UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 156

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LABORATORY STUDY OF A 6-INCH HOWELL-BUNGER VALVE
ROSS DAM - CITY OF SEATTLE, WASHINGTON

by

FRED LOCHER and J. N. BRADLEY

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Denver, Colorado,
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ROSS DAM - CITY OF SEATTLE, WASHINGTON

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By FRED LOCHER, ASSOCIATE ENGINEER
and
J. N. BRADLEY, ENGINEER

- - -

Under direction of

J. E. WARNOCK, SENIOR ENGINEER
and
R. F. BLANKS, SENIOR ENGINEER

- - -

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UNITED STATES
DEPARTMENT OF THE INTERIOR
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Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
October 14, 1944

Laboratory Report No. 156
Hydraulic Laboratory
Compiled by: Fred Locher
J. N. Bradley
Reviewed by: J. E. Warnock

Subject: Laboratory study of a 6-inch Howell-Bunger valve - Ross Dam, City of Seattle, Washington.

1. Purpose of investigation. Acting upon a request of the city of Seattle, a model of a 72-inch Howell-Bunger valve on a scale of 1:12 was constructed and tested in the hydraulic laboratory of the Bureau of Reclamation. It was desired to determine the operating characteristics relative to the installation of two of these valves at the downstream end of the lower outlet conduits at Ross Dam. The proposed location of the valves is shown on figure 1. The scope of the investigation involved the determination of pressure conditions and discharge coefficients for three conditions of operation: namely, (1) valve without hood, discharging freely into the atmosphere; (2) same valve with confining hood installed downstream, discharging into the atmosphere; and valve without hood, discharging submerged.

The above three conditions of operation are under consideration for the lower outlets shown on figure 1. In the first case the valves would be located as shown. The valve locations would be the same in the second case except that hoods would be installed on the downstream ends of the valves. In the third case consideration was given to eliminating the rise in the outlet conduits, shown on figure 1, by continuing them on the same grade. In this case the valves would be installed submerged, without hoods, and with center lines at about elevation 1191.3.

2. The model. The model consisted of a 6-inch diameter, bronze, cast valve machined on the inside to exact scale dimensions. A photograph of the model valve is shown in figure 2, and details of valve and

hood are shown on figures 3 and 4. For observing pressure conditions, three piezometers were installed in the valve gate, eleven along the contour of the hood, and one in the valve seat, as shown in the half horizontal section of figure 5.

The drawings furnished by the S. Morgan Smith Company were lacking in details concerning the shape of the downstream end of the valve gate. For this reason the details of this part, as used on the model, are shown on figure 3, detail A. The same figure shows the position of the valve sleeve with respect to the seat for 100 percent opening, as indicated by the drawings furnished.

3. Results of tests on valve, without hood, discharging into the atmosphere. A coefficient-of-discharge curve, plotted with respect to gate opening, for the valve discharging into the atmosphere is shown on figure 5. The coefficient in each case was computed as follows:

$$C = \frac{Q}{A\sqrt{2gH}}$$

in which

Q = discharge in second-feet,

A = area of the pipe upstream from valve, in square feet,

H = total head (pressure plus velocity head in feet of water) measured in pipe immediately upstream from valve. In cases of submerged flow, H = pressure plus velocity head measured in pipe immediately upstream from valve, minus submergence, in feet of water.

Model scale heads were ignored in these tests. The valve was operated under the maximum head obtainable in the laboratory. At full opening the coefficient of discharge was 0.343. Literature from the S. Morgan Smith Company states that coefficients as high as 0.96 have been obtained for Howell-Bunger valves operating under this condition, and the company recommends that a maximum coefficient of 0.90 be used for design purposes. While it is known that the coefficients of discharge obtained with models are not as high as those obtained with the prototype,

this does not explain the large difference between the model results and those claimed by the manufacturers. There may be some difference between the model and the prototype in the downstream end of the valve gate; however, any variation here would not change the coefficient more than 2 percent, which is a small part of the difference between 0.84 and 0.96. At the present time it appears that there is no logical explanation for the difference.

The pressure conditions at piezometer 2 for the valve discharging into the atmosphere without the hood are shown on figure 5. Piezometer 1 showed atmospheric pressure throughout the test, but no subatmospheric pressures were recorded at piezometers a and b, indicating that from a pressure viewpoint the valve was entirely satisfactory. A cone-shaped jet having a total central angle slightly less than 90 degrees issues from this type of valve, producing very effective dissipation of energy. The disadvantage in using the valves in this manner at Ross Dam is that the spray from the valves will disperse into the atmosphere. During the winter season the formation of ice on various parts of the dam and other structures would probably present a very serious maintenance problem. In addition, transformers and other outdoor electrical equipment near the dam might require special moisture protection.

4. Results of tests on valve, with hood, discharging into the atmosphere. Tests similar to those described in the previous section were made on the valve with the hood installed on the downstream end (figures 2 B and 3). The coefficient-of-discharge curve for this condition of operation is shown by the full line on figure 5. The curve practically coincides with the one described in section 3 up to a valve opening of 60 percent. From this point on, the slope of the latter curve is less, a result of back pressure created by the hood during the higher discharges. The coefficient obtained for the valve fully open, operating with the hood in place, was 0.67.

The pressure distribution at the various piezometer locations in valve and the hood are shown by the full lines on figure 5. Piezometer

1 indicated atmospheric pressure throughout the test. Piezometers a, b, 2, and 3 showed subatmospheric pressures between 30 and 80 percent of full opening with the most severe pressures occurring between 50 and 60 percent of full opening. The negative pressures at these openings are such that the valve should not be operated in this range when the reservoir head exceeds 100 feet. Higher heads will produce cavitation and the resulting pitting. This condition does not prohibit the use of the valve with the hood at higher heads if the valve is operated at openings zero to 30 percent or from 80 to 100 percent of full opening. In these ranges all pressures will be positive, or the negative pressures that do exist will not be serious.

The model tests have shown two disadvantages to operation of the valve with hood, discharging into the atmosphere: (1) a reduction in the coefficient of discharge at full opening and (2) limitation of the head that can be applied on the valve without producing destructive negative pressures. A third and important difficulty which would be experienced with the use of the hood is the unbalancing of the valve. This produces an appreciable thrust which acts opposite to the direction of flow. The magnitude of the force has been computed by integrating the results of the pressure measurements in the valve and the hood. These values have been reduced to the force on a 12-inch valve, under a one-foot head, to simplify the computation of the thrust on a valve of any diameter. The prototype thrust was obtained from the formula

$$T = n^2 Ht$$

where

n = valve diameter in feet,

H = total head, in feet of water, on the valve one diameter upstream from the valve,

t = a thrust value selected from figure 6 for a particular valve position.

The maximum unbalanced thrust is quite large and amounts to approxi-

mately 94,250 pounds per 100 feet of head on a 72-inch valve, which indicates that in the design of the operating mechanism ample provision should be made for this force.

A fourth disadvantage to the valve and hood arrangement, though minor, is that the hood is cantilevered out from the valve sleeve without any other support. Vibration of the valve would be accentuated in the hood which, in turn, would transmit the accentuated vibration back to the valve, operating mechanism, and outlet pipes. It appears that this may also be detrimental to the screws and the bevel gears in the operating equipment.

5. Results of tests on valve, without hood, discharging submerged. These tests were made with the valve submerged sufficiently to keep the jet from breaking the water surface. The coefficient-of-discharge curve for operation under this condition is shown by the dotted line on figure 7. The curve nearly coincides with the curve described in section 3 in which the operation differs only in that the valve was discharging freely into the atmosphere in the first case and discharging submerged in the latter case. This agreement was expected.

The pressures obtained with this arrangement indicate negative pressures on the valve gate and the seat of such a magnitude that cavitation and the resulting pitting will occur unless the operation is limited to very low heads or the gate be operated only between 50 and 70 percent of full gate opening, in which case the head limitation is 200 feet of water (figure 7). The pressure inside the jet and downstream from the valve is extremely low, and considerable noise and disturbances in the jet can be expected from this source.

It appears that 20 feet of submergence will be required to keep the jet from breaking through the water surface. This depth of submergence is not practical at Ross Dam. However, even with this submergence the jet was not stable and there were objectionable eddies which could cause considerable scour of erodible material. The instability of the jet can

be remedied by admitting air to its inner portion; however, this aeration will not relieve the negative pressures on the valve.

6. Results of tests on valve, with hood installed, discharging submerged. As a matter of record only, the valve with hood installed was operated submerged. The results, shown on figure 7, eliminate this type of operation. Extremely low negative pressures are indicated at piezometers 2, 3, and 7, with moderate subatmospheric pressure at piezometer 1. As a result of these negative pressures, the coefficient was raised from 0.67 (figure 5) to 0.78 (figure 7) for the submerged flow on the model. It is repeated that the results of this arrangement have no value except as a matter of record.

7. Preparation of the data on pressure and discharge characteristics. In figures 5 and 7 the pressure factor F is plotted against percent of full valve opening. The pressure factor was defined as the ratio of the measured piezometer pressure to the total head (static head plus velocity head) one inlet diameter upstream from the valve. This procedure reduces F to a dimensionless number, making it possible to obtain the pressure at a point on the valve by selecting from the curves the correct value of F and multiplying it by the total head on the valve one diameter upstream from the inlet. As an example, to find the pressure at piezometer a when the total head is 200 feet of water and the valve is 26 percent open, follow the 26-percent line until it intersects curve Pa, figure 7, and read the value of the pressure factor at the left which, in this case, is −0.38. Multiply 200 times −0.38 and the resulting pressure is −76.0 feet of water. As this pressure is unattainable, the result indicates that the vapor pressure of water will exist in the prototype and pitting due to cavitation may be expected with heads of this magnitude.

It has been found that if the scaled value of the pressure at any point extends below the vapor pressure, it is not possible by the above method to predict with accuracy the correct pressure at any point in the prototype for the particular head and valve position in question.

However, this does not preclude the use of the data at any other valve position or head where none of the scaled results exceeds the vapor pressure of water.

The details concerning the method for computing the thrust on a valve are contained in hydraulic laboratory report No. 148, "Model studies for the development of the hollow jet valve - Anderson Ranch Dam."

8. Conclusions. Positive pressures will exist on all parts of the valve for free discharge into the atmosphere without the hood attached. For these conditions, the maximum coefficient of discharge is 0.843 at approximately 92.6 percent of full gate travel.

The severity of the negative pressures and the instability of the jet when the valve is discharging submerged, without the hood, make it impractical to use the valve in this manner. The same limitations apply when the valve is discharging submerged, with the hood in place.

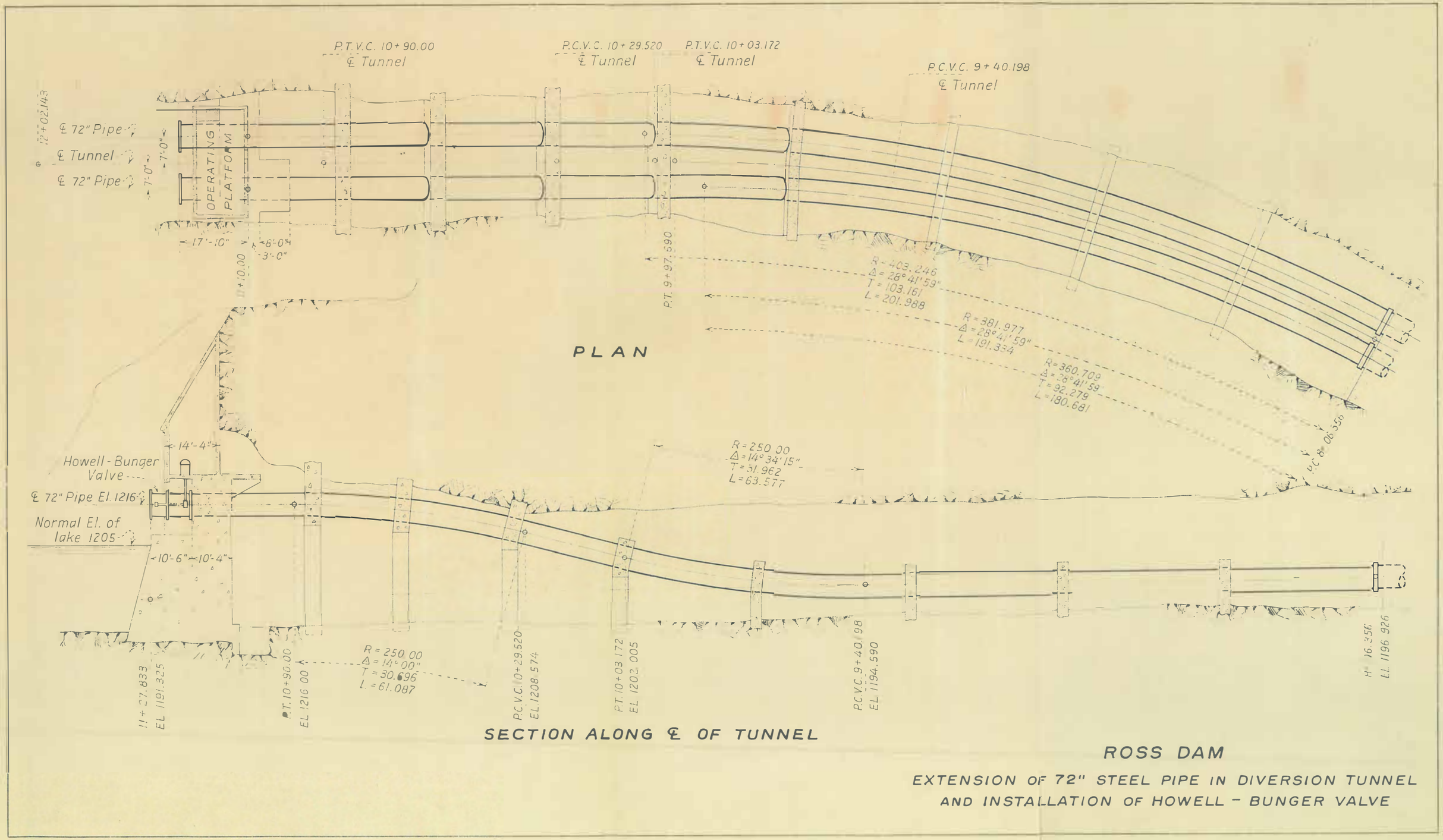
The valve discharging freely into the atmosphere, with the hood in place, should not be operated with heads of more than 125 feet of water between openings of 30 to 80 percent of full gate. The valve may be operated continuously at any head between openings of zero to 30 percent and from 80 to 100 percent of full gate. The maximum coefficient of discharge is 0.670 with the hood in place and it was obtained at approximately 92.6 percent of full gate travel.

The maximum unbalanced thrust for a 72-inch valve with the hood in place is approximately 94,250 pounds per 100 feet of total head. Ample provision for this thrust should be embodied in the design of the valve operating mechanism.

The jet emitting from the valve without the hood spreads at an angle of somewhat less than 45 degrees with the center line of the valve, figure 8, and causes a considerable amount of spray and fog which would be objectionable if the valve were near transformers or other

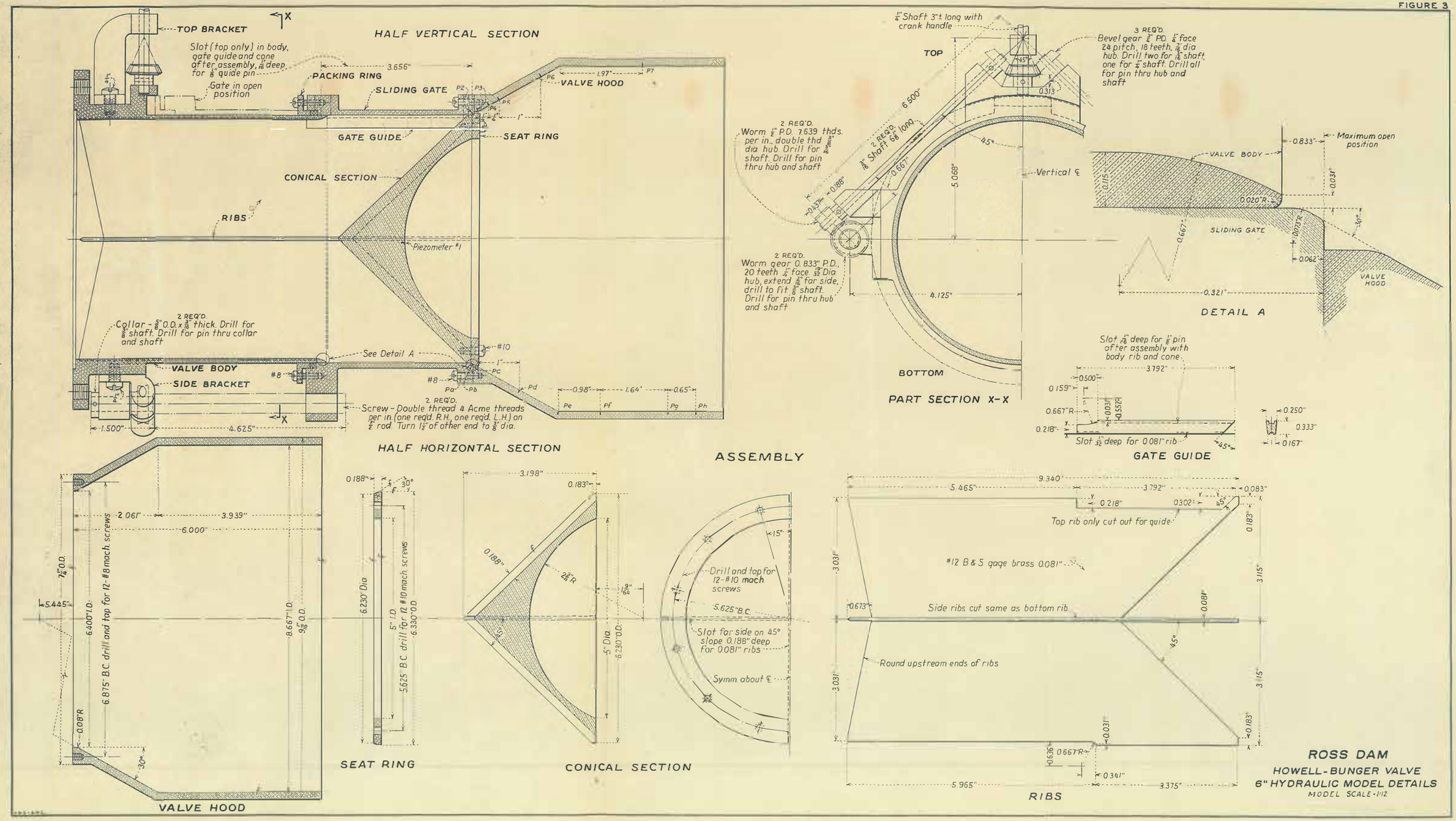
electrical equipment. In cold climates the resulting ice which would form from the spray might also be a serious hazard.

The use of the hood confines the jet and eliminates practically all of the spray (figure 8).



ROSS DAM

EXTENSION OF 72" STEEL PIPE IN DIVERSION TUNNEL AND INSTALLATION OF HOWELL - BUNGER VALVE

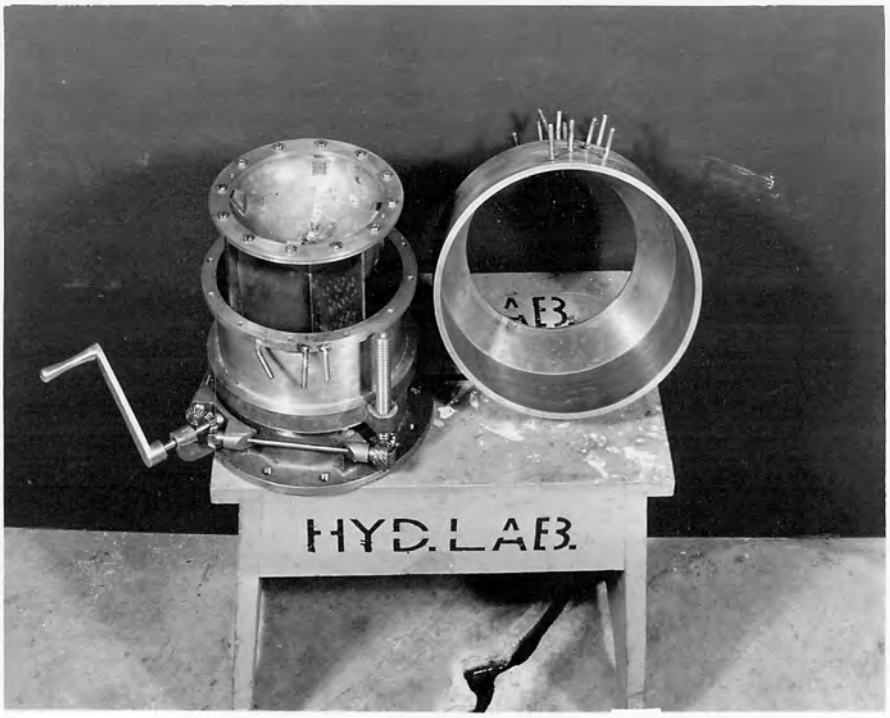


ROSS DAM

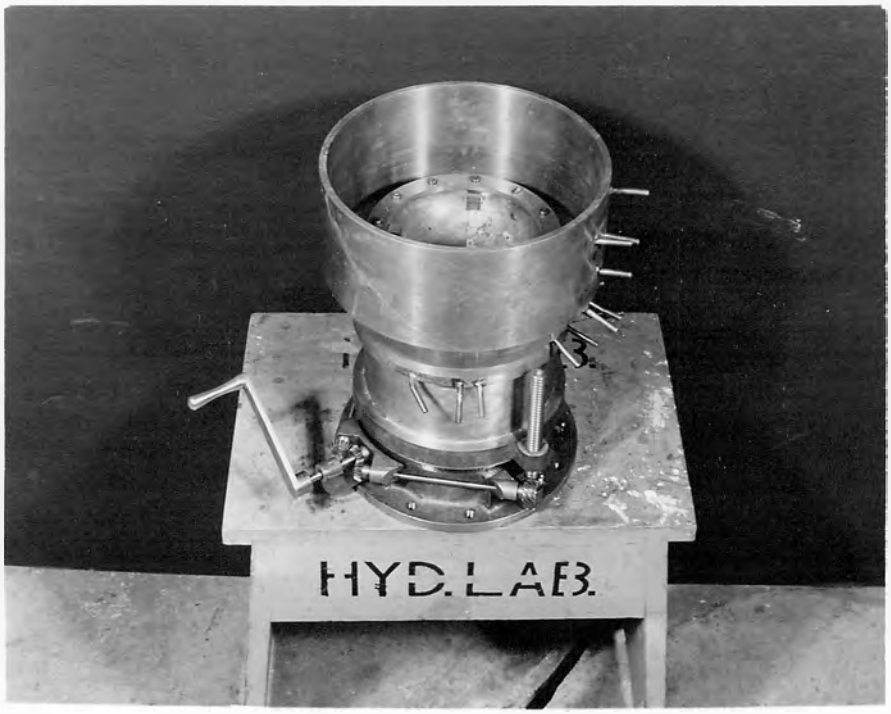
HOWELL-BUNGER VALVE

6" HYDRAULIC MODEL DETAILS

MODEL SCALE - 1:12



A - Valve and Hood



B - Hood in place

6-INCH HOWELL-BUNGER VALVE

FIGURE 4

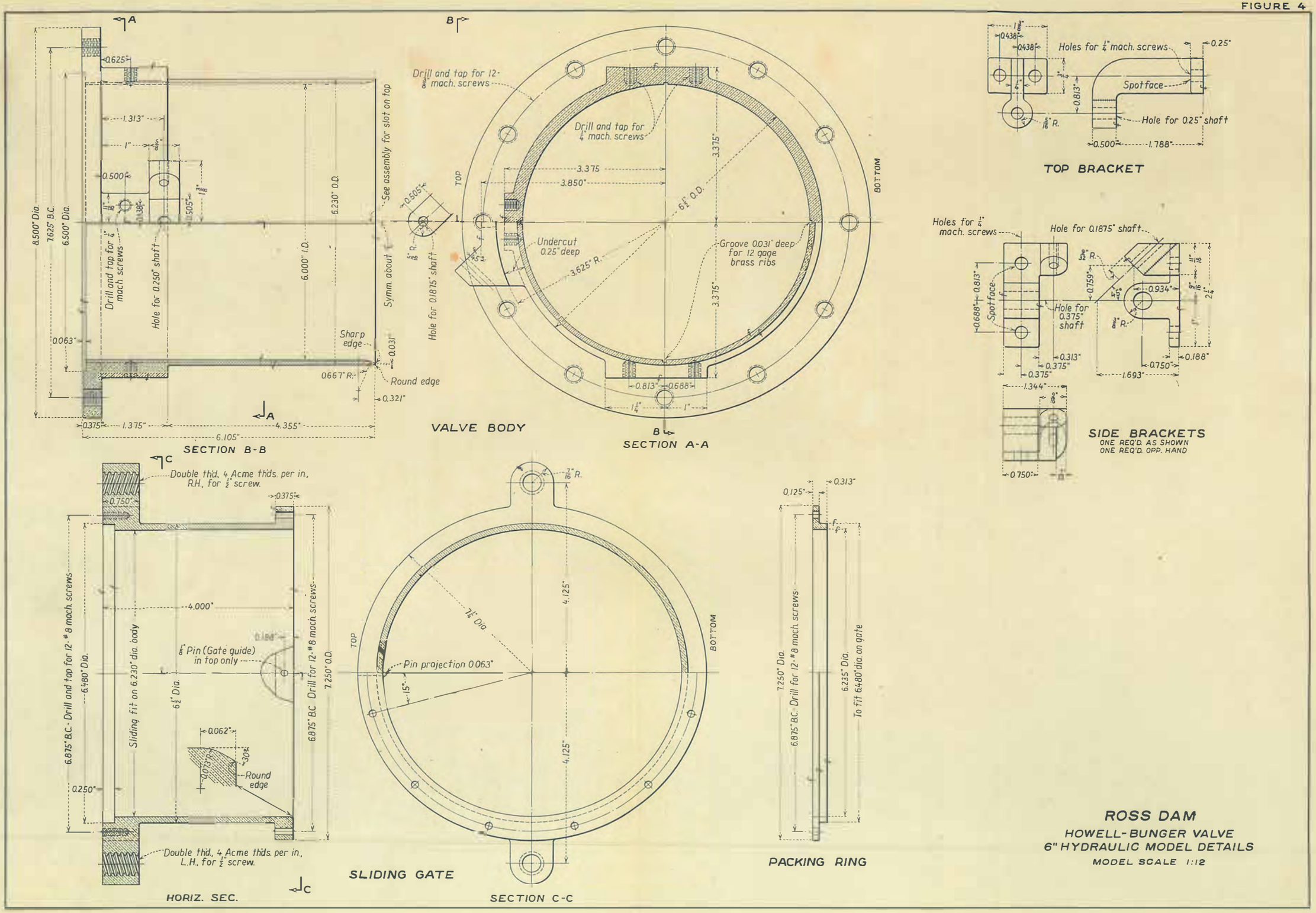
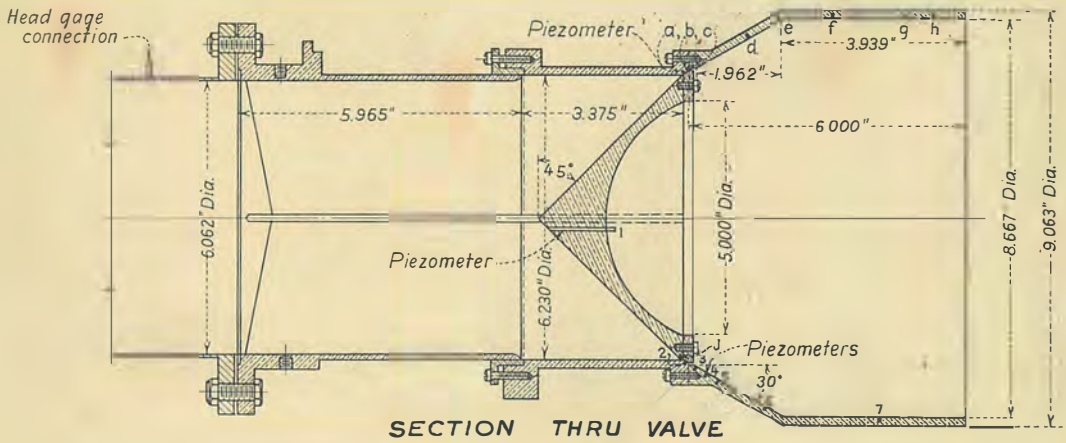
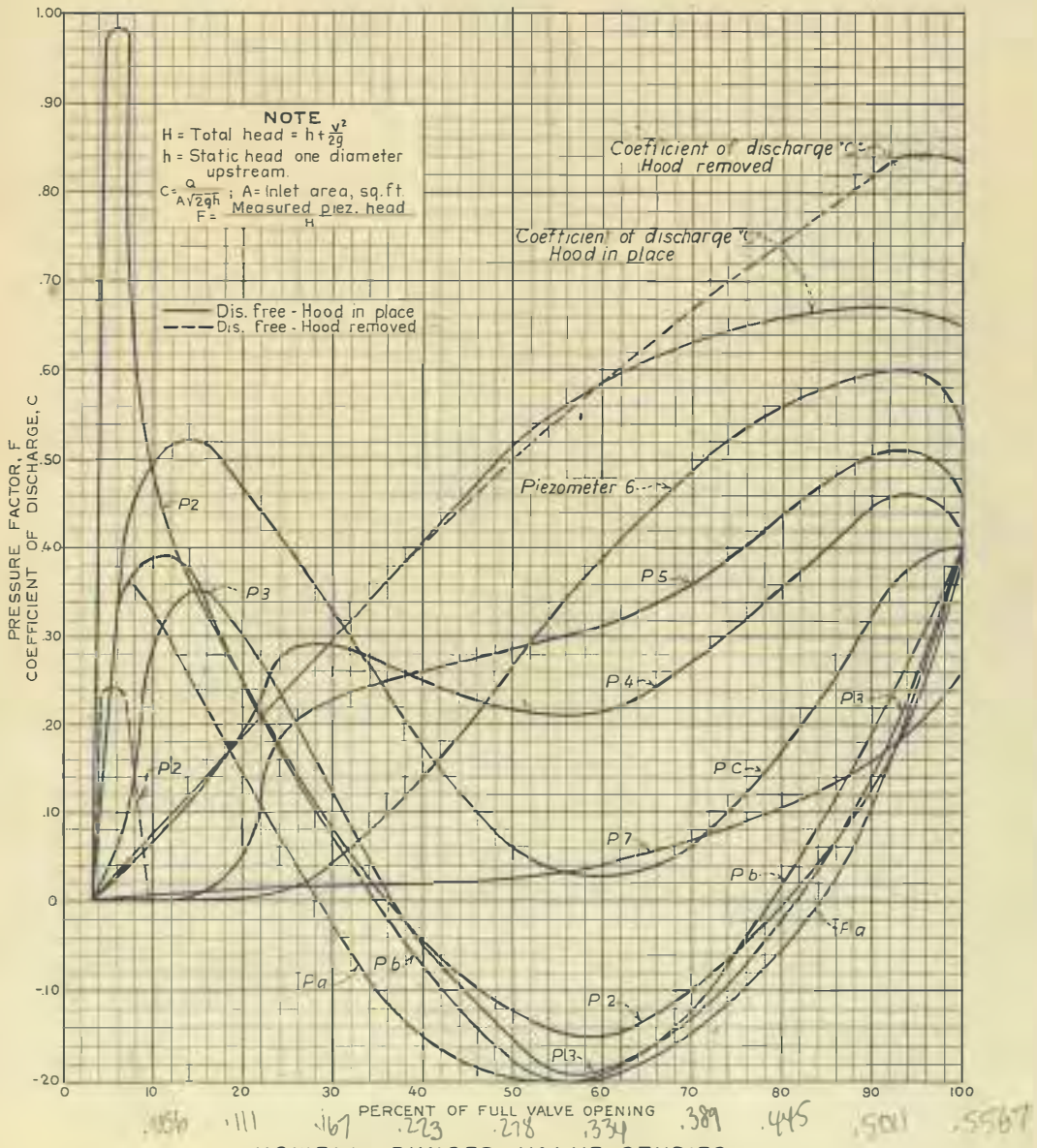

SECTION B-B
VALVE BODY
SECTION A-A
TOP BRACKET
SIDE BRACKETS
ONE REQ'D AS SHOWN
ONE REQ'D. OPP. HAND
HORIZ. SEC.
SLIDING GATE
SECTION C-C
PACKING RING
ROSS DAM
HOWELL-BUNGER VALVE
6" HYDRAULIC MODEL DETAILS
MODEL SCALE 1:12

FIGURE 5



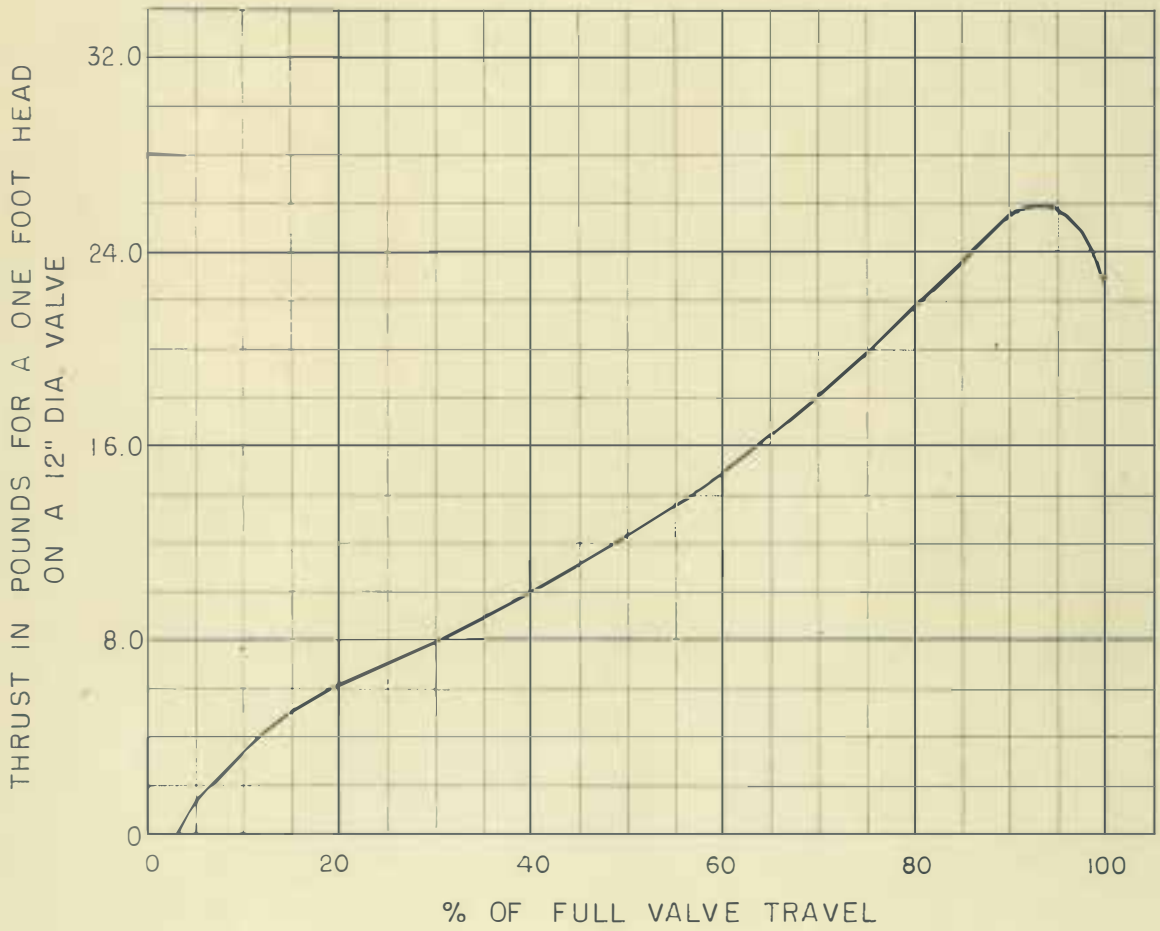
SECTION THRU VALVE



HOWELL-BUNGER VALVE STUDIES

COEFFICIENT AND PRESSURE FACTOR CURVES

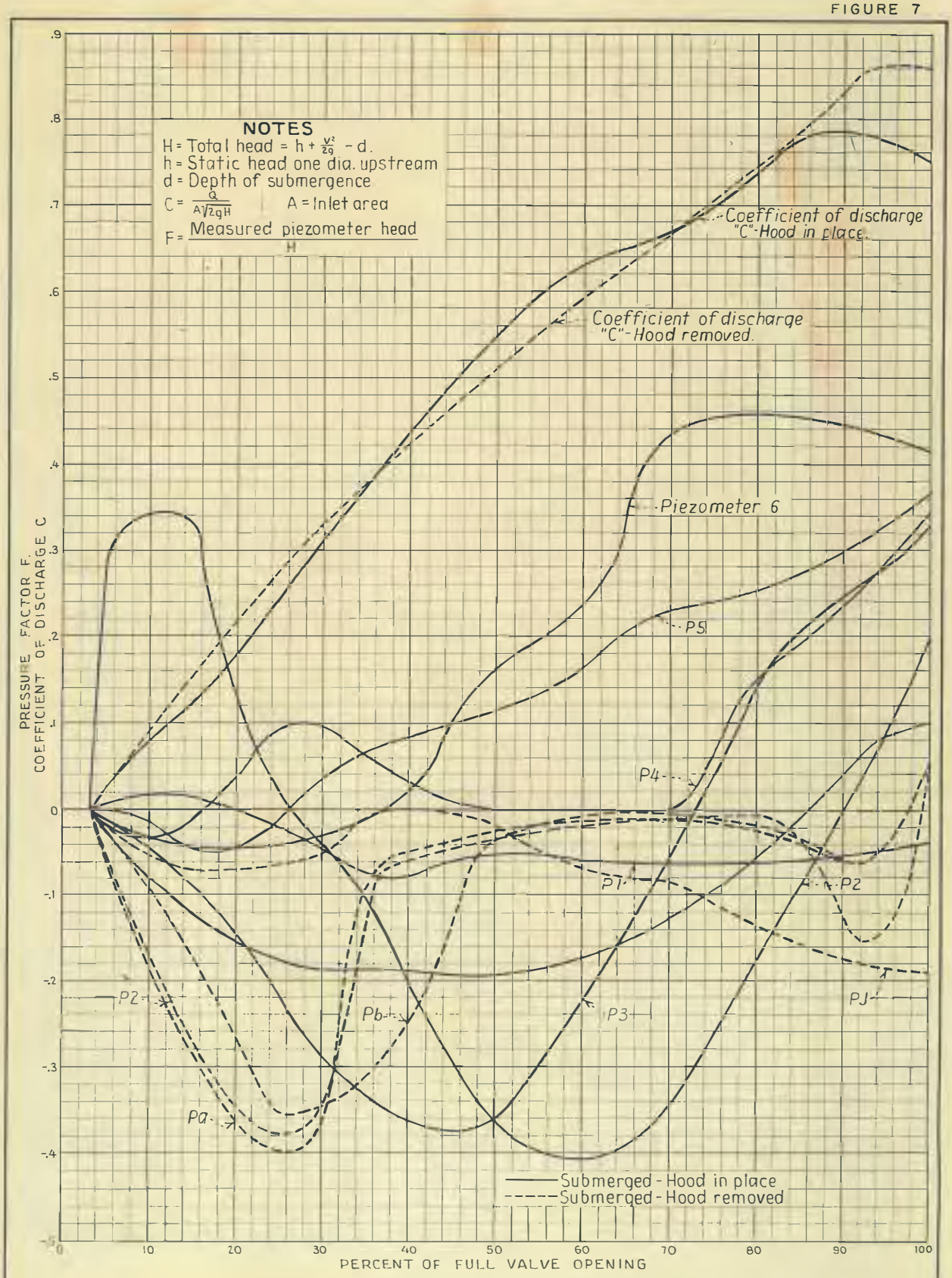
PRESSURES AND CHARACTERISTICS DETERMINED FROM 6-INCH HYDRAULIC MODEL VALVE DISCHARGING INTO ATMOSPHERE



HOWELL - BUNGER VALVE

UNBALANCED THRUST DETERMINED
FROM A 6 - INCH HYDRAULIC MODEL

FIGURE 7



HOWELL-BUNGER VALVE STUDIES

COEFFICIENT AND PRESSURE FACTOR CURVES

PRESSURES AND CHARACTERISTICS DETERMINED FROM 6-INCH HYDRAULIC MODEL VALVE DISCHARGING SUBMERGED

A. Hood removed

B. Hood in place

VALVE DISCHARING AT FULL OPENING