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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES TO DETERMINE SPILLWAY DISCHARGE CURVES FOR ROSS DAM CITY OF SEATTLE, WASHINGTON

Hydraulic Laboratory Report No. Hyd-375

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

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Laboratory Report No. 375
Hydraulic Laboratory Section
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Subject: Hydraulic model studies to determine spillway discharge curves for Ross Dam, City of Seattle, Washington

This is the final report of results of hydraulic model studies to determine spillway discharge curves for Ross Dam according to Contract No. 14-06-D-313 between the Bureau of Reclamation and the City of Seattle dated March 9, 1953.

The studies were conducted on a 1:24 scale model of the left end bay and two adjacent bays of the right spillway, Figure 1. The three bays represented one-half of one spillway with 20- by 19-1/2-foot radial gates installed between typical piers according to Drawings No. D-13296, D-13297, and D-17009. Since the cross section of the spillways for each of the twelve bays is different below elevation 1573.54 feet, the two extreme cross sections, R-22 and L-2, down to the P.C.C. at elevation 1500 feet, were constructed and tested separately in the three bays, Figure 2. The overflow sections were constructed of sheet metal formed to the wooden piers, Figure 1, while the hood was formed from transparent plastic to permit observation of the flow under the deflector hood. Twelve piezometers were installed in the spillway face and deflector hood at intervals along the center line of the center bay. Flow through the model was measured and checked by two independent banks of venturi meters. The completed model in operation is shown in Figure 3.

Initially, the steeper overflow section, R-22, was installed in the three bays of the model. Discharge curves were obtained for free flow and equal gate openings of 2, 4, 6, 8, 10, 14, and 16 feet in the three bays. The gate opening was the vertical distance from the spillway crest to the bottom of the radial gate. The final discharge curves for one bay, shown as R-22 in Figure 4, were obtained by dividing the metered flow in the model by three. Gate openings of 1, 3, 5, 7, 9, 11, 12, and 13 feet were determined by interpolation and spot-checked by actual calibration tests.

Following the calibration of Section R-22, Overflow Section L-2 was installed in the model and sufficient points were obtained to check the two sections against each other.

Excellent agreement between the discharge curves for the two overflow sections was obtained at all partial gate openings and for free-flow discharges of less than 8,330 second feet per bay. For free-flow discharges above 8,330 second feet, the space between the deflector hood and the spillway face filled with water to varying degrees, Figure 5, and distinctly different curves were obtained for the two overflow sections, Figure 4. The submergence effect on the discharge over Section R-22 was negligible for discharges of less than 10,200 second feet per bay at reservoir elevation 1607 feet, although water was splashing over the top of the hood in two of the bays, Figure 5A. However, with Overflow Section L-2 installed, the capacity of the spillway was limited to 9250 second feet per bay at maximum reservoir elevation of 1608 feet. Between reservoir elevations 1606 and 1608 feet, part of the flow passed over the top of deflector hood, Figure 5B. The following table shows a comparison of the flow conditions for the two overflow sections at discharges exceeding 8,330 second feet per bay:

Overflow Section	Submergence begins to affect discharge		Flow begins to overtop hood		Discharge at max res el 1608'
	Res el	Q in cfs	Res el	Q in cfs	cfs
R-22	1606'	9,580	1607'	10,160	10,600±
L-2	1604.2'	8,420	1606'	8,750	9,250

Since the cross-sectional shape of 10 of the 12 spillway bays fall between the two extreme test shapes, R-22 and L-2, determination of the discharge curve above reservoir elevation 1604 feet was made by interpolating discharge values for each bay between the limiting values found for Overflow Sections R-22 and L-2. Interpolation was based on a straight line variation in the horizontal distance from the upstream nose of the piers to the spillway face of each bay at elevation 1500 feet. The discharges for the 12 bays were then averaged to obtain the estimated mean discharge per bay as shown by the broken line on Figure 4.

To determine the effect of end contractions on the discharge, extensive tests were made with a single gate and with two adjacent gates operating, both fully open and partially open. At partial gate openings, no measurable difference between the discharge per bay could be detected when either one, two, or three gates were partially open. Therefore, the partial gate opening curves of Figure 4 are equally applicable regardless of the number of gates

operating or their relative positions. For free flow, a slight difference in discharge, due to the end contractions at the piers, was observed when only one or two gates are discharging at reservoir elevations exceeding 1591 feet, Figure 6. The percentage difference in discharge is as follows:

Reservoir elevation	Discharge per bay for one-half of one spillway	% decrease in Q per bay	
		One gate operating	Two adjacent gates operating
1,590	1,600	0	0
1,596	3,940	3.3	2
1,601	6,500	3.9	2.2

Below reservoir elevation 1591 feet, the discharge per bay is the same regardless of the number of gates operating. It is evident from the above table and Figure 6 that the percentage difference in discharge decreases as more gates are raised. Therefore, when three or more adjacent gates are operating, the free-flow discharge per gate will closely approximate the discharge shown in Figure 4. If extreme accuracy is desired for discharges greater than 2,000 second feet per bay for releases through one or two adjacent gates, corrections may be applied to the free-flow discharge curve in Figure 4 as indicated in Figure 6.

Several photographs were taken to record the approach conditions to the spillway and the flow conditions under the deflector hood. Figure 7 shows the general approach pattern and contractions at the end piers when one to three gates are fully open. Those photographs indicate to some extent the reason for variations in discharge per bay for one, two and three bays discharging. Flow conditions under the hood with three gates fully open for Overflow Sections R-22 and L-2 are shown in Figures 8 and 9 at discharges of 2,080, 4,160, 6,250, and 8,330 second feet per bay.

Piezometric pressures were observed on both overflow sections for the complete range of discharges. The locations of the piezometers are shown in Figure 10. Figure 11 shows the observed pressures, expressed in prototype feet of water, for discharges of approximately 8,500 second feet per bay.

In general, lower pressures were observed on the deflector hood and spillway face of the steeper overflow section, R-22. The lowest recorded pressure, 10 feet of water below atmospheric at elevation 1550 feet on Overflow Section R-22, is approximately the same as

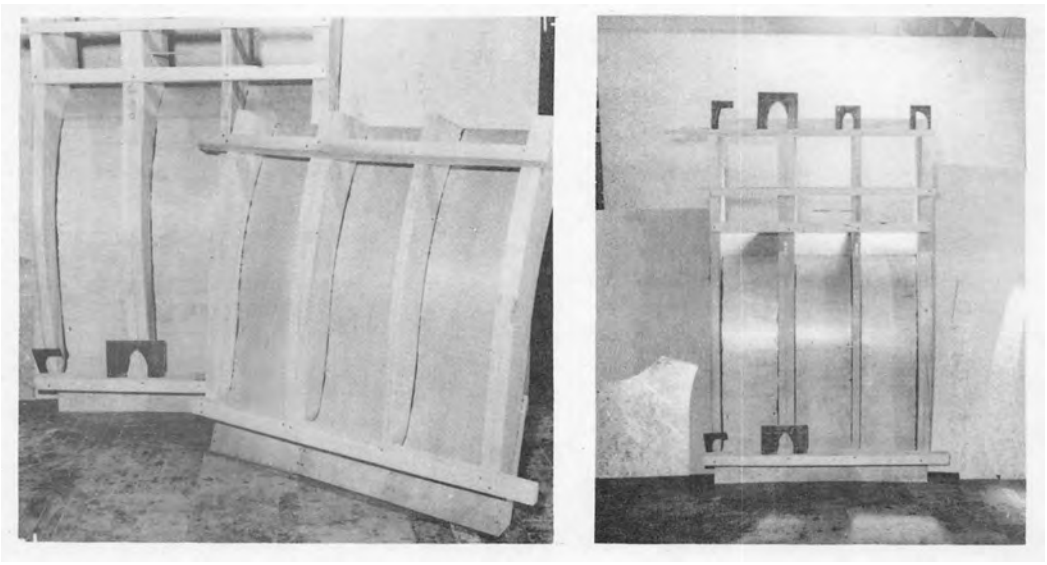
that observed on Overflow Section 9 in the 1946 model studies.1/ The lowest observed pressure on Overflow Section L-2 was minus 3 feet of water at elevation 1580 feet, which compares favorably with the pressures observed on Overflow Section 10 of the 1946 model studies. Considerably higher pressures were recorded at elevations below 1,550 feet on both overflow sections, since the space between the deflector hood and the spillway face filled with water at the lower elevations, Figure 9.

The final discharge curves resulting from the model study are shown in Figure 12, which was prepared for field use. Figure 12, which includes appropriate notes to aid the operator in using the discharge curves, is essentially the same as Figure 4 except for the omission of experimental data, such as calibration points and separate discharge curves for the two test sections. Figure 12 should be used, as indicated on the figure, to determine discharges for all ordinary operating procedures. The corrections indicated on Figures 4 and 6 should be used only to obtain greater accuracy at (1) near capacity flows with all gates fully open or (2) discharges through a single gate or two adjacent gates fully open with headwater above 1591.

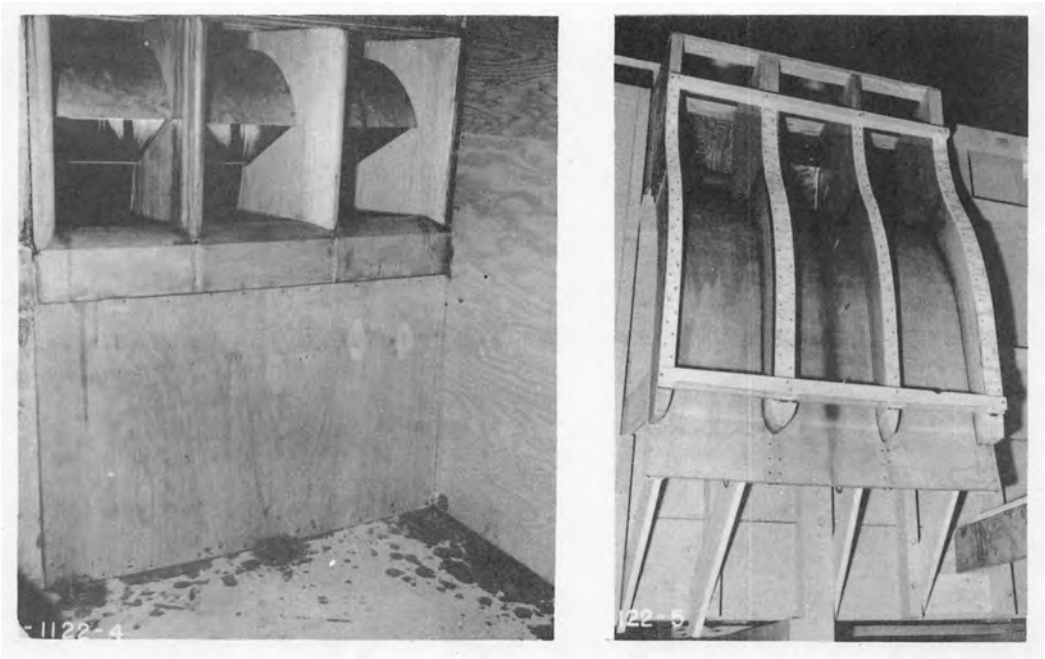
There has been prepared for the City of Seattle a full-scale, original-type linen of Figure 12, from which additional discharge curves may be reproduced to meet their requirements.

1/ Hydraulic Laboratory Report No. Hyd-207, "Hydraulic Model Studies on the Spillways and the Howell-Bunger Valve Hoods and a Proposed Ice Prevention System--Ross Dam."

FIGURE 1



Overflow Section R-22 and L-2 under construction



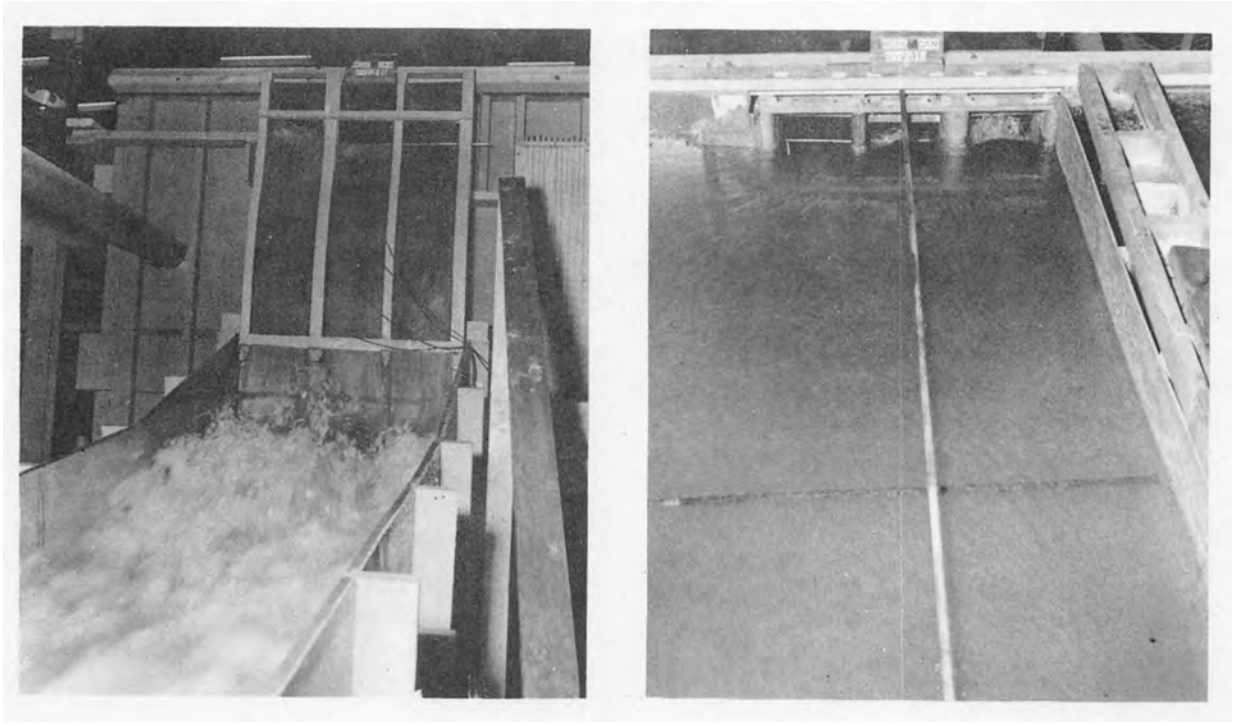
Overflow Section R-22 installed in the headbox

ROSS DAM SPILLWAY
1:24 Scale Model

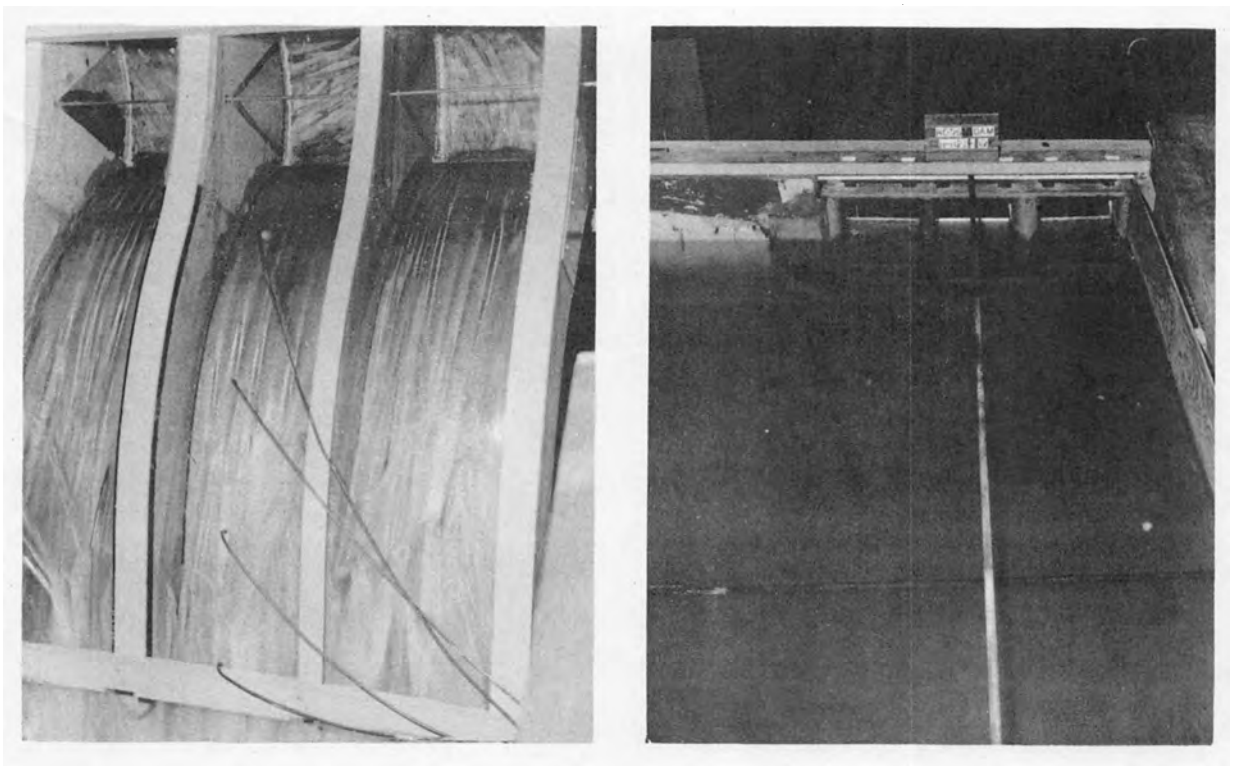
FIGURE 2

RCSS Dam SPILLWAY
Overflow Sections R-22 and L-2
1/2" Scale Model

FIGURE 3



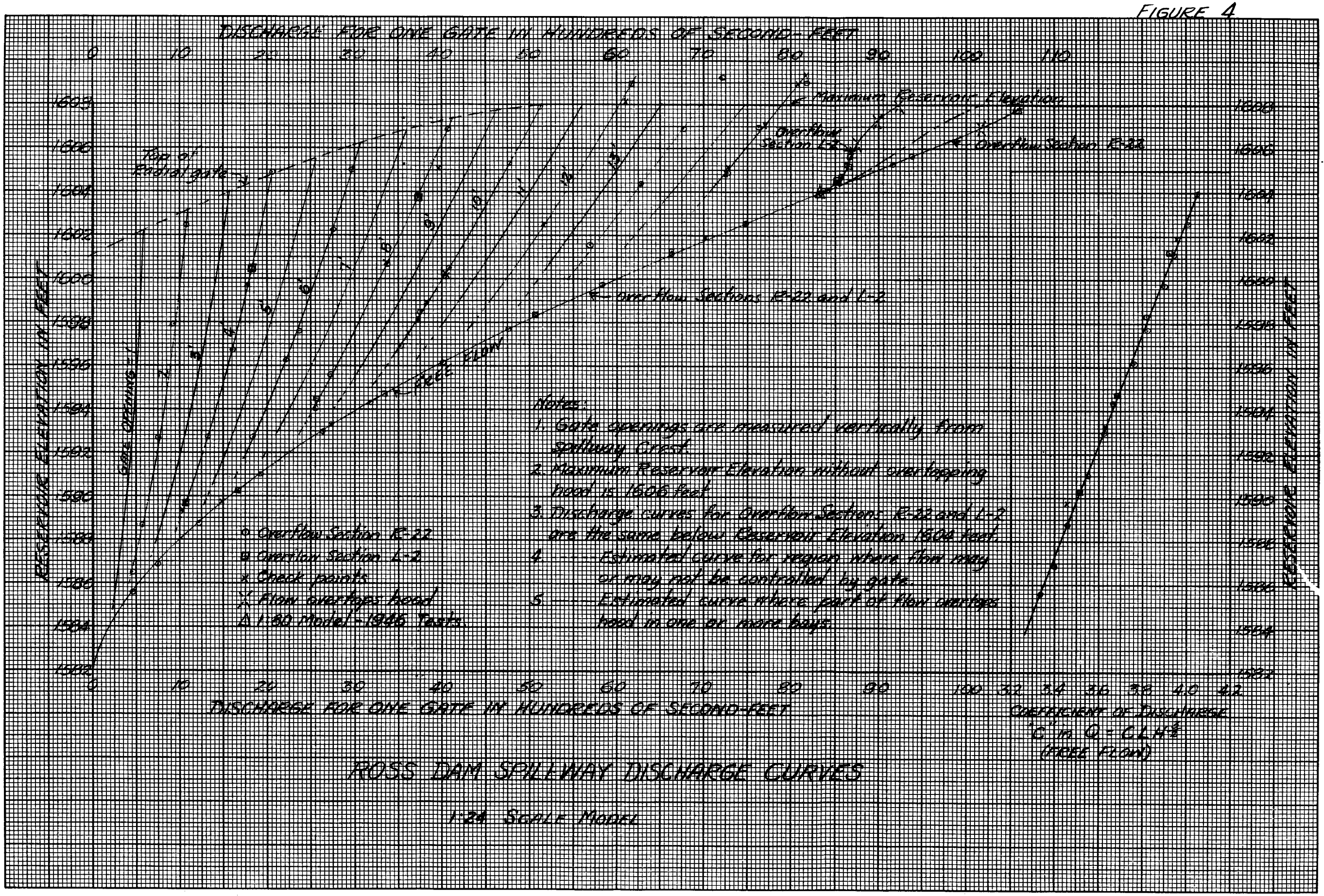
The completed model discharging 9, 500 second-feet per bay



2-Foot gate opening - Discharge = 580 second-feet per bay

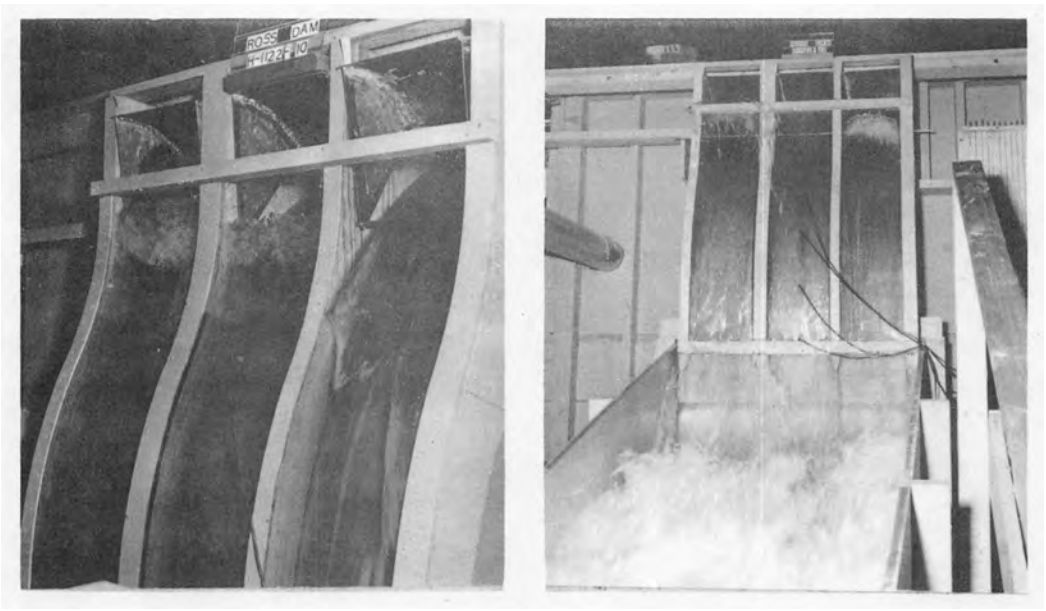
ROSS DAM SPILLWAY
Overflow Section R-22
1:24 Scale Model

FIGURE 4



ROSS DAM SPILLWAY DISCHARGE CURVES

1:24 Scale Model



Discharge = 9, 500 cfs at
Reservoir Elevation 1605.8 feet

Discharge = 10, 200 cfs at
Reservoir Elevation 1607 feet

A. Overflow Section R-22

Discharge = 8, 700 cfs at
Reservoir Elevation 1605.8 feet

Discharge = 9, 200 cfs at
Reservoir Elevation 1608 feet

B. Overflow Section L-2

ROSS DAM SPILLWAY
Operation of Overflow Sections R-22 & L-2
1:24 Scale Model

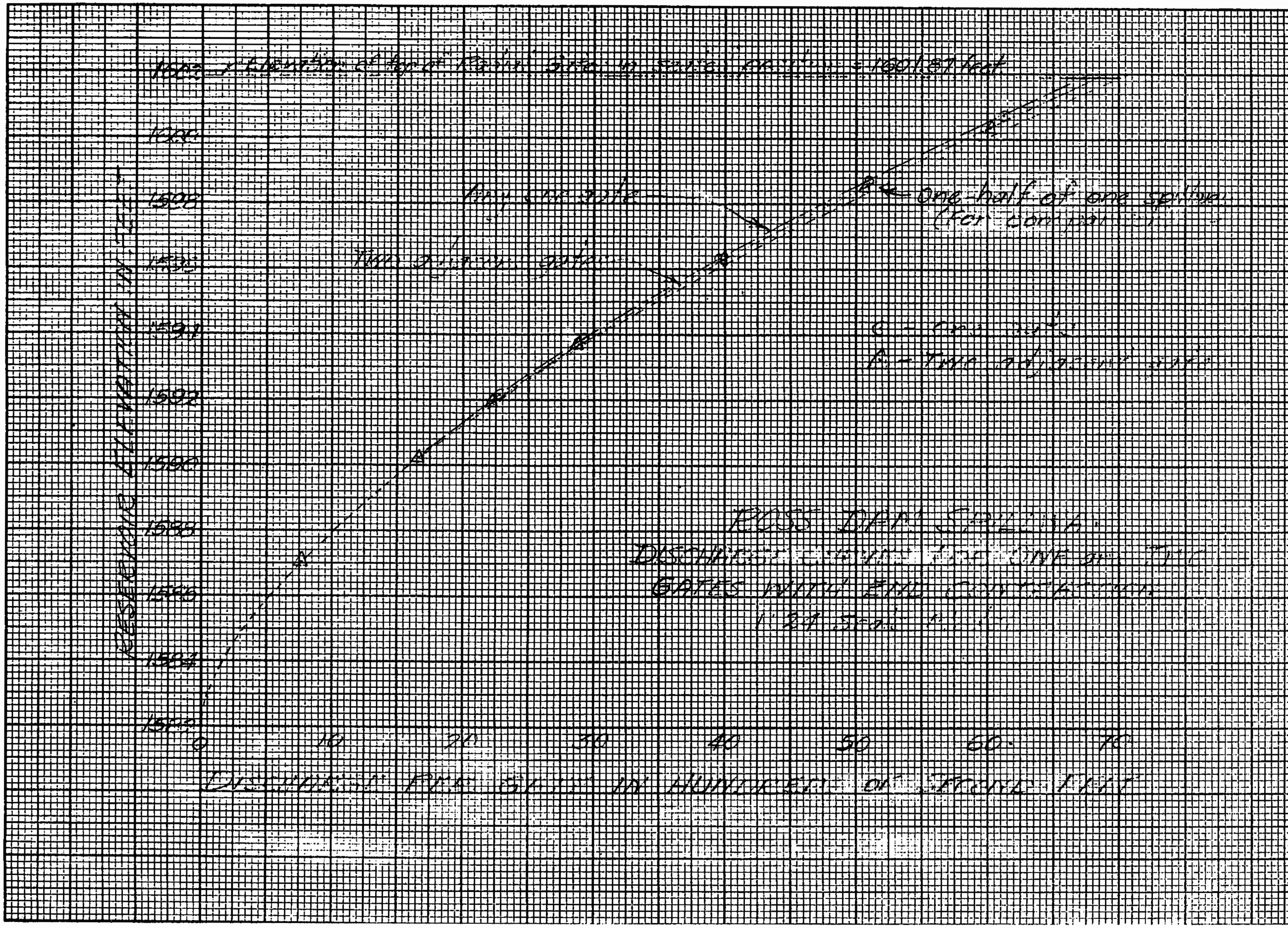
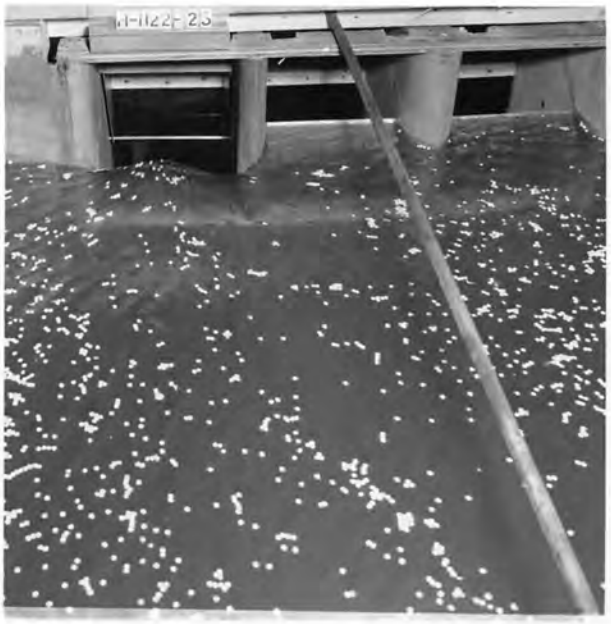

RESERVOIR ELEVATION IN FEET
1590
Any one gate
Two adjacent gates
one half of one spillway
ROSS DAM SPILLWAY
GATES WITH END CONTRACTION
0
10
20
30
40
50
60
70

FIGURE 6

FIGURE 7



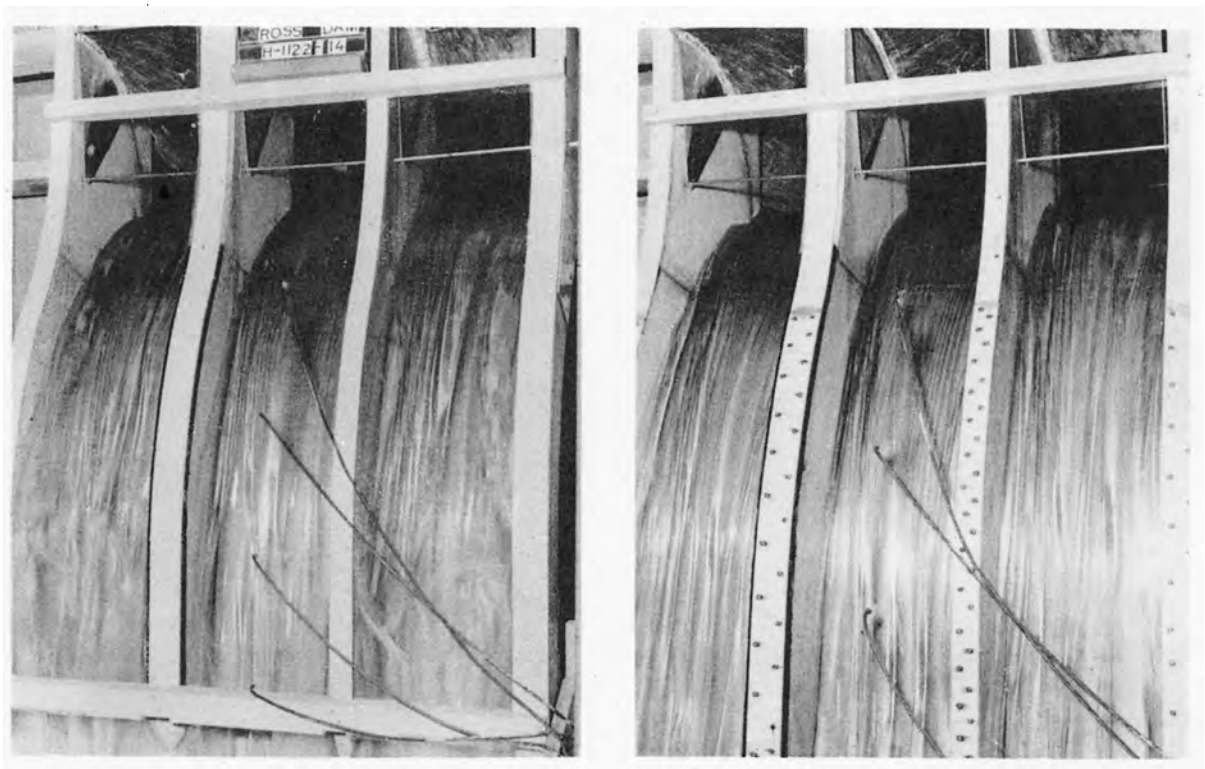
Left end bay discharging
5, 800 second-feet

Two adjacent bays discharging
11, 500 second-feet

Three bays discharging
14, 200 second-feet

Three bays discharging
26, 000 second-feet

ROSS DAM SPILLWAY
Approach Conditions with One to Three Gates Open
1:24 Scale Model



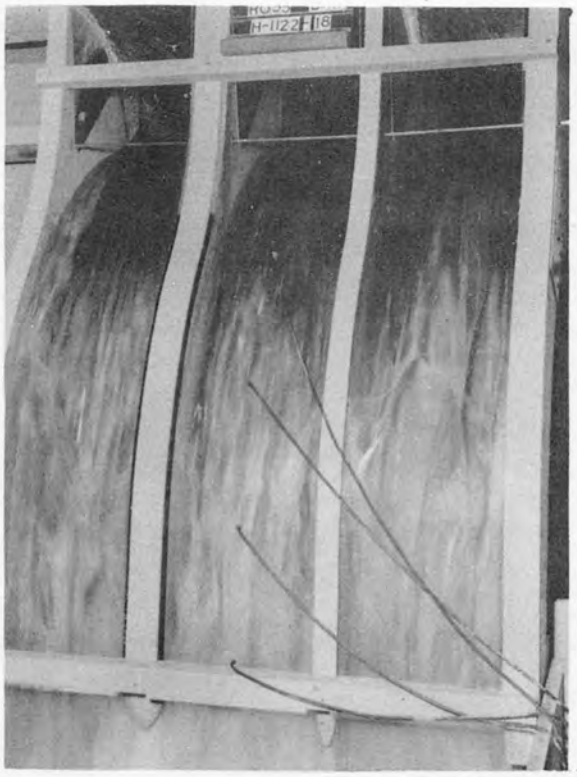
Overflow Section R-22 | Overflow Section L-2

Discharge = 2,080 second-feet per bay

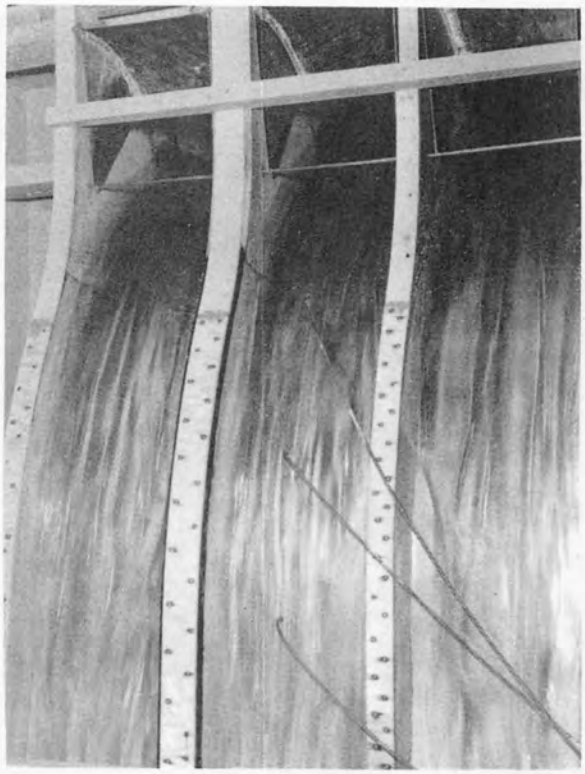
Overflow Section R-22 | Overflow Section L-2

Discharge = 4,160 second-feet per bay

ROSS DAM SPILLWAY
1:24 Scale Model

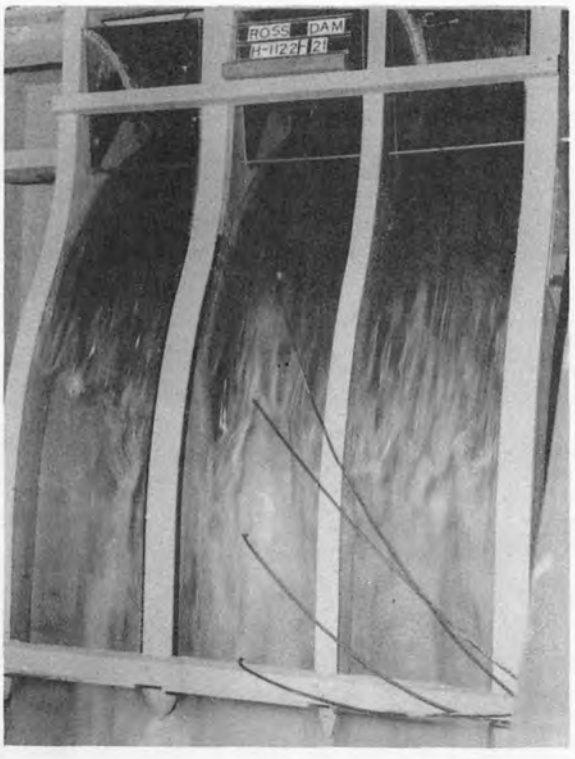


Overflow Section R-22

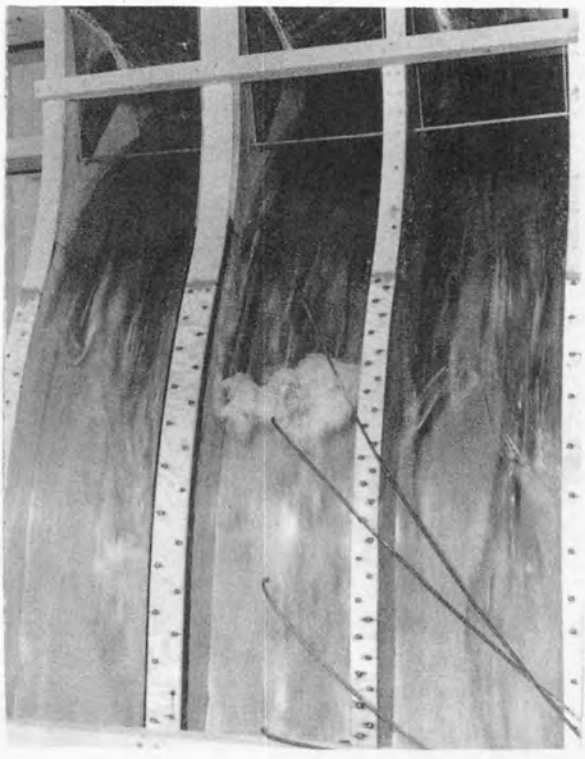


Overflow Section L-2

Discharge = 6, 250 second-feet per bay



Overflow Section R-22

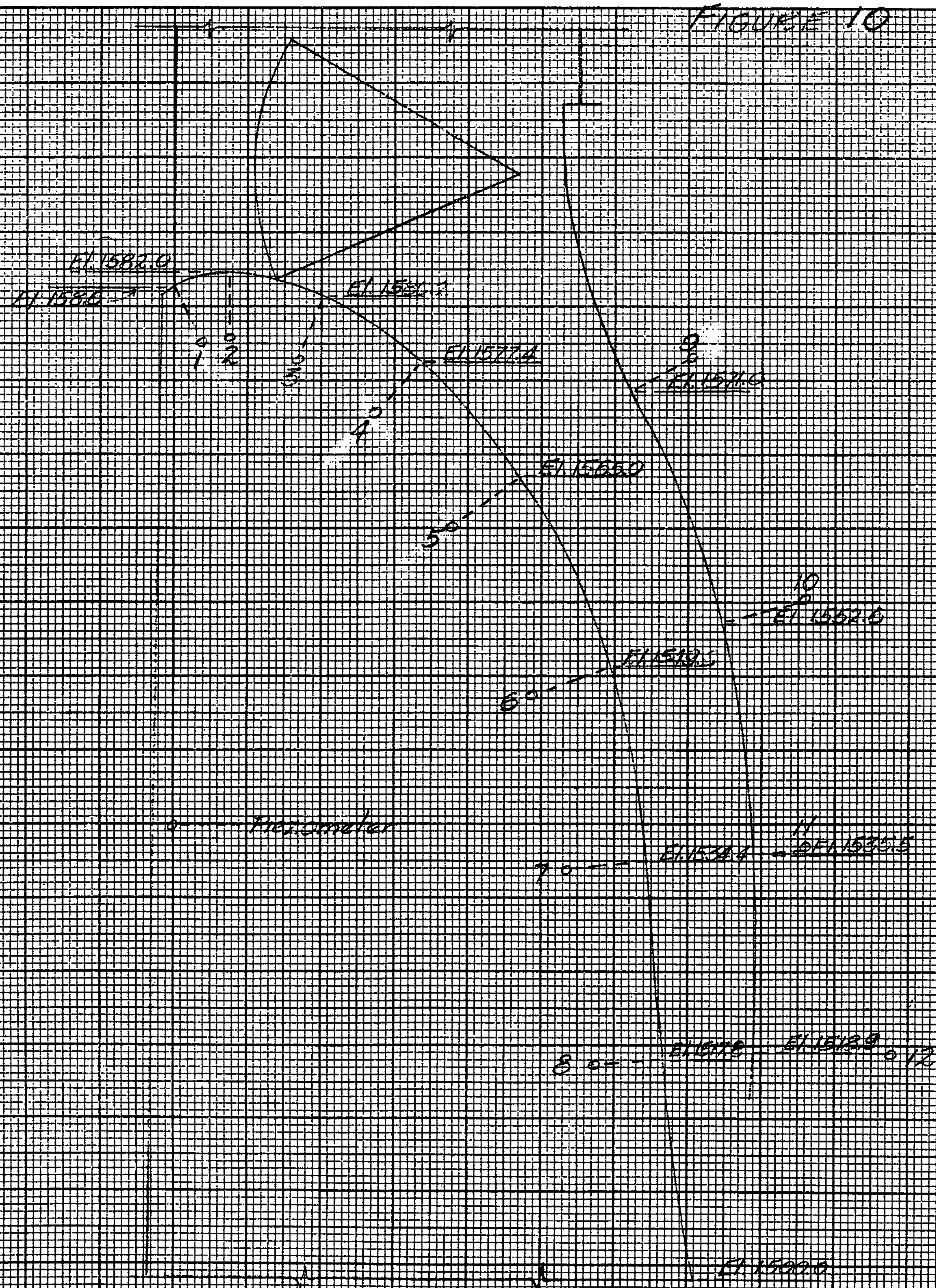


Overflow Section L-2

Discharge = 8, 330 second-feet per bay

ROSS DAM SPILLWAY
1:24 Scale Model

FIGURE 10



ROSS DAM SPILLWAY
PIEZOMETER LOCATIONS
1:24 Scale Model

FIGURE 11

	Discharge cfs		Res. Elev. in Ft.
	12 gate	1 gate	
Overflow Section R-22	100,000	8,333	1603.94
	110,000	9,167	1605.23
Overflow Section L-2	100,460	8,371	1604.06
	102,500	8,550	1604.63

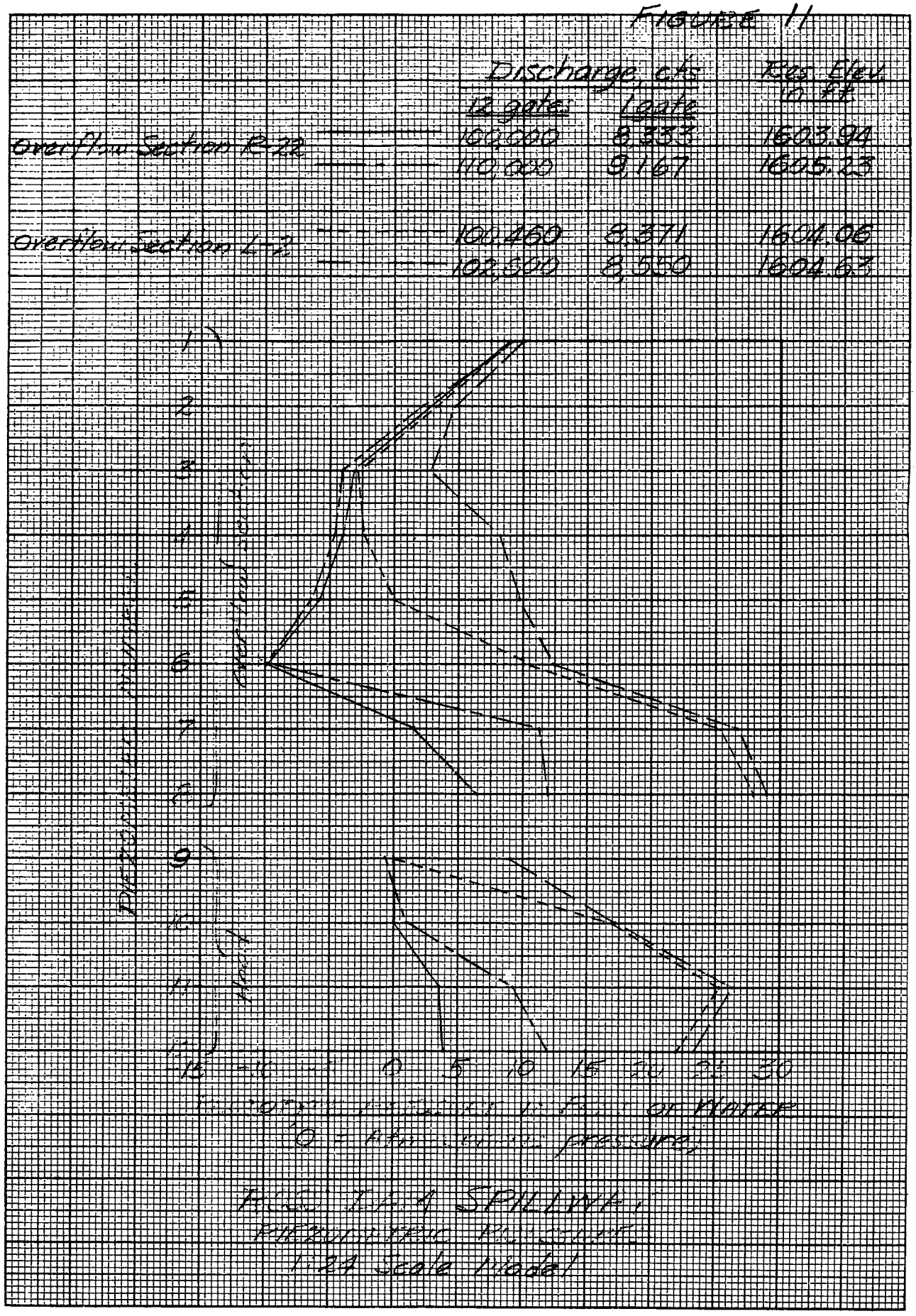


FIGURE 12

DISCHARGE FOR ONE GATE IN HUNDREDS OF SECOND FEET

--------Estimated curve for region where flow may or may not be controlled by gates.
-·-·-·-Estimated curve where part of flow over-tops hood in one or more bays.

MAXIMUM RESERVOIR ELEVATION

TOP OF GATE

GATE OPENING = 1'

2' 3' 4' 5' 6' 7' 8' 9' 10' 11' 12' 13' 14' 15' 16'

FREE FLOW

RESERVOIR ELEVATION IN FEET

1610 1608 1606 1604 1602 1600 1598 1596 1594 1592 1590 1588 1586 1584 1582

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110

Crest ℄

Gate opening measured vertically from crest

NOTES

1. Gate opening is measured from the spillway crest. (See sketch)
2. Discharge curves are for one gate. Add discharge through each gate to obtain total flow over spillways.
3. Open gates in the following order: 4,3,2,1,5 and 6; reverse the order in closing. (Gates on each spillway are numbered consecutively from the center of the arch toward the abutments.)
4. Operate the two spillways symmetrically whenever possible.

CITY OF SEATTLE - LIGHTING DEPARTMENT

ROSS DAM

SPILLWAY DISCHARGE CURVES

FOR ONE 20' x 19'-6" RADIAL GATE

BASED ON 1:24 SCALE MODEL OF THREE BAYS

TESTED BY ENGINEERING LABORATORIES BRANCH, BUREAU OF RECLAMATION, DENVER, COLORADO. JUNE 5, 1953.

DISCHARGE FOR ONE GATE IN HUNDREDS OF SECOND FEET

3.2 3.4 3.6 3.8 4.0 4.2

COEFFICIENT OF DISCHARGE "C" IN $Q = CLH^{3/2}$ (FREE FLOW)

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