UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

THE HYDRAULIC CHARACTERISTICS OF THE 96-INCH HOLLOW-JET VALVES CONTROLLING THE RIVER OUTLETS THROUGH FRIANT DAM CENTRAL VALLEY PROJECT, CALIFORNIA

Hydraulic Laboratory Report No. Hyd-388

ENGINEERING LABORATORIES

OFFICE OF THE ASSISTANT COMMISSIONER AND CHIEF ENGINEER
DENVER, COLORADO

November 26, 1954

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Office of the Assistant Commissioner and Chief Engineer
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Laboratory Report No. Hyd-388
Hydraulic Laboratory
Written by: Dale M. Lancaster
Checked by: R. B. Dexter
Reviewed by: D. J. Hebert

Subject: The hydraulic characteristics of the 96-inch hollow-jet valves controlling the river outlets through Friant Dam--Central Valley Project, California

PURPOSE

The purpose of this report is to describe the hydraulic characteristics of the hollow-jet valve based on special tests of the one installed on River Outlet No. 3 through Friant Dam. Also, comparison is made with the predictions from hydraulic models during the design studies.

CONCLUSIONS

The 96-inch hollow-jet valves installed on the river outlets through Friant Dam performed satisfactorily with only a slight amount of cavitation erosion in the unfinished portion of the body casting due to local irregularities. This erosion can undoubtedly be prevented in future structures by limiting the allowable roughness of the casting.

Although no subatmospheric pressures were predicted from the model studies except on the large vanes, such pressures did occur at three different piezometer locations but the magnitude of these low pressures was not conducive to cavitation erosion. Although the subatmospheric pressures on the large vanes were greater in magnitude than predicted, again the pressures were not sufficient to produce cavitation erosion.

The positive pressures were within the expected range of values, varying from the model pressures by an amount approximately equal to the variation between the two hydraulic models.

One of the most important lessons learned from the comprehensive studies is that the calibration curve determined from the hydraulic model is as accurate as the field calibration. Adoption of a policy of accepting model calibration curves would save considerable time and expense.

The differential thrust on the needle which determines the power required to open and close the valve corresponds closely to the predicted quantity, the maximum variation being at a valve opening of 10 percent when this unbalanced force was 29 percent greater than the value predicted from the model studies.

The action in the stilling basin was not satisfactory since a portion of the jump formed in the river channel downstream from the basin; however, this condition was predicted during the model studies but the river channel was considered sufficiently stable to withstand the action of the hydraulic jump. An underwater survey revealed that the channel has not been eroded but the concrete floor of the basin has been damaged by the erosive action of the small rocks carried into the basin.

ACKNOWLEDGMENTS

The special test program was initiated by the Hydraulic Laboratory in cooperation with the Mechanical Branch. The installation of the test apparatus and inauguration of the procedure to be followed were accomplished under the supervision of the author.1/ Appreciation is extended to the project personnel who performed the actual tests. William F. Boyle, Jr. and R. B. Dexter of the Hydraulic Laboratory assisted in the computation of the results.

INTRODUCTION

The search for a satisfactory valve to operate at any opening to control the flow through large conduits discharging under high heads has been in progress for nearly half a century. The need for such a control device was responsible for the development of the Ensign valve (Arrowrock Dam), the needle valve (Alcova Dam), and the tube valve (lower outlets through Shasta Dam). Other valves have also been developed for the same purpose but the ones named constitute those primarily used by the Bureau of Reclamation. All of these valves were inadequate and expensive to construct or maintain.

The increasing demand for a closer control of the releases through modern multiple-purpose structures prompted a continuation of studies to obtain a more suitable valve and led to the development of a new type termed a hollow-jet valve. This new type, however, is

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1/ Field trip report from D. M. Lancaster dated February 19, 1951, subject "Field measurements to determine the hydraulic performance of the river outlets through Friant Dam."

limited to use as a free discharge valve preventing its application in closed conduits. For those cases where the valve must discharge in a closed conduit, a recently developed type known as a jet-flow valve has been proven successful.2/

Description of Valve

The hollow-jet valve is patented by the designers, Byron M. Staats and G. J. Hornsby (Patent No. 2,297,082) with rights reserved for use by the Government without the payment of royalty. The design was accomplished with the aid of a 45° segment of a 12-inch-diameter air model and a 6-inch-diameter hydraulic model in the laboratory 3/ together with a 24-inch-diameter model tested at Boulder Dam under a high head.4/ The purpose of the larger model was principally to ascertain the hydraulic characteristics of the hollow-jet valve constructed under prototype conditions, that is, by casting the supporting vanes, the cylinder containing the needle, and the outer shell in one piece with a machine finish limited to the needle and that part of the outer shell upstream from the vanes. The rough finish of the casting could conceivably effect the boundary flow sufficiently to cause local areas of low pressures whereas in the 6-inch model all surfaces were machine finished. Since these model studies were made, laboratory tests have defined to a certain extent the relationship between the degree of roughness of a surface and the resulting effect on the boundary flow which will produce subatmospheric pressures. Such information will be of assistance in the preparation of specifications for castings permitting an allowable tolerance of roughness which will prevent local areas of subatmospheric pressures sufficient to cause cavitation erosion.

A second reason for studies on a 24-inch model was that some of the critical areas were too small for exploration by piezometers in the 6-inch model. A few revisions were found necessary as a result of the tests of the 24-inch valve which was later installed permanently at Jackson Gulch Dam, Mancos Project, Colorado.

Although the design studies relative to the hollow-jet valve were conducted in connection with facilities for Anderson Ranch Dam, the initial installation of large units was on the river outlets through Friant Dam, Figure 1. Details of the installation may be seen on

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2/ Hydraulic Laboratory Report No. Hyd-389. "Hydraulic performance of the control devices in the 102-inch river outlets of the middle and upper tiers--Shasta Dam--Central Valley Project."

3/ Hydraulic Laboratory Report No. Hyd-148. "Model studies for the development of the hollow-jet valve--Anderson Ranch Dam--Boise Project, Idaho."

4/ Hydraulic Laboratory Report No. Hyd-189. "Tests on 24-inch hollow-jet valve at Boulder Dam." November 29, 1945.

Figure 2 while the valve proper is better displayed on Figure 3. One of the four 96-inch valves was equipped with piezometer orifices to permit the performance of special tests to ascertain if this new type valve possessed the predicted hydraulic characteristics. The performance could conceivably be different from the hydraulic models due to the roughness of the casting as previously described or the larger tolerances necessarily allowed for the machined surfaces in the prototype valve could cause difficulty. The locations of the pressure taps are shown on Figure 3.

Field Tests

The field testing program was inaugurated in August 1950, although the valves were placed in operation in July 1949. The program consisted of pressure measurements at valve openings of 10, 20, 40, 60, 80, and 100 percent, with reservoir elevations of 434.0, 512.3, and 555.1 feet corresponding to heads on the valve of approximately 102, 180, and 223 feet, respectively. The maximum design head is 246 feet.

The discharge of the valves was obtained from operating records based on current meter measurements in the river channel a short distance downstream from the structure. In this instance, the flow in the river channel represents only the discharge through the outlets. Hence the current meter observations would not be subject to possible errors by substracting the quantity from other sources such as a powerhouse.

Other field observations included the general behavior of the hollow-jet valves, inspection of the interior of Unit No. 3 during a routine disassembling for maintenance, the character of the jet, and action in the stilling basin into which the outlets discharge.

Results of Pressure Measurements

The pressure measurements were obtained in the usual manner by connecting the piezometer orifices to manifolds joined to mercury gages. A valve on each connecting line permitted the determination of the pressure for any particular piezometer. Figure 4 shows the two manifolds and mercury gages.

All pressures have been referred to the elevation of the centerline of the valve at the upstream end. The head was measured one diameter upstream from the valve and referred to the same elevation as the other pressures. Hence, the outlet was considered to be on a horizontal centerline to correspond to the hydraulic model, while actually the centerline of the prototype structure slopes downward.

The pressures have been plotted by utilizing a pressure factor F, 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 method is utilized to permit a direct comparison with the model results which were plotted in this form. Quoting from the model report 3/:

"This procedure reduces F to a dimensionless number making it possible to obtain the pressure at any point on the valve by selecting from the curves the correct value of F and multiplying it by the total design head on the valve one diameter upstream from the inlet."

As an example, to find the pressure at a piezometer, when the design head is, say, 200 feet of water and the valve is 50 percent open, follow the 50 percent line until it intersects the curve for the particular piezometer and read the value of the pressure factor at the left. Multiply 200 times the pressure factor to obtain the pressure at the piezometer for the case being considered. Of course, if the piezometer pressure is below atmospheric then the F value will be negative. However, no subatmospheric pressures were shown on the plot of the model test results, but the report does say: "That positive pressures will exist on all parts of the valve except the large vanes is indicated by the results obtained from the hydraulic model."

The pressure in the air space just upstream from the vanes, although not shown on the plot of the hydraulic model data, was stated to be a negative 1.22 feet of water in the 24-inch valve when 100 percent open under a total head of 196.6 feet. This pressure corresponds to that of Piezometer 29P in the prototype where the negative pressure was practically constant at 4.9 feet for all valve openings with a total head of 196.6 feet, based on the tests at the two highest reservoir elevations. Based on the field test at the lowest reservoir elevation, the negative pressure was 9.8 feet under similar conditions of head and valve openings. The reason for the variation between the model and prototype as well as the variation in the prototype itself can be traced to the fact that this region is partly filled with an air-water mixture due to insufflation of the jet in the case of the full sized structure. This mixture could conceivably choke the air supply sufficiently to cause an increase in the subatmospheric pressure while in the case of the model valve, insufflation did not occur.

The report describing the tests of the 24-inch model states that:

"The piezometers located on the large vanes showed negative pressures at 10 and 20 percent of full opening. The maximum negative pressure was 2.78 feet of water at 20 percent opening where the total head was 330 feet of water. These negative pressures were probably the result of local irregularities in the rough casting and have no particular significance."

The negative pressures were not shown in the model report but have been included on Figures 5, 6, 7, and 8. It will be observed that the prototype tests revealed higher pressures, in general, than the model tests, except for Piezometer 25P at openings of 10 and 20 percent where the field tests showed a negative pressure of approximately 13 feet of water at the maximum design head.

Although the magnitude of subatmospheric pressures was greater than predicted from the model, none was sufficient to cause cavitation erosion.

A study of Figures 5 to 15, inclusive, will show that in general the pressures measured in the field differ from those measured in either the 6-inch model or 24-inch model by an amount approximately equal to the difference between the values determined in the models. The prototype values at a particular piezometer may be closer to the results of the 24-inch model than the 6-inch, but at another piezometer the reverse may be true. The average deviation between the model and prototype pressures may be considered less than 10 feet of water at the maximum head. Some of the deviation may be attributed to the slightly different location of a portion of the piezometer orifices.

The relatively high pressure obtained at Piezometer 17 in the 24-inch model was due to interference by a bolt immediately upstream from the pressure orifice. Piezometer 24 is another one which shows considerable variation in the three pressure curves but this is not surprising when the fact is considered that the orifice is located on the needle immediately adjacent to the point where the jet springs free. At this point a very slight change in the contour of the needle portion of the valve or a change in location of the orifice would materially effect the pressure. Figure 16 which shows the piezometer numbers employed in the 6- and 24-inch models and the prototype valves, together with the relative locations, reveals that Piezometer 24 was not located precisely at the same point in the full sized valve as in the two models.

As previously stated, no pressures measured were sufficiently low to cause cavitation erosion. However, inspection of the valve revealed that cavitation erosion had occurred on the valve body upstream from the vanes. Figure 17 is a view of the valve interior looking upstream. The dark spots in the light portion of the valve are areas of cavitation erosion. This erosion, although not severe, has actually pitted the metal and unquestionably is due to the rough surface of the casting. The following tabulation shows the hours of operation of the valve and other pertinent information during the entire period of operation prior to the time of inspection:

Valve opening (percent)	Head on valve	Hours of operation
2	163	432
2.5	108	625
10	91	210
10	161	480
11	78	550
18	162	264
19	101	790
23	207	1,080
24	144	925
31	179	270
66	193	270
	Total	5,896

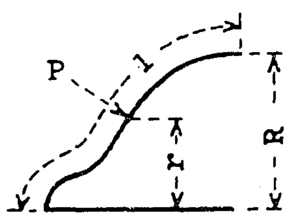
The fact that cavitation erosion occurred in the prototype but was not predicted in the model studies is attributed to the rough surface of the casting for the full sized valve, whereas the 6-inch model was machined on all surfaces and the casting for the 24-inch model was hand ground on all surfaces not machined. This condition illustrates one of the important reasons for the performance of field tests. For future construction, consideration should be given to writing specifications in such a way that roughness of the casting can be held within limits to prevent subatmospheric pressures sufficient to cause cavitation erosion. The laboratory studies mentioned previously would be helpful in this regard.

Results of Thrust Measurements

During the design studies, considerable emphasis was placed on the location and size of openings or ports through the needle portion of the valve to admit pressure into the interior, thereby balancing the pressure to minimize the power required to open and close the valve. Figure 18 shows the thrust in the two directions predicted from the 24-inch model together with comparable information obtained on the full-sized structure. For the sake of simplicity the units have been reduced to those applicable to a 1-foot valve under a 1-foot head; this permits computation of thrust forces for other size hollow-jet valves operating under various heads by multiplying the results shown on Figure 18 by both the head in feet and the square of the diameter in feet. The results of similar data obtained on a 6-inch model are not shown since the location of the balancing ports established by tests on this small model was changed after analysis of results from the 24-inch valve.

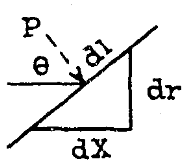
The values shown on the plot of Figure 18 reveal a very close agreement between the thrust predicted from the 24-inch model and the quantities determined by field measurements on the 96-inch valve. The greatest difference occurs in the downstream thrust at a valve opening of 10 percent where the prototype value is approximately 94 percent of that determined in the model study. Of course, the unbalanced force or the differential between the upstream and the downstream thrust is the most important, and the maximum unbalance occurs at a valve opening of 10 percent. This unbalanced force is 1.29 times the value predicted from the model studies.

The method of computing the thrust is believed worthy of description, although the procedure represents conventional practice. The thrust on the needle in the downstream direction was computed as follows:



Let P = measured piezometric pressure
l = length along surface of needle
r = radius to piezometer
$2\pi \ rPdl$ = total thrust on the increment dl
$2\pi \ rPdl \cos\theta$ = thrust on increment dl in X-direction

Total thrust in X-direction = $2\pi \int_0^l rP \cos\theta \, dl$



And since $dl = \frac{dr}{\cos\theta}$, then $2\pi \int_0^R rPdr$ = total thrust.

The integration was done graphically since the relationship of P to r was not known explicitly. The value of Pr was plotted against r for a valve opening of 10 percent, and the area under the curve was obtained with a planimeter to obtain $\int_0^R rPdr$ and that value of area was multiplied by 2π to obtain the total thrust on the needle in the downstream direction for a valve opening of 10 percent. The same procedure was utilized for valve openings of 20, 40, 60, 80, and 100 percent. The computations were based on a unit head one diameter upstream from the valve and the valve was reduced to a unit diameter. Only the prototype data obtained at the highest reservoir elevation was utilized. The following tabulation shows the computations:

COMPUTATION OF THRUST IN DOWNSTREAM DIRECTION

Piezometer No.	r	Percent valve opening											
		10		20		40		60		80		100	
		F	Pr	F	Pr	F	Pr	F	Pr	F	Pr	F	Pr
17	1.400	.997	1.396	.990	1.386	.963	1.348	.927	1.298	.897	1.256	.888	1.243
18	2.400	.991	2.378	.967	2.321	.881	2.114	.784	1.882	.715	1.716	.690	1.656
19	3.070	.979	3.006	.914	2.806	.730	2.241	.591	1.814	.526	1.615	.523	1.606
20	3.350	.955	3.199	.830	2.781	.550	1.843	.402	1.347	.347	1.162	.352	1.179
21	3.850	.774	2.980	.455	1.752	.218	0.839	.172	0.662	.158	0.608	.176	0.678
22	4.090	.447	1.828	.218	0.892	.143	0.585	.130	0.532	.126	0.515	.150	0.614
23	4.201	.259	1.088	.132	0.555	.110	0.462	.104	0.437	.103	0.433	.121	0.508
24	4.301	.040	0.172	.004	0.017	.006	0.026	.002	0.009	.000	0.000	.009	0.039
$\int_0^R rPdr$		7.5		6.8		5.5		5.0		4.4		4.4	
$2\pi \int_0^R rPdr$		47.12		42.73		34.56		31.42		27.65		27.65	
$62.4(2)\pi \int_0^R rPdr$		2940.29		2666.35		2156.54		1960.61		1725.36		1725.36	
$\frac{62.4(2)\pi \int_0^R rPdr}{8^2}$		45.94		41.66		33.70		30.63		26.96		26.96	

With the valve completely closed the thrust in the downstream direction would be equal to the area of the needle times 62.4 divided by the square of the diameter to obtain the thrust on a valve of 1 foot diameter or

$$\frac{\pi (8.667)^2 (62.4)}{4(64)} = 57.52 \text{ pounds thrust at 0 opening}$$

The thrust in the upstream direction is simply the pressure inside the needle times the area over which the pressure acts. This area is that of a 104-1/4-inch-diameter circle minus the area of a circle of 10-1/2-inch diameter, or 58.675 square feet. For a valve of 1-foot diameter the area is $\frac{58.675}{64}$ or 0.917 square feet.

Representing the pressure by the corresponding value of F, the following table reveals the computation for thrust in the upstream direction:

Valve opening %	F	Area A	Thrust in lb = 62.4(F)A
0	1	0.917	57.22
10	0.962	0.917	55.05
20	0.853	0.917	48.81
40	0.587	0.917	33.59
60	0.434	0.917	24.83
80	0.363	0.917	20.77
100	0.363	0.917	20.77

Rate of Discharge

The rate of discharge of the valve being considered is particularly important in relation to the comparison with the hydraulic model study since it serves to prove the accuracy of discharge curves prepared from laboratory calibrations. The importance of the advantages of dispensing with field calibration can only be evaluated by considering the tremendous expenditures of money and time in performing field calibrations.

It is not intended to convey the idea that all valves should be calibrated in the laboratory, but laboratory calibration of a valve will suffice for all installations of the same type, except for certain situations where complicated approach conditions disrupt the flow characteristics.

A concept may be had of the time and expense involved in performing a field calibration when considering the fact that approximately 600 current meter measurements were made over a period of 5 years to determine the discharge through the river outlet valves at Friant Dam. At this same structure similar current meter measurements were conducted to determine the discharge through the hollow-jet valves at the headworks to Friant-Kern Canal and also in connection with the quantity of water flowing into the Madera Canal through needle valves.

None of the current meter measurements were necessary as the discharge curves established by the model calibrations are as accurate as the curves determined by the field measurements.5/

Figure 19 represents data to support the accuracy of the predicted calibration curves. For valve openings greater than 15 percent, the variation between the model and prototype may be considered as 3 percent. For smaller valve openings, the difference is greater but this does not mean that the model calibration is incorrect, but suggests inaccuracy of the field data due to the fact that lower discharges are not susceptible to accurate measurements with a current meter. The particular valves being described in this report were equipped with verniers on the position indicators to permit accurate setting of the valve opening.

If all necessary precautions are taken there is reason to believe that the valves will operate as accurate measuring devices, thereby saving large expenditures of money and time in performing current meter measurements.

Other data exist to show the effectiveness of calibration curves determined from hydraulic models, but this report is limited to the particular installation at Friant Dam.

General Behavior of the Valve

The general behavior of the valve during tests was entirely satisfactory. Operation was quiet and free from vibration. The jets remained stable and well defined.

Stilling Basin

The action of the stilling basin was definitely not in accordance with accepted standards in that a large portion of the hydraulic jump formed in the river channel downstream from the stilling basin. As result of this observation during the field tests, an underwater survey was later conducted to determine the extent of any erosion in the river channel as well as the basin proper. This survey revealed that very little erosion had occurred in the river channel which is composed of rock. Some damage had occurred in the stilling basin, probably due to cavitation erosion as a result of the high velocities over rough surfaces combined with the erosive action of the small rocks carried into the basin by the hydraulic jump. In some areas, the erosion of the basin was sufficient to expose the reinforcing steel. Figure 20 shows the results of the last survey.

5/ Unfortunately the initial calibration nomographs were in error due to an arithmetical mistake but the conclusions stated were based on the corrected curves.

An important factor is that the substandard performance of the stilling basin was predicted from the hydraulic model studies during the design of the basin. In other words, the structure was designed with the knowledge that the performance would be substandard but the rock in the river channel adjacent to the stilling basin was considered to be of a quality sufficient to withstand the action thus permitting the construction of a shorter basin for the purpose of economy. However, damage to the concrete floor of the basin was not predicted. Had this difficulty been foreseen, undoubtedly the stilling basin would have been designed more conservatively.

Appendix I contains the details of the study of the stilling basin.

FIGURE 1
REPORT HYD. 388

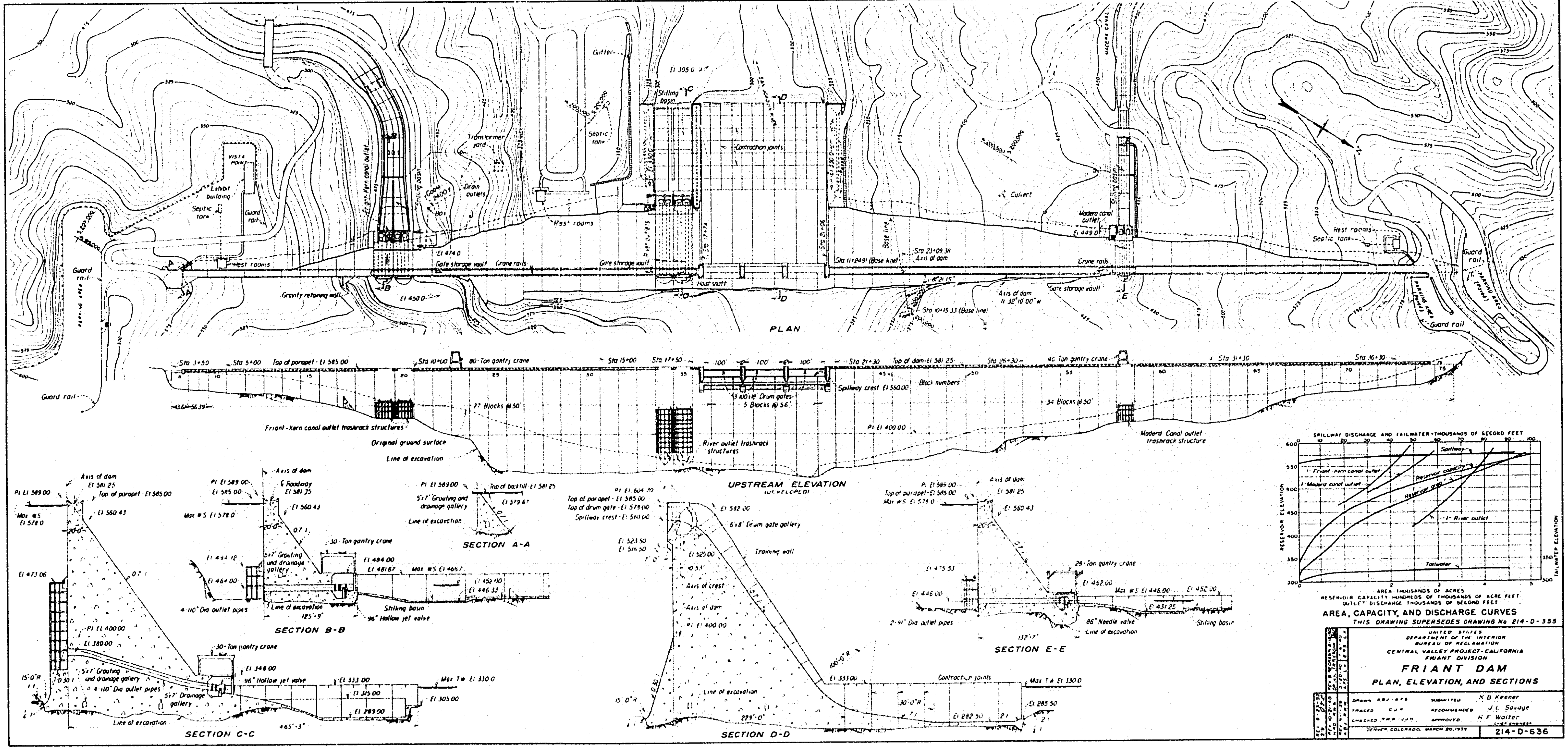
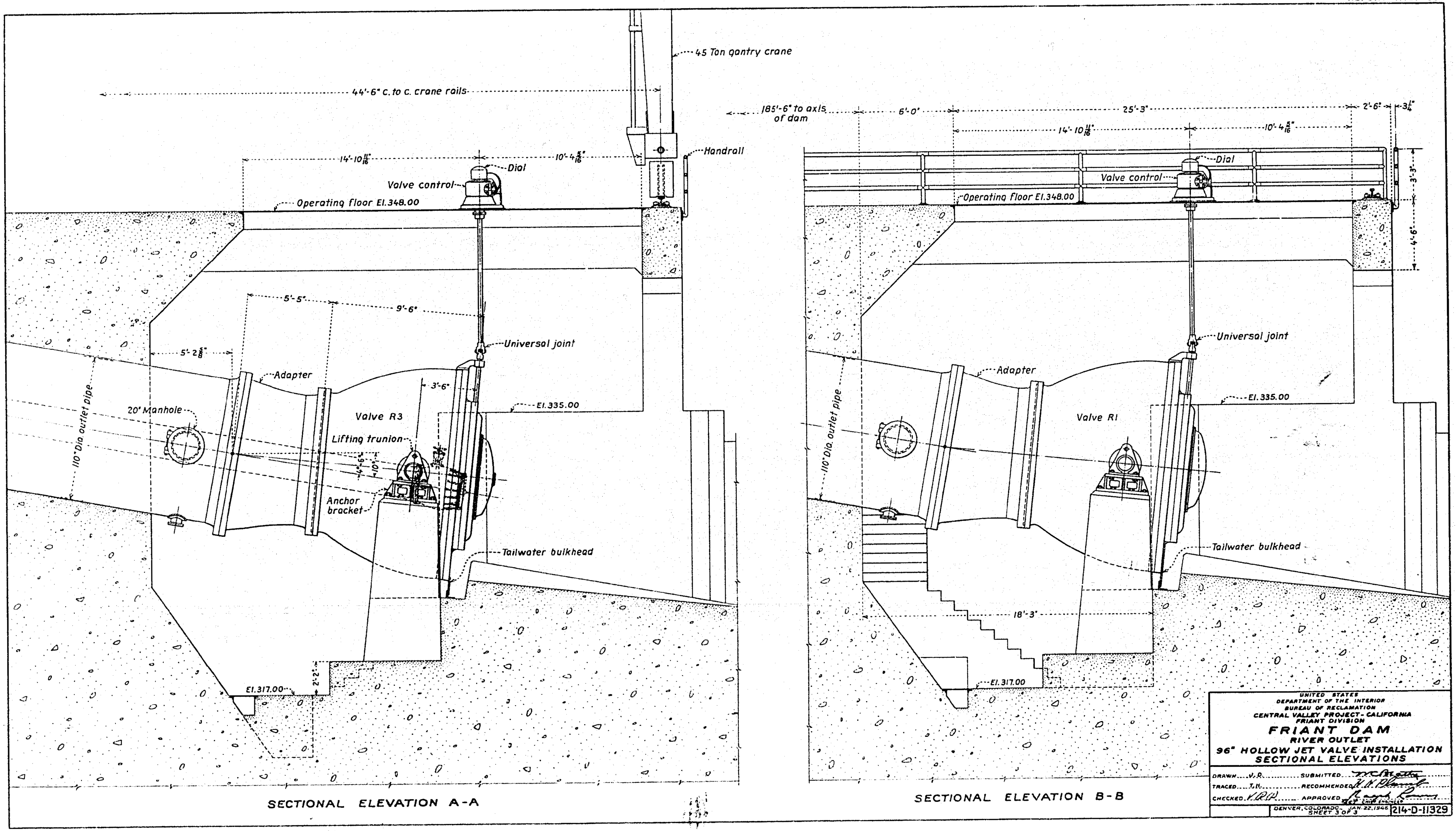
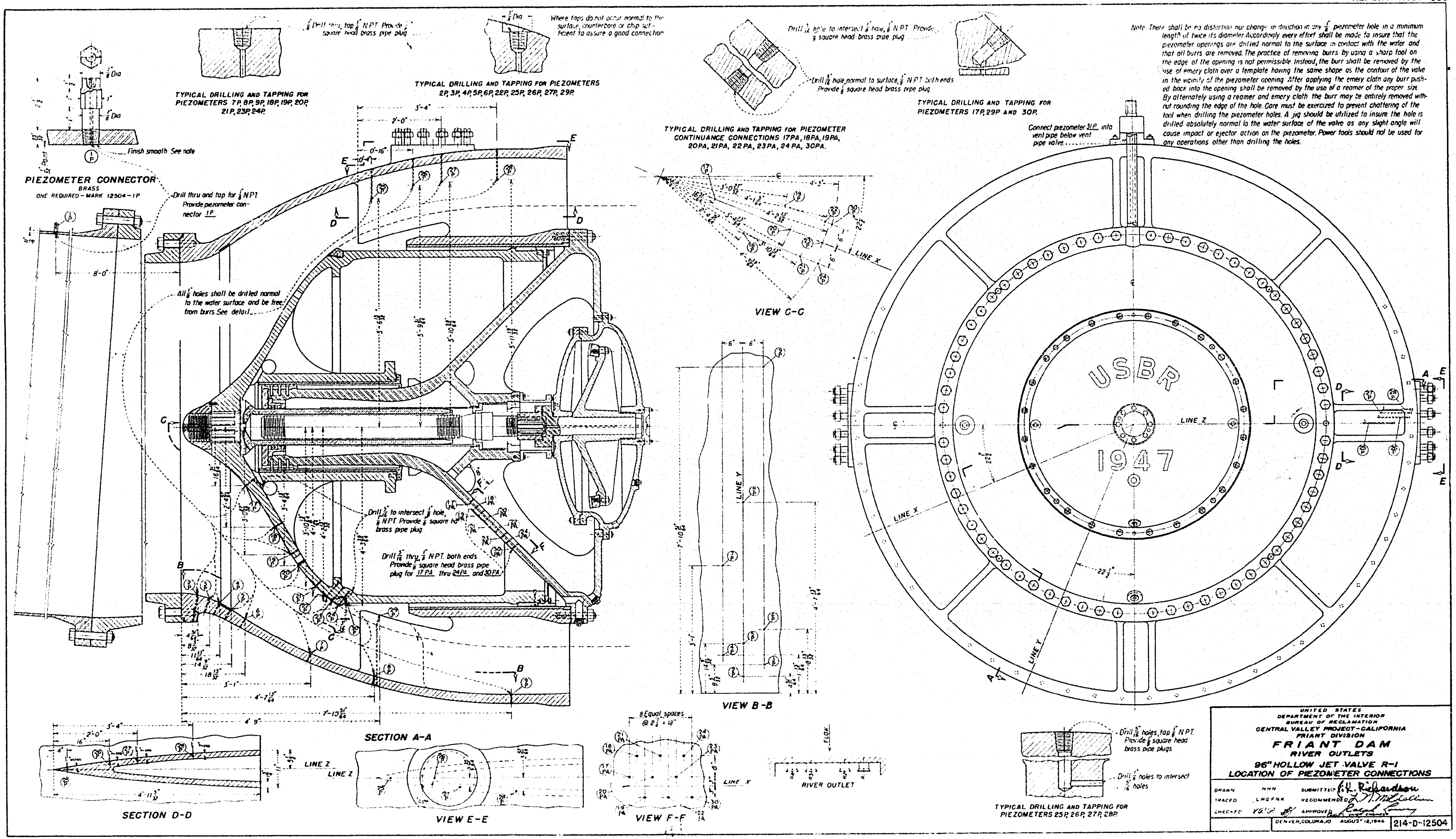
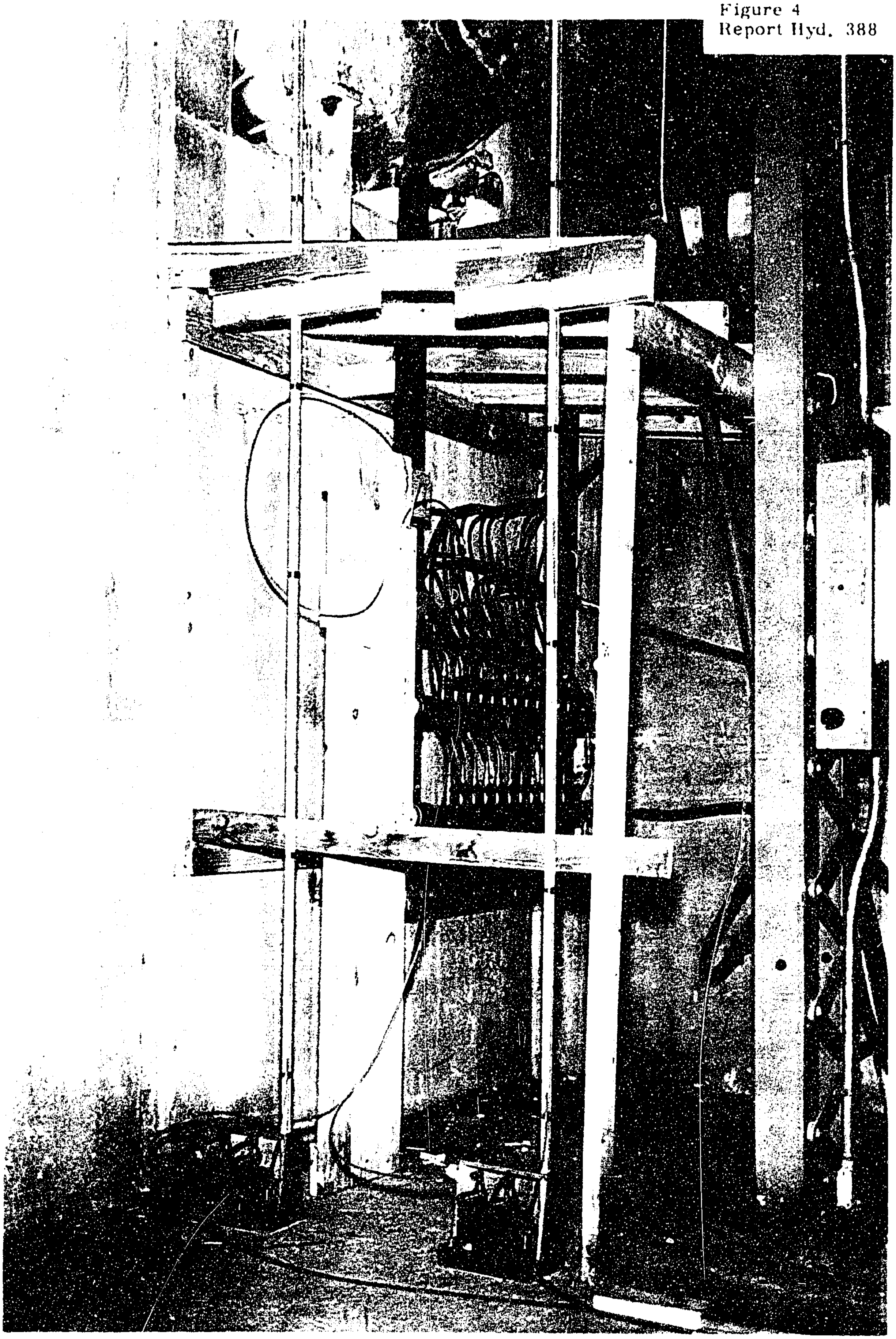


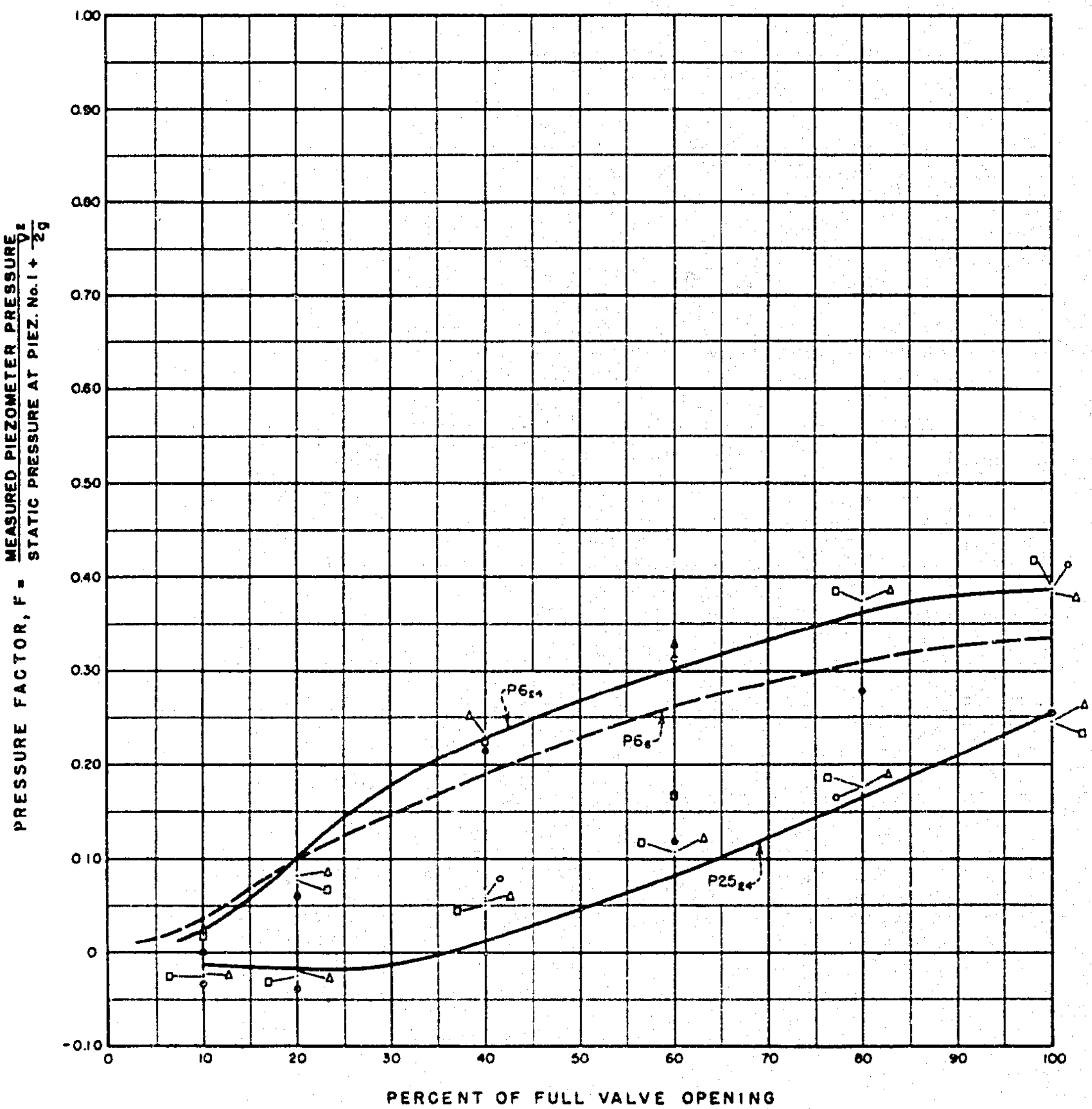
FIGURE 2
REPORT HYD. 388




PIEZOMETER CONNECTOR
BRASS
ONE REQUIRED - MARK 12504-1P
Finish smooth See note
TYPICAL DRILLING AND TAPPING FOR PIEZOMETERS 7P, 8P, 9P, 18P, 19P, 20P, 21P, 23P, 24P.
TYPICAL DRILLING AND TAPPING FOR PIEZOMETERS 2P, 3P, 4P, 5P, 6P, 22P, 25P, 26P, 27P, 29P.
Where taps do not occur normal to the surface, counterbore or chip sufficient to assure a good connection
TYPICAL DRILLING AND TAPPING FOR PIEZOMETER CONTINUANCE CONNECTIONS 17PA, 18PA, 19PA, 20PA, 21PA, 22 PA, 23 PA, 24 PA, 30PA.
TYPICAL DRILLING AND TAPPING FOR PIEZOMETERS 17P, 29P AND 30P.
Note: There shall be no distortion nor change in direction in any 1/8" piezometer hole in a minimum length of twice its diameter. Accordingly every effort shall be made to insure that the piezometer openings are drilled normal to the surface in contact with the water and that all burrs are removed. The practice of removing burrs by using a sharp tool on the edge of the opening is not permissible. Instead, the burr shall be removed by the use of emery cloth over a template having the same shape as the contour of the valve in the vicinity of the piezometer opening. After applying the emery cloth any burr pushed back into the opening shall be removed by the use of a reamer of the proper size. By alternately using a reamer and emery cloth the burr may be entirely removed without rounding the edge of the hole. Care must be exercized to prevent chattering of the tool when drilling the piezometer holes. A jig should be utilized to insure the hole is drilled absolutely normal to the water surface of the valve as any slight angle will cause impact or ejector action on the piezometer. Power tools should not be used for any operations other than drilling the holes.
Connect piezometer 31P into vent pipe below vent pipe valve
Drill thru and tap for 1/8" NPT. Provide piezometer connector 1P
All 1/8" holes shall be drilled normal to the water surface and be free from burrs. See detail
VIEW C-C
LINE X
LINE Y
LINE Z
USBR
1947
VIEW B-B
SECTION A-A
SECTION D-D
VIEW E-E
VIEW F-F
8 Equal spaces @ 2 1/4" = 18"
FLOW
RIVER OUTLET
TYPICAL DRILLING AND TAPPING FOR PIEZOMETERS 25P, 26P, 27P, 28P.
Drill 5/16" holes, tap 1/8" NPT. Provide 1/8" square head brass pipe plugs
Drill 1/8" holes to intersect 5/16" holes
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
FRIANT DIVISION
FRIANT DAM
RIVER OUTLETS
96" HOLLOW JET VALVE R-1
LOCATION OF PIEZOMETER CONNECTIONS
DENVER, COLORADO
214-D-12504



Manifolds and mercury gages for measuring pressures in river outlet hollow jet valve R-3, Friant Dam.



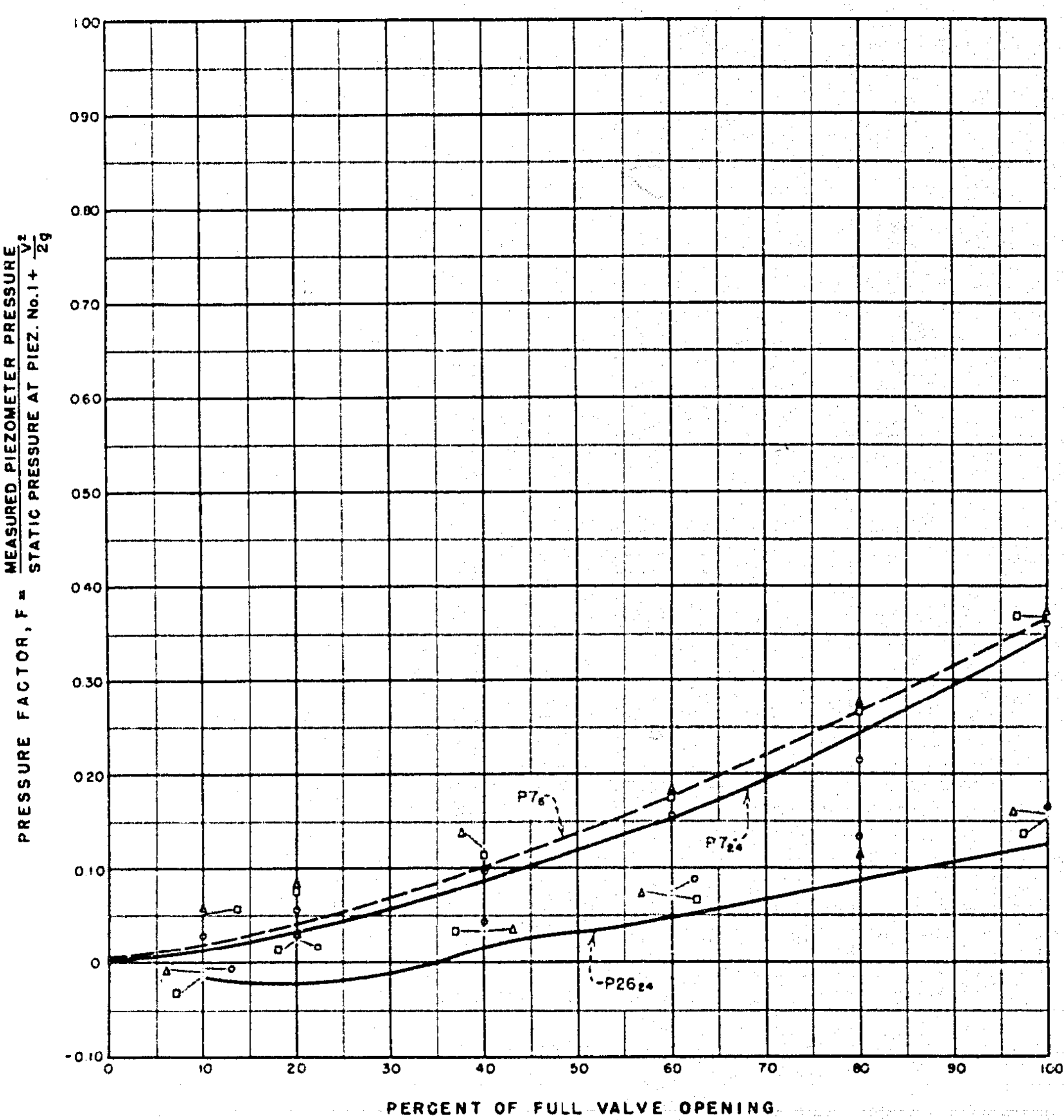
SYMBOLS

- ● RESERVOIR ELEVATION 433.98
- ■ RESERVOIR ELEVATION 512.32
- ▲ RESERVOIR ELEVATION 554.40

NOTE

Prototype data shown by symbols.
24-Inch model data shown by solid lines.
6-Inch model data shown by broken lines.

FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
PIEZOMETERS 6 AND 25



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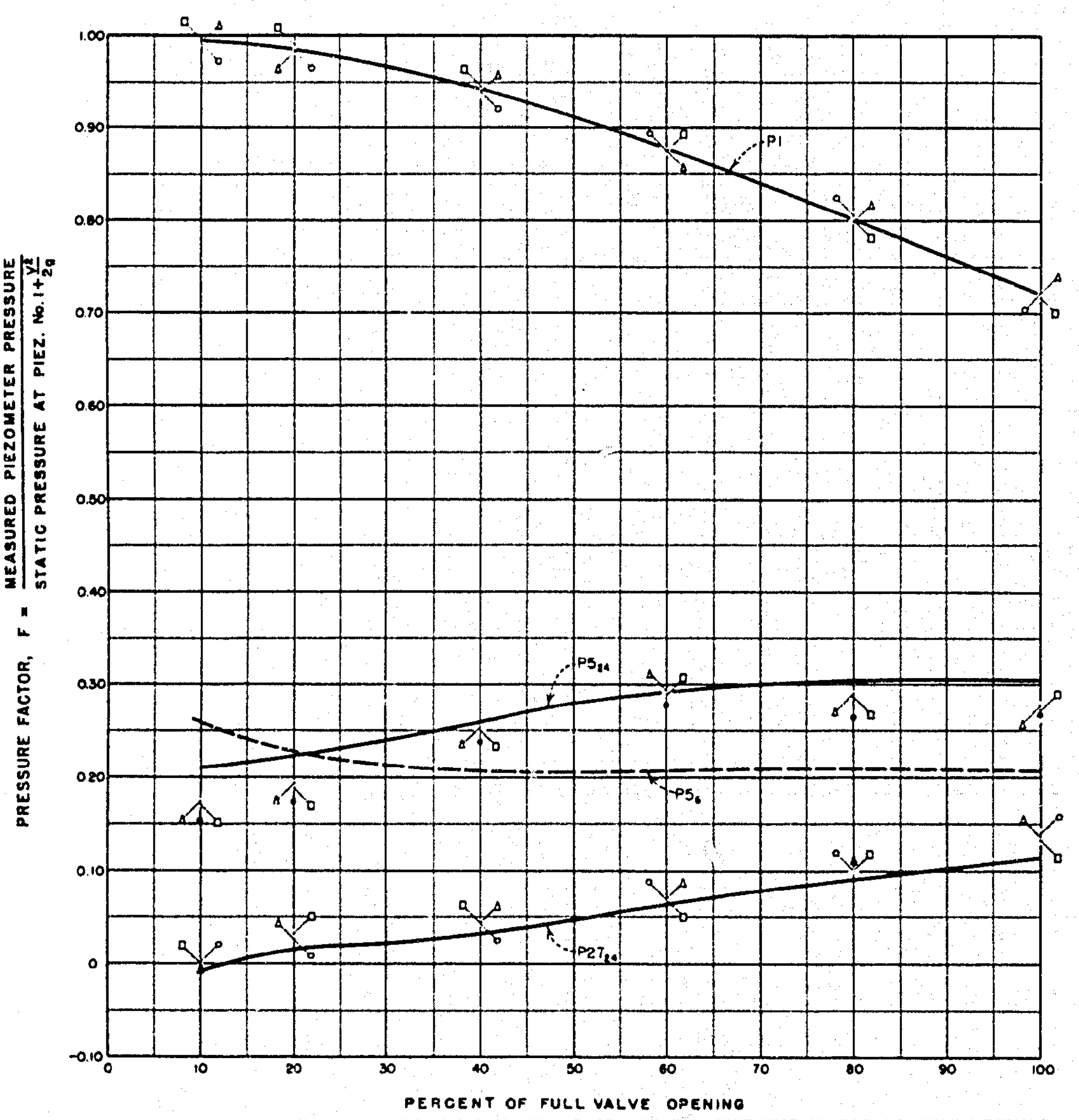
FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
PIEZOMETERS 7 AND 26

260   3-15-54 D.M.L.



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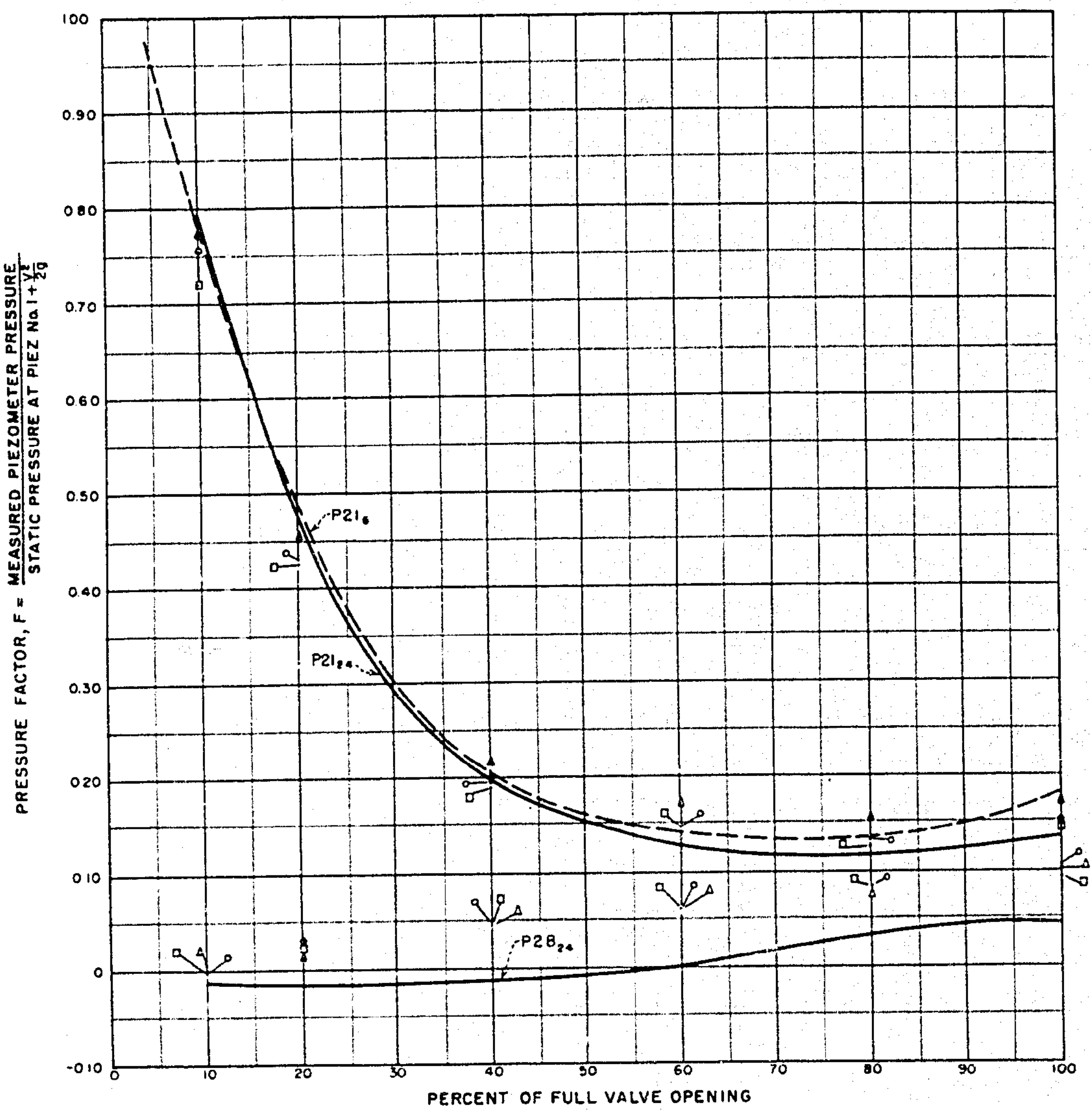
FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
PIEZOMETERS 1, 5 AND 27

3-18-54 D.N.L.



SYMBOLS

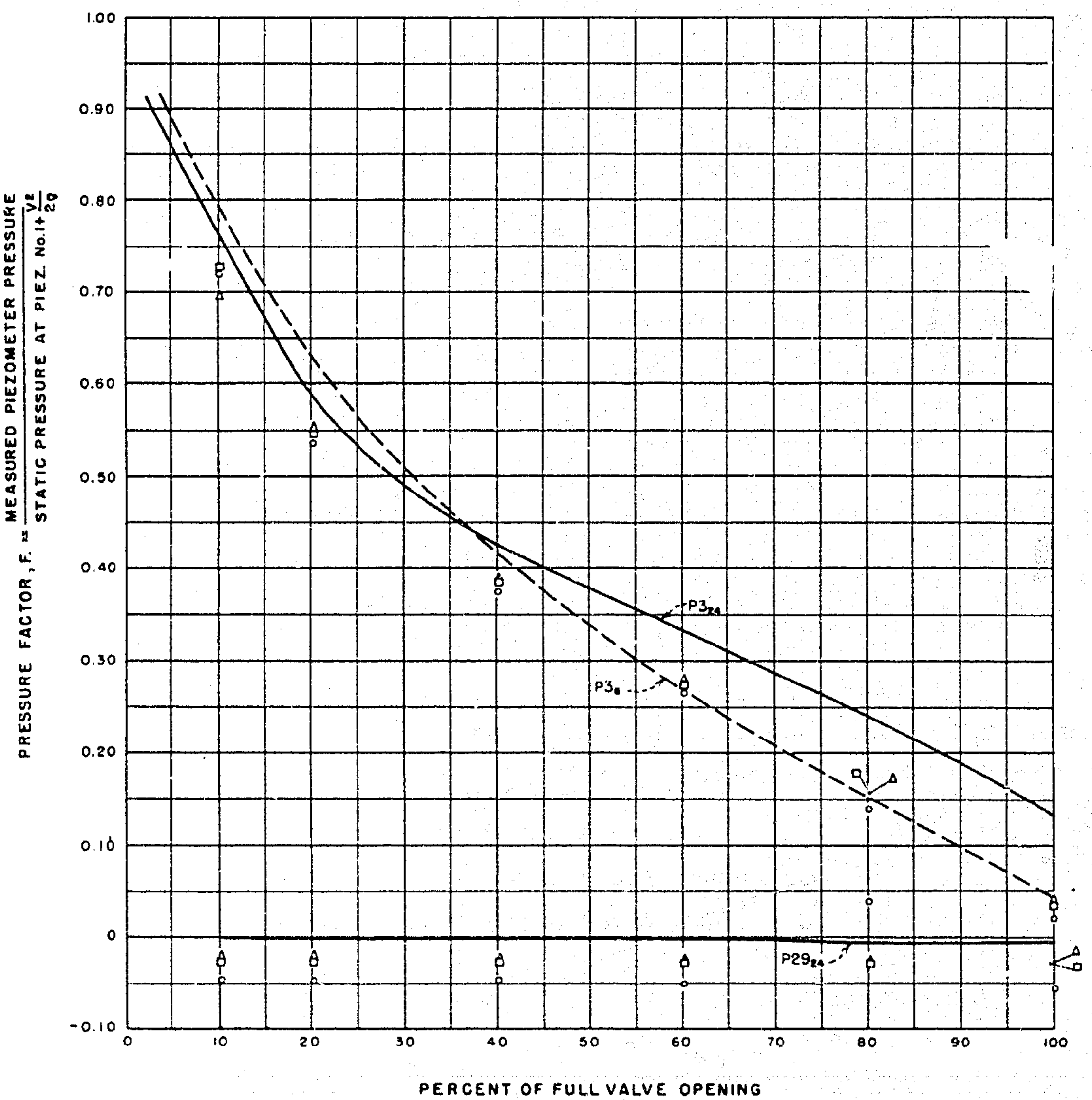
- ● RESERVOIR ELEVATION 433.98
- ▫ RESERVOIR ELEVATION 512.32
- ▲ RESERVOIR ELEVATION 554.40

NOTE

Prototype data shown by symbols.
24-Inch model data shown by solid lines.
6-Inch model data shown by broken lines.

FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
PIEZOMETERS 21 AND 28

 3-15-54 D.M.L.



SYMBOLS

- ○ RESERVOIR ELEVATION 433.98
- □ RESERVOIR ELEVATION 512.32
- △ RESERVOIR ELEVATION 554.40

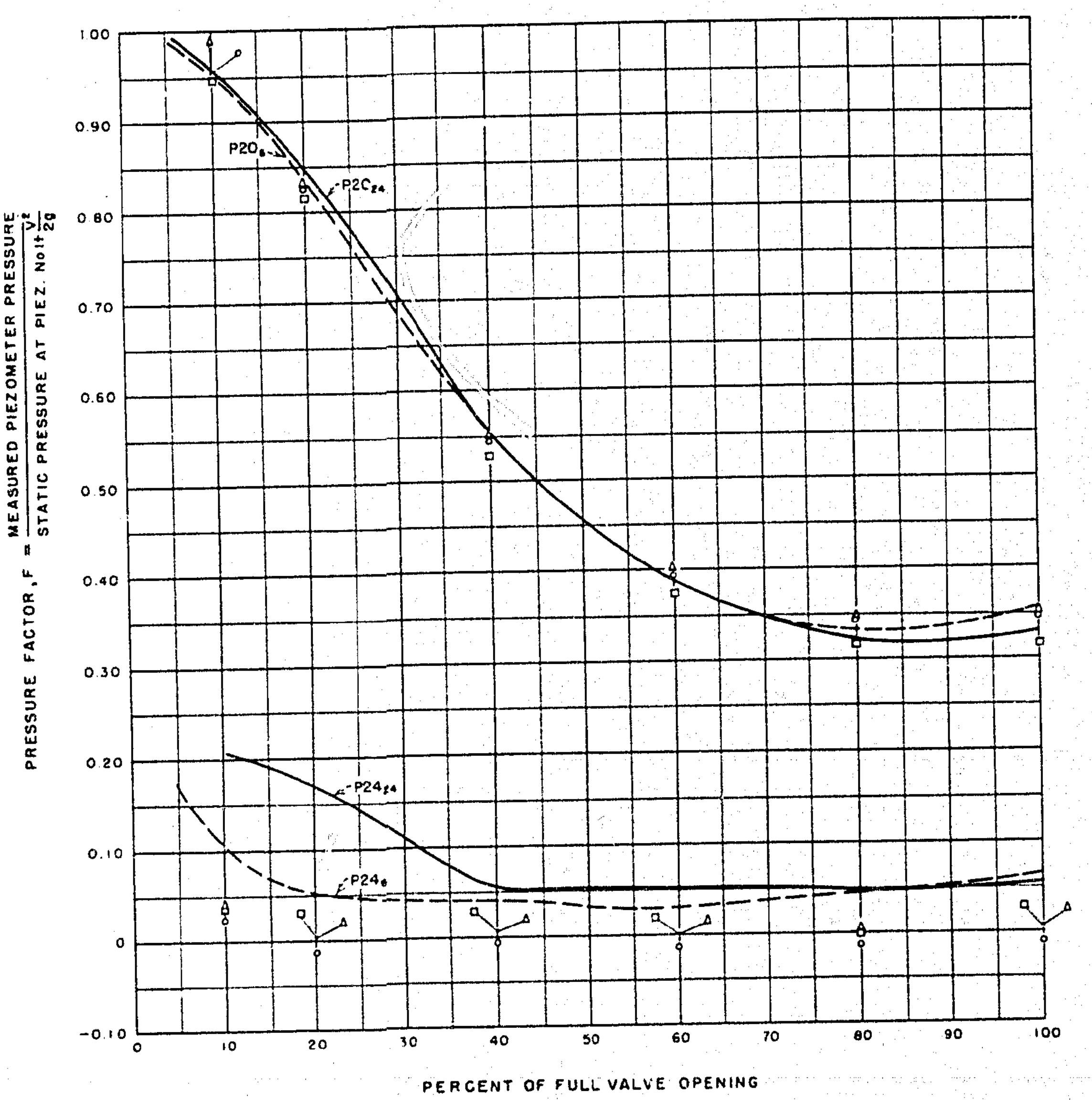
NOTE

Prototype data shown by symbols.
24-Inch model data shown by solid lines.
6-Inch model data shown by broken lines.

FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
PIEZOMETERS 3 AND 29

260 3-15-54 D.M.L.

FIGURE 10
REPORT HYD. 388



SYMBOLS

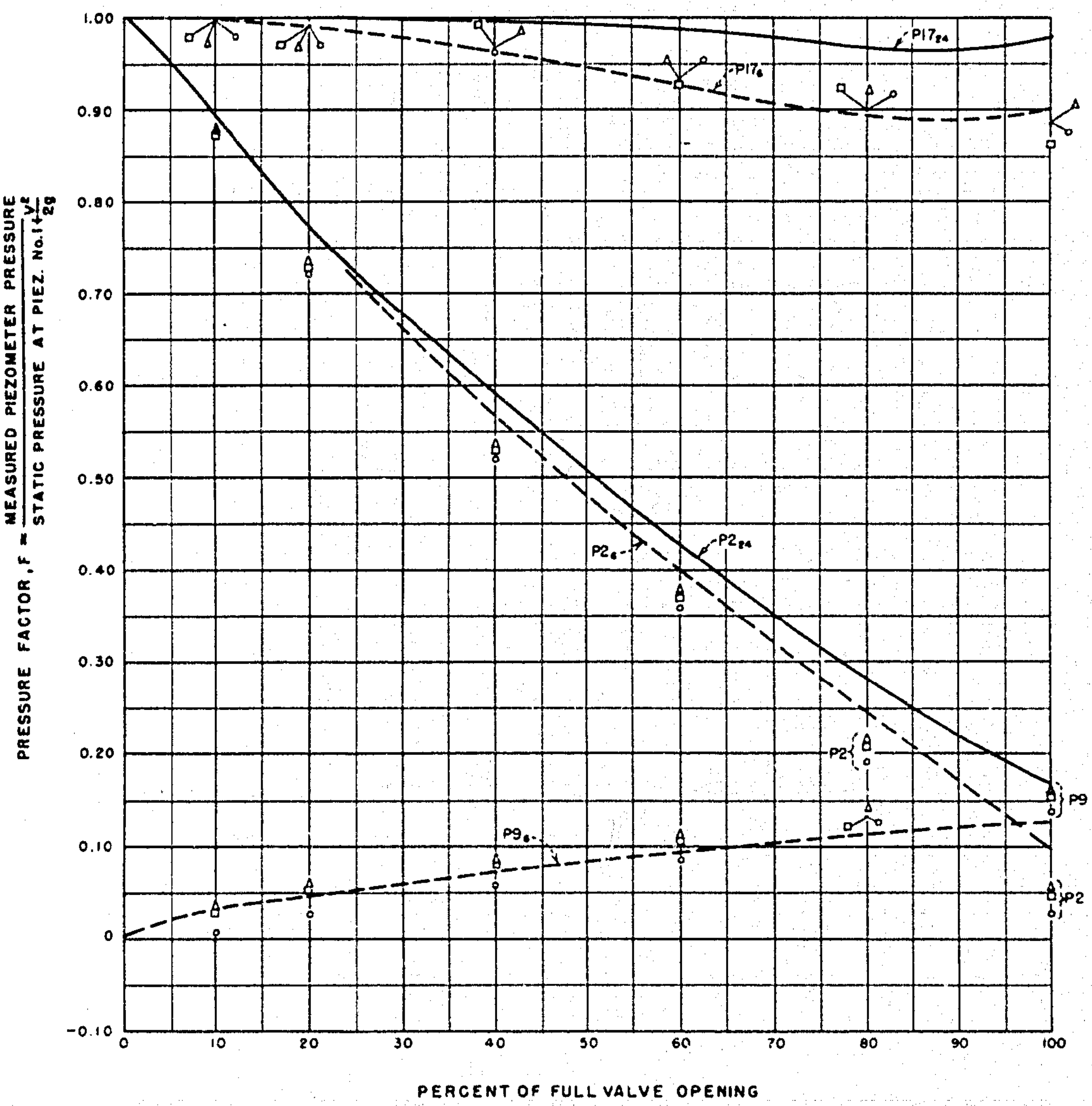
o RESERVOIR ELEVATION 433.98
□ RESERVOIR ELEVATION 512.32
Δ RESERVOIR ELEVATION 554.40

NOTE

Prototype data shown by symbols.
24-Inch model data shown by solid lines.
6-Inch model data shown by broken lines.

FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
PIEZOMETERS 20 AND 24

3-15-54 D.M.L



SYMBOLS

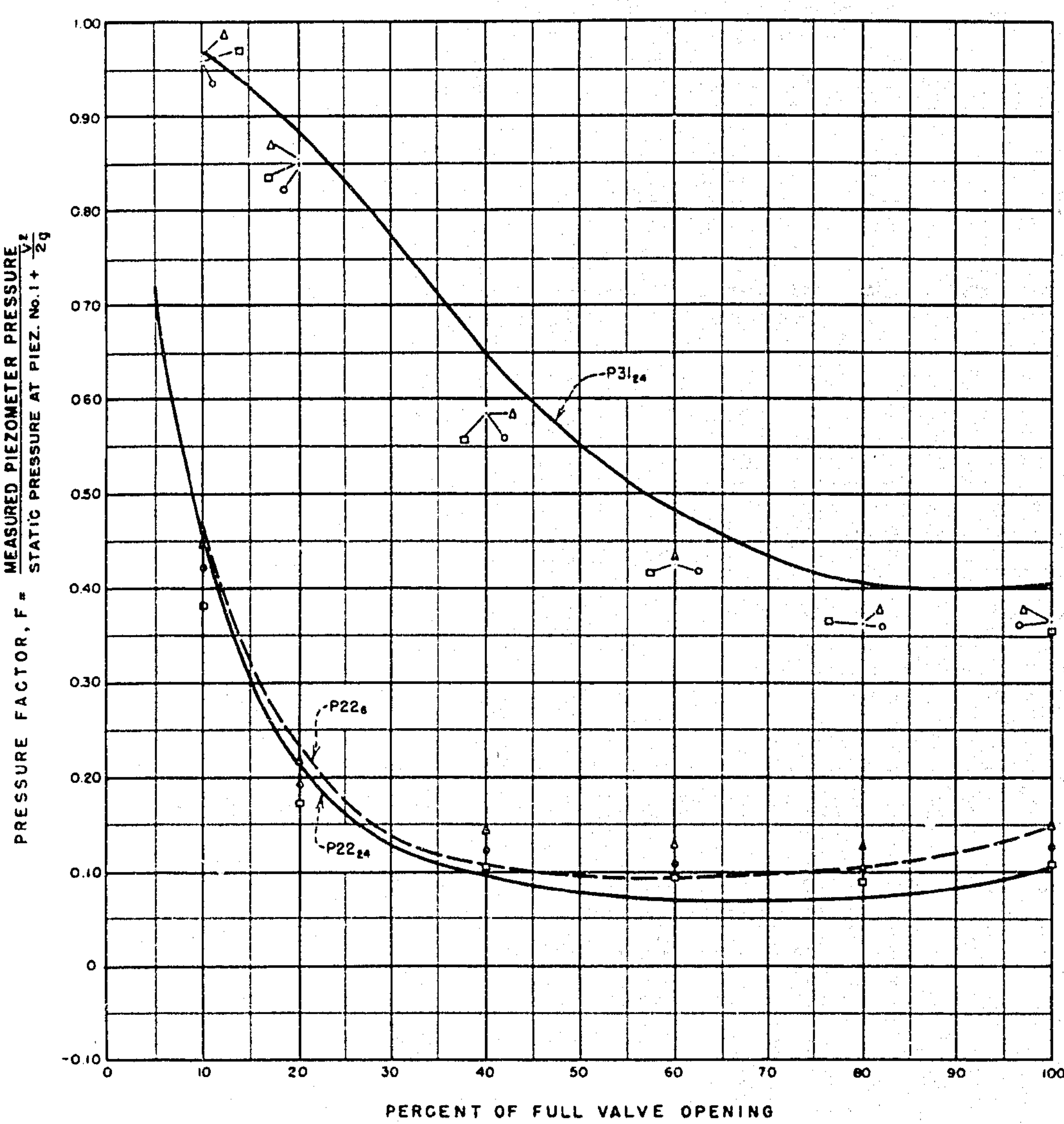
- ○ RESERVOIR ELEVATION 433.98
- □ RESERVOIR ELEVATION 512.32
- △ RESERVOIR ELEVATION 554.40

NOTE

Prototype data shown by symbols.
24-Inch model data shown by solid lines.
6-Inch model data shown by broken lines.

FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
PIEZOMETERS 2, 9 AND 17

880 3-18-54 D.M.L.



SYMBOLS

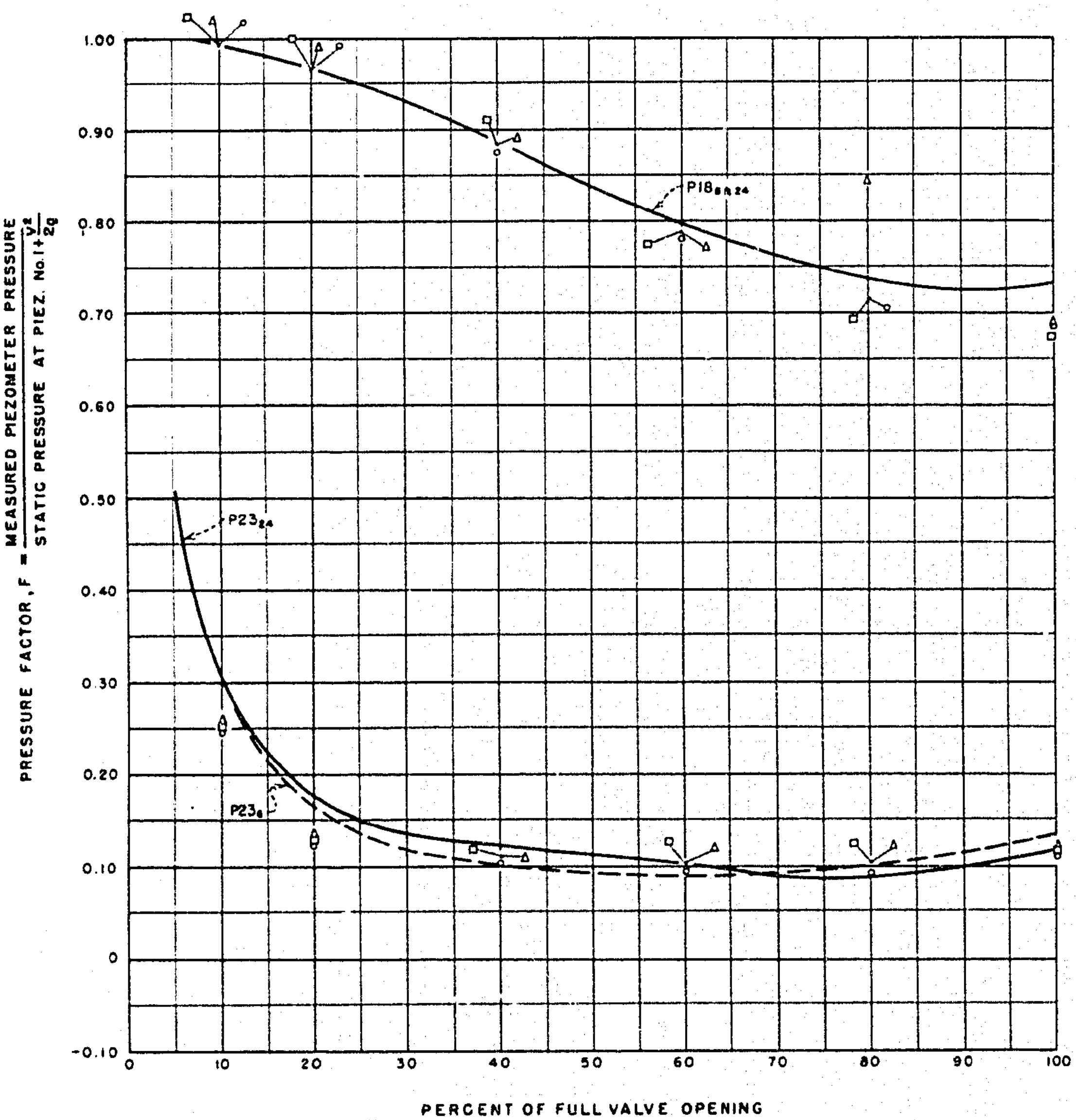
- ● RESERVOIR ELEVATION 433.98
- □ RESERVOIR ELEVATION 512.32
- ▲ RESERVOIR ELEVATION 554.40

NOTE

Prototype data shown by symbols.
24-inch model data shown by solid lines.
6-inch model data shown by broken lines.

FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
PIEZOMETERS 22 AND 31

3-15-54 D.M.L.



SYMBOLS

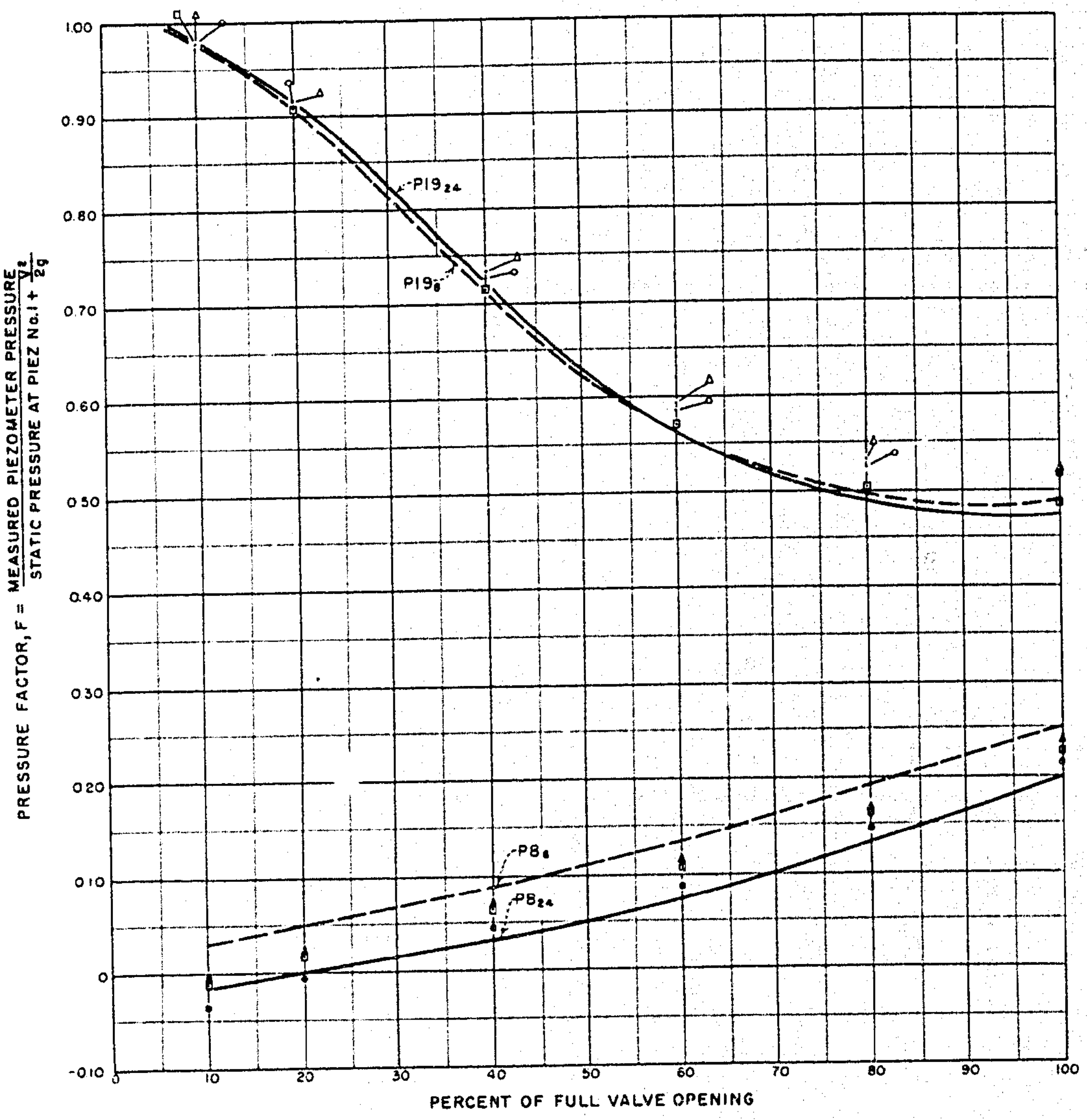
○ RESERVOIR ELEVATION 433.98
□ RESERVOIR ELEVATION 512.32
△ RESERVOIR ELEVATION 554.40

NOTE

Prototype data shown by symbols.
P23: {24-Inch model data shown by solid line. 6-Inch model data shown by broken line.
P18: 24-Inch and 6-Inch model data shown by solid line.

FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
PIEZOMETERS 18 AND 23

 3-15-54 D.M.L.



SYMBOLS

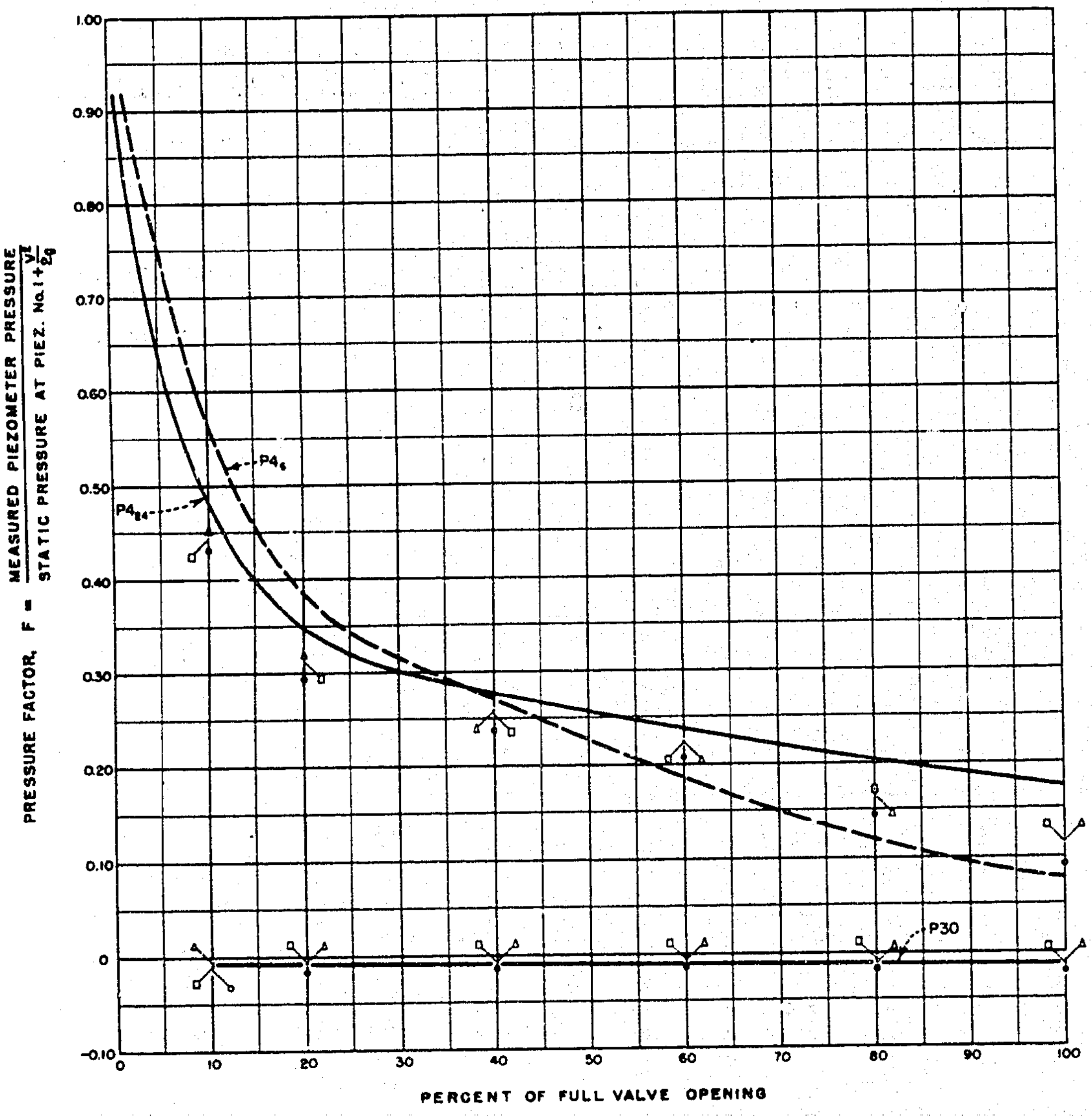
- ● RESERVOIR ELEVATION 433.98
- ◘ RESERVOIR ELEVATION 512.32
- ▲ RESERVOIR ELEVATION 554.40

NOTE

Prototype data shown by symbols.
24-inch model data shown by solid lines.
6-inch model data shown by broken lines.

FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
PIEZOMETERS 8 AND 19

 3-15-54 O.M.L.



SYMBOLS
○ RESERVOIR ELEVATION 433.98
□ RESERVOIR ELEVATION 512.32
△ RESERVOIR ELEVATION 554.40

NOTE
Prototype data shown by symbols.
24-Inch model data shown by solid lines.
6-Inch model data shown by broken lines.

FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
PIEZOMETERS 4 AND 30

280 3-18-54 D.M.L.

Figure 16
Report Hyd. 388

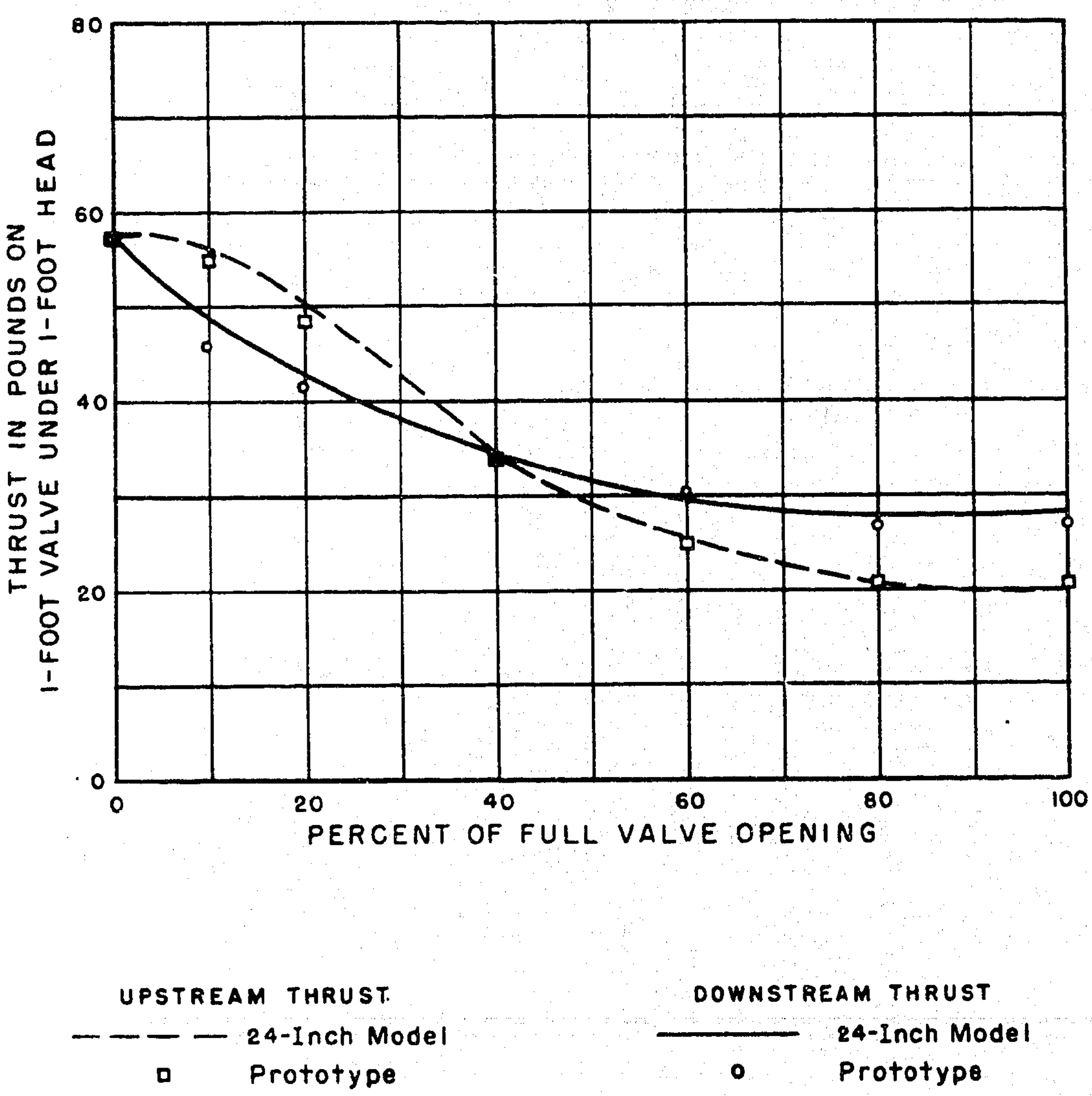
FRIANT DAM
HOLLOW JET RIVER OUTLET VALVE
Identification and Comparative Locations of Piezometers in the 6-inch Model, 24-inch Model, and 96-inch Prototype

Piezometer No.	6" model	24" model	96" prototype valve
1 to 7, incl.	Yes	Same	Same
8	Yes	Same	1/16" further upstream
9	Yes	None	5/16" further downstream
10 to 16, incl.	None	None	None
17 & 18	Yes	Same	Same
19 & 20	Yes	Same	3/64" further from ℄
21	Yes	Same	1/32" nearer ℄
22	Yes	Same	3/64" nearer ℄
23	Yes	Same	Same
24	Yes	Same	1/16" nearer ℄
25	None	Yes	Same
26	None	Yes	29/64" nearer ℄
27	None	Yes	1/64" nearer ℄
28	None	Yes	Same as 24-inch model
29	None	Yes*	Yes
30	None	None	Yes
31	Yes*	Yes*	Yes

*Exact location in the model unknown.

Figure 17
Report Hyd. 388

Cavitation erosion (dark spots) on body of river outlet hollow jet valve R-3, Friant Dam.



FRIANT DAM
RIVER OUTLETS
HYDRAULIC PERFORMANCE TESTS
THRUST ON NEEDLE

3-15-54. D.M.L.

FIGURE 19
REPORT HYD. 388

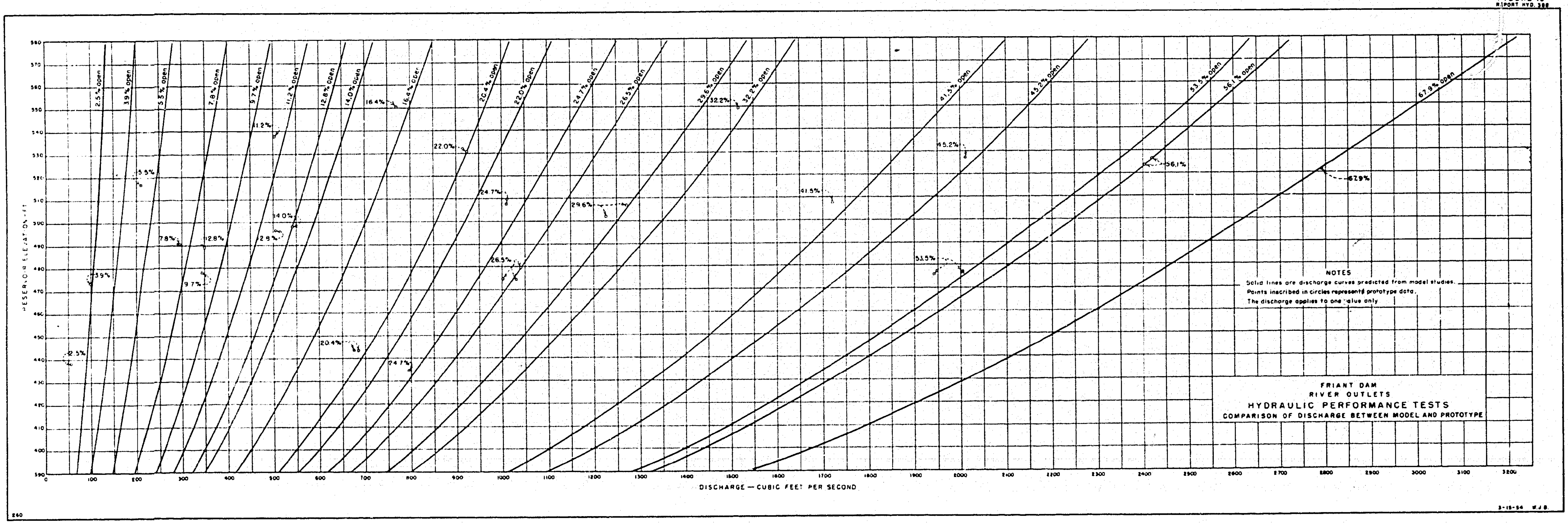
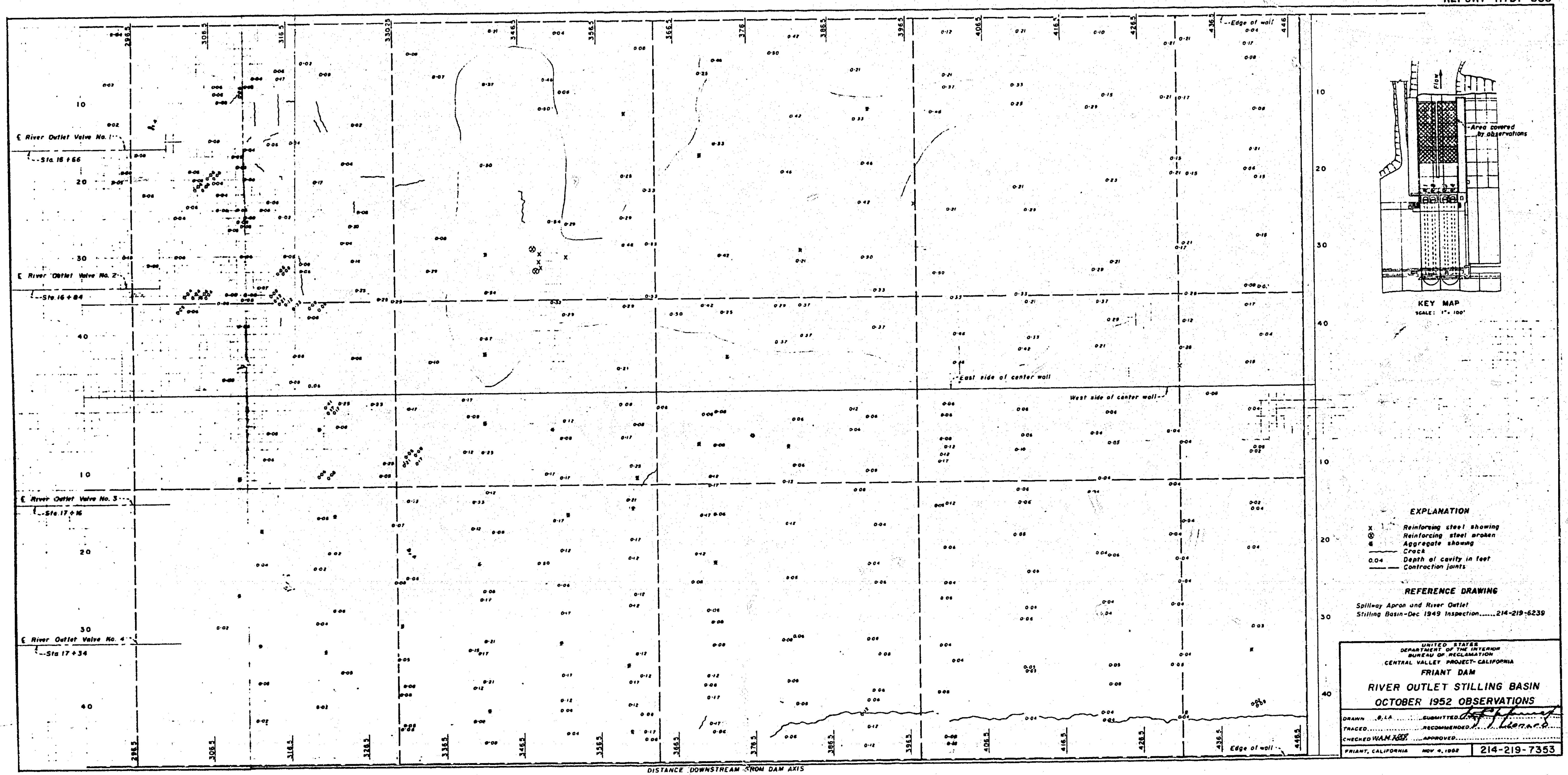


FIGURE 20
REPORT HYD. 388



APPENDIX I

Memorandum

Denver, Colorado
May 22, 1952

To: H. M. Martin

From: J. N. Bradley

Subject: Friant Dam river outlets

In accordance with your request, an investigation was made of the stilling basin for the Friant Dam river outlet works. D. M. Lancaster visited the project in October 1950 and observed the operation of the 96-inch hollow jet valves operating singly, with the reservoir at elevation 444, or 114 feet of head on the valves. Mr. Lancaster and the field personnel were not satisfied with the operation of the stilling basin, and all were of the opinion that the length was insufficient. A plan and section of the stilling basin are shown on Figure 1.

It was first desirable to determine the tail-water conditions under which the prototype stilling basin was operating. The only definite information that the project could offer in this respect was a table of water surface readings from the United States Geological Survey gaging station located 1-1/2 miles downstream. This information is plotted as the lower curve shown on Figure 2. The extreme upper curve on the same figure represents the estimated tail water at the dam and constitutes the curve that was used for the model study. The third or intermediate curve represents the present tail water at the dam which was scaled from photographs taken by Mr. Lancaster while the stilling basin was in operation. This was accomplished by noting the water surface with respect to the top of the dividing wall on the nonoperating side of the stilling basin (Figures 3, 4, and 5). The dividing wall is 4.0 feet wide. Figure 2 shows the present tail water at Friant Dam to be approximately one foot lower than the anticipated curve. It is not known whether the outlets were operated a sufficient time to allow the tail water in the river to build up to a maximum value. One foot difference in tail-water depth should not be critical in stilling basin operation.

It was next desirable to recall the operation of the model stilling basin. Figure 6 shows the model, which is on a scale of 1 to 32, with one valve operating at 3,000 cubic feet per second for maximum reservoir level. This is the best comparison available and corresponds to Figure 5 in so far as discharge is concerned. The comparison is not a true one, however, as the model was operated with reservoir at elevation 578 (332 feet of head) with anticipated tail water. While the prototype tests were made with the reservoir at elevation 444 (114 feet of head) with the present tail-water elevation.

The jump is practically out of the stilling basin in Figure 6A which is not considered satisfactory from either present or past standards. This can be remedied at the lower discharges, however, by operating more than one valve, as can be observed from the remainder of the model photographs on Figures 6 and 7. Regardless of valve combination, the discharge is limited to approximately 10,000 second feet for good operation at maximum head.

Figure 1 shows a section of the stilling basin as constructed. From personal recollection, although there is nothing to the effect mentioned in the report, good rock was experienced downstream from the stilling basin so it was decided to construct a short basin and allow some of the dissipation to occur downstream in the rock channel. There may have been a misconception at the time of the model tests as to the wall on the right side of the cut. This wall was carried up above high tail-water level in the model to confine the flow, Figures 6 and 7, whereas actually this wall is insufficient in height to extend above low tail-water level, Figures 3, 4, and 5. Energy dissipation in the two cases could be quite different.

The needle and tube valves for the river outlets were originally tilted downward at an angle of 10°. In 1944, after the stilling basin had been constructed, a second model was built in which the tube and needle valves were replaced with four 96-inch hollow jet valves. It was necessary, in this case, to reduce the tilt of the valves to 6° and remove as much as 15 inches of concrete from the trajectory face. As a result, the jets from the valves no longer followed the concrete trajectory for the maximum head, but struck in the pool proper as is evident in Figures 6, 7, and 8 effecting a reduction in the effective length of the pool. Referring to the final design, the following are excerpts from Hydraulic Laboratory Report No. 166.

> "All tests with any kind of valve have shown the pool to be under designed for the higher flows. Maximum capacity of the hollow jet valves was 16,000 second feet, but desirable pool conditions ended for a discharge of approximately 12,000 second feet. With the reduction in angle of tilt of the valves, the jets were not spread on the apron for operation at high heads and discharges. At the higher flows the jets persisted through the pool and struck the vertical end wall. The result was a violent

boil at the end of the pool and a sharp increase in velocity as the flow passed over the sill. Although the design was not entirely satisfactory for the higher flows, it was accepted as final, since the maximum flow conditions were not expected to occur often.

"When operating one or two valves with the corresponding tail-water elevation, the discharge for these valves was limited to a value lower than that which could be passed when more valves were operating. When the discharge per valve was high and only one or two valves were in operation, the energy of the jets was disproportionately high for corresponding tail-water elevations. Consequently, an insufficient amount of energy was dissipated in the pool to maintain the hydraulic jump. This condition was amplified with two valves discharging into one side of the pool. For operation with two valves, the most satisfactory conditions were obtained with one valve discharging into each half of the pool. The combined discharge should be limited to 5,000 second feet for any combination of two valves operating and to 2,000 second feet with one valve operation."

From the above, it is apparent that the model results were not in error, nor were the interpretations of the results. Design restrictions were imposed on the study which limited the end results. The limitations of the stilling basin, as determined by the laboratory, are clearly stated in the report. It recommends a maximum of 2,000 cfs for one-valve operation, a maximum of 5,000 cfs for two-valve operation, and a maximum of 12,000 cfs for four-valve operation, all at maximum head.

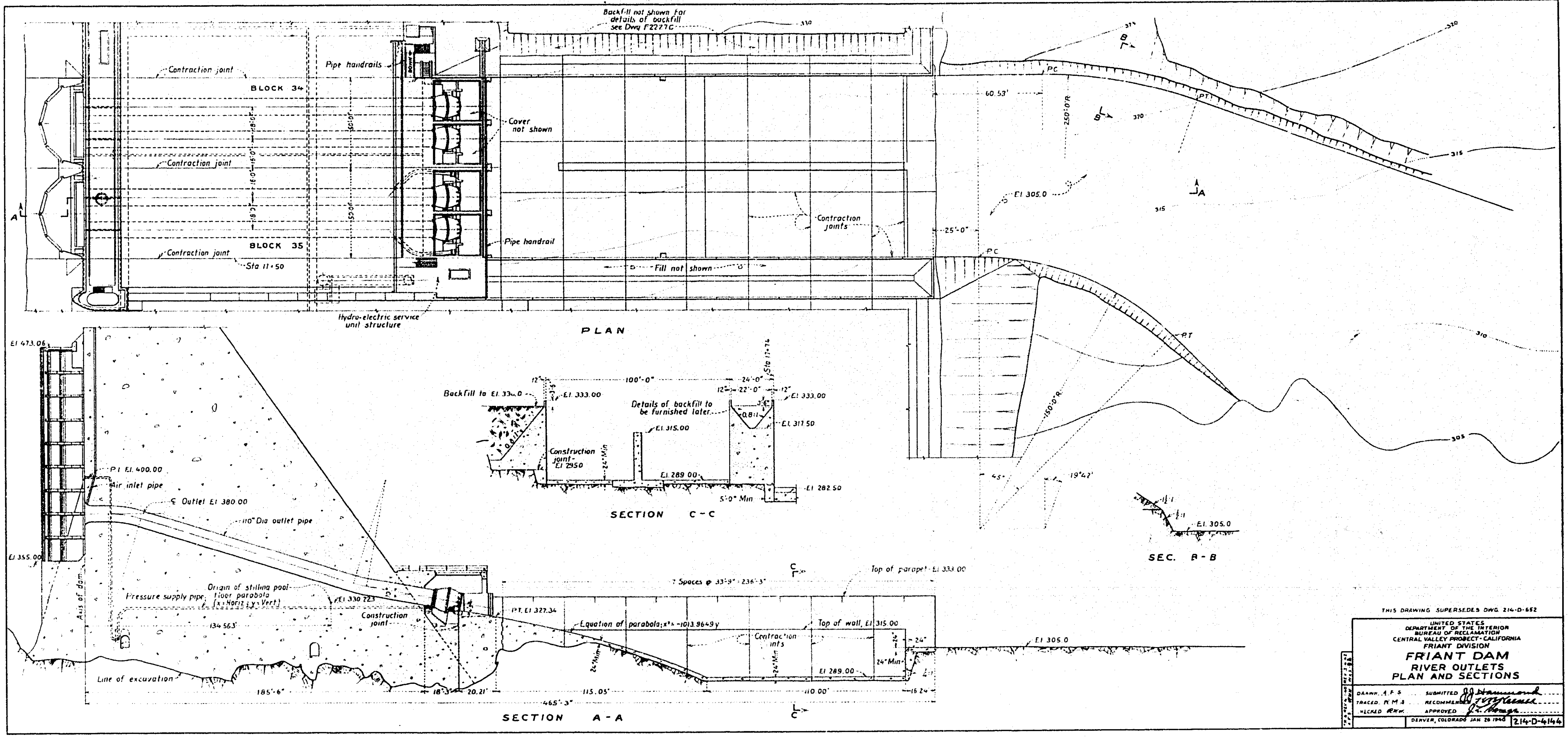
At the request of the laboratory the field made a survey of the rock cut immediately downstream from the stilling basin in January 1952. The results of this survey are included as Figure 8. A comparison of this figure with the design drawing, Figure 1 shows very little erosion to date. It should be made clear to the operating personnel and others concerned that the Friant River outlet works stilling basin was intended to operate with a very turbulent water surface downstream. There may be secondary effects such as erosion of riverbanks or scouring around bridge piers but it is felt that the structure proper will operate safely for sometime. Removal of some of the rock by erosion may improve the over-all effectiveness of the stilling basin. No immediate corrective measures are recommended, however, accurate records of erosion downstream should be taken periodically and filed.

There are two lessons to be learned from the experiences with the Friant Dam River outlets:

> First, the laboratory is probably partly at fault for not insisting that the structure operate properly for all anticipated flow conditions. It may be well to keep this incident in mind when testing future hydraulic structures. The designers are prone at times to impose restrictions in operation which are not compatible with necessary field operation. Also, they are occasionally too easily satisfied with a model test because of economic restrictions placed upon their activities. It is partly, without a doubt, our responsibility to see that these and future designs are considered with a long-range viewpoint.

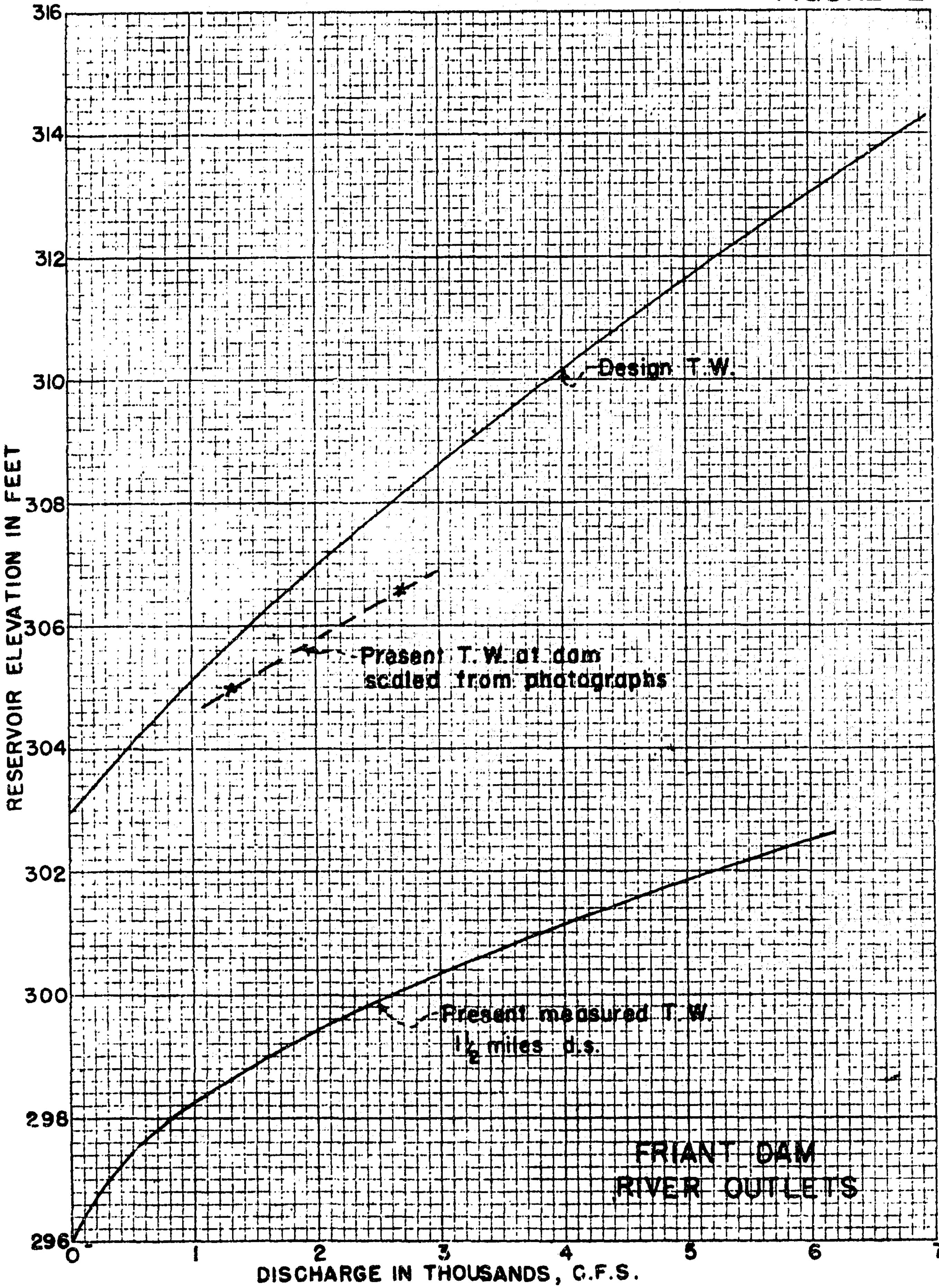
> Secondly, training walls and the walls resulting from excavation should not be extended higher in models than they actually are in the prototype, as was done here. This can lead to misinterpretation of results and erroneous reasoning as the result of viewing tests on models which are not constructed correctly.

FIGURE 1

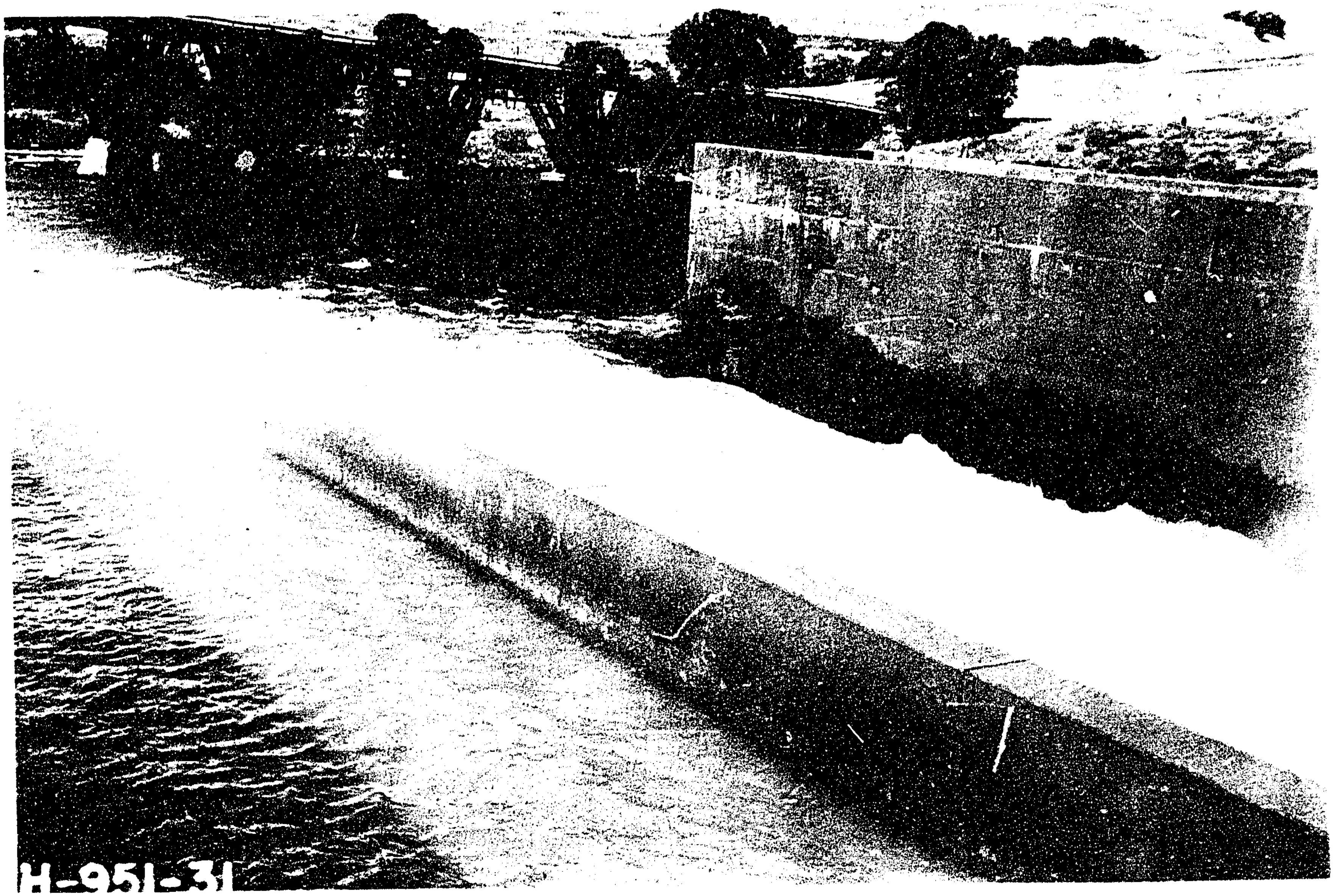


Backfill not shown for details of backfill see Dwg F2227C
Contraction joint
BLOCK 34
BLOCK 35
Pipe handrails
Cover not shown
Pipe handrail
Sta 11+50
Fill not shown
Hydro-electric service unit structure
Contraction joints
PLAN
P.C.
P.T.
250'-0" R
60.53'
25'-0"
El. 305.0
150'-0" R
19°47'
45°
SEC. B-B
El. 473.06
P.T. El. 400.00
Air inlet pipe
℄ Outlet El. 380.00
110" Dia outlet pipe
El. 355.00
Axis of dam
Origin of stilling pool floor parabola
Pressure supply pipe
El. 330.223
Construction joint
P.T. El. 327.34
Equation of parabola: x² = -1013.9649y
Top of parapet El. 333.00
7 Spaces @ 33'-9" = 236'-3"
Top of wall El. 315.00
Contraction joints
El. 289.00
Line of excavation
134.563'
185'-6"
18.3'
20.21'
115.05'
110.00'
465'-3"
SECTION A-A
Backfill to El. 334.0
El. 333.00
100'-0"
24'-0"
22'-0"
Details of backfill to be furnished later
El. 315.00
El. 317.50
Construction joint El. 295.0
El. 289.00
El. 282.50
5'-0" Min
SECTION C-C
THIS DRAWING SUPERSEDES DWG. 214-D-652
UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
FRIANT DIVISION
FRIANT DAM
RIVER OUTLETS
PLAN AND SECTIONS
DRAWN A.F.S.
TRACED R.M.S.
CHECKED R.W.W.
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO JAN 26 1940
214-D-4144

FIGURE 2

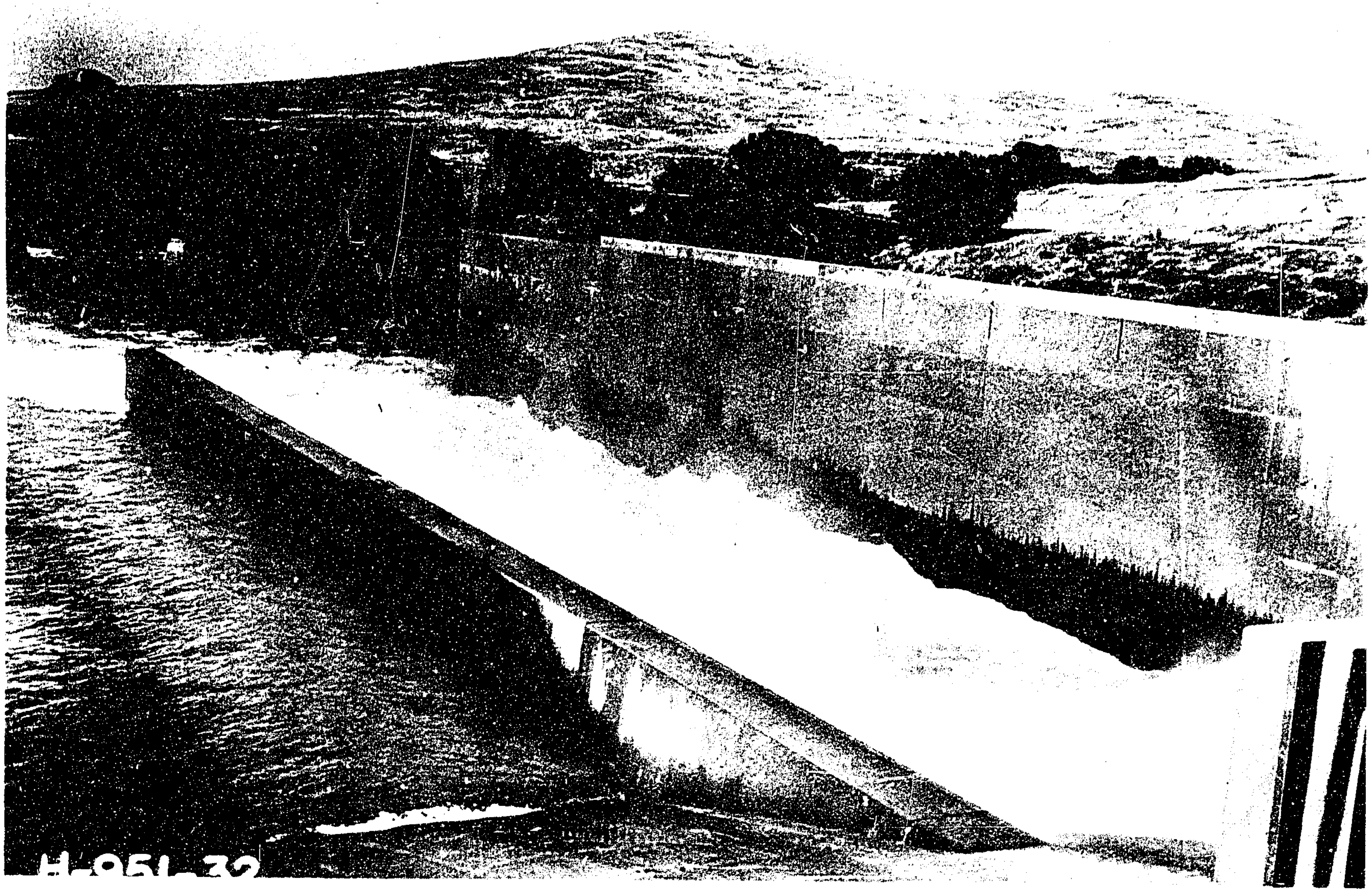


316
314
312
310
308
306
304
302
300
298
296
0
1
2
3
4
5
6
7
RESERVOIR ELEVATION IN FEET
DISCHARGE IN THOUSANDS, C.F.S.
Design T.W.
Present T.W. at dam scaled from photographs
Present measured T.W. 1½ miles d.s.
FRIANT DAM
RIVER OUTLETS



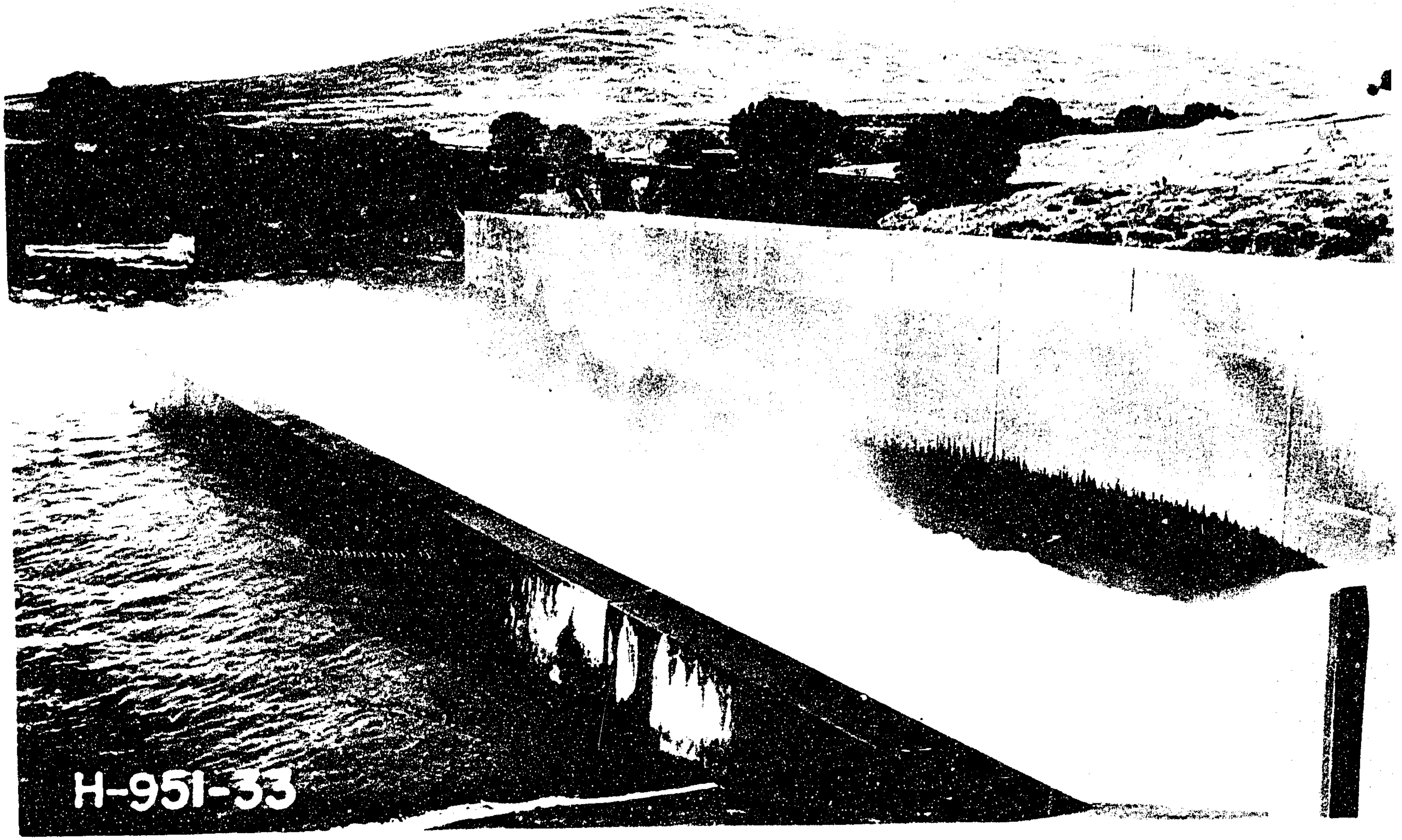
River Outlets--Friant Dam
Third Valve from Left Open 40%
Head 114 feet -- Q = 1,300 cfs

Figure 3



River Outlets - Friant Dam
Third Valve from Left Open 40%
Head 114 feet -- Q = 1,300 cfs

Figure 4



River Outlets--Friant Dam
Third Valve from Left 100% Open
Head 114 feet -- Q = 2,700 cfs

Figure 5

Figure 6

A--Discharge 3,000 cfs
One valve 62% open

B--Discharge 4,000 cfs
One valve 81% open

C--Discharge 5,000 cfs
Two valves 50% open

D--Discharge 5,000 cfs
Two valves 50% open

RIVER OUTLETS--FRIANT DAM
HEAD 332 FEET
1:32 Scale Model
FINAL DESIGN

A--Discharge 3,000 cfs
One valve 62% open

B--Discharge 4,000 cfs
One valve 81% open

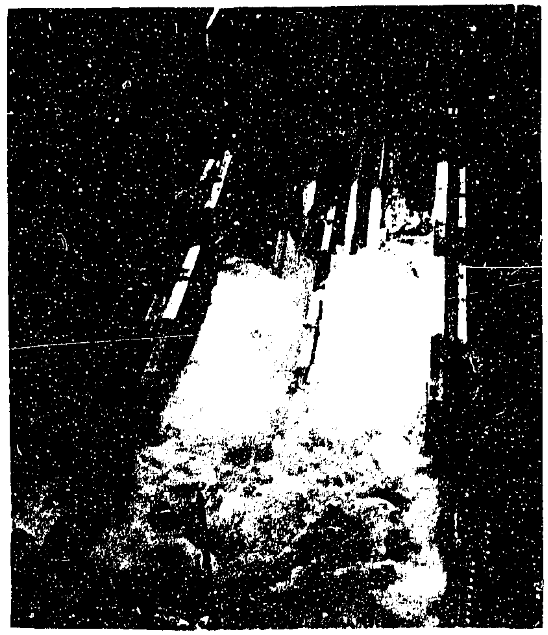
C--Discharge 5,000 cfs
Two valves 50% open

D--Discharge 5,000 cfs
Two valves 50% open

RIVER OUTLETS--FRIANT DAM
HEAD 332 FEET
1:32 Scale Model
FINAL DESIGN

Figure 7

A--Discharge 8,000 cfs
Two valves 90% open

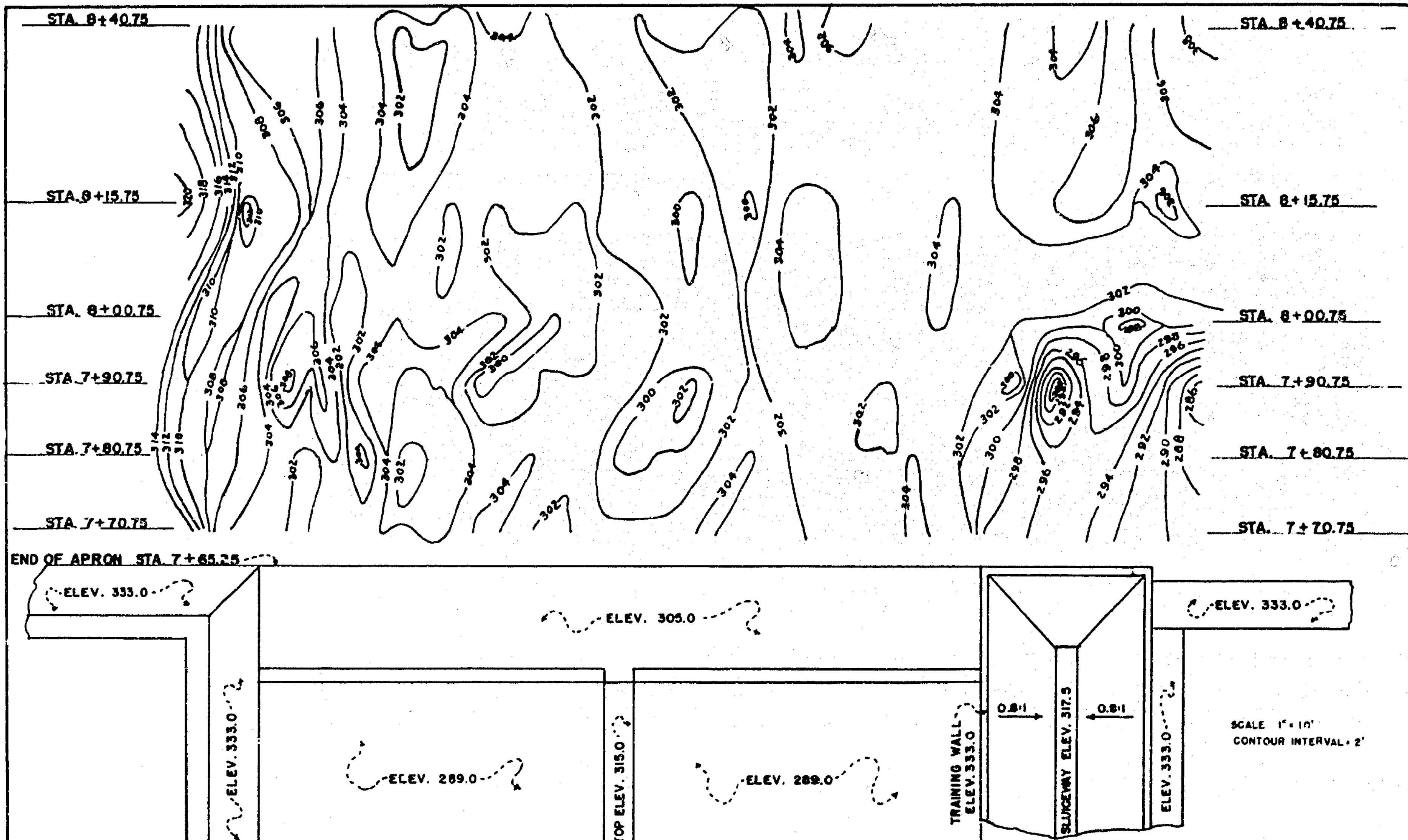


B--Discharge 8,000 cfs
Two valves 90% open

C--Discharge 6,000 cfs
Four valves 30% open

D--Discharge 16,000 cfs
Four vlaves 91% open

RIVER OUTLETS--FRIANT DAM
HEAD 332 FEET
1:32 Scale Model
FINAL DESIGN



FRIANT DAM

SCOUR DOWNSTREAM FROM RIVER OUTLET STILLING POOL AS OF JANUARY, 1952

FIGURE 8