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HYDRAULIC LABORATORY REPORT NO. 157

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LABORATORY INVESTIGATION OF PRESSURE CONDITIONS IN THE OUTLETS IN ROSS DAM - CITY OF SEATTLE, WASHINGTON

by

FRED LOCHER, ASSOCIATE ENGINEER

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Denver, Colorado
October 20, 1944

UNITED STATES
DEPARTMENT OF THE INTERIOR
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SUBJECT: LABORATORY INVESTIGATIONS OF PRESSURE CONDITIONS IN THE OUTLETS IN ROSS DAM CITY OF SEATTLE, WASHINGTON

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By FRED LOCHER, ASSOCIATE ENGINEER

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Under Direction of

J. E. WARNOCK, SENIOR ENGINEER

and

R. F. BLANKS, SENIOR ENGINEER

- - - - -

Denver, Colorado,
Oct. 20, 1944

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
October 20, 1944

Laboratory Report No. 157
Hydraulic Laboratory

Compiled by: Fred Locher
Reviewed by: J. E. Warnock

Subject: Laboratory investigation of pressure conditions in the outlets in Ross Dam - City of Seattle, Washington.

1. Outlets at elevations 1250 and 1265. At the present stage of construction the reservoir at Ross Dam is being utilized for storage only. During periods of low flow in the Skagit River the impounded water is released through bypasses at elevations 1250 and 1265, respectively, into Diablo Reservoir where the flow produces power for the city of Seattle - Department of Lighting.

During January of 1943 an attempt was made to close the gate at elevation 1250, but, due to circumstances then not clearly determined, the gate failed to close completely and the cable was ruptured during the procedure. The repairs were made in the following April, at which time it was found that the entire roller train on one side of the gate was gone and that several rollers from the other side were missing.

Conditions made it impossible to inspect the interior of the bypass pipes until July 1943, when it was found that a large section in the top of the lower pipe was torn and pulled out of place. Several other small holes and pitted areas were found in both pipes. The damaged areas were repaired by welding patches over the holes and filling the pitted areas with weld.

A second inspection was made in October 1943, when it was found that the pipe was again damaged in the same areas and, in addition, that farther down on the pipes other places were showing signs of pitting.

At the time of completion of installation of the bypass conduit without downstream controls, it was realized that operation under those circumstances was not sound engineering practice; but it was decided that since the omission was temporary, the savings effected by the storage of water behind Ross Dam warranted such use. However, neither the extent nor the amount of the damage that resulted from the operation was anticipated.

From the traces of pitting described in Mr. Hofman's letter of April 6, 1944, it is evident that the pressure gradient in the pipes is very close to the vapor pressure of water and that any irregularity or protrusion in the pipe, such as an unground welded joint or one which is slightly offset, was sufficient to cause the pitting that results from cavitation. In the fabrication of the remainder of these pipes it is desirable to have all welded joints and other protrusions on the conduit ground to a reasonable degree of smoothness. Since the final installation in these bypasses cannot be completed for some time, the installation of a constriction on the end of each bypass to raise the pressure gradient in the pipe to a minimum of one-half an atmosphere under the severest operating condition has been advised (sections 9 and 10, appendix A).

Computations show the pressure conditions in the bypasses to be as indicated in the upper set of curves marked "existing design" on figure 1. These curves indicate that the bypass at elevation 1250 should not be operated without either the cone or the valve in place when the reservoir is below elevation 1385 and that the bypass at elevation 1265 will require a much higher reservoir elevation for safe operation. The other curves on figure 1 show the pressures and discharges that may be expected with the discharge cone or the valves in place. If, in the ultimate development, the Bunger valves are installed with the hood, the pressures will be considerably higher and the discharges much lower than indicated on figure 1 because the curves are based on a valve coefficient of 0.90, whereas these valves

with the hood have a coefficient of 0.67.

2. Outlets at elevation 1340. At the present time construction of the second stage of Ross Dam is in progress, where another pair of outlets will be placed at elevation 1340. These outlets are similar in design to those in place at elevations 1250 and 1265 except that the conduit passing through the dam will be horizontal and butterfly valves will be used instead of Bunger valves. The similarity of the entrances in the two designs and the difficulty in operating the 6- by 8-foot Broome gates at the 1250 outlets led to the belief that considerable trouble might be experienced with the new installation.

Due to the complex nature of the problem, Engineer J. E. Warnock visited the project to study the situation with the engineering staff of the city of Seattle. During a series of conferences at Seattle and at Ross Dam a program of model studies was proposed whereby the possible difficulties of operation could be examined and possible modifications studied, utilizing the material already purchased for the project.

3. Model studies of the Philips and Davies design. A 1:12 scale model of the original design of the 1340 outlets was constructed according to the drawings furnished by the city of Seattle. The design consisted of a trashrack structure, a 6- by 8-foot Broome gate, and a rectangular transition to a 72-inch conduit which terminated at the butterfly valve. The details of the original trashrack design and the Philips and Davies transition are shown on figure 2- B, D, and G. The details of the butterfly valve and the Broome gate are shown on figures 3 and 4. Tests with this arrangement indicated positive pressures throughout for any head or operating condition expected at Ross Dam. The pressure conditions in the transition were obtained from 19 piezometers and 3 pitot tubes placed in a regular pattern about the transition. The results of these measurements are shown on figure 5. The solid line represents the pressures in the

transition with the butterfly valve in place, and the special symbols indicate the pitot tube measurements. The pitot tubes were placed opposite a particular piezometer with the dynamic leg pointed downstream. The pressures obtained from these tubes were higher than those from the adjacent piezometers, indicating that in these regions of the transition the flow along the boundary was opposite to the main flow in the transition. This condition was not objectionable, but it does indicate that the flow from the transition entrance skips the transition sides and that the void that would be thus formed is filled by an eddy which relieves any negative pressures that would tend to form. The coefficient of discharge of the butterfly valve, based on the inlet diameter and the total head, was 0.604, and the over-all coefficient of the entire outlet, based on the conduit diameter, was 0.563.

A computation of the trashrack velocities for the original trashrack was made as shown on figure 6, from which it was found that with the original trashrack design excessive velocities would prevail in the region upstream from the gate. The material for the gates and the trashracks was already purchased and partially fabricated, and the contracts for the concrete work were already awarded; so any modified designs of the trashrack, to be economically feasible, had to be based on material on hand. Two modified arrangements were tested - an elliptical plan (figure 2C) and a straight plan (figure 2E). The proposed elliptical trashrack arrangement was, for structural reasons, abandoned in favor of the revised original design of figure 2E. The computed trashrack velocities for this design are shown on figure 6. The piezometric pressures in the transition with this rack in place, for operation with and without the butterfly valve, are shown on figure 7. All pressures were positive, and satisfactory operation may be expected with this design.

4. Hydraulic drawdown forces on the Broome gate. The Broome gates will be used normally for unwatering the penstocks and the out-

lets for inspection and maintenance of the conduits and the valves. Under these conditions the gate would be opened and closed under balanced hydrostatic pressure, with no flow through the conduit. This would not cause any undue load on the hoisting apparatus as the weight of the gate and friction are the only forces involved. Under emergency conditions, when the gate is closed under an unbalanced head on the upstream side and with maximum flow through the conduit, the gate would become a definite control in the conduit, causing low pressures on the downstream side. In addition, a force termed the "hydraulic drawdown force" occurs. This downward pull on the gate is caused by the increased velocity under the gate which reduces the pressure on the bottom, thus setting up a differential head on the gate which acts downward. This force is important in the design of a gate hoist as it may be equal to or greater than the weight of the gate. The calculation of the hydraulic drawdown force can be only approximate. The pressure reduction at any point on the gate is a function of the velocity head at that point. Calculations of drawdown are based upon the velocity distribution under the gate and they vary with the gate opening and the shape of the gate bottom.

The drawdown forces on the 6- by 8-foot Broome gates were determined from the model and are shown on figure 8. The forces have been computed for operation with and without the butterfly valve and a reservoir head of 300 feet. As this force is proportional to the head on the gate, it may be converted to the value at any other head by multiplying the values shown on the curves by the ratio of the heads.

5. The rectangular bellmouth transition and trashrack. The rectangular bellmouth of figure 9, in combination with the elliptical trashrack of figure 2C, was tested to determine the advantages of this design over the previous design, if any. Tests with this arrangement indicated positive pressures throughout. The piezometric pressures are shown by the dashed lines of figure 5. The over-all

coefficient of discharge based on the conduit diameter and the total head was 0.573 as compared to 0.563 for the Philips and Davies design. This represents a 1.78-percent increase in discharge which was not sufficient to warrant its use in the proposed bypass in view of the additional cost. However, in a turbine penstock the additional saving in head might justify the cost.

6. Conclusions. The pressures obtained in the model indicate that the prototype outlets at elevation 1340 as originally designed will be free from negative pressures at any head.

The negative pressures prevailing at the seat of the butterfly valves are not sufficiently low to cause cavitation, with the heads at Ross Dam. No negative pressures were present when the valve was operated at full opening. The coefficient of discharge, based on the inlet diameter and the total head, was 0.604.

The over-all coefficient of discharge for the original design with the revised trashrack was 0.563. This was increased to 0.573 with the bellmouth entrance and the elliptical trashrack.

The hydraulic drawdown forces on the Broome gates are of sufficient magnitude to cause considerable operating difficulties during an emergency closure unless ample provisions are made for these forces in the design of the hoisting apparatus.

The trashrack velocities of the original design will be materially reduced by the use of the revised design of figure 23.

The cavitation and the pitting in the outlets at elevations 1250 and 1265 (figures 10 and 11) were the result of operating the outlets at low reservoir elevations without an adequate control on the downstream end to raise the pressure gradient in the pipes sufficiently above the vapor pressure of water.

Until the Howell-Bunger valves are installed, the condition in the outlets at elevations 1250 and 1265 can be remedied by placing a 6- to 4.5-foot discharge cone 8 feet long at the end of each pipe.

As a further safeguard, all joints and other protrusions should be ground smooth. With these cones the bypasses should not be operated when the reservoir elevation drops below 1270. With the Howell-Bunger valves, without hoods, the bypass should not be operated with full valve opening when the reservoir drops below elevation 1290.

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APPENDIX A

Denver 2, Colorado, May 23, 1944.

MEMORANDUM TO CHIEF ENGINEER (THROUGH R. F. BLANKS)
(J. E. Warnock)

Subject: Hydraulic model studies of outlets at Elevation 1340 and lower bypass outlets in Ross Dam - City of Seattle, Washington.

1. In a letter of March 28, 1944, Mr. E. R. Hoffman, Superintendent of Lighting, Department of Lighting, City of Seattle, Washington, made a request for an estimate and a contract for his signature, covering a model of the proposed outlet installation for Ross Dam at Elevation 1340. The purpose of the model would be to determine the possibility of cavitation in the outlet due to the flow of water under various heads between Elevation 1350 and the water surface at Elevation 1635. The following drawings were transmitted by the letter:

Philips and Davies Drawings:

20548	Roller Chain, Riveted Type
32154	16-inch Side Casting
32155	Guard Plate
32720	Lift Bars (Revised 4-29-43)
32735	Changes in Transition
41031	Bottom Seat Casting
41034	Broome Gate
41035	Gate Frame
41815	Frame (Revised 10-20-43)
41816	Transition
41822	Grout Plates - Guards and Roller Path (Revised 10-20-43)
41855	Assembly Drawing

Pelton Water Wheel Company Drawings:

A-32729-43-01	72-inch Butterfly Valve
B-32729-43-02	Body for 72-inch Butterfly Valve

City Light Drawings:

D-13150-A	Outlet Structure at Elev. 1340
D-13168-A	Details of Outlet Structure at Elev. 1340

D-13171	Steel Details - Outlet Structure, Elev. 1340 (Revised to 1-19-44)
D-13202-1	Valve House at Elev. 1340, Plan and Elevations
D-13229	Details of Gate Chute Grating from Elev. 1450 to Elev. 1550 for Outlets at Elev. 1340

2. In a subsequent letter, of April 6, 1944, the following drawings were transmitted regarding damage due to cavitation and pitting, which had occurred in the steel bypass pipes at Elevations 1250 and 1265 at Ross Dam:

Philips and Davies Drawings:

41037	Lower Transition Lining (Revised 11-7-38)
41038	Assembly Drawing (Revised 10-24-38)
41044	Upper Transition Lining (Revised 11-7-38)

City Light Drawings:

D-13010-A	General Layout of Bypass Inlet Structure, as Constructed
D-13027-A	Trash Rack Details (Revised to 11-22-38)
D-13029-A	Steel Pipe for Bypass Tunnel (Revised to 6-14-38)(Marked to show breaks and pitted areas in pipe)
D-13041	Two 8- by 6-foot Self-Closing Sluice Gates for Bypass Tunnel (Revised to 11-18-38)
D-13054	Bypass Tunnel Pipes, Grade and Alignment Sheet (Revised to 4-5-39)
D-13129	Plan to Elev. 1550 and Key Details (Revised to 1-16-44)

Also transmitted by the same letter, were photographs LT-1405 to 1409, inclusive, showing the break in the crown of the lower bypass pipe, and photograph RD-379, showing termination of the bypass pipe in the diversion tunnel. This information was submitted for its value in making the study and model of the outlet installation at Elevation 1340.

3. Based on the information contained in these two letters, a reply dated April 14, 1944, outlined the difficulties of operation which might be expected from the design which is delineated on the drawings listed in paragraph 1. The suggestion was also made that certain changes be made in the design, using information in the Bureau files before making a model study. In a telephone conversation between Mr. Wolfendale, of the City of Seattle, and Mr. Blanks, of this office, we were informed that all of the gates, valves and penstocks for the Elevation 1340 outlets have been purchased. The 72-inch butterfly valves have been delivered by the Pelton Water

Wheel Company, and delivery of the 6- by 8-foot Broome gates by Philips and Davies Company, Kenton, Ohio, is expected by midsummer. The penstocks have been fabricated but not delivered. In view of the complexity of the problem, the suggestion was made that the writer be sent to Seattle to study thoroughly the situation with the City of Seattle engineers to which Mr. Wolfendale agreed.

4. In a series of conferences in Seattle and at Ross Dam, from April 26 to May 4, with Mr. Wolfendale and his engineering staff, a program of model studies was prepared, whereby the possible difficulties of operation in the ultimate installation of the lower bypass outlets and the Elevation 1340 outlets could be examined, and possible modifications studied, utilizing the equipment already purchased and partly delivered. A solution to the present pitting in the lower bypass outlets was also suggested, the details of which will be described later. The proposed program of studies on a model of the outlets at Elevation 1340, tentatively includes eight tests as follows:

Test 1. Measure pressure distribution in the present design of the outlet structure and butterfly valve, as shown on drawings D-13150-A and D-13168-A, with gate slot, trashrack slot, and stoplog slot in place; and measure forces on lifting cables for Broome gate during an emergency closure.

Test 2. Same as Test 1 except using a rectangular bellmouth entrance instead of the design by Philips and Davies.

Test 3. Measure pressure distribution in the present design of the outlet structure and butterfly valve, as shown on drawings D-13150-A and D-13168-A, with the portion of the intake structure upstream from the plane of the gate roller bearing seat removed; and measure forces on lifting cables for Broome gate during an emergency closure. This test is to evaluate the effect of the lack of streamlining in the intake structure upstream from the roller train seat on the pressure conditions in the outlet conduit.

Test 4. Same as Test 3 except using a rectangular bellmouth transition instead of the Philips and Davies design.

Test 5. Measure pressure distribution in the outlet transition and conduit with a rectangular bellmouth transition similar to those in the Shasta Dam power penstock intakes; with the Broome gate as furnished by the manufacturer; and with a trashrack circular in plan over both conduit entrances; and measure forces on lifting cables for Broome gates during an emergency closure. This test is to evaluate the effect of a rectangular bellmouth transition on the pressure conditions in the outlet

conduit with no change in the arrangement of the Broome gate seat and roller train seat.

Test 6. Same as Test 3 except that the roller train will be moved forward on the Broome gate until the roller train seat and the gate seat will be in the same plane at the bottom of the gate (Case 1, drawing D-12303). The purpose of this test is to determine the effect of the sharp corners on the local pressure conditions in the transition.

Test 7. Same as Test 3, except that the roller train will be moved forward on the Broome gate until the roller train seat and the gate seat will be in the same plane at the top of the gate (Case 2, drawing 12303). This completely eliminates the projecting sharp edges produced by the difference in slope between the roller train seat and the gate seat, and allows further streamlining of the sides of the transition.

Test 8. Measure pressure distribution in an outlet design using a fixed-wheel coaster gate similar to those for the Friant Dam outlets, closing in an emergency over a fully-developed circular bellmouth transition and with the Pelton Water Wheel Company 72-inch butterfly valve on the downstream end. This test is to evaluate the difference in pressure distribution between a rectangular bellmouth transition and a fully-developed bellmouth entrance.

All of these tests should be made with a wide range of operating head, so that the maximum allowable head could be determined in each case. The maximum allowable head should be that head which would produce not less than approximately one-half atmosphere of subatmospheric pressure at the point of lowest pressure in the outlet structure. This approach is proposed since the decision has not been made as to the future installation of outlets above Elevation 1340; therefore the maximum operating head on the Elevation 1340 outlets cannot be stated at this time.

5. In a letter of May 12, 1944, additional drawings and photographs requested while I was in Seattle were transmitted as follows:

Pelton Water Wheel Drawings: (photostats)

B-32729-43-03	Disc for 72-inch Butterfly Valve
C-32729-43-05	Disc Seat Ring for 72-inch Butterfly Valve

City Light Drawings:

D-12303	Schemes for Relocating Roller Path of 6' x 8' Broome Gates
D-13077	Details of Reinforcing Steel in Temporary Openings and Stub Steel and Keys for Future Valve House and Outlet Structure for Dam to Elev. 1365 (Revised 8-28-40)
D-13132-A	Plan for Extending 72-in. Steel Pipes in Diversion Tunnel and Installing Howell-Bunger Valves (Preliminary)
D-13196	Valve House at Downstream of Diversion Tunnel (Preliminary)
D-13217	Plan for Grouting Contraction Joints (Revised 2-29-44)
D-13242	Proposed Rectangular Bellmouth Transition for Relocated Intake at Elev. 1342.5

Two photographs RD2-143 and 144, were also enclosed, showing the upstream face of the openings at Elevation 1340. Drawing D-13217 was transmitted for another purpose and will be discussed in separate letter.

6. A rectangular bellmouth design for the transition has been adapted from the design of the Shasta power penstock intake bellmouth by the City Light engineers. Sketches (drawing D-13242) have also been prepared, showing new positions of the roller chain carriages as proposed for Tests 6 and 7.

7. According to the present design of the outlet structure, as shown on drawings D-13150-A and D-13168-A, the Broome gates are to operate in a gate chute 2' 4-1/2" wide by 8'5" long, extending in a straight line from the top of the future construction at Elevation 1650, down to approximately Elevation 1335 (Section A-A, drawing D-13168-A). Since the face of the dam is not vertical from top to bottom, the gate chute extends a maximum of five feet upstream from the face of the dam. Since it appears highly desirable to eliminate the slots with sharp corners in front of the penstock intakes, a logical revision would be to eliminate this gate chute all the way to the top of the dam, and substitute an embedded track in which guide hooks, attached to the Broome gate, could travel. This type of design has been used satisfactorily on Grand Coulee Dam and has been installed at Friant and Shasta Dams. This change of design will effect a considerable saving, due to the elimination of the gate chute and supporting structure. This change is discussed here because if it is made, it will affect favorably the position of the transition to the penstock, inasmuch as the gate seat will be moved downstream slightly, providing more room in the trashrack area.

8. The new 6- by 8-foot Broome gates, mentioned in paragraph 3, now being fabricated, will be placed in the bypass penstocks at Elevations 1250 and 1265, to replace the present gates, which will be moved to the Elevation 1340 outlets.

9. In his letter of April 6, Mr. Hoffman described damage in the bypass pipe at Elevation 1250, in which a large section in the crown of the pipe was torn and pulled down with several pitted areas around it. The size and location of the holes and pitted areas were shown on drawing D-13029-A. Traces of pitting by cavitation were also found in the bypass pipe at Elevation 1265. The torn section has been replaced and the pitted areas covered with 1/4-inch plates welded in place. These bypass pipes were inspected on April 28. Judging from the traces of pitting all through the pipes, it is evident that the pressure gradient throughout the pipes is very close to the vapor pressure of water. The reservoir is only partially filled at the present time. With a decrease in head should the reservoir be drawn lower, and a slight increase in the vapor pressure of the water, due to summer temperatures, the extent of the cavitation will increase. Since it is not contemplated that the extension of these pipes and the Howell-Bunger valves at the downstream end can be installed for some time, it is recommended that a constriction be placed on the end of each bypass pipe to raise the pressure gradient throughout the pipe, so that the maximum subatmospheric pressure will be approximately one-half atmosphere under the severest operating condition. This constriction should be the frustrum of a right cone to fit the present pipe, with an exit diameter of 4.5 feet and a length of 8.0 feet. The present pipes should be removed sufficiently far back so that the nozzles will not extend much farther out from the supports than the present pipe.

10. Computations show the pressure conditions in the two lower bypass conduits to be as indicated by the upper set of curves marked "existing design" on figure 1. For the range of heads available at the present time, the pressure conditions in both the upper and lower bypass conduits are sufficiently low to develop cavitation. With subatmospheric pressures of this magnitude existing initially in the conduit, pitting resulting from cavitation, is aggravated by the slightest change in section, roughness in the conduit, or protrusion at a joint. This is evident from drawing D-13029-A which shows pitting as most severe in localized areas. The minimum pressures to be expected with the nozzle on the end of each conduit are shown in the upper graph of figure 1. Pressures as low as one-half of an atmosphere can still exist in the upper conduit for very low heads. It was not thought advisable to constrict the nozzle any farther as the 4.5-foot diameter reduces the discharge of the outlets some 40 percent compared with the existing bypass layout.

11. While it has not been mentioned in previous correspondence,

the question was discussed in the conferences in Seattle and at Ross Dam, as to the spray conditions which will occur with the Howell-Bunger valves discharging into the atmosphere without shields. The arrangement of the valves according to the present proposal is shown on drawings D-13196 and D-13132-A. One solution is the installation of shields as developed by the S. Morgan Smith Company to form a jet of the water from the valves. However, there will still be a detrimental amount of spray which will cause bad icing conditions in the area immediately below the dam in the winter season. Another solution considered during my visit and which appears to have considerable merit, is to place the valves so that they will discharge under water. If the centerline of the valves were placed at approximately Elevation 1192 there would be from 5 to 10 feet of water over the top of the valves depending upon the stage of the Diablo Reservoir. The only apparent fault at this time is the possibility of adverse pressures on the stationary part of the valve seat. To check this feature and to study the action of the valve when submerged, a model is proposed as discussed with Mr. Wolfendale. That study has been included in contract which is being prepared for execution. It is proposed, however, to have the studies for the Elevation 1340 outlets have precedence over the lower bypass valve studies as the former are more urgently needed.

12. A computation has been made of the pressure conditions in the lower bypass conduits after the Howell-Bunger valves are installed. The minimum expected pressures in the conduits after completion are as shown in figure 1. A coefficient of discharge of 0.90 has been assumed for the valves and it has been assumed that the valves are discharging submerged. The pressures in the lower outlet of this installation will be satisfactory for any reservoir water surface although they can approach one-half of an atmosphere for very low reservoir elevations. Minimum pressures in the upper outlet, however, will approach absolute zero with low water surfaces in the reservoir. In that case, an operating restriction should be established whereby the valve on that conduit will be throttled when the reservoir water surface drops below Elevation 1300. These conclusions have been based entirely on the assumption of a coefficient of discharge of 0.90 based on the area of the conduit upstream from the valves. That coefficient is not certain at the present time. This coefficient will be determined during the course of the studies on the performance of the valve with a shield as proposed by S. Morgan Smith, discharging submerged, and with free discharge. If the shields are installed, the pressure conditions in the conduits should be improved due to the increase of friction loss in the installation. Discharge curves for the ultimate bypass installation are shown on figure 1. These show lower discharges than the curves on City Light

drawings D-1635 and D-1685B for equivalent heads.

- - -

J. E. Warnock

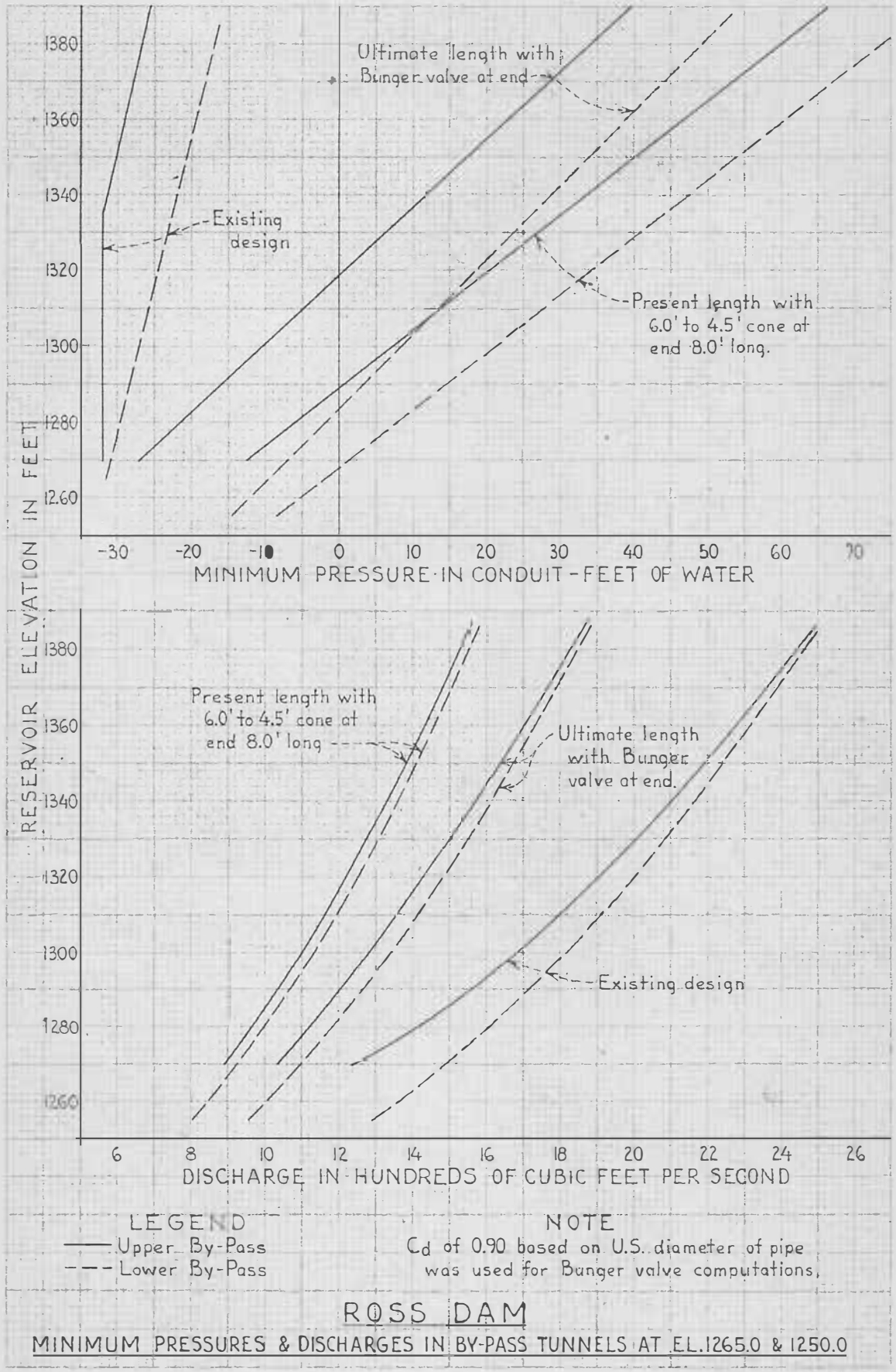
Approval recommended:

(Sgd.) R. F. Blanks

Approved:

(Sgd.) S. O. Harper

FIGURE 1

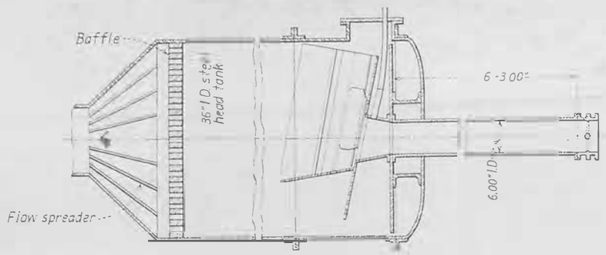


ROSS DAM

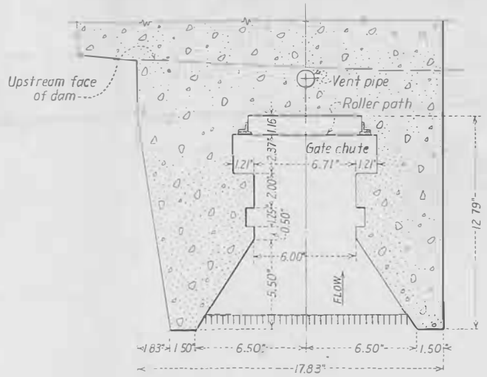
MINIMUM PRESSURES & DISCHARGES IN BY-PASS TUNNELS AT EL.1265.0 & 1250.0

Smith-Brooks Ptg. Co., Denver

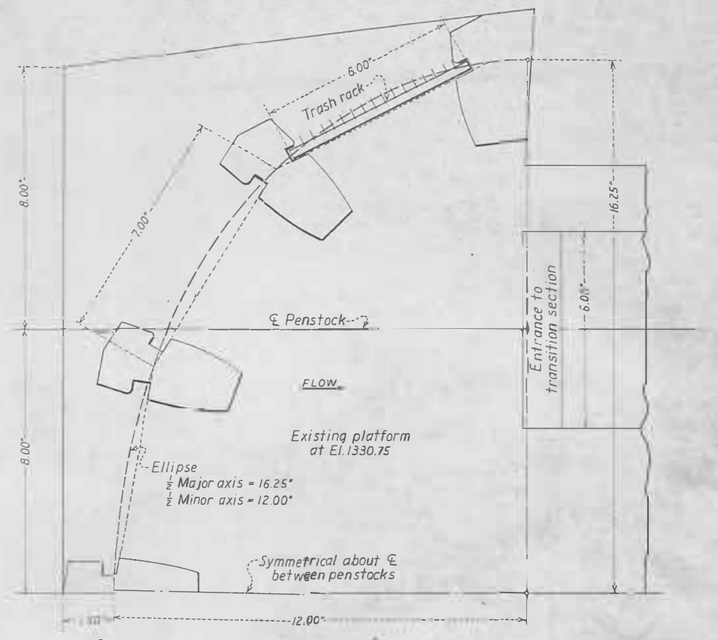
HYD-157



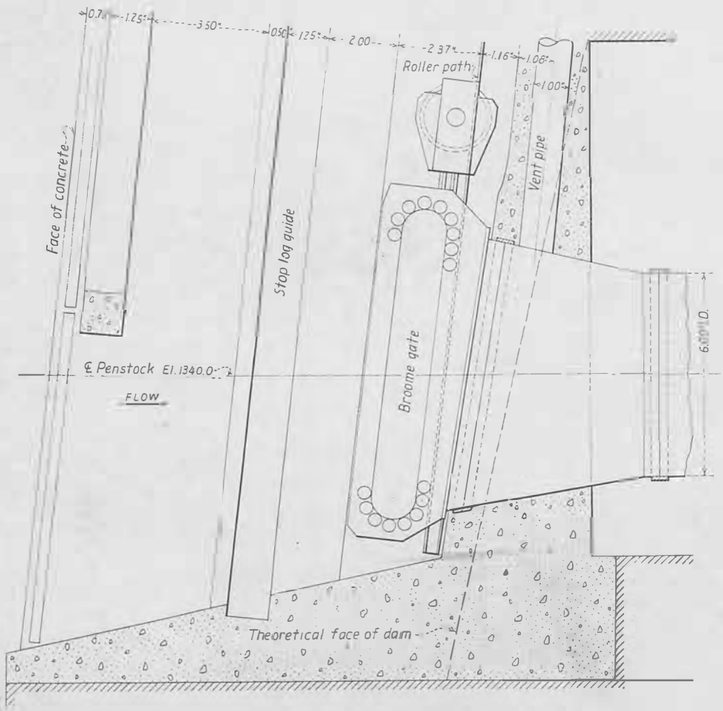
A. MODEL ASSEMBLY
ORIGINAL TRASH RACK WITH PHILIPS AND DAVIES TRANSITION



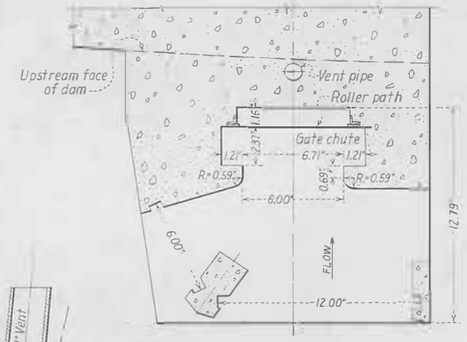
B. SECTION SHOWING ORIGINAL TRASH RACK IN PLACE



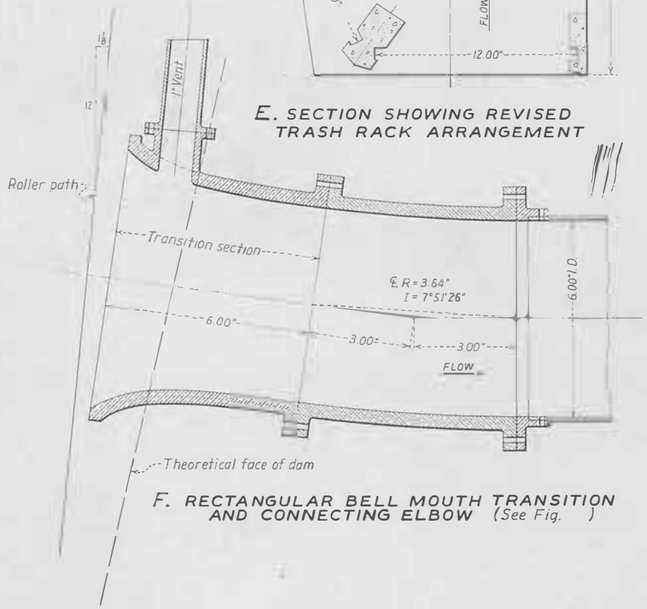
C. PLAN OF TRASH RACK ACCOMPANYING RECTANGULAR BELL MOUTH TRANSITION



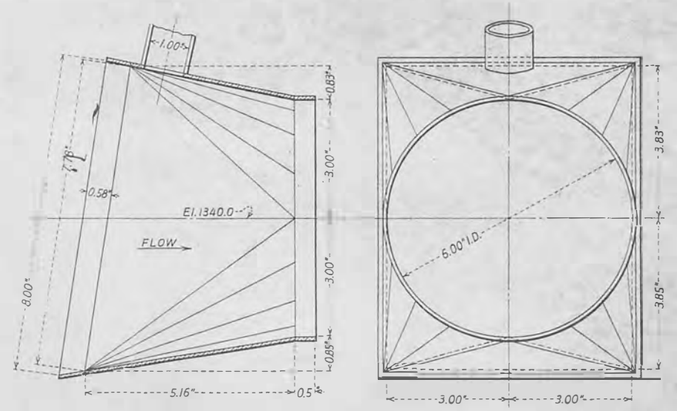
D. SECTION SHOWING BROOME GATE AND TRANSITION IN PLACE
BROOME GATE DETAILS SHOWN ON FIGURE



E. SECTION SHOWING REVISED TRASH RACK ARRANGEMENT



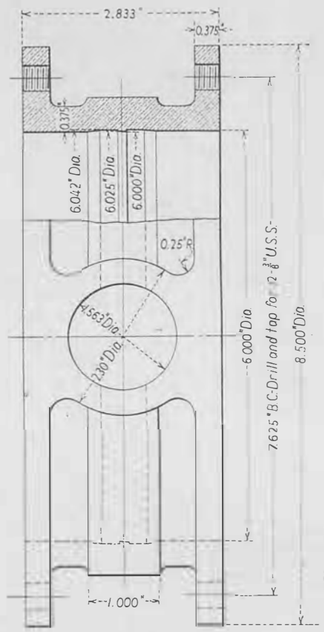
F. RECTANGULAR BELL MOUTH TRANSITION AND CONNECTING ELBOW (See Fig.)



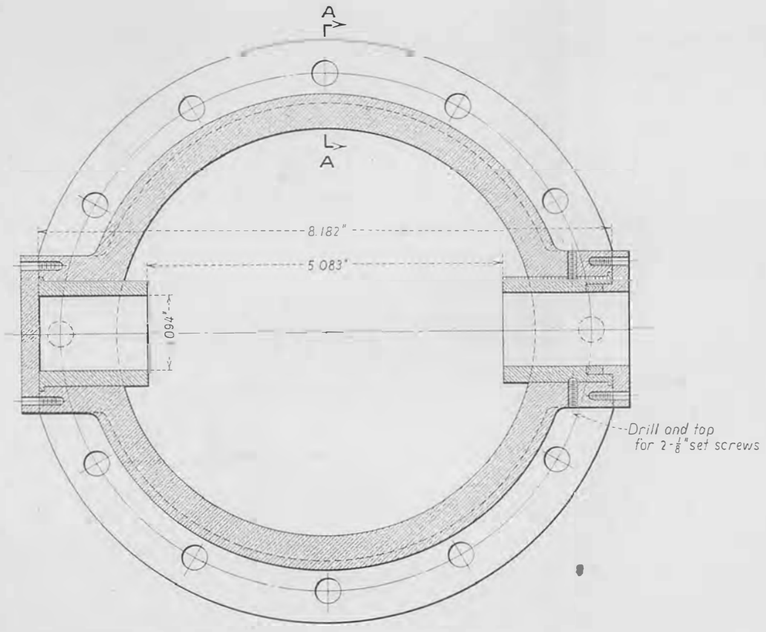
G. PHILIPS AND DAVIES TRANSITION

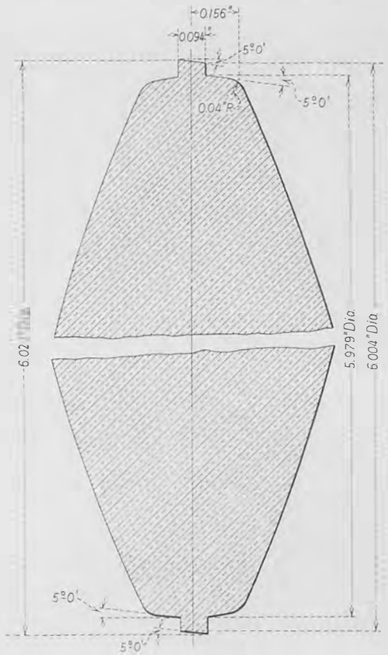
ROSS DAM - SECOND STEP
ASSEMBLY AND DETAILS OF NEAT LINES OF WATER PASSAGES FOR 6" HYDRAULIC MODEL

H-VO-157

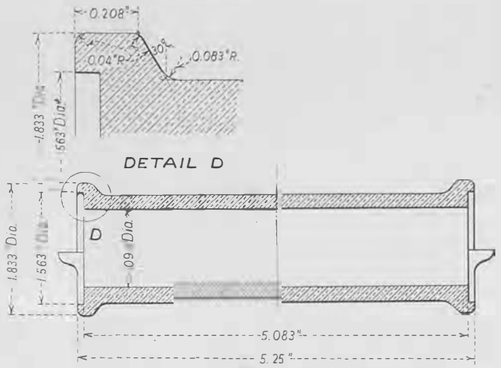


VALVE BODY

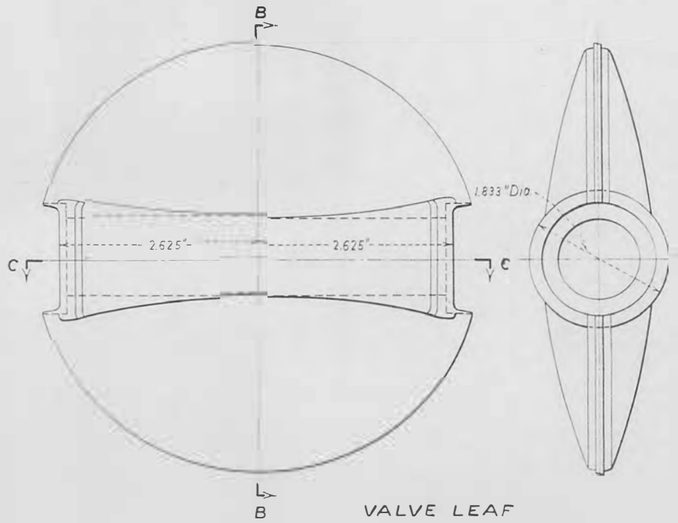




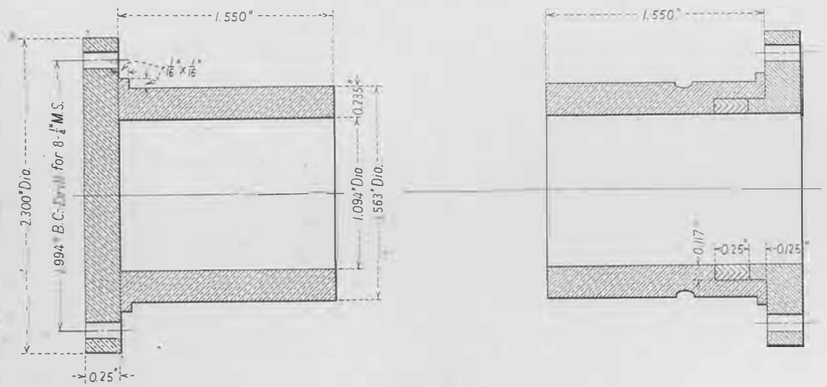
SECTION B-B



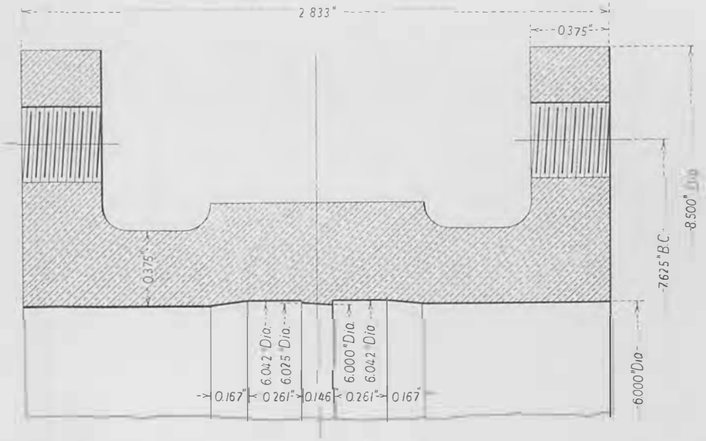
SECTION C-C



VALVE LEAF



BEARINGS



SECTION A-A

ROSS DAM - SECOND STEP

BUTTERFLY VALVE
6" HYDRAULIC MODEL DETAILS

TR. J.E.O.L.

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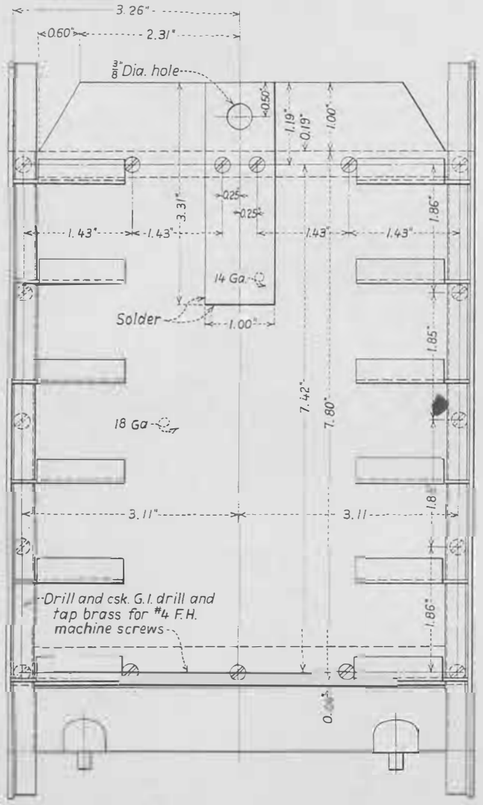
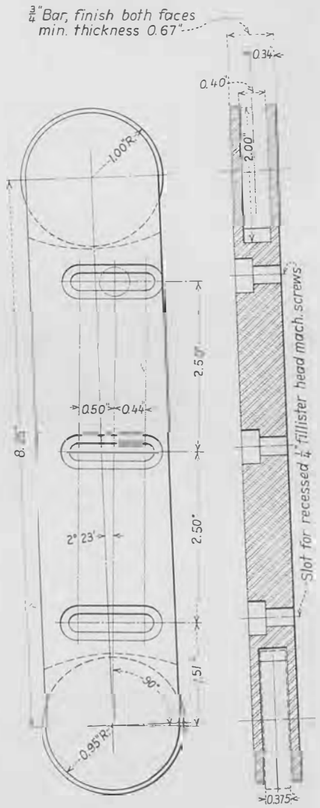
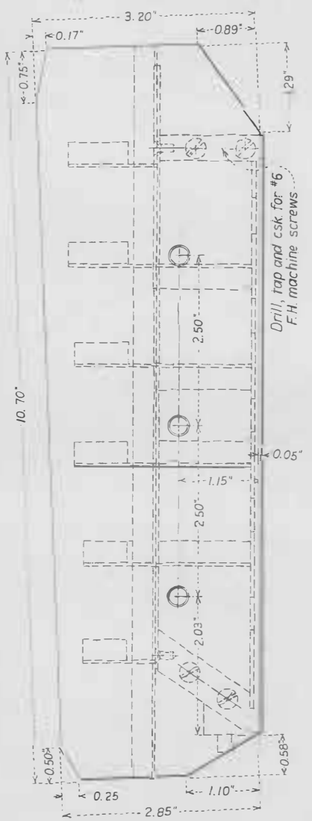


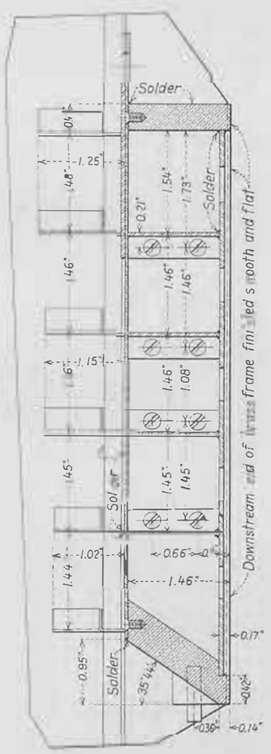
UPSTREAM ELEVATION



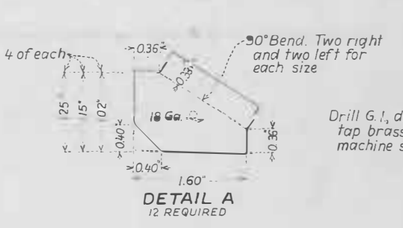
ROLLER GUIDE
ONE REQ'D. AS SHOWN
ONE REQ'D. OPP. HAND



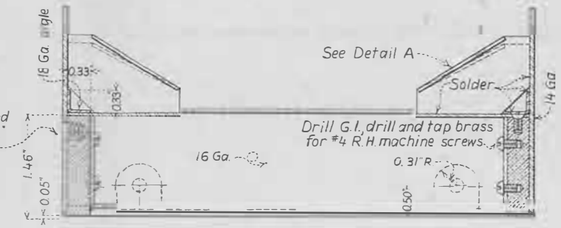
SIDE ELEVATION



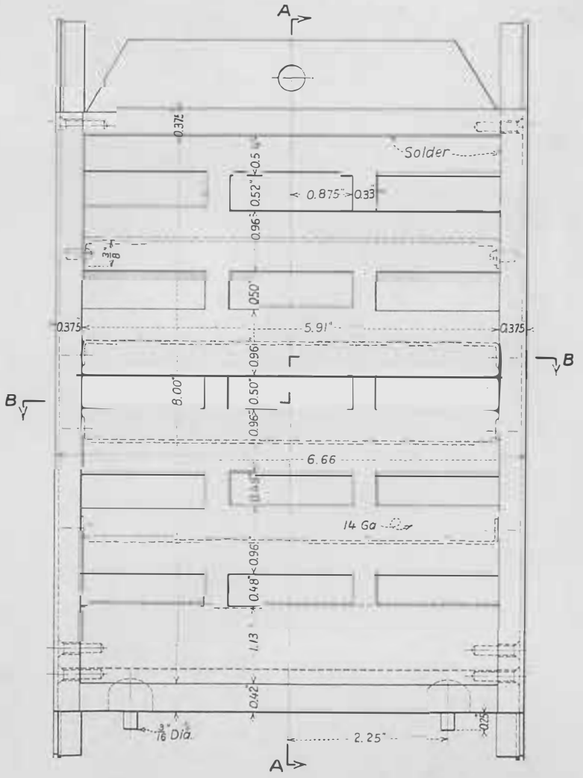
SECTION A-A



DETAIL A
12 REQUIRED



SECTION B-B



DOWNSTREAM ELEVATION

ROSS DAM
6' x 8' BROOME GATE
1:12 SCALE HYDRAULIC MODEL

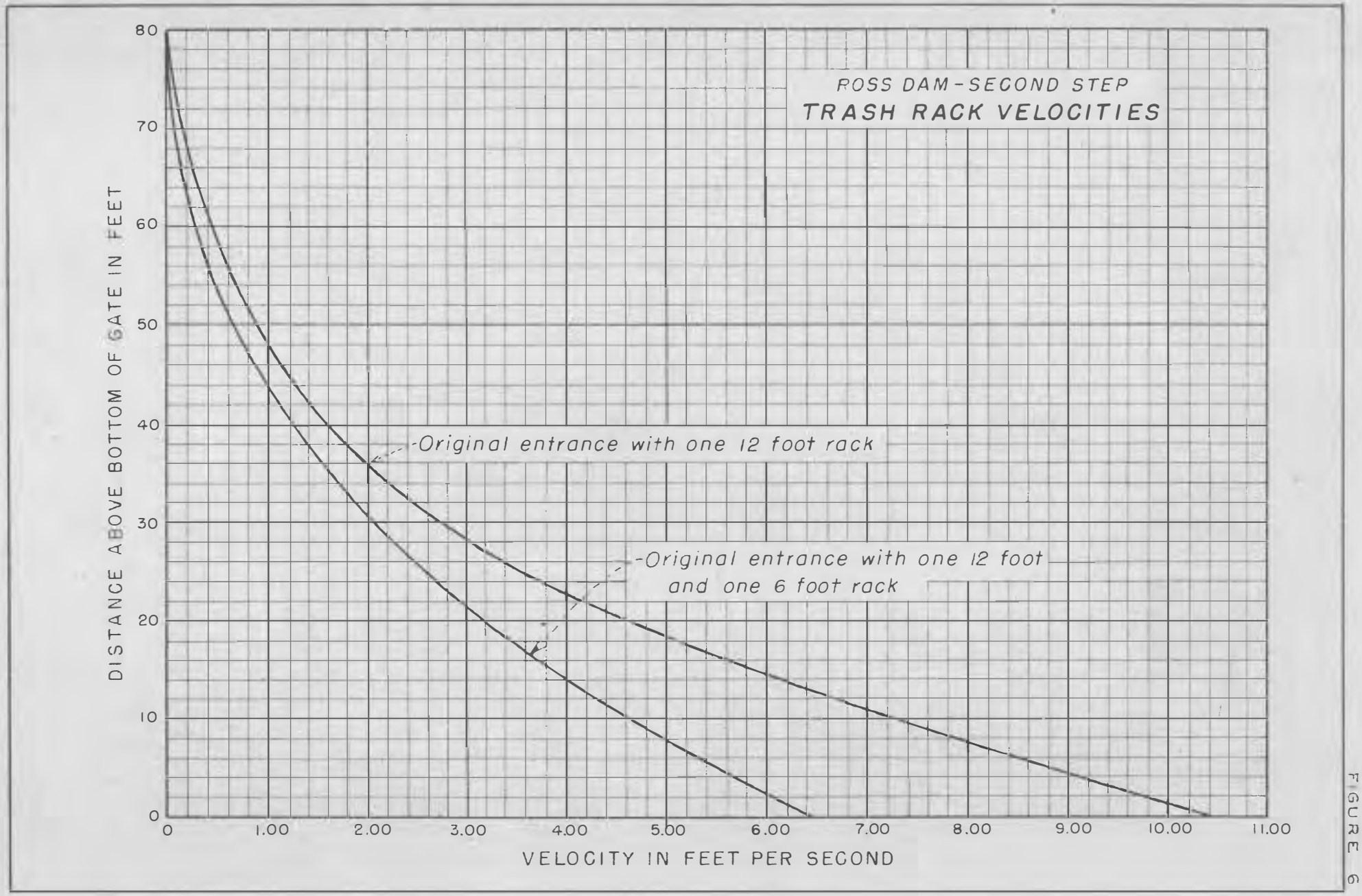

ROSS DAM - SECOND STEP
TRASH RACK VELOCITIES
Original entrance with one 12 foot rack
Original entrance with one 12 foot and one 6 foot rack
DISTANCE ABOVE BOTTOM OF GATE IN FEET
VELOCITY IN FEET PER SECOND
0
10
20
30
40
50
60
70
80
0
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00

FIGURE 6

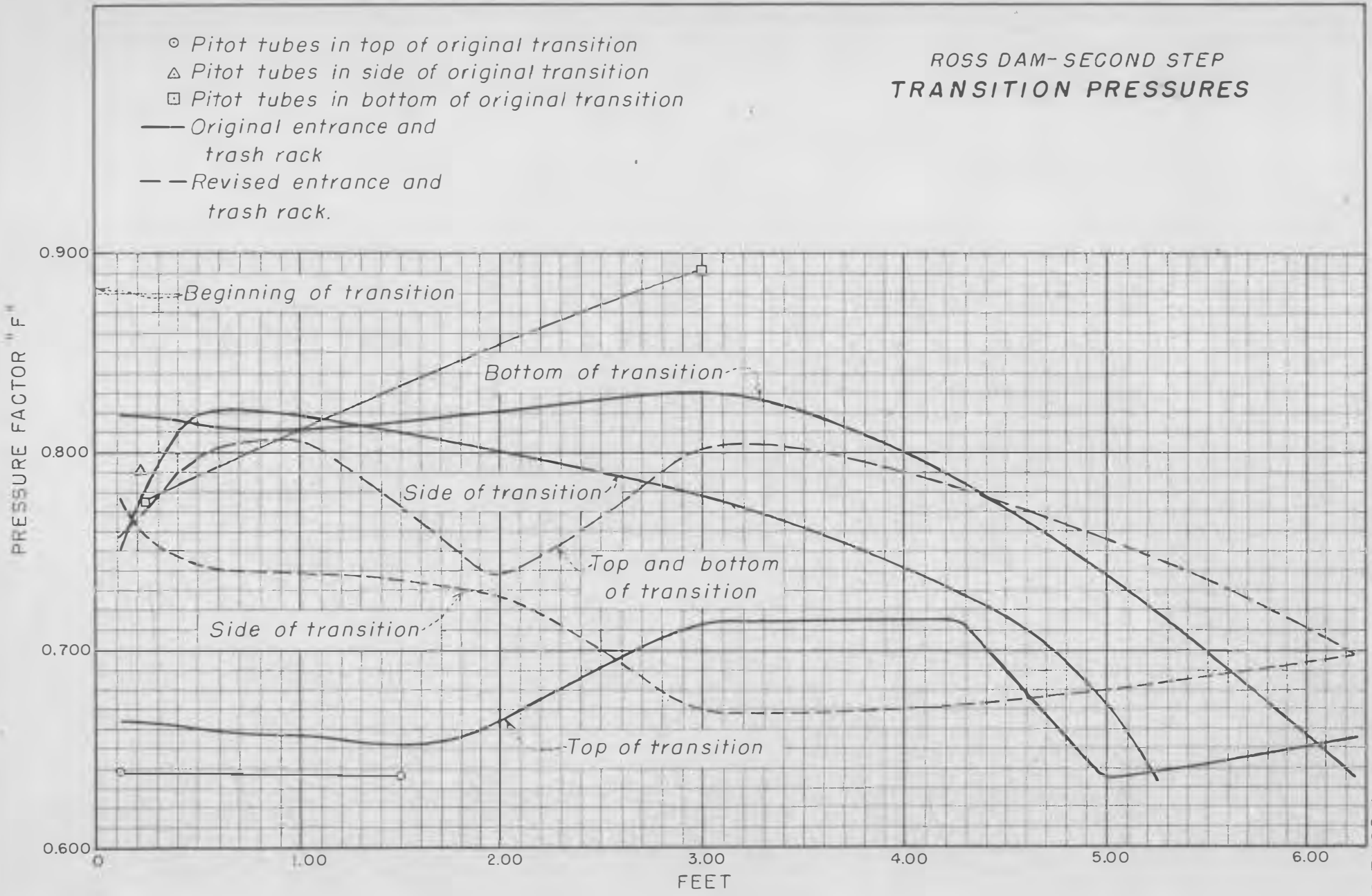

⊙ Pitot tubes in top of original transition
△ Pitot tubes in side of original transition
⊡ Pitot tubes in bottom of original transition
—— Original entrance and trash rack
– – Revised entrance and trash rack.
ROSS DAM- SECOND STEP
TRANSITION PRESSURES
PRESSURE FACTOR "F"
0.900
0.800
0.700
0.600
Beginning of transition
Bottom of transition
Side of transition
Top and bottom of transition
Side of transition
Top of transition
0
1.00
2.00
3.00
4.00
5.00
6.00
FEET

FIGURE 5

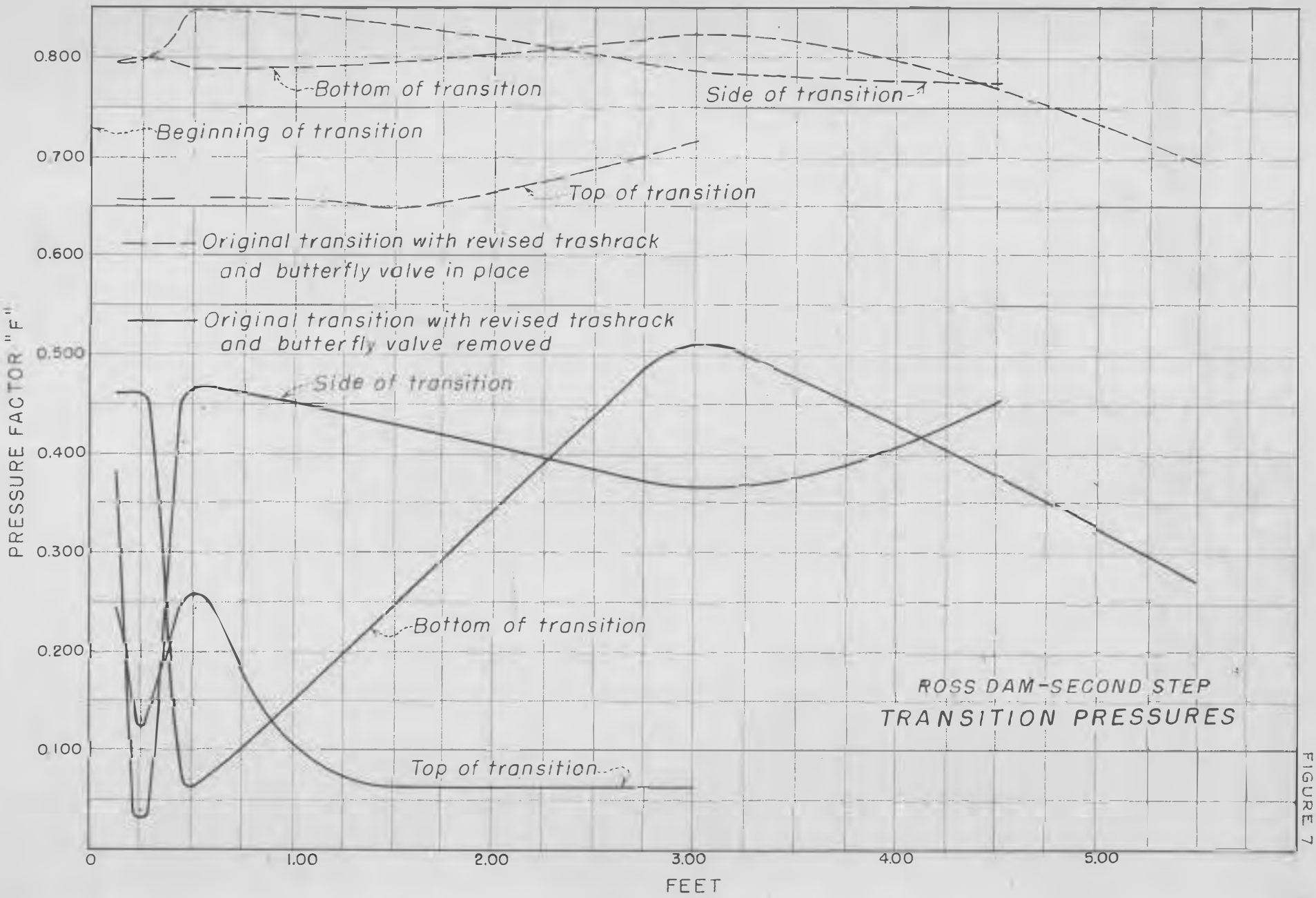
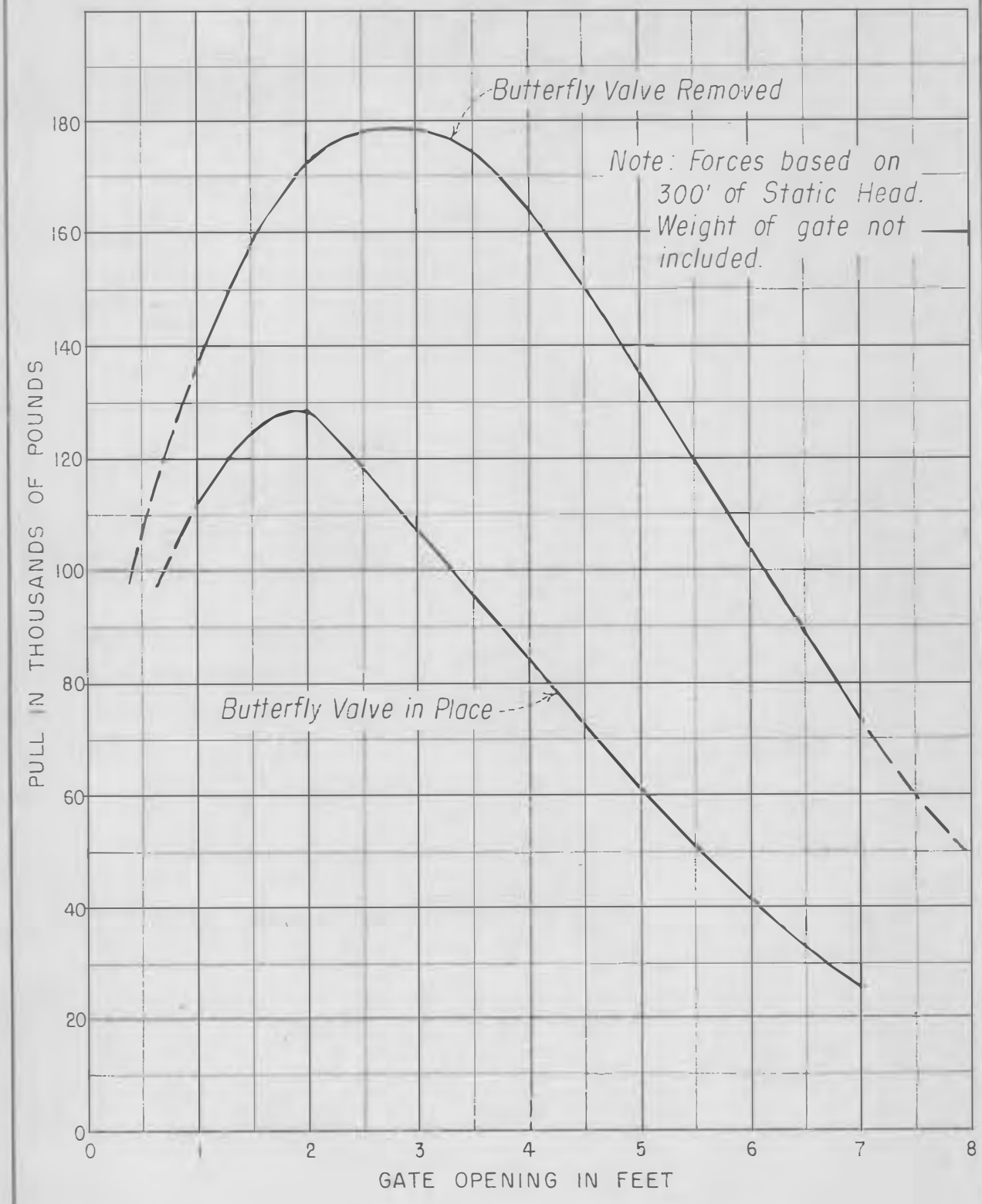

0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
PRESSURE FACTOR "F"
Bottom of transition
Beginning of transition
Side of transition
Top of transition
Original transition with revised trashrack and butterfly valve in place
Original transition with revised trashrack and butterfly valve removed
Side of transition
Bottom of transition
Top of transition
ROSS DAM-SECOND STEP
TRANSITION PRESSURES
0
1.00
2.00
3.00
4.00
5.00
FEET

FIGURE 7



HYDRAULIC DRAWDOWN FORCES
PHILIPS AND DAVIES GATE AND TRANSITION

HYD-157

SECTION	a	b	c	d	e	f	g	h	i	j	k
DIST FROM FACE	0.050	0.285	0.400	0.600	0.800	1.000	1.400	1.800	2.200	3.000	3.800
HEIGHT	7.728	7.278	7.140	6.948	6.796	6.668	6.462	6.308	6.192	6.046	6.000
SEMI-MINOR AXIS	0	0.400	0.570	0.800	1.000	1.200	1.450	1.700	1.950	2.360	3.000

ROSS DAM – SECOND STEP

RECTANGULAR BELLMOUTH ENTRANCE
6" HYDRAULIC MODEL DETAILS

FIGURE 9

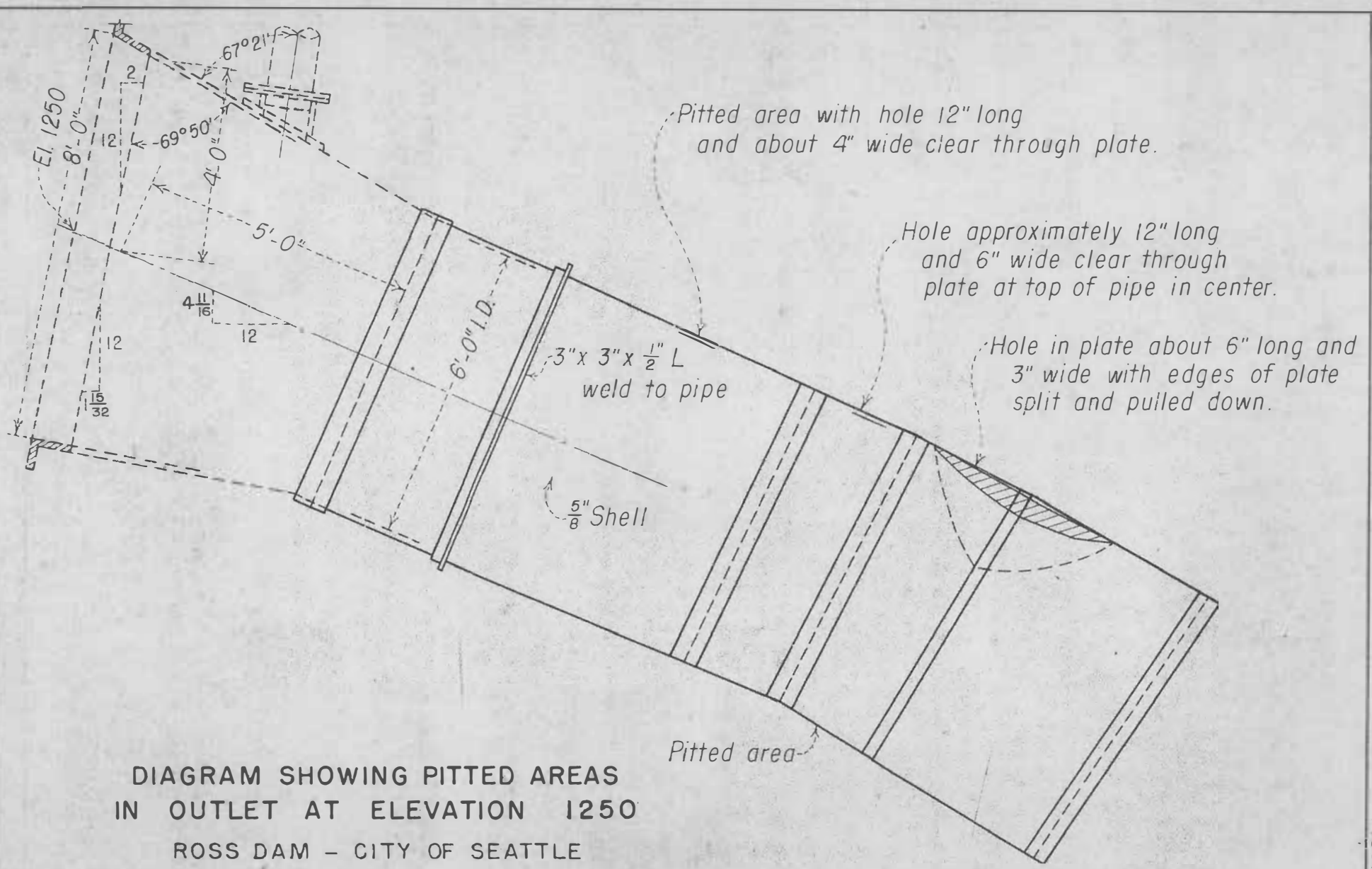


DIAGRAM SHOWING PITTED AREAS
IN OUTLET AT ELEVATION 1250
ROSS DAM – CITY OF SEATTLE

FIGURE 11

FIGURE 10

CAVITATION SPECIMEN FROM ELEV. 1250 OUTLET