UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF TWITCHELL (VAQUERO) DAM OUTLET WORKS SANTA MARIA PROJECT--CALIFORNIA

Hydraulic Laboratory Report No. Hyd-449

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

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Commissioner's Office--Denver
Division of Engineering Laboratories
Hydrualic Laboratory Branch
Hydraulic Structures and Equipment Section
Date: November 20, 1959

Laboratory Report No. Hyd-449
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Subject: Hydraulic model studies of Twitchell (Vaquero) Dam Outlet Works--Santa Maria Project, California

PURPOSE OF THE STUDY

The purpose of this Hydraulic Laboratory study was to develop an acceptable shape for the control structure water passage and the optimum proportions of the stilling basin for Twitchell Dam Outlet Works.

CONCLUSIONS

1. The long, streamlined center pier downstream from the control gates (Figure 5) will guide the jets from the two gates and prevent objectionable fins forming where the jets come together in the horseshoe tunnel (Figure 7).

2. The upstream pier with a 4:1 elliptical nose (Figure 13) will be cavitation free for all discharges with both gates opened the same amount.

3. With one gate only operating, and with certain combinations of reservoir elevation and gate opening, cavitation pressures will exist on the open-gate side of the upstream pier nose. Operation in these regions should be avoided as recommended subsequently.

4. With one gate only operating, and with normal reservoir elevation 651.5, the flow distribution in the tunnel downstream from the control structure will be poor for gate openings less than about 90 percent, and will be unacceptable for gate openings greater than 90 percent because the jet will spiral across the top of the horseshoe tunnel (Figure 14).

5. A stilling basin with appurtenances and dimensions as shown in Figure 20 will adequately handle the outlet works discharges.

6. At normal reservoir, and with symmetrical gate operation at openings smaller than about 60 percent, the stream will tend to pull away from the diverging side walls of the stilling basin chute and be concentrated near the center line of the basin where the jet enters the hydraulic jump. However, the basin is sufficiently large to adequately handle this adverse flow condition.

7. Pressures on the floor of the chute will be atmospheric or above, for all discharges. (Figure 20)

8. A stilling basin with 18-foot high chute blocks and 21-foot high baffle piers (Figure 23) also produced satisfactory basin operation. However, these appurtenances are considered to be too massive for the Twitchell Dam Outlet Works.

RECOMMENDATIONS

It is recommended that one gate operation be prohibited at gate openings and reservoir elevations greater than those shown by the heavy dotted line on the discharge chart, Figure 15, because of the danger of damage to the installation. The dotted line below elevation 650 is a restriction imposed to prevent spiral flow in the tunnel; such a flow condition would create excessive air demand in the tunnel and cause adverse flow distribution in the stilling basin. The dotted line above elevation 650 is a restriction imposed to prevent cavitation pressures on the open-gate side of the upstream pier nose.

INTRODUCTION

Twitchell Dam is located on the Cuyama River about 8 miles northeast of Santa Maria, California (Figure 1). The earth-filled structure is 216 feet high with a crest length of 1,840 feet at elevation 692 (Figure 2). Both the spillway and the outlet works are located in the right abutment.

The maximum reservoir water surface is elevation 686.5. The spillway crest is at elevation 652 and is designed for a maximum capacity of 26,300 cfs. The outlet works intake is at elevation 504 and has a maximum capacity of 14,300 cfs. The combined flow from the spillway and the outlet works will be the maximum design flood of 40,600 cfs.

The discharge of the outlet works is 13,050 cfs at normal reservoir elevation 651.5 and with tail water elevation 470.3. When the outlet works operates in conjunction with the spillway to pass the maximum flood, the tail water will be at elevation 480.0.

Subsequent to these model studies, the name of the structure was changed from "Vaquero Dam" to "Twitchell Dam." All photos and drawings which predate the name change are labeled "Vaquero Dam," and those which postdate the change are labeled "Twitchell (Vaquero) Dam."

All dimensions and quantities mentioned in this report are for the prototype unless otherwise stated. All pressures are referred to atmospheric.

THE MODELS

Three separate and distinct models were constructed to study the various shapes and operating phenomenon pertinent to the Twitchell Dam Outlet Works.

A model of the upstream portion of the gate chamber dividing pier, with appropriate flow passages, was fabricated for installation in the laboratory air test facility (Figure 3B). The air model was used for the general study of the upstream pier nose since differenct shapes could be readily installed, tested and removed from the apparatus. The adequacy of the recommended shape, as determined by the air model study, was confirmed by the water model.

Two 1:24-scale water models were constructed, one to study the various hydraulic Phenomenon of the control structure (Figure 3A), and the other to study the operation of the stilling basin (Figure 4, A and B). The use of two separate water models was preferred over a single model since, with two models, modifications could be made to one model while testing continued on the other.

THE INVESTIGATION

Control Structure

The 1:24-scale model of the control structure (Figures 3A and 5) was constructed in three sections: the upstream transition with the dividing pier to Station 12+06.25; the 32.42-foot-long control section, including the gates and two parallel water passages each 7 feet wide by 12 feet high (Figure 6); and the downstream transition and pier with 288 feet of horseshoe tunnel. The 15-foot-diameter approach conduit was modeled for 16 diameters upstream from the upstream transition to assure that proper flow conditions entered the control structure.

Downstream pier. In the preliminary operation of the control structure, both gates were operated at the same opening. As the jets from the two gates impinged together downstream from the short, blunt, downstream pier, a large fin formed and projected upward against the roof of the horseshoe tunnel (Figure 7A). This undesirable flow condition was eliminated by extending and streamlining the downstream pier as shown on Figure 5. The streamlined pier directed the jets from the two gates in such a manner that they merged without forming an objectionable fin (Figure 7B).

Pressures on sides of upstream transition. Pressures were measured on one side of the upstream transition for both gates operating at the same opening and for one gate operating alone. Pressures on the side of the transition were satisfactory for all discharges and all methods of operation (Figure 8). The minimum pressure on the side wall was about 10 feet of water above atmospheric.

Pressures on preliminary upstream pier nose. The preliminary pier nose (Figure 9A) was formed with a 6-inch radius. With both gates operating fully opened at a discharge of 13,400 cfs, the pressures were in the cavitation range on the sides of the pier for a short distance downstream from the pier nose (Figure 10). With one gate only operating with a discharge of 7,900 cfs, the pressure on the closed-gate side of the pier was about 145 feet of water, and on the open-gate side of the pier the pressure was in the cavitation range for a considerable distance downstream from the pier nose. It was apparent that this extremely low pressure would exist for any practical pier nose shape with one gate only operating fully opened.

The radius of the pier nose was changed from 6 inches to 12 inches, leaving the shape of the pier downstream from the tangent point unchanged. With both gates fully opened, the pressures on the sides of this pier followed the same trend and reached about the same minimum values as with the smaller radius pier nose (Figure 10).

Pier nose shape study. The removal, reshaping, and reinstallation of the pier in the water model, although not a difficult task, was time consuming. It was decided that a general pier nose shape study should be made in a model using air as the test fluid (Figure 3B). In such an apparatus, made of lightweight sheet metal and plywood, model changes can be readily and accurately made. For simplicity, the test section was of constant height, and the side walls were so shaped that the relative areas of the flow passages in the model followed very closely the relative areas in the proposed prototype (Figure 11).

The preliminary design pier (6-inch-radius nose) was tested in the air model for correlation of the air and water model test results. Although the minimum pressure in the air model scaled slightly lower than that indicated by the water model, the shape of the pressure curve and the point of minimum pressure was the same in both cases (Figure 12). Since one gate operation caused a very high side thrust on the pier resulting from near reservoir pressure on the closed-gate side and cavitation pressures on the open-gate side, it was determined that the pier should be about 32 inches thick at the tangent point of the nose to be structurally sound. Using this thickness as a minimum, a pier nose with a 16-1/2-inch radius was tested. The pressures on this pier nose followed the same trend as the pressures on the previously tested pier and reached about the same minimum value (Figure 10).

The air model study was continued by testing elliptically shaped pier noses. The elliptical pier noses varied in length, and each was formed by making the elliptical curve tangent to the tapered sides of the pier at the point where the pier thickness was 33 inches (Figure 12). These shapes varied in minor to major axis ratios from 1.25:1 to 5:1. It was found that for an axis ratio of 4:1 and both gates fully opened, the minimum pressure was about negative 10 feet. The 4:1 ratio was considered adequate for the prototype pier; therefore, this shape was constructed and installed in the water model (Figure 9B). The scaled pressures in the water model were the same as those measured in the air model.

The results of these pier nose studies were consolidated and are presented in dimensionless form in Figure 12. The pressures which would exist at Twitchell Dam for various simple curve pier noses and for the 4:1 ellipse pier nose are shown on Figure 10.

The pressures which would exist on the pier with one gate only operating with the maximum disharge of 7,900 cfs are shown in Figure 13. The resultant unbalance in pressure on the sides of the pier, or the total pressure producing side thrust, is also shown in this figure. Although the pier is sufficiently massive to withstand the side thrust caused by the pressure unbalance, it is recommended that one-gate operation at large gate openings be limited to emergency flows because of the certainty that cavitation pressures will occur on the open-gate side of the pier. The dotted line above elevation 650 (labeled) in Figure 15 shows the limiting conditions of single-gate openings and reservoir elevations to prevent cavitation pressures occurring on the side of the upstream pier.

Downstream flow conditions--One-gate operation. Normally the control structure should be operated with both gates opened the same amount. However, if some emergency existed, discharges could be made through one gate only. When one gate operated singly, the unsupported side of the jet spread diagonally across the tunnel, piled up on the tunnel wall, and was deflected back across the tunnel, causing a buildup first on one side, then on the other side of the tunnel. At large gate openings, the jet climbed the opposite wall and swept across the top of the tunnel. Figure 14 shows one gate operating at openings of 50, 80, 90, and 100 percent.

Discharge chart. During preliminary releases from the reservoir, the intake sill will be at elevation 474. After completion of the intake structure, the tunnel portal will be plugged and the intake sill will be raised to elevation 504 (Figure 2). The discharge chart (Figure 15) shows the discharge in thousands of second-feet versus reservoir elevation for the outlet works with the completed intake structure for both one-gate and two-gate operation. Because of adverse flow conditions, it is recommended that one-gate operation be limited to reservoir elevations and gate openings as shown by the "maximum one-gate operation" line on the chart.

During the preliminary planning stages when the model studies were being made, the design discharges with both gates opened 100 percent were 14,700 cfs, for the maximum reservoir elevation 686.5, and 13,400 cfs for normal reservoir elevation 651.5. However, for the recommended design and with the completed intake structure, it was determined from model calibration that the maximum discharge would be 14,300 cfs and normal discharge would be 13,050 cfs.

Stilling Basin

The stilling basin studies were conducted in a 1:24-scale model of the stilling basin and outlet channel (Figure 4). A single streamlined gate (Figure 16) was used to control the proper depth and velocity of flow in the tunnel to represent the flow from the two prototype control gates operating at equal openings. The preliminary stilling basin (Figures 4 and 16) included a chute 173.58 feet long in which the floor followed a 105-foot vertical curve and the side walls diverged from 19 feet to 35 feet apart. The 150-foot long by 35-foot wide stilling basin had appurtenances consisting of four 4.50-foot high chute blocks, three 8.75-foot high baffle piers 39.50 feet downstream from the chute blocks, and an end sill 7.25 feet high with a 2:1 sloping upstream face.

For the preliminary tests of the stilling basin, water was admitted to the outlet tunnel to represent a discharge of about 13,500 cfs with a depth of 8.9 feet at Station 16+30. With the preliminary basin (Figure 16), the jet entering the pool was humped slightly at midstream. The jump roller was unstable and swept downstream past the chute blocks and back upstream about 50 feet. The jump was quite rough throughout the full length of the basin, and large waves formed in the outlet channel (Figure 17).

With about 8,000 cfs entering the basin, a large fin formed at the point of curvature of the vertical curve. The jet failed to spread and was completely clear of the side walls where it entered the jump. Several flow spreaders were installed in an attempt to spread the jet the full width of the basin (Figure 18). Flow spreader Design 4 consisted of a single hump starting at about the point of curvature of the vertical curve and extending 81.55 feet downstream (Figures 19A and B). This hump was apparently too abrupt and tended to accentuate the rising jet (Figure 19C). The upstream nose of the flow spreader was extended 75 feet upstream to a sharp point (see flow spreader Design 6, Figure 18A and Figures 19D and E). With this design, the flow spread satisfactorily at all discharges (Figure 19F).

Since the humps would be difficult to fabricate in the field, an attempt was made to spread the jet with a reverse curve at Station 17+07.4 (flow spreader Design 7, Figure 18C). This design satisfactorily spread the jet for 4,700 cfs but caused high fins to form on the chute side walls for the design discharge of 13,400 cfs.

Since the flow distribution into the basin was acceptable at the design discharge with the preliminary design, and the fin for the lower discharges did not cause the flow to overtop the training walls, it was decided by the designers that flow spreaders would not be necessary in this installation.

In order to stabilize the hydraulic jump, the height of the chute blocks was increased from the preliminary 4-1/2 feet to 9 feet. The 1-foot-high step between the blocks and the block width of 4.38 was retained. This larger chute block decreased the fluctuation of the jump roller; however, considerable roughness persisted and large waves continued to sweep from the basin into the downstream channel. The length of the basin was extended 48.2 feet to Station 20+01.78. This longer basin aided in decreasing the surges in the outlet channel; however, the jump continued to oscillate laterally in the basin. Two additional baffle piers were installed 19.75 feet downstream from the three piers of the preliminary design, Figure 20. These piers were the same size and shape as the preliminary piers.

With the lengthened basin, including larger chute blocks and two additional baffle piers (Figures 20 and 21), the hydraulic jump was controlled and stabilized for all discharges (Figure 22). For the design discharge of 13,400 cfs and normal tail water elevation 470.3, the water flowed smoothly from the basin and caused practically no undulations in the outlet channel (Figure 22A). For the maximum flood discharge of 14,700 cfs and tail water elevation 480.0, which would result from a combination of outlet works and spillway discharges, the action in the basin was fairly steady; however, waves periodically overtopped the training walls as shown in Figure 22B.

Becasue of the simplicity of this latter design, it is recommended for prototype construction. Specific details and dimensions are shown on Figure 20.

Additional Basin Studies

In the preliminary study, it was assumed that the foundation at the downstream end of the basin was backfill material; therefore, it was desired to make the basin as short as possible and still contain the hydraulic jump. Since the normal length of this basin without chute blocks or baffle piers would be over 300 feet, it was deemed necessary to hold the hydraulic jump in the basin with appropriate appurtenances. Various sizes, shapes and positioning of baffle piers and chute blocks were studied until optimum conditions were realized. It was found that chute blocks 18 feet high and baffle piers 21 feet high held the jump well upstream in the basin. Smaller appurtenances would permit the jump roller to sweep further downstream, and larger ones caused excessive roughness in the basin.

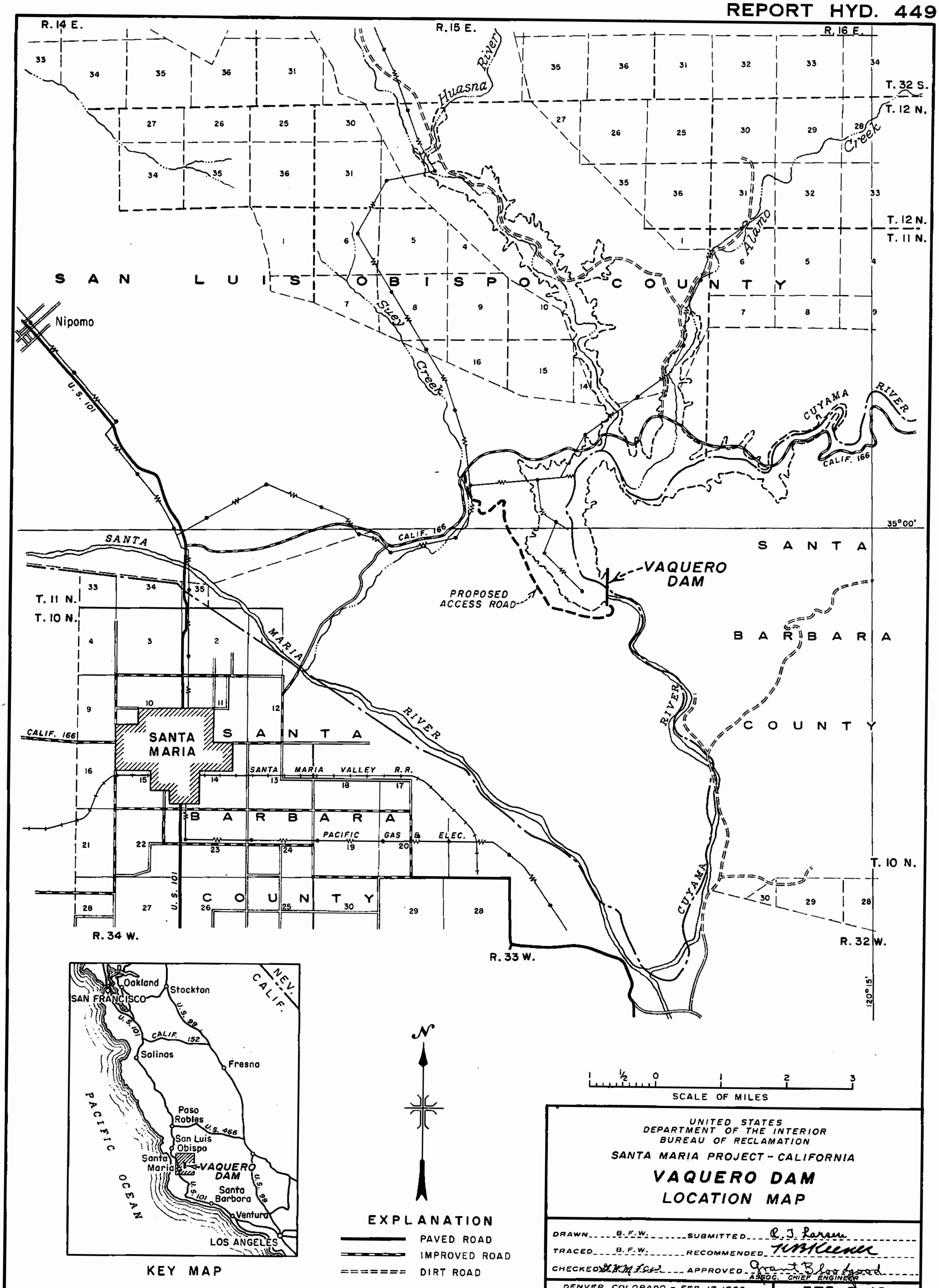
The 18-foot-high by 36-foot-long by 6.5-foot-wide chute blocks were beveled on 45° on the top corners. The blocks were spaced 3.67 feet apart with the two outside ones merging into the diverging side walls of the chute. The step between the blocks was 6 feet high. The three baffle piers were streamlined with elliptical leading edges and increased in thickness in the direction of flow. Piezometers were located in the baffle piers for pressure measurements. Details of the dimensions of the appurtenances and the basin are shown in Figure 23, and an overall view of the installation is shown in Figure 24.

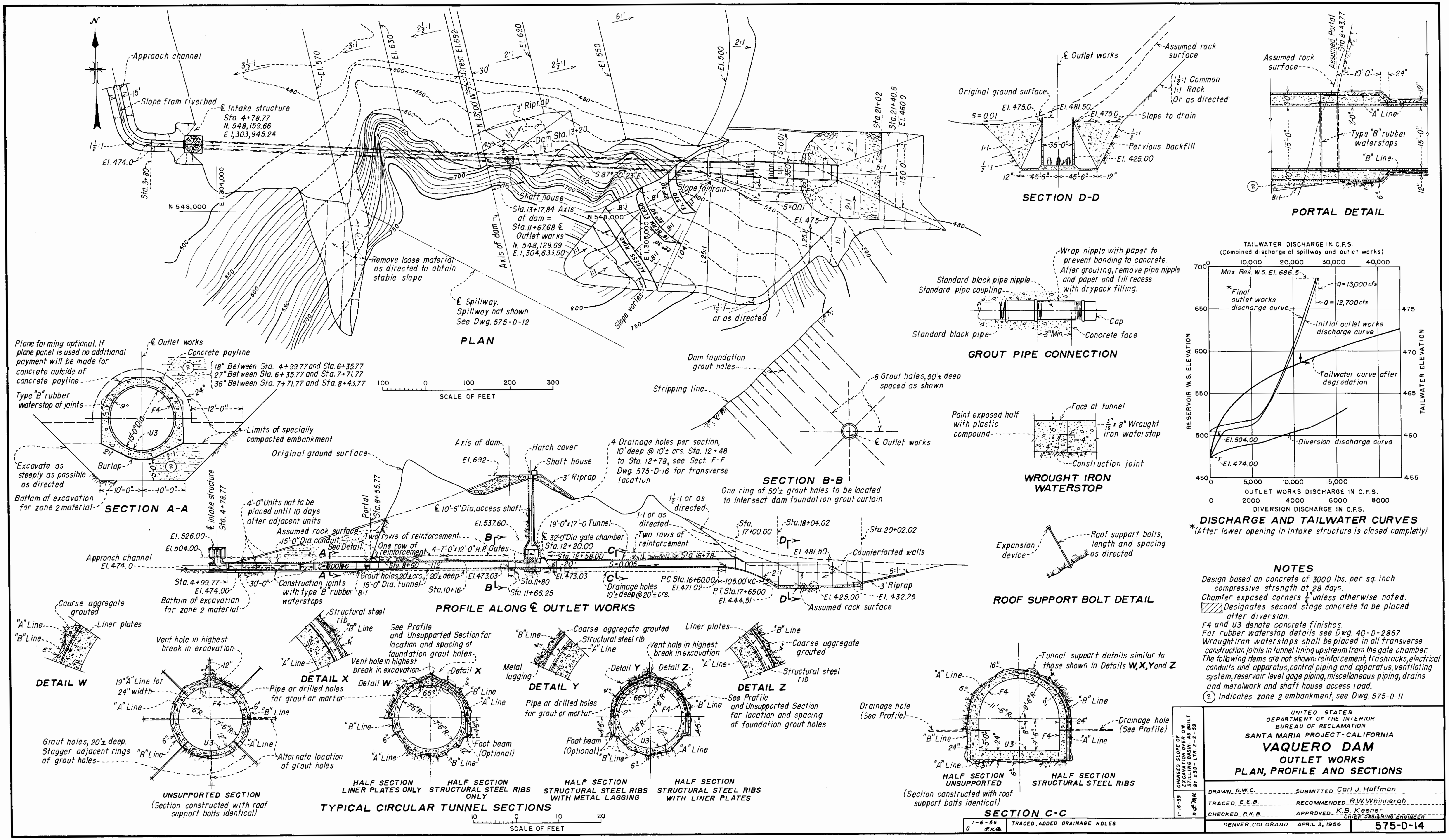
With the basin terminating at Station 20+01.76 and with the preliminary design end sill (Stilling Basin Design 16, Figure 23), the flow from the basin was quite tranquil, causing negligible disturbance in the outlet channel. Figure 25 shows the flow with both normal and flood discharges at corresponding tail waters. From the study of these flow conditions, it appeared the basin could be shortened about 70 feet.

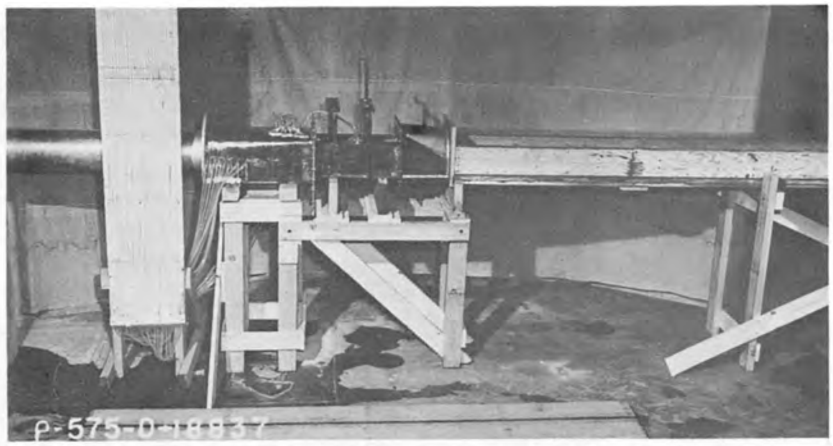
The basin was terminated at Station 19+31, and the end sill was installed at this station (Stilling Basin Design 17, Figure 23). Figure 26 shows the normal and flood discharges with the shortened basin. The water surface profiles for the latter two designs and the pressures on the baffle pier are shown in Figure 23. Although this design with the large clocks and piers operated very well in the model, the extremely large appurtenances precluded their installation in the stilling basin at Twitchell Dam.

Subsequent information from the field indicated that the foundation as far downstream as Station 20+00 was satisfactory for construction of the stilling basin. Therefore, the recommended design for the outlet works stilling basin at Twitchell Dam is that shown in Figure 20.

FIGURE 1
REPORT HYD. 449




PLAN
SCALE OF FEET
SECTION A-A
PROFILE ALONG ℄ OUTLET WORKS
SECTION B-B
One ring of 50'± grout holes to be located to intersect dam foundation grout curtain
SECTION D-D
PORTAL DETAIL
GROUT PIPE CONNECTION
WROUGHT IRON WATERSTOP
ROOF SUPPORT BOLT DETAIL
DISCHARGE AND TAILWATER CURVES
*(After lower opening in intake structure is closed completely)
TAILWATER DISCHARGE IN C.F.S.
(Combined discharge of spillway and outlet works)
RESERVOIR W.S. ELEVATION
TAILWATER ELEVATION
OUTLET WORKS DISCHARGE IN C.F.S.
DIVERSION DISCHARGE IN C.F.S.
DETAIL W
DETAIL X
DETAIL Y
DETAIL Z
UNSUPPORTED SECTION
(Section constructed with roof support bolts identical)
HALF SECTION LINER PLATES ONLY
HALF SECTION STRUCTURAL STEEL RIBS ONLY
HALF SECTION STRUCTURAL STEEL RIBS WITH METAL LAGGING
HALF SECTION STRUCTURAL STEEL RIBS WITH LINER PLATES
TYPICAL CIRCULAR TUNNEL SECTIONS
HALF SECTION UNSUPPORTED
HALF SECTION STRUCTURAL STEEL RIBS
(Section constructed with roof support bolts identical)
SECTION C-C
NOTES
Design based on concrete of 3000 lbs. per sq. inch compressive strength at 28 days.
Chamfer exposed corners 3/4" unless otherwise noted.
Designates second stage concrete to be placed after diversion.
F4 and U3 denote concrete finishes.
For rubber waterstop details see Dwg. 40-D-2867
Wrought iron waterstops shall be placed in all transverse construction joints in tunnel lining upstream from the gate chamber.
The following items are not shown: reinforcement, trashracks, electrical conduits and apparatus, control piping and apparatus, ventilating system, reservoir level gage piping, miscellaneous piping, drains and metalwork and shaft house access road.
(2) Indicates zone 2 embankment, see Dwg. 575-D-11
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SANTA MARIA PROJECT-CALIFORNIA
VAQUERO DAM
OUTLET WORKS
PLAN, PROFILE AND SECTIONS
DRAWN G.W.C.
SUBMITTED Carl J. Hoffman
TRACED E.E.B.
RECOMMENDED R.W. Whinnerah
CHECKED P.K.B.
APPROVED K.B. Keener
CHIEF DESIGNING ENGINEER
DENVER, COLORADO APRIL 3, 1956
575-D-14
TRACED. ADDED DRAINAGE HOLES



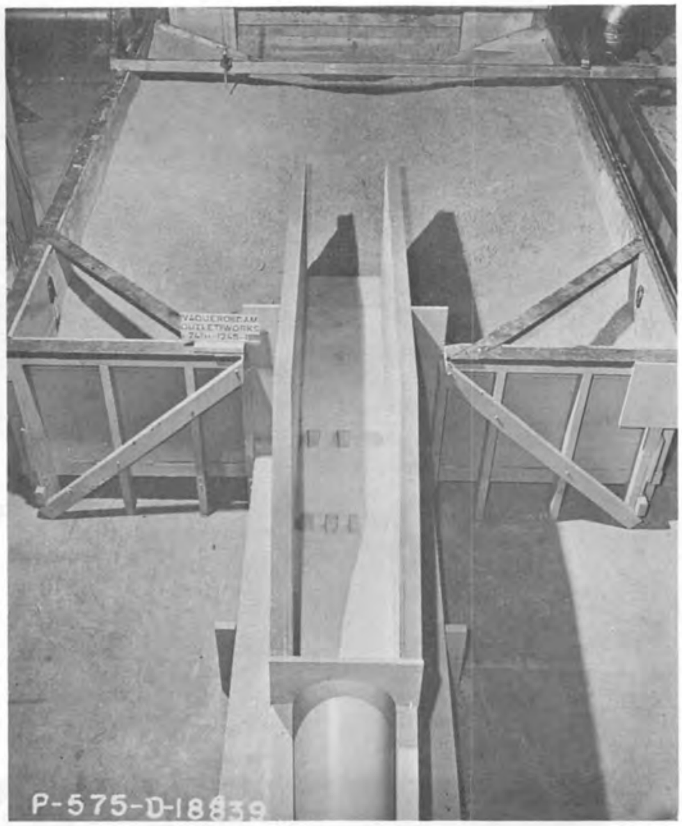
A Gate Chamber - Model Scale 1:24 Water Model

B. Upstream Pier Shape Study
Air Model

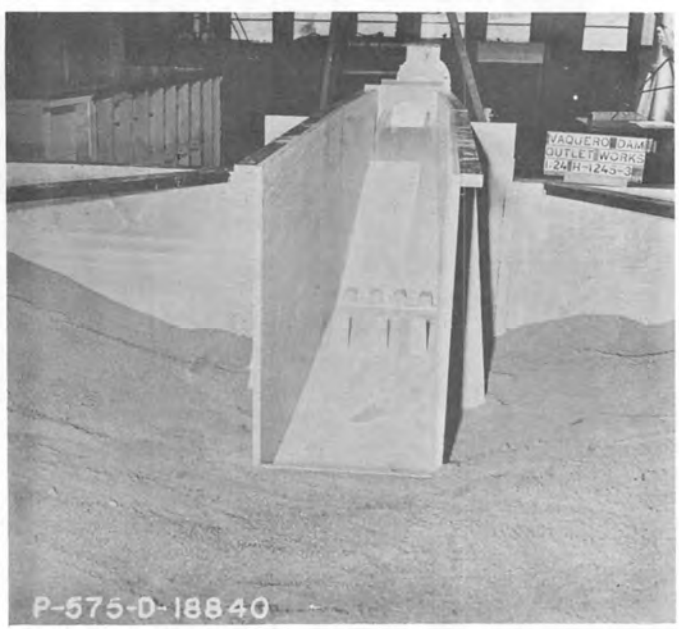
Santa Maria Project - California
Twitchell (Vaquero) Dam - Outlet Works

Laboratory Installation - Gate Chamber Study

Figure 4
Report Hyd 449



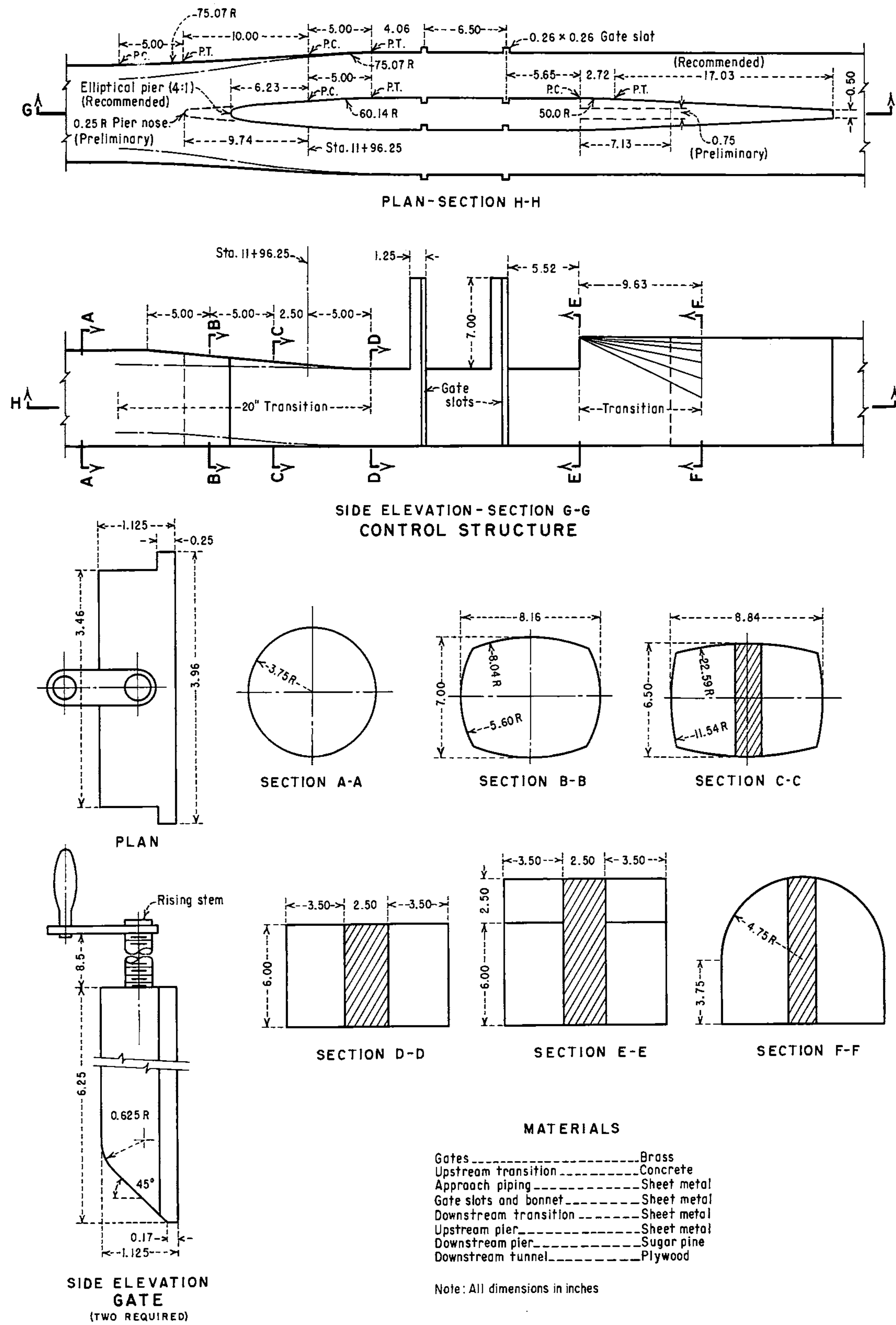
A. Looking Downstream



B. Looking Upstream

Santa Maria Project - California
Twitchell (Vaquero) Dam - Outlet Works

Preliminary. Laboratory Installation - Stilling Basin Study
Model Scale 1:24



MATERIALS

Gates	Brass
Upstream transition	Concrete
Approach piping	Sheet metal
Gate slots and bonnet	Sheet metal
Downstream transition	Sheet metal
Upstream pier	Sheet metal
Downstream pier	Sugar pine
Downstream tunnel	Plywood

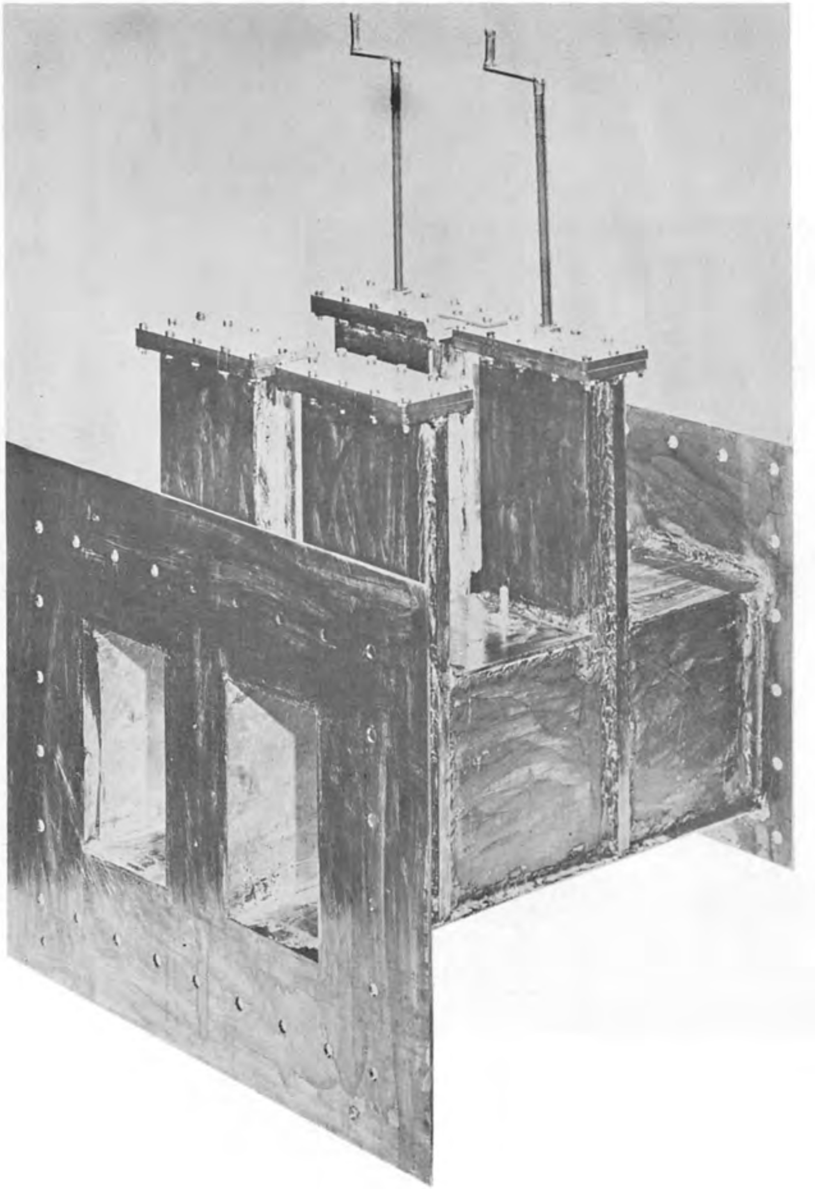
Note: All dimensions in inches

SANTA MARIA PROJECT – CALIFORNIA

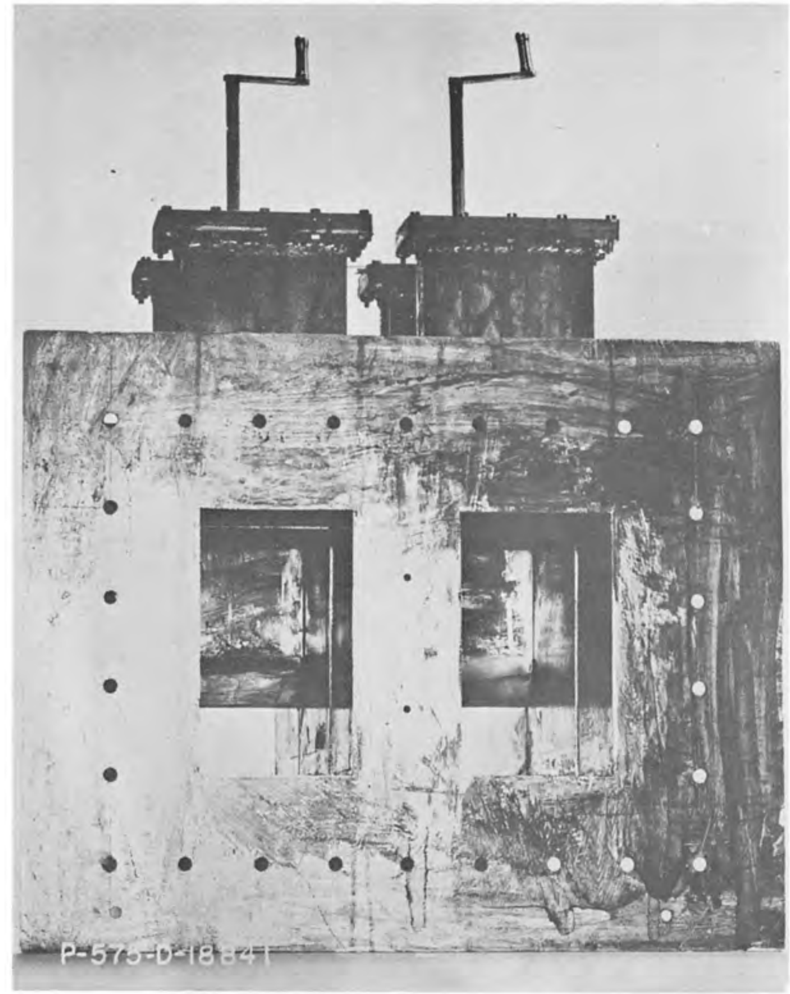
TWITCHELL (VAQUERO) DAM OUTLET WORKS

GATE AND GATE CHAMBER
MODEL DETAILS

MODEL SCALE 1 : 24



A. Side View

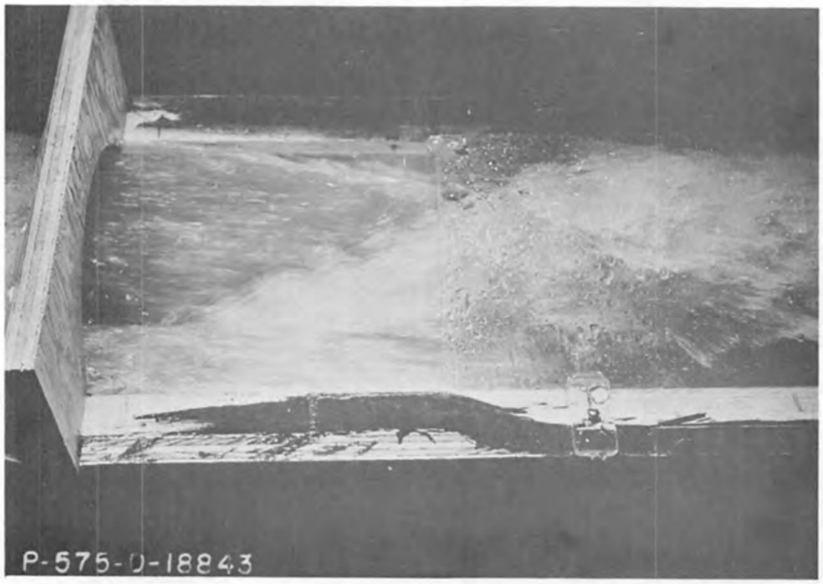


B. Looking Downstream

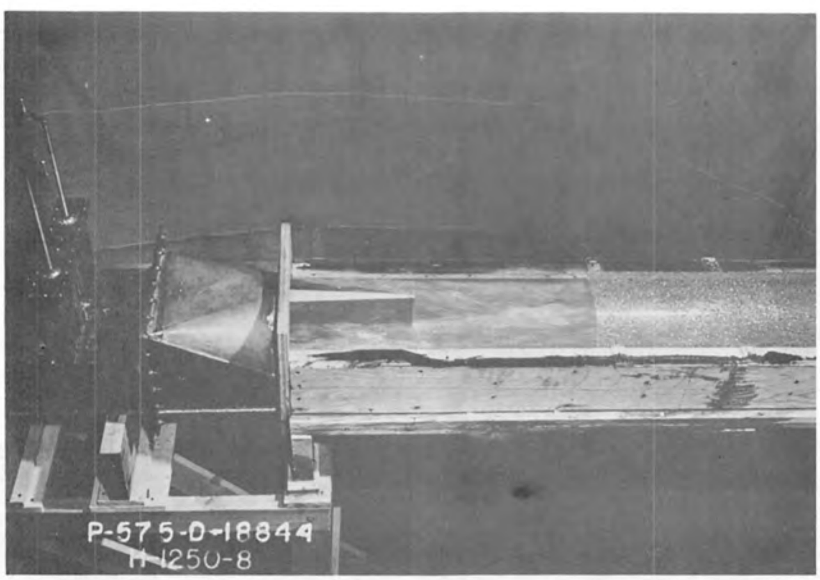
Santa Maria Project - California
Twitchell (Vaquero) Dam - Outlet Works

7 ft x 12 ft High Pressure Slide Gate
Model Scale 1:24

Figure 6
Report Hyd 449



A. Flow Conditions - Preliminary Design



B. Flow Conditions - Recommended Design

Santa Maria Project - California
Twitchell (Vaquero) Dam - Outlet Works

Downstream Gate Pier Study
Both Gates Opened 100% - Q = 13,400 cfs
Model Scale 1:24

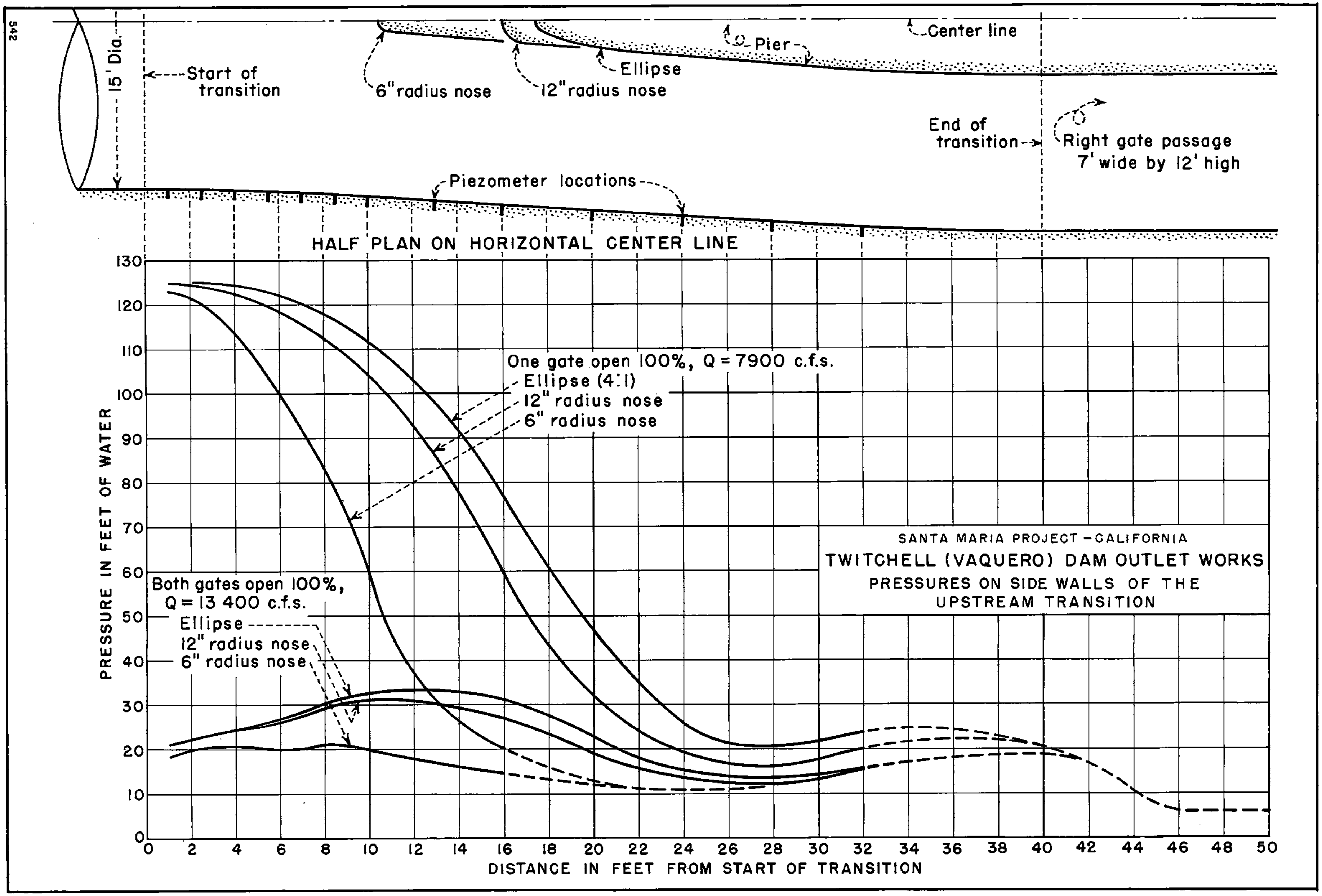
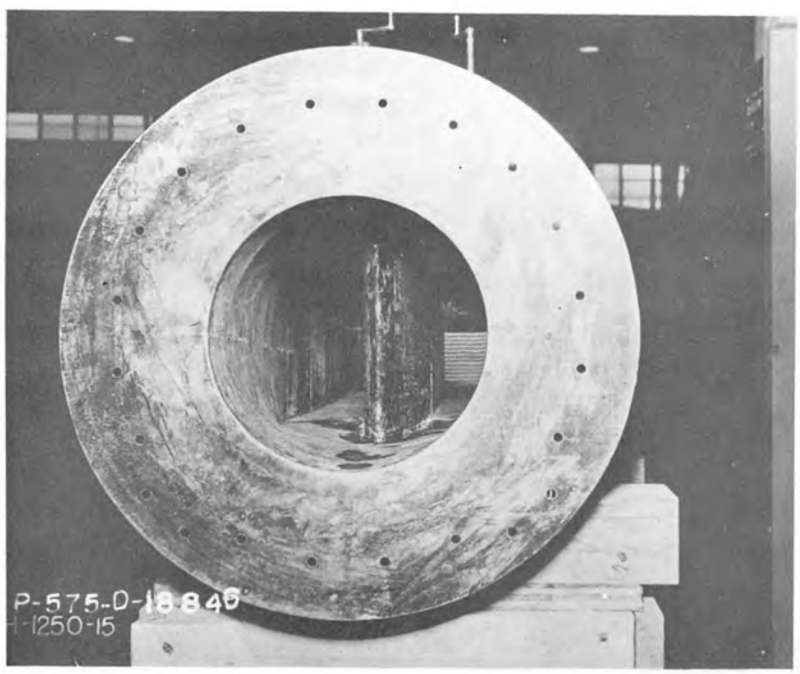


FIGURE 8
REPORT HYD. 449

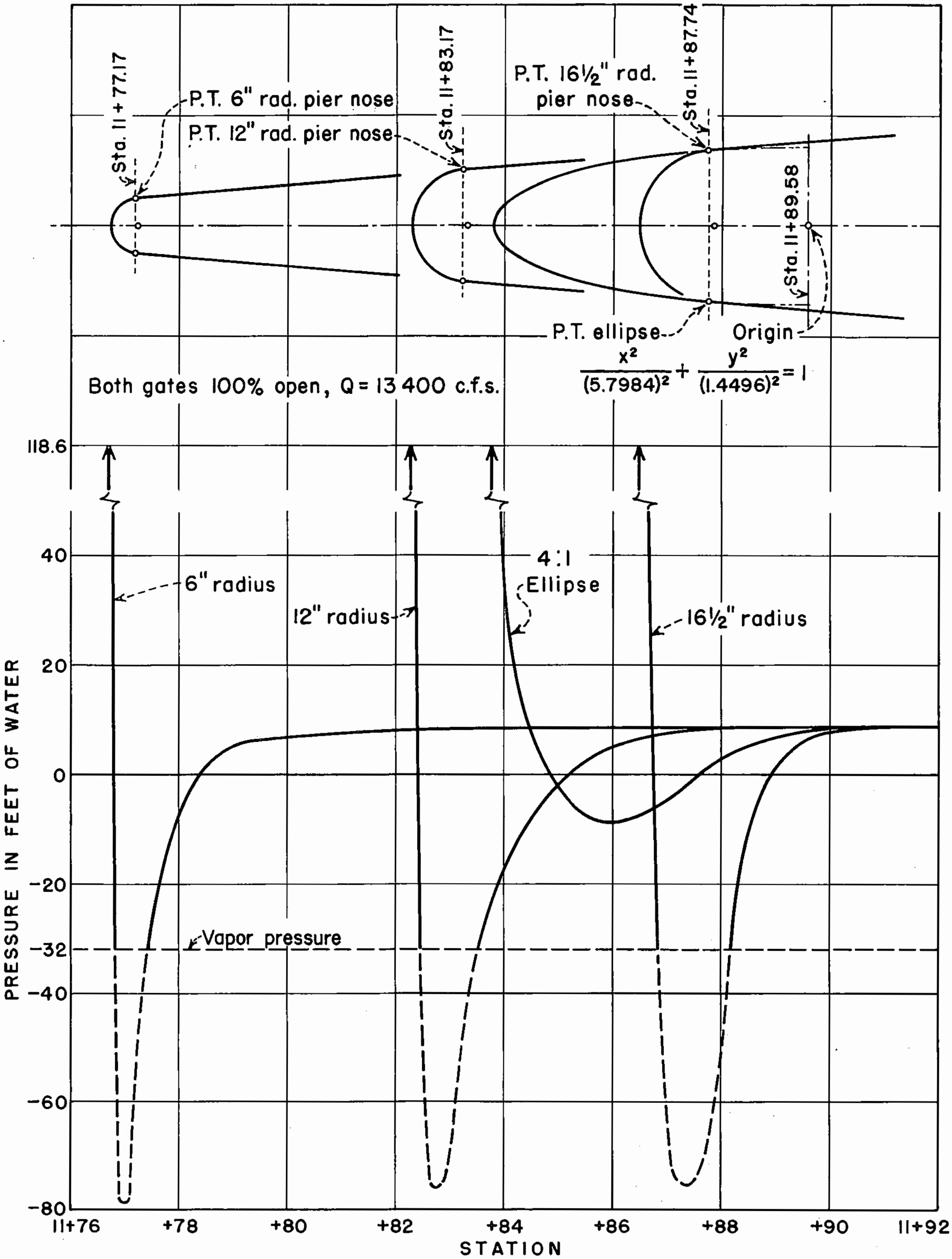
A. Preliminary (6" radius) Upstream Pier Nose



B. Recommended (4:1 ellipse) Upstream Pier Nose

Santa Maria Project - California
Twitchell (Vaquero) Dam - Outlet Works

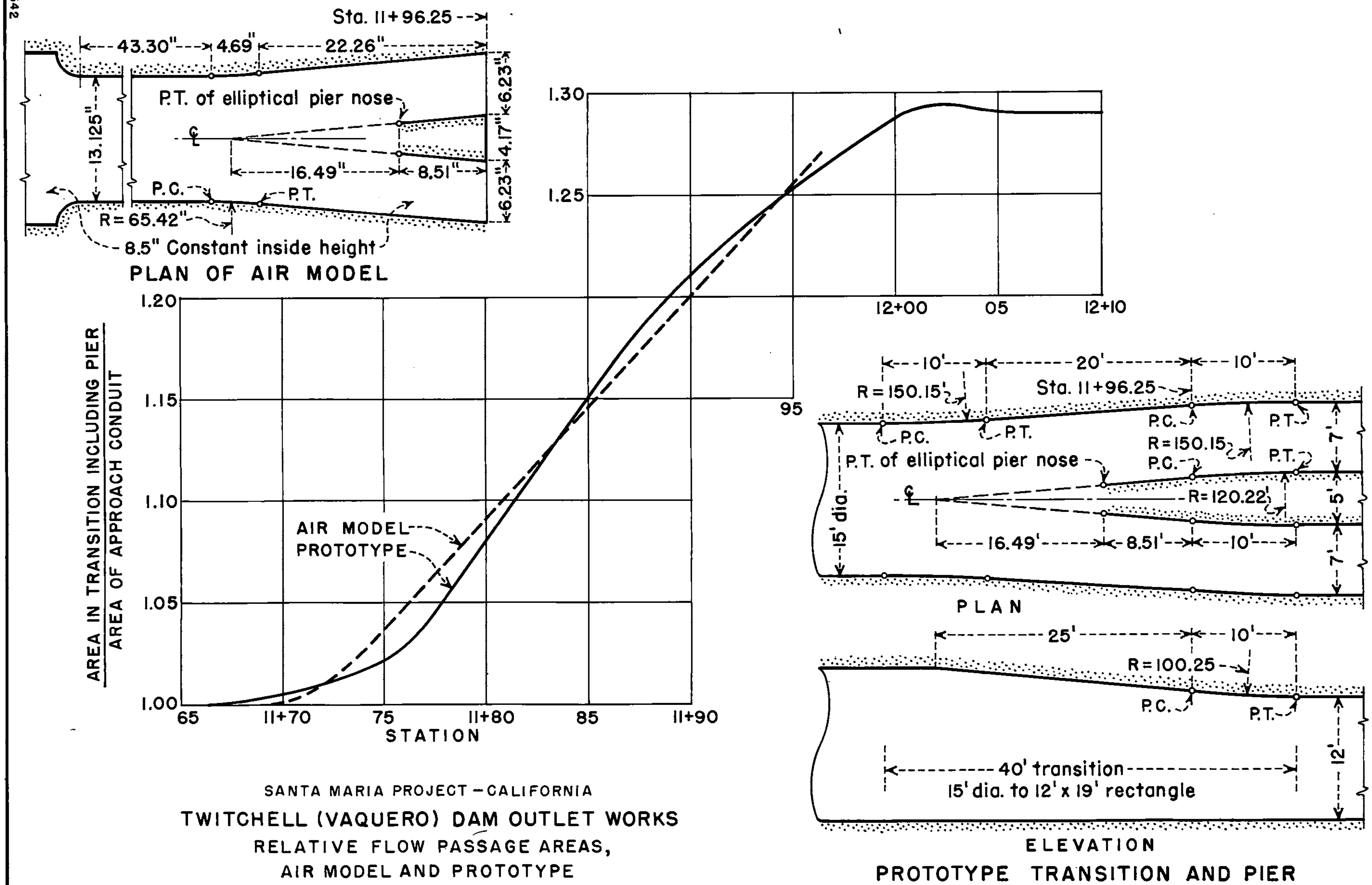
Upstream Pier Nose - Model Scale 1:24



SANTA MARIA PROJECT – CALIFORNIA

TWITCHELL (VAQUERO) DAM OUTLET WORKS

PRESSURES ON THE PIER NOSE, VARIOUS SHAPES

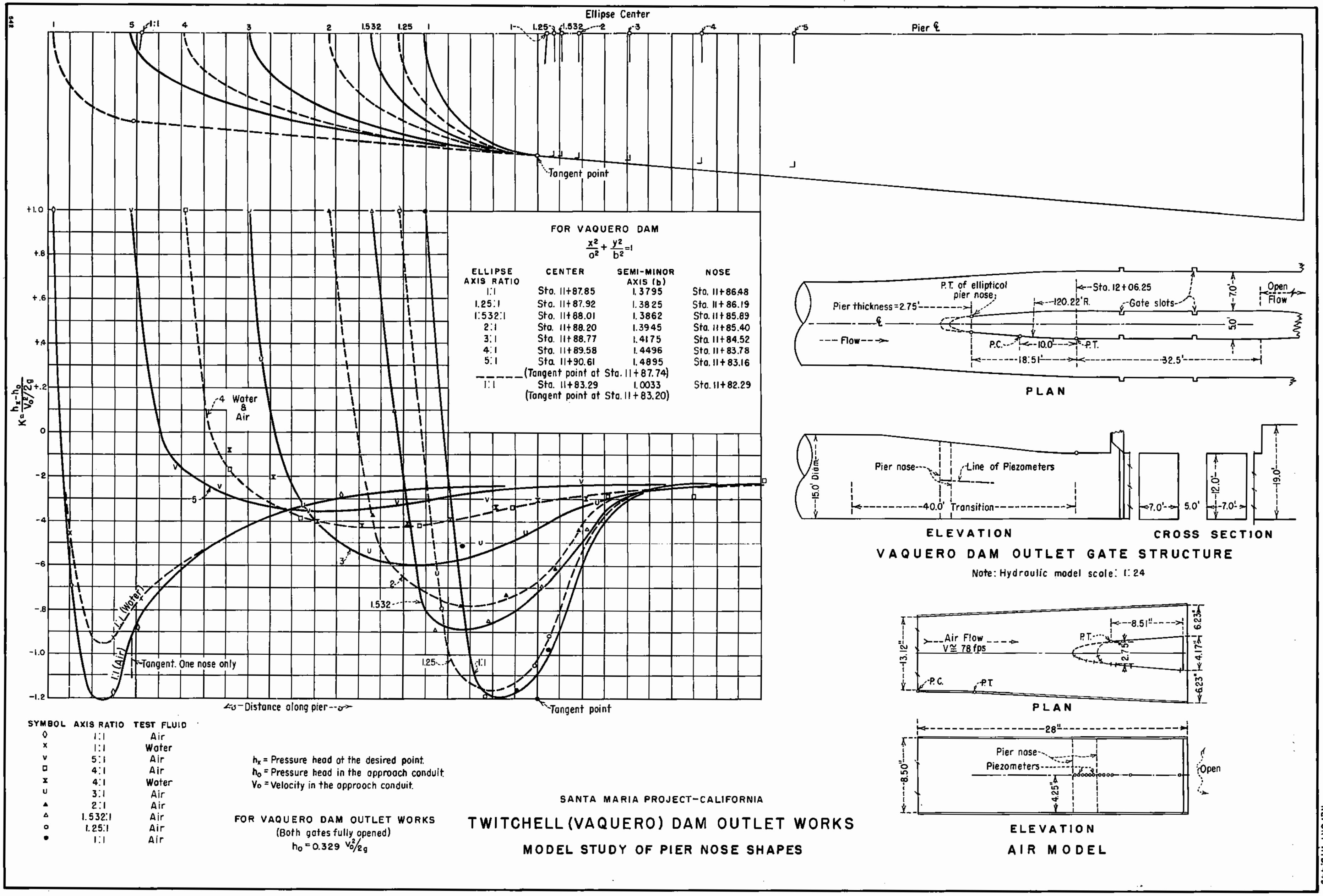


SANTA MARIA PROJECT – CALIFORNIA

TWITCHELL (VAQUERO) DAM OUTLET WORKS

RELATIVE FLOW PASSAGE AREAS,

AIR MODEL AND PROTOTYPE



FOR VAQUERO DAM

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$$

ELLIPSE AXIS RATIO	CENTER	SEMI-MINOR AXIS (b)	NOSE
1:1	Sta. 11+87.85	1.3795	Sta. 11+86.48
1.25:1	Sta. 11+87.92	1.3825	Sta. 11+86.19
1.532:1	Sta. 11+88.01	1.3862	Sta. 11+85.89
2:1	Sta. 11+88.20	1.3945	Sta. 11+85.40
3:1	Sta. 11+88.77	1.4175	Sta. 11+84.52
4:1	Sta. 11+89.58	1.4496	Sta. 11+83.78
5:1	Sta. 11+90.61	1.4895	Sta. 11+83.16
------	(Tangent point at Sta. 11+87.74)		
1:1	Sta. 11+83.29	1.0033	Sta. 11+82.29
	(Tangent point at Sta. 11+83.20)		

SYMBOL	AXIS RATIO	TEST FLUID
◊	1:1	Air
x	1:1	Water
v	5:1	Air
□	4:1	Air
⌶	4:1	Water
u	3:1	Air
▲	2:1	Air
△	1.532:1	Air
o	1.25:1	Air
●	1:1	Air

h_x = Pressure head at the desired point.
h_o = Pressure head in the approach conduit.
V_o = Velocity in the approach conduit.

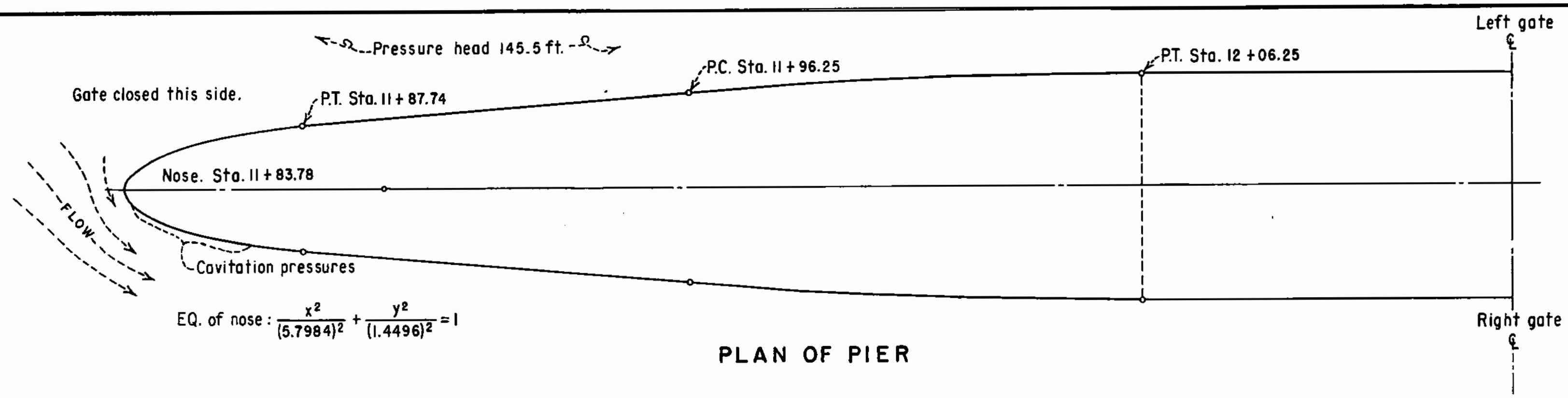
FOR VAQUERO DAM OUTLET WORKS
(Both gates fully opened)
$h_o = 0.329\ V_o^2/2g$

SANTA MARIA PROJECT—CALIFORNIA

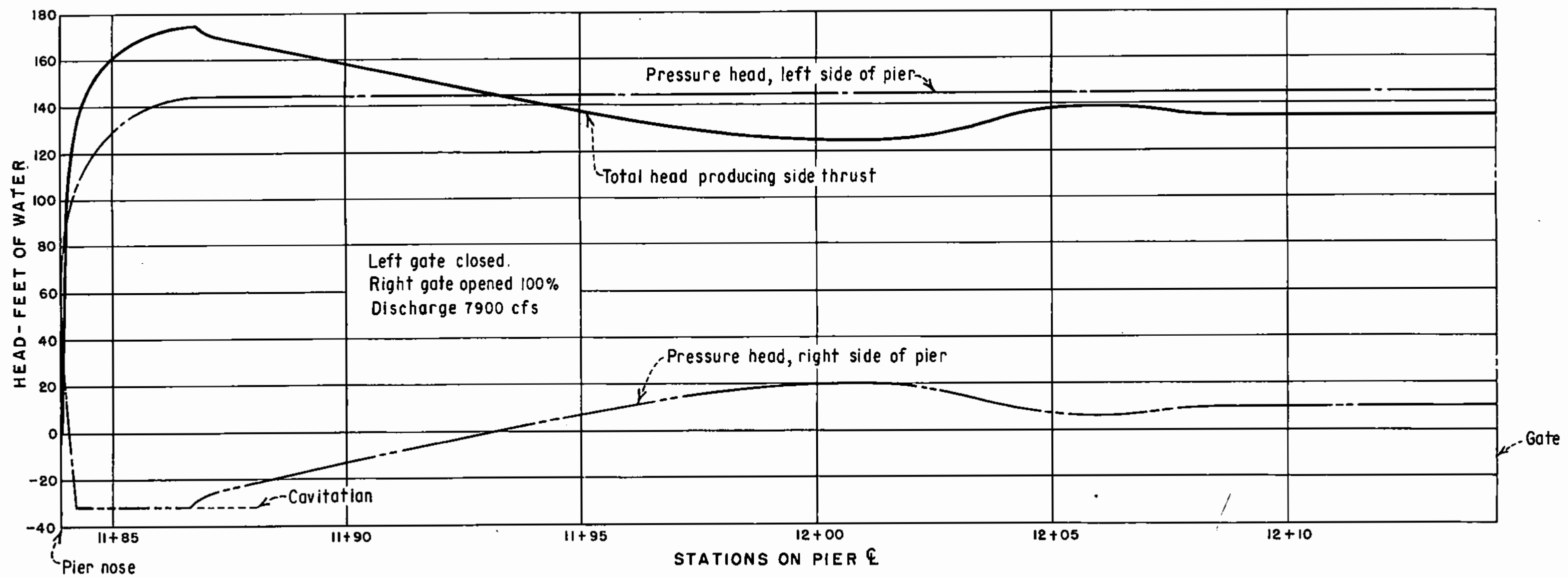
TWITCHELL (VAQUERO) DAM OUTLET WORKS

MODEL STUDY OF PIER NOSE SHAPES

FIGURE 12
REPORT HYD.449



PLAN OF PIER



PRESSURES ON SIDES OF PIER

SANTA MARIA PROJECT – CALIFORNIA

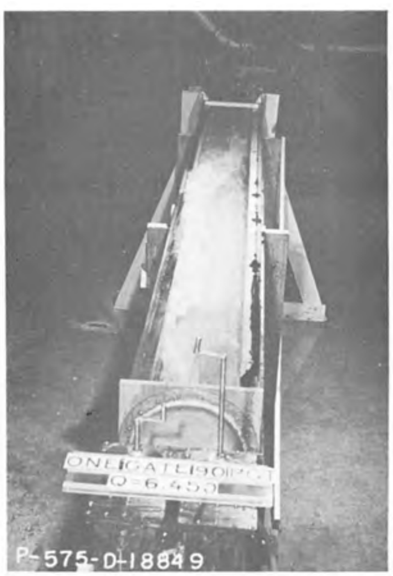
TWITCHELL (VAQUERO) DAM OUTLET WORKS

TOTAL COMBINED PRESSURE CAUSING
SIDE THRUST ON THE UPSTREAM PIER

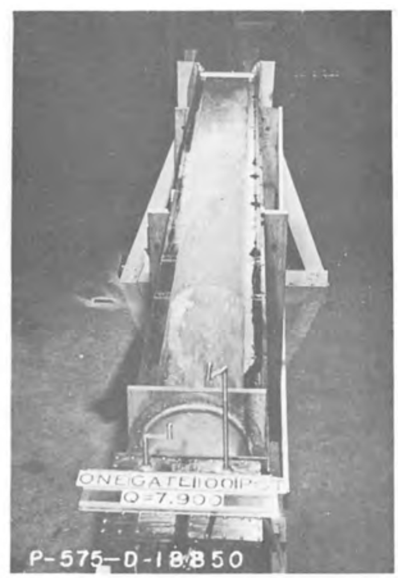
RIGHT GATE OPENED 100%, LEFT GATE CLOSED, Q=7900 C.F.S.

A. Right Gate Opened 50%
Q = 3,230 cfs

B. Right Gate Opened 80%
Q = 5,480 cfs



C. Right Gate Opened 90%
Q = 6,450 cfs



D. Right Gate Opened 100%
Q = 7,900 cfs

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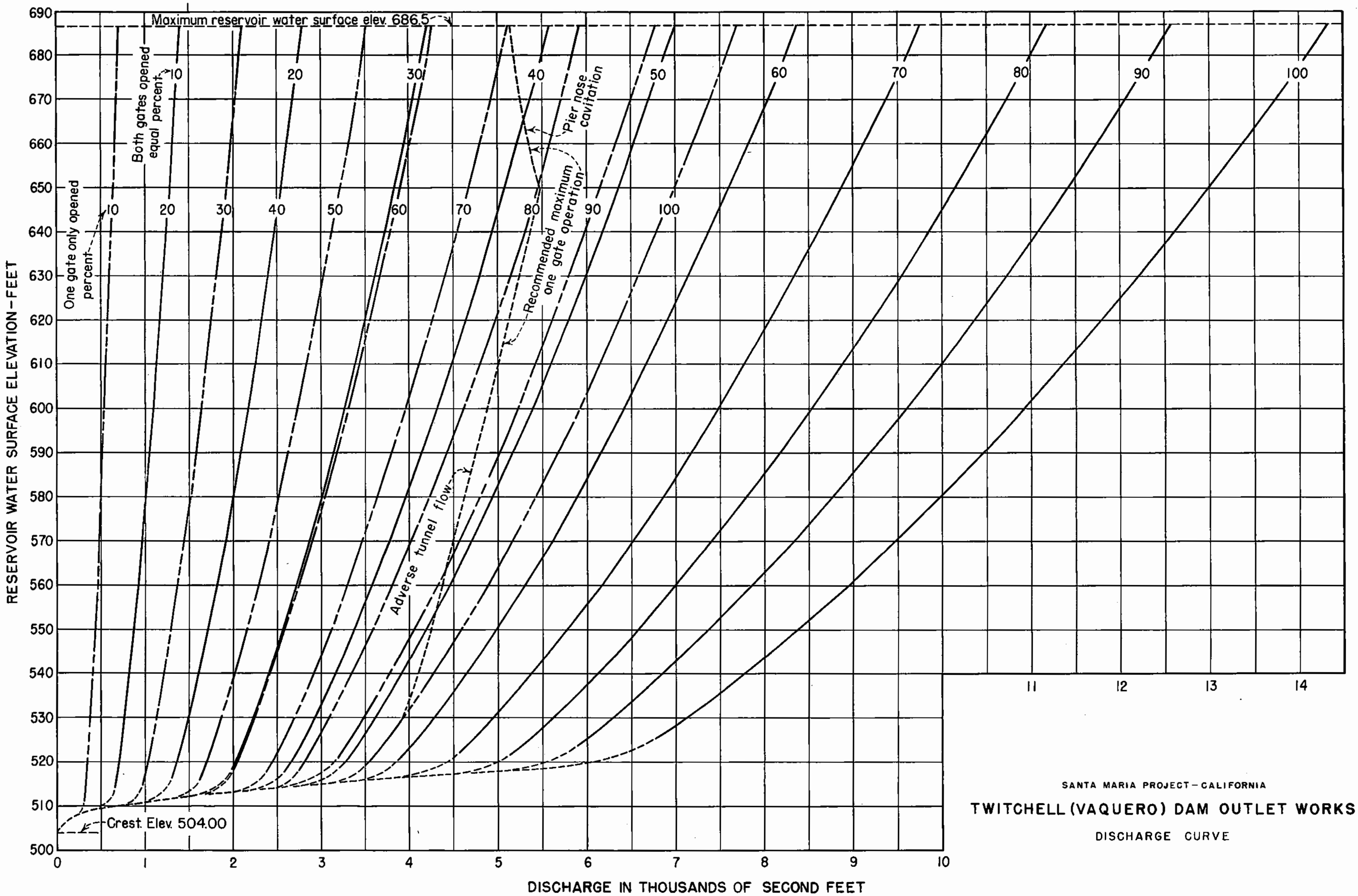
Twitchell (Vaquero) Dam - Outlet Works

One Gate Operation - Recommended Design



SANTA MARIA PROJECT—CALIFORNIA

TWITCHELL (VAQUERO) DAM OUTLET WORKS

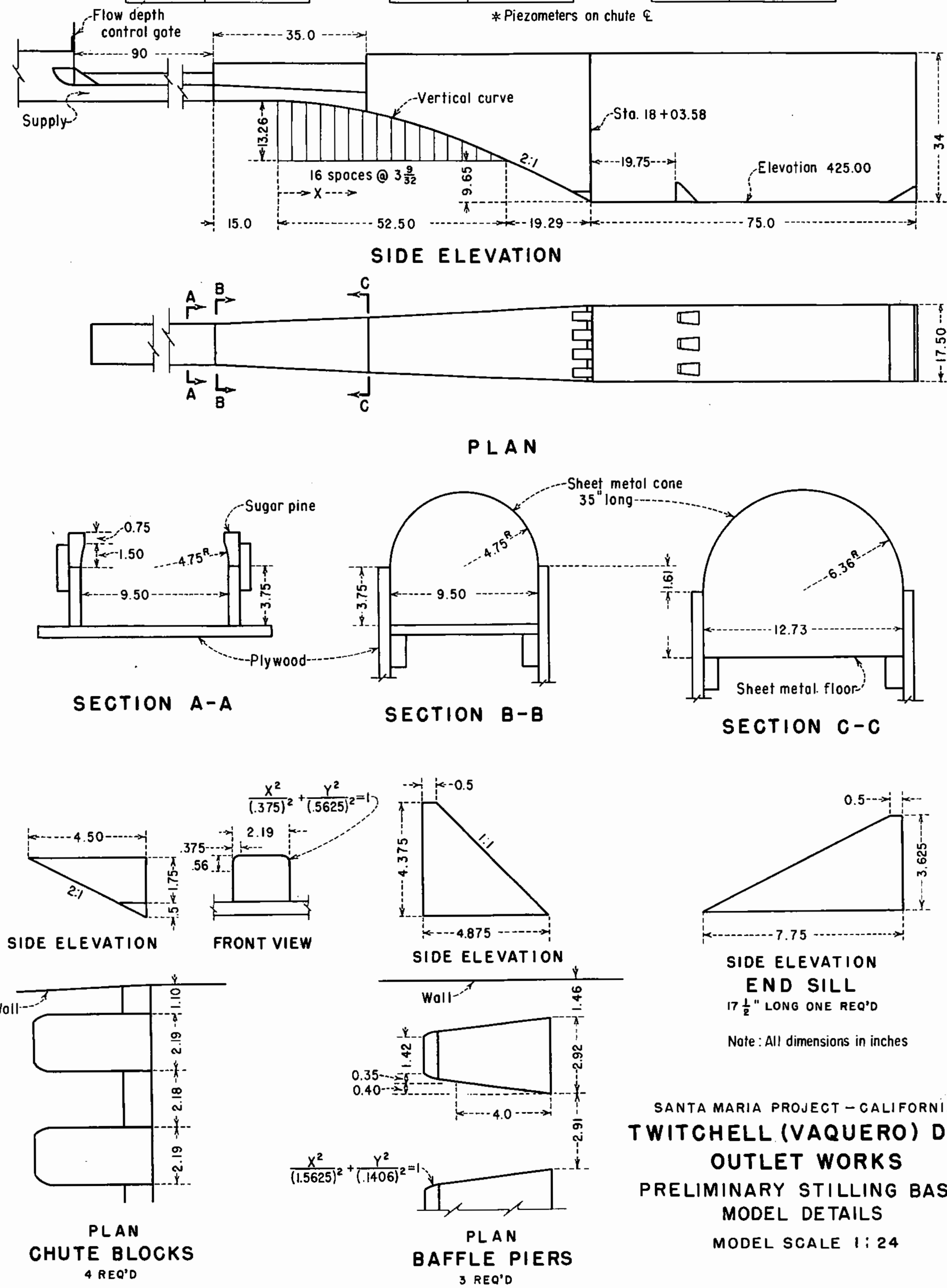
DISCHARGE CURVE

FIGURE 15
REPORT HYD. 449

VERTICAL CURVE

X	UP FROM HORIZONTAL	X	UP FROM HORIZONTAL	X	UP FROM HORIZONTAL
0	13 1/4 *	19 11/16	11 21/64 *	39 3/8	5 3/4 *
3 9/32	13 3/16	22 31/32	10 21/32	42 21/32	4 15/32
6 9/16	13 1/64 *	26 1/4	9 7/8	45 15/16	3 5/64
9 27/32	12 3/4	29 17/32	9 *	49 7/32	1 19/32
13 1/8	12 3/8 *	32 13/16	8 1/64	52 1/2	0 *
16 13/32	11 29/32	36 3/32	6 15/16		

* Piezometers on chute ℄



Note: All dimensions in inches

SANTA MARIA PROJECT – CALIFORNIA

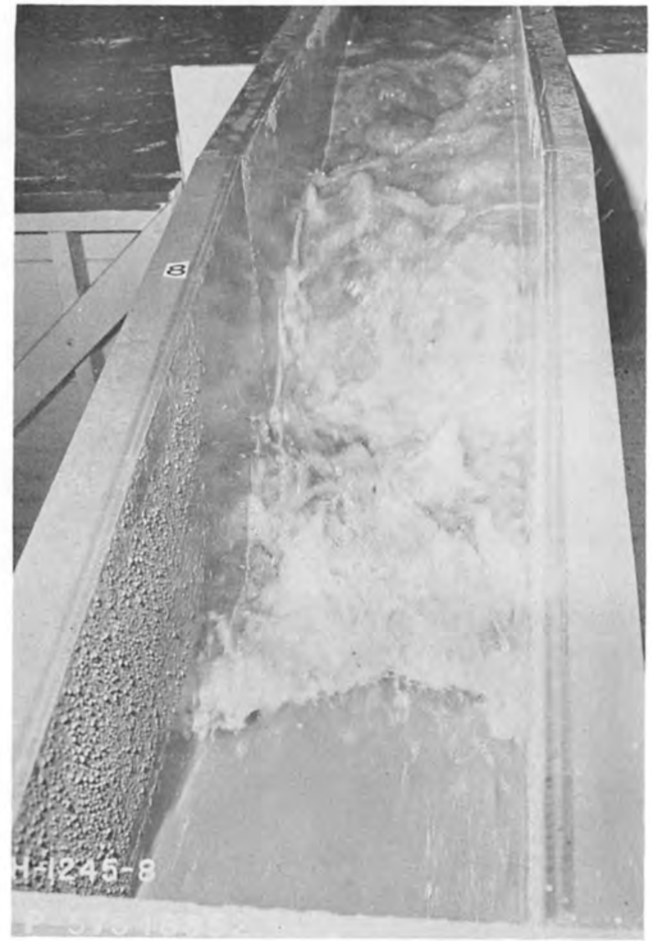
TWITCHELL (VAQUERO) DAM
OUTLET WORKS

PRELIMINARY STILLING BASIN
MODEL DETAILS

MODEL SCALE 1:24

542

Looking Upstream

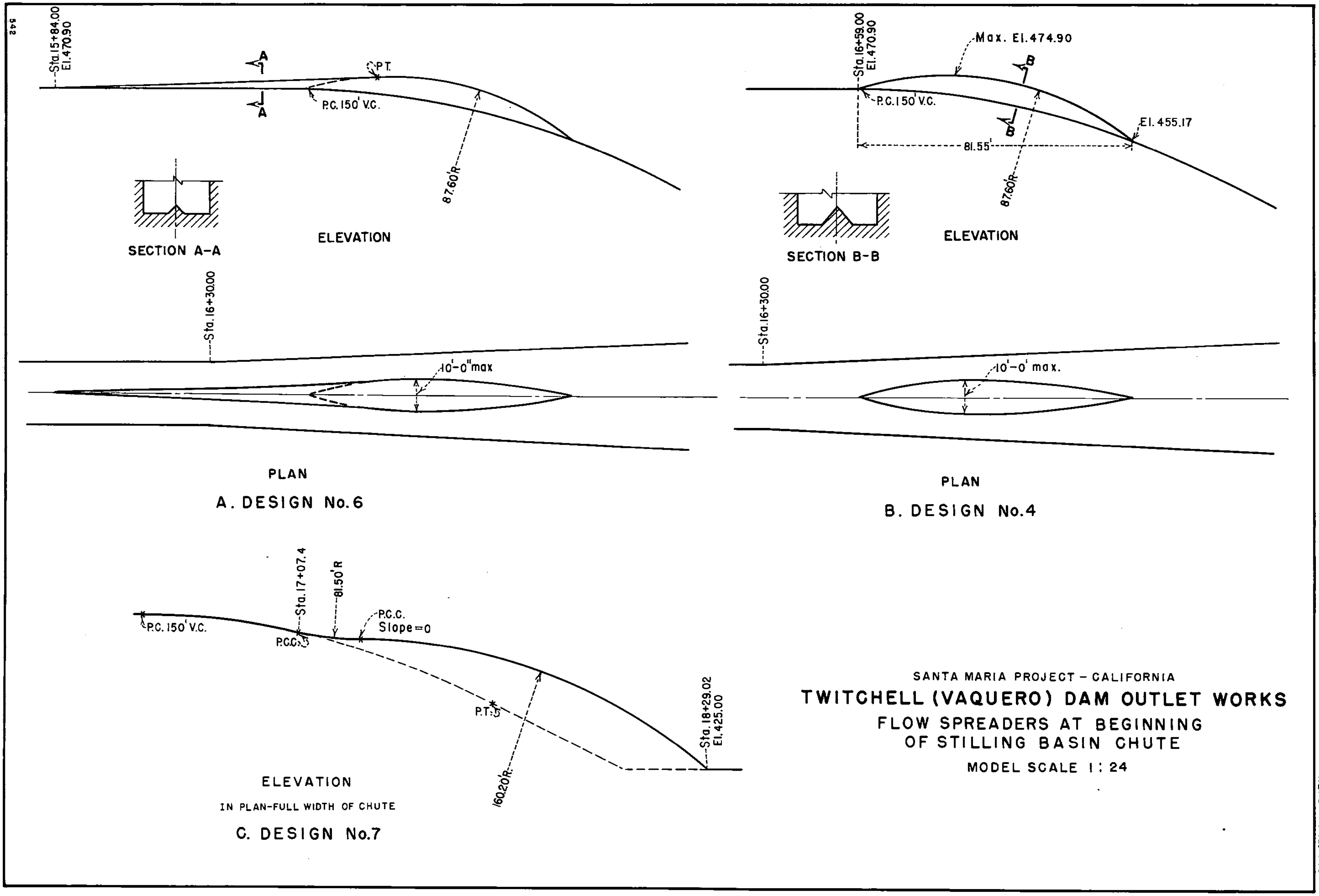


Looking Downstream

Santa Maria Project - California
Twitchell (Vaquero) Dam - Outlet Works

Preliminary Stilling Basin - Model Scale 1:24
Q = 13,570 cfs
Both Gates Opened 100%

Figure 17
Report Hyd 449



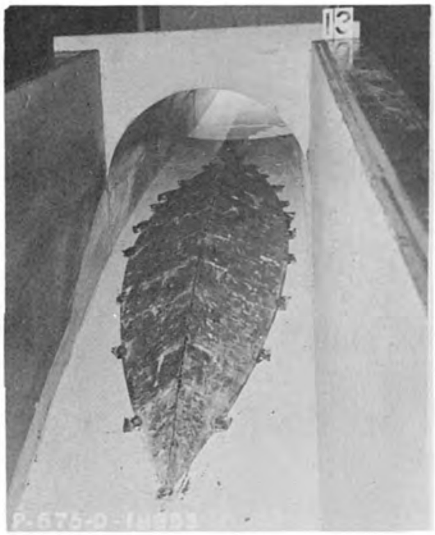
SANTA MARIA PROJECT – CALIFORNIA

TWITCHELL (VAQUERO) DAM OUTLET WORKS

FLOW SPREADERS AT BEGINNING OF STILLING BASIN CHUTE

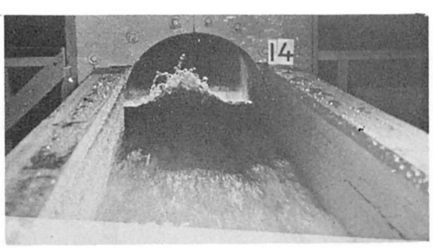
MODEL SCALE 1 : 24

FIGURE 18
REPORT HYD. 449



A. Looking Upstream

B. Looking Downstream

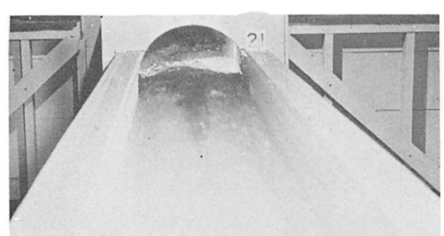


C. Q = 4,700 cfs
Both Gates Opened 35%

Flow Spreader Design 4

D. Looking Upstream

E. Looking Downstream



F. Q = 4,780 cfs
Both Gates Opened 35%

Flow Spreader Design 6

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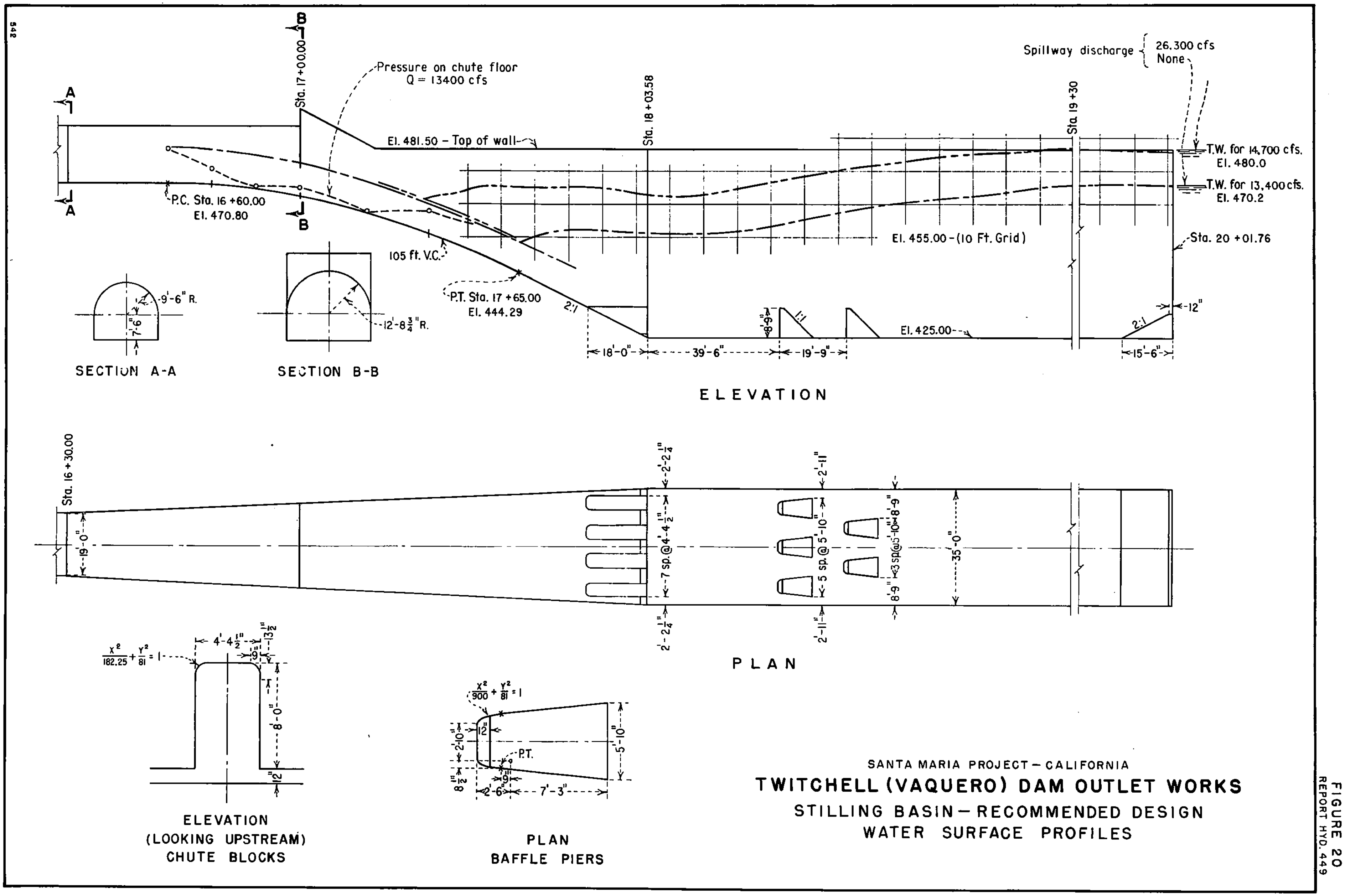
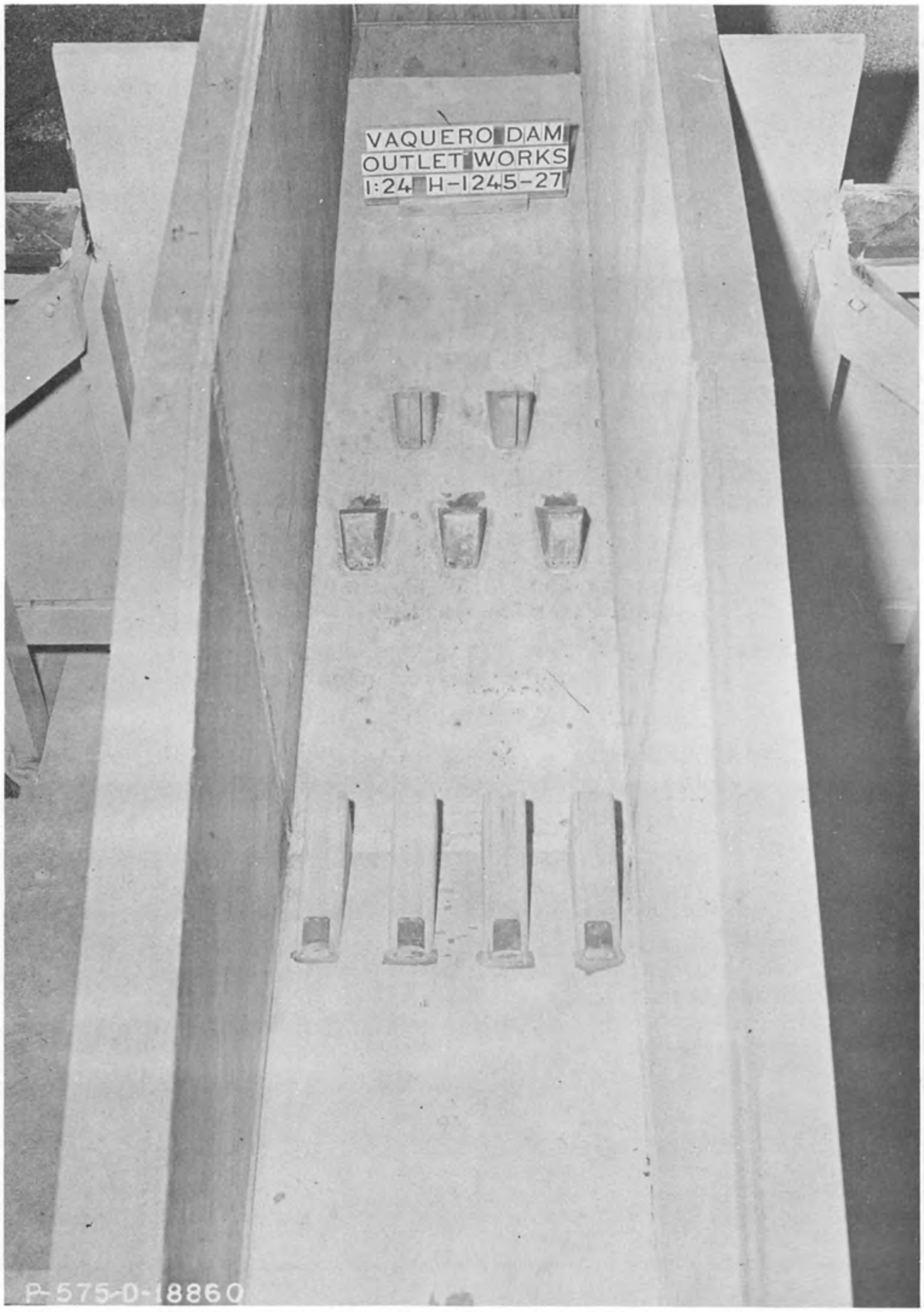
Flow Spreaders on Stilling Basin Chute
See Figure 18 for Spreader Details



SANTA MARIA PROJECT – CALIFORNIA
TWITCHELL (VAQUERO) DAM OUTLET WORKS
STILLING BASIN – RECOMMENDED DESIGN
WATER SURFACE PROFILES

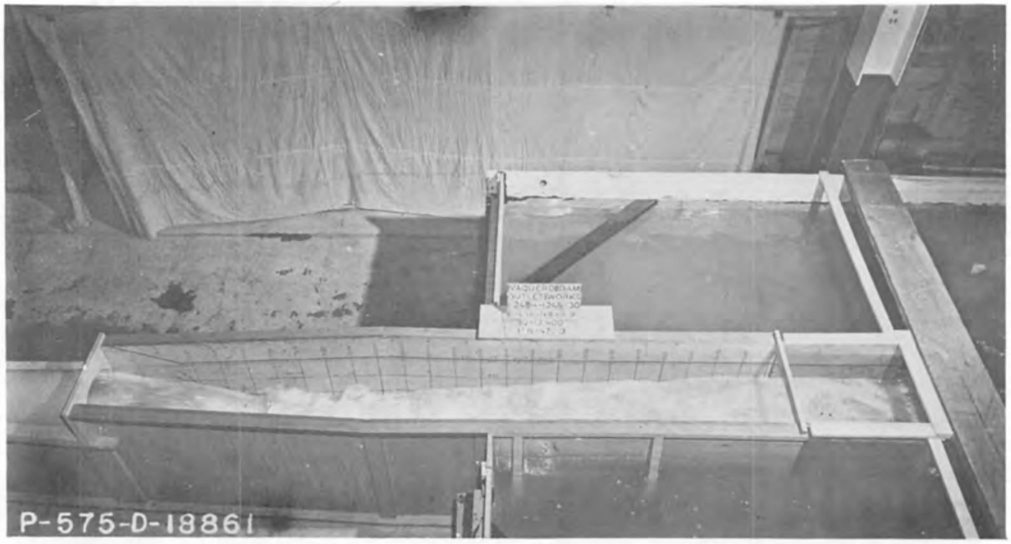


View Looking Downstream Showing
Chute Blocks and Baffle Piers

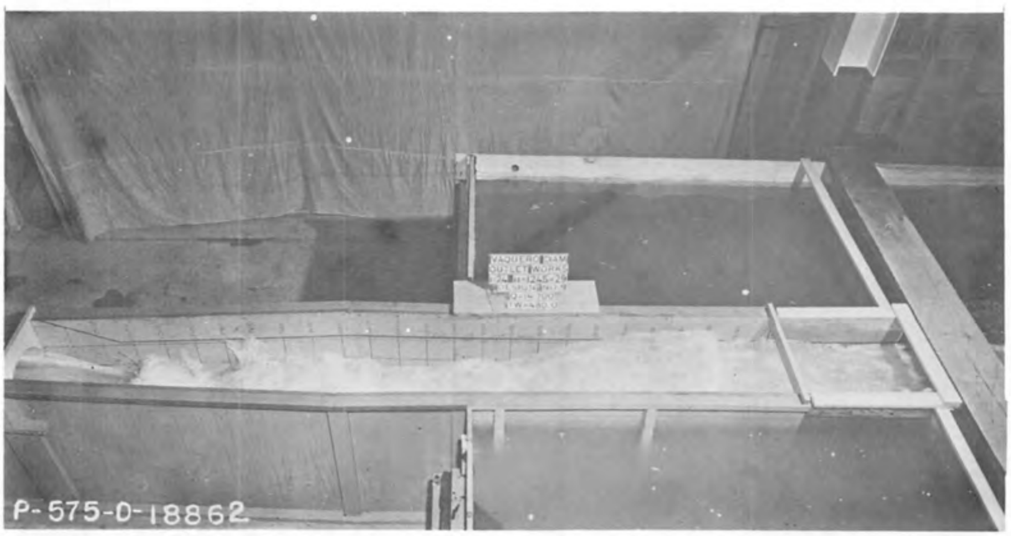
Santa Maria Project - California
Twitchell (Vaquero) Dam - Outlet Works

Stilling Basin - Recommended Design
Model Scale 1:24

Figure 22
Report Hyd 449



A. Q = 13,400 cfs; T.W. Elev. = 470.3
Both Gates Opened 100%



B. Q = 14,700 cfs; T.W. Elev. = 480.0
Both Gates Opened 100%

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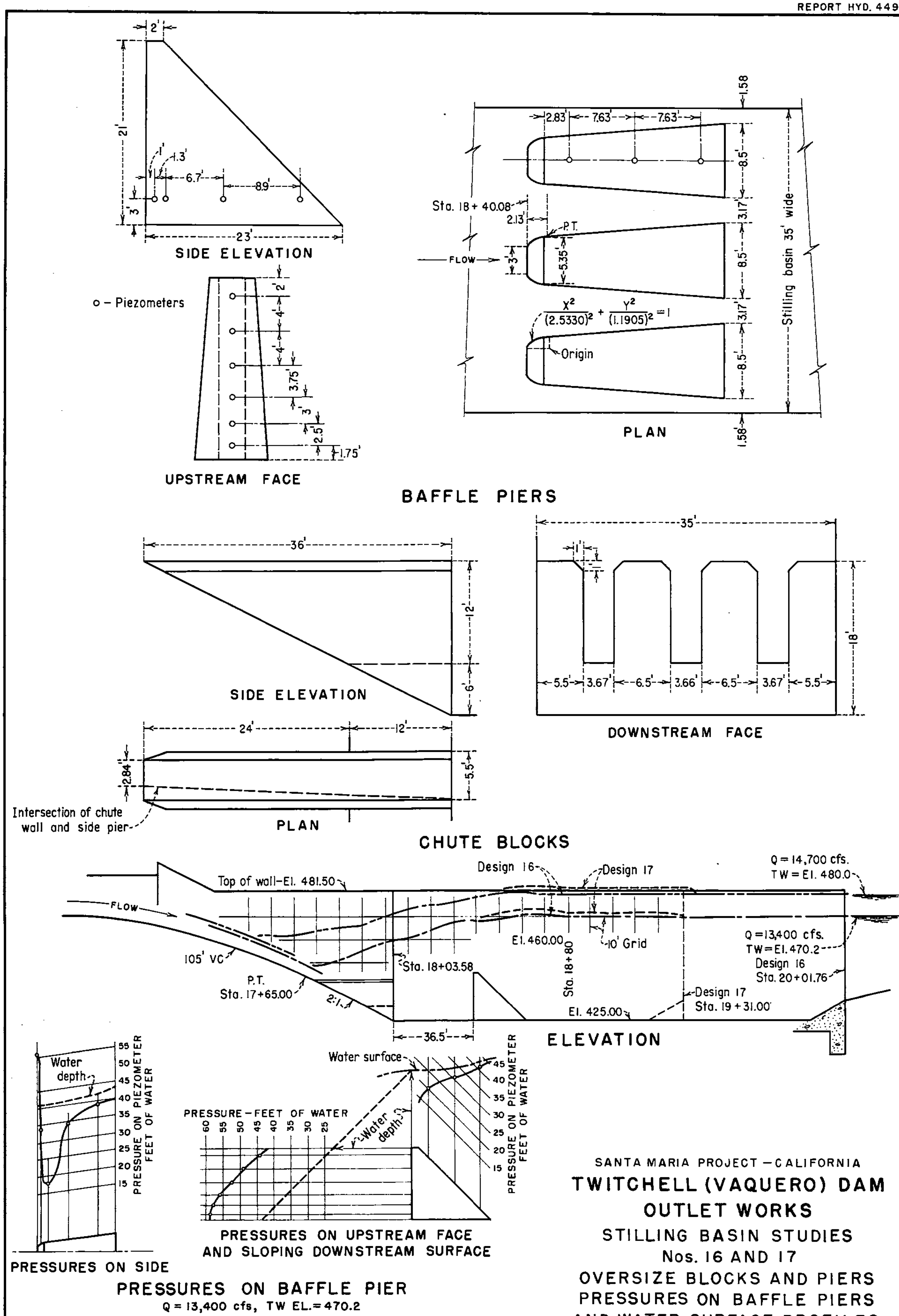
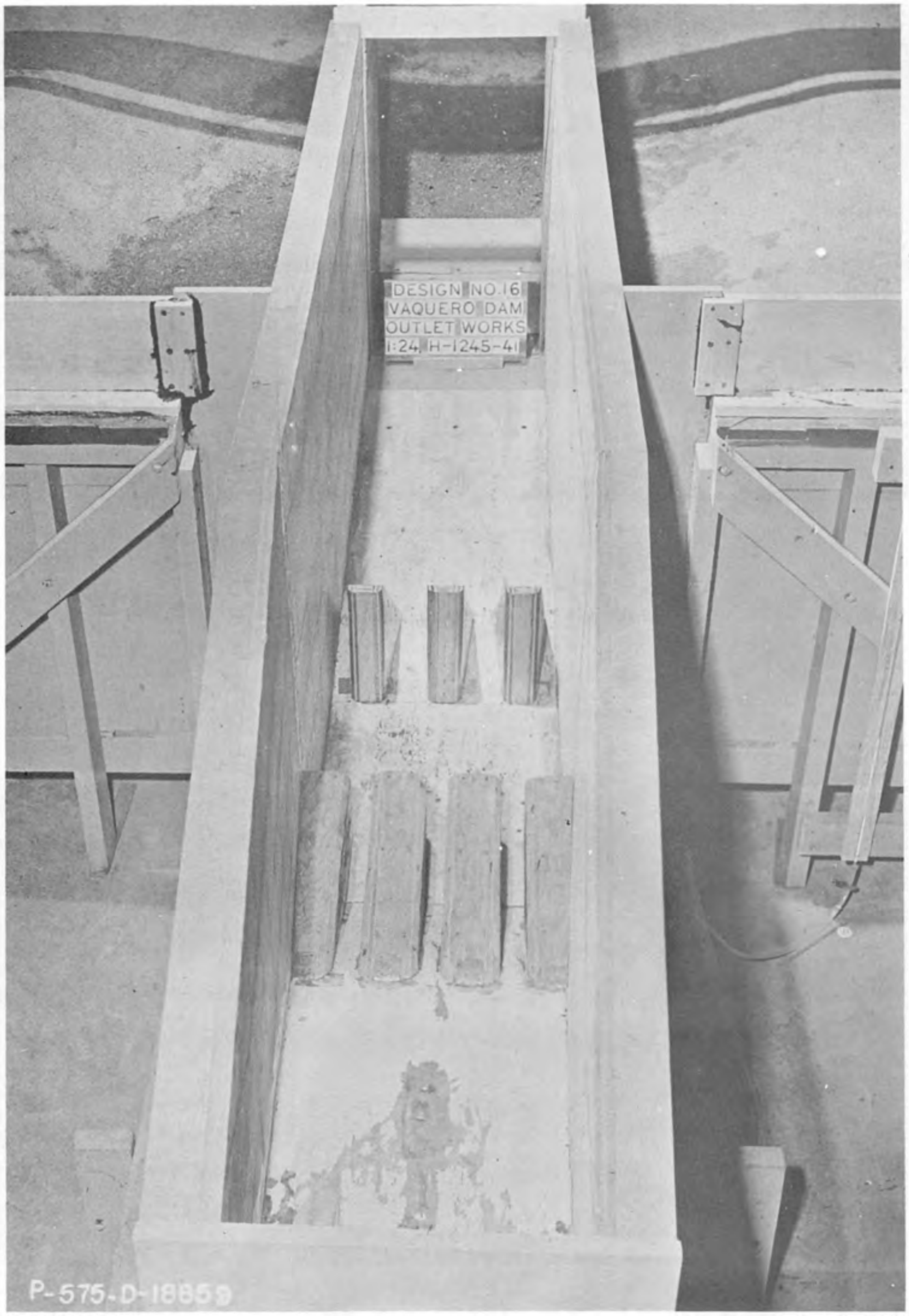
Twitchell (Vaquero) Dam - Outlet Works

Basin Operation - Recommended Design



SANTA MARIA PROJECT – CALIFORNIA

TWITCHELL (VAQUERO) DAM
OUTLET WORKS
STILLING BASIN STUDIES
Nos. 16 AND 17
OVERSIZE BLOCKS AND PIERS
PRESSURES ON BAFFLE PIERS
AND WATER SURFACE PROFILES

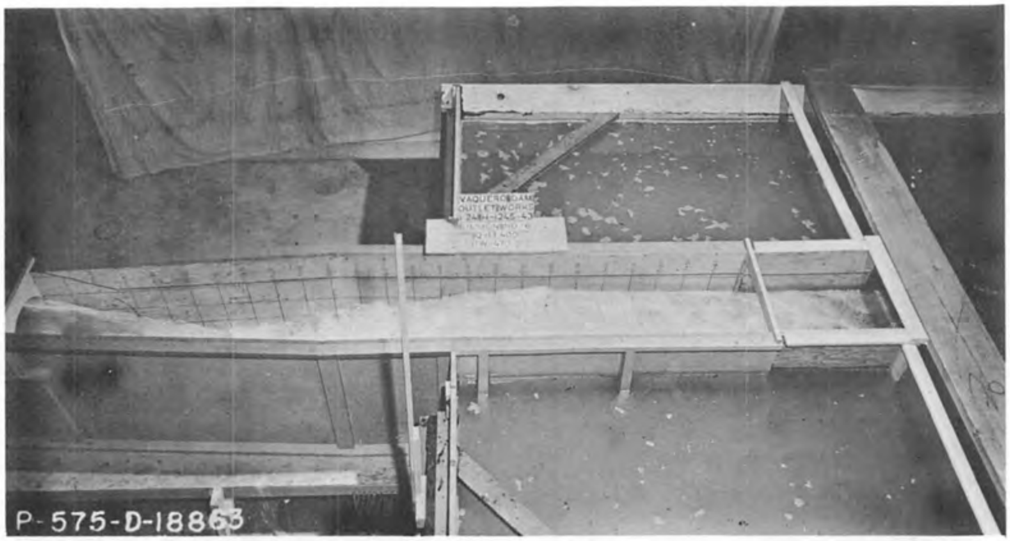


View Looking Downstream Showing
Chute Blocks and Baffle Piers

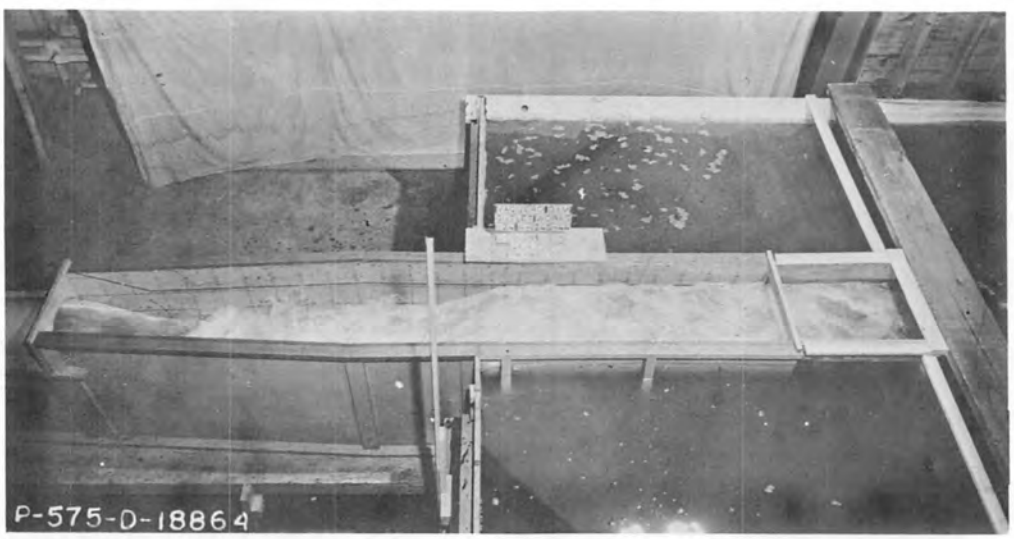
Santa Maria Project - California
Twitchell (Vaquero) Dam - Outlet Works

Oversize Blocks and Piers - Design No. 16
Model Scale 1:24

Figure 25
Report Hyd 449



A. Q = 13,400 cfs; T.W. Elev. = 470.2
Both Gates Opened 100%



B. Q = 14,700 cfs; T.W. Elev. = 480.0
Both Gates Opened 100%

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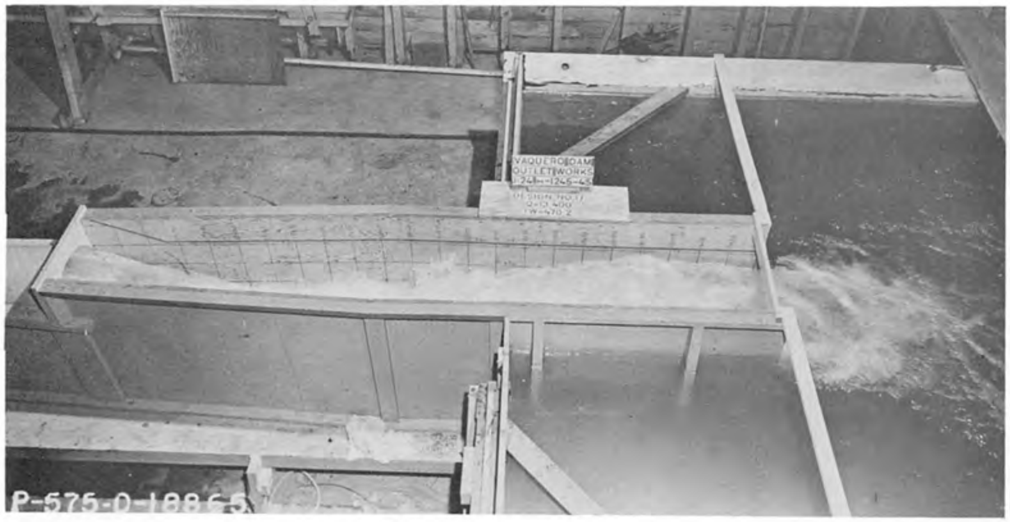
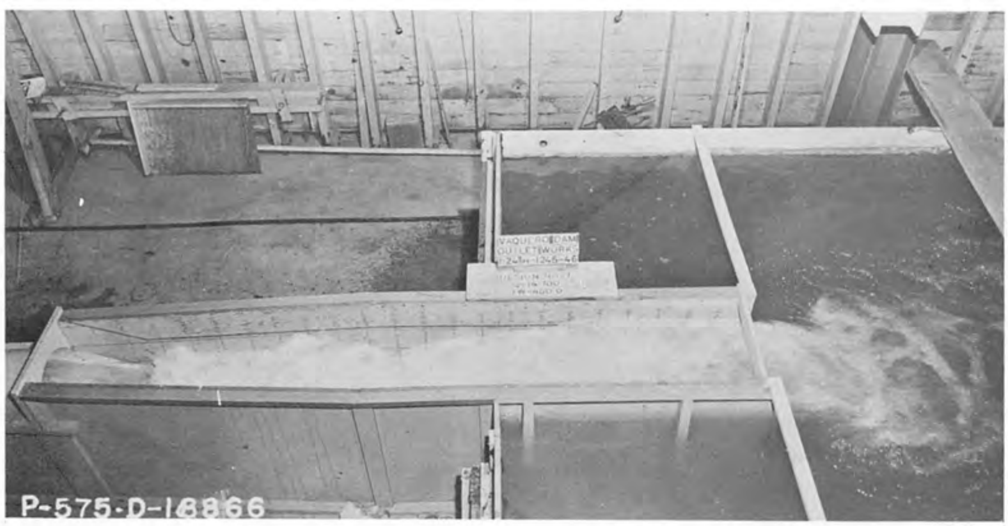
Twitchell (Vaquero) Dam - Outlet Works

Basin Operation - Design No. 16
Basin Length = 198.18 ft.



A. Q = 13,400 cfs; T.W. Elev. = 470.2
Both Gates Opened 100%



B. Q = 14,700 cfs; T.W. Elev. = 480.0
Both Gates Opened 100%

Santa Maria Project - California
Twitchell (Vaquero) Dam - Outlet Works

Basin Operation - Design No. 17
Basin Length = 127.42 ft.