Interim Report

BOCONO DAM RIVER OUTLET TESTS

Prepared for
Tipton and Kalmbach, Inc.

Civil Engineering Section, Colorado State University
Fort Collins, Colorado

May 1958

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(CSU Hydraulic Laboratory Project No. 752)

Objectives

These tests were made to investigate the pressure distribution and flow conditions in the elbow of the river outlets for varying reservoir elevations, gate openings, and air vent openings.

The Model

A 1:20 scale model of the river outlet was constructed as shown on Dwg. No. RO-1. The main conduit downstream of the regulating gate was of horseshoe section $4\frac{13}{16}$ inches high by $4\frac{13}{16}$ inches wide. Part of its length upstream of the elbow and the entire elbow were made from transparent plastic to permit visual observation of the flows through the outlet. In all 44 piezometers of $\frac{3}{32}$ inch inside diameter were installed on the sides of the elbow, located as shown on Dwg. No. RO-1.

The air vent downstream of the regulating gate was represented by a 2 inch diameter gate valve, which was normally adjusted to give 1.77 square inches of open area corresponding to the area of the 30 inches diameter header on the prototype. This opening was varied for some of the tests to observe its effect on flow characteristics in the outlet conduit and elbow. The side air vents at the stepped transition from the horseshoe conduit to the approximately square shaped elbow section were represented by short lengths of plastic pipe each of 0.5 inch internal diameter, corresponding to the four 10 inch diameter vents on the prototype. These vents were left open for all the tests.

The regulating gate used (see schematic view on Dwg. RO-1) was a simple vertical leaf gate sliding between two flange plates; the upstream flange consisted of a flat plate with a circular opening of 4.2 inches internal diameter corresponding to the control section of the 84 inch jet-flow gate.

All tests were made by theoretically computing the discharges at the jet-flow regulating gate in the prototype, at various reservoir levels and gate-openings, and using a discharge for the model given by $Q_M = (L_r)^{5/2} Q_p$, where L_r was the model scale ratio of 1/20.

Tests

Discharges through the jet-flow gate were computed from $Q = 0.8A\sqrt{2gh}$. The following flow conditions were investigated

1. Max. Reservoir Level (El. 290.0)

   Gate opening 100 percent Q_{100} = 104.0 m^3/s (3,670 cfs)
   Gate opening 80 percent Q_{80} = 82.2 m^3/s (2,900 cfs)

2. Reservoir Level at Spillcrest (El. 276.5)

   Gate opening 100 percent Q_{100} = 93.3 m^3/s (3,290 cfs)
   Gate opening 80 percent Q_{80} = 73.5 m^3/s (2,585 cfs)

The pressure distributions observed on the crown, bottom and sides of the elbow are shown on Dwg. Nos. RO-2 and RO-3. The character of flow for the cases tested is summarized on Dwg. No. RO-4. To investigate the pressure variations caused in the elbow by changes in vent area at the regulating gate, representative piezometers were selected in zones of critical pressures. During these tests the regulating gate was kept 80 percent open and discharge corresponded to maximum reservoir level of El. 290.0; under these conditions the positive and negative pressures were expected to reach their peak values. Typical pressure variations observed are shown plotted on Dwg. No. RO-5.

Observations

1. With RWL 290.0 (max. water surface) and 100 percent gate opening the conduit section upstream from the elbow appeared to flow full but the top layer of the flow contained entrained air. In the elbow the flow

was not in contact with the crown in the vicinity of the top vents but farther downstream it impinged on the roof and built up large positive pressures between piezometers 26 and 31. In the same general region flow was not in contact with the bottom and negative pressures measured in the air pocket were fairly uniform. With RWL 290.0 and 80 percent gate opening, free or open channel flow occurred up to the point of impingement against the crown, between piezometers 26-30; the flow was free of the bottom as before, (Figures 1 and 4).

2. With RWL 276.5 (spillway crest) and 100 percent gate opening the flow in the approach conduit and elbow was nearly full; in the elbow the flow did not contact the bottom. For 80 percent gate opening there was free flow in the approach conduit for some distance upstream of the elbow. The maximum positive pressures occurred near the zone of impingement. The negative pressures on the bottom of elbow remained uniform, (Figures 5 to 14).

3. With RWL 260 and gate opening 80 percent or 60 percent, the approach conduit flowed partially full. In the elbow, both the positive and negative pressure distributions were similar to the previous patterns but of distinctly lesser magnitudes, (Figures 15 to 19).

4. The air vent area provided at the jet-flow gate was found to have considerable effect on the character of flow and pressures within the elbow for values up to about 3 percent of the conduit area (Dwg. No. RO-5). Beyond this value increases in air vent area had little effect. The side air vents at the stepped transition were fully open during all tests.

Results

The significant results are presented in Dwg. No. RO-2 and RO-3 and are summarized on the following page:

	Max. positive pressure	Min. negative pressure	Remarks
RWL 290.0			
G. O. 100%	62.6 ft	-7.1 ft	See section x-x on Dwg.
80%	73.0 ft	-6.3 ft	Nos. RO 2 and 3
			Max. positive pressures occur away from
RWL 276.5			
G. O. 100%	52.4 ft	-7.6 ft	center line.
80%	70.8 ft	-6.6 ft	Min. negative pressures along the center line.

At lower reservoir elevations, both the positive and negative pressures were of lesser magnitudes at corresponding gate openings. For RWL 290.0 and G. O. = 80 percent variation in air vent area at the regulating gate indicated on the model that vent areas in excess of 3 to 4 percent of the conduit area would produce satisfactory venting and stable pressure conditions in the outlet elbow.

Comments

1. Assuming that the river outlets will be functioning primarily when the reservoir elevation is at or below spillcrest (El. 276.5) the maximum positive pressures would reach about 70 feet inside the elbow on the crown; at the downstream end, the maximum pressure would be about 54 feet, (see Dwg. RO-3).

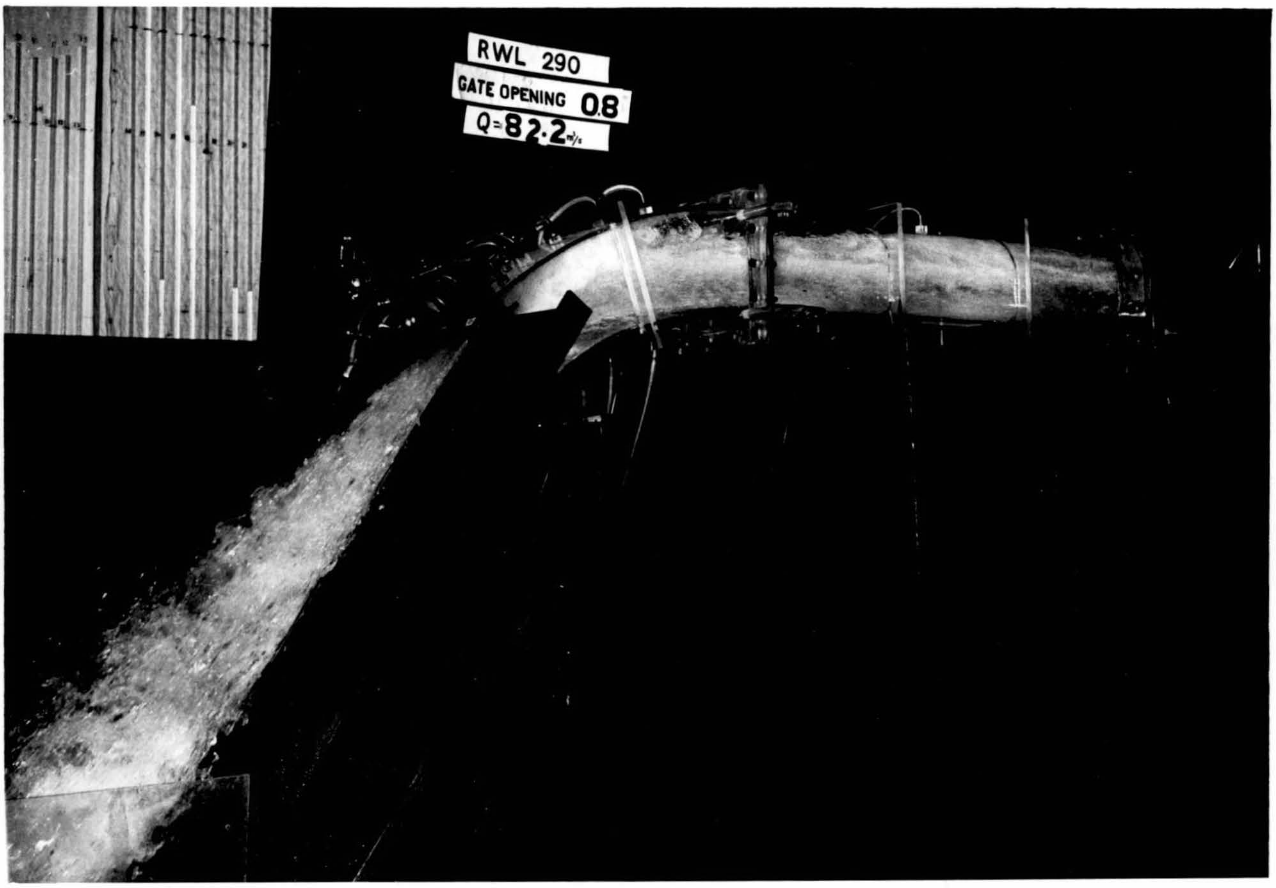
2. For the same operating conditions, the lowest negative pressure would be about -7.5 feet (subatmospheric) on the bottom or invert of the elbow. Considering that the flow does not come in contact with this boundary and that the space is aerated, no cavitation tendencies should be expected.

3. For the maximum reservoir level (El. 290.0) the pressures would be slightly greater (see Dwg. RO-2) but this operation would be rare if ever; for operations with reservoir level lower than spillcrest (El. 276.50) flow corresponds closely to that of a jet discharging freely into the air and impinging against the crown, (Figures 15 to 19). The positive pressures are maximum at the point of impingement and decrease with head.

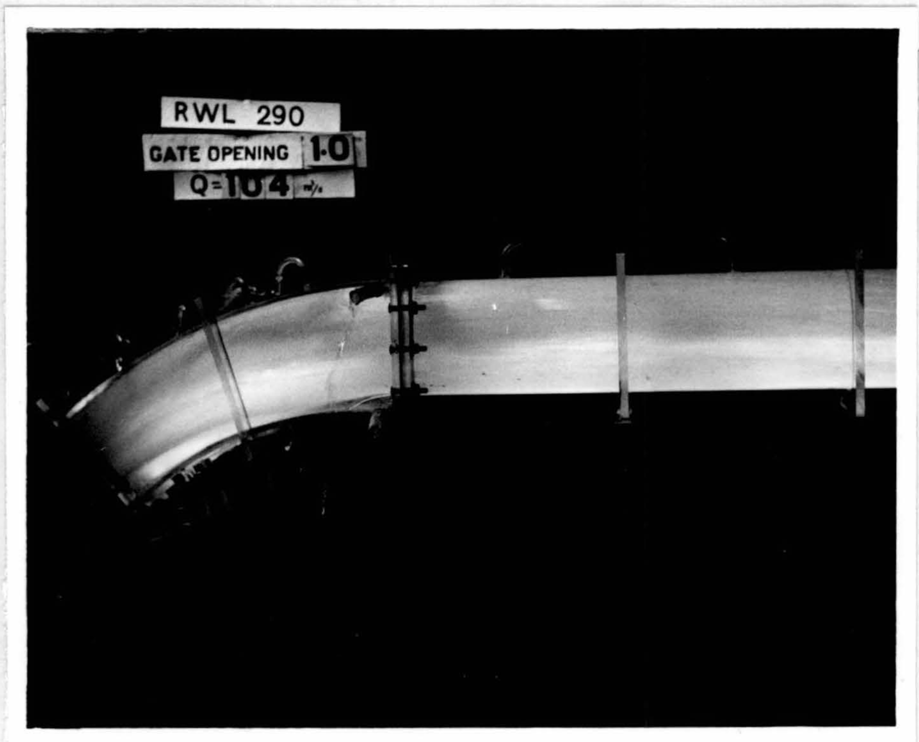
4. Generally the maximum air demand for a regulating gate in a concrete dam occurs at about 60 to 80 percent gate opening. [1], [2] Observations of pressure variations due to changing areas of the gate vent (Dwg. No. RO-5) indicate that satisfactory aeration is obtained in the model at a minimum vent area of 3 percent of the conduit area. Increasing the vent area further had little effect on pressures in the elbow. The design area specified (12.8 percent) is in excess of the minimum value; it should provide satisfactory venting and stable pressure conditions in the elbow. Lack of established model prototype conformity for this phenomenon does not permit any suggestion for reduction in gate vent area, precedence being accepted as a good guide.

[1] U. S. Corps of Engineers, Hydraulic Design Criteria, Sheet 050-1, para. 4.

[2] U. S. Bureau of Reclamation, Hydraulic Laboratory Report No. 201, Fig. 18.

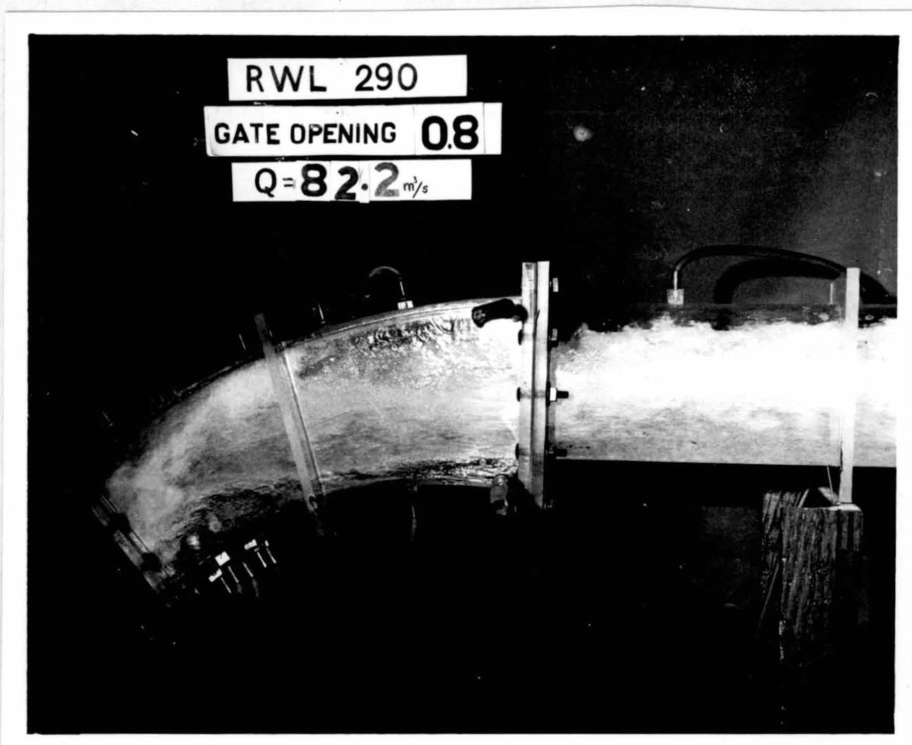


RO - Fig. 1

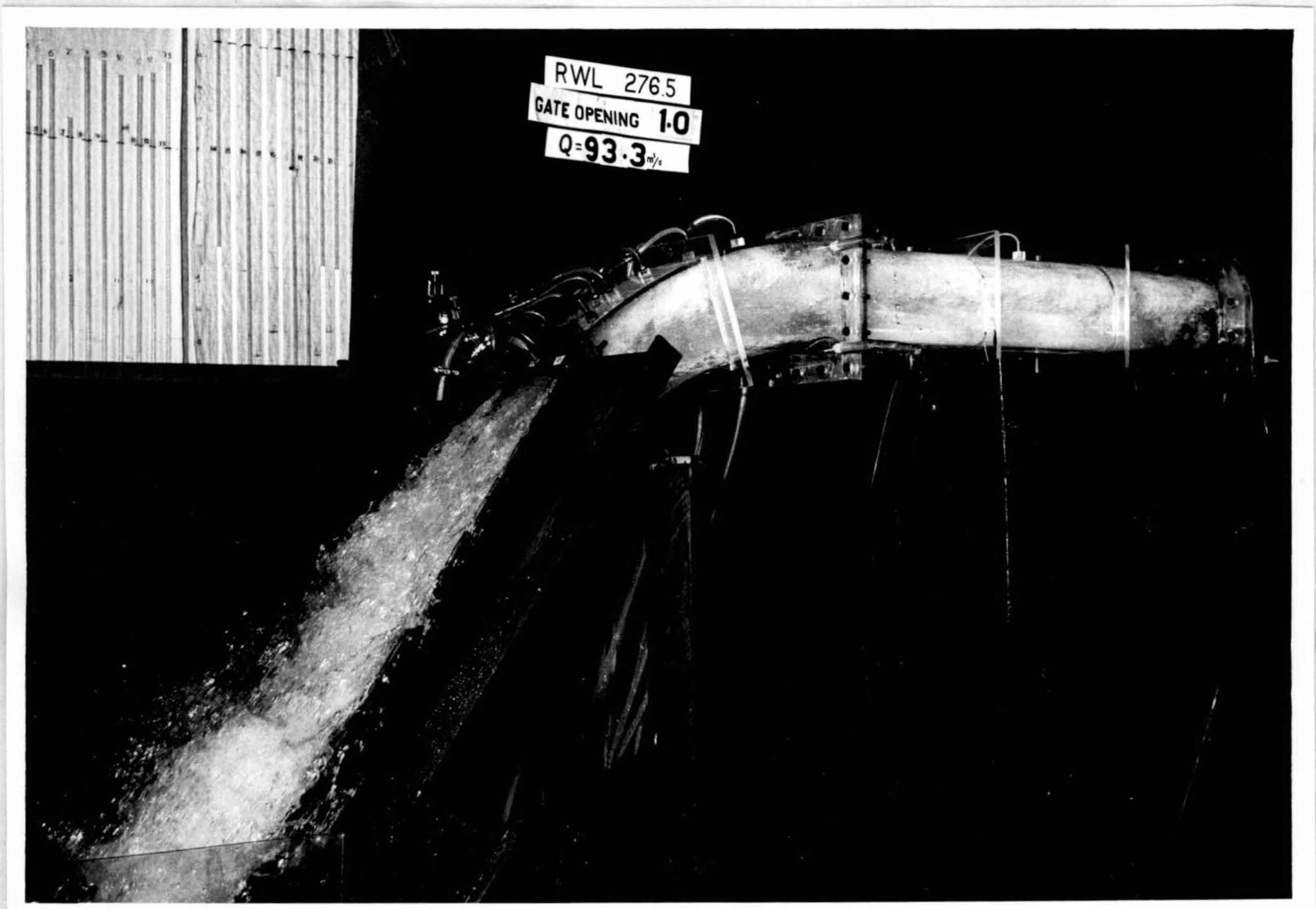


RO - Fig. 2

RO - Fig. 3

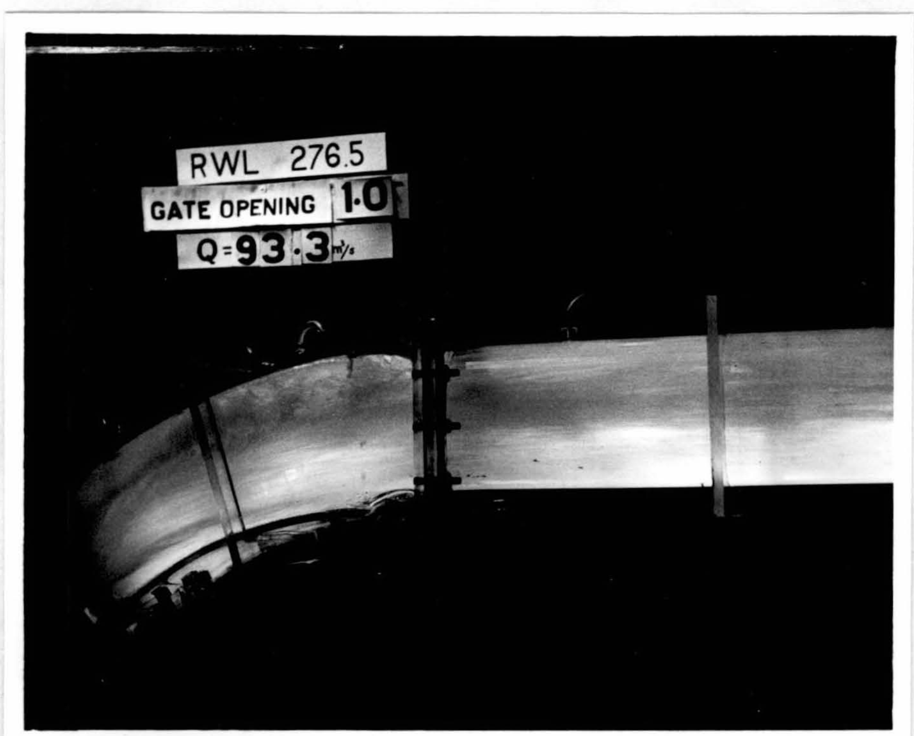


RO Fig. 4

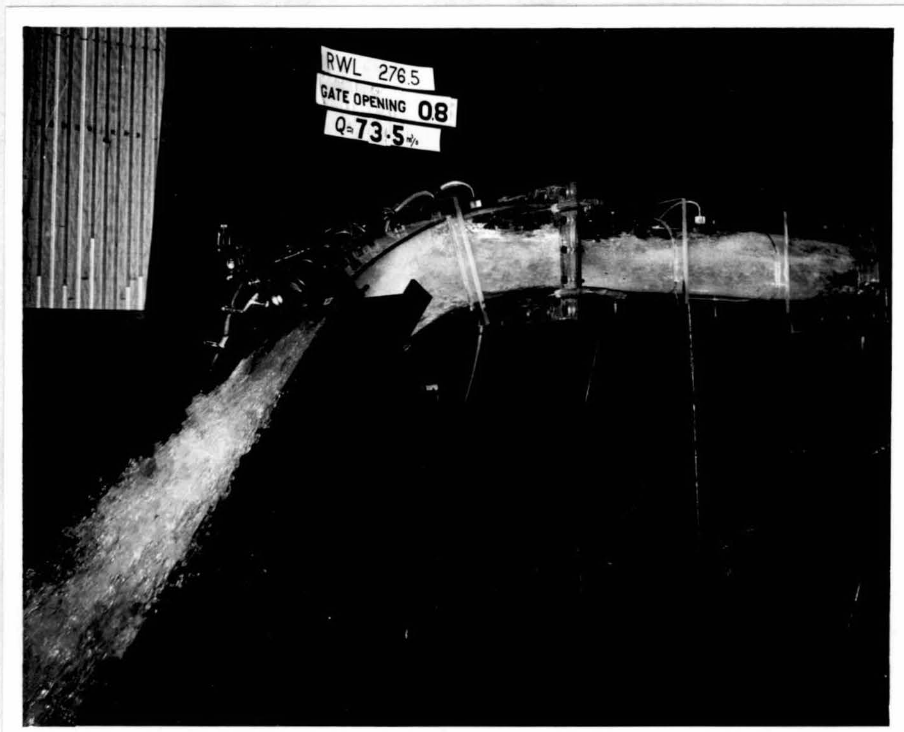


RO Fig. 5

RO Fig. 6



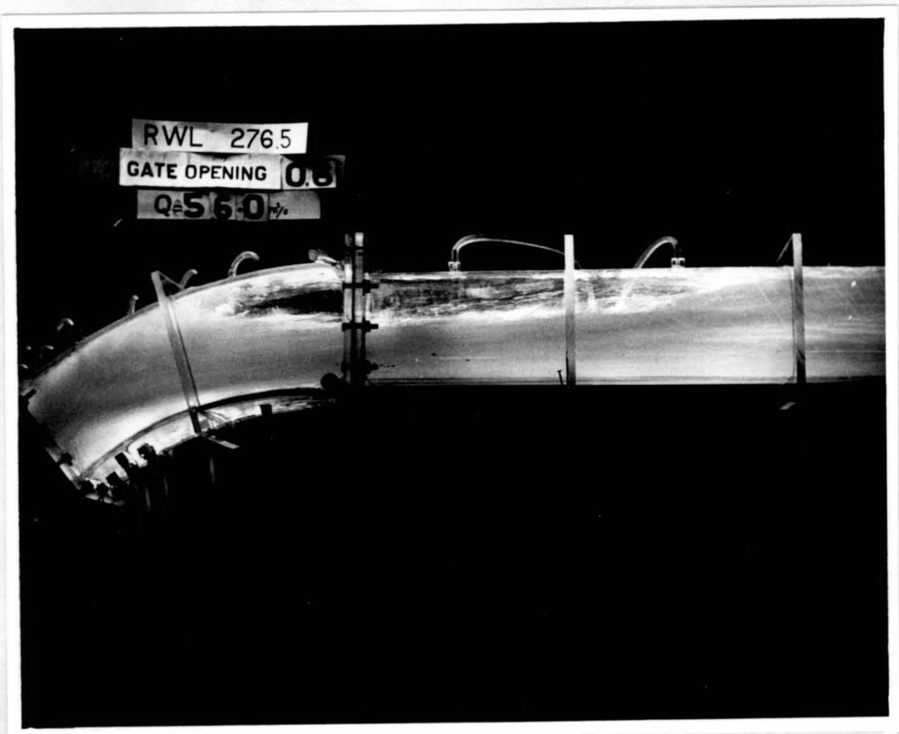
RO Fig. 7



RO Fig. 8

RO Fig. 9

RO Fig. 10

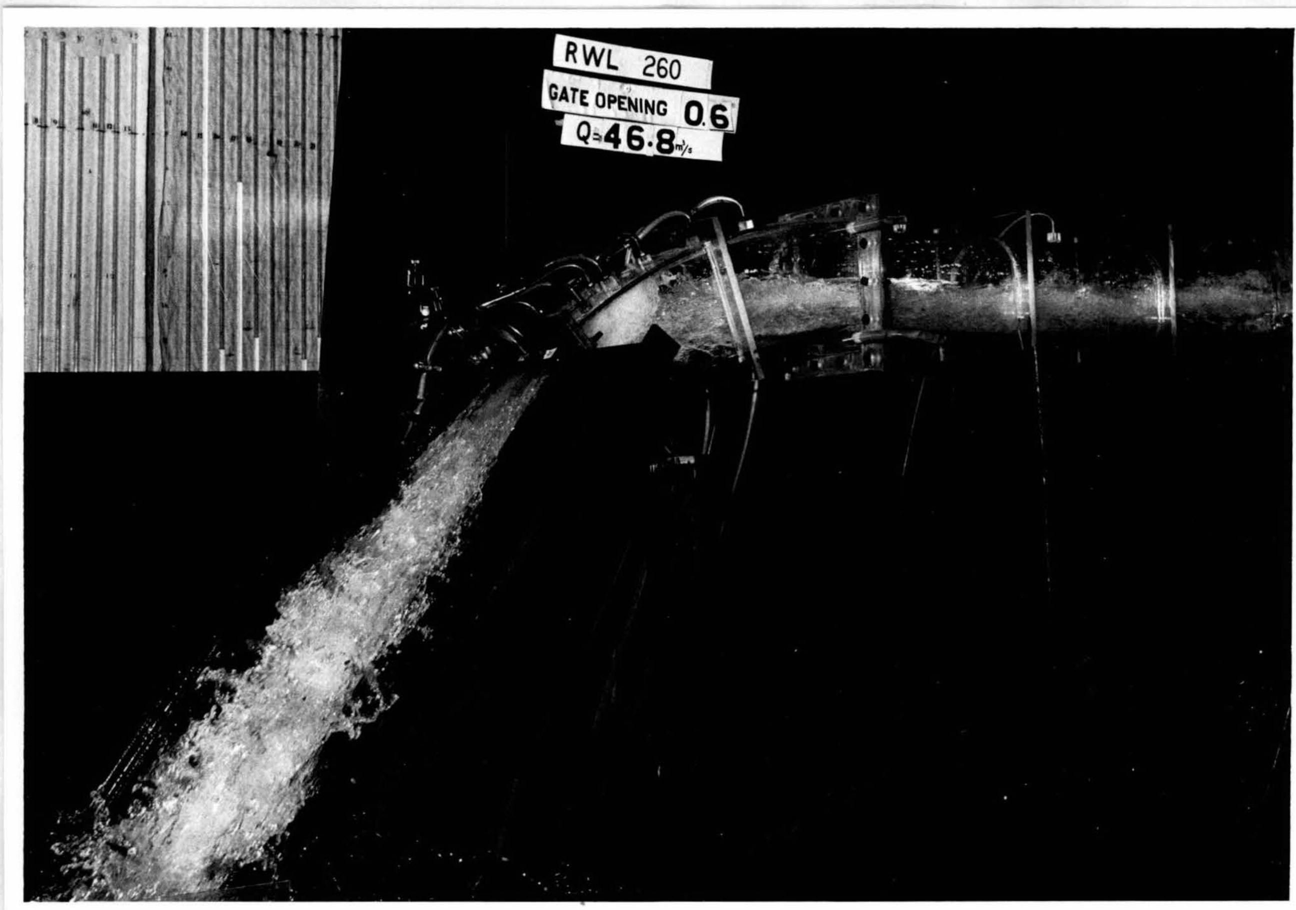


RO Fig. 11

RO Fig. 12

RO Fig. 13

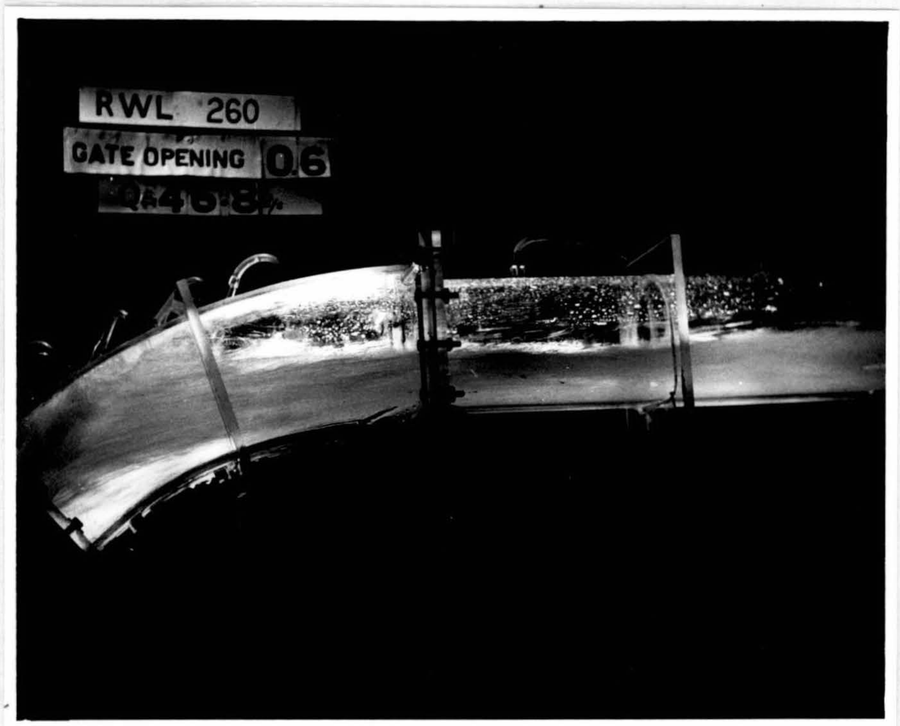
RO Fig. 14



RO Fig. 15

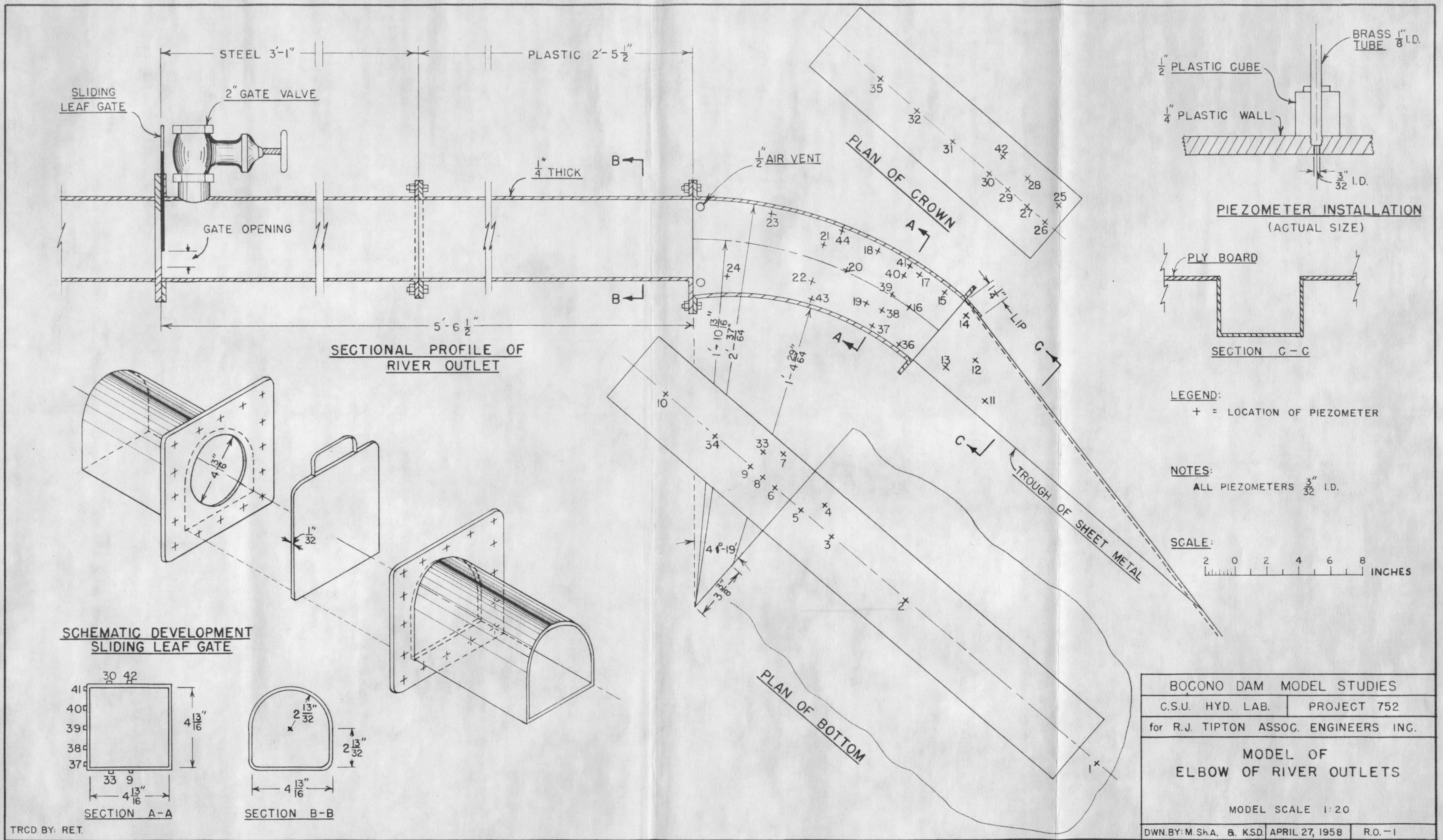
RO Fig. 16

RO Fig. 17

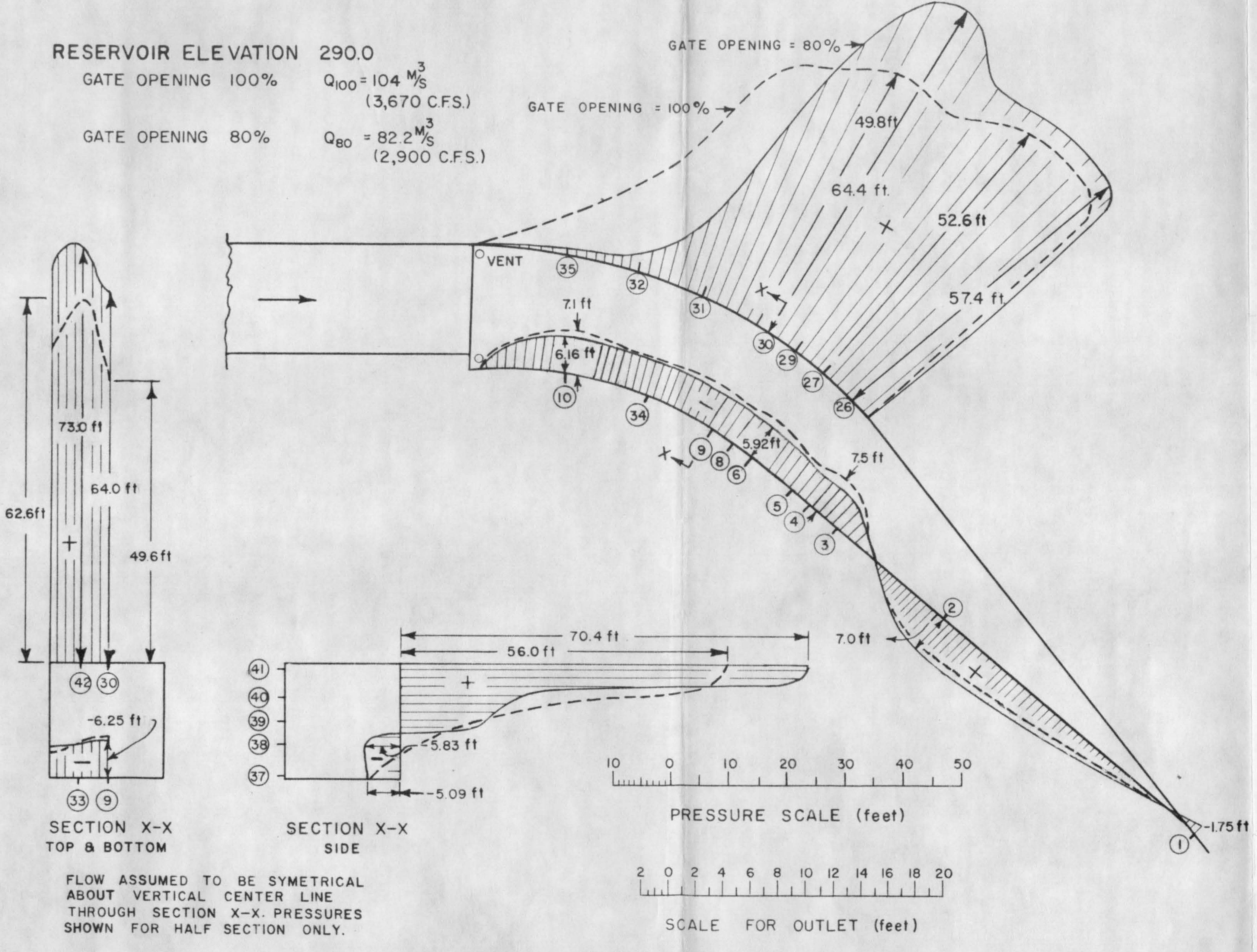


RO Fig. 18

RO Fig. 19



STEEL 3'-1"
PLASTIC 2'-5 1/2"
SLIDING LEAF GATE
2" GATE VALVE
1/4" THICK
B
1/2" AIR VENT
GATE OPENING
5'-6 1/2"
SECTIONAL PROFILE OF RIVER OUTLET
PLAN OF CROWN
PLAN OF BOTTOM
A
C
LIP
1/4"
TROUGH OF SHEET METAL
1'-10 13/16"
2'-3 37/64"
1'-4 29/64"
4 1/2°-19'
3 3/8"
SCHEMATIC DEVELOPMENT SLIDING LEAF GATE
1/32"
4 13/16"
SECTION A-A
SECTION B-B
2 13/32"
BRASS TUBE 1/8" I.D.
1/2" PLASTIC CUBE
1/4" PLASTIC WALL
3/32" I.D.
PIEZOMETER INSTALLATION
(ACTUAL SIZE)
PLY BOARD
SECTION C-C
LEGEND:
+ = LOCATION OF PIEZOMETER
NOTES:
ALL PIEZOMETERS 3/32" I.D.
SCALE:
2 0 2 4 6 8 INCHES
BOCONO DAM MODEL STUDIES
C.S.U. HYD. LAB.
PROJECT 752
for R.J. TIPTON ASSOC. ENGINEERS INC.
MODEL OF ELBOW OF RIVER OUTLETS
MODEL SCALE 1:20
DWN. BY: M. Sh.A. & K.S.D.
APRIL 27, 1958
R.O.-1
TRCD BY: R.E.T.



FLOW ASSUMED TO BE SYMETRICAL ABOUT VERTICAL CENTER LINE THROUGH SECTION X-X. PRESSURES SHOWN FOR HALF SECTION ONLY.

LEGEND:

- (31) = NUMBER OF PIEZOMETER
- + = PRESSURES ABOVE ATMOSPHERIC
- — = PRESSURES BELOW ATMOSPHERIC
- - - - = PRESSURES FOR GATE OPENING = 100%
- ——— = PRESSURES FOR GATE OPENING = 80%
- Q_{100} = DISCHARGE FOR 100% GATE OPENING
- Q_{80} = DISCHARGE FOR 80% GATE OPENING

NOTES:

1. DISCHARGE FOR JET-FLOW GATE COMPUTED FROM $Q = 0.8A\sqrt{2gh}$.
2. ALL VENT OPENINGS REPRODUCED TO SCALE. THEY WERE FULLY OPEN DURING THESE TESTS.
3. PRESSURES ON CROWN AND BOTTOM OF ELBOW WERE MEASURED ALONG THE CENTER LINE.

BOCONO DAM MODEL STUDIES

C.S.U. HYD. LAB. — PROJECT 752

for R.J. TIPTON ASSOC. ENGINEERS INC.

PRESSURE DISTRIBUTION IN ELBOW OF RIVER OUTLETS

RWL = 290.0

MODEL SCALE 1:20

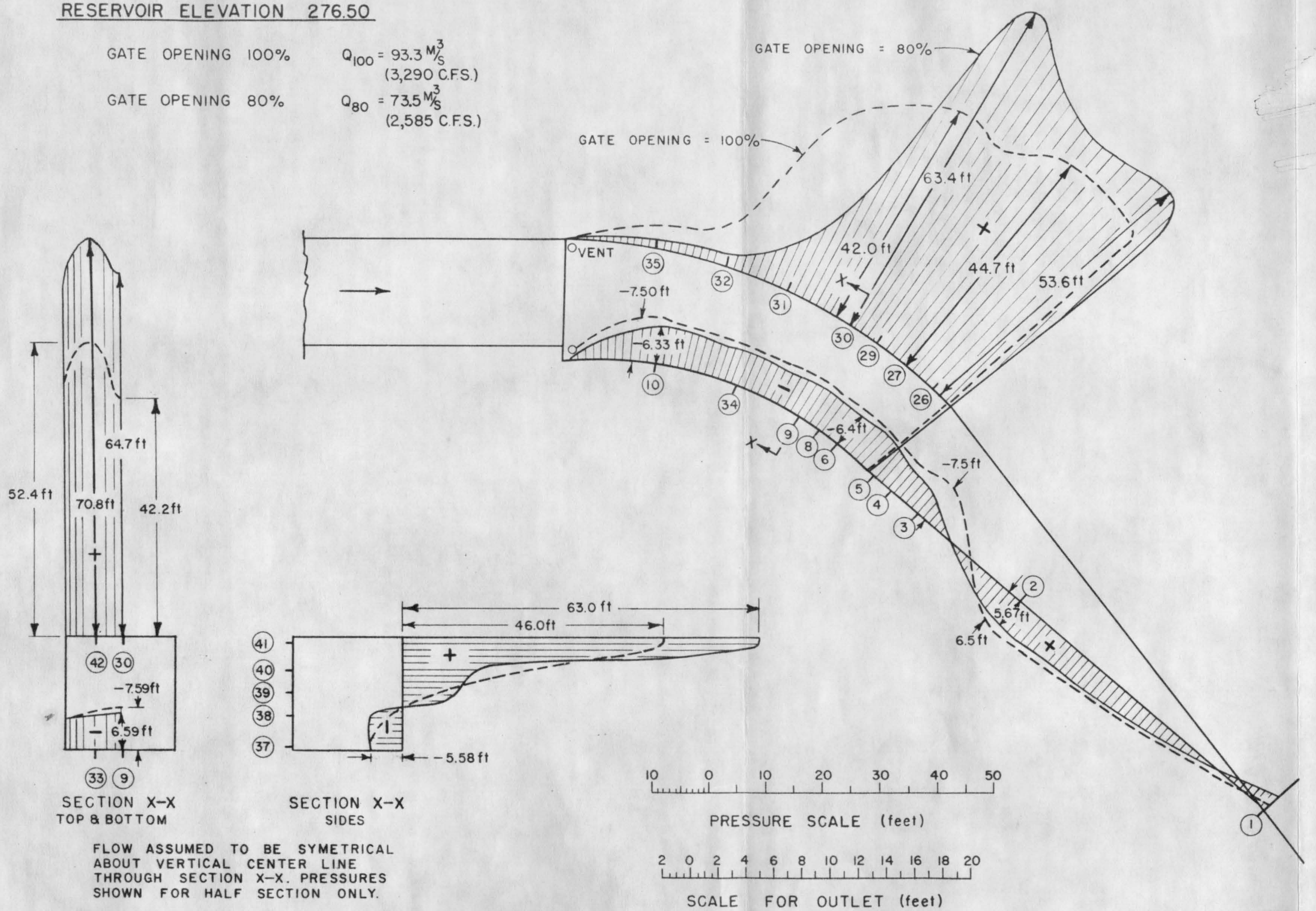
DWN. BY: M. Sh.A. & K.S.D — MARCH 5, 1958 — NO. R.O-2

TRCD. BY: R.E.T.

RESERVOIR ELEVATION 276.50

GATE OPENING 100% $Q_{100} = 93.3\ M^3/S$ (3,290 C.F.S.)

GATE OPENING 80% $Q_{80} = 73.5\ M^3/S$ (2,585 C.F.S.)



FLOW ASSUMED TO BE SYMETRICAL ABOUT VERTICAL CENTER LINE THROUGH SECTION X-X. PRESSURES SHOWN FOR HALF SECTION ONLY.

LEGEND:

- (31) = NUMBER OF PIEZOMETER
- + = PRESSURES ABOVE ATMOSPHERIC
- − = PRESSURES BELOW ATMOSPHERIC
- - - - = PRESSURES FOR GATE OPENING = 100%
- —— = PRESSURES FOR GATE OPENING = 80%
- Q_{100} = DISCHARGE FOR 100% GATE OPENING
- Q_{80} = DISCHARGE FOR 80% GATE OPENING

NOTES:

1. DISCHARGE FOR JET-FLOW GATE COMPUTED FROM $Q = 0.8A\sqrt{2gh}$
2. ALL VENT OPENINGS REPRODUCED TO SCALE. THEY WERE FULLY OPEN DURING THESE TESTS.
3. PRESSURES ON CROWN AND BOTTOM OF ELBOW WERE MEASURED ALONG THE CENTER LINE.

BOCONO DAM MODEL STUDIES	
C.S.U. HYD. LAB.	PROJECT 752
for R.J. TIPTON ASSOC. ENGINEERS INC.	
PRESSURE DISTRIBUTION IN ELBOW OF RIVER OUTLETS RWL = 276.50 MODEL SCALE 1:20	
DWN. BY: M. Sh. A. & K.S.D. MARCH 12, 1958	NO. R.O.-3

TRCD. BY: R.E.T.

RWL 290.0

GATE OPENING = 100%

Q_{100} = 104.0 M^3/S
(3,670 C.F.S.)

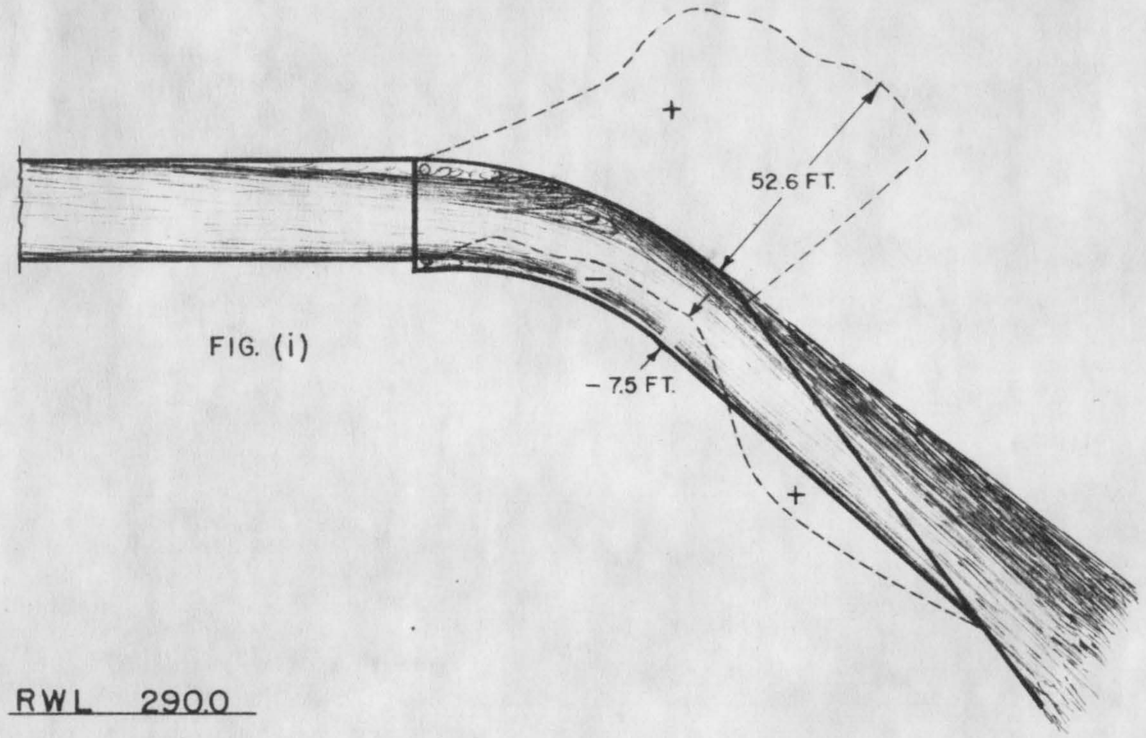


FIG. (i)

RWL 276.5

GATE OPENING = 100%

Q_{100} = 93.3 M^3/S
(3,290 C.F.S.)

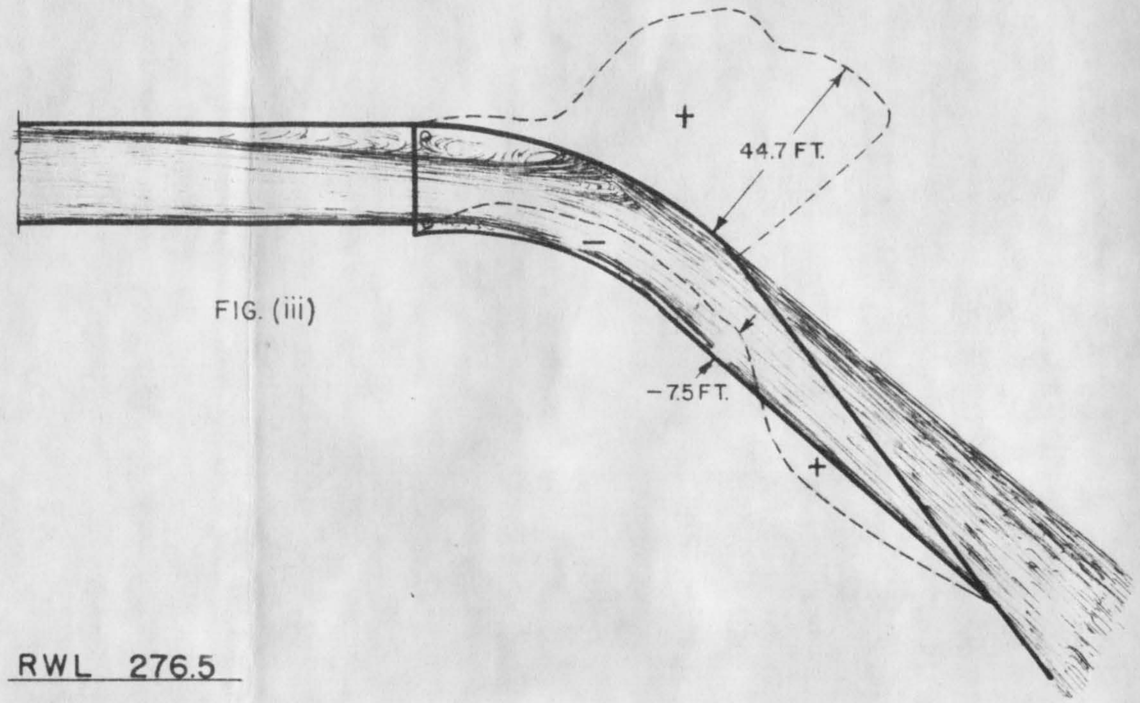


FIG. (iii)

RWL 290.0

GATE OPENING = 80%

Q_{80} = 82.2 M^3/S
(2,900 C.F.S.)

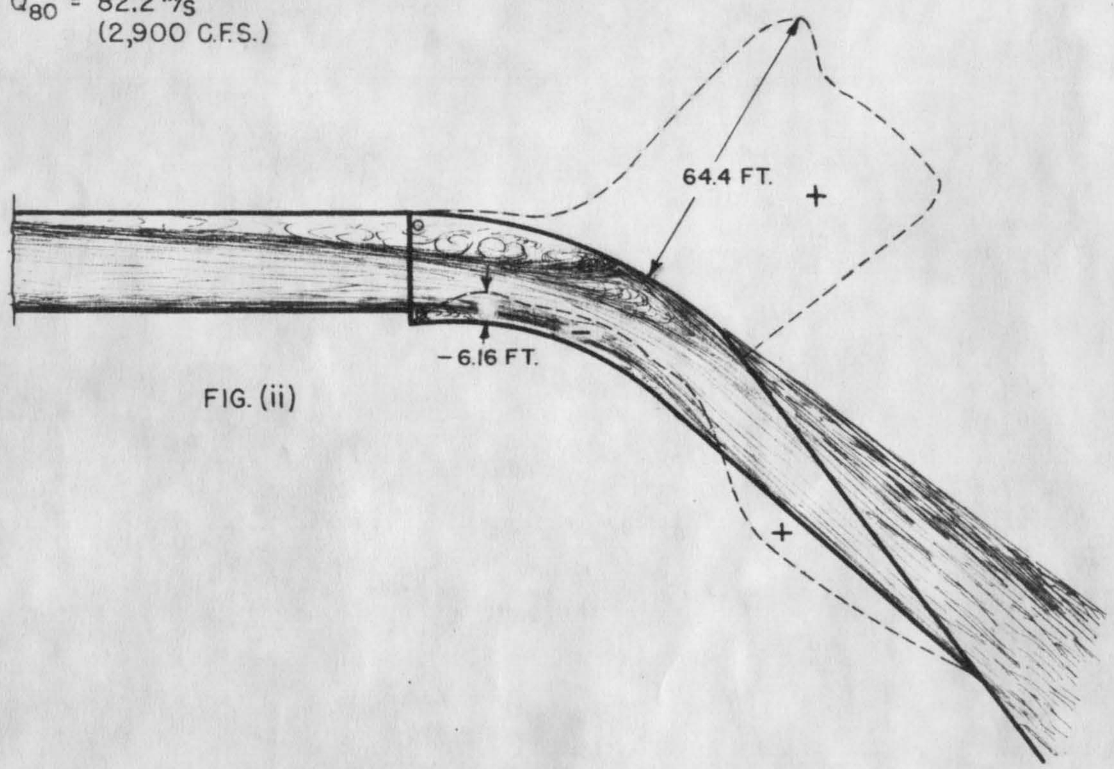


FIG. (ii)

RWL 276.5

GATE OPENING = 80%

Q_{80} = 73.5 M^3/S
(2,585 C.F.S.)

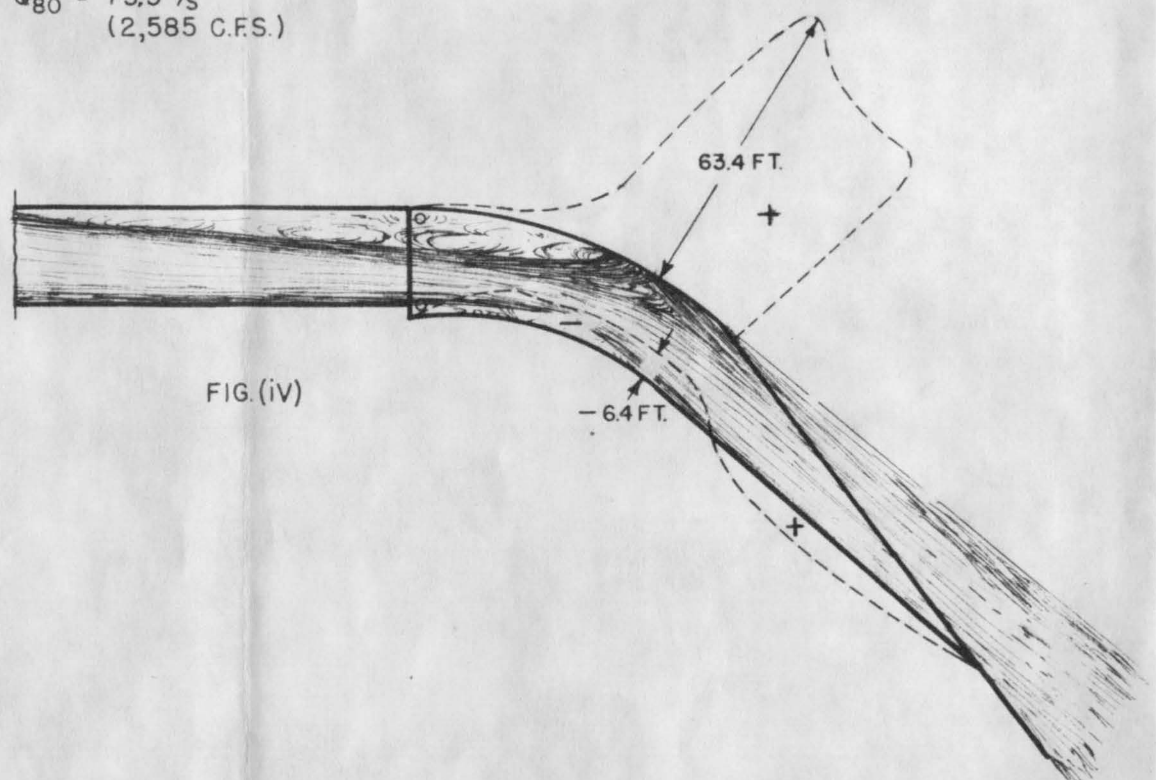


FIG. (iv)

LEGEND:

RWL = RESERVOIR WATER LEVEL

Q_{100} = DISCHARGE FOR 100% GATE OPENING

Q_{80} = DISCHARGE FOR 80% GATE OPENING

NOTES:

1. DISCHARGE FOR JET-FLOW GATE COMPUTED FROM $Q = 0.8A\sqrt{2gh}$
2. ALL VENT OPENINGS REPRODUCED TO SCALE. THEY WERE FULLY OPEN DURING THESE TESTS.
3. PRESSURES ON CROWN AND BOTTOM OF ELBOW WERE MEASURED ALONG THE CENTER LINE.

10 0 10 20 30 40 50

PRESSURE SCALE
(feet)

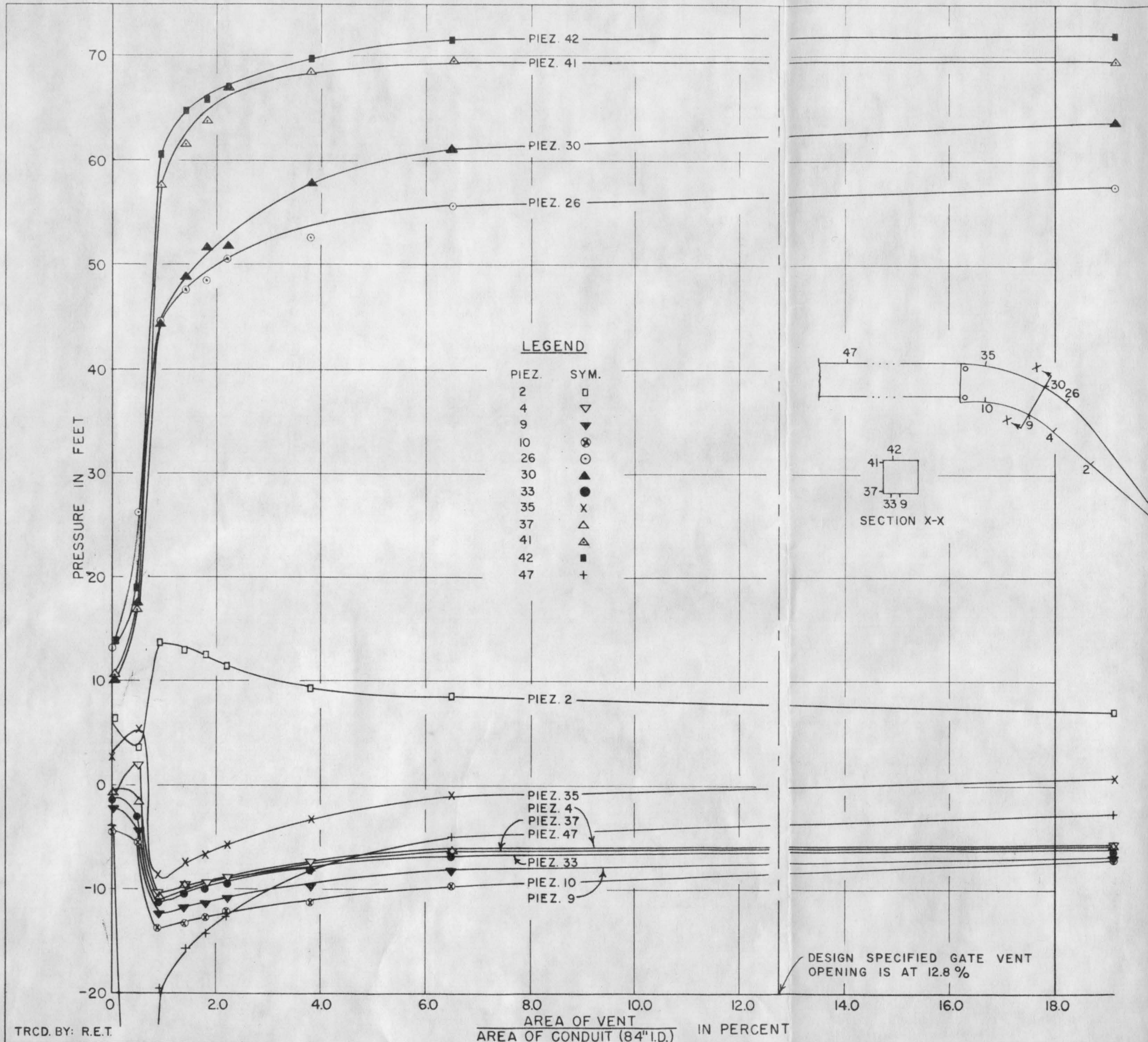
0 4 8 12 16 20

SCALE OF DRAWING
(feet)

THE FLOWS AND PRESSURES SHOWN ARE ALONG ℄ OF OUTLET

TRCD. BY: R.E.T.

BOCONO DAM MODEL STUDIES		
C.S.U. HYD. LAB.	PROJECT 752	
for R.J. TIPTON ASSOC. ENGINEERS INC.		
SUMMARY OF FLOW AND PRESSURES IN ELBOW MODEL SCALE 1:20		
DWN. BY: M.Sh.A & K.S.D	MARCH 15, 1958	NO. R.O.-4



NOTES:

THE SIDE VENTS AT THE STEPPED TRANSITION ARE REPRODUCED TO SCALE. THEY WERE FULLY OPEN DURING THESE TESTS.

BOCONO DAM MODEL STUDIES	
C.S.U. HYD. LAB.	PROJECT 752
for R.J. TIPTON ASSOC. ENGINEERS INC.	

INFLUENCE OF GATE VENT OPENING ON PRESSURES IN ELBOW

R.W.L. 290.0 METERS

G.O. = 80%

DWN. M.S.&A. & E.Y.	MAR. 21, 1958	NO. R.O.-5