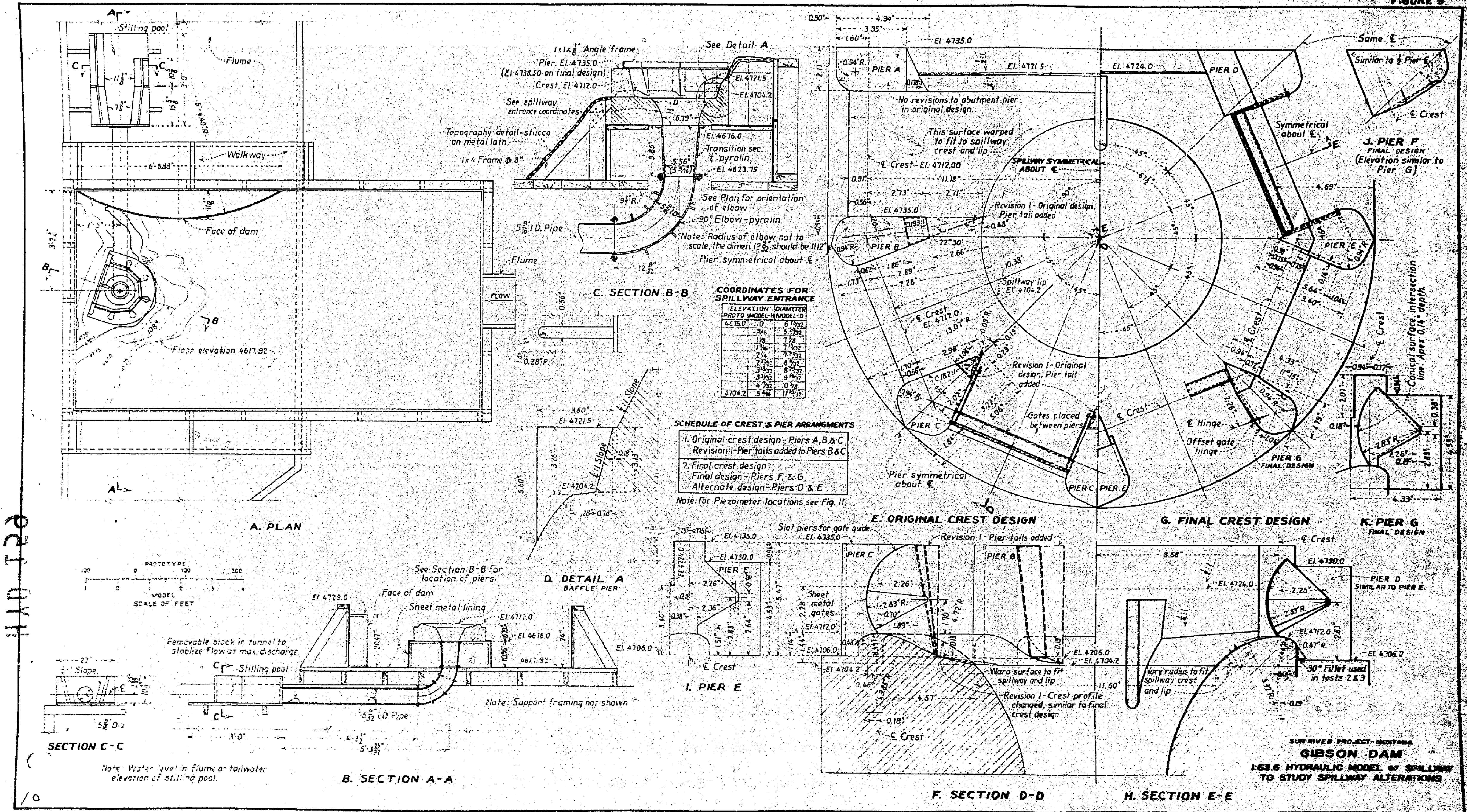
was 12.28 inches when it should have been 11.12 inches. The sheet-metal discharge tunnel connected to the downstream side of the elbow was thus placed 1.18 inches too low. However, such a discrepancy was not considered important because it did not affect the flow past the gates and into the spillway.

The piers, bobtail in the original design, were made of treated redwood held in position by an angle frame joining them together at the top. The radial gates, of sheet metal, were fitted into slots between the piers on the original designs, but were pivoted on hinges in the final designs.

To measure pressures in the model, piezometers were placed in the spillway entrance, as shown in figure 11A. Other piezometers in the transition and the elbow were available but not used, except for qualitative observations. The discharge was measured over a V-notched weir and was brought to the model through a flume.

9. The original design of the Gibson Dam spillway-gate structure. Tests were divided into two groups; in the first, or original design, the radial gates faced upstream, and in the second, or final design, the gates were reversed and faced downstream. Radial gates of the type used at Gibson Dam are ordinarily swung facing upstream with the hinge pins swung downstream. Thus, they are accessible for maintenance at all times. However, during the course of the studies on the spillway for Gibson Dam, it was found that a more compact arrangement would be possible if the gates were reversed from their conventional position.

Only visual tests were made on the original design because several adverse features were apparent immediately. The bobtail piers caused large fins downstream. The bobtail piers caused large fins downstream. Severe negative pressures occurred in the spillway entrance below the break in profile at elev. 4704.2. There was an unstable flow condition at the maximum discharge, causing a surging action where the spillway shaft alternately filled and emptied, as was observed in the Owyhee model. The original design was therefore revised. By adding pier tails,



COORDINATES FOR SPILLWAY ENTRANCE

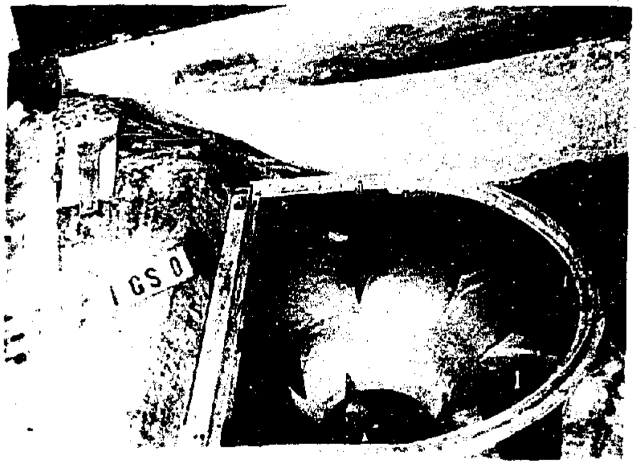
ELEVATION PROTO	ELEVATION MODEL-H	DIAMETER MODEL-D
4676.0	0	6 25/32
	9/16	6 29/32
	1 1/8	7 1/8
	1 11/16	7 13/32
	2 1/4	7 23/32
	2 27/32	8 1/32
	3 13/32	8 23/32
	3 31/32	9 15/32
	4 17/32	10 3/8
4704.2	5 5/16	11 15/32

SCHEDULE OF CREST & PIER ARRANGMENTS

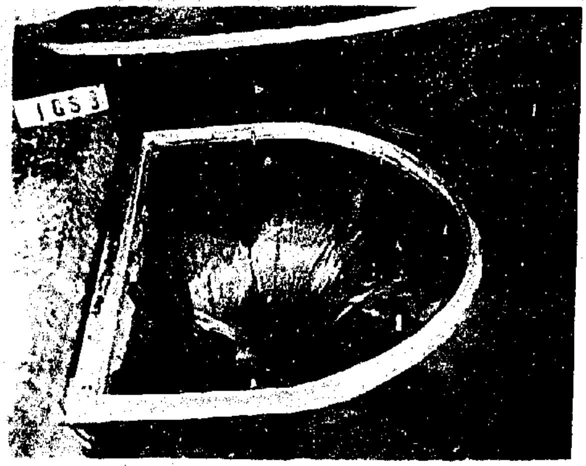
1. Original crest design - Piers A, B & C Revision 1-Pier tails added to Piers B & C
2. Final crest design Final design - Piers F & G Alternate design - Piers D & E

Note: For Piezometer locations see Fig. 11.

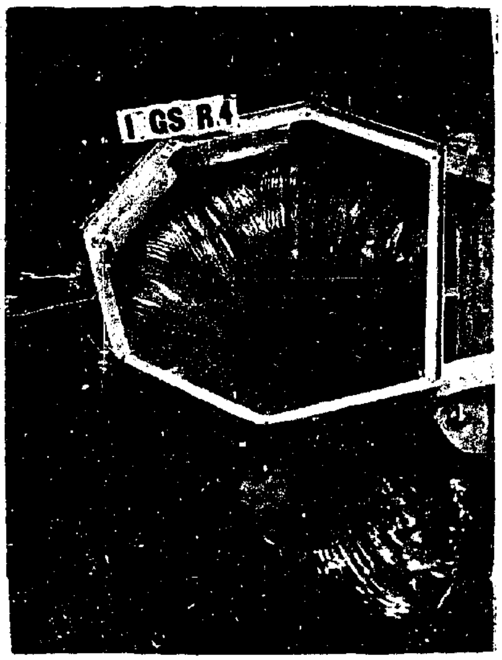
Figure 10



A. REVISED ORIGINAL DESIGN
PLASTICENE FILLET IN CREST
AND PIER TAILS ADDED



B. REVISED ORIGINAL DESIGN
DISCHARGE = 30,000 C.F.S.

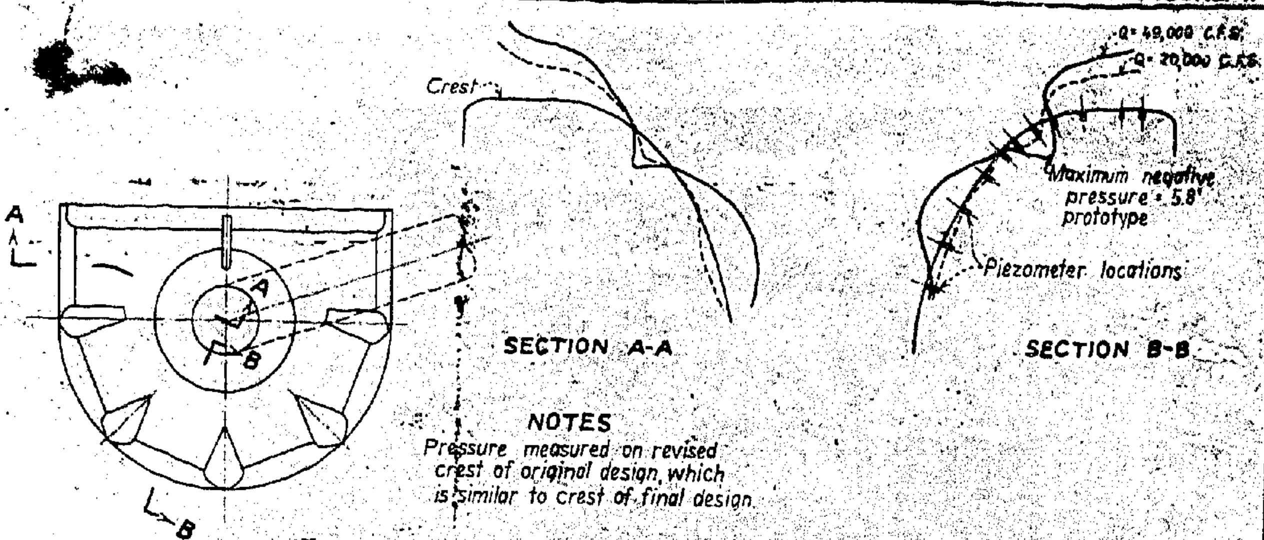


C. FINAL DESIGN - $22\frac{1}{2}°$ PIERS
GATES OPEN
DISCHARGE = 35,000 C.F.S.

D. DESIGN USING 45° PIERS
GATES RAISED 3 FEET
DISCHARGE = 13,000 C.F.S.

THE 1:63.6 HYDRAULIC MODEL OF
THE GIBSON DAM SPILLWAY

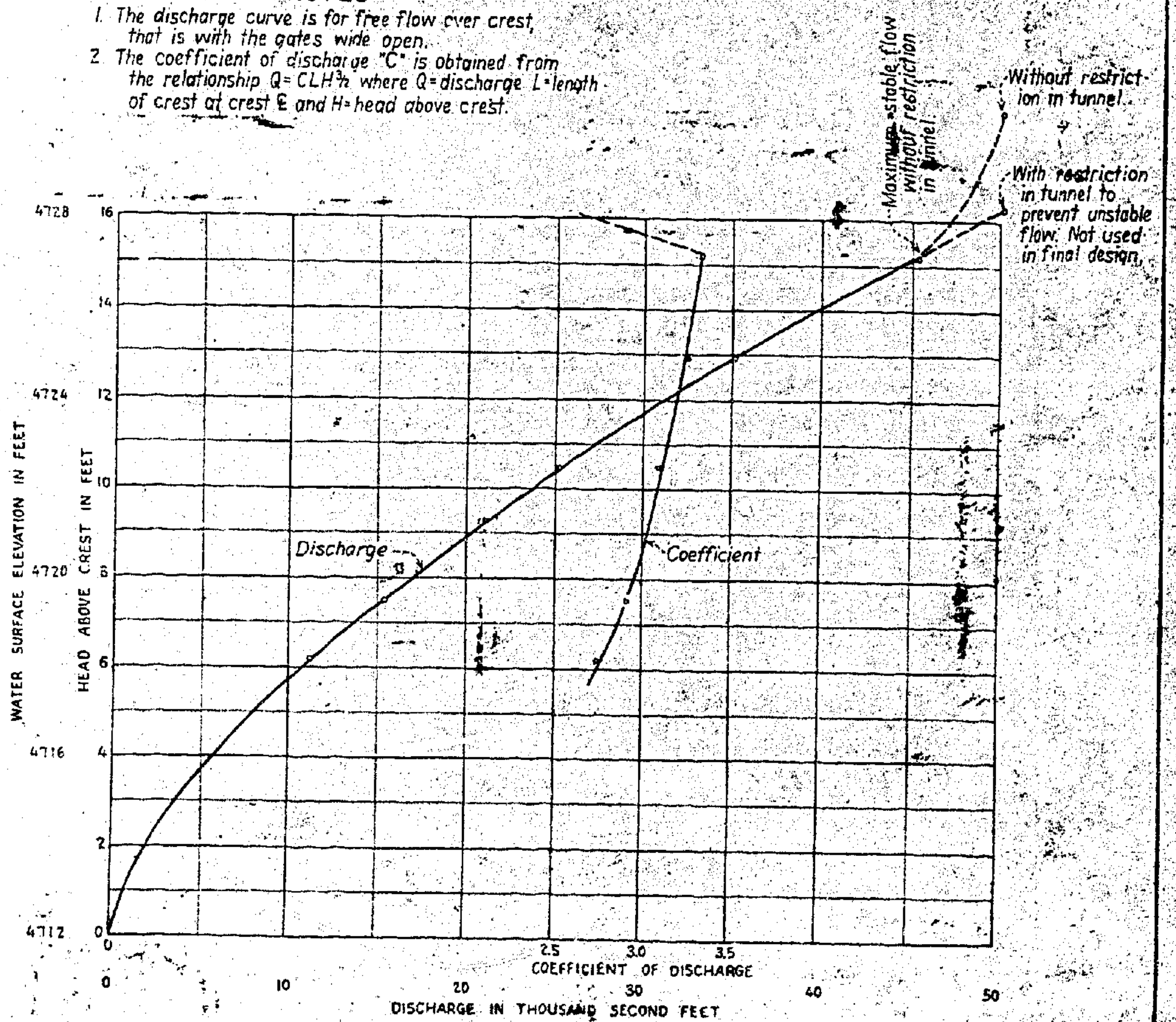
FIGURE 11



A. APPROXIMATE PRESSURE DISTRIBUTION ON SPILLWAY CREST

NOTES

1. The discharge curve is for free flow over crest, that is with the gates wide open.
2. The coefficient of discharge "C" is obtained from the relationship $Q = CLH^{3/2}$ where Q = discharge L = length of crest at crest ℄ and H = head above crest.



B. RELATION OF HEAD TO DISCHARGE

GIBSON DAM - SPILLWAY ALTERATIONS

HYDRAULIC MODEL STUDIES 1:63.6

PRESSURE AND DISCHARGE CURVES FOR FINAL DESIGN

the fins downstream from the piers were reduced; by rounding the crest with a plasticine fillet, negative pressures caused by the break in the crest profile at elev. 4704.30 were eliminated; and by placing a block in the tunnel near the exit, the surging flow at maximum discharge was avoided (figure 9 E and F, revision 1).

10. Pressures on crest. As this revised crest design appeared satisfactory, detailed pressure measurements were made (figure 11). Pressure curves for discharges of 20,000 and 49,000 second-feet, respectively, shown in this figure, are typical of pressure measurements at other discharges. A maximum negative pressure of 5.8 feet was recorded at the spillway entrance. It is possible that more severe negative pressures, and even cavitation, might exist in the prototype below the spillway entrance should the spillway become submerged. However, as this would be a rare occurrence of relatively short duration, no great damage should result.

11. Cause of surging at maximum discharge. A study was made to determine the cause of surging at maximum discharge when the shaft alternately filled and emptied. It was found experimentally that a block, or a choke, near the tunnel exit would effectively reduce or eliminate this action. The explanation seemed to lie in the fact that there was a change in flow regimen and a shift of controls when the shaft filled. Actually, the control may be located at three points. At normal discharge, the control was at the circular crest; but, as the head increased, a flow was reached when the crest submerged and the control shifted, either to an orifice near the top of the shaft, the location depending upon the shape of the inlet, or to a control at the bottom of the shaft. This third control was really hypothetical and included the resistance and the obstructions in the tunnel, the elbow, and the vertical shaft. For moderate discharges when the control was at the crest, the control at the bottom of the shaft would also back water up the shaft some height, depending upon the discharge. As the head increased, increasing the discharge, water would back up the shaft

and it was apparent that eventually the shaft would be filled and the crest submerged. However, before the shaft filled, a head was reached at which the control shifted from the crest to the orifice at the top of the spillway, submerging the crest before the shaft below was filled. When this occurred, pressures at the orifice were negative as soon as the crest submerged. The negative pressures acted to increase the velocity and the discharge in the shaft, and to lower the head; so the control shifted back to the crest, whereupon the shaft emptied and the negative pressures were relieved by an inhalation of air. Then, with less discharge in the shaft, the control again shifted to the orifice, the crest submerged, and the cycle was repeated.

As the experiments indicated, it was possible to avoid this unfavorable condition by placing a restriction in the tunnel near the exit to increase the resistance of the control at the bottom of the shaft. The water rising in the shaft would then submerge the crest before the head was sufficient to cause the control to shift from the crest to the orifice. However, such a restriction not being a practical solution, nothing was done to alleviate this unfavorable condition at the Gibson spillway. In future designs of glory-hole spillways, the shaft might be so proportioned that the combined resistance in the tunnel and the shaft would be sufficient to fill the shaft before the control could shift from the crest to the orifice.

12. Air in the shaft. Another method of eliminating surging flow at maximum discharge would be to provide air vents in the shaft to relieve negative pressures. The use of air vents was not considered because the events that might occur in the prototype are extremely uncertain as far as the inhalation and the ejection of air are concerned. Air bubbles that were drawn into the model were compressed at the bottom of the shaft and in the tunnel and then ejected from the tunnel in such manner as to suggest that if similar bubbles existed in the prototype, they would virtually explode at the exit. Nothing could be done to prevent the entrainment of air in the prototype; but a flood great

enough to cause a surging flow, with the inhalation of air in large gulps, would be a rare occurrence of short duration. So any damage that might result should not be extensive.

Since the model studies on the Gibson spillway (1936), this condition, explosion of air bubbles at the tunnel exit, actually occurred in a similar type of spillway at San Pablo Dam in California. Intense vibration resulted, and the tunnel lining at the exit portal was ruptured. A complete revision of the San Pablo spillway was necessary to prevent recurrence of damage. At other spillways, however, it has been observed that the action of air is not always the same; it may be ejected as a strong wind; it may be mixed with water to form foam; as observed at Owyhee, it may regurgitate from the entrance; or, as also observed at Owyhee, it may cause an explosion when reflected waves seal the entrance, as described in section 6. In the case of the San Pablo Dam, the fact that the exit was submerged may have been the cause of the trouble. However, this is not certain. To understand, to predict, and to control the action of air in a glory-hole spillway is a problem for the future. The use of air vents in the bottom of the tunnel has been suggested; but they may not be completely effective. If the air is mixed with the water, only a small portion may be vented, or, if the air is compressed as bubbles, the relief into the vent may cause vibration in the same manner as would the discharge from the tunnel exit.

13. The final design of Gibson Dam spillway with radial gates faced downstream. As far as the hydraulics were concerned, the revised original design was satisfactory; however, a more compact arrangement was desirable. This was accomplished by reversing the gates so that they faced downstream. The final crest design was similar to the crest of the revised original design, but much shorter. The piers were laid out in a more symmetrical pattern than before, although their general location was the same (figure 9K). Two types of piers were proposed, a 22-1/2-degree pier and a 45-degree pier. The 22-1/2-degree pier was tested first and selected as the final design when no marked improvements

could be seen in later tests on the 45-degree piers. Four tests on this final arrangement were made. In test 1, 22-1/2-degree piers and abutments were used (piers F and G, figure 9G). Runs were made at discharges of 11,100, 15,200, 25,200, 35,000, 45,300, and 50,100 second-feet, respectively. A run was also made at maximum discharge with a block in the tunnel to stabilize the flow. No detailed pressure measurements were made in this test. Test 2 was similar to test 1 except that a 30-degree fillet was placed at the upstream edge of the crest to improve the flow over the crest. The fillet, however, was not very effective. Test 3 was similar to test 2 except that 45-degree piers and abutments were used instead of the 22-1/2-degree piers (piers E and F, figure 9G). No marked improvement of the flow conditions was observed. Test 4 was similar to test 3 except that the fillet at the upstream edge of the crest was removed.

Test 1 was selected for the final design. No pressure measurements were made, as the crest was similar to the revised crest of the original design and it was considered that those pressure measurements would suffice (figure 11). A discharge rating curve and a discharge-coefficient curve, with the gates raised, is shown for the final design on figure 11. The discharge rating curve shows a maximum stable flow of 45,000 second-feet with a 15-foot head over the crest. The coefficient of discharge, which is about 3.4 for this head, was based upon the relation $Q = CL(H)^{3/2}$, where L is the total crest length between the piers. This coefficient cannot be compared with the coefficient for the Owyhee spillway, or others, because, as already mentioned, the coefficient of a glory-hole spillway is not an index of the spillway capacity.

To conclude tests on the Gibson spillway, a series of runs were made with the gates at partial openings, varying the discharge and the head. From all appearances, the operation of the prototype would be satisfactory under all conditions.

REFERENCES TO OTHER GLORY-HOLE SPILLWAYS

14. The Davis Bridge Dam spillway. The widespread use of earth-fill dams at locations not suitable for masonry dams was largely responsible for the introduction of shaft spillways. When a masonry dam is located in a narrow valley with steeply rising hills on both sides, a bypass for the spillway is not feasible and the spillway is incorporated in the dam. In the case of an earth-fill dam at a similar location, a spillway over the dam itself would not always be safe, and one solution is to use a shaft spillway. An attractive design was the vertical-shaft or glory-hole spillway because of the economy of construction, especially when a diversion tunnel was necessary, for, in such circumstances, the shaft could be joined with the diversion tunnel.

However, many engineers were reluctant to use glory-hole spillways as there were several apparent disadvantages. For instance, the discharge capacity was limited; also, the water falling into the shaft would act as an air pump, compressing large quantities of air in the shaft, with uncertain results. Prior to 1924 there were very few spillways of this type in existance, and practically no information concerning their design was available. A paper by Ford Kurtz, "The Hydraulic Design of the Shaft Spillway for the Davis Bridge Dam and Hydraulic Tests on Working Models," Trans. A.S.C.E., vol. 88, 1925, was one of the first comprehensive treatments of the subject. To this paper were added the discussions of several prominent engineers. Much of their criticism was adverse. Nevertheless, the use of this type of spillway has increased, and there is now more literature upon the subject covering prototype installations, model studies, and basic investigations.

The Davis Bridge Dam, an earth-fill structure 200 feet high, is located on the Deerfield River about three quarters of a mile south of Whitingham, Vermont. This dam is situated in the neck of a narrow valley with high, surrounding hills, making the use of an overflow type of spillway impractical. A glory-hole or shaft spillway was both practical and economical. The entrance of the vertical shaft, 22.5 feet in diameter, was placed on a shelf above the diversion tunnel and connected to the tunnel by a 90-degree elbow.

The basis of the theoretical design was to make the entrance circular and reduce it to a uniform diameter of 22.5 feet as soon as the water falling over the lip could be accelerated to the required velocity. To accomplish this, the design was separated into four distinct parts:

(a) A circular, broad-crested weir was used at the upstream edge of the entrance, with the coefficient assumed to be the same as that for a similar rectilinear weir.

(b) Below the downstream edge of the weir there was an open section which was designed to fit the nappe of the freely falling jet. The shape of the nappe was determined by assuming the path of the water at the center line of the jet to be a parabola. This section continued until the jet closed upon itself.

(c) The closed portion of the freely falling jet. This section continued until the required velocity throughout the remainder of the shaft was reached.

(d) The remainder of the design involved the closed vertical shaft, the elbow, and the diversion tunnel. These sections were designed from regular formulae for pipes and bends.

To check this theoretical design, a model was built on a scale of 1 to 36 and tested at the Alden Hydraulic Laboratory of the Worcester Polytechnic Institute at Worcester, Mass. Later, the model was moved to the testing flume of the Power Construction Company on Sadawga Brook, near Whitingham, Vermont.

The Worcester tests were to ascertain the capacity of the spillway and to observe the manner in which the water entered the spillway. No topography was included in these tests, so the flow was symmetrical. The discharge capacity checked the theoretical capacity, and the flow conditions were as anticipated except that a mushroom of water appeared where the jet came together. This mushroom had no effect upon the flow into the spillway. Negative pressures were observed on several sections of the spillway entrance.

In the Whitingham tests the effect of the topography, a spiral approach to the spillway, and the effect of piers and flashboards set between the piers were studied. The capacity was the same as before. The piers were useful in forcing the water to flow into the spillway in a more symmetrical pattern.

15. Model experiments by British engineers. The glory-hole or shaft spillway has been used in England as far back as 1896. Although it is doubtful that model studies were made in connection with the design of the earlier spillways, at more recent installations model studies have been used. Of particular importance are investigations which have been described in a series of papers by W. J. E. Binnie, G. M. Binnie, A. M. Binnie, and R. K. Wright.

In "Bellmouthed Weirs and Tunnel Outlets for the Disposal of Flood Water," by W. J. E. Binnie, Transactions of the Institution of Water Engineers, vol. XLII, 1937, there are descriptions of seven bellmouthed or glory-hole spillways in the British Empire and in the United States, followed by a resumé and results of model studies involved in the designs of some of these structures. The spillways described were:

(1) The spillway for the Taf Fechan Reservoir in Wales, designed in 1912. The bellmouthed entrance of this spillway flared inward from a 66-foot diameter crest to a 16-foot diameter shaft 30 feet below the crest. The shaft was connected to a 13-foot diameter tunnel 93.7 feet below the crest. The capacity was 3,040 second-feet. To prevent the formation of a vortex, four fins, 9 inches wide, were placed on the bellmouth entrance.

(2) A similar spillway for the Silent Valley Reservoir in Ireland, designed in 1926, whose entrance flared inward from an 80-foot diameter crest to a 16-foot diameter shaft 27.5 feet below the crest. The shaft was connected to a 16-foot diameter tunnel 46.6 feet below the crest. The capacity was 2,600 second-feet. Four fins were used to prevent the formation of a vortex.

(3) The spillway for the Pontian Ketchil Reservoir at Singapore, designed in 1927, had an entrance which flared inward from a 50-foot diameter crest to a 13-foot diameter shaft 23 feet

below the crest. The shaft was connected to a 13-foot diameter tunnel 53 feet below the crest. The maximum capacity was 2,700 second-feet. To prevent the formation of a vortex, 15 radial piers were placed on the crest instead of using fins in the bellmouth entrance. This design resulted from model tests of the Davis Bridge Dam spillway which indicated that piers improved the flow into the spillway.

(4) The shaft spillway at Davis Bridge Dam, which was discussed in section 14.

(5) The spillway for the Burnhope Reservoir in England, designed in 1932-34. The entrance flared inward from a 50-foot diameter crest to a 12-foot diameter shaft 25 feet below the crest. The shaft was connected to a 12-foot diameter tunnel 97.6 feet below the crest. The capacity was 2,630 second-feet. A curtain wall and two fins were used to prevent the formation of a vortex, as the results of tests on a model of the Manuherikia Falls spillway indicated that a curtain wall was the best device for vortex prevention.

(6) The spillway for the Manuherikia Falls Dam in New Zealand, designed in 1932. The entrance flared inward from a 102-foot diameter crest to a 17-foot diameter shaft 55 feet below the crest. This shaft connected to a 17-foot diameter tunnel. The capacity was 19,400 second-feet. Six piers were used to prevent the formation of a vortex.

(7) The spillway for the Jubilee Reservoir at Hong Kong, China, designed about 1933. The entrance differed from other spillways in that it consisted of a conical shaft instead of a bellmouth. This conical entrance tapered inward from a 74-foot diameter crest to a 25-foot diameter shaft 37 feet below the crest. This shaft, only 3 feet 2-1/2 inches long, immediately connected with a sloping tunnel 15 feet in diameter and several hundred feet long. A curtain wall was used to prevent the formation of a vortex. The capacity of this spillway was 11,300 second-feet.

The model experiments by the British considered first the reliability of the model results applied to the prototype. For the Jubilee Reservoir, experiments made with models constructed to scales of 1:19, 1:24, 1:29.4, and 1:43.5 indicated that the model would predict closely the performance of the prototype. To study the effect of entrained air, measurements were made on a 1:24 scale model of the Burnhope spillway. The results demonstrated that entrained air had no effect upon the discharge at maximum capacity, and that at lesser discharges the effect and the volume of the entrained air was immaterial. A large number of experiments were made to study the formation and the prevention of vortex flow in the spillways. The importance of preventing vortex flow is emphasized in the Jubilee experiments where the formation of a vortex decreased the discharge from 14,000 to 9,000 second-feet. Model experiments showed that the depth at which a vortex forms is not constant and that it is influenced by the surrounding topography, other conditions which may cause tangential velocities, and the form of the spillway itself. The use of fins in the bellmouth, radial piers, and curtain walls will delay the formation of a vortex, the curtain wall being the most effective device. The curtain wall divides the bellmouth into two semicircular weirs. Tests were made to find the optimum depth that the curtain wall should extend into the entrance.

This article describes the experiments on the four models of the Jubilee Reservoir. At the other spillways described, the likelihood of floods great enough to choke the spillways was remote. However, in the region of China, where the Jubilee Reservoir is located, rainstorms occur so severe that the possibility of the inlet becoming gorged is one of major concern. This necessitated, first, an auxiliary spillway consisting of six siphons capable of discharging 6,000 second-feet. A more careful consideration of the conditions occurring in the bellmouth spillway at maximum capacity was also necessary. The bellmouth entrance of the original design was shaped similar to those previously constructed. A curtain wall was used to prevent the formation of a vortex, and air vents were used to relieve negative pressures below the bellmouthed entrance. Without air vents, a maximum discharge of 15,000 second-feet was reached; but at a discharge of 9,700 second-feet, violent surging of the water level in the entrance took place (such as was observed in the Owyhee and the Gibson models). As this surging was caused by vacuums below the entrance, the air vents eliminated this condition; but the discharge was considerably reduced, and unstable, varying from 11,300 to 9,000 second-feet.

A theoretical design was proposed to eliminate negative pressures in the shaft. This design consisted of a conical shaft tapered inward to a minimum diameter at the bottom so that there could be no control except at the bottom. Such a design could not be used in the prototype, for it required a horizontal tunnel, whereas the inclined tunnel in the Jubilee Reservoir spillway was nearly completed at the time of the experiments. Nevertheless, the entrance section of the final design was modified by using a conical shaft instead of the bellmouthed shape as used in the previous installations. This revision considerably improved the performance of the spillway by reducing the vacuums, increasing the discharge from 11,300 to 14,000 second-feet (with air vents), and by greatly reducing the degree of surging in the entrance. There were negative pressures in the sloping tunnel, so air vents were used to avoid the possibility of absolute vacuums in the prototype.

A hood was placed over the spillway entrance to form a siphon-bellmouth overflow. The siphon primed successfully, and the scheme offered possibilities although it was not adopted at the Jubilee Reservoir.

The conclusions from these experiments were;

"(a) That model experiments, provided the model ratio is not too small, can be used to predict approximately the relation between Q and H for the prototype.

"(b) That the rate of discharge obtained with the prototype will be better at corresponding depths than predicted by the model.

"(c) That a steadier flow at high rates of discharge is obtained by using a conical shaft rather than the type of bellmouth hitherto adopted.

"(d) That better results, as far as reduction of vacuums is concerned, are obtained with a nearly horizontal tunnel rather than with one which is steeply inclined.

"(e) That a curtain wall, extending across the waterway so as to divide the bellmouth into two semi-circular weirs, is the best anti-vortex device.

"(f) That the cross-sectional area of the channel of approach should be such as to limit the tangential velocity to 3.5 feet per second at any cross section.

"(g) That the tunnel should be made of such cross-sectional area as to prevent the formation of considerable vacuums.

"(h) That the radius of the bend where the shaft joins the tunnel should also be such as to prevent the setting up of an appreciable vacuum at the maximum rate of discharge."

In "Model Experiments of Bellmouth and Siphon-Bellmouth Overflow Spillways," Institution of Civil Engineers, vol. 10, November 1938-January 1939, G. M. Binnie describes in greater detail the experiments on the Jubilee Reservoir spillway.

In a paper, "The Use of a Vertical Pipe as an Overflow for a Large Tank," Proc. Royal Society of London, Series A, vol. 168, 1938, p. 219, A. M. Binnie describes an investigation concerned mainly with the behavior of vertical pipes of uniform diameter. A few experiments were performed with bellmouths of different shapes for purposes of comparison. In these tests it was demonstrated that there was a definite limit to the discharge through the overflow. Above a certain head, depending upon the form of the inlet and the tailpiece, the outlet virtually refused to pass more water.

In "Laboratory Experiments on Bellmouth Spillways," by A. M. Binnie and R. K. Wright, Institution of Civil Engineers, vol. 15, November 1940-February 1941, there are descriptions of further studies. The apparatus was a circular tank with an overflow pipe in the center whose inside diameter was 1 inch. Different types of bellmouth entrances could be placed on this overflow pipe, and different types of tailpieces could be used below it. Water flowed into the tank in a radial manner, so the stream filaments approaching the entrance were radial and there were no tangential velocities which could cause vortex flow. An apparatus was developed for measuring air.

The tests studied two types of bellmouth entrances; one, a shallow bellmouth, and the other, a deep, conical bellmouth such as was used at the Jubilee Reservoir spillway. Seven tests were made, with each entrance, by changing the tailpiece, or exit:

(1) The tailpiece was a 1-inch vertical pipe 5 feet long, unobstructed.

(2) The same as (1), with an orifice 0.880 inch in diameter at the exit.

(3) The same as (1), with an orifice 0.687 inch in diameter at the exit.

(4) The same as (1), with a horizontal pipe 20 feet long added, being connected to the vertical pipe with a 90-degree bend having a radius of 3.15 inches.

(5) The same as (4), but with an orifice 0.880 inch in diameter at the exit.

(6) The same as (4), but with an orifice 0.687 inch in diameter at the exit.

(7) The same as (4), but with the exit connected to the suction side of a pump.

The results of the experiments were:

"(a) Whatever the arrangement of the bellmouth and tailpiece that was tested with rising head under ideal conditions, there was at first a quiet stage with no important entrainment of air. This was followed by a noisy phase when the air in the form of bubbles was drawn down; but the air flow diminished as the head increased further. Above a sharply marked critical head, the bellmouth and pipe ran full and the water flow remained almost constant at its critical value. Below the critical head the bellmouth acted as a weir; the water flow was not reduced by the entrainment of air.

"(b) At heads above critical, no permanent vortices were formed. Transient vortices were more common with bellmouth B (a shallow, curved trumpet) than with bellmouth A (a deep cone). This result is attributable to the large negative pressures generated in bellmouth B near its crest.

"(c) All of the critical heads and water flows for the various tailpieces attached to either bellmouth lay on the head-discharge curve obtained with the tailpiece that caused the greatest flow. This result can be utilized when the discharge through a new tailpiece is to be predicted.

"(d) Owing to the better form of the crest, the coefficient of discharge of bellmouth A was considerably higher than that of bellmouth B. An improved and practicable form of bellmouth could therefore be designed, combining the upper part of the former with the lower part of the latter.

"(e) When a small tangential velocity was imparted to the water entering the bellmouth B, the coefficients of discharge were practically unaltered but the critical head and flow were reduced considerably. At heads above critical, a permanent vortex was formed."

It was pointed out that the model tests were on such a small scale it would be unwise and unfair to attempt to apply the results to a larger structure quantitatively, especially for measurements of air.

Discussions of this paper are given in the Institution of Civil Engineers, vol. 16, March-October, 1941, pp. 451-459.

16. Bibliography of additional literature.

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2. Connor, A. P.

"Glory-Hole Spillway." Power Plant Engineering, November 1933.

Description of control at Owyhee Dam, Oregon, by ring gate, vertical spillway intake into a horizontal tunnel.

3. Jaeger, C.

"Notes sur le cacul des deversoirs de seuils." Bul. Technique de la Suisse Romande, v. 59, n 13 and 14, June 24, 1933, pp. 153-56, and July 8, pp. 166-69.

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4. Van Norman, H. A.

"Bouquet Canyon Reservoir and Dam." Civil Engineering, vol. 4, No. 8, August 1934, pp. 393-97.

A gen ıl description of the construction of Bouquet Canyon Dam, an earth-fill dam located about four miles east of Los Angeles, California, and used to store water from the Owens Valley Aqueduct. For a spillway, this dam uses a vertical shaft, or glory-hole, having an inside diameter of 8 feet, a drop of 163 feet, and designed for a maximum flood of 7,200 second-feet.

5. Anonymous.

"Tests of Shaft Spillway Models." Engineering News-Record, Oct. 17, 1935.

An outline of results of tests on a shaft spillway for the proposed Sulak Reservoir in northern Caucasia, U.S.S.R., and for a smaller shaft spillway for the Sion Reservoir. The shaft spillway for the Sulak Reservoir, 31 feet in diameter, with a vertical drop of 656 feet, was designed to pass a discharge of 60,000 second-feet. Air inlets were used to relieve negative pressures in the shaft. The smaller shaft, for the Sion Reservoir, had a capacity of 14,400 second-feet when the design was modified along the lines of the Owyhee shaft spillway in Oregon. Training walls were found necessary to prevent vortex action.

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Description of glory-hole type of spillway at Owyhee Dam in Oregon, noted for its unprecedented height of 309 feet, with 60-foot crest diameter, having 12-foot overflow height controlled with steel ring gate; description of gate controls and performance.

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Determination of capacity of weirs with fully rounded and partially rounded crests; formula and values of discharge coefficient appearing in Rehbock equation; mathematical and graphical method of calculation.

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Air was entrapped, with destructive results, in a vertical-shaft wasteway at the San Pablo Reservoir in California; changes in design to prevent free fall of water in air are expected to end trouble, an expectation confirmed by tests on a model of the revised design. (Air was ejected as exploding bubbles from the submerged exit portal and caused sufficient vibration to rupture the tunnel lining at the portal.)

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