HYD 470

Master file

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

AERODYNAMIC MODEL STUDIES OF THE OUTLET WORKS INTAKE STRUCTURE FOR TWIN BUTTES DAM SAN ANGELO PROJECT, TEXAS

Hydraulics Branch Laboratory Report No. HYD-470

DIVISION OF ENGINEERING LABORATORIES

OFFICE OF ASSISTANT COMMISSIONER AND CHIEF ENGINEER
DENVER, COLORADO

August 31, 1962

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FIGURES

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Office of Assistant Commissioner
and Chief Engineer
Division of Engineering Laboratories
Hydraulics Branch
Denver, Colorado
August 31, 1962

Report No. Hyd-470
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Checked by: W. P. Simmons
Reviewed by: W. E. Wagner
Submitted by: H. M. Martin

Subject: Aerodynamic model studies of the outlet works intake structure for Twin Buttes Dam--San Angelo Project, Texas

PURPOSE

Tests were made to develop cavitation-free entrances and to determine losses for the three-barrelled inlet structure of the outlet works.

CONCLUSIONS

1. The circular bellmouth entrances initially proposed produced cavitation pressures on some of the flow surfaces when the outlet gates (or a gate) were fully opened and the reservoir elevation was high (Figures 4, 6, 7, and 8).

2. The severe subatmospheric pressures found in the circular bellmouths were relieved by disrupting the flow with spoilers at the entrances (Figures 5B and 10). The spoilers presented construction problems that precluded their use on this structure.

3. Subatmospheric pressures that occurred on the crown of the circular entrances were relieved by lowering the approach floor (Figure 9). However, the amount of relief was inadequate, and lowering the approach floor in the field was impractical.

4. Larger circular bellmouths with less rapid curvatures were precluded by the desirability of maintaining the conduits on 20-foot centers.

5. Rectangular bellmouth entrances with watertight stoplog slot covers produced positive pressures on all flow surfaces for any reservoir elevation and any combination of gate openings (Figures 11, 12, 15, and 16). The rectangular entrances allow retaining the 20-foot spacing between conduits.

6. If water is permitted to enter the conduit through the stoplog slots during outlet operations, cavitation pressures will exist on the tunnel roofs just downstream from the slot (Figure 14). Use of covers over the top openings of the slots will prevent this difficulty.

7. The maximum downward hydraulic force on each stoplog slot cover is 97,500 pounds.

8. The head loss through the rectangular inlets from the reservoir to the circular conduit just downstream from the transition is:

$$0.116 \frac{V^2}{2g} \text{ for all three outlets operating}$$

and

$$0.118 \frac{V^2}{2g} \text{ for one outlet only,}$$

where V is the velocity in the 15.5-foot-diameter conduit.

ACKNOWLEDGEMENT

The achievements made through this model study were the result of close cooperative efforts between members of the Spillways and Outlet Works Section and the Hydraulics Branch of the Office of Assistant Commissioner and Chief Engineer, in Denver, Colorado.

INTRODUCTION

The San Angelo Project provides irrigation water for about 10,000 acres that were previously dry farmed, and furnishes 29,000 acre-feet of water annually for San Angelo municipal and industrial uses. Twin Buttes Dam is the major feature of the project and is located 9 miles southwest of the city of San Angelo, Texas (Figure 1). It is constructed across the Middle and South Concho Rivers and Spring Creek. The dam is 8 miles long, has a volume of about 21,000,000 cubic yards, and creates a reservoir of 600,000 acre-feet.

The spillway is located on the left abutment and has a maximum design capacity of 47,000 cubic feet per second (Figure 2). The outlet works is also on the left abutment and includes an approach channel, an intake structure, three conduits with radial control gates, a chute, and a stilling basin (Figures 2 and 3). The conduits extending from the intake structure to the gate chamber are circular, concrete lined, and 15.5 feet in diameter. From the gate chambers to the chute the conduits are 17 feet in diameter, concrete lined, and horseshoe in cross section. A concrete chute carries the water from the conduits to the outlet works stilling basin.[1] A 12- by 15-foot fixed-wheel guard gate is placed upstream from each of the 12- by 15-foot radial control gates. A 2- by 2-foot regulating gate is built

1/ "Hydraulic Model Studies of Twin Buttes Dam Outlet Works," Laboratory Report No. Hyd-463, by T. J. Rhone.

into each of the guard gates to control releases up to 600 cubic feet per second. 2/ Releases greater than 600 cubic feet per second, and up to the maximum of 35,700 cubic feet per second, are controlled by the three 12- by 15-foot top seal radial regulating gates. The conduits are placed as close together as possible for practical and economic reasons.

At the highest discharges, flow velocities up to 63 feet per second will occur in the circular conduits. Correspondingly high velocities will occur within and near the bellmouth inlet structure where the flow experiences appreciable turning and rapid accelerations. These factors tend to induce subatmospheric pressures on the boundaries and to produce damaging cavitation. Also, unsymmetrical releases, which might at some time be necessary due to a gate malfunction, could aggravate the severe pressure problems to produce even more dangerous conditions. Model studies of the inlet structure were therefore made to determine the operating conditions and to develop the design most appropriate for construction.

THE MODEL

In studies where the system flows completely full, low velocity air may be used as a test fluid for hydraulic structures without introducing appreciable error. 3/ Aerodynamic models are characterized by simplicity of construction, ease of obtaining data, and economy. The laboratory study on the Twin Buttes intake structure concerned a deeply submerged, completely filled structure, and was made using air as the testing fluid.

The model was constructed on a linear scale of 1:23.25 (Figure 4). It included an approach apron, the triple-bellmouth entrance structure, and three parallel circular conduits representing 70 feet of the prototype tunnels. The conduits terminated in a 200-cubic-foot plenum chamber which was connected to the inlet of an air blower. Thus, air was drawn through the bellmouth entrances from the atmosphere. Air could be drawn through one of the 8-inch-diameter tunnels at a velocity of 150 feet per second, or through all three tunnels at 53 feet per second. Gates were provided at the stoplog slots of each conduit so the individual tunnels could be shut off or opened as desired.

In the preliminary design, circular bellmouths were used (Figures 4 and 5). The bellmouth surfaces were formed of smoothly screeded concrete, the approach apron was made of plywood, and the remainder of the model was constructed of sheet metal. Pressure taps (piezometers) were located in regions where adverse pressures were considered possible. In particular, these regions included surfaces of the bellmouths lying on the horizontal and vertical centerlines where flow contractions would be most severe.

2/ "Hydraulic Model Studies of the 2- by 2-Foot Twin Buttes Regulating Gate," Laboratory Report No. Hyd-476 by H. T. Falvey.
3/ "Model Tests Using Low Velocity Air" by J. W. Ball, Transactions, ASCE, Vol. 117, 1952, Paper No. 2517.

The most unfavorable pressure conditions will exist with the reservoir at maximum elevation and the control gates of the operating tunnels fully opened. All pressures given in this report are based on this condition. All dimensions and values given are for the prototype, unless otherwise stated.

From a previous model study it was determined that at maximum reservoir elevation and fully opened control gates the pressure head on the crown of the tunnel 57 feet downstream from the inlet was 7.34 feet.[1] The tunnel crown at this point is 84.81 feet below maximum reservoir, and thus, for maximum discharge, the head drop from the reservoir to the tunnel crown is 77.47 feet. A piezometer was placed in each model conduit at the point representing 57 feet from the entrance to measure the corresponding model head drop. A suitable pressure factor, $\frac{77.47}{\text{Head drop, model}}$, was determined for each test run. The prototype head at any given point was computed by multiplying the measured model head drop from the atmosphere to the point by the pressure factor for that test run. The resulting prototype head drop was subtracted from the depth of water above the point (maximum water surface elevation minus elevation of the point) to obtain the net prototype pressure which is shown and discussed in this report. Tests were conducted with all three outlets opened, and with all combinations of one or two outlets opened.

INVESTIGATION

Circular Bellmouth Entrances

Preliminary design. Pressures acting on the surfaces of the left, center, and right circular bellmouth entrances with one, two, or three outlets operating are shown in Figures 6, 7, and 8. Pressures measured on the inverts were strongly positive, and hence satisfactory, for all combinations of outlets operating. However, subatmospheric pressures, including cavitation pressures, were found just inside the bellmouths on the sides and tops of the conduits for some operating conditions. The most severe subatmospheric pressures were encountered at the crown of the center outlet with all three outlets operating. These subatmospheric pressures indicated that cavitation would occur in the prototype structure.

Effect of approach floor elevation. In the preliminary design, the floor leading to the intake structure was 2.25 feet below the invert of the tunnels. A study was made to determine the effect of lowering the floor 3 feet, 6 feet, and of removing it entirely. Pressures were measured on the crown of the center outlet for each floor elevation (Figure 9). Steady improvement in pressures resulted from lowering the floor, and

1/op. cit. 4.

finally removing it, but subatmospheric pressures persisted even when the floor was removed. The improvements in the pressures achieved with reasonable amounts of lowering of the floor were insufficient to make this solution practical.

Flow spoilers. To disrupt the flow approaching the low pressure areas, spoilers of various types were fastened to the upstream face of the wall surrounding the entrances (Figure 5B). The most satisfactory combination consisted of vertical cylindrical piers between the outlets, semicircular piers of larger diameter on either side, and a large-diameter semicircular brow over the tops. Increasing the diameter of the cylindrical piers greatly improved the pressures (Figure 10). Excellent results were obtained with cylindrical piers having a diameter of 24.4 inches, and semicircular piers and a brow having diameters of 48.4 inches. In these tests the approach floor was lowered 3 feet to a position 5.25 feet below the tunnel invert. No pressure measurements were made on circular and semicircular piers and the loadings on them are not known.

In spite of the fact that spoilers produced satisfactory pressures on the entrances for all combinations of outlets operating, the spoilers were considered infeasible from a construction standpoint. Larger bellmouths with more gradual curvature could be designed to produce positive pressures on all surfaces, but would require increased spacing between the tunnels, and considerable additional expense. Tests concerning circular bellmouth entrances were subsequently discontinued and the use of rectangular bellmouths which retained the same spacing between tunnels was investigated.

Rectangular Bellmouth Entrances

Design. Rectangular bellmouths flared in three directions and representing entrances 26 feet high and 20 feet wide at the upstream face were installed in the model (Figures 11, 12, and 13). The rectangular entrances were 24.4 feet long and were followed by rectangular-to-circular transitions 18 feet long. The 15.5-foot-diameter circular tunnels downstream from the transitions were retained. A stoplog slot was installed in each tunnel 15.5 feet from the upstream face. The approach floor was raised 2.5 feet above the initial design to the elevation of the tunnel invert. Considerable excavation was avoided by this change. Piezometers were placed on all surfaces considered critical (Figure 12).

Stoplog slot covers. In the first tests of the rectangular entrances, cavitation pressures were found on the crowns of the tunnels just downstream from the stoplog slots (Figure 14). It was apparent that these adverse pressures were caused by flow entering the conduit through the slots. When the tops of the slots were sealed to prevent this flow, the adverse pressures were eliminated (Figure 14). Watertight stoplog slot covers were used in all subsequent tests.

The hydraulic forces acting on the stoplog slots were investigated to assist in their proper design. Pressure measurements showed that for maximum flow through the outlets and maximum water surface elevation a pressure differential of 54.2 feet of water acted across the covers (Figure 17). This differential produces a downward hydraulic force of about 97,500 pounds on each stoplog cover.

Pressure conditions. The test showed that the pressures on the flow surfaces would be positive for all combinations of outlet operation (Figures 15 and 16). The expected drop in pressure gradient was noted in the vicinity of the stoplog slots at the crown and at the sidewalls, but this drop was small and the pressures remained positive.

Entrance head loss. The head loss from the reservoir to the downstream ends of the transitions was determined for the rectangular entrances. When all three outlets were operating the head loss in each inlet was 0.116 $(V^2/2g)$, where V is the velocity in the 15-1/2-foot circular conduit (Figure 18). When only one outlet was operating, its head loss was 0.118 $(V^2/2g)$.

SUMMARY

Studies showed that circular bellmouth entrances (Figure 4) would be unsatisfactory for Twin Buttes outlet works due to the existence of cavitation pressures on some of the flow surfaces during operation at maximum discharge. Larger circular bellmouths with less rapid curvatures were precluded by the necessity of keeping the three tunnels close together. Rectangular bellmouth entrances allowed the same tunnel spacings and, with watertight stoplog slot covers, produced positive, and hence satisfactory, pressures throughout the system. The rectangular entrances are recommended for the outlet works intake structure.

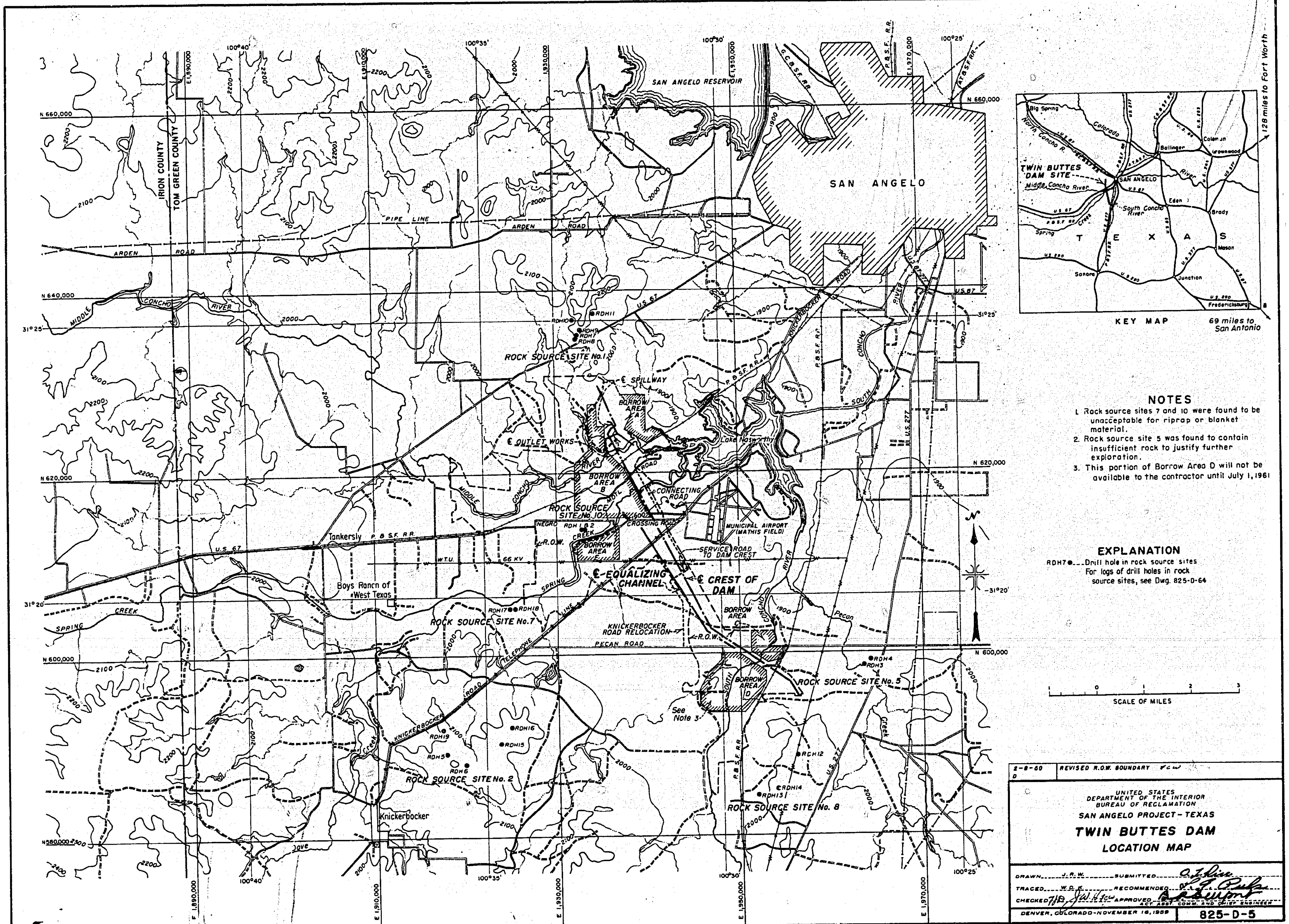

SAN ANGELO RESERVOIR
SAN ANGELO
IRION COUNTY
TOM GREEN COUNTY
ARDEN ROAD
PIPE LINE
MIDDLE CONCHO RIVER
ROCK SOURCE SITE No. 1
SPILLWAY
BORROW AREA A
OUTLET WORKS
Lake Nasworthy
BORROW AREA B
CONNECTING ROAD
ROCK SOURCE SITE No. 10
CROSSING ROAD
MUNICIPAL AIRPORT (MATHIS FIELD)
SERVICE ROAD TO DAM CREST
BORROW AREA E
EQUALIZING CHANNEL
CREST OF DAM
Tankersly
Boys Ranch of West Texas
SPRING CREEK
ROCK SOURCE SITE No. 7
KNICKERBOCKER ROAD RELOCATION
PECAN ROAD
BORROW AREA C
BORROW AREA D
ROCK SOURCE SITE No. 5
See Note 3
ROCK SOURCE SITE No. 2
ROCK SOURCE SITE No. 8
Knickerbocker
KEY MAP
TWIN BUTTES DAM SITE
128 miles to Fort Worth
69 miles to San Antonio
NOTES
1. Rock source sites 7 and 10 were found to be unacceptable for riprap or blanket material.
2. Rock source site 5 was found to contain insufficient rock to justify further exploration.
3. This portion of Borrow Area D will not be available to the contractor until July 1, 1961
EXPLANATION
RDH7 ● Drill hole in rock source sites
For logs of drill holes in rock source sites, see Dwg. 825-D-64
SCALE OF MILES
2-8-60 D REVISED R.O.W. BOUNDARY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN ANGELO PROJECT - TEXAS
TWIN BUTTES DAM
LOCATION MAP
DRAWN J.R.W. SUBMITTED
TRACED W.O.K. RECOMMENDED
CHECKED APPROVED
ACT. ASST. COMM. AND CHIEF ENGINEER
DENVER, COLORADO - NOVEMBER 16, 1959
825-D-5

FIGURE 2
REPORT HYD. 470

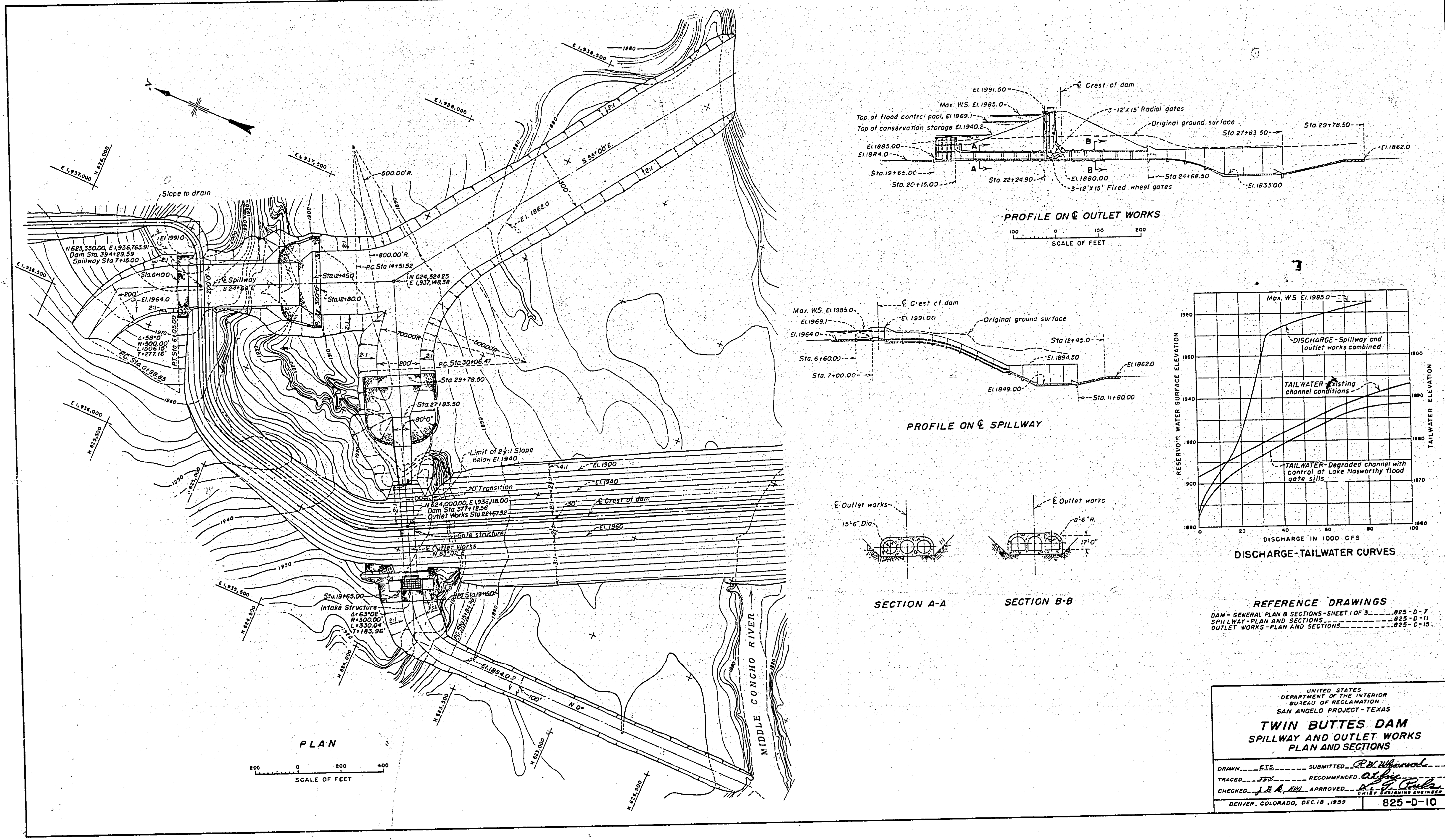
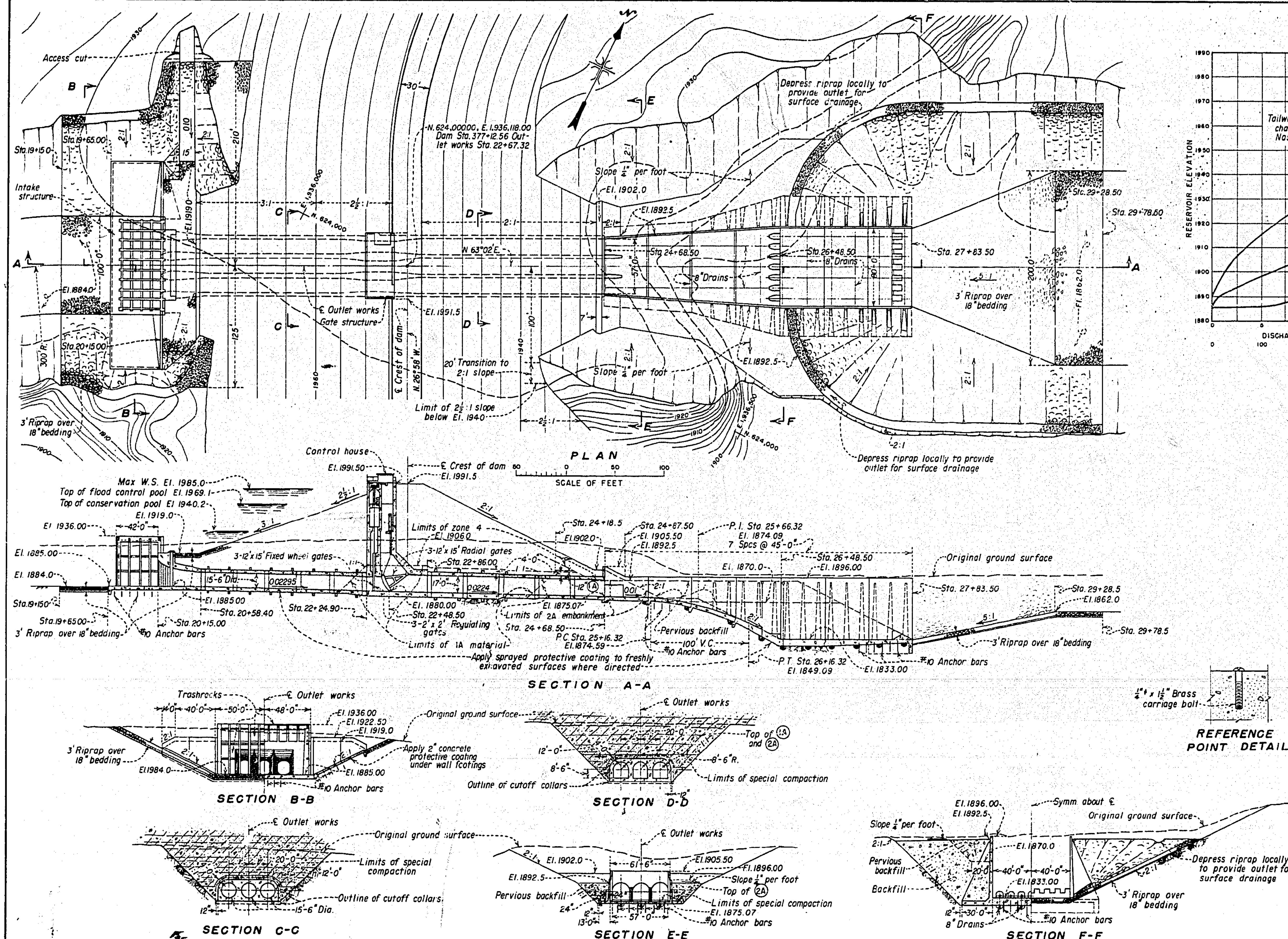
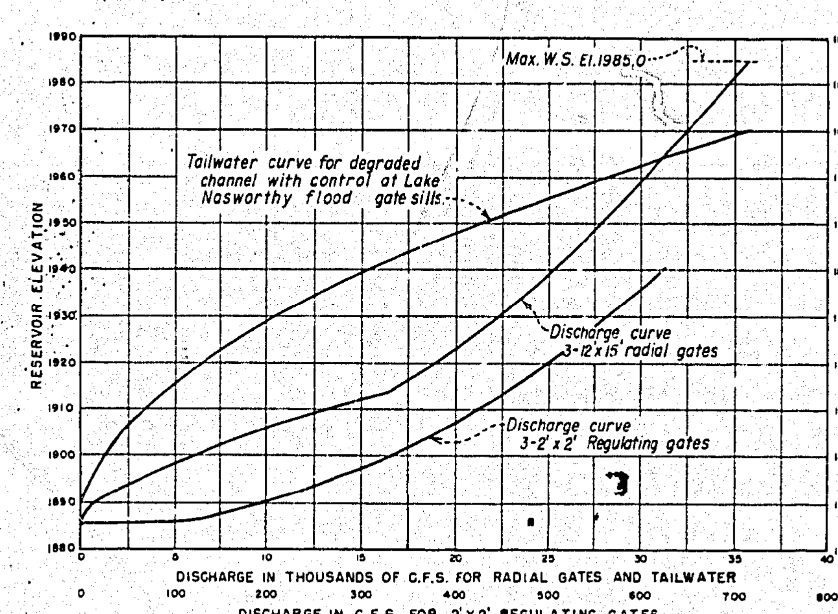


FIGURE 3
REPORT HYD. 470





DISCHARGE - TAILWATER CURVES

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

REFERENCE POINT DETAIL

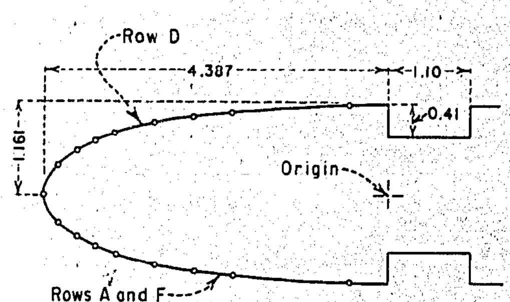
2-23-60 ADDED TWO COUNTERFORTS TO CHUTE WALLS

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN ANGELO PROJECT-TEXAS

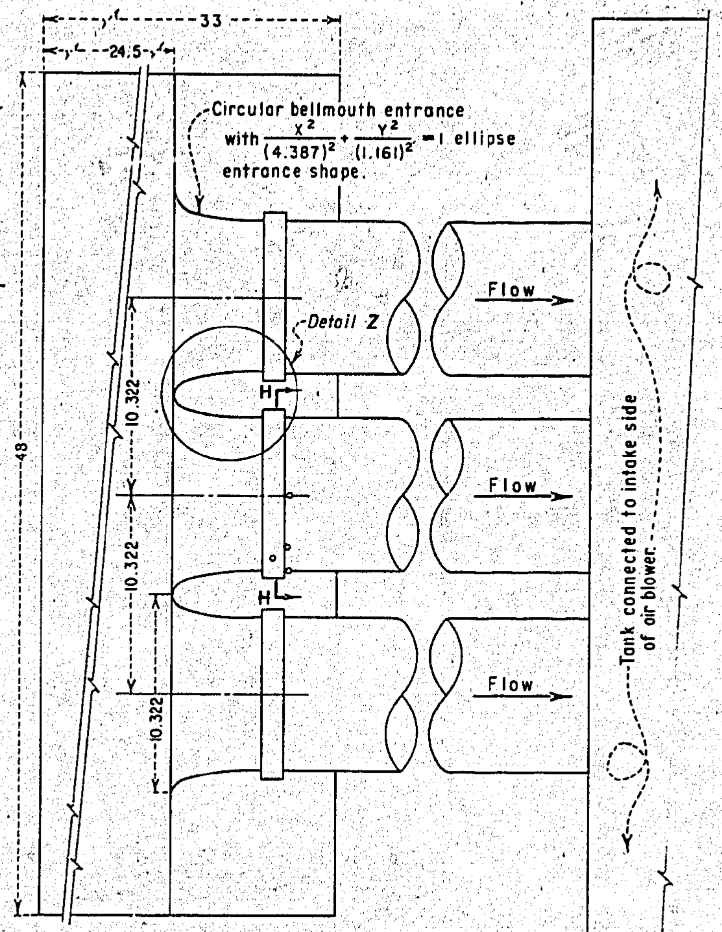
TWIN BUTTES DAM
OUTLET WORKS
PLAN AND SECTIONS

DRAWN J.E.H. SUBMITTED R.W. Whinnerah
TRACED R.T.A. RECOMMENDED
CHECKED APPROVED

DENVER, COLORADO, DEC. 18, 1959 — 825-D-15

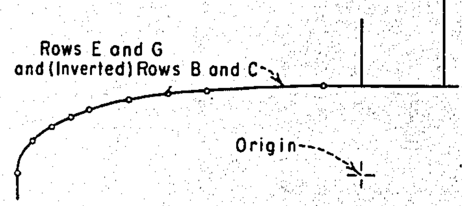


DETAIL Z



PLAN

NOTES
1. Circular bellmouth entrance formed in concrete.
2. Other construction of light weight sheet metal and plywood.
3. All dimensions are in inches - model.

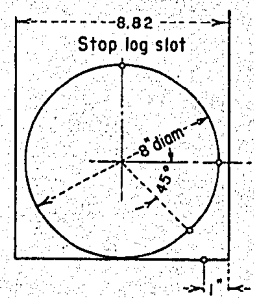


SECTION J-J

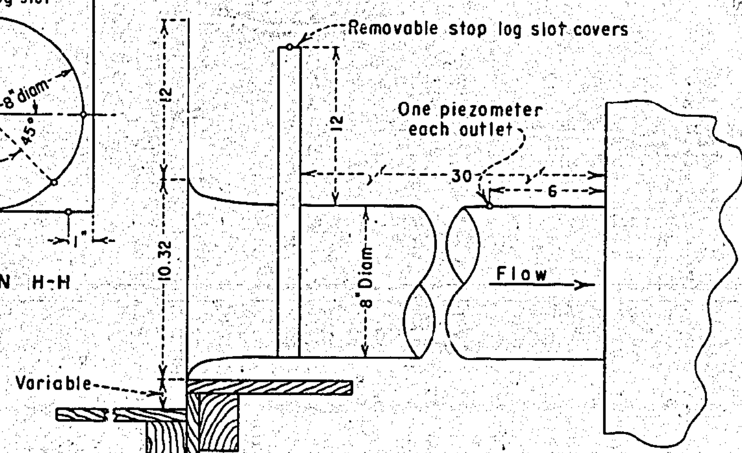
$$\frac{X^2}{(4.387)^2}+\frac{Y^2}{(1.161)^2}=1$$

PIEZOMETER LOCATIONS	X	Y
	0.0	1.161
✓	0.5	1.15
	1.0	1.13
	1.5	1.09
✓	2.0	1.03
✓	2.5	0.96
✓	3.0	0.85
✓	3.5	0.70
✓	3.75	0.60
✓	4.0	0.48
✓	4.25	0.29
✓	4.387	0.00

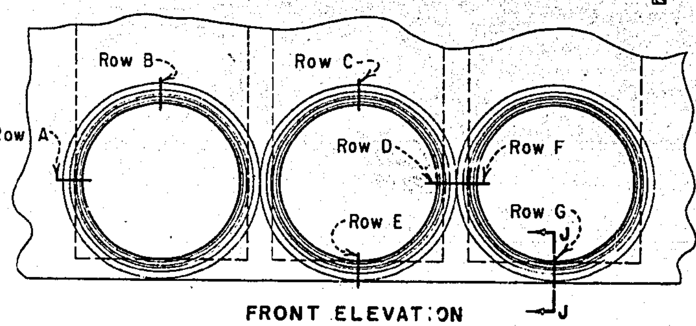
ELLIPSE COORDINATES
AND
ENTRANCE PIEZOMETER LOCATIONS



SECTION H-H



SIDE ELEVATION

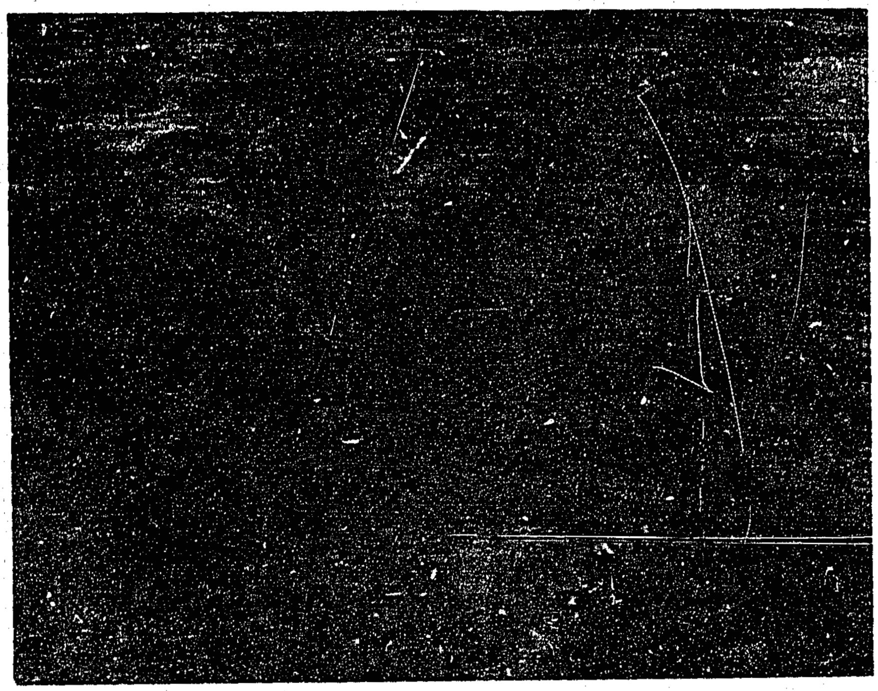


FRONT ELEVATION

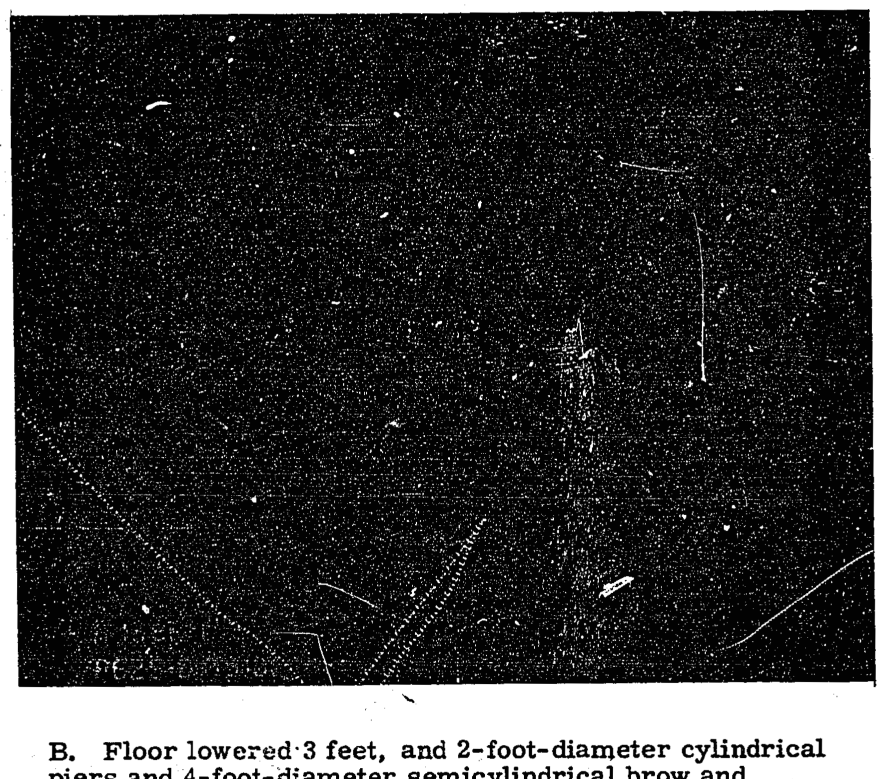
SAN ANGELO PROJECT, TEXAS
TWIN BUTTES DAM
OUTLET WORKS INTAKE STRUCTURE
CIRCULAR BELLMOUTH ENTRANCES
DRAWING FOR MODEL CONSTRUCTION
AND PIEZOMETER LOCATIONS
MODEL SCALE — 1:23.25

618

Figure 5
Report Hyd 470



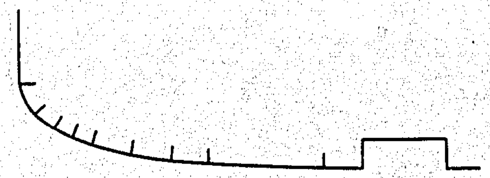
A. Preliminary Design



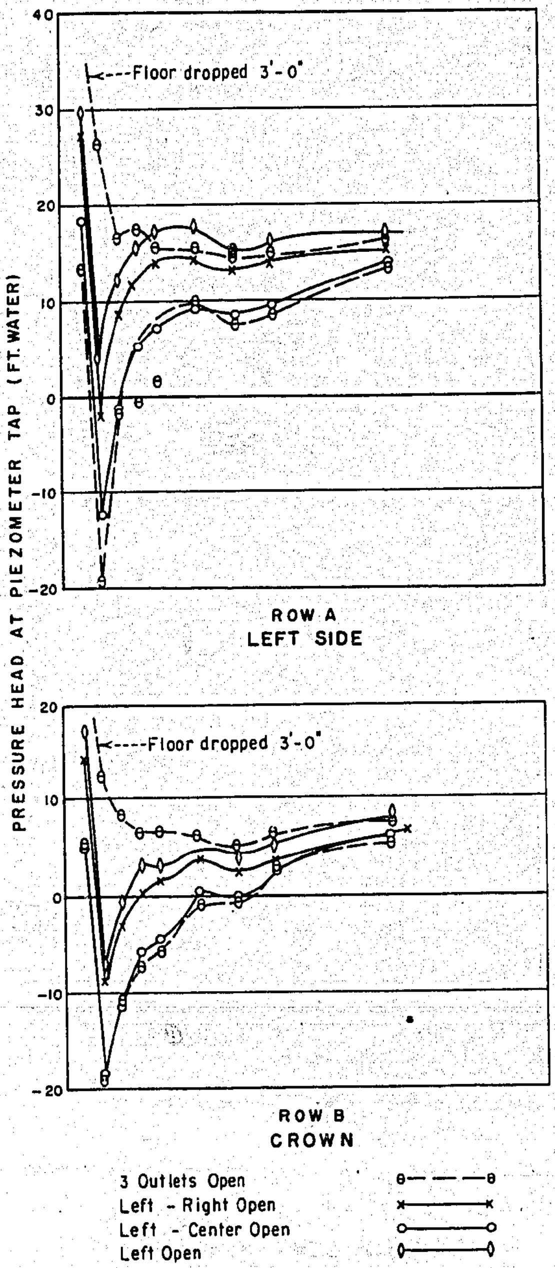
B. Floor lowered 3 feet, and 2-foot-diameter cylindrical piers and 4-foot-diameter semicylindrical brow and side piers

TWIN BUTTES DAM
OUTLET WORKS INTAKE STRUCTURE

Circular Bellmouth Entrances
1:23.25 Scale Model



LEFT CONDUIT



ROW A
LEFT SIDE

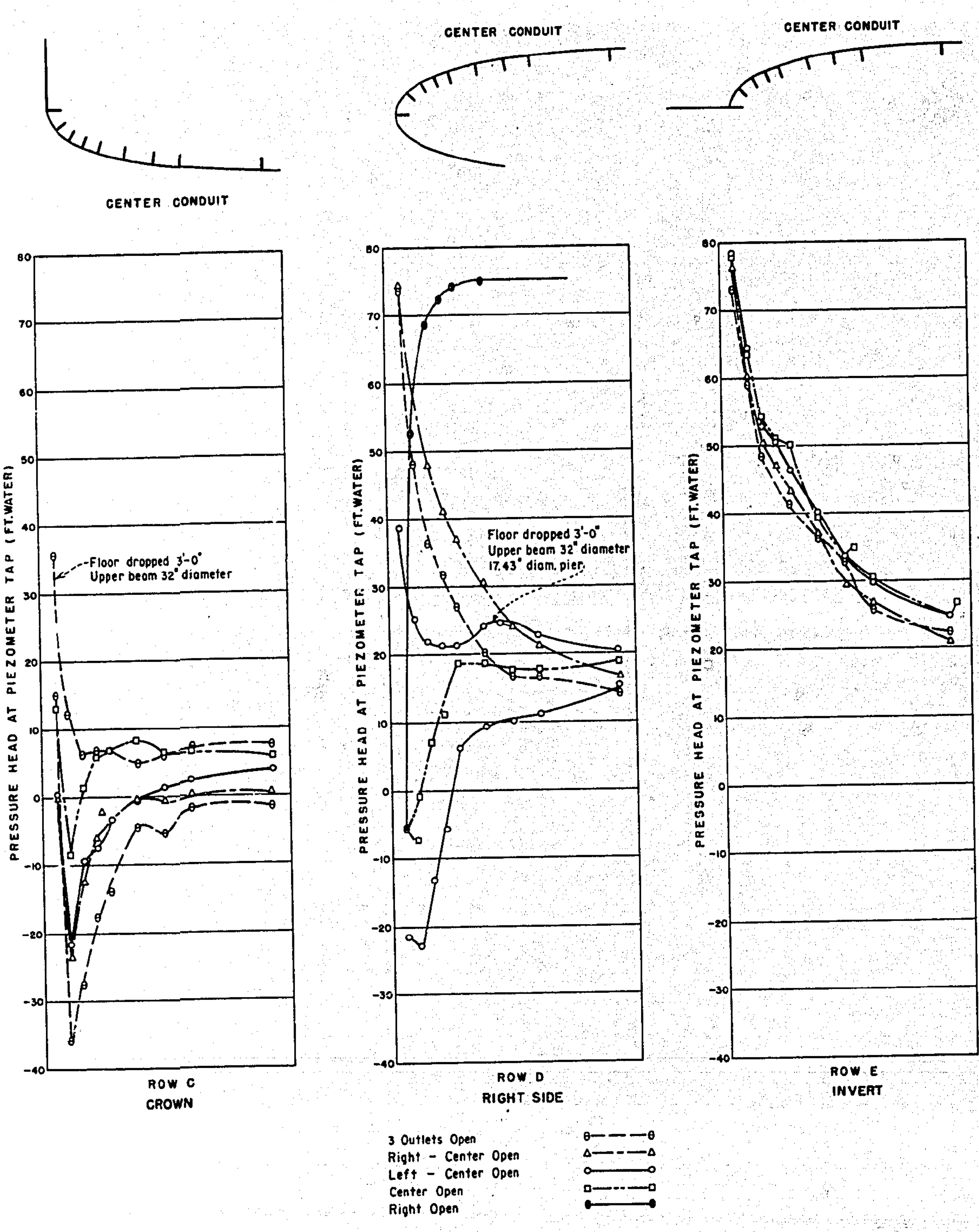
ROW B
CROWN

SAN ANGELO PROJECT, TEXAS

TWIN BUTTES DAM
OUTLET WORKS INTAKE STRUCTURE

CIRCULAR BELLMOUTH ENTRANCES
PRESSURES, LEFT CONDUIT

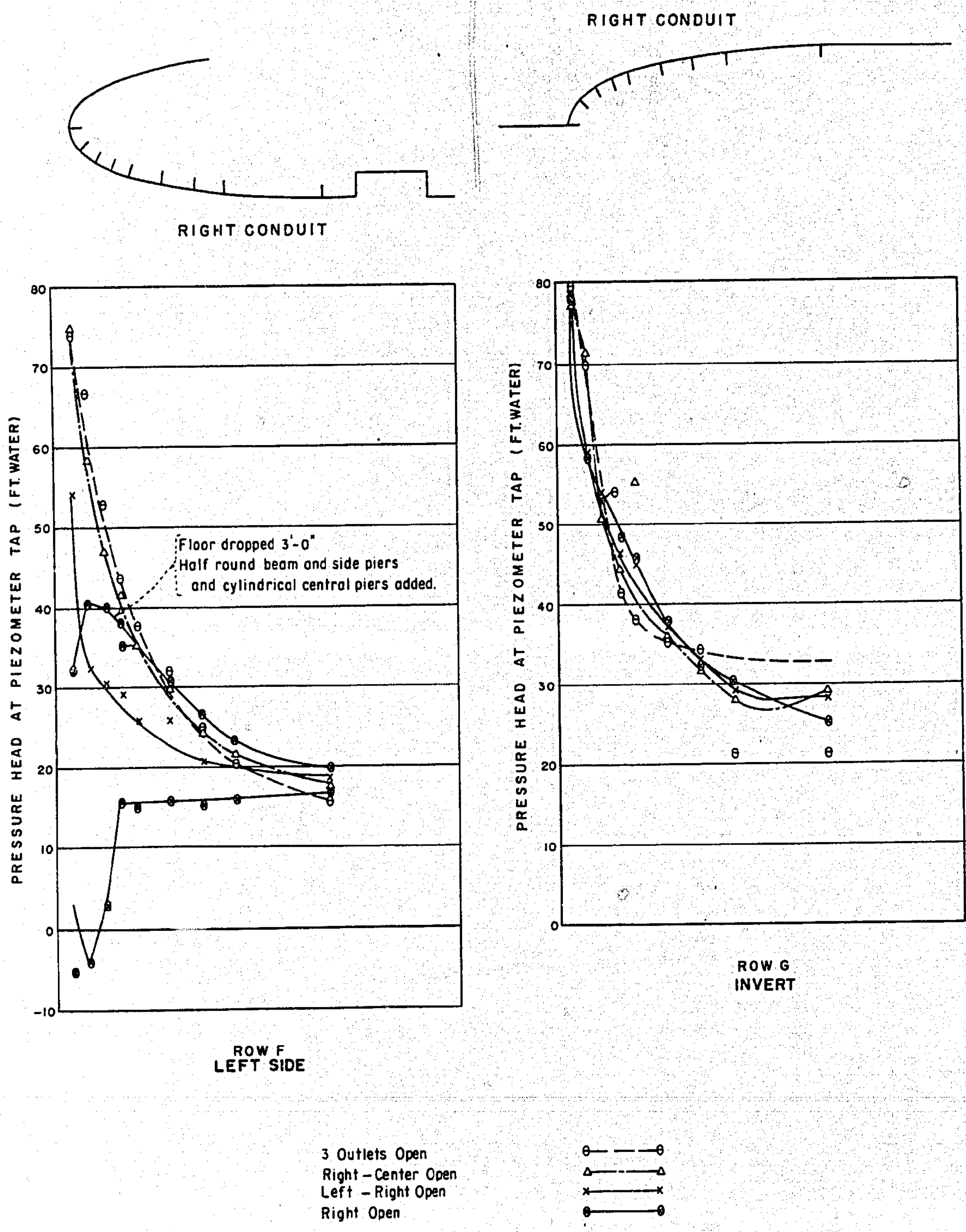
FIGURE 7
REPORT HYD. 470



SAN ANGELO PROJECT, TEXAS

TWIN BUTTES DAM
OUTLET WORKS INTAKE STRUCTURE

CIRCULAR BELLMOUTH ENTRANCES
PRESSURES, CENTER CONDUIT



SAN ANGELO PROJECT, TEXAS

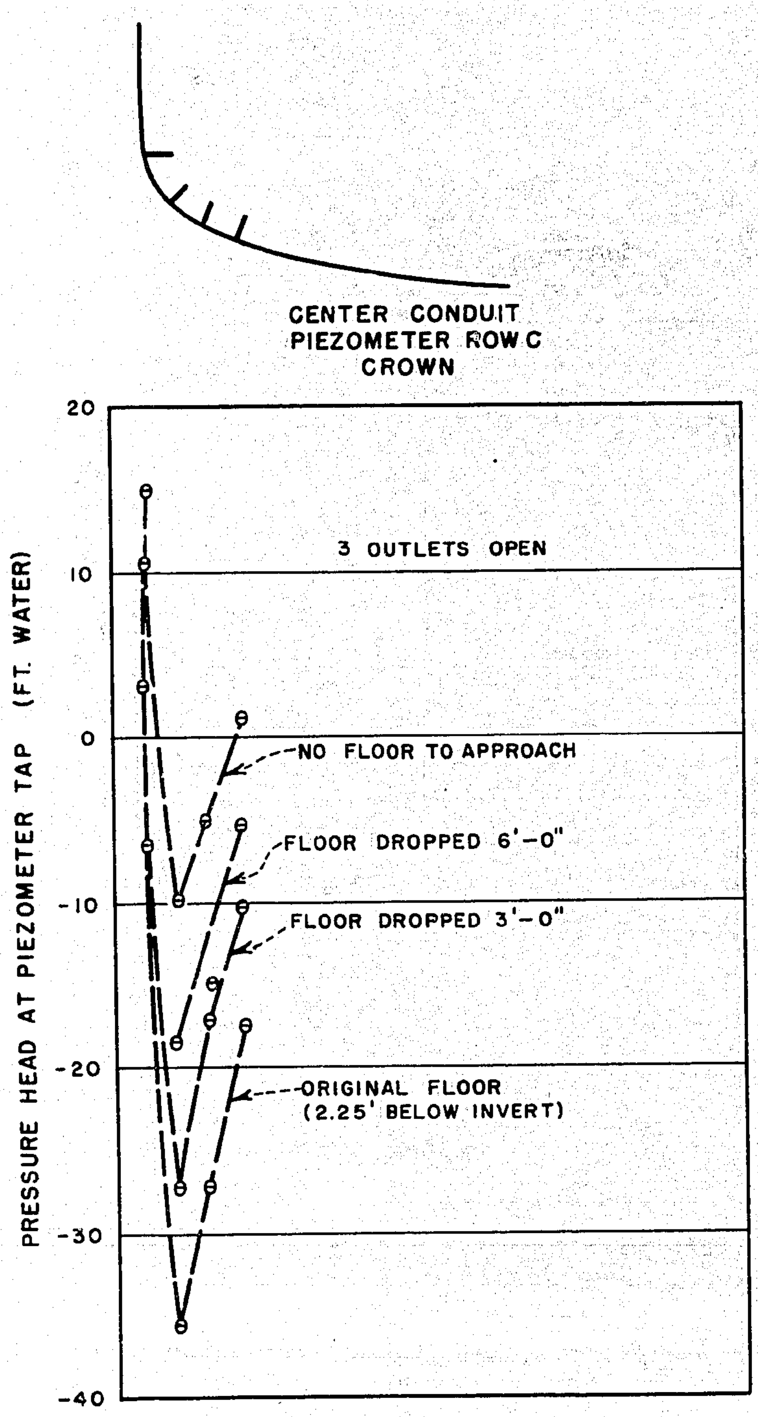
TWIN BUTTES DAM

OUTLET WORKS INTAKE STRUCTURE

CIRCULAR BELLMOUTH ENTRANCES

PRESSURES, RIGHT CONDUIT

FIGURE 9
REPORT HYD. 470



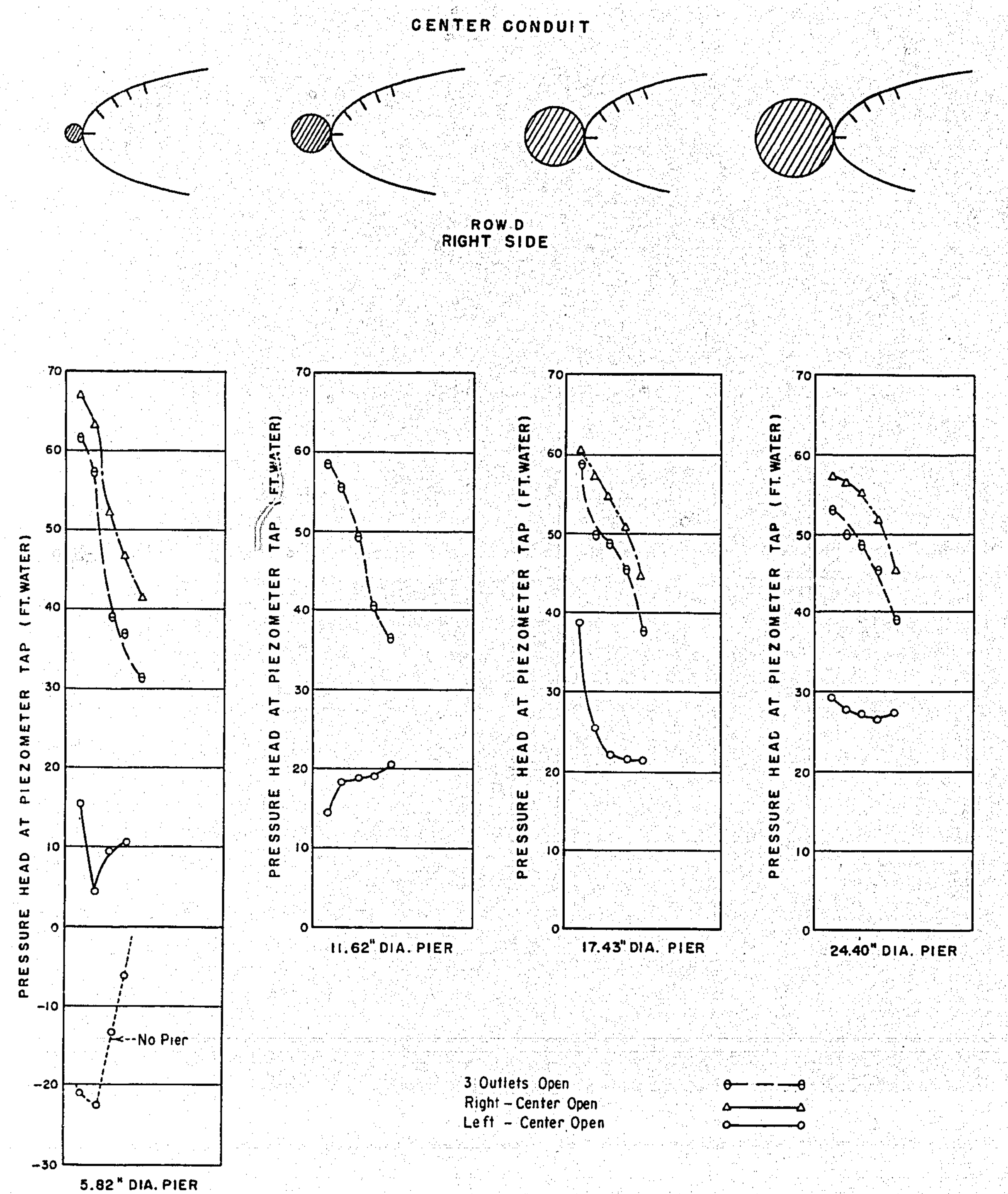
SAN ANGELO PROJECT, TEXAS

TWIN BUTTES DAM

OUTLET WORKS INTAKE STRUCTURE

CIRCULAR BELLMOUTH ENTRANCES

PRESSURE EFFECT ON THE CROWN OF THE CENTER CONDUIT CAUSED BY VARYING THE ELEVATION OF THE APPROACH FLOOR



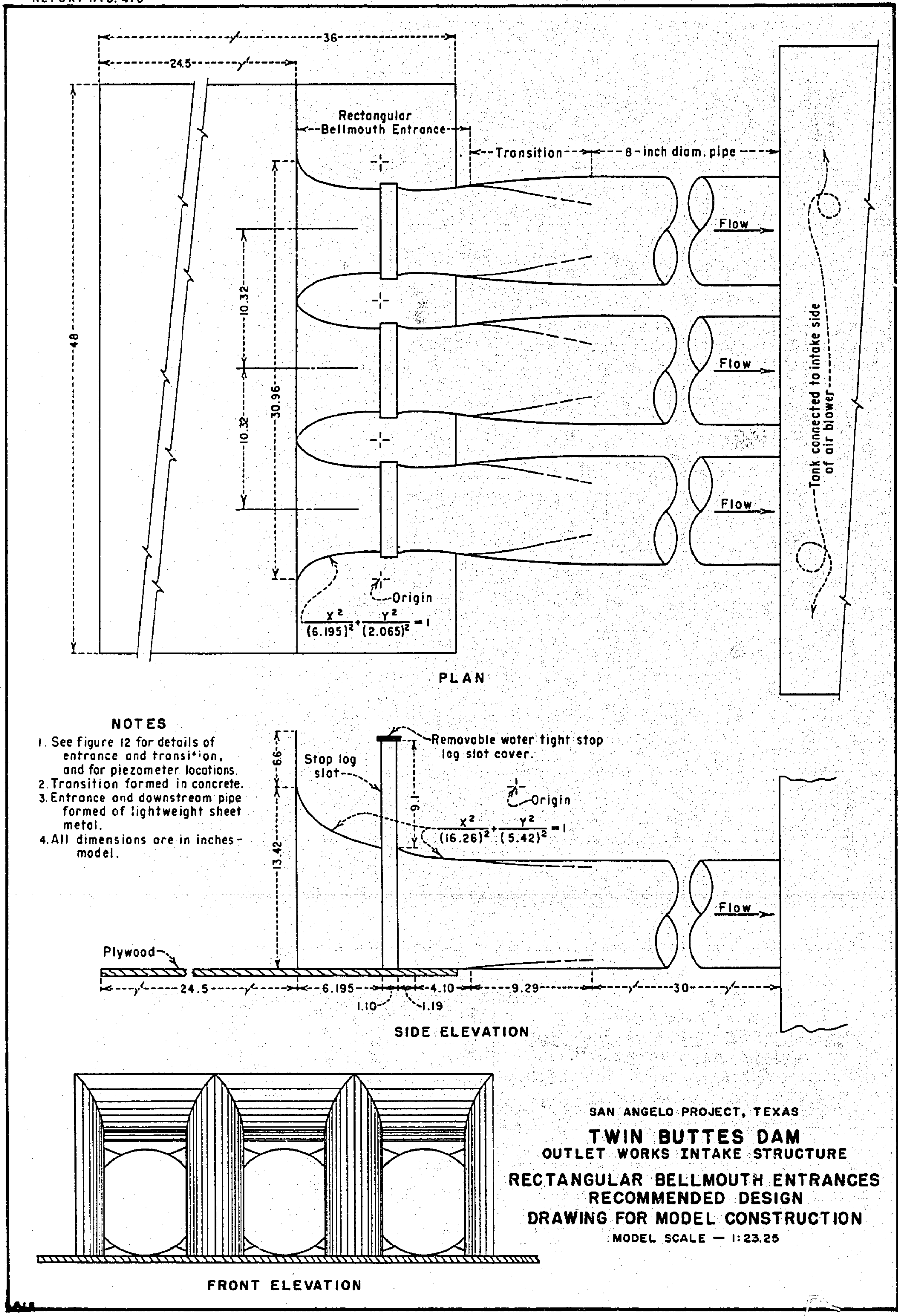
SAN ANGELO PROJECT, TEXAS

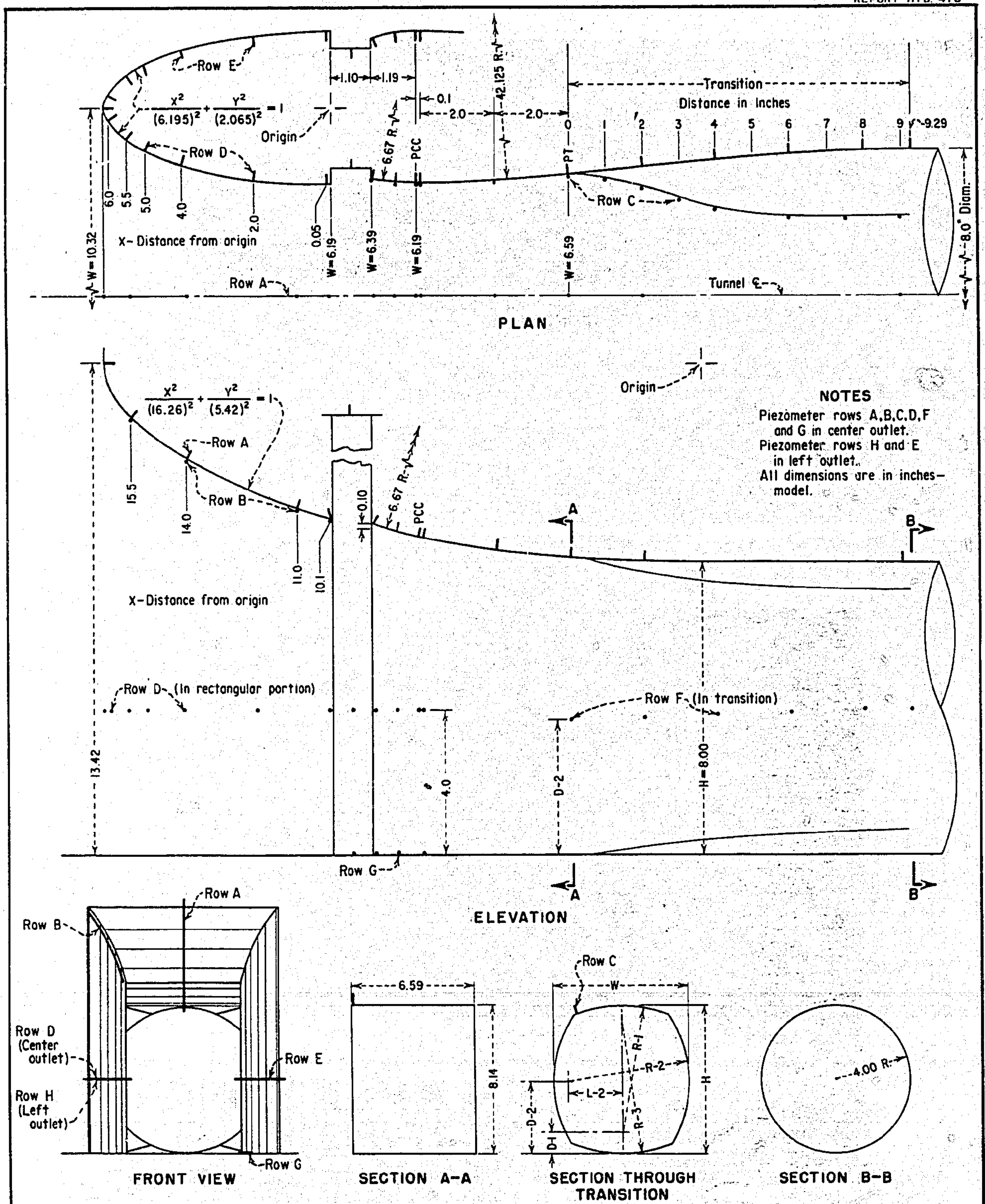
TWIN BUTTES DAM

OUTLET WORKS INTAKE STRUCTURE

CIRCULAR BELLMOUTH ENTRANCES
PRESSURE EFFECT OF CYLINDRICAL
PIERS AS FLOW SPOILERS

FIGURE 11
REPORT HYD. 470





TRANSITION DIMENSIONS								
DIST	H	W	D-1	R-1	D-2	L-2	R-2	R-3
0	8.14	6.59	—	—	—	—	—	—
1	8.07	6.79	-26.93	35.00	3.82	24.10	27.50	29.25
2	8.03	6.98	-7.55	15.58	3.84	9.73	13.22	14.14
3	8.00	7.18	-1.45	9.45	3.86	5.12	8.71	9.30
4	8.00	7.37	+1.11	6.89	3.88	2.91	6.60	7.05
5	8.00	7.57	2.50	5.50	3.90	1.65	5.44	5.78
6	8.00	7.75	3.34	4.66	3.92	0.84	4.72	4.97
7	8.00	7.88	3.77	4.23	3.94	0.36	4.30	4.50
8	8.00	7.97	3.93	4.07	3.96	0.08	4.07	4.18
9	8.00	8.00-	4.00-	4.00+	3.99	0.00+	4.00+	4.01
9.29	8.00	8.00	4.00	4.00	4.00	-0-	4.00	4.00

SAN ANGELO PROJECT, TEXAS

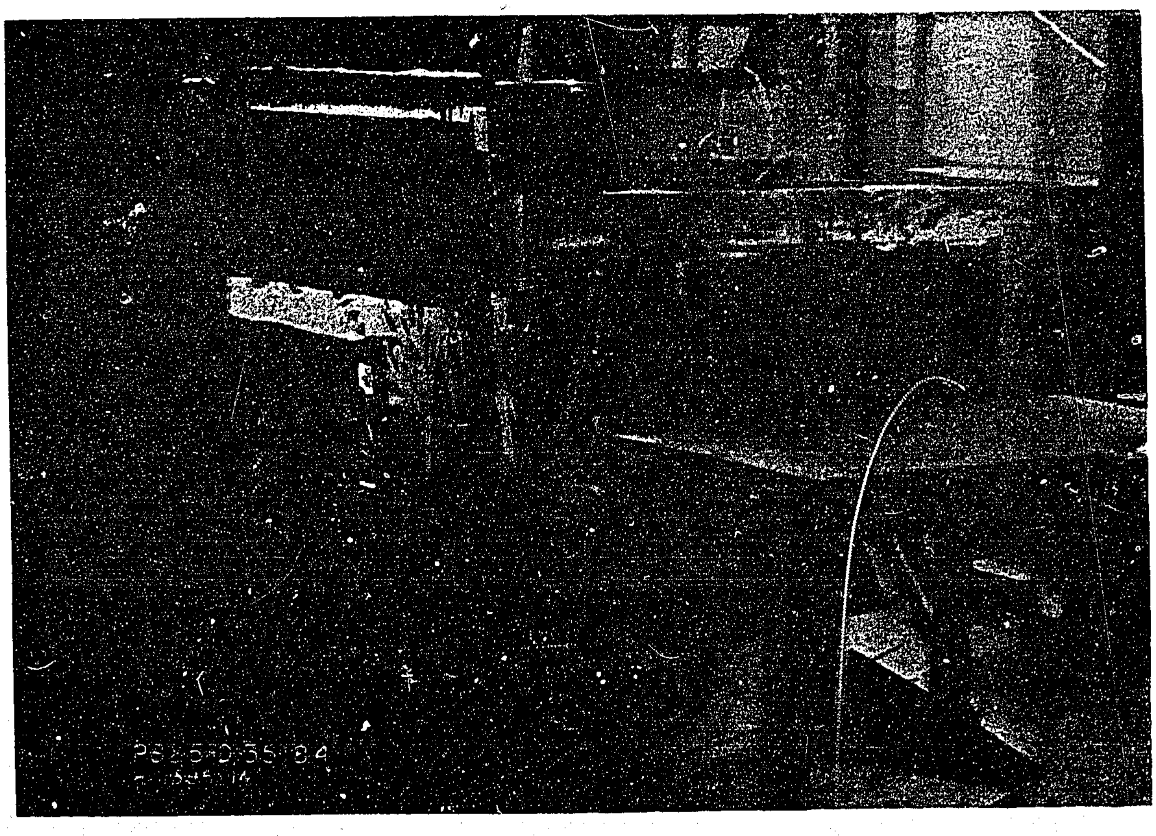
TWIN BUTTES DAM
OUTLET WORKS INTAKE STRUCTURE

RECTANGULAR BELLMOUTH ENTRANCES
RECOMMENDED DESIGN
TRANSITION DIMENSIONS
AND PIEZOMETER LOCATIONS

618

Figure 13
Report Hyd 470

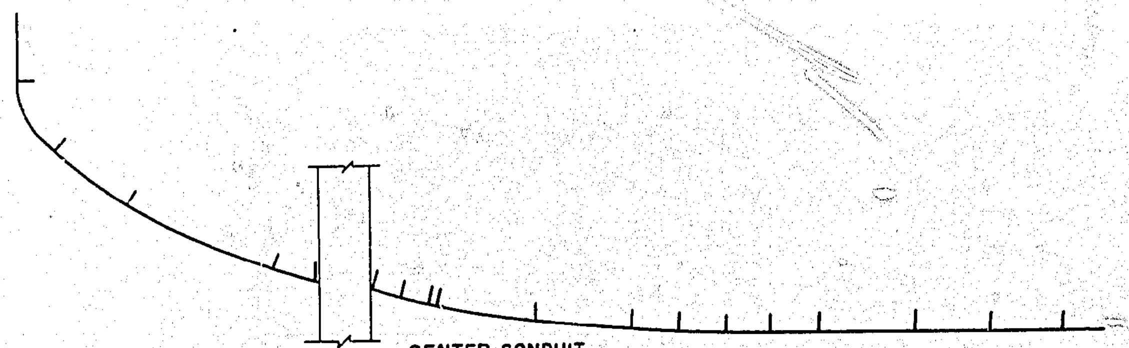
A. Recommended Design

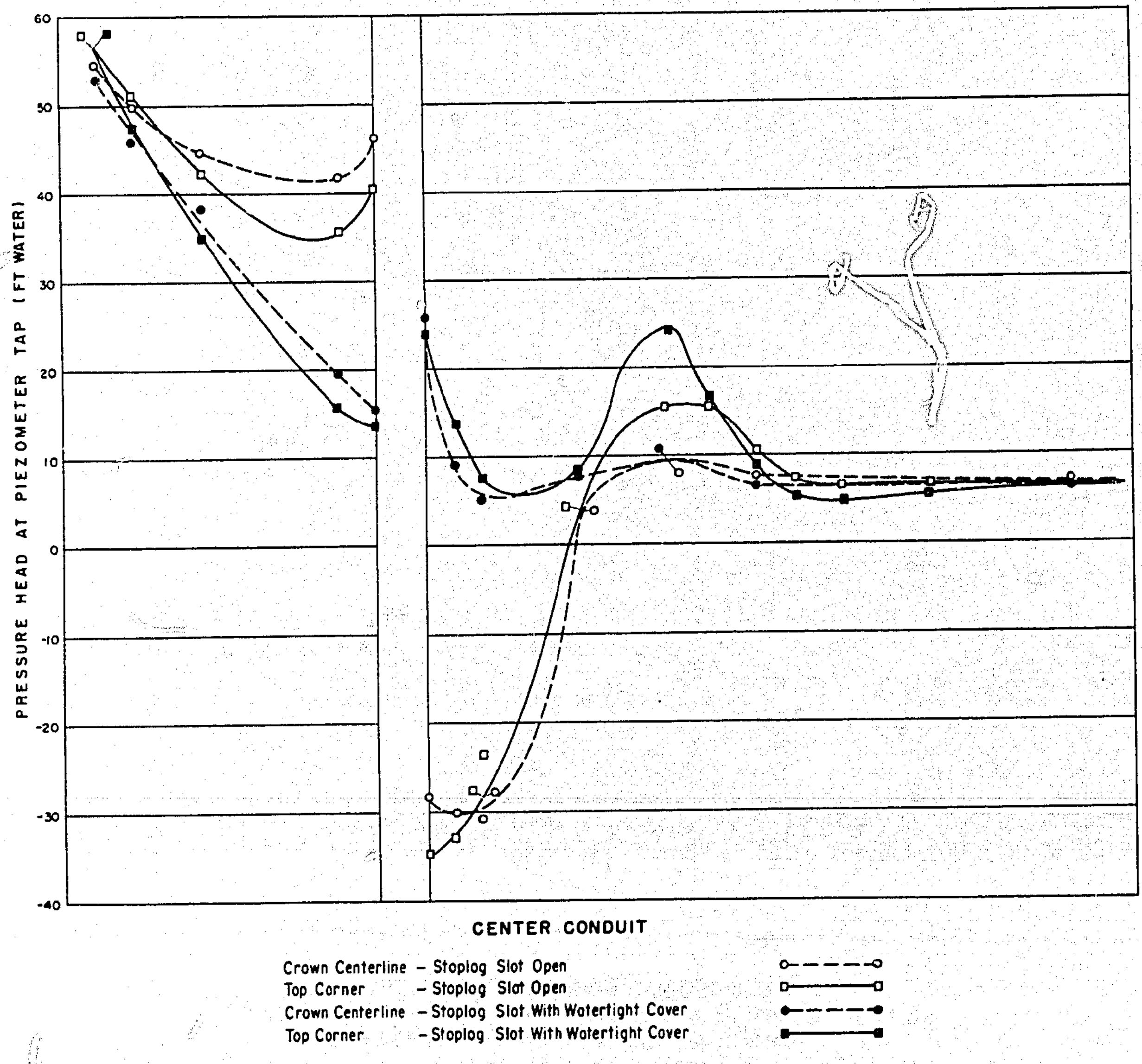


B. General view of the model

TWIN BUTTES DAM
OUTLET WORKS INTAKE STRUCTURE

Rectangular Entrances and Test Facilities
1:23.25 Scale Model





SAN ANGELO PROJECT, TEXAS

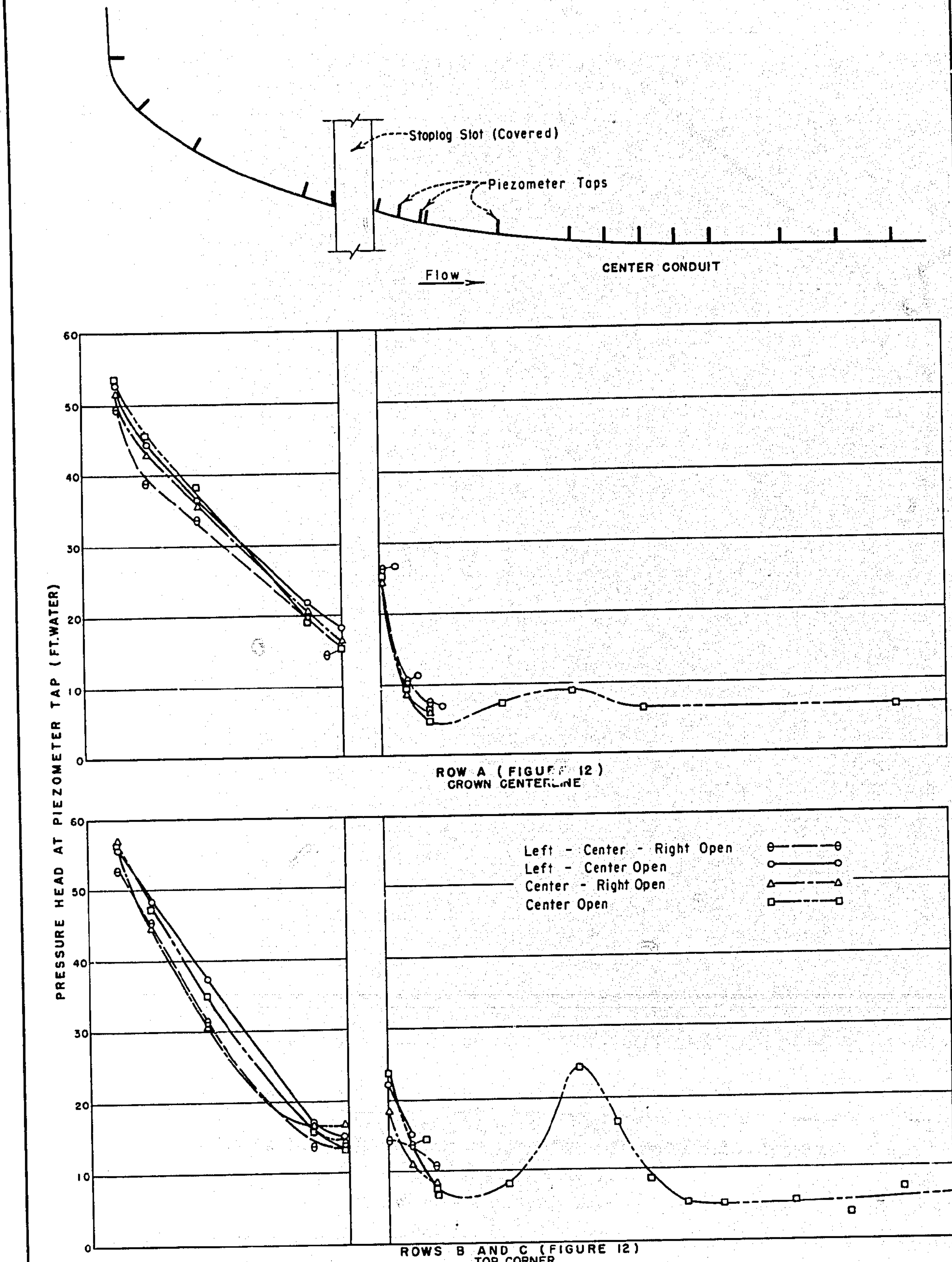
TWIN BUTTES DAM

OUTLET WORKS INTAKE STRUCTURE

RECTANGULAR BELLMOUTH ENTRANCES
EFFECT OF COVERED AND UNCOVERED STOPLOG SLOTS ON TUNNEL CROWN PRESSURES

618

FIGURE 15
REPORT HYD 470



SAN ANGELO PROJECT, TEXAS

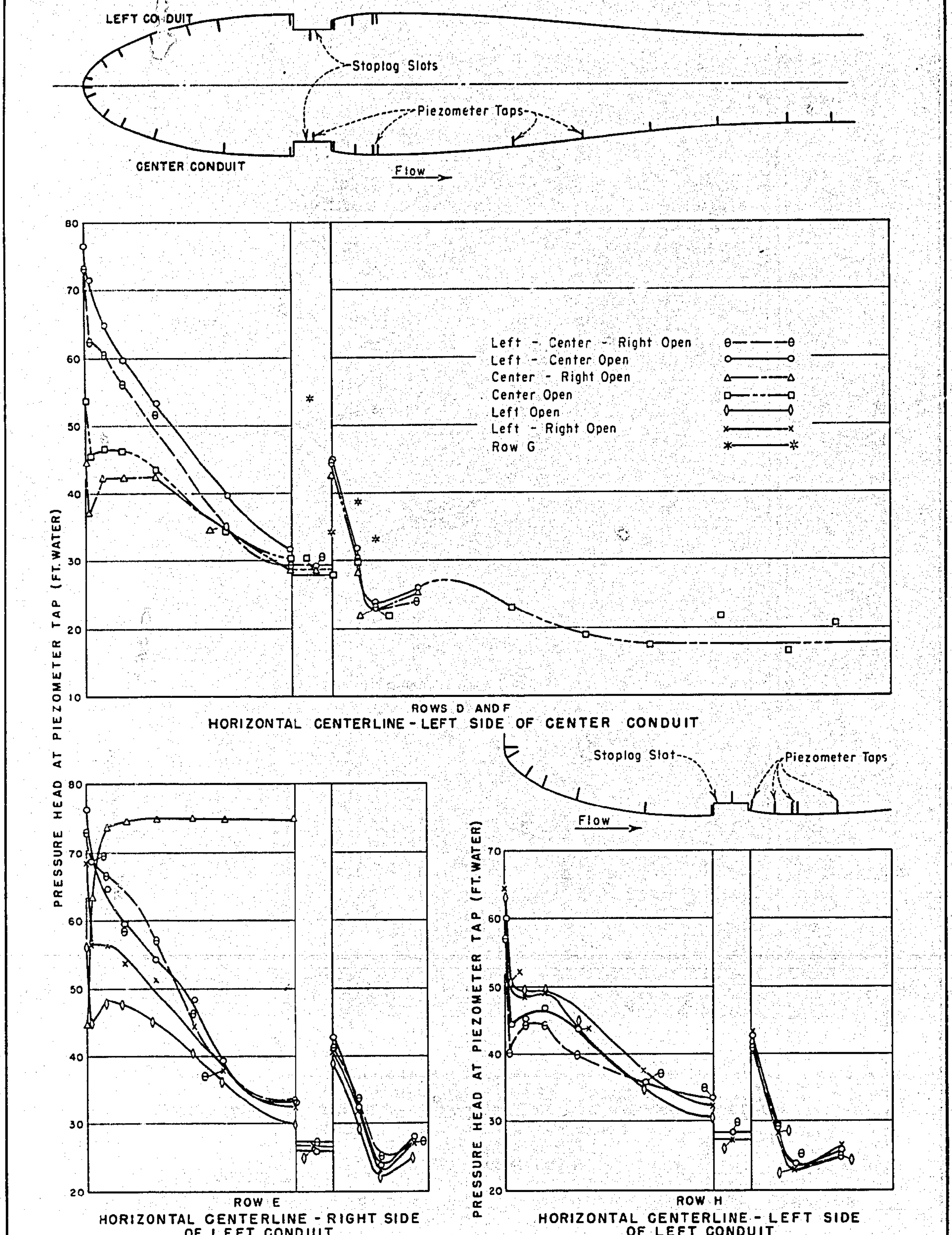
TWIN BUTTES DAM

OUTLET WORKS INTAKE STRUCTURE

RECTANGULAR BELLMOUTH ENTRANCES, RECOMMENDED DESIGN

PRESSURES, CENTER CONDUIT

618



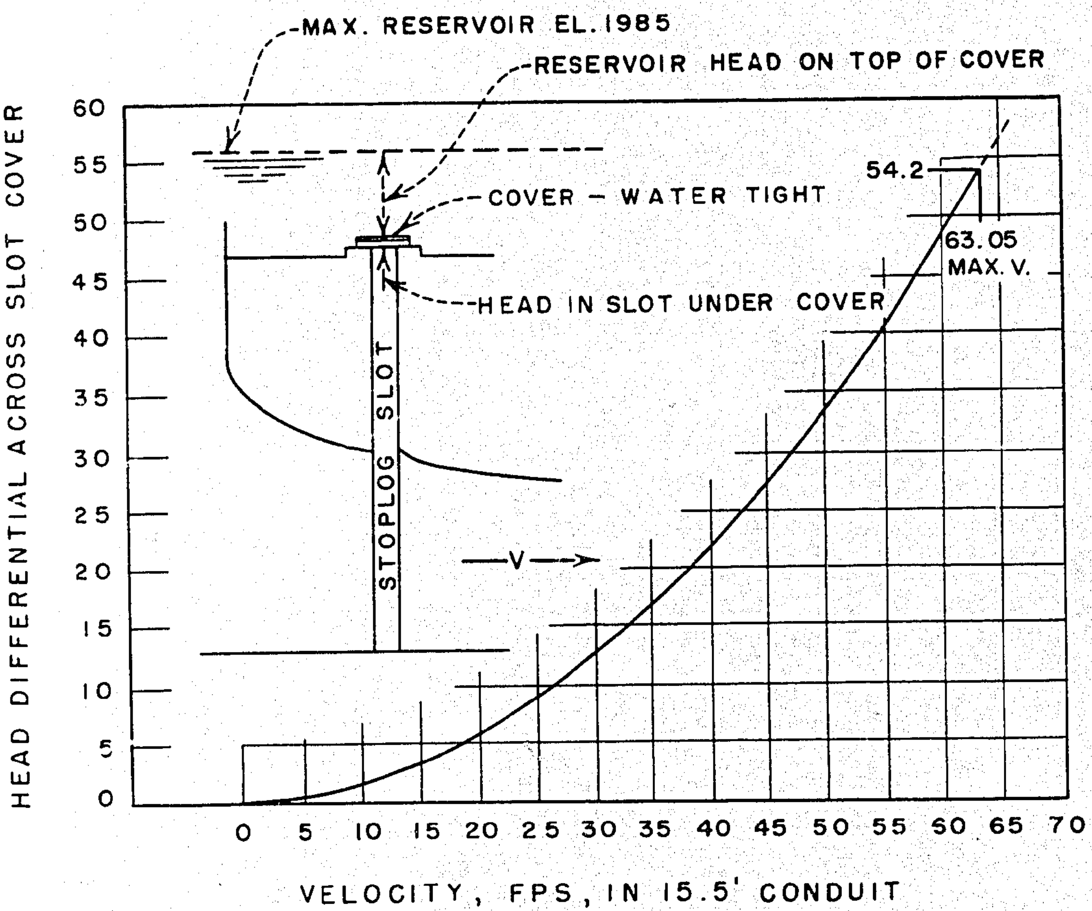
SAN ANGELO PROJECT, TEXAS

TWIN BUTTES DAM

OUTLET WORKS INTAKE STRUCTURE

RECTANGULAR BELLMOUTH ENTRANCES, RECOMMENDED DESIGN

PRESSURES, CENTER AND LEFT CONDUITS



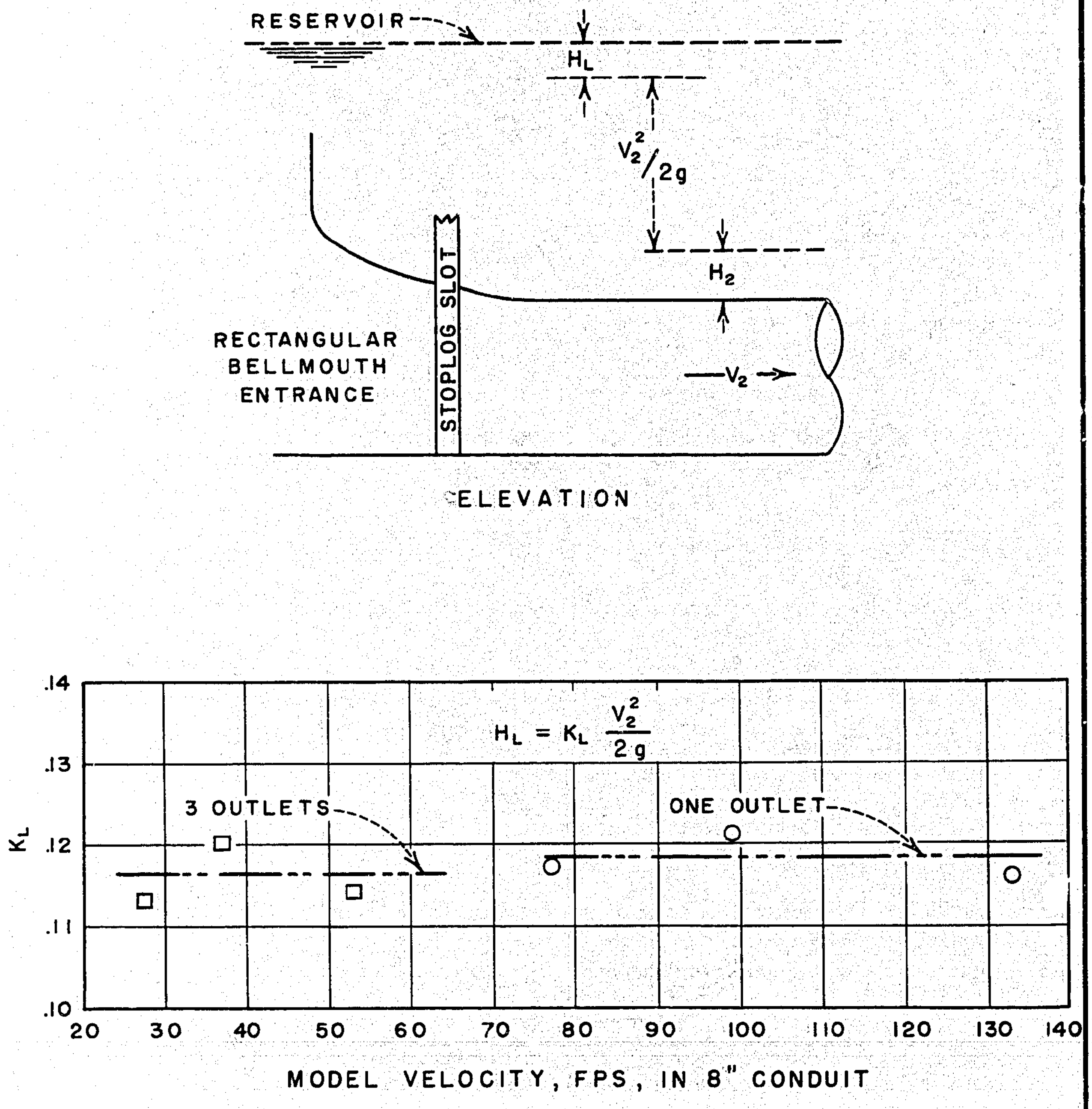
SAN ANGELO PROJECT, TEXAS

TWIN BUTTES DAM

OUTLET WORKS INTAKE STRUCTURE

RECTANGULAR BELLMOUTH ENTRANCES, RECOMMENDED DESIGN

HEAD DIFFERENTIAL ACROSS THE
WATER-TIGHT STOPLOG SLOT COVER



SAN ANGELO PROJECT, TEXAS

TWIN BUTTES DAM

OUTLET WORKS INTAKE STRUCTURE

RECTANGULAR BELLMOUTH ENTRANCES, RECOMMENDED DESIGN
COEFFICIENT OF LOSS FROM THE RESERVOIR
TO THE DOWNSTREAM END OF THE TRANSITION

618