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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE 2- BY 2-FOOT TWIN BUTTES REGULATING GATE SAN ANGELO PROJECT--TEXAS

Hydraulic Laboratory Report No. Hyd-476

DIVISION OF ENGINEERING LABORATORIES

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CONTENTS

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Laboratory Report No. Hyd-476
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Subject: Hydraulic model studies of the 2- by 2-foot Twin Buttes regulating gate--San Angelo Project, Texas

PURPOSE

The purpose of this study was to develop a satisfactory shape for the bellmouth which must be fitted within the relatively short distance between the upstream and downstream faces of the fixed-wheel gate. In addition, flow conditions in the conduit downstream from the gate leaf were studied and a head-discharge curve for various gate openings was determined.

CONCLUSIONS

1. The elliptical bellmouth entrance of the form

$$\frac{X^2}{D^2} + \frac{Y^2}{(D/3)^2} = 1$$

results in satisfactory pressures for this application.

2. Slightly subatmospheric pressures are found in the top and bottom corners of the bellmouth entrance immediately upstream from the gate slot. The magnitude of the maximum subatmospheric pressure is 2 feet of water with 100 percent gate opening and maximum water surface elevation in the reservoir. The pressures are all above atmospheric in the bellmouth entrance for gate openings less than 100 percent.

3. The maximum subatmospheric pressure in the conduit downstream from the gate slot is 5 feet of water. This pressure occurs in the bottom corners of the conduit immediately upstream from the downstream face of the fixed-wheel gate. The lowest pressure occurs at a gate opening of 30 percent and maximum reservoir elevation. For gate openings greater than 60 percent, the pressures in the downstream conduit are equal to or greater than atmospheric.

4. The discharge coefficient, $C_d = \frac{Q}{A\sqrt{2gH}}$, for 100 percent gate opening is 0.93.

5. For reservoir elevations greater than 1920, the jet will clear the radial gate seat.

6. For gate openings between 10 and 70 percent, crossflow and spray are present on top of the nappe.

7. To prevent objectionable operating conditions at small gate openings, the gate should not operate at openings of less than 2 inches for extended periods.

8. The 2- by 2-foot regulating gate should not be opened more than 25 percent when filling the space between the fixed-wheel and radial gates.

ACKNOWLEDGMENT

The development and testing of the bellmouth entrance and gate described in this report were the result of the cooperative efforts of the Mechanical Branch, the Dams Branch, and the Hydraulic Laboratory Branch.

INTRODUCTION

Twin Buttes Dam is located across the Middle Concho River, Spring Creek, and the South Concho River about 9 miles southwest of San Angelo, Texas, Figure 1. The dam will be an earthfill structure with a crest length of 8 miles and will rise about 134 feet above the Middle Concho riverbed.

The outlet works, Figure 2, is located near the left abutment of the dam and is designed for a maximum discharge of 34,000 cfs. The outlet works consist of an intake structure, three 15.5-foot-diameter conduits from the intake structure to the gate chamber, three 12- by 15-foot emergency fixed-wheel gates located just upstream from three 12- by 15-foot topseal radial regulating gates, three 17-foot-diameter horseshoe conduits from the gate chamber to the stilling basin chute, the chute, a stilling basin, and an excavated channel extending from the stilling basin to the river, Figure 3.

Located within each of the three 12- by 15-foot emergency fixed-wheel gates is a 2- by 2-foot regulating gate. The purpose of the three small 2- by 2-foot gates is to release flows up to 600 cfs. For flows greater than 600 cfs, the 12- by 15-foot fixed-wheel gates will be opened, and outlet releases will be made through the three 12- by 15-foot topseal radial regulating gates.

Placing the 2- by 2-foot regulating gate in the fixed-wheel gate required fitting a bellmouth entrance and gate within the relatively short distance between the upstream and downstream faces of the fixed-wheel gate. It was, therefore, necessary to investigate the pressures in the bellmouth and in the short conduit downstream from the gate leaf to determine if critical subatmospheric pressures would occur. Flow conditions and head-discharge relationships are also presented in this report.

THE MODEL

The studies were conducted on a 1:5 scale model of the bellmouth entrance, gate leaf, and conduit downstream from the 2- by 2-foot regulating gate. The 15.5-foot-diameter conduit upstream from the fixed-wheel gate was represented in the model by a 3-foot-diameter tank 6.4 feet long, Figure 4. The short transition just upstream from the 12- by 15-foot fixed-wheel gate was not represented in the model. The inlet end of the tank was connected to a 12-inch main by a transition 1.6 feet long. A baffle placed in the inlet end of the tank distributed the flow to simulate the flow conditions in the 15.5-foot-diameter conduit.

Discharges in the model were measured with calibrated venturi meters located permanently in the laboratory. Reservoir head was measured by means of a piezometer tap in the side of the 3-foot-diameter tank. The piezometer tap was connected to a direct reading differential manometer (pot gage). Piezometers were placed in probable low pressure regions on the bellmouth entrance and downstream conduit, Figure 5. The pressures acting on the piezometers were measured with single-leg, water-filled manometers mounted on a manometer board. Pressures that exceeded the range of the manometer board were read on a mercury-filled pot gage.

THE INVESTIGATION

In testing the model, a series of runs were made with a head equivalent to the maximum reservoir surface above the gate center line, or 101 feet prototype. Then, a series of runs were made with a head equivalent to the normal operating head of 56 feet. Finally, a run was made at 100 percent gate opening with a head equal to twice the maximum reservoir elevation above the gate. The pressures at each piezometer, the discharge, and head on the gate center line were determined for each run. In computing the reservoir head, the hydraulic losses were ignored because their magnitude from the reservoir to the gate was only 0.05 foot (prototype).

Bellmouth Entrance Design

Considerable data are available for shaping the bellmouth entrance to rectangular conduits. The entrant flow surfaces usually follow elliptical curves based on the height or width of the conduit. However, three factors in bellmouth design that have not fully been investigated are: (1) the effect of ending portions of the bellmouth before the full curvature has been developed, (2) the effect of seating a gate on the curved portion of the bellmouth, and (3) the effect of a short length of downstream conduit. These three factors became important in fitting the streamlined entrance and small regulating gate between the upstream and downstream faces of the 12- by 15-foot fixed-wheel gate. A trial curve was formulated for the bellmouth shape from data presented in Technical Memorandum No. 2-428, U. S. Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. This curve,

$$\frac{X^2}{D^2} + \frac{Y^2}{(D/3)^2} = 1$$

where

X = distance from the minor axis of the ellipse

Y = distance from the major axis of the ellipse

D = dimension of the conduit in the direction concerned, 22.5 inches in this bellmouth

was then tested in a water model for critical subatmospheric pressures and to determine discharge-gate opening relationships. Tests on the bellmouth entrance, indicated below, show this curve to be satisfactory.

Bellmouth and Downstream Conduit Pressures

In order to facilitate the comparison of pressures at various points in the model under various heads, the following pressure coefficient was used:

$$C_p = \frac{h_t - h_x}{h_t}$$

where

C_p = pressure coefficient

h_t = total head at center line of gate

h_x = piezometric head at the piezometer

Figures 6, 7, 8, 9, 10, and 11 are plots of these pressure coefficients for various gate openings.

The model tests show this coefficient to be independent of reservoir head. Thus, the pressure gradient can be computed for any reservoir head by expressing the pressure data in this dimensionless form.

The only subatmospheric pressures on the bellmouth entrance are found in the corners immediately upstream from the gate slot for maximum gate opening. With the reservoir at the maximum water surface elevation and the gate 100 percent open, the average subatmospheric prototype pressure is 2 feet of water. A pressure fluctuation of ±1.7 feet of water with a frequency of 33 cps is superimposed on the average subatmospheric pressure. These instantaneous pressures were measured with a pressure transducer placed on the critical piezometers.

In general, the downstream conduit pressures are lowest near the downstream end of the conduit. In fact, subatmospheric pressures exist in the corners and on the sides of the conduits for less than 70 percent gate openings. The minimum pressure occurs at a gate opening of 30 percent with the reservoir at the maximum water surface elevation when an average subatmospheric pressure of 5 feet of water was recorded. A pressure fluctuation of only ±0.6 foot of water is superimposed on the average subatmospheric pressure with a frequency of 31 cps at the downstream corners of the downstream conduit.

Discharge Coefficient

Several reservoir heads and discharge readings were obtained for gate openings in increments of 10 percent, and in addition, for 5 and 95 percent gate openings. The expression used to determine the discharge coefficient is $Q = C_d A \sqrt{2gH}$

where

Q = discharge in cfs

C_d = discharge coefficient

A = area of actual gate opening; or area of gate opening when 100 percent open

H = reservoir head on the center line of the gate opening

The discharge coefficient for the gate fully open was found to be 0.93. Discharge coefficients for the full range of gate openings are given in Figure 12.

Flow Characteristics

At partial gate openings, a crossflow was noticed on top of the nappe, Figure 13. Water leaving the upstream edge of the gate slot spread into the slot and impinged upon the downstream slot corner. This flow in the slot was then deflected across the top of the jet, causing a rough surface and considerable spray. The jet also impinged upon the walls of the downstream conduit, forming a fin of water on each side of the nappe. These fins are most prominent for gate openings between 20 and 50 percent.

At 100 percent opening, the center portion of the nappe struck the crown of the downstream conduit, causing only minor spray; but the corners of the conduit were fully aerated.

The model tests showed that the free jet coming from the 2- by 2-foot regulating gate does not strike the seat of the 12- by 15-foot radial gate, Figure 2, for reservoir elevations greater than 1920.

PROTOTYPE DESIGN CHANGES

After the completion of the model tests, the following changes were made in the prototype design: (1) gate leaf moved upstream 1 inch, (2) top and bottom of bellmouth moved inward to maintain 1-foot 11-3/4-inch height of opening, (3) sides of bellmouth moved inward to maintain 24-inch width of opening, (4) sides of downstream conduit moved outward 1/2 inch; new width is 2 feet 2-3/4 inches, and (5) top of downstream conduit unchanged. These changes were required to provide proper balance in the 12- by 15-foot fixed-wheel gate.

These alterations should have no effect upon the coefficients of discharge noted in this report. The magnitude of the subatmospheric pressures in the downstream conduit should decrease. It is also expected that the severity of the crossflow and splashing will decrease with the aforementioned changes.

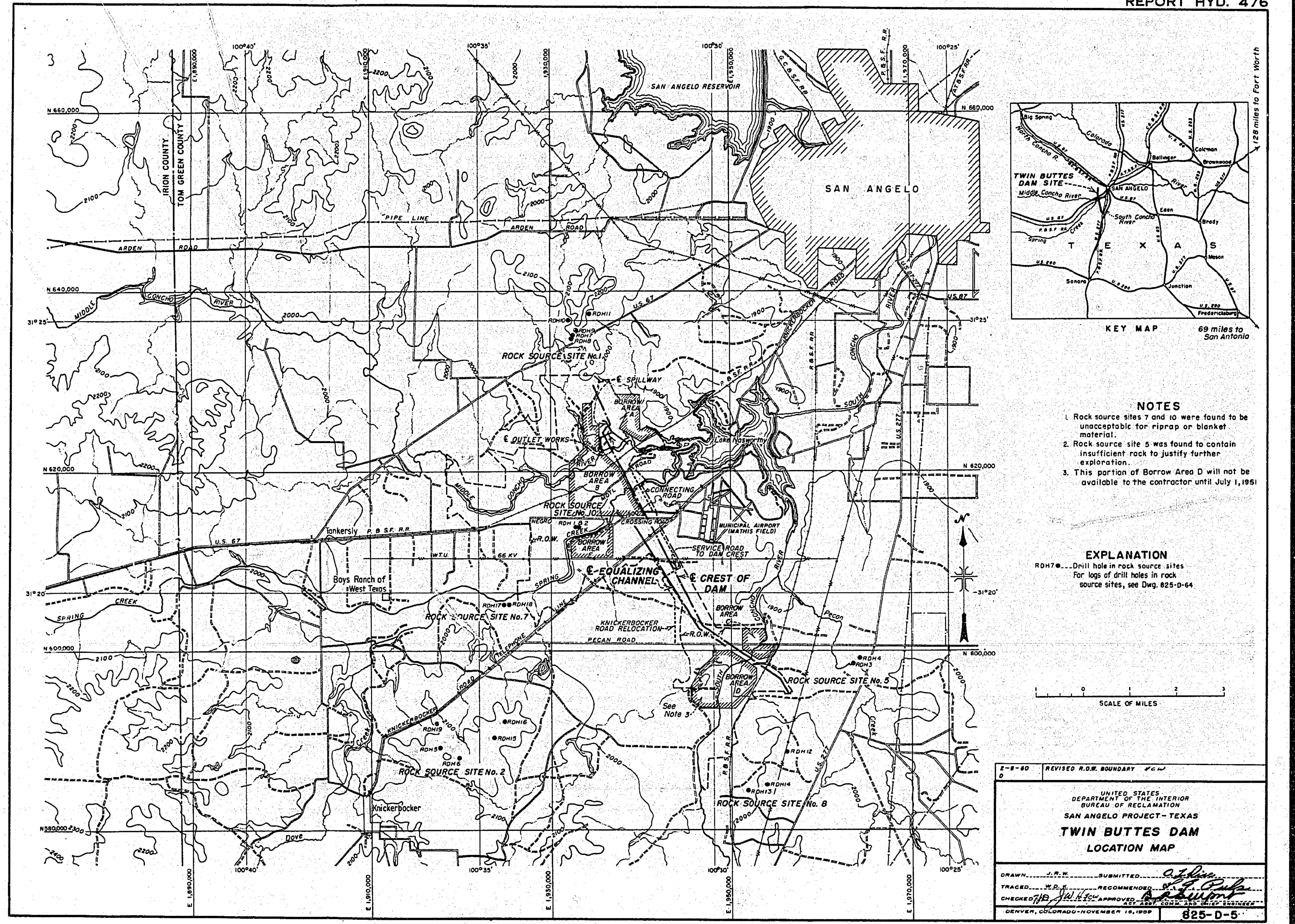
Limitations on Operation of Gate

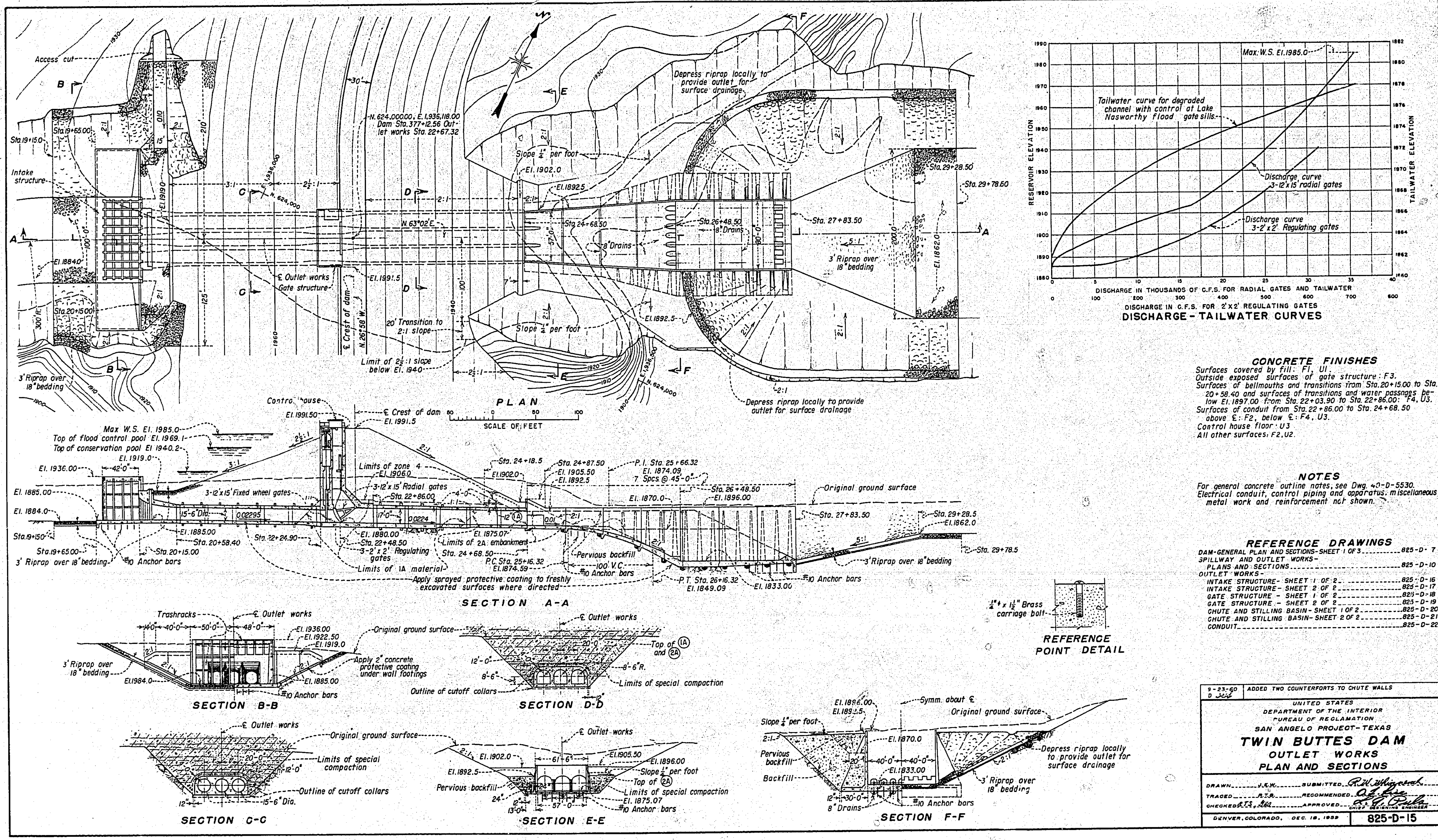
The model tests indicate that the gate will operate satisfactorily at free discharge through the full range of gate openings from 5 percent to 100 percent.

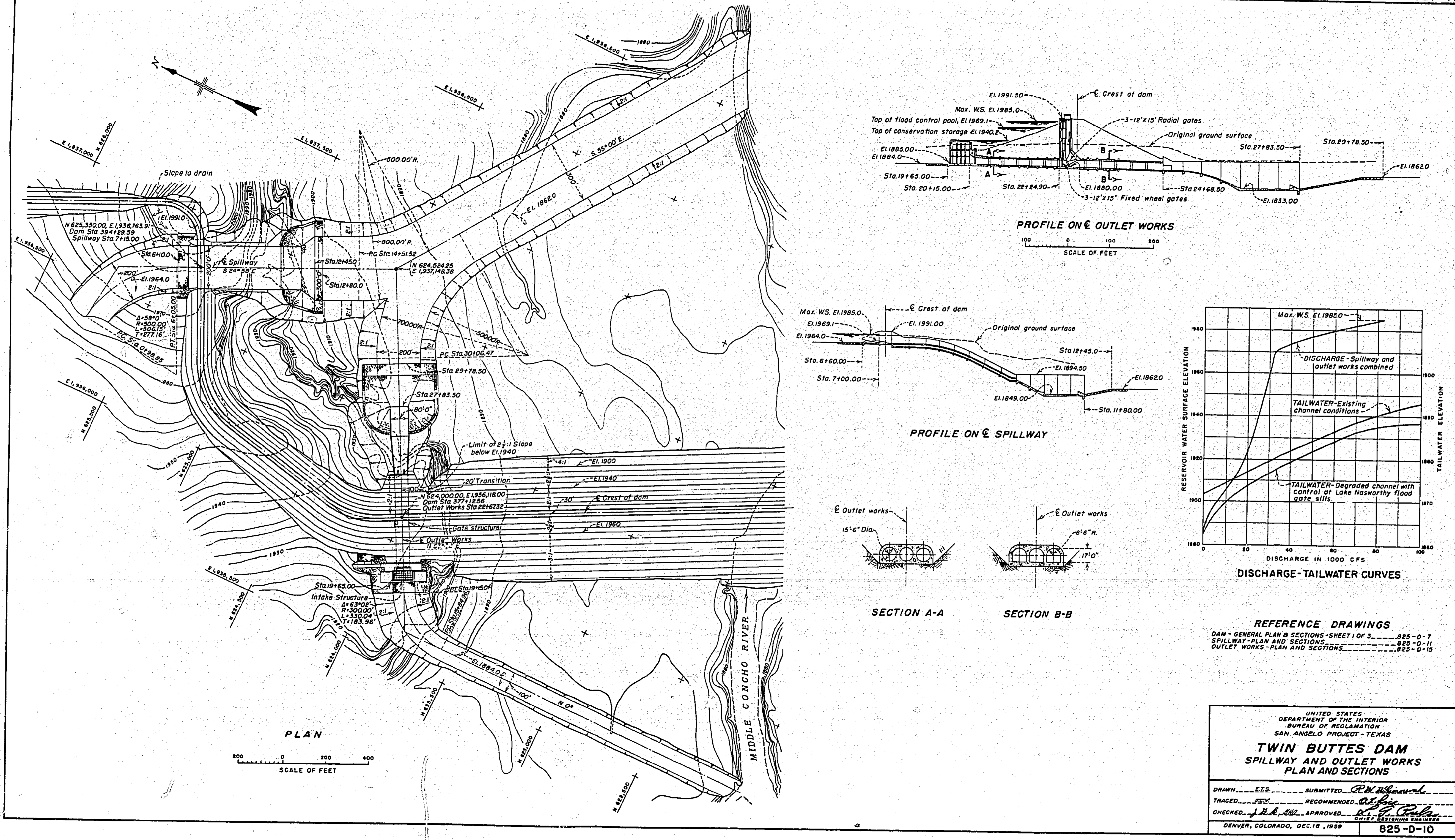
Computations show, however, that the jet contraction is such that the top of jet will strike the bottom gate seal at gate openings less than 1 inch. To prevent vibration in the gate when the space between the spring point and bottom gate seal fills, as in a short tube, and allowing for inaccurate gate settings and imperfections in the spring point, it is recommended that the gate should not be operated for extended periods at gate openings less than 2 inches.

The regulating gate is not designed to operate submerged at low back pressures. It may be necessary, however, to operate the gate submerged while filling the tunnel space between the 12- by 15-foot fixed-wheel gate and radial gate. During this tunnel-filling operation, it is recommended that the 2- by 2-foot gate be opened no more than 25 percent to permit maximum water circulation in the short conduit immediately downstream from the gate leaf.

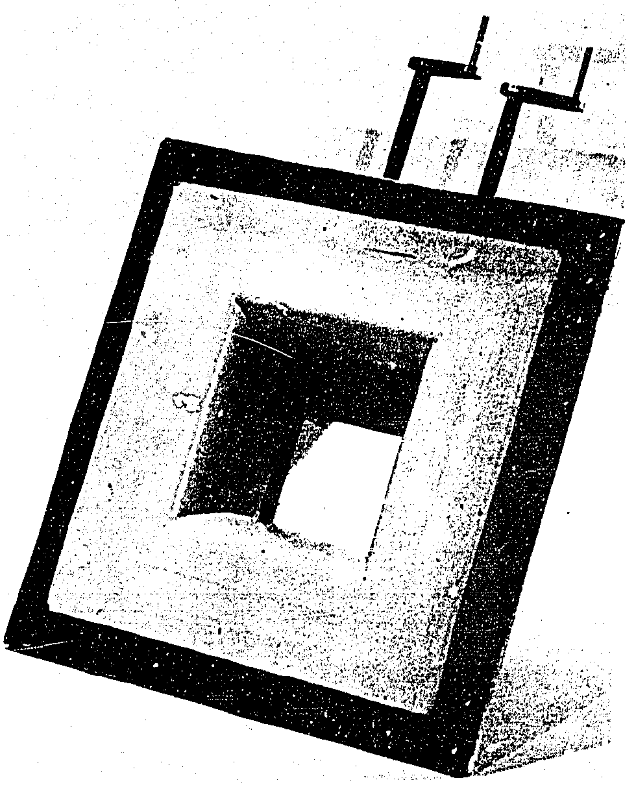
FIGURE 1
REPORT HYD. 476



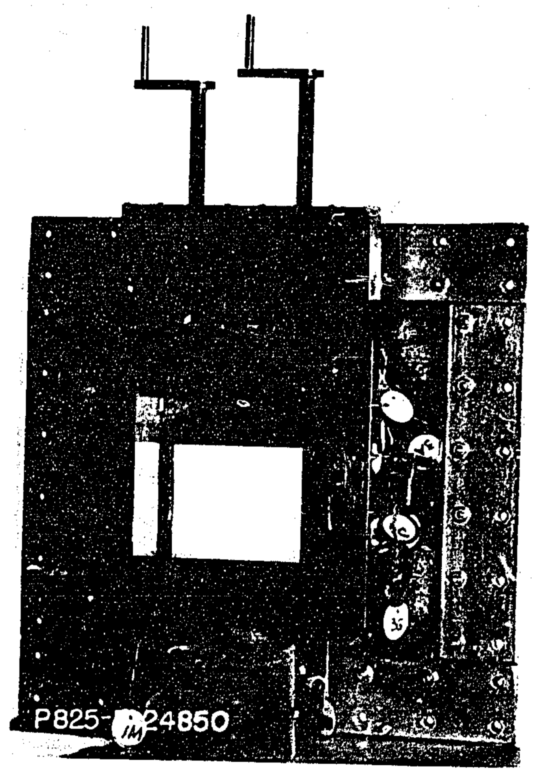

PLAN
SCALE OF FEET
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
REFERENCE POINT DETAIL
1/4" x 1 1/2" Brass carriage bolt
DISCHARGE - TAILWATER CURVES
RESERVOIR ELEVATION
TAILWATER ELEVATION
DISCHARGE IN THOUSANDS OF C.F.S. FOR RADIAL GATES AND TAILWATER
DISCHARGE IN C.F.S. FOR 2'x2' REGULATING GATES
Max. W.S. El. 1985.0
Tailwater curve for degraded channel with control at Lake Nasworthy flood gate sills.
Discharge curve 3-12'x15' radial gates
Discharge curve 3-2'x2' Regulating gates
CONCRETE FINISHES
Surfaces covered by fill: F1, U1.
Outside exposed surfaces of gate structure: F3.
Surfaces of bellmouths and transitions from Sta. 20+15.00 to Sta. 20+58.40 and surfaces of transitions and water passages below El. 1897.00 from Sta. 22+03.90 to Sta. 22+86.00: F4, U3.
Surfaces of conduit from Sta. 22+86.00 to Sta. 24+68.50 above ℄: F2, below ℄: F4, U3.
Control house floor: U3
All other surfaces: F2, U2.
NOTES
For general concrete outline notes, see Dwg. 40-D-5530.
Electrical conduit, control piping and apparatus, miscellaneous metal work and reinforcement not shown.
REFERENCE DRAWINGS
DAM-GENERAL PLAN AND SECTIONS-SHEET 1 OF 3 ... 825-D-7
SPILLWAY AND OUTLET WORKS-PLANS AND SECTIONS ... 825-D-10
OUTLET WORKS-
INTAKE STRUCTURE- SHEET 1 OF 2 ... 825-D-16
INTAKE STRUCTURE- SHEET 2 OF 2 ... 825-D-17
GATE STRUCTURE - SHEET 1 OF 2 ... 825-D-18
GATE STRUCTURE - SHEET 2 OF 2 ... 825-D-19
CHUTE AND STILLING BASIN- SHEET 1 OF 2 ... 825-D-20
CHUTE AND STILLING BASIN- SHEET 2 OF 2 ... 825-D-21
CONDUIT ... 825-D-22
9-23-60 ADDED TWO COUNTERFORTS TO CHUTE WALLS
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN ANGELO PROJECT-TEXAS
TWIN BUTTES DAM
OUTLET WORKS
PLAN AND SECTIONS
DENVER, COLORADO, DEC. 18, 1959
825-D-15


PLAN
SCALE OF FEET
MIDDLE CONCHO RIVER
Slope to drain
€ Spillway
Intake Structure
Gate structure
€ Outlet Works
€ Crest of dam
20' Transition
Limit of 2½:1 Slope below El. 1940
PROFILE ON € OUTLET WORKS
Top of flood control pool, El. 1969.1
Top of conservation storage El. 1940.2
3-12'x15' Radial gates
3-12'x15' Fixed wheel gates
Original ground surface
PROFILE ON € SPILLWAY
SECTION A-A
SECTION B-B
DISCHARGE-Spillway and outlet works combined
TAILWATER-Existing channel conditions
TAILWATER-Degraded channel with control at Lake Nasworthy flood gate sills
RESERVOIR WATER SURFACE ELEVATION
TAILWATER ELEVATION
DISCHARGE IN 1000 CFS
DISCHARGE-TAILWATER CURVES
REFERENCE DRAWINGS
DAM - GENERAL PLAN & SECTIONS - SHEET 1 OF 3 ..... 825-D-7
SPILLWAY - PLAN AND SECTIONS 825-D-11
OUTLET WORKS - PLAN AND SECTIONS 825-D-15
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN ANGELO PROJECT - TEXAS
TWIN BUTTES DAM
SPILLWAY AND OUTLET WORKS
PLAN AND SECTIONS
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHIEF DESIGNING ENGINEER
DENVER, COLORADO, DEC. 18, 1959
825-D-10

Test Installation

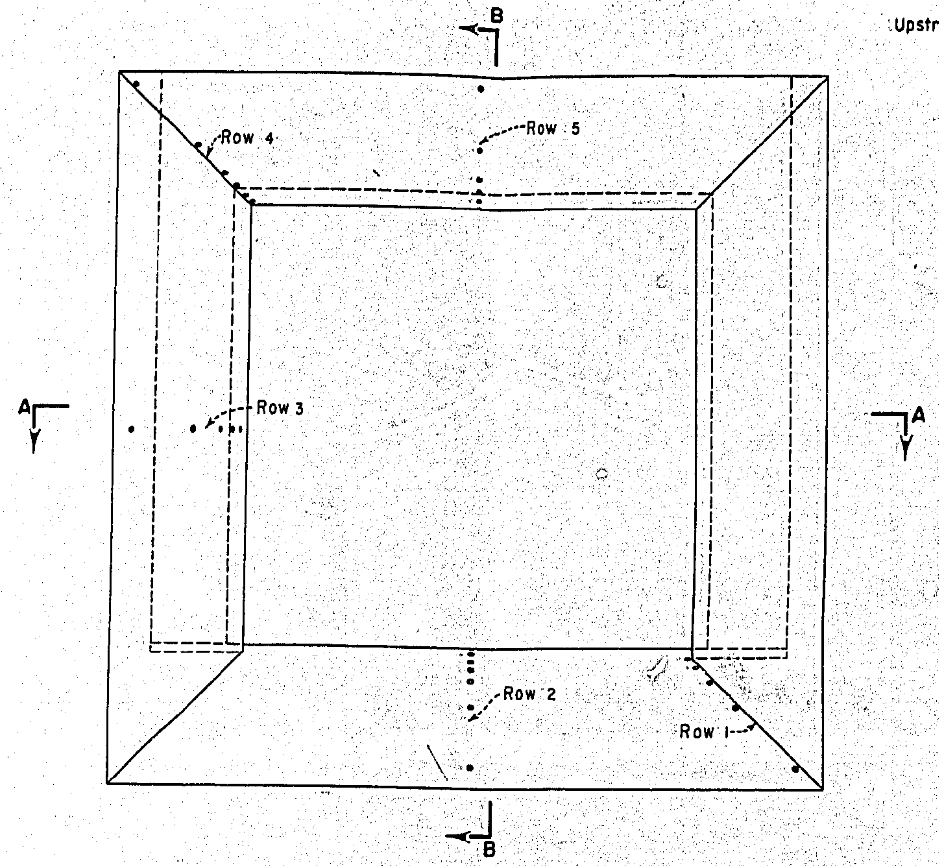


Bellmouth Ent

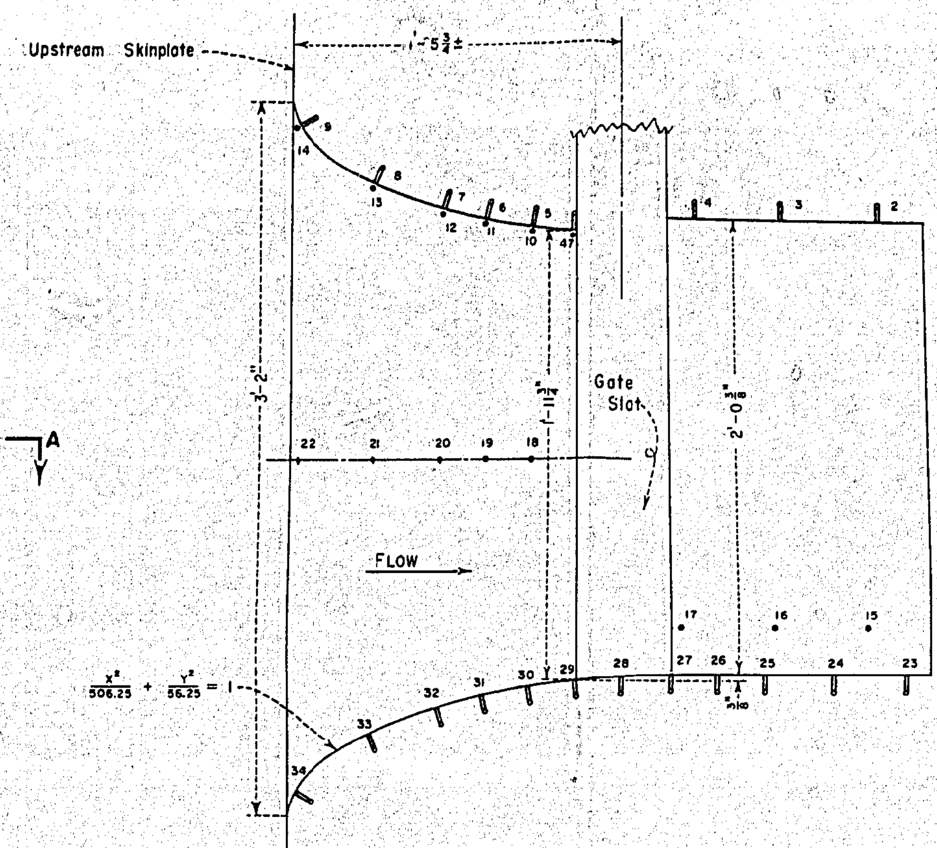


Downstream Conduit

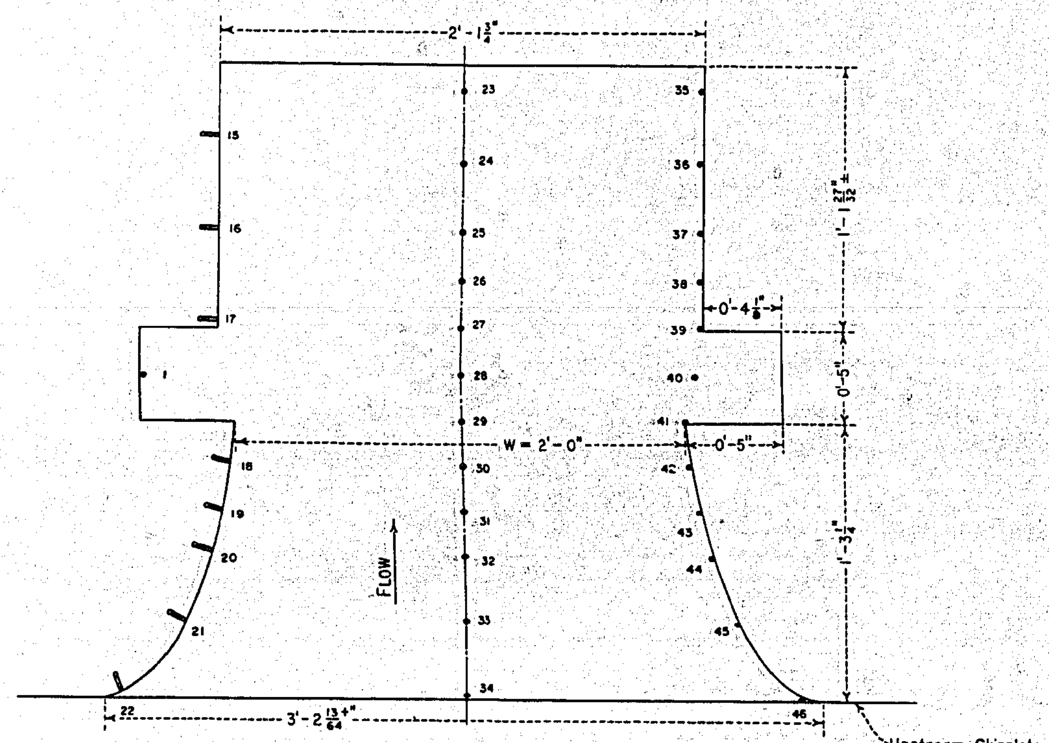
TWIN BUTTES DAM
2' x 2' REGULATING GATE
1:5 Scale Model



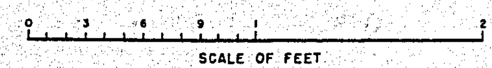
UPSTREAM FACE



SECTION B-B



SECTION A-A



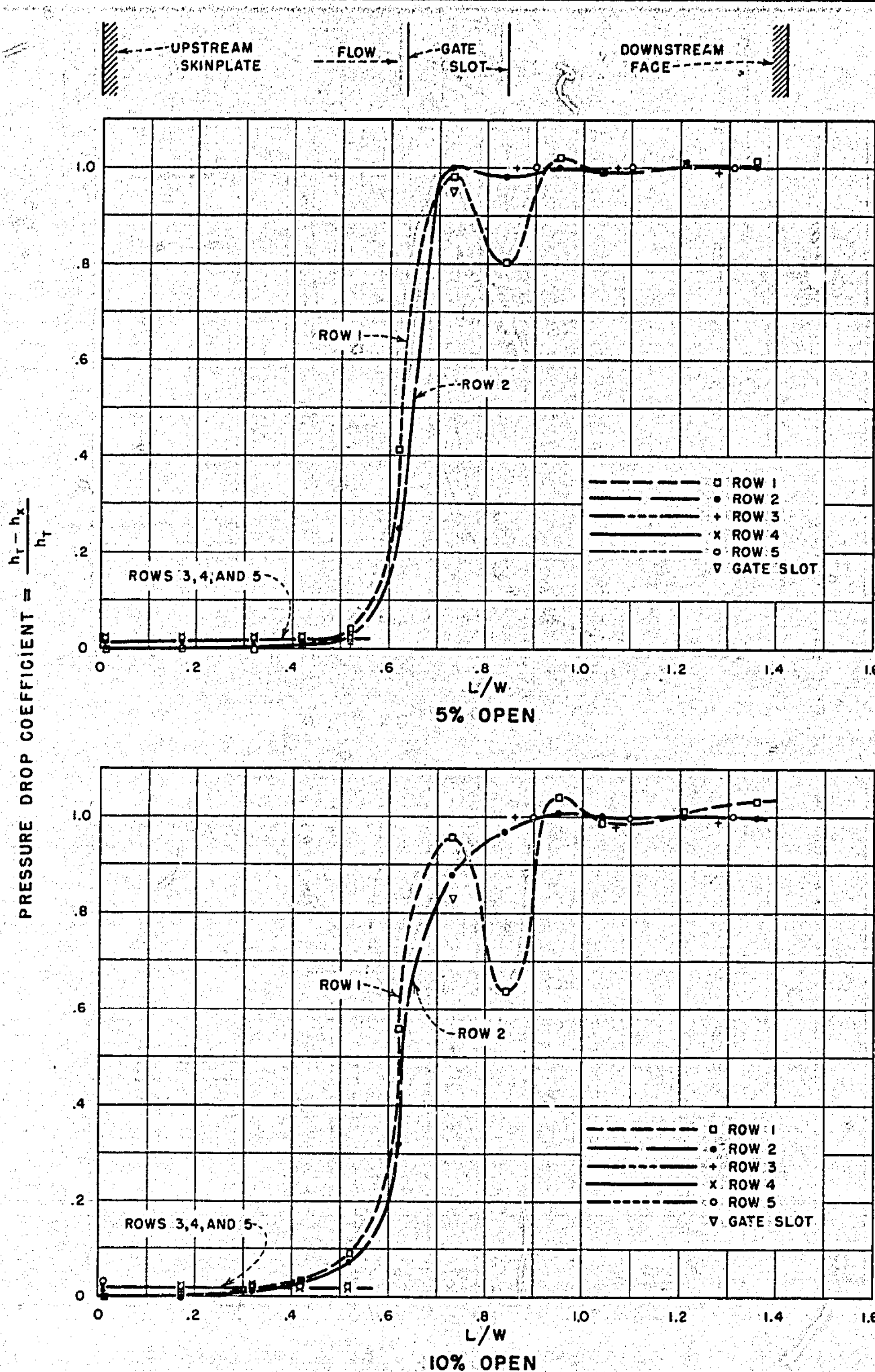
PIEZ. NO.	L/W
ROW 1	
35	1.36
36	1.21
37	1.04
38	.95
39	.84
40	.73
41	.62
42	.52
43	.42
44	.32
45	.17
46	.01
ROW 2	
23	1.36
24	1.21
25	1.04
26	.95
27	.84
28	.73
29	.62
30	.52
31	.42
32	.32
33	.17
34	.01
ROW 3	
15	1.28
16	1.07
17	.86
18	.52
19	.42
20	.32
21	.17
22	.01
ROW 4	
47	.62
10	.52
11	.42
12	.32
13	.17
14	.01
ROW 5	
2	1.31
3	1.10
4	.90
5	.52
6	.42
7	.32
8	.17
9	.01
GATE SLOT	
1	.73

NOTES

L = Distance from a piezometer to the upstream skinplate.
W = Width of bellmouth at gate opening. See Section A-A

TWIN BUTTES DAM
2' x 2' REGULATING GATE
PIEZOMETER LOCATIONS
1:5 SCALE MODEL

618



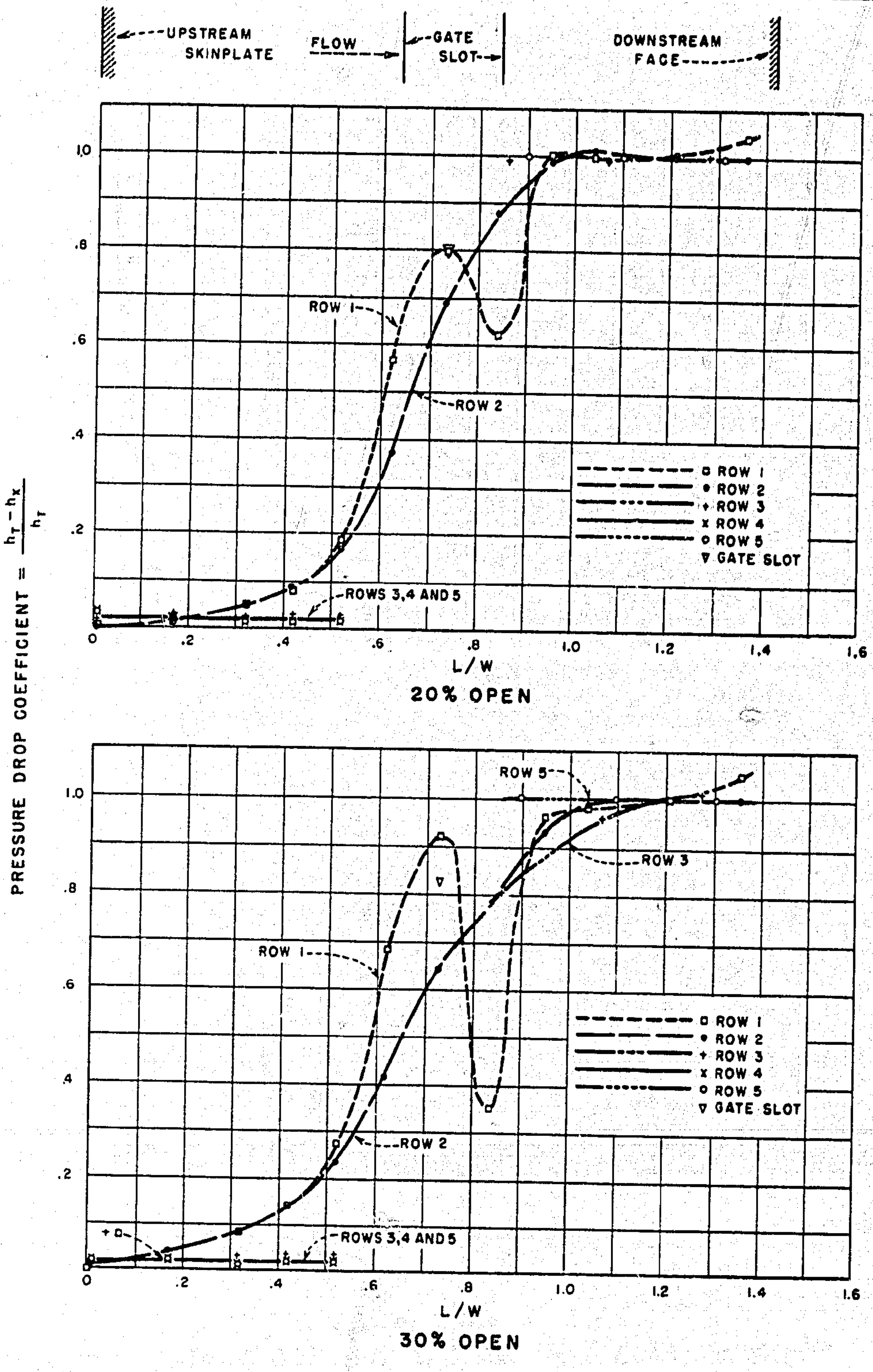
TWIN BUTTES DAM

2' x 2' REGULATING GATE

PRESSURE COEFFICIENT FOR 5% AND 10% GATE OPENINGS

1:5 SCALE MODEL

618

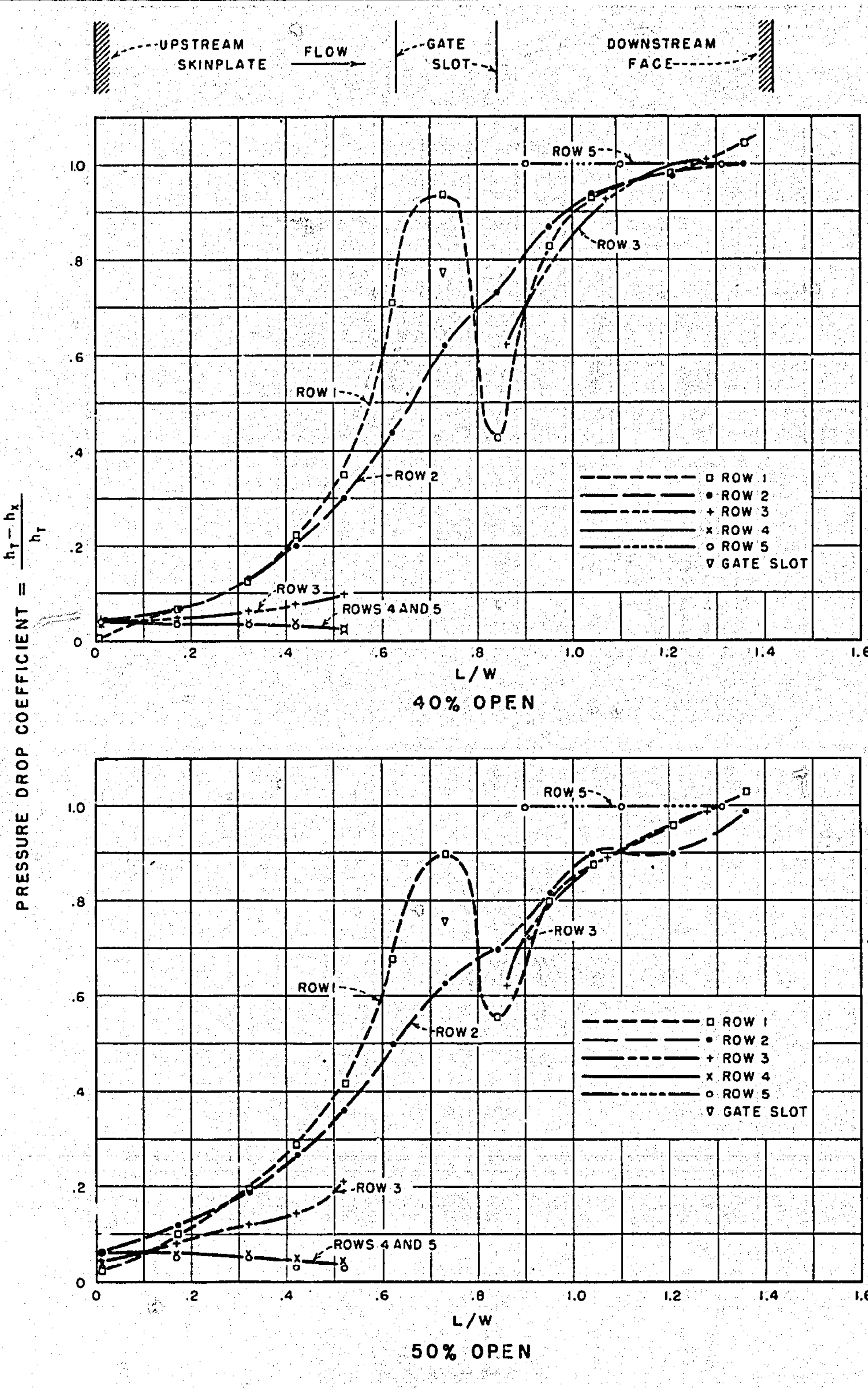


TWIN BUTTES DAM

2'x 2' REGULATING GATE

PRESSURE COEFFICIENT FOR 20% AND 30% GATE OPENINGS

1:5 SCALE MODEL

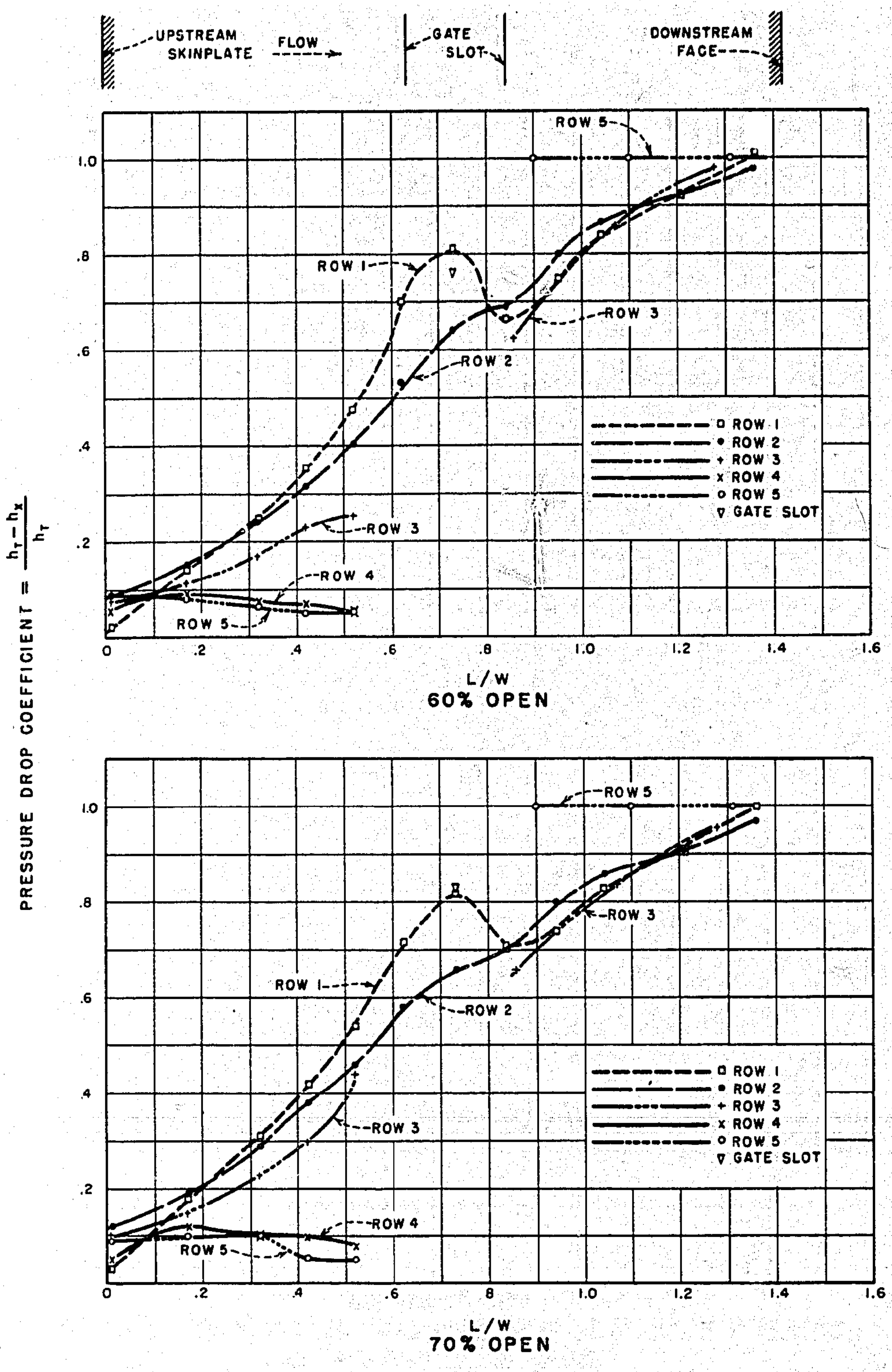


TWIN BUTTES DAM

2' x 2' REGULATING GATE

PRESSURE COEFFICIENT FOR 40% AND 50% GATE OPENINGS

1:5 SCALE MODEL

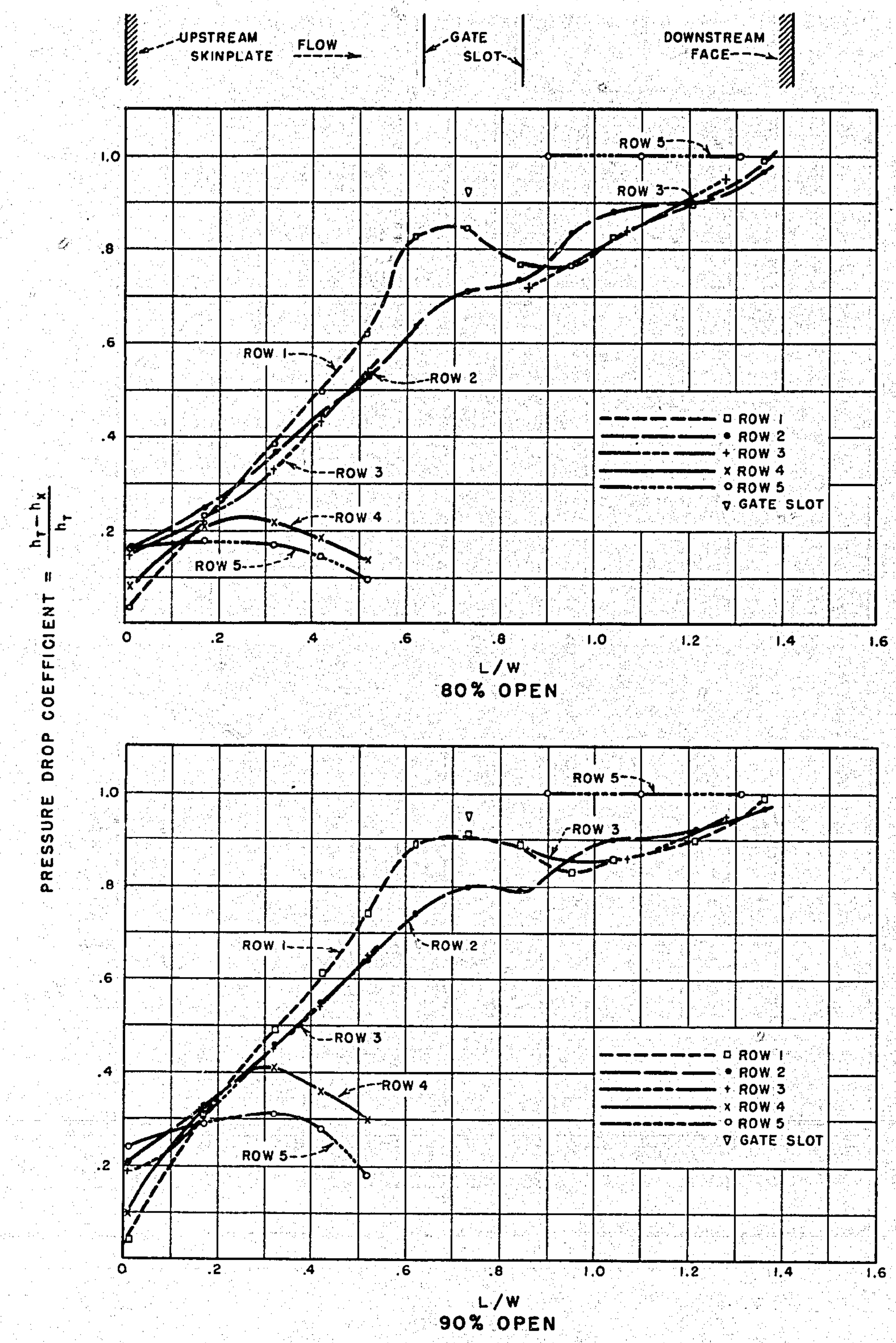


TWIN BUTTES DAM

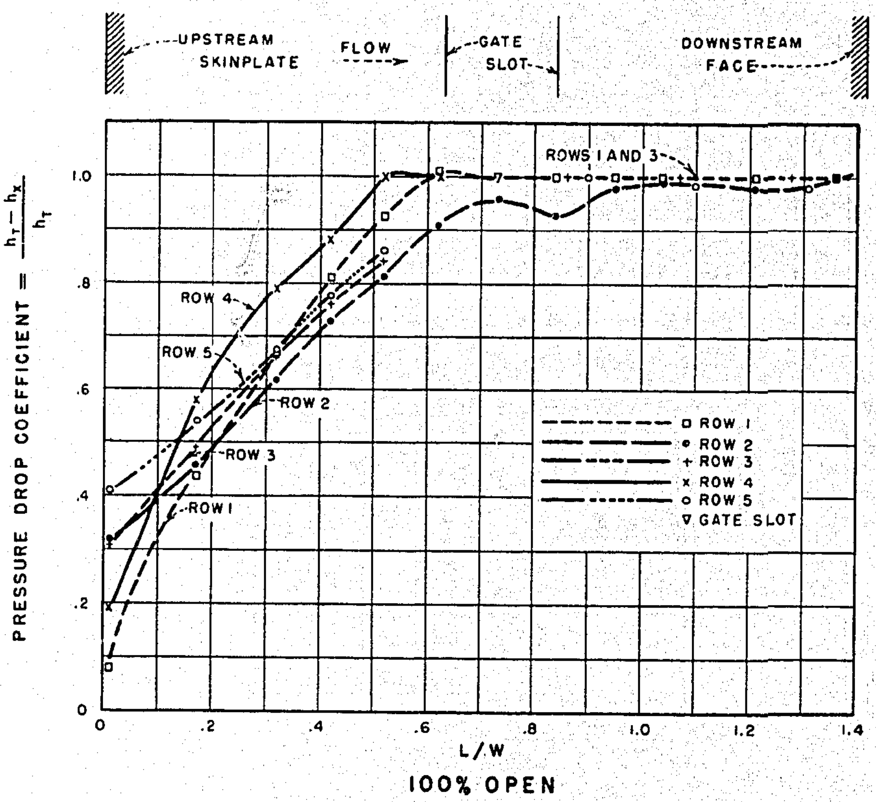
2' x 2' REGULATING GATE

PRESSURE COEFFICIENT FOR 60% AND 70% GATE OPENINGS

1:5 SCALE MODEL



TWIN BUTTES DAM
2'x 2' REGULATING GATE
PRESSURE COEFFICIENT FOR 80% AND 90% GATE OPENINGS
1:5 SCALE MODEL

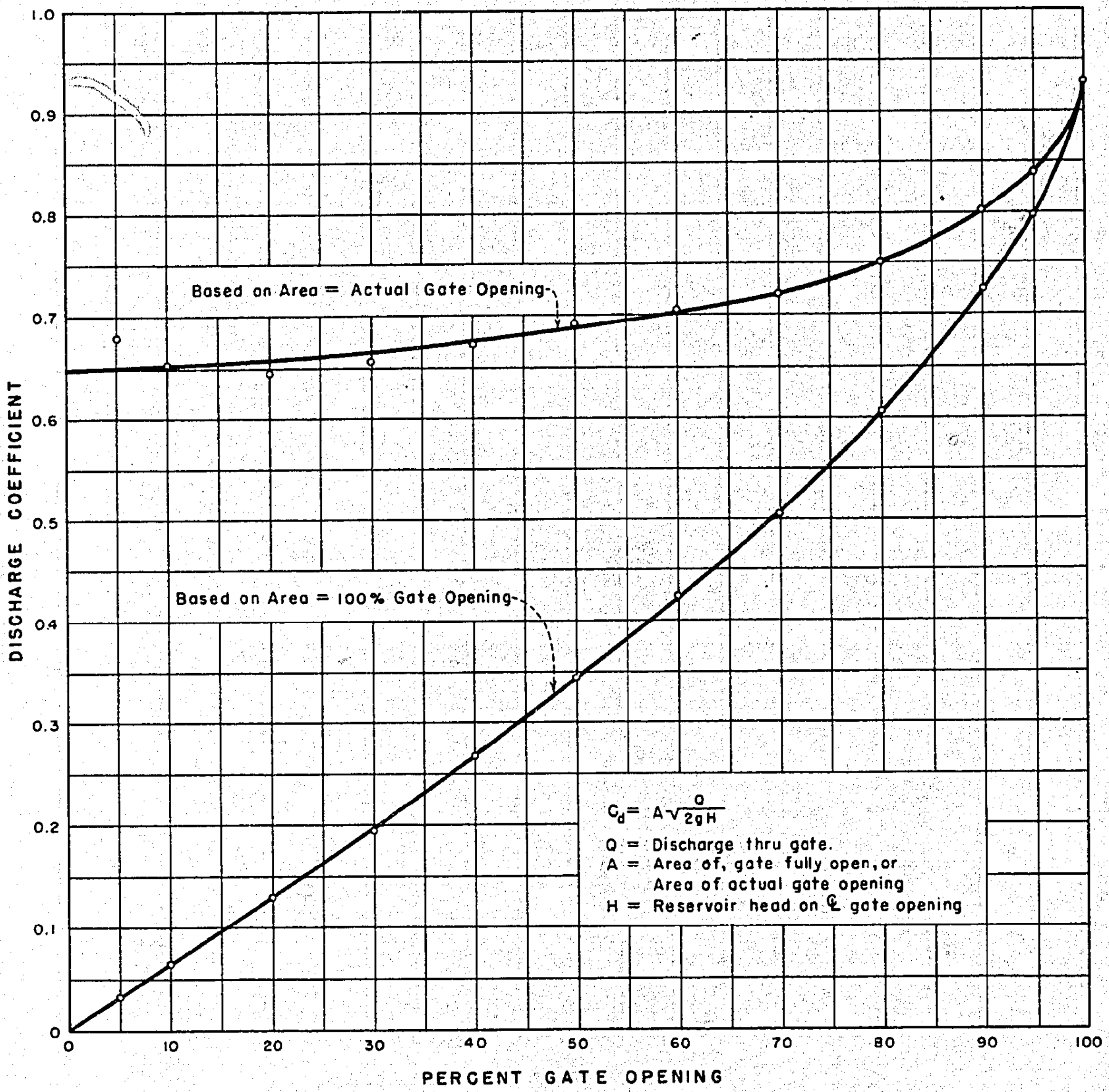


TWIN BUTTES DAM

2'x 2' REGULATING GATE

PRESSURE COEFFICIENT FOR 100% GATE OPENING

1:5 SCALE MODEL

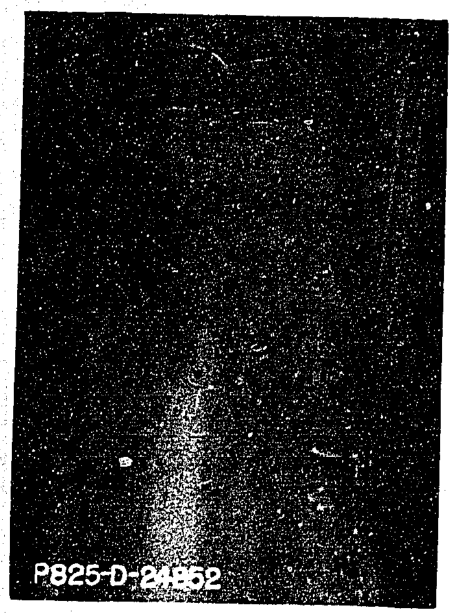


TWIN BUTTES DAM
2'x 2' REGULATING GATE
DISCHARGE COEFFICIENTS FOR VARIOUS GATE OPENINGS

1:5 SCALE MODEL

618

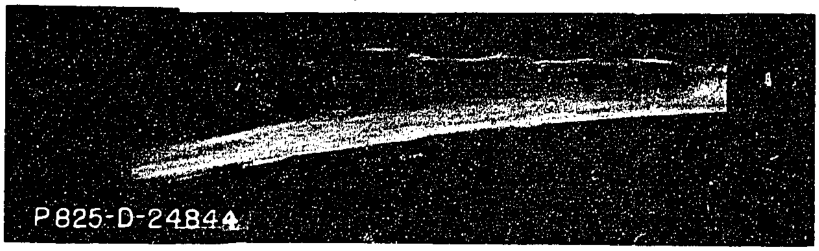
30% Gate Opening, Reservoir Elev. 1985.0



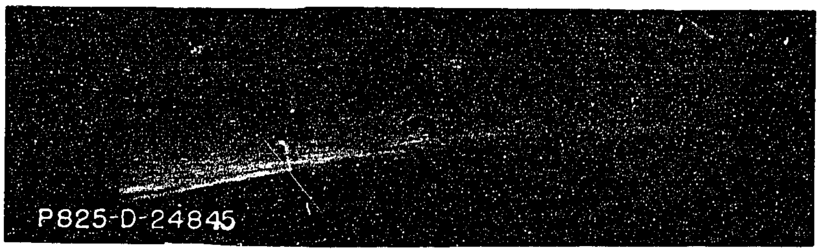
50% Gate Opening, Reservoir Elev. 1940.2

TWIN BUTTES DAM
2' x 2' REGULATING GATE
Crossflow And Spray
1:5 Scale Model

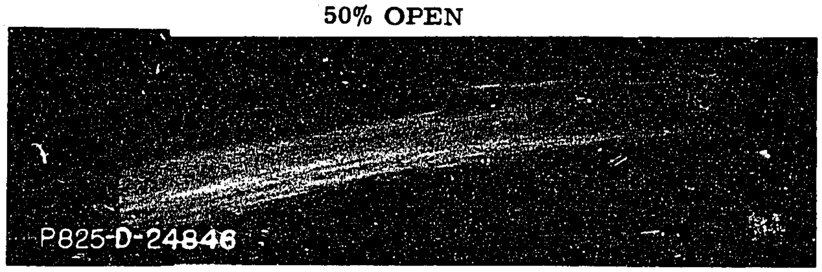
5% OPEN



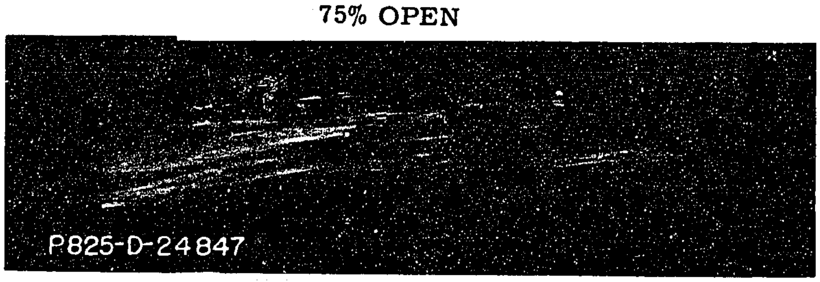
25% OPEN



50% OPEN



75% OPEN



100% OPEN

TWIN BUTTES DAM
2' x 2' REGULATING GATE
Flow At Various Gate Openings, Reservoir Elev. 1940.2
1:5 Scale Model