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DEPARTMENT OF THE INTERIOR
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HYDRAULIC LABORATORY REPORT NO. HYD-56.1

Technical Memorandum No. 578

HYDRAULIC MODEL STUDIES FOR THE DESIGN OF THE BOULDER DAM POWER PLANT ENERGY ABSORBERS

By

HAROLD D. BRILEY and G. J. HORNSBY

Denver, Colorado,
July 14, 1938

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

- - - -

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: HYDRAULIC MODEL STUDIES FOR THE DESIGN OF THE BOULDER DAM POWER PLANT ENERGY ABSORBERS

- - - -

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TECHNICAL MEMORANDUM NO. 578

Denver, Colorado,

July 14, 1938

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CONTENTS

Page No.

Introduction and Summary

Introduction:
1. History and description..... 1
2. Personnel..... 2
3. Scope of tests..... 2

Summary:
4. Results and conclusions,
(a) Elbow and bowl types..... 5
(b) Cylindrical types,
(1) Horseshoe-shaped exit..... 6
(2) Circular exit..... 7

Model Tests of Energy Absorbers:
5. Description of the models,
(a) General..... 7
(b) Elbow type,
(1) Two-inch section model..... 8
(2) One-half section model..... 8
(c) Bowl type..... 8
(d) Modified bowl type..... 13
(e) Circular chamber type..... 13

Discussion of Results

Original and Replacement Units:
6. Tests 1 and 2 - Two-inch section model..... 19
7. Test 4 - Half-section model..... 19
8. Test 5 - Bowl-type model..... 24
9. Tests 13 to 22 - Modified bowl-type model... 29

Cylindrical Type with Horseshoe-Shaped Exit:
10. Test 6..... 42
11. Test 7..... 42
12. Test 8..... 49
13. Test 9..... 49
14. General..... 49
15. Flow lines..... 53

Cylindrical Type with Circular Exit:
16. Test 10..... 53

Summary of Field Reports and Tests

Field Tests of N-1 to N-4 Type of Relief Valve and Energy Absorber..... 60
Field Tests of N-5 and N-6 Type of Relief Valve and Energy Absorber..... 65

ILLUSTRATIONS

Figure No.		Page No.
1	Energy absorber - Units N-5 and N-6.....	3
2	Design of relief valve and energy absorber for units N-1 to N-4, inclusive.....	4
3	Location of piezometers in 2-inch section model.....	9
4	Test set-up for model of Boulder Dam energy absorber.....	10
5	Location of piezometers in one-half section model.....	12
6	Location of piezometers in bowl-type model....	14
7	Units N-1 to N-4, inclusive, Boulder Dam energy dissipator.....	15
8	Assembly section of test model.....	16
9	Location of piezometers on model (cylindrical type).....	18
10	Flow lines in energy absorber model.....	23
11	Energy absorber - Replacement units N-5 and N-6.....	25
12	Flow lines in energy absorber model.....	26
13	Flow lines in energy absorber model.....	27
14	Test set-up of model of Boulder Dam energy dissipator - Units N-1 to N-4, inclusive....	30
15	Chamber-type unit.....	43
16	Flow lines in energy absorber model.....	46
17	Flow lines in energy absorber model.....	47
18	Flow lines in energy absorber model.....	48

ILLUSTRATIONS (Continued)

Figure No.		Page No.
19	Flow lines in energy absorber model.....	50
20	Flow lines in energy absorber model.....	54
21	Coefficient of loss of energy absorber.....	56
22	Coefficient of loss of energy absorber.....	57
23	Boulder Dam energy absorber - Location of piezometer for field test data.....	63
24	Gate opening - Performance test of N-6 (at actual test heads) September 1938.....	67

INTRODUCTION AND SUMMARY

Introduction

1. History and description. The energy absorbers, or energy dissipators as they are sometimes called, are defined by A. Schoklitsch as follows: "Water released at dams or outlet works arrives at the foot of the structure with such a high kinetic energy that without particular precaution, deep scouring at the foundation is to be feared, which may endanger the safety of the entire structure. In order to forestall such dangers, this kinetic energy is transformed, as much as possible, into heat energy which is not readily reconvertible into mechanical energy. From the standpoint of the hydraulic engineer, this destructive energy of motion is rendered harmless and is also dissipated at the same time. The auxiliary structure which produces this transformation of energy is called in short, an energy destroyer, or energy dissipator."

In order to describe the action of energy dissipators, it is necessary to divide them into two groups. In the first group may be included all devices such as sills, baffles, buckets, and piers which are used at the foot of overflow dams, chutes, and drops, or in short all hydraulic structures in which the flow is open to the atmosphere. The second group includes all devices used for energy dissipation when the water is confined and under pressure. It is with this second group that this report deals and is an attempt to clarify this confined flow phenomena in certain types.

The purpose of the energy absorbers, or so-called dissipators, when used in connection with water turbine power units, is to relieve the excess pressure in the scroll cases and penstocks of the turbine units which would result from sudden or rapid closure of the wicket gates. Sudden closure of the gates may be caused by mechanical failure of the governor or gate-operating mechanism, while rapid closure of the gates will result from sudden dropping of the electrical load from the generator.

This energy absorber consists of a relief valve connected directly to the scroll case and discharging into a chamber connected to a water passage leading to the tailrace. The relief valve is controlled by the gate-operating mechanism and the pressure in the scroll case. The purpose of the chamber is to dissipate the energy of the water flowing at high velocity through the relief valve in case of abnormally rapid closure of the gates.

In connection with the installation of the power units at Boulder Dam, it was thus necessary to equip each such installation with one of these devices. In accordance with the specifications, these were to be designed and installed by the contractor under the supervision of the United States Bureau of Reclamation. During the operating test conducted on unit N-1, which is similar to units N-5 and N-6, excessive vibration and water-hammer disturbances set up by cavitation in the discharge passage were noted. Upon examination of the absorber unit after the test, the plate vanes supporting the baffle plate were found to have failed, and the unit was rejected by the Bureau of Reclamation. These two designs are shown on figures 1 and 2. For the first model tests, the type designed for units N-5 and N-6 was tested with piezometers installed as shown on figure 3. After this test, it was suggested that it would be advisable to build a model of the original unit (N-1) to determine, if possible, the cause for this failure and to make sure that the unit designed for replacement would be satisfactory. From and upon the merits of the results from these model tests, it was recommended that the other types which were proposed to accompany the later power-unit installations be tested in the same manner before they were built. It is upon this basis that this report has come to order.

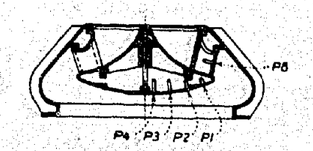
2. Personnel. The hydraulic model studies on the Boulder Dam energy absorbers, as described in this report, were made in the hydraulic laboratory of the United States Bureau of Reclamation at Denver, Colorado. These studies were begun under the direction of J. E. Warnock, Research Engineer, and completed under G. J. Hornsby, Engineer.

The construction and testing of the model were done under the supervision of Harold D. Briley, Junior Engineer, assisted by Frank Tessitor, Junior Engineer.

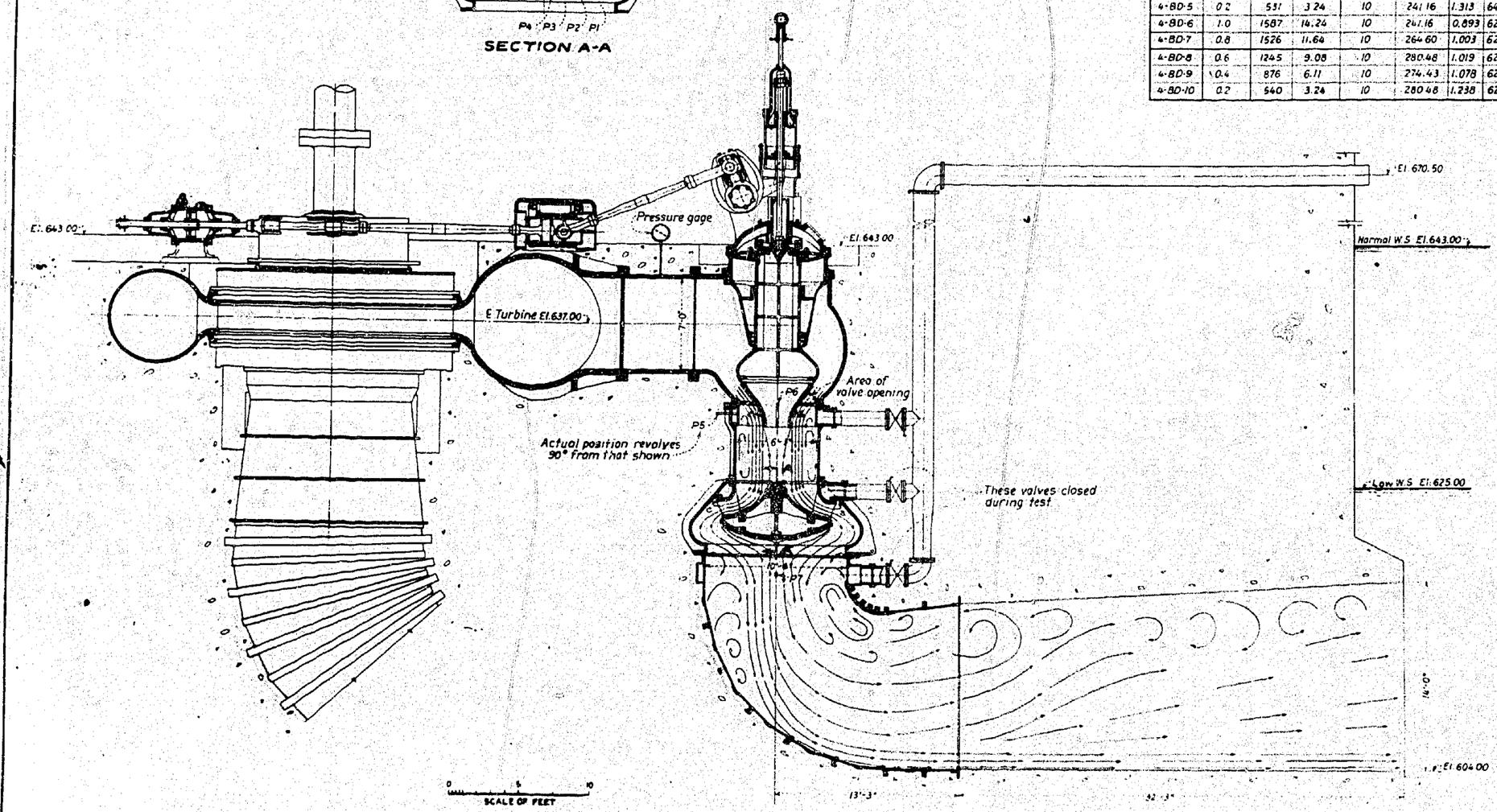
These studies were made under the general supervision of J. L. Savage, Chief Designing Engineer, and Arthur Ruettgers, Senior Engineer. All engineering work of the Bureau of Reclamation is under the direction of R. F. Walter, Chief Engineer, and all activities of the Bureau are under the direction of John C. Page, Commissioner.

3. Scope of tests. The models of the energy absorbers were studied qualitatively and quantitatively in order to determine the cause for the failure of the original unit and to verify the anticipated results of the new units.

FIGURE 1



SECTION A-A



FLOW CONDITIONS WITH FULL VALVE STROKE AND NORMAL TAILWATER AT EL. 643.0

TEST No.	GATE OPENING	Q SEC. FT	AREA OF VALVE OPENING	PRESSURE POUNDS	HEAD (h) LOSS ABOVE T.W. ELEV	C	TAIL-WATER	P1	P2	P3	P4	P5	P6	P7	P8
4-BD-1	1.0	1523	14.24 ▫'	10	223.02	0.892	642.76	-1.50	10.99'	19.10'	22.98	2.95	0.00	16.56	21.84
4-BD-2	0.8	1400	11.64	10	245.70	0.955	642.76	0.90	12.79	17.94	24.06	-30.65	-12.00	15.64	19.56
4-BD-3	0.6	1234	9.08	10	244.94	1.081	642.76	4.86	14.83	21.14	24.78	-47.87	-41.40	17.54	16.62
4-BD-4	0.4	876	6.11	10	261.58	1.105	643.00	12.66	21.19	25.94	29.10	-43.67	-45.00	18.93	14.88
4-BD-5	0.2	531	3.24	10	241.16	1.313	642.52	15.90	12.27	20.86	26.82	-28.73	-45.00	21.50	16.44
4-BD-6	1.0	1587	14.24	10	241.16	0.893	625.00	-20.10	-5.81	3.86	7.14	-13.37		-7.15	4.26
4-BD-7	0.8	1526	11.64	10	264.60	1.003	625.24	-18.18	-4.85	3.98	8.46	-50.39	-45.48	-5.74	2.04
4-BD-8	0.6	1245	9.08	10	280.48	1.019	625.12	-10.50	1.99	9.50	13.50	-62.99	-70.80	-2.86	3.84
4-BD-9	0.4	876	6.11	10	274.43	1.078	625.00	-4.50	4.51	9.38	12.06	-61.43	-68.88	-1.66	-3.00
4-BD-10	0.2	540	3.24	10	280.48	1.238	624.64	-1.50	4.75	7.58	9.90	-50.87	-63.00	3.62	-1.98

From these tests the following deductions may be made:
(a). A positive pressure exists on the under side of the conical baffle at points P1 to P4 except at low tailwater, when low negative pressures occur toward the edges of the baffle. This indicates that the pipe and valve provided for the admission of atmospheric air to the under side of the baffle are not required.
(b). A positive pressure is maintained at the outlets from the annular wind box at P7 except at low tailwater. Therefore the air pipe and valve provided for the admission of atmospheric air to the wind box are not required.
(c). A negative pressure exists for practically all conditions of flow and elevation of tailwater at P5, which accounts for the coefficient of discharge of the relief valve being greater than unity. With admission of atmospheric air it is expected that the coefficient will remain at approximately 0.90. Therefore the air pipe and valve provided at this point are necessary.
(d). The high negative pressures maintained at point P6, for all conditions of flow and elevation of tailwater, indicate the necessity of aeration at this point to avoid hydraulic shock due to cavitation and formation of vapor.

NOTES

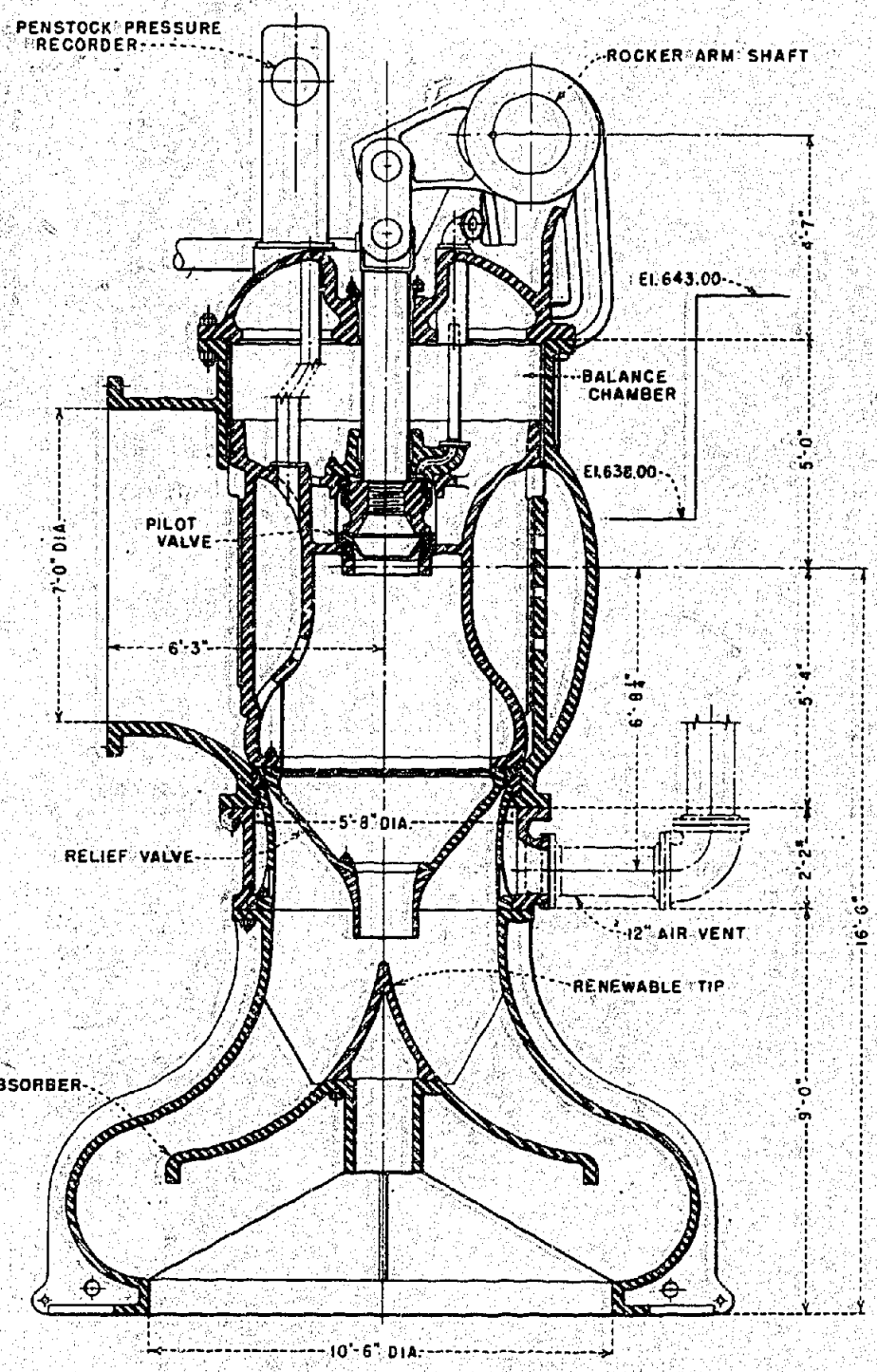
The column headed "C" is the coefficient obtained from the formula, $C = \frac{Q}{A\sqrt{2gh}}$
The scale of the model used in this test was 1"=1'-0".
For pressure and flow studies of bowl type energy absorber see Dwg. 45-D-11309

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
BOULDER POWER PLANT
TURBINES AND AUXILIARIES
ENERGY ABSORBER - UNITS N5 AND N6
PRESSURE AND FLOW STUDIES FROM MODEL TESTS

DRAWN P.S.O. SUBMITTED
TRACED N.T. RECOMMENDED
CHECKED R.B.K. APPROVED

DENVER, COLO. JUNE 15, 1937 | 45-D-10988

FIGURE 2



DESIGN OF RELIEF VALVE AND ENERGY ABSORBER FOR UNITS N-1 TO N-4

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Summary

4. Results and conclusions. (a) Elbow and bowl types.--The results obtained from the first model tested were very enlightening and furnished a basis for comparative study. When the second model of the original design was tested, it was possible, by comparison of pressures and flow conditions, to explain the causes for the conditions which had existed in the field. Although the pressures recorded from the second model did not exactly check with the ones from the first model, it was believed that the differences were due to the model designs.

The model of the replacement unit (bowl-type), as tested, indicated more nearly homologous flow conditions and dissipation of energy over the original elbow-type design, and it was well believed, from the model tests, that this type of energy absorber was an improvement over the original design, and this fact has been verified by later field tests.

Field reports indicate that the operation of the rebuilt type used for units N-1 to N-4 are now satisfactory and superior in performance to the type used for units N-5 and N-6, the difference in design of the two types of absorbers being in the design of the baffle plate, the supporting vanes, and the relief-valve chamber.

Although the recorded model pressures may be excessive, it is felt that they are quite closely related to the pressures that may be expected in the prototype, and, if used carefully, they may be of great value in future design. The flow conditions that existed in the bowl-type energy absorber have been carefully drawn on figures 10 and 11. It is believed that, by intelligent use of these indicated flow lines, the measured pressures, and the complete record of moving pictures, it will be possible to explain certain conditions and to foretell other conditions which might possibly arise.

After the model and field tests on the remodeled elbow type (bowl type) had indicated that the change from the elbow to the bowl would not entirely remedy the condition which existed, it was suggested by the manufacturers that a change be made immediately below the relief valve. This change was brought about by their observations and tests in the field and consisted of installing a steel throat liner extending from a point near the relief valve seat to a point near the lower air inlet entirely through the area formerly occupied by the baffle plate. Accordingly, a model, on a scale of 1 to 12, was constructed and tested in the laboratory. This model indicated without doubt that it was necessary to admit air to the area below the relief valve and that the inlet provided was suffi-

ciently large. The throat liner acted, in part, as a long tube which prevented a reversal of flow from the absorber chamber up to the valve seat. The reversal flow inherent with the first design caused alternate vacuum and pressure at the valve seat with resulting violent vapor explosions. These tests also indicated that improved flow conditions and dissipation of energy could be had by allowing the throat liner to extend into the large main chamber a short distance. It was also found that these flow conditions could be duplicated, if not improved, by a much simpler type of main-chamber roof. These two types of roofs are shown on figure 14.

(b) Cylindrical types.--

(1) Horseshoe-shaped exit.--It is felt that the results of these tests may be construed as being more nearly adapted to the conditions that will result in the prototype than the results found in the previous models. This differentiation can be made although the scale ratio used was smaller than that of the previous models. This model was a full section, whereas the other models were, with one exception, only part sections. Since no definite rule or formula has as yet been devised whereby the values derived from sectional models can be translated to full-section prototype dimensions, some hesitancy in predicting probable pressures or flow conditions is to be noted in the material presented on these sectional models. Although some of the recorded negative prototype pressures are unmistakably excessive, it is believed that, by careful use of both the positive and negative values, these data can be freely interpreted by the designer. To substantiate these recorded values, a complete set of observed flow lines under the various valve settings is shown on figures 17, 18, 19, and 20. Also, this flow phenomenon has been recorded by use of the slow-motion moving-picture camera and is available for study.

These tests have proven conclusively the need for the proposed wind chambers to aerate certain areas of the unit. It was found that the proposed two chambers would be sufficient and that it would not be necessary to provide additional air vents.

The coefficient of discharge was found to remain fairly constant and did not depend upon the valve opening or the discharge. At the same time, it was found that the velocities in the bottom of the draft tube did, as would be expected, depend upon the discharge, increasing as the discharge increased.

But even with a high discharge, the velocity, which reached a maximum of only 35 feet per second, was not exceedingly high. These conclusions have been verified by soundings in the tailrace opposite the relief-valve discharge opening where erosion of the sand and gravel backfill has reached a depth of only three feet. From these tests it was found that the main chamber of the unit could be shortened, effecting a material saving in rock excavation, construction work, and cost of the unit. From and upon the merits of these tests it is recommended that the wind chambers be installed as designed, that the spider guide arm be aerated at all possible points, and that the main chamber of the unit be shortened. It is also believed, from the study of these tests, that a definite and sufficient dissipation of energy will result and that there will not result any adverse flow conditions. It is again advised that caution be used and that careful interpretation be made in the use of these data.

(2) Circular exit.--The tests of this type of energy absorber have indicated that it should operate effectively in the field. That is, as far as can be determined from the model, the shock to and the vibration of the unit will be at a minimum. The pressures recorded from the model parallel very closely the values found in the previous model while operating under the same conditions. As commented upon before, these values are all within the design range and represent, with one exception, conditions of stable flow. This exception is in the area immediately below the circular valve. In the set of check runs made, values quite different from the previous ones were found to exist in this area. When this condition was discovered, more data were taken at these points, and it was also found to vary, which indicates unstable flow.

The observed and measured velocities in the draft tube varied slightly in this case. Visually, the flow appeared to be more evenly distributed throughout the draft tube whereas, in the previous model, it had appeared to be concentrated along the bottom of the tube. Slightly higher average measured velocities were recorded from this model, which were due, no doubt, to the smaller discharge area from the main unit.

Model Tests of Energy Absorbers

5. Description of the models. (a) General.--Six models of the energy absorbers were constructed in the Denver hydraulic laboratory which is located in the basement of the Customhouse building. The water was supplied to the models by pump, through a cir-

culating system, and the flow was controlled by a gate valve (fig. 4). The tail-water level was also controlled by a gate valve below the tail-water box. The discharge was measured over a 2-foot sharp-crested weir located in the return flume to the pump sump. The head on this weir was measured by a hook gage located in a stilling well connected to the return flume. The pressure in the supply line was held constant for all tests on the models. In order to have the test material available for later study and demonstration, a complete record of each test was made by use of the slow-motion moving-picture camera, which, due to the scale ratio, reduced the model velocity to very near that of the prototype.

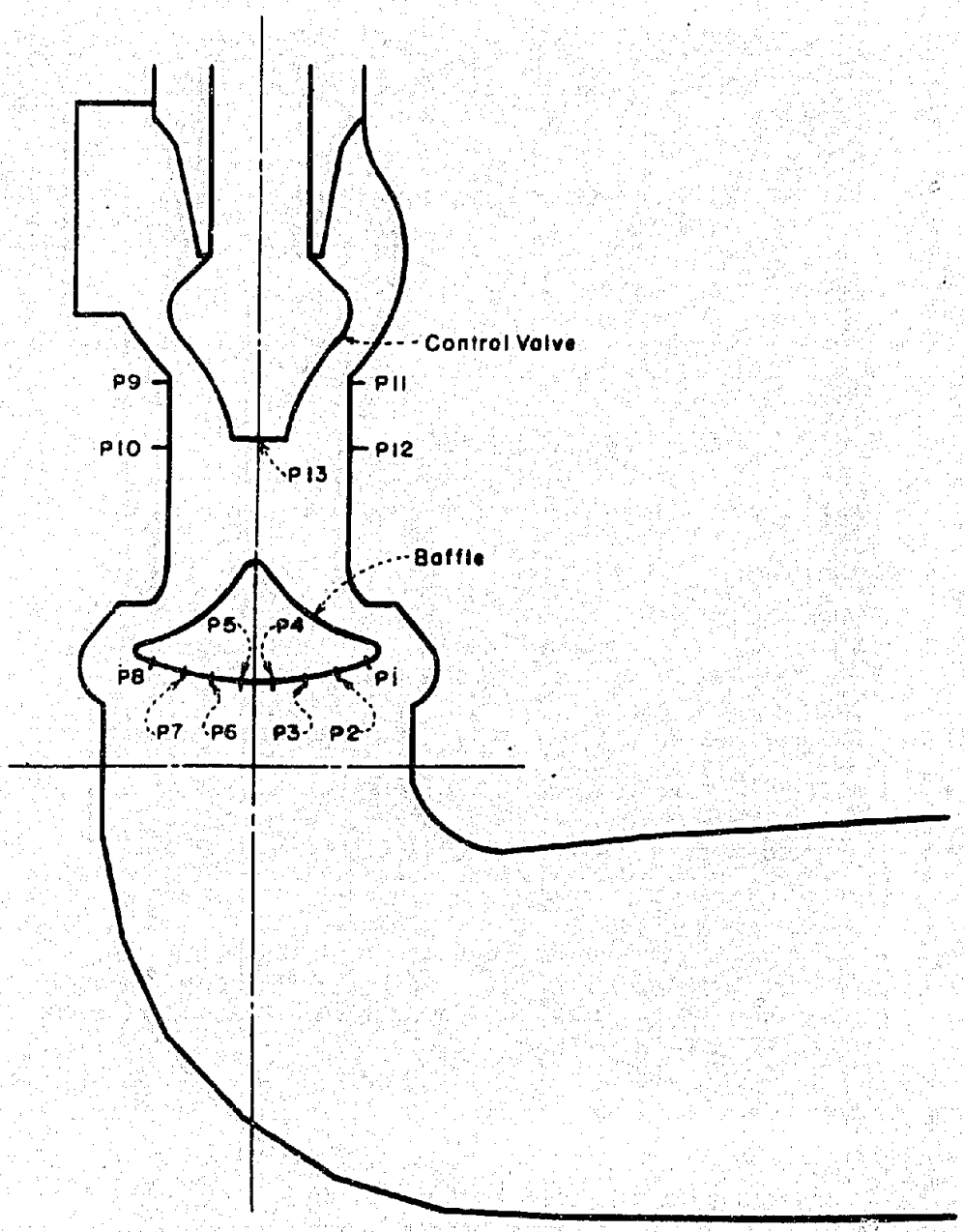
(b) Elbow type.--

(1) Two-inch section model.--This model was built on a scale of 1 to 12 and was only two inches thick, that is, one inch in thickness on each side of the vertical plane in the downstream direction. Due to this fact, it was possible to form the model by cutting from a 2-inch timber the outline of the energy absorber and then covering both faces with 1/4-inch thick pyralin to form the closed section and to facilitate the viewing of the flow phenomena (photograph A, plate 1). The baffle and the control vavle were also made of wood. It was possible to regulate the discharge opening by moving this control valve with a screw arrangement. Piezometers for pressure measurements were installed on the model, as shown on figure 3.

(2) One-half section model.--The models of the elbow and the bowl type were constructed in half section on a scale ratio of 1 to 12. The back and the upper part of the model were formed of wood in semicircular section, while the face and the lower part or elbow section were formed of pyralin (photograph B, plate 1). By use of the pyralin on the back and the face of the model, it was possible to light this area for photographing and visual study of the flow conditions. The control valve and the baffle were constructed of wood, as were the six vanes which support the baffle. Movement of the control valve and elevation of the tail-water were controlled as in the previous model. Piezometers for pressure measurements were installed at the same points as on the previous model (fig. 5).

(c) Bowl type.--The only portion of this model that differed from the previous type was the removal of the baffle and the replacement of the elbow by a circular bowl which was also constructed of pyralin (photograph C, plate 1). The remainder of the

FIGURE 3



LOCATION OF PIEZOMETERS
IN 2-INCH SECTION MODEL

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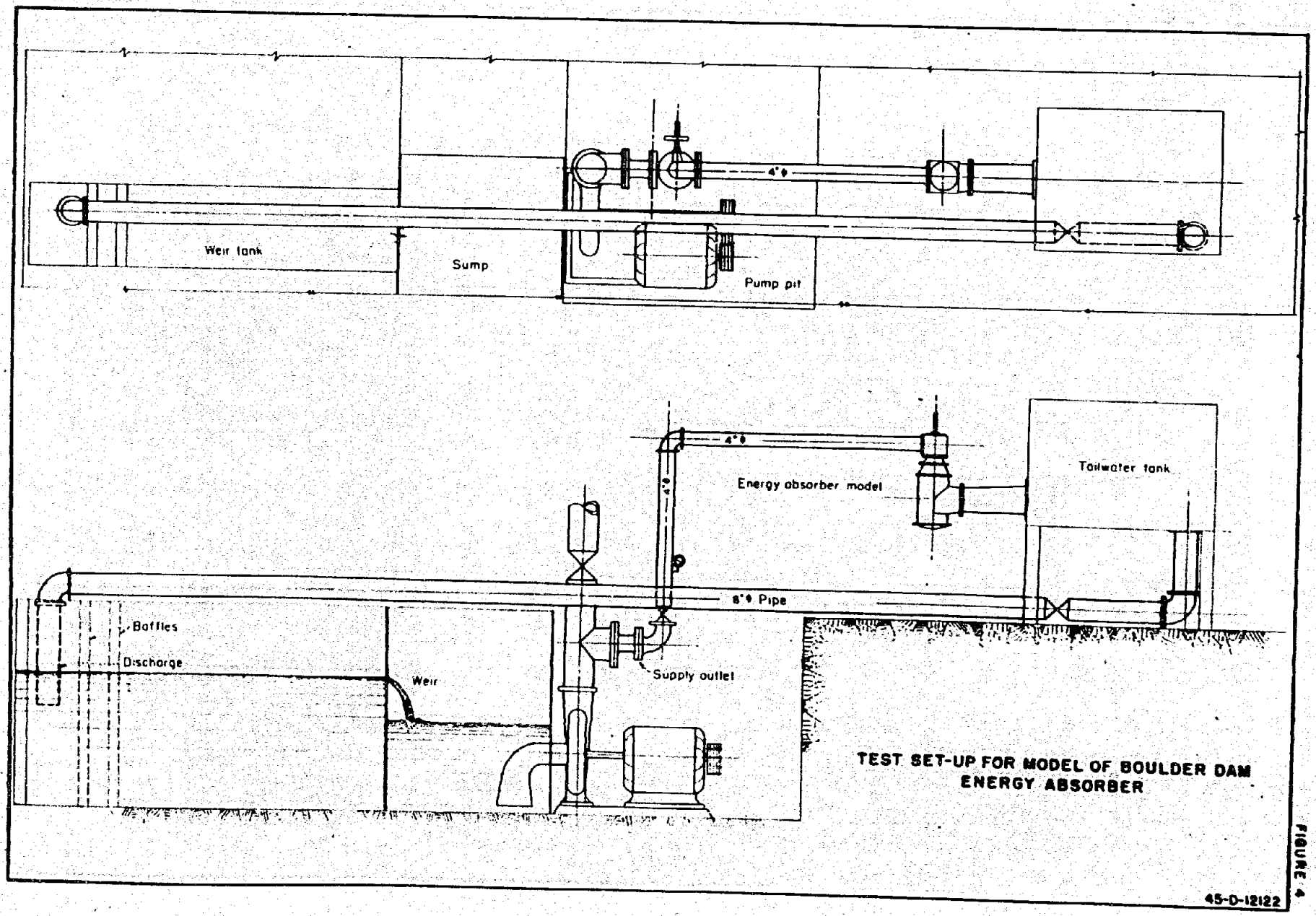
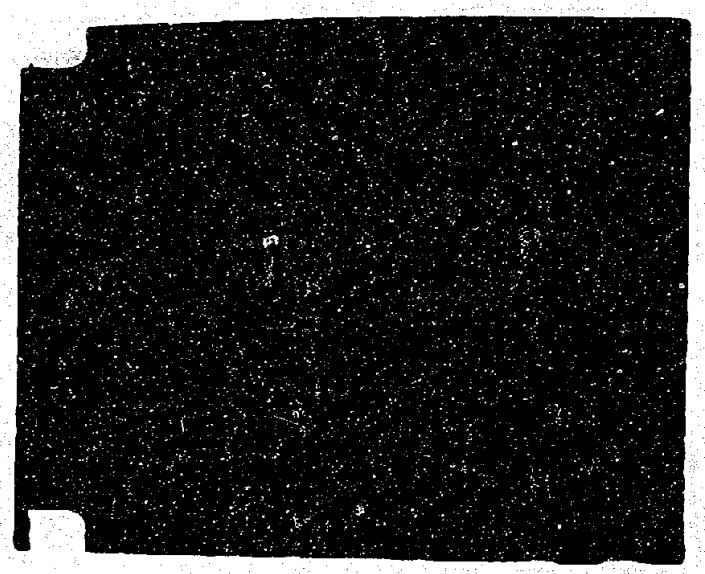


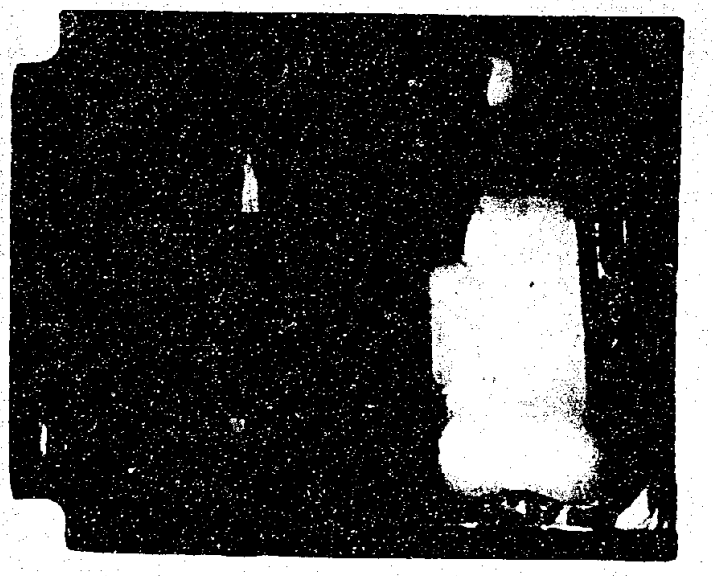
TEST SET-UP FOR MODEL OF BOULDER DAM ENERGY ABSORBER

FIGURE 4



A. - Flow in two-inch section of elbow-type model

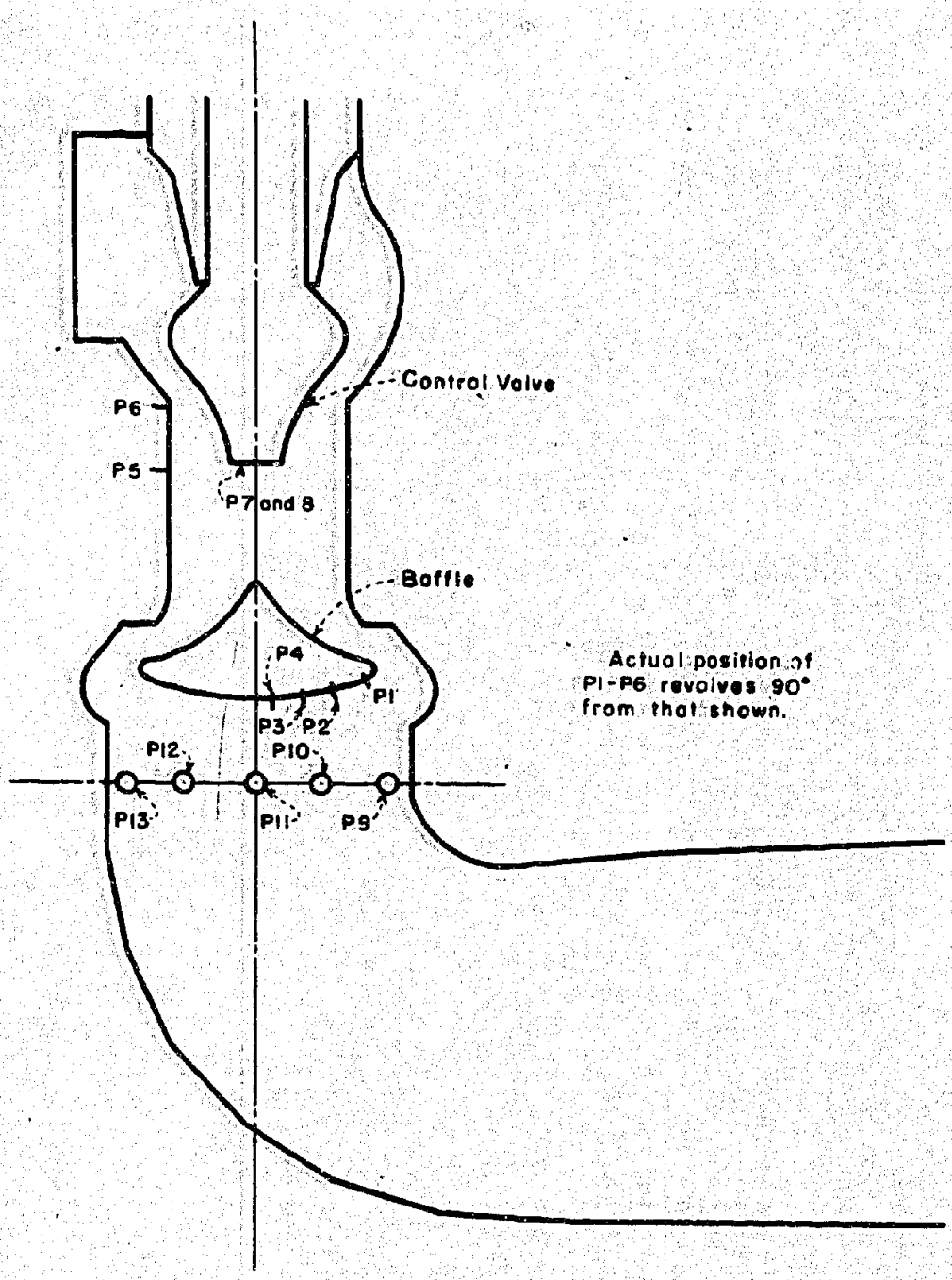
B. - Flow in one-half section of elbow-type section



C. Flow in one-half section of bowl-type model

D. Flow through circular type model without tailwater

PLATE 1



LOCATION OF PIEZOMETERS
IN ONE-HALF SECTION MODEL

H.D.B.

45-D-12124

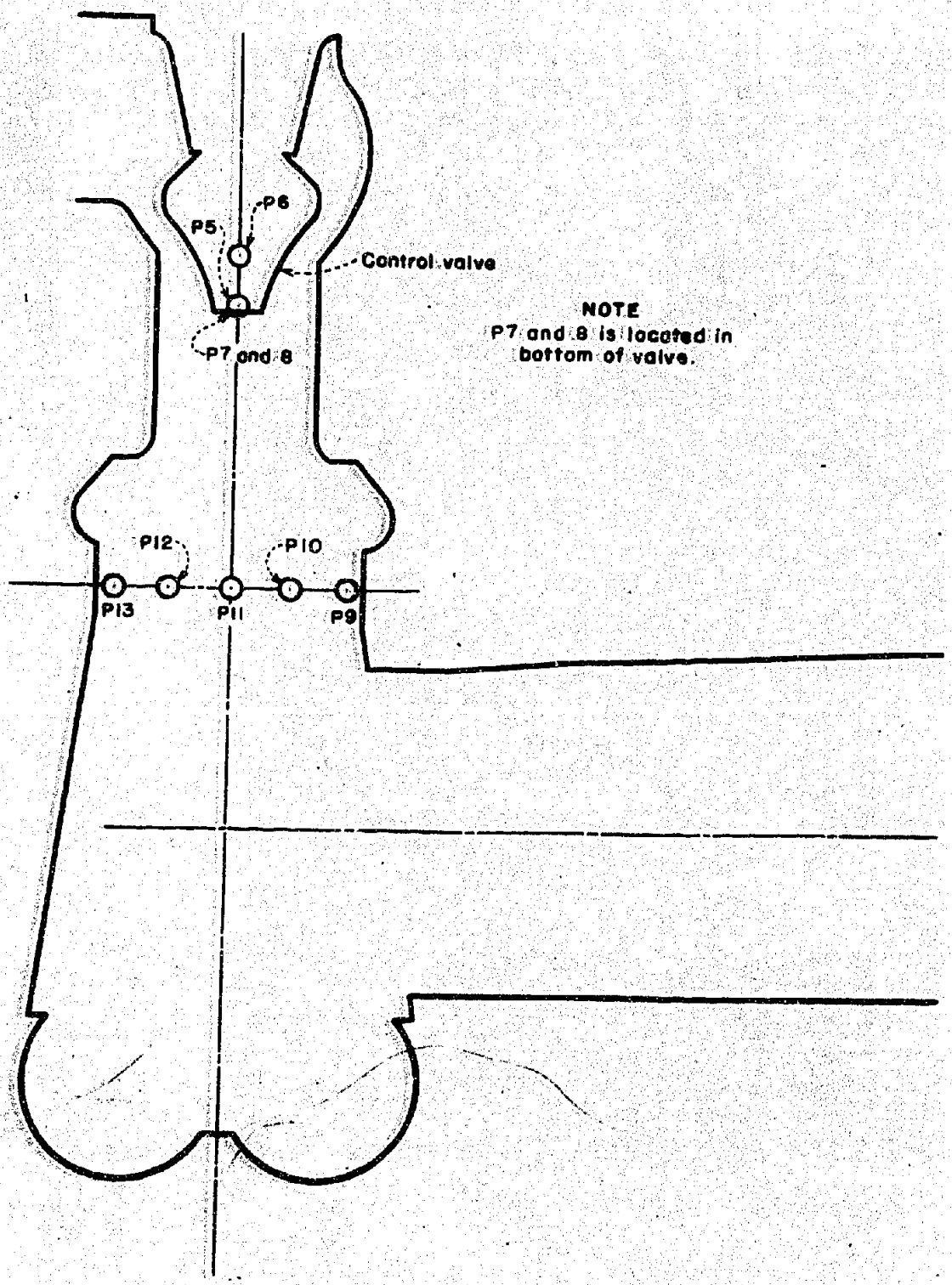
model was left as used in the previous test, and the tail-water elevation was controlled as before. The positions of the piezometers as installed in this model are shown on figure 6.

(d) Modified bowl type.--This model was constructed in full section on a scale of 1 to 12. The entire model, with the exception of the bowl which was of wood, was constructed of pyralin. The air chamber and the inlet immediately below the relief valve were constructed so that tests could be run either with or without air being admitted at this point. Provisions were also made for changing the length of the throat protrusion into the main chamber. Two types of main chamber roofs were also tested. Pressures in the model were measured by means of piezometers, the locations of which are shown on figure 7.

(e) Circular chamber type.--The model of the energy absorber designed for units A-6 and A-7 was constructed in full section, as was the modified bowl type, whereas the previous ones tested were only part sections. Only one model was constructed, but it was built so that it could be tested with the bottom in four positions, as shown on figure 8. A scale ratio of 1 to 20 was used for this model. The unit was constructed entirely of pyralin, with the exception of the valve and the valve chamber which were cast from brass (plate 2). The entrance chamber was formed from wood and connected directly to a 4-inch supply line fed by an 8-inch centrifugal pump. The flow through this circulating system to the model was controlled by a 4-inch gate valve, while the tail water was controlled by an 8-inch gate valve in the discharge line (fig. 4). The discharge was measured as in the previous tests. The pressure in the supply line was held constant and represented a head on the prototype structure of 405 feet above the tail-water level. Piezometers were installed in the model, as shown on figure 9, and all pressures referred to in the accompanying tables are in feet of water above or below the respective piezometer openings (photograph B, plate 3).

The only difference between the design accepted for installation in units A-6 and A-7 and the design proposed for installation in units N-7 and N-8 is in the shape of the draft tube which connects to the vertical chamber of the unit. This draft tube is circular in cross section at the junction point with the vertical chamber and extends to the connection with the concrete draft tube which flares to a filleted rectangle at the discharge end. The piezometers installed in this model were in the same positions as in the previous model and their location is shown on figure 9. The pitot tubes for velocity measurements in the draft tube were also installed as shown on this figure.

FIGURE 8



LOCATION OF PIEZOMETERS

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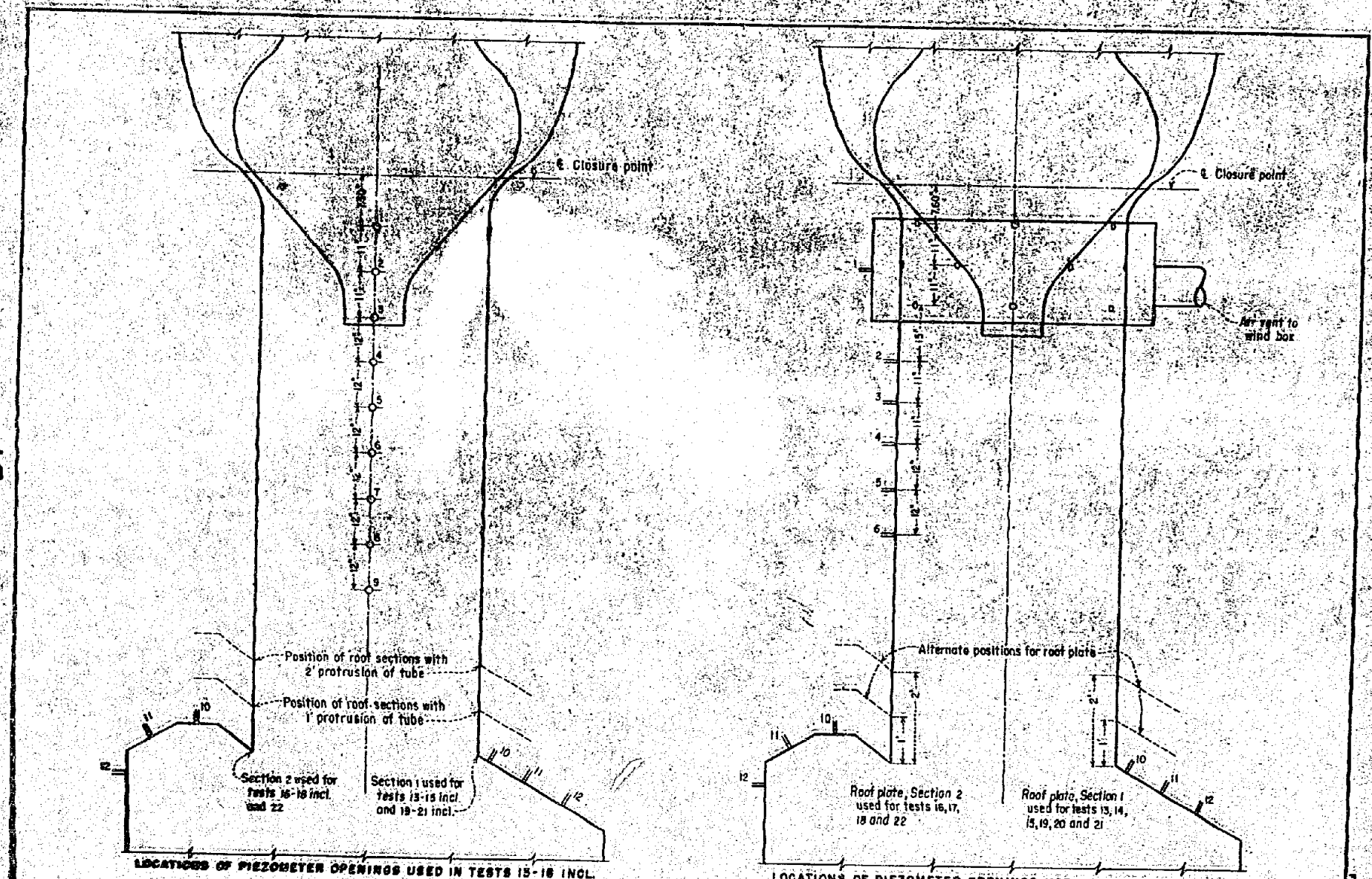
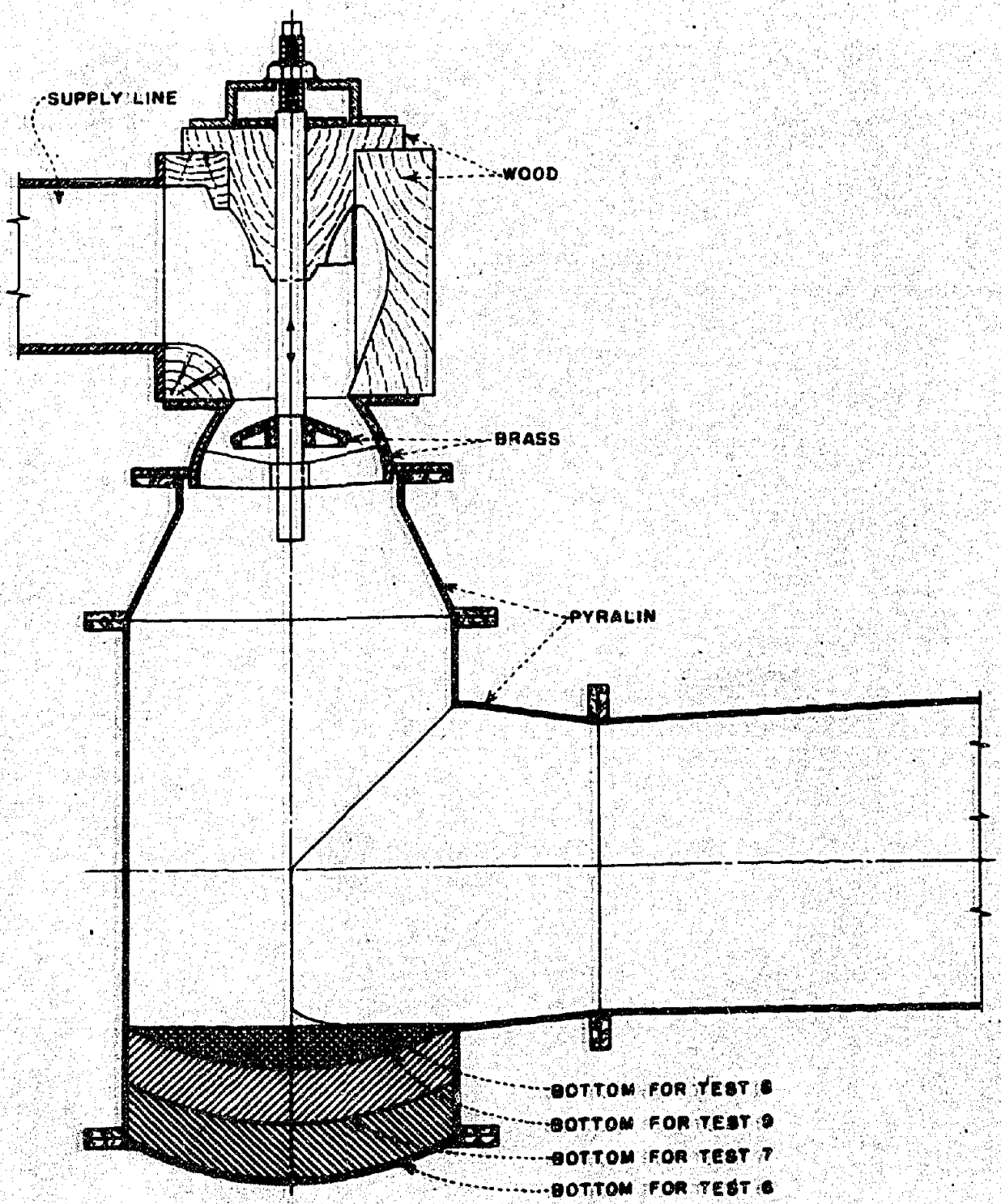


UNITS N-1-N-4 BOULDER DAM ENERGY DISSIPATOR

FIGURE 7

FIGURE 8



ASSEMBLY SECTION OF TEST MODEL

F.T.

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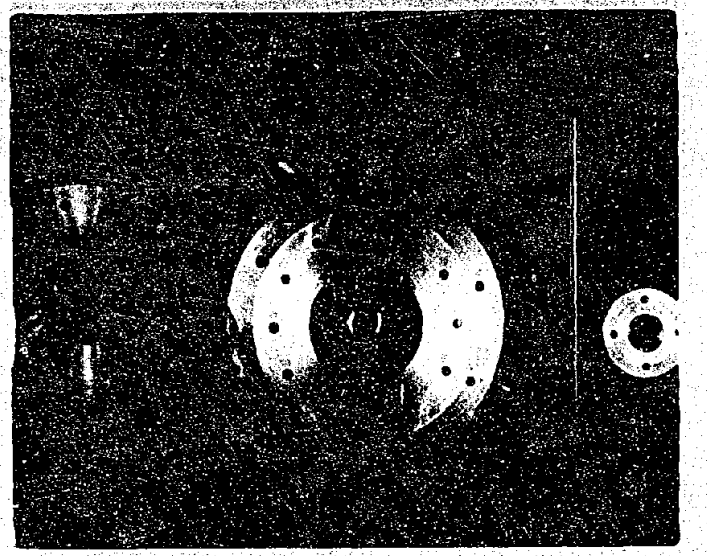
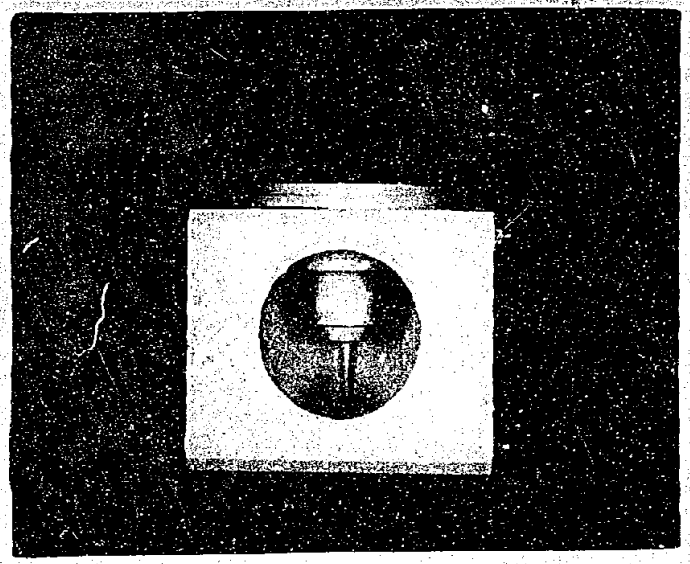
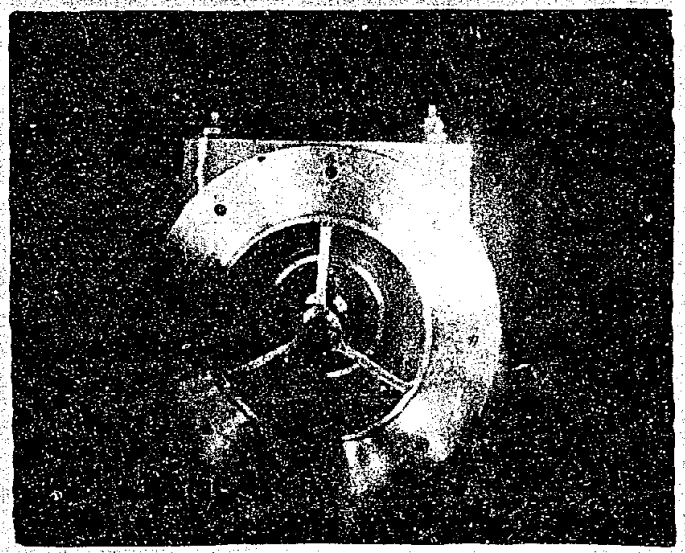


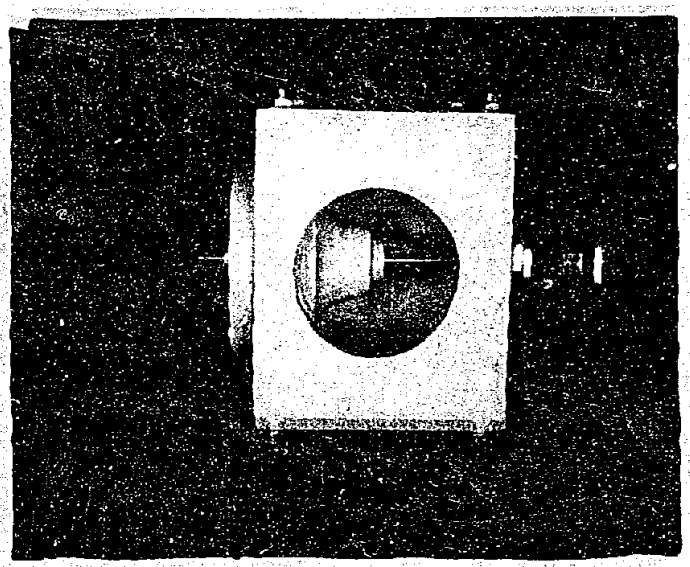
A. - Valve and valve-chamber assembly



B. - Entrance chamber showing guide vane in back



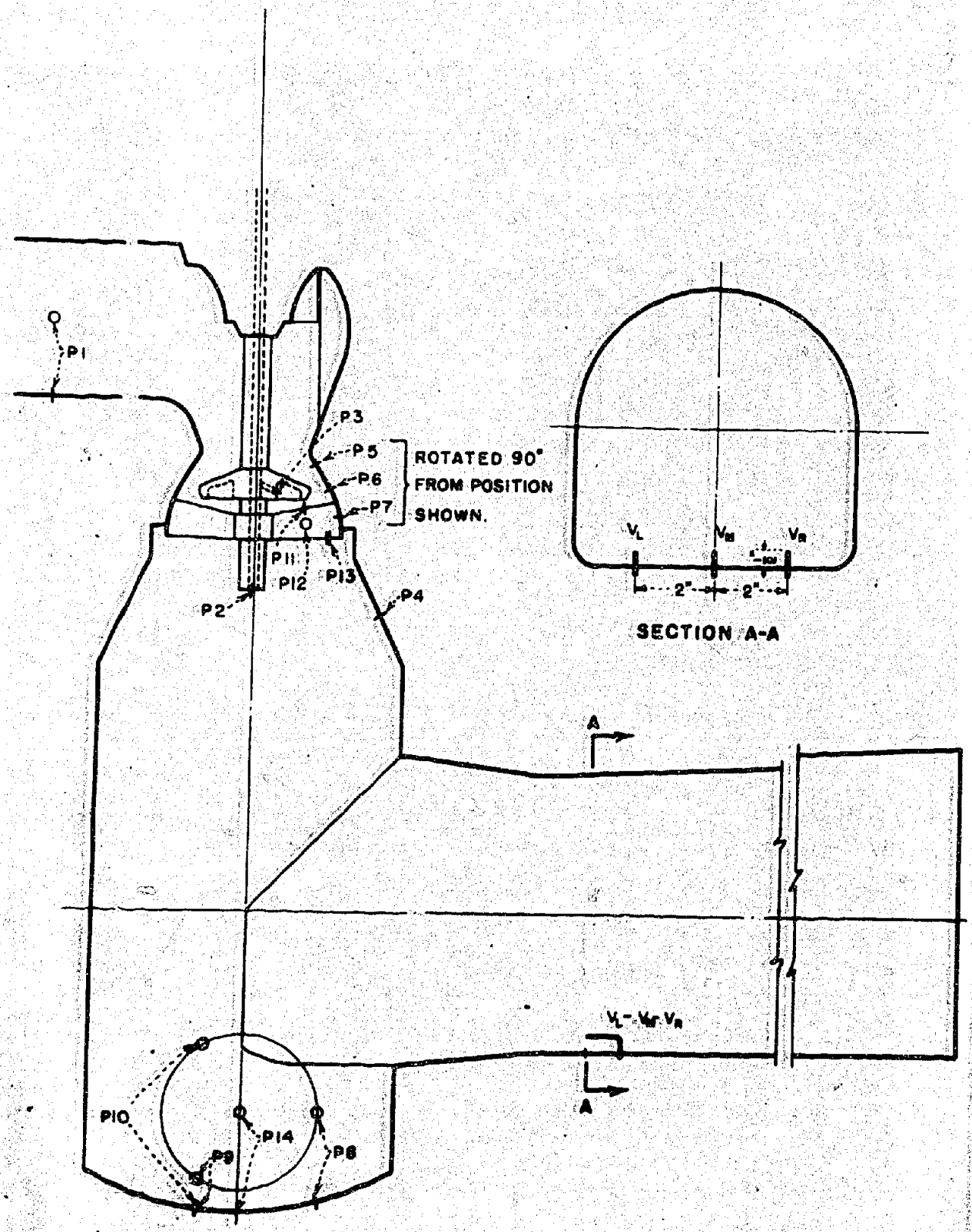
C. - View of bottom of valve chamber showing guide spider



D. - Entrance and valve chamber assembled

PLATE 2

FIGURE 9



LOCATION OF PIEZOMETERS ON MODEL

F.T. 12-17-57

48-D-11786

DISCUSSION OF RESULTS

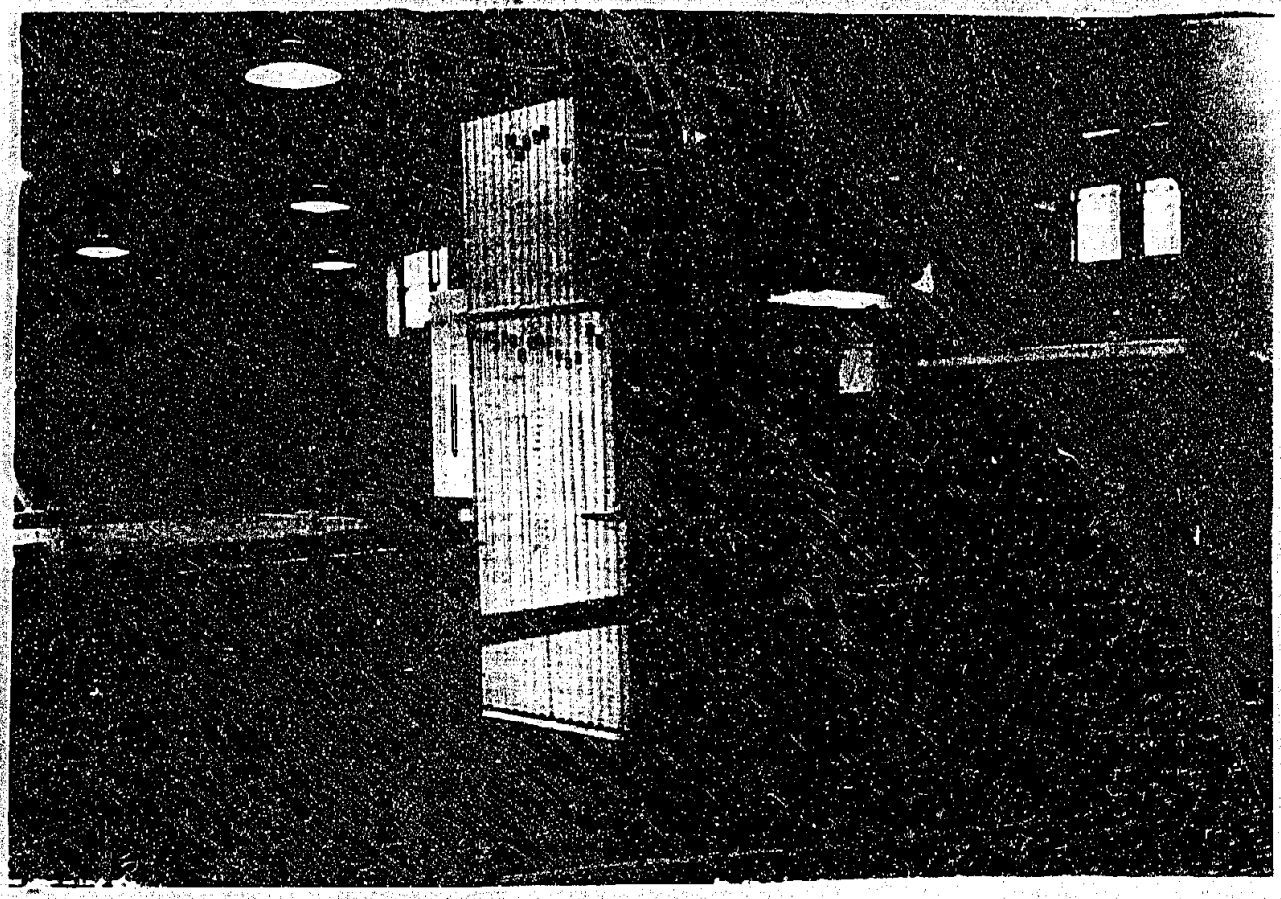
Original and Replacement Units

6. Tests 1 and 2. Two-inch section model.--The first model of the original design to be constructed consisted of a two-inch section taken on the center line. This slice of the unit yielded some very interesting data and flow characteristics for observation. Pressures as measured on the model and transferred to the prototype in feet of water are shown in table 1 and the points at which these pressures were taken are indicated on figure 3. Negative values in the table indicate less than atmospheric pressures at the respective points. Series 1 of the tests was made with the baffle in place and with a normal tail water at elevation 643.00. Series 2 of the tests was made without the baffle and with tail-water elevations of 643.00 and 625.00.

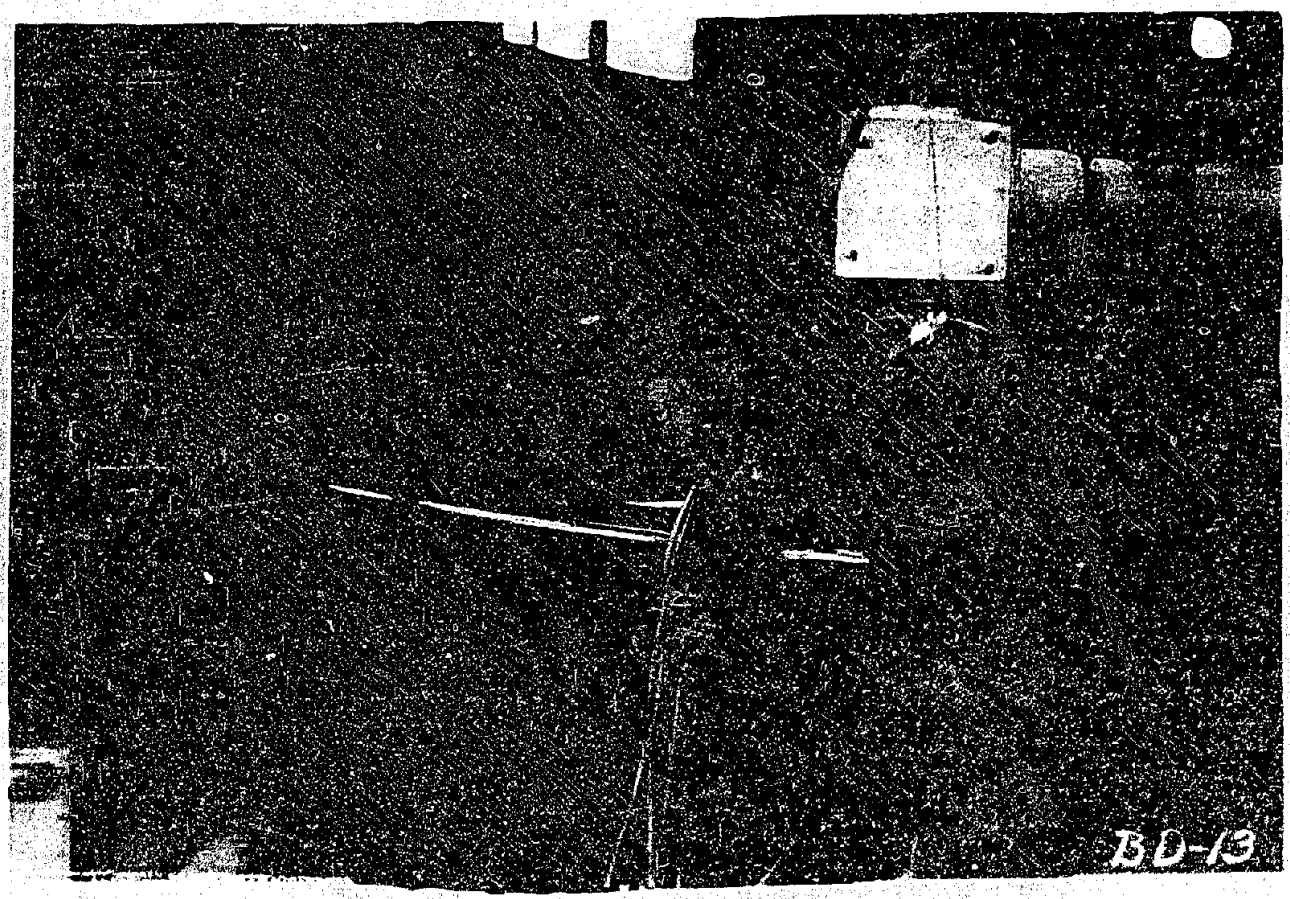
Flow conditions around and below the baffle changed very little with different valve openings, but when the baffle was removed a considerable change was noted in the area around and below the place formerly occupied by it, due, no doubt, to the unstable condition immediately below the valve. This condition could be increased and be made more unstable by admitting air at vents 9, 10, 11, and 12; that is, if air were admitted at vents 9 and 10, pressures would be shown at vents 11 and 12, and the jet below the gate would swing away from the side at which the air was being admitted. This condition could be reversed by plugging vents 9 and 10 and admitting air at atmospheric pressure to vents 11 and 12. Pressures as read on the monometer board were reversed and were approximately of the same magnitude on the opposite side of the model. This condition existed at both normal and low tail-water elevations and was most pronounced with an 0.8 gate opening. After a study of the flow and pressure data, it was decided to build a new model which was to be a full half section on the same scale.

7. Test 4. Half-section model.--As will be noted from a comparison between tables 1 and 2, there is a considerable difference between the pressures, which are in feet of water, as obtained from the two models. It is fully agreed that the pressures taken from the two-inch section model should be interpreted as being only indicative of the pressures that are to be expected in the prototype, while those taken from the half-section model may be considered as more nearly true of the prototype pressures. Although these pressures are excessive at some points, they furnish an excellent basis for study and should be used only in that capacity.

The six vanes which supported the baffles were installed with piezometer openings in the downstream edge of two only. The



A. - Test set-up, showing model, tail-water box, piezometer board.



B. - The cylindrical-type model.

TABLE 1

MEASURED PRESSURES AT THE POINTS AS SHOWN ON FIGURE 3

Test No.	Valve Opening	Q Sec.Ft.	Tail Water	PRESSURES (Feet of water)												
				1	2	3	4	5	6	7	8	9	10	11	12	13
1-BD-1	1.0	304	643.42	3.18	1.39	3.50	10.38	-7.74	-6.94	-3.89	-2.70	92.54	98.18	97.38	96.07	89.20
1-BD-2	0.8	278	643.02	7.74	7.75	8.18	12.42	10.26	6.98	7.05	7.74	63.72	68.60	67.95	66.03	46.32
1-BD-3	0.6	234	642.94	10.74	10.87	10.82	14.10	13.50	10.94	10.63	10.86	27.65	32.59	32.59	30.31	24.55
1-BD-4	0.4	165	642.70	14.70	15.31	15.62	18.18	18.06	15.74	14.71	13.26	0.31	4.89	3.91	3.19	-14.11
1-BD-5	0.2	89	643.00	17.70	17.59	18.14	19.74	20.10	18.26	17.83	13.74	-4.73	-1.25	-1.97	-2.33	-13.42
2-BD-1	1.0	386	642.86	-	-	-	-	-	-	-	-	-31.40	-32.56	10.63	11.47	-63.15
2-BD-2	1.0	386	625.16	-	-	-	-	-	-	-	-	-48.34	-50.56	-2.81	-1.85	-81.16

HYD-56.1

TABLE 2
MEASURED PRESSURES AT THE POINTS AS SHOWN ON FIGURE 5

TEST NO.	GATE OPEN-ING	Q SEC. FT.	PRESS-URE POUNDS	HEAD LOSS ABOVE T.W. EL.	C	TAIL-WATER	PRESSURES														
							1	2	3	4	5	6	7 AND 8	9	10	11	12	13	14	15
4-BD-1	1.0	1523	10	223.02	89.2	642.76	-1.50	10.99	19.10	22.98	5.59	0.31	0.00	26.42	11.54	8.90	12.62	23.30	17.28	26.40
4-BD-2	0.8	1400	10	245.70	95.5	642.76	0.90	12.79	17.94	24.06	-32.45	-28.85	-12.00	16.20	14.30	11.18	13.34	23.18	12.84	26.28
4-BD-3	0.6	1234	10	244.94	108.1	642.76	4.86	14.83	21.14	24.78	-48.89	-46.85	-41.40	18.50	16.34	13.82	15.02	24.02	10.44	22.80
4-BD-4	0.4	876	10	261.58	110.5	643.00	12.66	21.19	25.94	29.10	-44.69	-42.65	-45.00	20.78	20.18	18.50	17.06	18.14	11.64	18.12
4-BD-5	0.2	531	10	241.16	131.3	642.52	15.90	12.27	24.86	26.82	-32.69	-24.77	-45.00	22.10	21.86	21.62	21.26	20.66	15.84	17.04
4-BD-6	1.0	1587	10	241.16	89.3	625.00	-20.10	-5.81	3.86	7.14	-11.81	-14.93	--	-4.90	-7.54	-11.50	-4.66	8.78	-0.60	9.12
4-BD-7	0.8	1526	10	264.60	100.3	625.24	-18.18	-4.85	3.98	8.46	-50.93	-49.85	-45.48	-3.22	-5.74	-9.46	-4.54	8.90	-4.92	9.00
4-BD-8	0.6	1245	10	280.48	101.9	625.12	-10.50	1.99	9.50	13.50	-62.21	-63.77	-70.30	-0.34	-1.90	-5.38	-3.82	5.30	-6.60	14.28
4-BD-9	0.4	876	10	274.43	107.8	625.00	-4.50	4.51	9.38	12.06	-62.21	-60.65	-68.88	-2.98	1.58	-3.70	-1.54	0.14	-6.36	0.36
4-BD-10	0.2	540	10	280.48	123.8	624.64	-1.50	4.75	7.58	9.90	-47.09	-54.65	-63.00	4.22	3.86	3.50	2.90	2.30	-2.40	-1.56

Pressures are in feet of water

TABLE 2

45-D-12140

opening in the downstream vane was designated as number 15, while the opening in the third from downstream vane was known as number 14. The positions of the piezometer openings in this model are shown on figure 5. Positive pressures were recorded for all positions of the gate with a tail-water elevation of 643.00, while with tail-water elevation of 625.00 negative values were recorded on the vane at the back of the model. Low, positive pressures were evident on the vane next to the face of the model. This was due, no doubt, to restricted flow at this point.

Observed flow conditions in the two models were also quite different, especially in the area below the baffle. Flow eddies in the two-inch section model were quite violent and rotated in the vertical plane, while in the half-section model this direction of rotation was in a right-handed downstream direction, tending to improve the draft and to dissipate more energy of the flowing water. Conditions in the tailrace were very good, with little or no surface agitation due to boils or whirls which might have been emitted from the draft tube. The sketches on figure 10 indicate the general direction of flow through the dissipator.

Included in table 2 is a column headed "Head Loss above T. W. El.," which indicates the loss between a point near the upper part of the relief valve to the tail-water level. The column headed "C" is the coefficient derived from these data by use of the following formula: $Q = CAV$, which may be written $C = Q/AV$, and since $V = \sqrt{2gh}$ we may substitute and obtain

$$C = \frac{Q}{A \times 8.03 \sqrt{h}}$$

Substituting real values in the above formula, we have

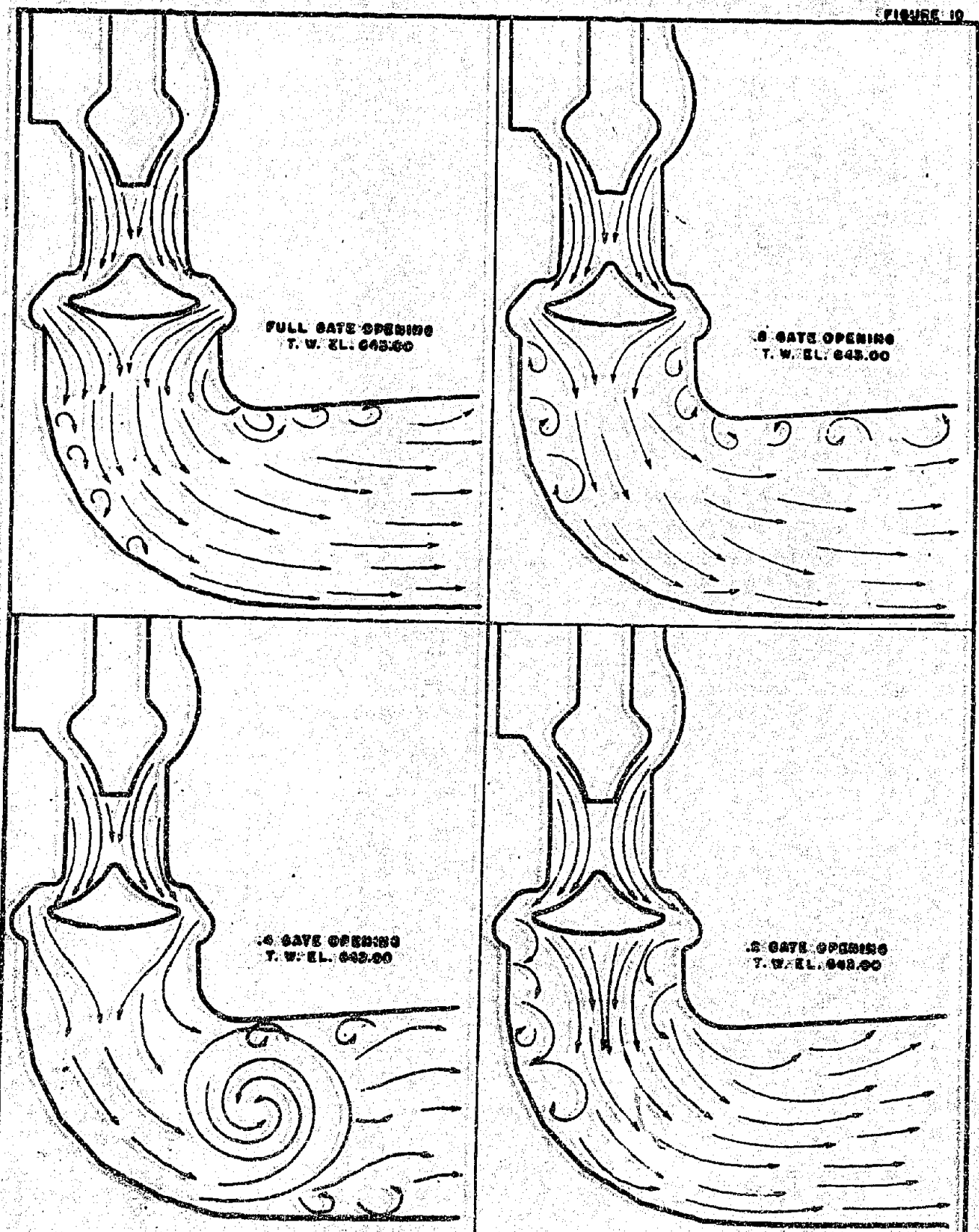
$$C = \frac{1523}{1424 \times 8.03 \sqrt{223.03}} = 89.2$$

which is the coefficient of loss through the unit.

The pressures in table 2 are the values as taken at the points shown on figure 5 and are as measured on the model and translated to the prototype. The values indicated in the table on figure 1 are those values averaged and renumbered to correspond to the piezometer openings as indicated on this same figure. All pressures referred to in the following discussion are of the values in this table on figure 1 and refer to the positions shown on this figure.

From these tests the following general deductions may be

FIGURE 10



FLOW LINES IN ENERGY ABSORBER MODEL

made: (a) A positive pressure exists on the under side of the baffle at points P-1 to P-4, except at low tail water, when low negative pressures occur toward the edges of the baffle. This would tend to indicate that the pipe and valve provided for the admission of atmospheric air to the under side of the baffle are not required. (Tests in the field have verified these conclusions.) (b) A positive pressure is maintained at the outlets from the annular air chamber at P-7, except at the low tail water. Again it is indicated, therefore, that the air pipe and the valve provided for admission of atmospheric air to the air chamber are not required. (c) A negative pressure exists for practically all conditions of flow and elevations of tail water at P-5, which accounts for the coefficient of discharge of the relief valve being greater than unity. With the admission of atmospheric air it is expected that the coefficient will remain at approximately 0.90. Therefore, the air pipe and the valve provided at this point are necessary. (d) The high negative pressures maintained at point P-6 for all conditions of flow and elevations of tail water indicate the necessity of aeration at this point to avoid hydraulic shock due to cavitation and formation of vapor.

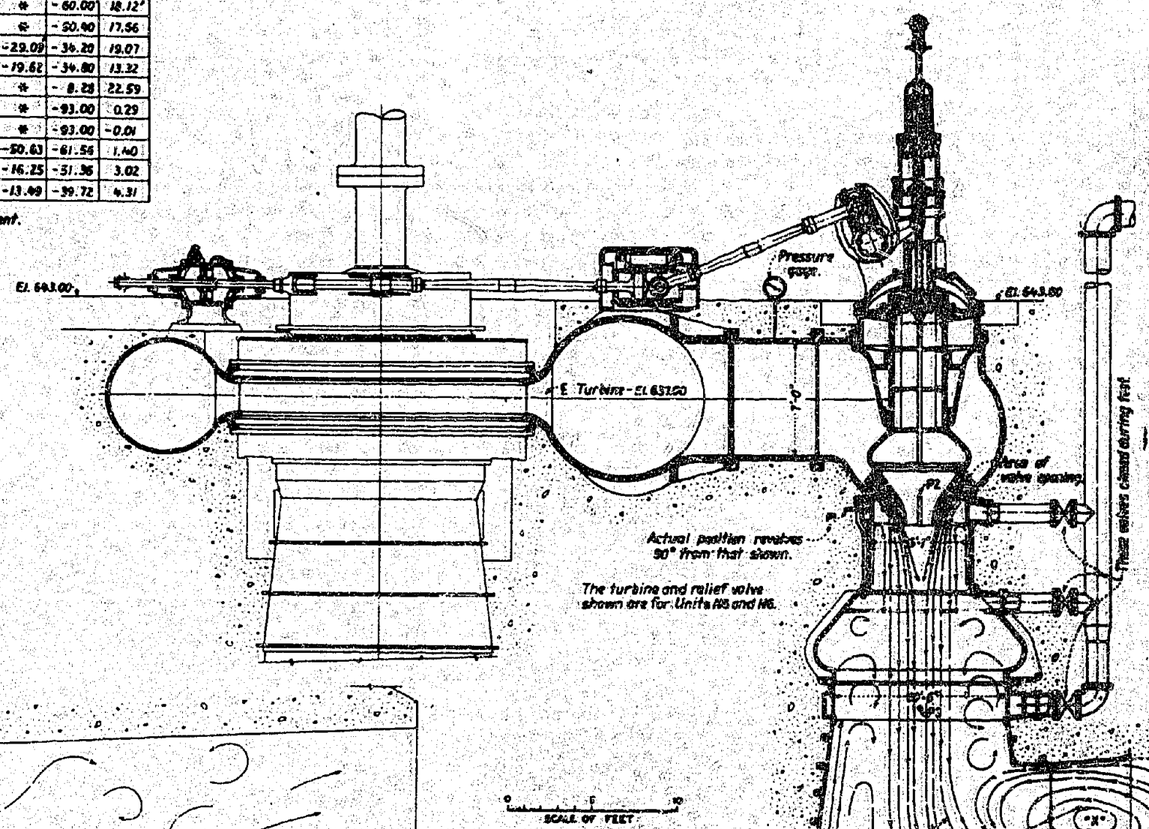
8. Test 6. Bowl-type model.--The change in design as tentatively agreed upon between the manufacturer and the Bureau of Reclamation consisted in removing the baffle plate and in changing the shape of the lower portion or elbow near the exit. This new design is shown on figure 11. Flow conditions in this model were quite symmetrical and indicated a marked improvement over the original design. Rather than attempt to write a description of the flow characteristics under the various conditions tested, sketches of the flow lines were carefully made by E. B. Moses, and these are reproduced on figures 12 and 13.

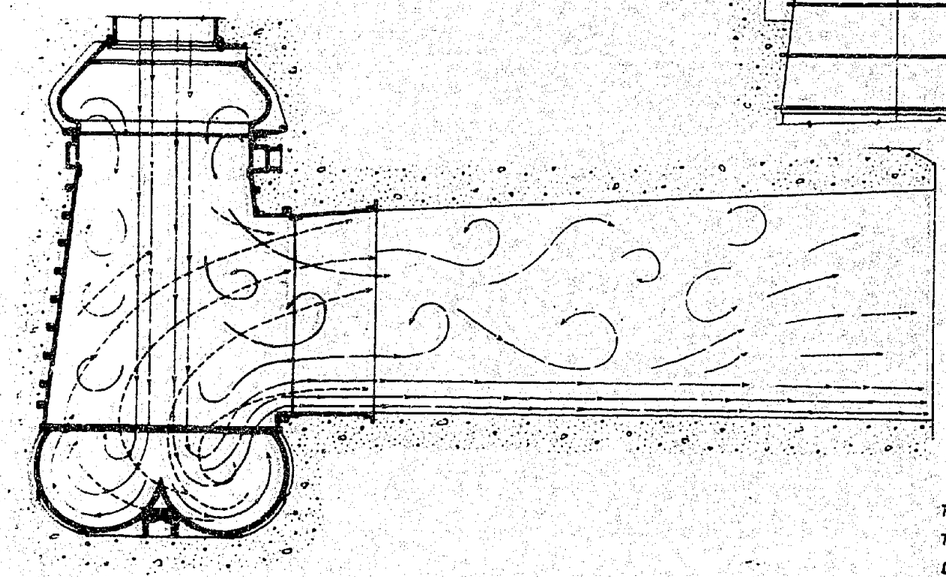
Pressures omitted from table 3 were excessive negative pressures which could not be measured on the manometer board without a change, and due to the short period of time allotted to the tests, it was not felt that this change in the model was justifiable. Due to the magnitude of these pressures, it is again advised that caution be used in applying them to a definite case and that they be used as previously suggested, merely as a basis for study and comparison.

The pressures in table 3 are the values as taken at the points shown on figure 5 and referred to the elevation of the respective openings, and they are as measured in the model and translated to the prototype. The values indicated in the table on figure 11 are these values averaged and numbered to correspond to the piezometer openings as indicated on this same figure. All pressures referred to in the following discussion are of the values in this table on figure 11 and refer to the positions shown on this figure.

TEST NUMBER	GATE OPENING	Q SEC. FT.	AREA OF VALVE OPENING	PRESSURE IN LBS.	HEAD IN FEET ABOVE TW. ELEV.	C	TAIL-WATER	P1	P2	P3
5-BD-1	1.0	1,745	14.24 □"	10	204.12	1.068	642.75	*	-60.00'	18.12'
5-BD-2	0.8	1,501	11.64 □"	10	202.52	1.030	642.40	*	-50.40	17.56
5-BD-3	0.6	1,161	9.05 □"	10	246.46	.996	642.46	-29.09	-34.20	19.07
5-BD-4	0.4	755	6.11 □"	10	193.84	1.107	643.00	-19.62	-34.80	13.32
5-BD-5	0.2	417	3.24 □"	10			642.88	*	-8.28	22.59
5-BD-6	1.0	1,854	14.24 □"	10			625.36	*	-93.00	0.29
5-BD-7	0.8	1,500	11.64 □"	10	175.39	1.292	625.36	*	-93.00	-0.01
5-BD-8	0.6	1,231	9.08 □"	10	199.58	1.194	624.82	-50.63	-61.56	1.40
5-BD-9	0.4	835	6.11 □"	10	199.58	1.206	624.88	-16.25	-51.36	3.02
5-BD-10	0.2	491	3.24 □"	10	190.51	1.367	624.88	-13.49	-39.72	4.31

* Negative pressures beyond range of measuring instrument.





FLOW CONDITIONS WITH 20-PER CENT. VALVE STROKE AND NORMAL TAILWATER AT EL. 643.0

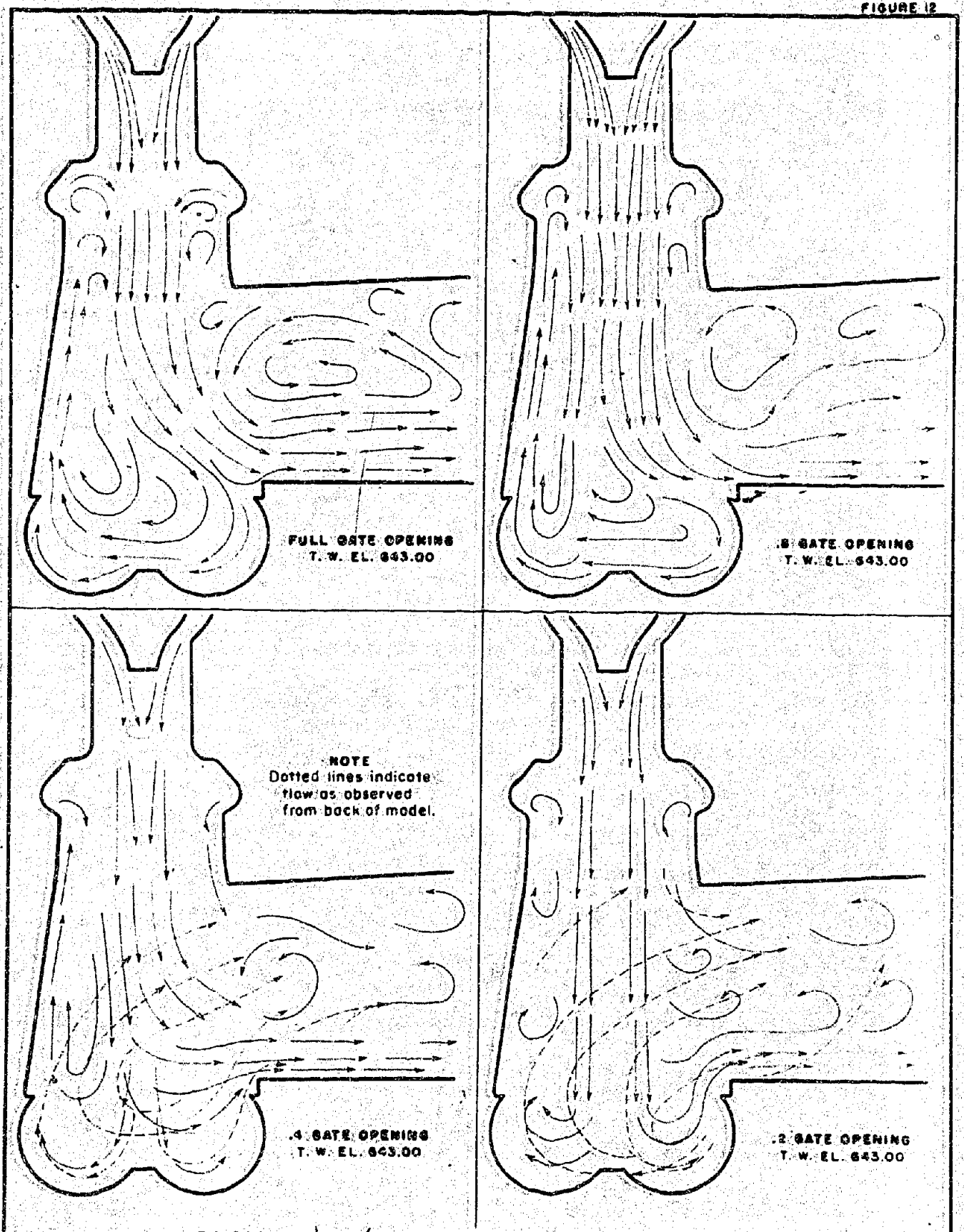
NOTES

The column headed "C" is the coefficient obtained from the formula, C= [illegible]
The scale of the model used in this test was 1" = 1'-0"
Dotted arrows indicate flow along outer walls of absorber.
For pressure and flow studies of "through" type energy absorber see Dwg. 65-D-1080.

From these tests the following deductions may be made
(a). A positive pressure exists for all conditions of flow and elevation of tailwater at point P3, where an ample vent has to provided for the admission of atmospheric air. Therefore the air pipe and valve provided at this point are not required.
(b). A negative pressure exists for all conditions of flow and elevation of tailwater at point P1, which accounts for the coefficient of discharge of the relief valve being greater than unity. With the admission of atmospheric air it is expected that the coefficient will remain at approximately unity. Therefore the air pipe and valve provided at this point are necessary.
(c). The high negative pressure maintained at point P2 for all conditions of flow and elevation of tailwater indicate the necessity of aeration at this point to avoid hydraulic shock due to cavitation and formation of vapor.
(d). Up to 20 percent of valve stroke, the energy absorber functioned approximately as designed, but at greater openings of valve the area of outflow to the horizontal discharge passage is such that the water does not flow away from the absorber sufficiently as required for satisfactory operation. Therefore the water leaving the relief valve cannot flow in the designed course but is deflected to one side by the horizontal radius and passes out of the discharge passage as if through a simple elbow. In this connection it may be noted that the case has indicated against erosion due to high velocity in the [illegible] and after installation of unit R5 showed no sign of flow on the painted surface. The horizontal radius following point "X" occurs under conditions of partial discharge. As previously the tailwater will rise to discharge under partial flows at this point and is necessary the main of causing a sudden change in pressure and violent shaking of the structure. The area of the [illegible] of the horizontal discharge passage should be much larger than the usual basis, to permit free passage of the water around the main jet.

FLOW CONDITIONS WITH FULL VALVE STROKE AND NORMAL TAILWATER AT EL. 643.0

FIGURE 12

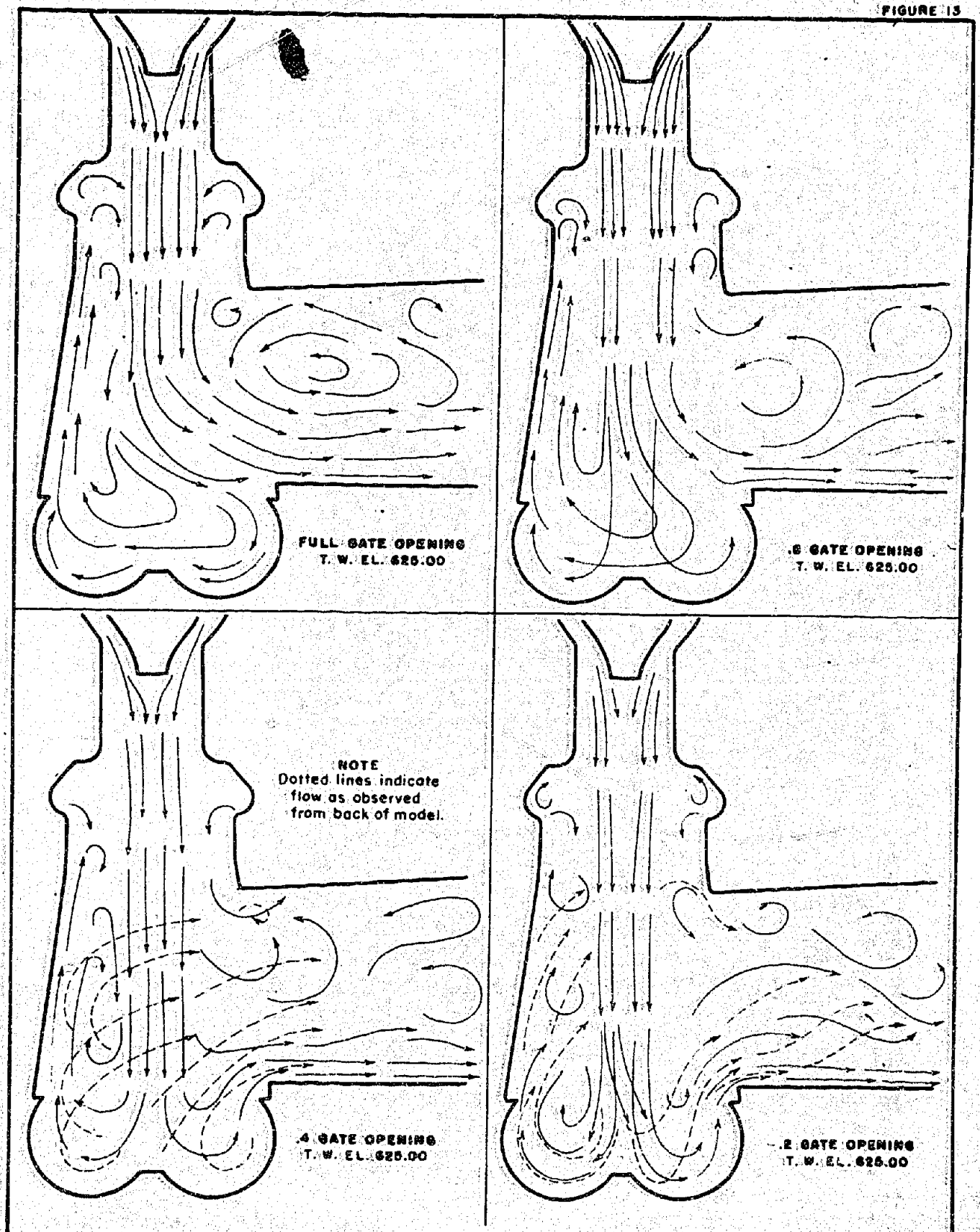


FLOW LINES IN ENERGY ABSORBER MODEL

E.B.H.-H.O.B.

45-D-12132

FIGURE 13



FLOW LINES IN ENERGY ABSORBER MODEL

C.B.M.-H.O.B.

45-D-12133

TABLE 3

MEASURED PRESSURES AT THE POINTS AS SHOWN ON FIGURE 6

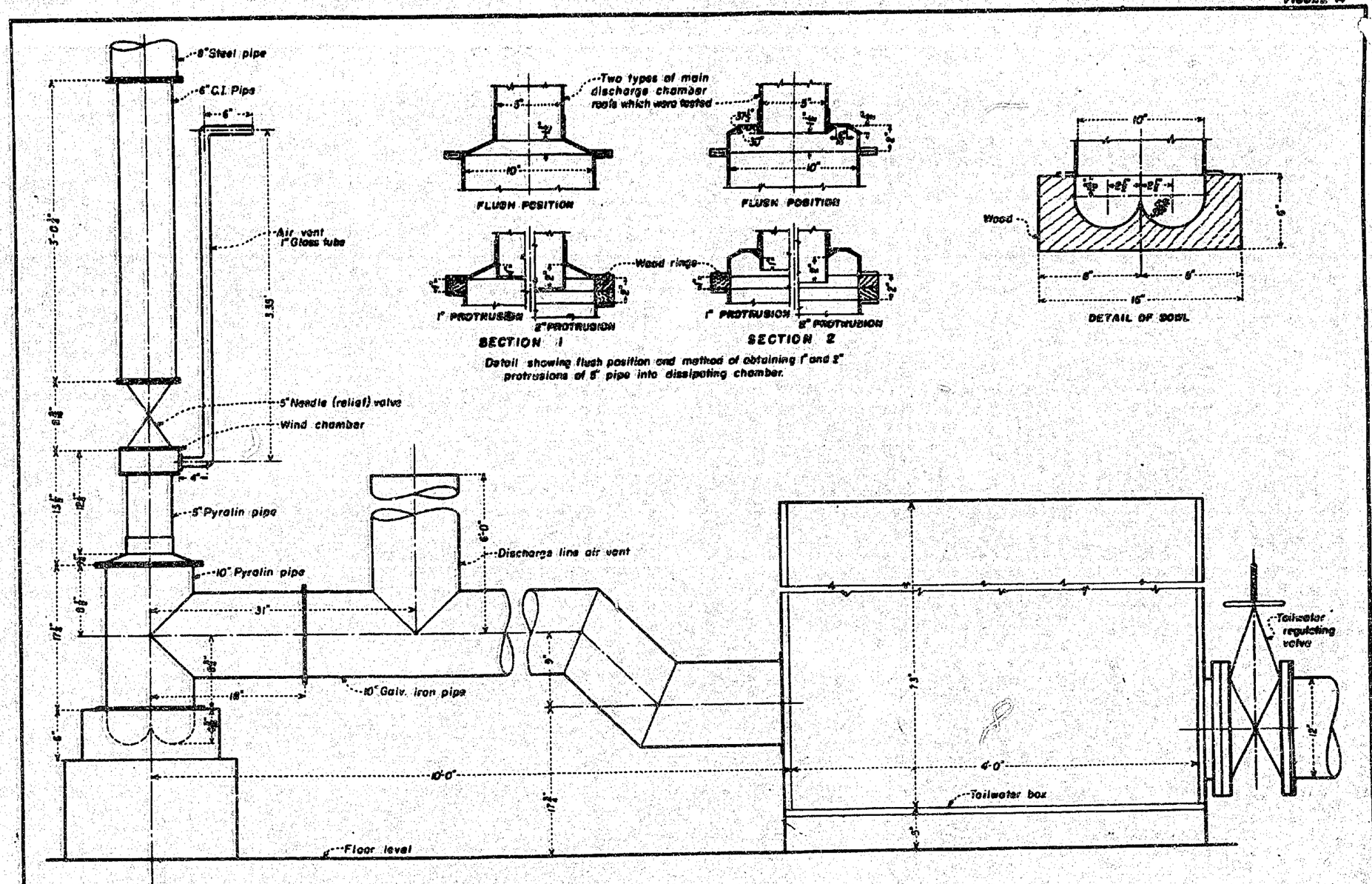
Test No.	Valve Opening	Q Sec.Ft.	Line Pressure (Pounds)	Head Loss Above T.W.El.	Coef. of Loss	Tail Water	Pressures (Feet of water)							
							5	6	7 + 8	9	10	11	12	13
5-BD-1	1.0	1,745*	10	204.12	106.79	642.76	-	-	-60.00	17.36	19.94	-8.99	16.94	18.26
5-BD-2	0.8	1,501	10	242.52	103.01	642.40	-	-	-50.40	18.76	17.06	-9.53	16.94	17.90
5-BD-3	0.6	1,141	10	246.46	99.55	642.46	-31.01	-27.17	-34.20	20.78	19.46	-10.54	17.78	18.26
5-BD-4	0.4	755*	10	193.84	110.65	643.00	-21.41	-17.83	-34.80	23.10	11.54	-11.02	9.02	9.62
5-BD-5	0.2	417	10	-	-	642.86	3.67	-	-8.28	23.19	23.20	-10.90	21.26	22.71
5-BD-6	1.0	1,854	10	-	-	625.36	-	-	-93.00	-2.02	2.54	-13.30	-0.22	0.86
5-BD-7	0.8	1,600	10	175.39	129.19	625.36	-	-	-93.00	1.58	1.70	-13.78	-2.26	-1.06
5-BD-8	0.6	1,231	10	199.58	119.40	624.82	-47.09	-54.17	-61.56	4.58	2.06	-13.54	-0.82	-0.22
5-BD-9	0.4	835	10	199.58	120.56	624.88	-4.73	-27.77	-51.36	5.66	3.14	-13.54	1.94	1.34
5-BD-10	0.2	491	10	190.51	136.65	624.88	-14.33	-12.65	-39.72	5.42	4.82	-13.54	3.14	3.86

*Estimated

From those tests the following general deductions may be made: (a) A positive pressure exists for all conditions of flow and elevations of tail water at point P-3, where an annular air chamber is provided for the admission of atmospheric air. Therefore, the air pipe and the valve provided at this point are not required. (b) A negative pressure exists for all conditions of flow and elevations of tail water at P-1, which may account for the coefficient of discharge of the relief valve being greater than unity. With the admission of atmospheric air it is expected that the coefficient will remain at approximately 0.90. Therefore, the air pipe and the valve provided at this point are necessary. (c) The high negative pressures maintained at point P-2 for all conditions of flow and elevations of tail water indicate the necessity of aeration at this point to avoid hydraulic shock due to cavitation and formation of vapor. (d) Up to 20 percent of valve stroke, the energy absorber functioned approximately as designed, but at greater valve openings the area of inflow to the horizontal discharge passage is such that the water does not flow away from the absorber bowl as rapidly as required for satisfactory operation. Therefore, the water leaving the relief valve cannot flow in the designed course but is deflected to one side by a large horizontal roller and passes out of the discharge passage as if through a simple elbow. Flow line observed on the painted surfaces in the prototype show this characteristic flow and piezometer readings at various points in the bowl show a constant pressure, which indicates no flow in the bowl. In this connection it may be noted that the cone tip (nitrided against erosion due to high velocity) in the bowl on a similar installation at unit A-8 showed no sign of flow on the painted surface. The horizontal roller indicated at point P occurs under conditions of prolonged discharge. At extremely low tail water and high discharge, an air pocket forms at this point and is entrapped by the main jet, causing a sudden change in pressure and violent shaking of the structure. The area of the inlet of the horizontal discharge passage should be much larger than the area of the model tested, to permit free passage of the water around the main jet.

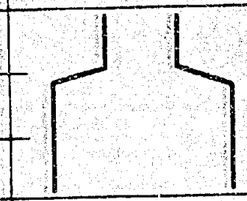
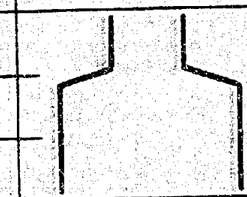
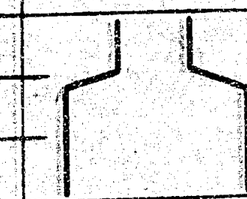
9. Tests 13 to 22. Modified bowl-type model.--The change in design as finally agreed upon between the manufacturer and the Bureau of Reclamation consisted of removing the baffle plate and supporting vanes, replacing the elbow with a circular bowl, and the placing of a cylindrical throat liner through the area formerly occupied by the baffle plate. This liner extended from a point near the relief-valve seat to slightly below the lower air inlet.

The model of this design and the test set-up are shown on figure 14. The locations of the piezometer openings without the air chamber and with it in place are shown on figure 15. The pressures shown on tables 4 to 13, inclusive, were taken from the full-section



Detail showing flush position and method of obtaining 1" and 2" protrusions of 8" pipe into dissipating chamber.

TEST SET-UP OF MODEL OF
BOULDER DAM ENERGY DISSIPATOR
UNITS N-1 — N-4

CONDITIONS					PRESSURES - FEET OF WATER											
RUN	VALVE OPENING	QUANTITY	AIR	SHAPE	1	2	3	4	5	6	7	8	9	10	11	12
HEAD-250'					TEST No. 13							T.W. - 625'				
1	0.2	400.0	NO		- 54.66	- 47.53	- 57.46	- 59.52	- 53.84	- 51.07	- 37.54	- 36.58	+ 26.18	3.62	5.68	7.85
2	0.4	862.5	NO		- 120.75	- 123.05	- 129.83	- 125.60	- 108.92	- 112.44	- 82.37	- 62.54	- 35.62	0.48	0.96	7.85
3	0.6	1360.0	NO		- 208.84	- 208.75	- 195.10	- 175.15	- 135.65	- 97.48	- 67.40	- 42.86	- 4.18	- 0.94	- 0.21	- 6.62
4	0.8	1840.0	NO		- 249.70	- 247.30	- 219.43	- 175.91	- 137.22	- 67.16	- 23.39	- 4.32	- 11.54	- 14.47	- 20.76	- 30.31
5	1.0	2160.0	NO		- 263.86	- 255.16	- 223.39	- 155.53	- 86.86	- 47.93	- 2.14	- 6.65	+ 4.50	+ 3.62	+ 8.82	+ 17.28
HEAD-250'					TEST No. 13							T.W. - 643'				
6	0.2	410.0	NO		- 37.37	- 33.38	- 27.59	- 29.65	- 28.69	- 10.20	- 23.39	- 19.28	- 3.36	24.88	22.21	24.38
7	0.4	837.5	NO		- 99.49	- 86.83	- 90.47	- 91.78	- 80.57	- 71.51	- 56.40	- 35.00	- 17.51	- 4.32	- 10.61	- 6.74
8	0.6	1300.0	NO		- 150.61	- 163.92	- 147.12	- 118.72	- 107.35	- 73.08	- 46.97	- 21.61	+ 21.04	53.23	45.79	47.96
9	0.8	1725.0	NO		- 207.26	- 196.93	- 169.13	- 133.40	- 72.71	- 22.78	+ 12.83	29.51	43.04	57.89	55.22	65.26
10	1.0	2060.0	NO		- 213.55	- 192.28	- 132.97	- 76.87	- 11.40	+ 18.16	34.84	43.86	37.76	59.46	58.37	62.11
HEAD-250'					TEST No. 13							T.W. - 655'				
11	0.2		NO													
12	0.4		NO													
13	0.6	1260.0	NO		- 131.75	- 130.91	- 110.96	- 88.88	- 71.95	- 38.50	+ 9.24	+ 9.83	19.46	57.89	55.22	58.97
14	0.8	1695.0	NO		- 169.54	- 181.27	- 151.90	- 103.60	- 50.70	- 14.92	+ 8.11	+ 34.22	22.61	46.88	68.82	81.79
15	1.0	2050.0	NO		- 219.84	- 206.42	- 142.40	- 81.89	+ 16.12	+ 11.81	29.55	42.08	19.76	37.45	44.22	65.28

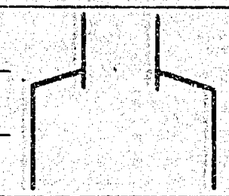
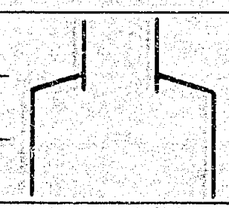
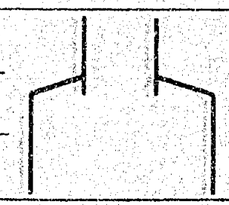
CONDITIONS					PRESSURES - FEET OF WATER											
RUN	VALVE OPENING	QUANTITY	AIR	SHAPE	1	2	3	4	5	6	7	8	9	10	11	12
HEAD-250'					TEST No. 14							T.W. - 625'				
1	0.2	405.0	NO		- 31.08	- 30.24	- 17.16	- 24.94	- 23.98	- 16.49	- 15.53	- 11.42	- 7.32	28.33	25.97	24.18
2	0.4	870.0	NO		- 95.59	- 97.90	- 98.39	- 98.88	- 88.49	- 77.86	- 64.26	- 38.15	- 23.04	12.91	21.25	21.85
3	0.6	1350.0	NO		-158.53	-165.55	-172.33	-164.96	- 135.41	- 90.43	- 61.12	- 33.43	- 18.32	- 6.97	- 6.49	+5.08
4	0.8	1880.0	NO		-257.57	-263.02	-239.93	- 191.69	- 162.43	-107.42	- 48.54	- 13.00	- 7.32	+23.10	+35.40	24.18
5	1.0	2175.0	NO		-262.34	- 261.50	- 244.70	- 196.46	- 165.58	- 35.35	- 12.38	+ 29.51	+ 24.18	+28.63	36.97	61.97
HEAD-250'					TEST No. 14							T.W. - 643'				
6	0.2	365.0	NO		- 16.93	+ 1.20	+ 4.67	+ 4.18	+ 5.14	+ 6.34	+ 7.30	+ 21.89	+ 20.98	42.78	44.83	51.72
7	0.4	810.0	NO		- 49.94	- 47.23	- 51.17	- 51.66	- 53.84	- 41.64	- 23.39	- 5.14	+ 9.22	45.92	51.12	48.56
8	0.6	1315.0	NO		-141.24	-140.40	-118.82	- 122.52	- 96.35	- 55.85	- 31.25	- 6.71	+ 10.79	47.50	42.26	47.00
9	0.8	1775.0	NO		-200.98	- 200.14	-161.33	-157.10	- 72.77	- 29.06	+ 5.72	+ 16.93	+27.32	+53.78	65.27	61.15
10	1.0	2125.0	NO		-221.41	-212.71	-170.76	- 80.02	- 25.46	-27.53	50.56	73.52	52.48	69.56	81.05	70.58
HEAD-250'					TEST No. 14							T.W. - 655'				
11	0.2	360.0	NO		+ 13.75	+ 17.74	+ 16.49	+ 14.42	+ 15.38	+ 19.73	+ 20.69	+ 24.73	+ 42.47	58.50	56.59	61.15
12	0.4	790.0	NO		- 35.80	- 39.67	- 48.78	- 42.23	- 36.55	- 24.35	- 46.67	- 33.43	- 13.61	41.21	36.97	40.72
13	0.6	1250.0	NO		-153.76	-152.92	- 149.51	-138.18	- 99.43	-69.94	- 40.68	- 17.71	+ 6.07	31.78	51.12	34.43
14	0.8	1750.0	NO		-211.98	-213.47	-186.42	-135.04	- 72.71	- 29.06	- 5.28	+ 27.94	+ 24.18	52.21	66.84	73.73
15	1.0	2075.0	NO		- 215.12	-239.50	-192.77	-103.60	- 22.40	+ 4.76	+ 26.98	+ 37.37	+ 35.18	44.35	58.98	62.72

TABLE 9

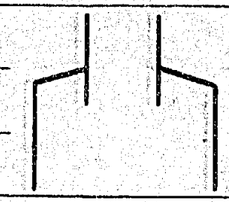
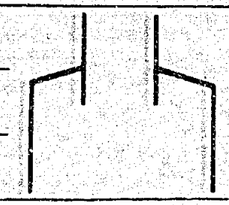
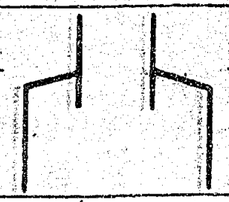
CONDITIONS					PRESSURES - FEET OF WATER											
RUN	VALVE OPENING	QUANTITY	AIR	SHAPE	1	2	3	4	5	6	7	8	9	10	11	12
HEAD-250'					TEST No. 15							T. W. - 625'				
1	0.2	375.0	NO		- 73.58	- 49.10	- 51.17	- 54.80	- 49.13	- 51.07	- 40.68	- 39.72	—	+ 4.03	- 6.49	+2.78
2	0.4	875.0	NO		-105.02	-119.90	-125.11	-124.03	-113.64	-106.15	- 86.33	-63.30	—	4.84	8.47	7.50
3	0.6	1345.0	NO		-174.25	-190.75	-192.77	-177.54	-149.86	-115.58	- 78.47	-53.93	—	24.53	26.58	24.04
4	0.8	1800.0	NO		-232.42	-248.93	-224.21	-190.06	- 126.22	- 52.64	- 34.39	- 4.32	—	33.14	45.44	44.47
5	1.0	2150.0	NO		-259.20	-258.36	-217.98	-146.10	- 47.56	- 13.34	- 10.81	+ 38.94	—	35.53	59.59	52.33
HEAD-250'					TEST No. 15							T. W. - 643'				
6	0.2	390.0	NO		- 5.11	+ 6.73	+ 1.52	+ 2.60	+ 0.42	+ 1.62	+ 7.30	+ 18.50	—	44.96	47.02	50.76
7	0.4	835.0	NO		- 64.09	- 61.66	- 57.46	- 62.66	- 56.99	- 46.36	- 28.10	- 20.84	—	31.39	48.59	49.19
8	0.6	1280.0	NO		-126.36	-134.11	-133.03	-119.32	- 88.49	- 60.50	- 20.24	+ 3.54	—	51.25	50.16	52.33
9	0.8	1735.0	NO		-189.97	-189.13	-156.61	-127.24	- 75.91	-27.49	+ 5.72	+26.36	—	59.11	54.88	58.62
10	1.0	2100.0	NO		-207.32	-209.57	-158.18	-100.45	- 14.54	+ 8.66	+22.26	54.66	—	76.40	69.02	58.62
HEAD-250'					TEST No. 15							T. W. - 655'				
11	0.2	385.0	NO		+ 8.28	+ 12.26	+ 16.49	+ 12.85	+ 12.24	+ 16.58	+ 20.69	+24.79	—	55.97	59.59	60.19
12	0.4	815.0	NO		- 45.23	- 45.96	- 54.31	- 50.09	- 41.27	- 32.21	- 20.24	- 1.99	—	57.54	58.02	64.91
13	0.6	1265.0	NO		- 98.74	-113.62	-112.54	-102.02	- 64.85	-49.20	- 10.75	+ 10.64	—	59.11	59.59	58.62
14	0.8	1690.0	NO		-152.18	-165.55	-143.98	- 100.45	- 47.56	- 18.06	- 15.97	+ 35.80	—	55.97	62.74	60.19
15	1.0	2000.0	NO		-166.39	-168.70	-121.97	- 83.23	+ 0.42	+ 18.18	+ 36.41	+40.51	—	46.54	58.02	66.48

TABLE 7

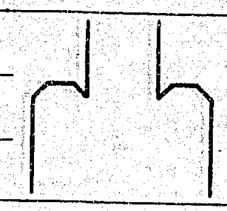
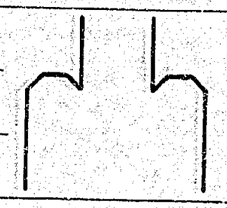
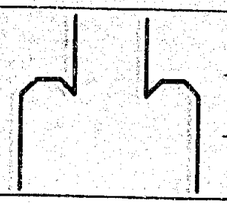
CONDITIONS					PRESSURES - FEET OF WATER											
RUN	VALVE OPENING	QUANTITY	AIR	SHAPE	1	2	3	4	5	6	7	8	9	10	11	12
HEAD-250'					TEST No. 16							T.W. - 625'				
1	0.2	350.0	NO		- 64.91	- 45.96	- 51.17	- 48.52	- 47.56	- 46.36	- 45.50	- 36.58	—	- 0.36	3.14	5.74
2	0.4	775.0	NO		- 120.74	- 104.18	- 118.82	- 114.60	- 113.64	- 99.86	- 83.18	- 71.22	—	5.93	6.17	8.88
3	0.6	1250.0	NO		- 191.54	- 178.13	- 183.28	- 161.76	- 146.71	- 121.93	- 80.04	- 50.72	—	10.64	11.00	17.56
4	0.8	1675.0	NO		- 254.60	- 242.64	- 238.42	- 182.26	- 142.00	- 87.29	- 50.11	- 8.58	—	30.32	22.82	42.71
5	1.0	2010.0	NO		- 273.29	- 263.02	- 232.37	- 182.26	- 63.28	- 66.79	- 37.54	+ 23.22	—	38.18	38.54	53.71
HEAD-250'					TEST No. 16							T.W. - 643'				
6	0.2		NO		+ 2.75	+ 9.88	+ 6.24	+ 3.68	+ 3.56	+ 3.19	+ 5.72	+ 12.97	—	50.76	49.55	50.57
7	0.4		NO		- 59.38	- 66.40	- 60.60	- 72.10	- 58.56	- 46.36	- 8.64	- 17.71	—	53.90	54.26	55.28
8	0.6		NO		- 131.75	- 137.20	- 123.54	- 127.18	- 101.06	- 62.08	- 35.96	- 3.56	—	52.33	55.84	52.14
9	0.8		NO		- 213.61	- 203.28	- 183.34	- 141.32	- 80.57	- 46.36	- 2.95	+ 11.40	—	52.33	57.41	47.42
10	1.0		NO		- 215.12	- 214.28	- 172.39	- 83.16	- 28.69	+ 7.91	+ 33.26	+ 49.94	—	74.40	93.32	81.25
HEAD-250'					TEST No. 16							T.W. - 655'				
11	0.2		NO		+ 24.00	+ 16.98	+ 10.20	+ 8.89	+ 15.38	+ 15.01	+ 22.26	+ 26.36	—	60.19	60.55	58.43
12	0.4		NO		- 40.51	- 39.67	- 38.59	- 48.52	- 47.56	- 32.21	- 15.47	+ 1.97	—	61.76	62.12	61.57
13	0.6		NO		- 119.17	- 118.33	- 110.96	- 109.88	- 82.20	- 43.21	- 20.24	+ 9.83	—	57.05	51.12	53.71
14	0.8		NO		- 84.59	- 176.56	- 145.55	- 95.74	- 47.56	- 13.34	+ 15.16	+ 32.65	—	58.62	65.27	69.43
15	1.0		NO		- 169.54	- 171.84	- 129.89	- 70.52	- 20.83	+ 7.15	+ 19.12	+ 31.08	—	49.19	60.55	56.86

TABLE 9

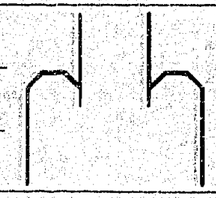
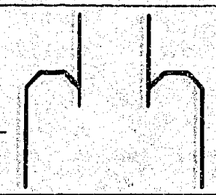
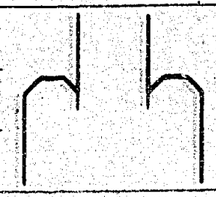
CONDITIONS					PRESSURES - FEET OF WATER											
RUN	VALVE OPENING	QUANTITY	AIR	SHAPE	1	2	3	4	5	6	7	8	9	10	11	12
HEAD-250'					TEST No. 17							T.W. - 625'				
1	0.2	400.0	NO		- 54.66	- 44.39	- 62.17	- 56.38	- 56.99	- 51.07	- 48.54	- 41.29	—	1.82	2.18	1.63
2	0.4	845.0	NO		- 119.17	- 108.90	- 117.19	- 116.12	- 115.15	- 95.15	- 84.74	- 60.16	—	6.54	12.43	7.92
3	0.6	1330.0	NO		- 197.83	- 196.99	- 199.06	- 179.11	- 141.94	- 117.16	- 80.04	- 46.01	—	18.36	15.52	21.25
4	0.8	1805.0	NO		- 234.05	- 220.63	- 219.55	- 191.69	- 119.93	- 79.37	- 34.39	- 8.28	—	40.37	31.30	35.46
5	1.0	2115.0	NO		- 232.42	- 247.30	- 210.12	- 117.74	- 104.21	- 9.38	- 27.00	- 22.66	—	35.65	39.16	51.18
HEAD-250'					TEST No. 17							T.W. - 643'				
6	0.2	390.0	NO		- 8.26	- 7.42	- 9.48	- 5.26	+ 1.99	- 0.53	- 8.42	- 4.32	—	33.26	32.05	34.64
7	0.4	820.0	NO		- 64.85	- 70.30	- 72.36	- 68.14	- 54.60	- 65.98	- 52.44	- 35.76	—	30.12	30.48	31.50
8	0.6	1305.0	NO		- 140.30	- 145.75	- 141.53	- 127.87	- 92.33	- 91.13	- 55.58	- 29.47	—	33.26	30.48	34.64
9	0.8	1750.0	NO		- 182.75	- 177.19	- 168.25	- 124.73	- 68.75	- 21.96	+ 7.30	+ 22.40	—	56.84	69.78	55.08
10	1.0	2090.0	NO		- 212.62	- 202.31	- 154.10	- 61.85	- 10.58	+ 31.49	+ 29.30	+ 56.99	—	80.42	68.21	61.39
HEAD-250'					TEST No. 17							T.W. - 655'				
11	0.2	365.0	NO		+ 14.96	+ 17.74	+ 14.10	+ 15.18	+ 22.43	9.48	13.58	17.69	—	47.41	50.92	51.94
12	0.4	780.0	NO		- 36.55	- 32.57	- 31.85	- 35.12	- 20.02	- 32.96	- 3.71	+ 0.40	—	56.84	58.78	58.22
13	0.6	1240.0	NO		- 130.87	- 120.60	- 119.88	- 102.72	- 76.61	- 73.84	- 43.01	- 23.18	—	36.41	39.91	36.22
14	0.8	1710.0	NO		- 178.03	- 189.77	- 154.46	- 109.01	- 57.74	- 34.54	- 6.85	+ 1.61	—	52.13	57.20	53.22
15	1.0	2030.0	NO		- 214.18	- 191.34	- 132.46	- 53.99	+ 1.99	+ 23.63	+ 38.74	+ 49.13	—	77.28	77.64	67.68

TABLE 8

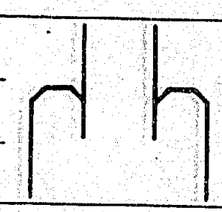
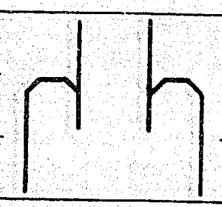
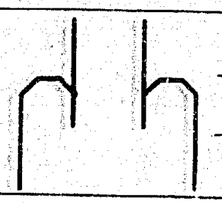
CONDITIONS					PRESSURES - FEET OF WATER											
RUN	VALVE OPENING	QUANTITY	AIR	SHAPE	1	2	3	4	5	6	7	8	9	10	11	12
HEAD-250'					TEST No. 18							T.W - 625'				
1	0.2	410.0	NO		- 16.12	- 13.70	- 17.70	- 24.12	- 20.02	-21.96	- 17.86	- 7.46	—	24.44	26.38	30.54
2	0.4	860.0	NO		- 74.28	- 78.16	- 83.72	- 87.00	- 73.46	-65.98	- 49.30	- 32.62	—	29.16	32.66	36.83
3	0.6	1340.0	NO		-165.48	-170.90	-173.33	-165.60	-133.20	- 97.42	- 65.02	- 32.62	—	32.30	29.52	33.60
4	0.8	1780.0	NO		-222.05	-233.78	-204.77	-175.03	- 123.77	-87.98	- 39.86	- 7.46	—	38.59	23.23	27.40
5	1.0				-247.20	-236.93	-201.62	- 115.30	- 60.89	- 6.24	+ 13.58	+ 23.98	—	38.59	38.95	47.83
HEAD-250'					TEST No. 18							T.W. - 643'				
6	0.2	400.0	NO		+ 2.75	+ 0.44	+ 2.74	- 6.83	- 2.72	+ 1.62	+ 7.30	+ 6.68	—	43.31	45.24	44.69
7	0.4	837.5	NO		- 96.29	- 79.73	- 85.30	- 93.29	- 73.46	- 72.46	- 71.30	- 26.33	—	70.03	70.39	27.40
8	0.6	1280.0	NO		-112.01	-120.60	-123.02	-112.15	- 89.18	-59.69	- 27.29	- 4.32	—	54.31	51.53	52.55
9	0.8	1715.0	NO		- 196.90	- 189.77	- 163.90	-146.74	- 82.90	-56.54	- 11.57	+ 1.97	—	41.74	42.10	36.83
10	1.0	2070.0	NO		-237.77	-227.50	-157.61	- 74.42	- 20.02	+18.91	+ 38.74	+52.27	—	54.31	51.53	58.84
HEAD-250'					TEST No. 18							T. W. - 655'				
11	0.2	395.0	NO		+ 12.18	+ 11.45	+ 13.74	+ 7.32	+ 9.85	11.05	10.44	22.40	—	57.46	57.82	58.84
12	0.4	820.0	NO		- 74.28	- 64.01	- 72.72	- 77.57	- 60.89	- 53.40	- 43.01	-20.04	—	35.45	38.95	39.97
13	0.6	1250.0	NO		-118.30	- 98.54	- 94.73	- 93.29	- 73.46	- 43.97	- 11.57	+ 5.11	—	63.74	66.89	68.27
14	0.8	1705.0	NO		-159.17	-142.61	-126.17	- 96.38	- 42.02	- 6.24	+29.30	39.70	—	66.89	70.39	71.41
15	1.0	2020.0	NO		- 193.75	-177.31	-126.17	- 52.42	+ 1.99	+ 18.91	+ 54.46	55.42	—	70.03	86.11	74.56

TABLE 10

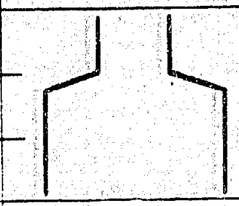
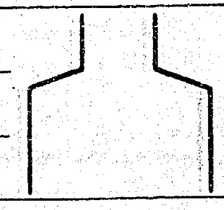
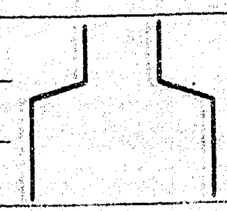
CONDITIONS					PRESSURES - FEET OF WATER											
RUN	VALVE OPENING	QUANTITY	AIR	SHAPE	1	2	3	4	5	6	7	8	9	10	11	12
HEAD-250'					TEST No. 19						T.W. - 625'					
1	0.2	375.0	YES		- 6.82	- 8.10	- 5.51	- 2.98	- 1.90	- 2.39	—	—	—	7.37	7.73	6.52
2	0.4	715.0	YES		- 5.24	- 8.10	- 7.08	- 6.12	- 3.47	- 3.96	—	—	—	4.22	6.16	4.94
3	0.6	1040.0	YES		- 5.24	- 8.10	- 8.65	- 9.26	- 11.33	- 8.68	—	—	—	16.80	17.16	19.09
4	0.8	1310.0	YES		- 6.82	- 11.24	- 13.37	- 13.98	- 12.90	- 13.39	—	—	—	23.09	20.30	26.95
5	1.0	1537.5	YES		- 8.39	- 12.82	- 11.80	- 12.41	- 12.90	- 11.82	—	—	—	26.23	32.88	36.38
HEAD-250'					TEST No. 19						T.W. - 643'					
6	0.2	370.0	YES		- 2.10	- 1.81	- 2.36	+ 0.17	- 0.32	+ 0.76	—	—	—	19.94	23.45	23.81
7	0.4	715.0	YES		- 8.39	- 8.10	- 5.51	- 2.98	- 3.47	- 2.39	—	—	—	18.37	23.45	25.38
8	0.6	1032.5	YES		- 5.24	- 6.53	- 7.08	- 7.69	- 6.61	- 7.10	—	—	—	29.38	29.74	36.38
9	0.8	1302.5	YES		- 6.82	- 9.67	- 10.22	- 9.26	- 9.76	- 10.25	—	—	—	30.95	32.88	34.81
10	1.0	1537.5	YES		- 8.39	- 11.24	- 11.80	- 10.84	- 9.76	- 10.25	—	—	—	32.52	37.60	48.96
HEAD-250'					TEST No. 19						T.W. - 655'					
11	0.2	355.0	YES		- 3.67	- 1.81	- 0.79	- 1.40	+ 2.82	5.47	—	—	—	34.09	32.88	34.81
12	0.4	715.0	YES		- 3.67	- 3.38	- 3.94	- 2.98	- 3.47	- 2.39	—	—	—	32.52	34.45	36.38
13	0.6	1030.0	YES		- 3.67	- 6.53	- 7.08	- 6.12	- 6.61	- 5.53	—	—	—	41.95	42.31	42.67
14	0.8	1300.0	YES		- 6.82	- 9.67	- 8.65	- 9.26	- 8.18	- 8.68	—	—	—	35.66	42.31	48.96
15	1.0	1530.0	YES		- 6.82	- 9.67	- 8.65	- 10.84	- 9.76	- 8.68	—	—	—	34.09	34.45	48.96

TABLE 13

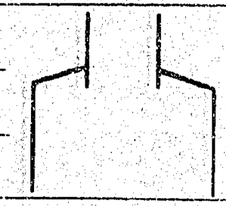
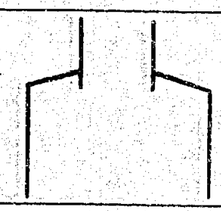
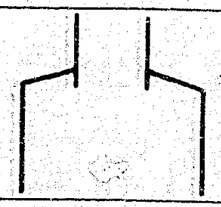
CONDITIONS					PRESSURES - FEET OF WATER											
RUN	VALVE OPENING	QUANTITY	AIR	SHAPE	1	2	3	4	5	6	7	8	9	10	11	12
HEAD-250'					TEST No. 20						T. W. - 625'					
1	0.2	375.0	YES		- 3.67	- 4.96	- 3.94	- 2.98	- 3.47	- 2.39	—	—	—	6.41	8.34	7.13
2	0.4	735.0	YES		- 5.24	- 9.67	- 8.65	- 7.69	- 8.18	- 7.10	—	—	—	12.70	9.91	10.27
3	0.6	1047.5	YES		- 6.82	- 9.67	- 10.22	- 10.84	- 11.33	- 8.68	—	—	—	12.70	17.77	19.70
4	0.8	1320.0	YES		- 6.82	- 11.24	- 10.22	- 10.84	- 11.33	- 10.25	—	—	—	18.98	25.63	25.99
5	1.0	1540.0	YES		- 8.39	- 11.24	- 11.80	- 10.84	- 14.47	- 11.82	—	—	—	23.70	22.49	29.14
HEAD-250'					TEST No. 20						T. W. - 643'					
6	0.2	365.0	YES		- 3.67	- 3.38	- 3.94	- 1.40	- 0.32	- 0.82	—	—	—	18.98	22.49	22.85
7	0.4	735.0	YES		- 5.24	- 4.96	- 5.51	- 4.55	- 5.04	- 3.96	—	—	—	22.13	25.63	25.99
8	0.6	1045.0	YES		- 6.82	- 9.67	- 7.08	- 7.69	- 9.76	- 7.10	—	—	—	25.27	33.49	35.42
9	0.8	1315.0	YES		- 5.24	- 9.67	- 8.65	- 9.26	- 8.18	- 8.68	—	—	—	31.56	41.35	35.42
10	1.0	1537.5	YES		- 6.82	- 9.67	- 10.22	- 9.26	- 9.76	- 10.25	—	—	—	31.56	38.21	41.71
HEAD-250'					TEST No. 20						T. W. - 655'					
11	0.2	365.0	YES		- 2.10	- 1.81	- 2.36	- 2.98	- 0.32	+ 3.90	—	—	—	33.13	33.49	32.28
12	0.4	740.0	YES		- 3.67	- 4.96	- 3.94	- 4.55	- 3.47	- 2.39	—	—	—	1.69	31.92	33.85
13	0.6	1052.5	YES		- 5.24	- 8.10	- 7.08	- 7.69	- 6.61	- 5.53	—	—	—	34.70	38.21	41.71
14	0.8	1310.0	YES		- 5.24	- 8.10	- 8.65	- 7.69	- 8.18	- 8.68	—	—	—	40.99	47.64	51.14
15	1.0	1535.0	YES		- 6.82	- 9.67	- 10.22	- 9.26	- 8.18	- 8.68	—	—	—	40.99	47.64	48.00

TABLE 18

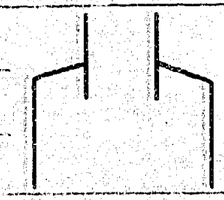
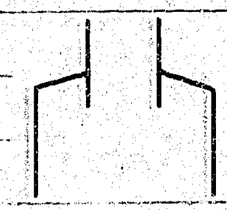
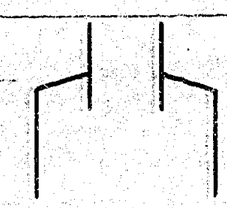
CONDITIONS					PRESSURES - FEET OF WATER											
RUN	VALVE OPENING	QUANTITY	AIR	SHAPE	1	2	3	4	5	6	7	8	9	10	11	12
HEAD-250'					TEST No. 21						T. W. - 625'					
1	0.2	365.0	YES		- 5.24	- 6.53	- 5.51	- 2.98	- 3.47	- 2.39	—	—	—	7.02	4.24	7.74
2	0.4	735.0	YES		- 8.39	- 8.10	- 7.08	- 7.69	- 8.18	- 5.47	—	—	—	11.74	12.10	10.88
3	0.6	1040.0	YES		- 6.82	- 9.67	- 8.65	- 10.84	- 9.76	- 7.10	—	—	—	14.88	16.81	15.60
4	0.8	1310.0	YES		- 8.39	- 11.24	- 13.37	- 12.41	- 11.33	- 10.25	—	—	—	18.02	21.53	25.03
5	1.0	1512.5	YES		- 8.39	- 11.24	- 11.80	- 13.98	- 11.33	- 8.68	—	—	—	11.74	15.24	25.03
HEAD-250'					TEST No. 21						T. W. - 643'					
6	0.2	365.0	YES		- 2.10	- 3.38	- 0.79	- 2.98	- 0.32	+ 2.33	—	—	—	19.60	21.53	21.89
7	0.4	725.0	YES		- 3.67	- 6.53	- 5.51	- 4.55	- 5.04	- 2.39	—	—	—	19.60	21.53	21.89
8	0.6	1040.0	YES		- 5.24	- 8.10	- 8.65	- 7.69	- 5.04	- 7.10	—	—	—	30.60	34.10	31.32
9	0.8	1305.0	YES		- 6.82	- 9.67	- 10.22	- 7.69	- 6.61	- 7.10	—	—	—	33.74	37.25	34.46
10	1.0	1510.0	YES		- 6.82	- 8.10	- 10.22	- 7.69	- 8.18	- 8.68	—	—	—	30.60	43.54	40.75
HEAD-250'					TEST No. 21						T. W. - 655'					
11	0.2	367.5	YES		- 2.10	- 1.81	- 0.79	+ 0.17	+ 2.82	+ 3.90	—	—	—	30.60	34.10	34.46
12	0.4	730.0	YES		- 3.67	- 4.96	- 5.51	- 4.55	- 5.04	- 3.96	—	—	—	27.46	34.10	31.32
13	0.6	1040.0	YES		- 5.24	- 6.53	- 7.08	- 7.69	- 8.18	- 5.53	—	—	—	43.18	40.39	40.75
14	0.8	1300.0	YES		- 5.24	- 8.18	- 8.65	- 9.26	- 9.76	- 7.10	—	—	—	40.03	43.54	47.04
15	1.0	1510.0	YES		- 5.24	- 8.10	- 8.65	- 9.26	- 8.18	- 8.68	—	—	—	43.18	46.68	47.04

TABLE II

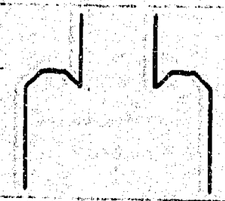
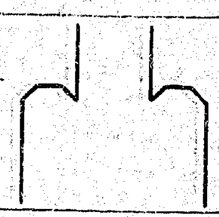
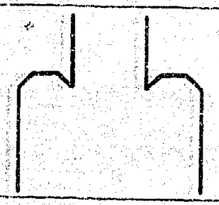
CONDITIONS					PRESSURES - FEET OF WATER											
RUN	VALVE OPENING	QUANTITY	AIR	SHAPE	1	2	3	4	5	6	7	8	9	10	11	12
HEAD-250'					TEST No. 22						T.W. - 625'					
1	0.2	365.0	YES		- 0.53	- 4.96	- 5.51	- 4.55	- 3.47	- 2.39	—	—	—	9.91	7.13	4.82
2	0.4	720.0	YES		- 5.24	- 8.10	- 5.51	- 6.12	- 5.04	- 3.96	—	—	—	8.34	10.27	14.26
3	0.6	1027.5	YES		- 5.24	- 8.10	- 8.65	- 9.26	- 9.76	- 7.10	—	—	—	16.20	19.70	17.40
4	0.8	1312.5	YES		- 5.24	- 8.10	- 5.51	- 9.26	- 9.76	- 10.25	—	—	—	22.49	25.99	23.69
5	1.0	1515.0	YES		- 6.82	- 12.83	- 13.37	- 10.84	- 9.76	- 10.25	—	—	—	22.49	29.14	33.12
HEAD-250'					TEST No. 22						T.W. - 643'					
6	0.2	360.0	YES		- 2.10	- 1.81	- 2.36	- 2.98	- 0.32	- 0.82	—	—	—	16.20	22.85	22.12
7	0.4	715.0	YES		- 3.67	- 6.53	- 3.94	- 2.98	- 5.04	- 2.39	—	—	—	25.63	22.85	26.83
8	0.6	1030.0	YES		- 5.24	- 8.10	- 5.51	- 4.92	- 6.61	- 5.53	—	—	—	25.63	32.28	36.26
9	0.8	1307.5	YES		- 5.24	- 8.10	- 8.65	- 7.69	- 8.18	- 8.68	—	—	—	31.92	35.42	39.41
10	1.0	1522.5	YES		- 6.82	- 9.67	- 10.22	- 9.26	- 9.76	- 8.68	—	—	—	41.35	41.71	42.55
HEAD-250'					TEST No. 22						T.W. - 655'					
11	0.2	365.0	YES		- 2.10	- 1.81	+ 0.78	+ 0.17	+ 1.25	+ 3.90	—	—	—	31.92	32.28	33.12
12	0.4	717.5	YES		- 2.10	- 3.38	- 3.94	- 4.55	- 3.47	+ 0.76	—	—	—	35.06	35.42	34.69
13	0.6	1025.0	YES		- 5.24	- 6.53	- 7.08	- 4.55	- 5.04	- 3.96	—	—	—	44.50	44.86	42.55
14	0.8	1305.0	YES		- 5.24	- 8.10	- 8.65	- 7.69	- 8.18	- 7.10	—	—	—	41.35	44.86	48.84
15	1.0	1512.5	YES		- 6.82	- 9.67	- 7.08	- 9.26	- 8.18	- 8.68	—	—	—	47.64	51.14	42.55

TABLE 6

45-D-12494

1 to 12 model of the unit and have been enlarged to the prototype dimensions. They are in feet of water above or below the respective piezometer. The negative values indicate a vacuum at the piezometer, many of which are far in excess of the negative pressure obtainable at this altitude, which indicates the amount of energy to be dissipated by the generation of steam vapor with resulting hydraulic pounding or noise of cavitation when the vapor is condensed in a region of higher pressure.

From the flow conditions observed in the model and the recorded data, the following conclusions are quite evident:

(a) The amount of air entrained through the 12-inch air vent is not materially affected by the type of roof placed around the lower end of the vertical discharge tube, the extension of the cylindrical discharge tube into the discharge passage, nor the elevation of the tail water.

(b) The pressure in the cylindrical discharge tube where air enters from the 12-inch vent line is affected only slightly by a change in elevation of the tail water. The free surface of the water surrounding the jet from the relief valve (which is at a point approximately halfway up the tube) rises slightly when the tail-water elevation is increased from 625 to 655. It is possible that this rise is in proportion to the reduction in total head on the relief valve, which is relatively small. At no time does the free surface of the water reach the valve seat, except for momentary splashes of water up to this point.

(c) The air-vent line on the model was constructed of glass to enable visual study of the water column with the valve operating. No evidence of oscillatory flow in the horizontal portion of this line was observed at any valve opening.

(d) A study of the accompanying tables will show that with the admission of atmospheric air through the 12-inch air-vent line much smaller negative pressures were measured, often becoming positive in value, while the positive pressures were generally increased and were more stable. With the admission of air, the flow was much more stable, and there was less "bouncing" and "pounding" of the water in both the small discharge tube and in the large discharge chamber. Flow through the horizontal discharge tube was also much quieter, as was the surface of the tail water.

(e) The conical roof (section 1, fig. 14) around the lower end of the small discharge tube gave good vacuum conditions for entraining air when the air inlet valves were closed. The arched roof (section 2, fig. 14) did not perform as satisfactorily in this

respect, which is undoubtedly due to an excessive loss in velocity head at the point of sudden expansion. This would indicate that the conical roof is the more logical design as it approaches, in principle, the expanding section of the Venturi tube and does not direct the return jet up toward the valve seat as was first believed. There is no apparent advantage for either type of roof when the valve is fully aerated. It is believed that the 12-inch air-vent line is adequate under all conditions of valve opening and elevations of tail water.

After these tests had indicated that the flow conditions would be satisfactory, the main unit was altered, and the subsequent field tests and operation reports have shown the operation in the field to parallel very closely the model tests.

Cylindrical Type with Horseshoe-Shaped Exit

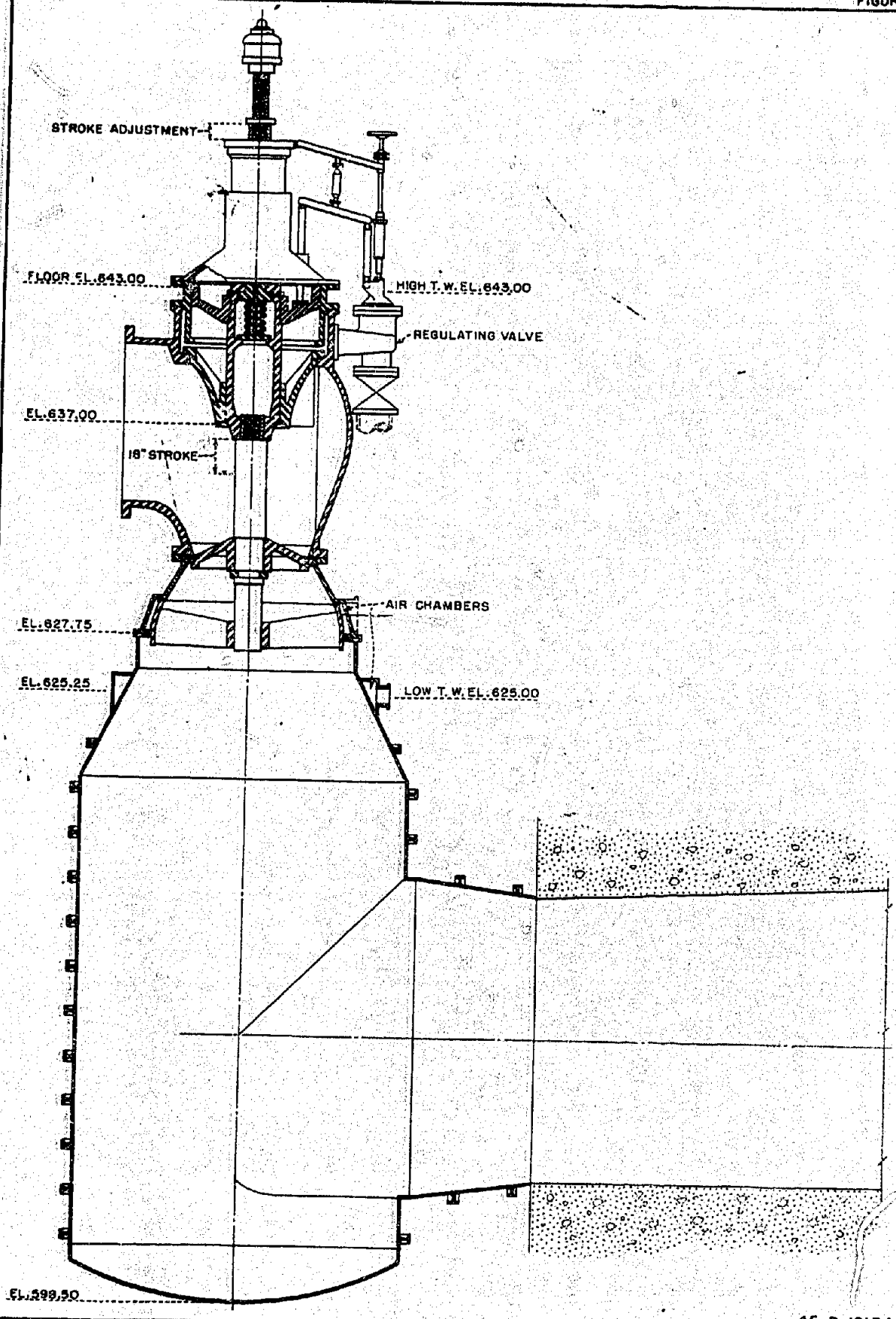
10. Test 6. The first test was made on this unit as originally designed (fig. 15), and although the performance appeared to be fairly smooth, it was believed that improvements could be made (photograph D, plate 1). The coefficient of discharge with a high tail water was very nearly constant, varying only 0.011 throughout the various valve settings, while with the lower tail-water level the coefficient varied 0.039, which would tend to indicate that the flow is less stable at the lower level.

The velocities measured on the bottom of the draft tube increased as the discharge increased, varying from 6.50 to 33.50 feet per second with the high tail water. The flow was fairly evenly distributed across the bottom of the tube, as shown by these pressures (tables 14 and 15) and the flow lines on figure 16. The average of the velocities with a full valve opening was only 31.10 feet per second, being the lowest average velocity of any of the bottom positions tested. With the low tail-water level these velocities increased from 7.00 to 34.50 feet per second, but the average velocity across the bottom of the draft tube with a full valve opening was only 32.92 feet per second.

11. Test 7. This test was made on the same unit, the only change being that the bottom was raised to a point midway between its original position and the bottom of the draft-tube opening. The observed flow lines are shown on figures 17 and 18 for both high and low tail-water levels. The minimum to maximum velocity range was identical with the previous tests, but the average velocity with full valve opening was slightly higher, being 32.59 feet per second with the high tail water and 33.17 feet per second at the low level.

The variation in the discharge coefficient was 0.057 for

FIGURE 15



45-D-12134

TABLE 14

PROTOTYPE VALUES FROM MODEL DATA TAKEN AT POINTS SHOWN ON FIGURE 8

CONDITIONS				DISCHARGE	VELOCITY FT./SEC.			PRESSURES – FEET OF WATER												
VALVE OPENING	HEAD FEET	TAIL-WATER ELEV.	QUANTITY SECOND-FEET	COEF. "C"	V_L	V_M	V_R	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14
TEST No. 6 - B.D. RUN 1-5																				
.2	402.4	643.5	325.5	.822	6.44	6.44	6.79	-2.72	-15.44	13.16	19.26	20.66	19.16	48.04	48.00	47.90	7.00	6.10	- 8.50	48.44
.4	407.0	642.6	682.5	.830	13.41	12.38	12.92	-2.72	-15.54	6.86	42.70	37.10	31.46	49.80	49.20	49.00	- 0.14	- 2.60	-36.90	49.60
.6	408.4	643.0	1062.7	.833	20.56	18.28	20.56	-2.52	-15.54	1.96	118.90	68.10	53.06	52.96	52.74	52.40	- 7.30	- 9.40	-64.40	53.00
.8	407.2	642.9	1436.6	.825	27.89	24.45	27.45	-2.32	-15.54	- 2.54	155.50	85.30	77.06	57.40	57.60	56.90	-13.00	-15.50	*-99.24	57.80
1.0	408.8	643.3	1851.6	.828	33.44	29.95	29.90	-2.18	-13.34	- 6.74	168.90	124.30	104.06	62.50	62.90	62.30	-17.60	-20.10	*-123.40	63.30
CK.4	407.0	642.9	687.3	.833	13.01	12.65	12.83	-2.58	-15.54	7.06	43.60	37.30	31.76	50.40	49.60	49.20	- 0.10	- 2.20	-37.00	49.80
TEST No. 7 - B.D. RUN 1-5																				
.2	405.8	643.3	311.5	.783	5.68	4.39	5.68	-2.42	-15.44	13.26	18.50	20.90	20.06				6.96	*6.90	- 6.70	
.4	405.6	643.2	676.2	.823	13.77	12.38	12.78	-2.32	-15.54	7.42	43.80	37.34	31.86				- 0.60	- 4.40	-35.90	
.6	407.4	642.7	1062.7	.835	20.12	18.77	20.87	-2.22	-15.54	0.18	118.84	57.90	52.76				- 7.60	- 9.20	-65.60	
.8	407.2	643.0	1465.2	.840	27.98	23.11	27.98	-2.02	-15.54	- 2.78	155.50	85.24	75.86				-13.20	-15.70	-83.00	
1.0	409.2	643.0	1863.6	.832	33.17	30.53	34.06	-0.17	-13.34	- 7.14	175.50	125.24	104.96				-18.10	-20.50	-92.40	
TEST No. 8 - B.D. RUN 1-5																				
.2	406.8	643.5	316.1	.795	8.05	7.15	7.15	-2.52	-15.54	13.06	18.70	21.10	19.26				6.76	6.30	- 8.04	
.4	406.6	643.0	670.9	.823	13.90	14.57	14.13	-2.42	-15.58	6.96	42.70	37.30	31.70				- 0.80	- 2.00	-34.50	
.6	408.2	642.8	1062.7	.833	20.92	21.81	21.23	-2.28	-15.64	0.14	118.00	57.50	52.46				- 7.90	- 9.88	-65.30	
.8	409.8	642.9	1465.2	.837	27.80	28.87	28.56	-2.12	-15.54	- 3.04	158.84	86.06	77.46				-13.80	-16.20	-76.20	
1.0	412.2	643.3	1862.4	.829	33.35	35.18	35.49	-7.12	-13.94	- 8.44	175.50	123.56	104.12				-18.70	-21.10	-91.94	
TEST No. 9 - B.D. RUN 1-5																				
.2	403.8	643.3	278.0	.702	7.15	7.15	7.15	1.88	-16.14	13.26	18.90	19.90	18.46				6.60	6.60	- 9.34	
.4	400.0	643.1	597.5	.733	13.41	13.85	13.19	1.78	-16.24	7.18	41.40	36.30	31.10				- 0.80	- 1.40	-44.40	
.6	407.8	643.2	1048.0	.825	18.64	20.74	20.58	1.98	-16.24	2.06	65.50	57.50	52.66				- 7.40	- 8.84	-65.00	
.8	416.0	643.0	1436.0	.815	23.25	27.98	27.31	2.14	-16.24	- 3.64	152.16	85.56	75.26				-13.40	-15.10	-88.40	
1.0	413.2	642.8	1863.0	.829	33.90	34.65	33.75	2.18	-14.24	- 8.04	175.50	123.56	104.12				-19.10	-20.80	-91.60	

*RERUNS

Test No. 6 - Original design.
Test No. 7 - Bottom raised to point midway between original position and bottom of draft tube
Test No. 8 - Flat bottom made flush with bottom of draft tube.
Test No. 9 - Curved bottom made flush with bottom of draft tube.

45-D-12128

TABLE 14

TABLE 15

PROTOTYPE VALUES FROM MODEL DATA TAKEN AT POINTS SHOWN ON FIGURE 9

CONDITIONS				DISCHARGE COEF. "C"	VELOCITY FT./SEC.			PRESSURES - FEET OF WATER												
VALVE OPENING	HEAD FEET	TAIL-WATER ELEV.	QUANTITY SECOND-FEET		V_L	V_M	V_B	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14
TEST No. 6 - B.D. RUN 6-10																				
.2	405.0	625.0	322.0	.810	7.05	7.05	7.05	- 3.32	-16.54	- 5.02	0.01	3.00	1.06	29.60	29.60	29.40	-11.70	-12.10	- 27.80	29.90
.4	406.8	625.0	685.2	.834	13.90	12.95	13.14	- 3.22	-16.64	-11.14	26.00	20.40	15.06	31.90	31.70	31.40	-19.20	-20.40	- 55.80	32.00
.6	407.4	625.1	1077.0	.849	20.29	18.95	21.23	- 3.02	-16.74	-16.84	105.50	41.66	36.36	35.36	35.00	34.50	-26.40	-28.40	- 72.00	35.20
.8	408.4	625.5	1483.1	.848	27.98	25.21	28.25	- 3.90	-16.64	-21.24	146.50	69.90	61.26	39.80	40.10	39.30	-31.60	-33.90	- 73.40	40.00
1.0	409.2	625.5	1889.5	.835	34.51	30.13	34.11	- 2.82	-14.74	-25.42	152.10	109.30	89.06	44.70	45.40	44.80	-38.20	-38.40	-102.40	45.60
CK. .8	408.4	624.8	1495.6	.854	27.58	24.85	27.98	- 3.02	-16.74	-21.84	143.90	69.90	61.46	39.50	39.50	39.10	-33.00	-35.40	- 77.80	39.80
TEST No. 7 - B.D. RUN 6-10																				
.2	405.8	624.3	336.3	.845	7.15	7.60	6.82	- 3.12	-16.64	- 5.14	0.30	3.00	0.76				-11.04	-12.56	- 26.74	
.4	407.4	624.8	696.0	.847	13.41	12.38	13.14	- 2.92	-16.64	-11.30	26.50	20.10	14.46				-19.40	-20.80	- 54.70	
.6	408.2	624.8	1077.0	.845	20.47	18.95	20.92	- 2.82	-16.84	-16.64	103.84	41.06	35.86				-26.50	-28.10	- 32.64	
.8	407.2	624.6	1483.1	.850	27.54	23.60	28.87	- 2.66	-16.74	-21.74	142.16	67.90	60.46				-32.50	-35.10	- 57.70	
1.0	409.6	624.7	1874.9	.838	33.93	31.02	34.51	- 2.52	-14.54	-26.34	152.16	108.56	89.96				-37.10	-39.30	- 83.00	
TEST No. 8 - B.D. RUN 6-10																				
.2	405.8	625.4	339.1	.849	6.79	7.78	7.42	- 6.36	-16.82	- 4.94	0.30	2.50	0.76				-11.48	-11.90	- 27.60	
.4	407.0	625.1	685.2	.835	15.91	14.97	14.13	-11.68	-16.90	-11.30	27.10	19.30	15.46				-19.40	-20.50	- 46.22	
.6	409.2	625.3	1086.9	.850	20.43	22.21	22.17	-17.52	-16.84	-17.54	105.50	41.40	36.46				-27.16	-29.70	- 44.36	
.8	411.8	624.7	1508.1	.859	28.25	29.90	29.59	-23.02	-17.04	-22.84	146.50	70.30	61.76				-33.84	-35.10	- 70.20	
1.0	406.2	624.3	1874.9	.841	34.02	35.89	35.95	-27.02	-14.94	-27.74	152.16	106.90	89.46				-38.80	-41.20	-110.80	
TEST No. 9 - B.D. RUN 6-10																				
.2	405.2	625.2	283.3	.713	7.15	7.15	6.62	-11.22	-17.24	- 4.74	- 2.14	2.94	-0.94				-13.60	-12.04	- 28.16	
.4	405.6	624.3	696.0	.848	10.46	14.57	13.41	-11.82	-17.34	-11.24	25.50	19.30	15.66				-20.40	-20.90	- 56.10	
.6	408.4	625.0	1074.0	.846	19.95	21.01	20.60	-17.42	-17.44	-17.14	103.84	40.90	35.82				-26.80	-28.44	- 86.32	
.8	406.6	625.6	1483.0	.850	27.22	28.70	28.11	-21.62	-17.54	-21.44	145.50	69.90	61.36				-32.70	-34.90	- 64.20	
1.0	406.2	624.8	1882.0	.845	32.55	35.10	33.90	-26.52	-15.44	-26.78	152.16	108.56	88.30				-38.44	-40.40	-100.60	

Test No. 6 – Original design.
Test No. 7 – Bottom raised to point midway between original position and bottom of draft tube.
Test No. 8 – Flat bottom made flush with bottom of draft tube.
Test No. 9 – Curved bottom made flush with bottom of draft tube.

45-D-12129

TABLE 15

So most pressures

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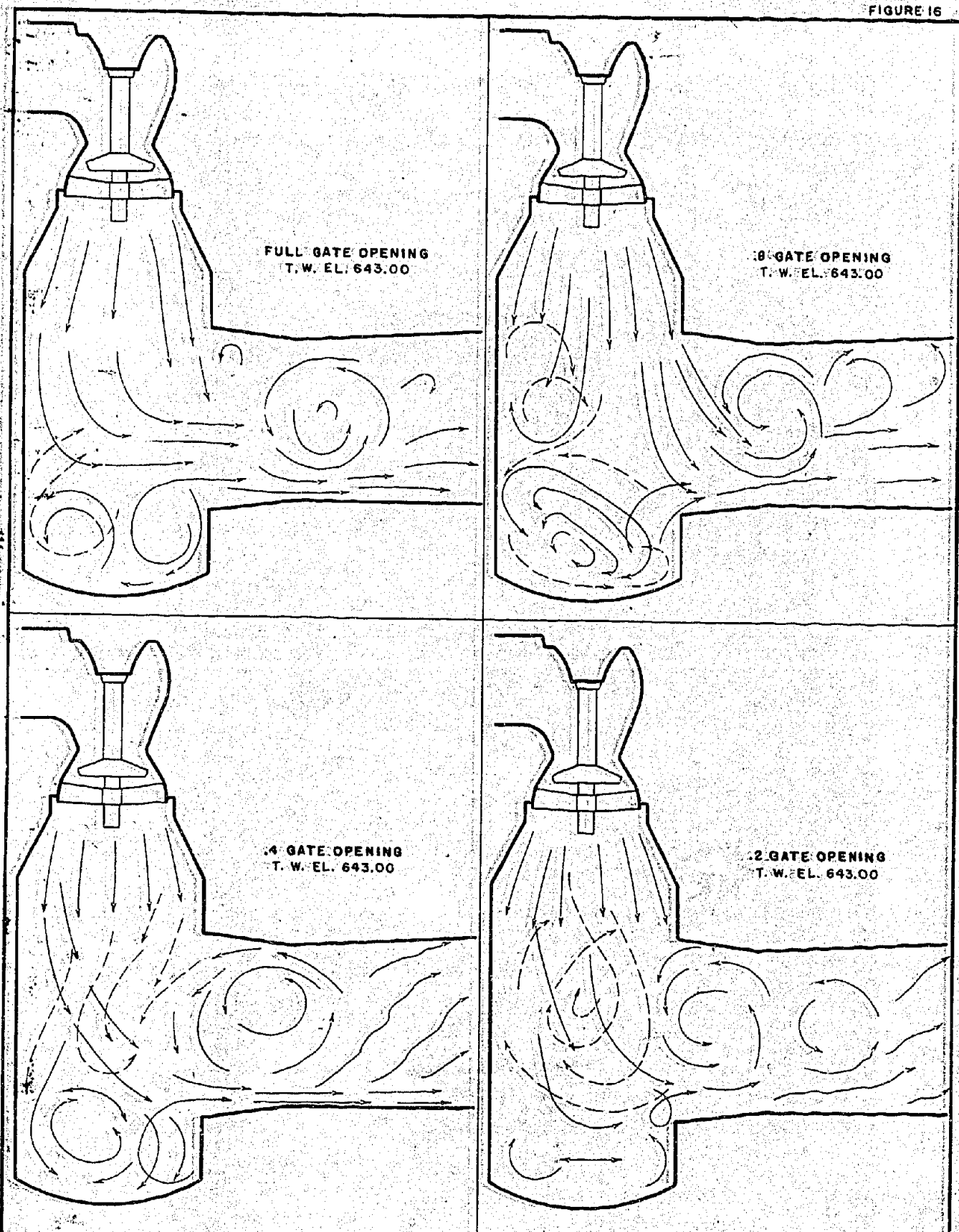
FIGURE 16

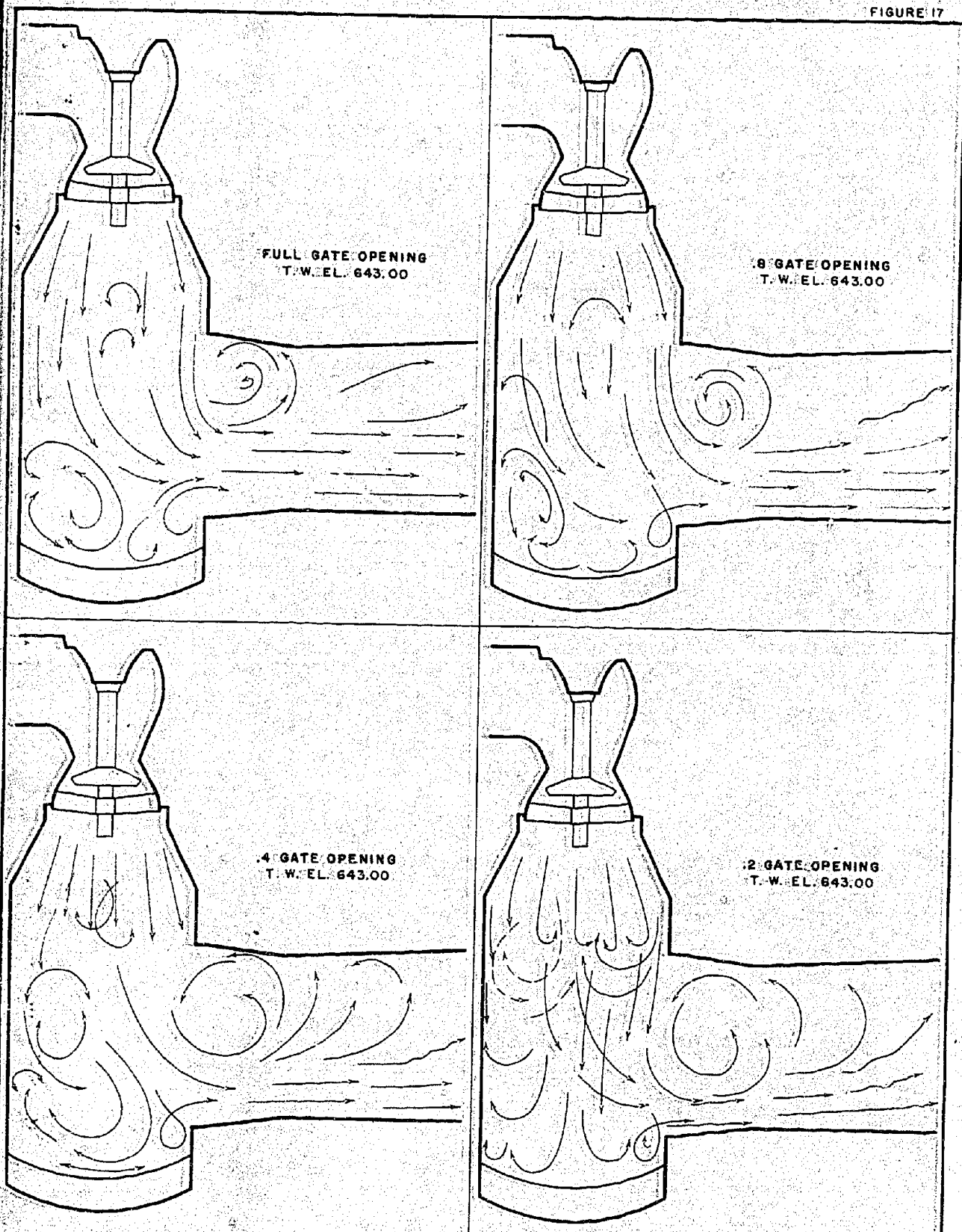


FLOW LINES IN ENERGY ABSORBER MODEL

E.B.M.-F.T.

45-D-12135

FIGURE 17



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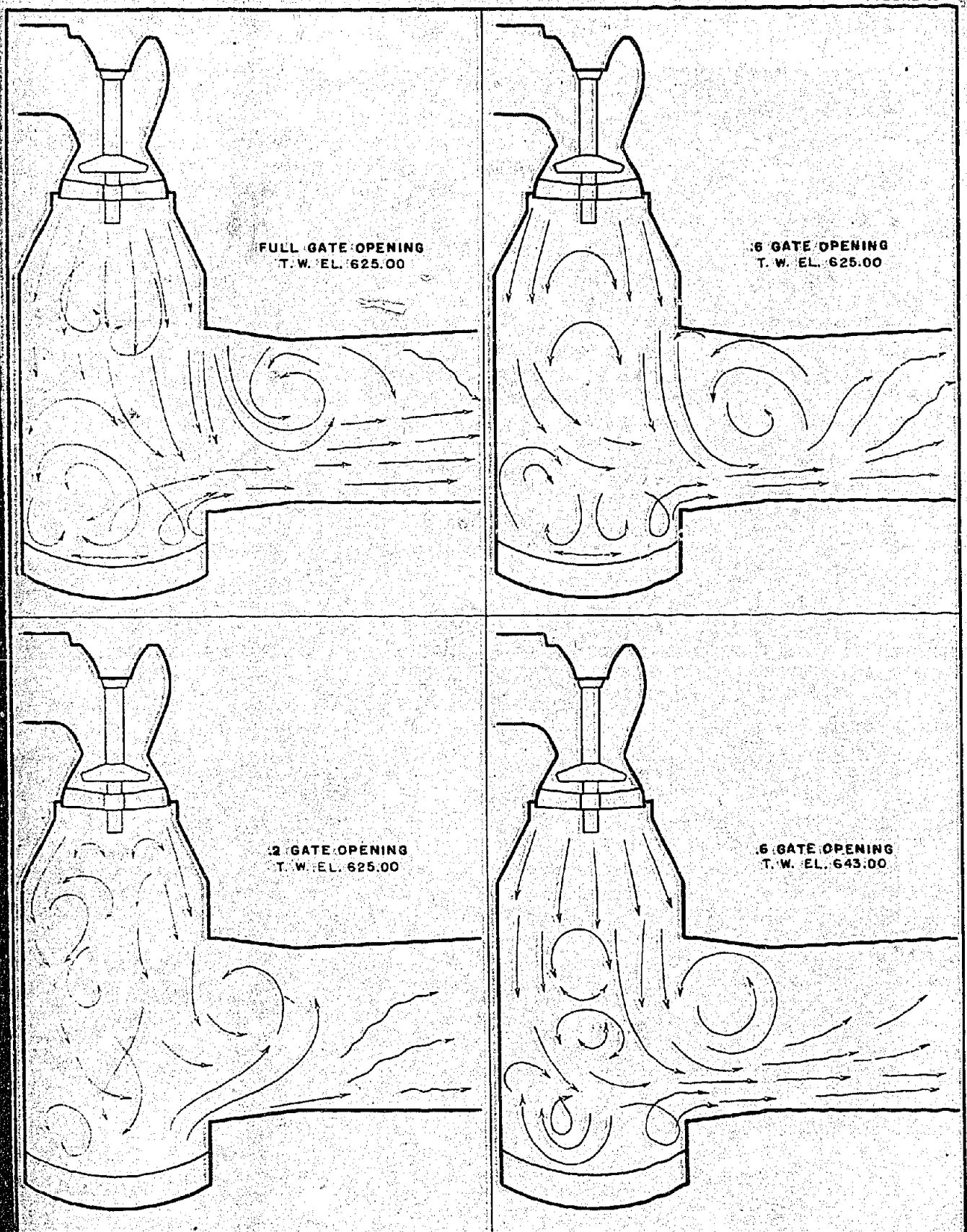
45-D-12136

FIGURE 18



FLOW LINES IN ENERGY ABSORBER MODEL

E.B.M.-F.

45-D-12137

the high tail water, while with the lower tail water it was only 0.012, being very nearly constant throughout and again proving that there was but slight back pressure due to the surge in the lower chamber.

Due to the improvement in the observed flow conditions, the low velocities on the bottom of the draft tube, the constant coefficient of discharge, and the low, even pressures recorded at the piezometer openings, it is recommended that this change be made in the plans for the proposed unit (fig. 15). In addition to improving the flow and the performance conditions, there will result a large saving in excavation of rock, construction work, and cost of the unit.

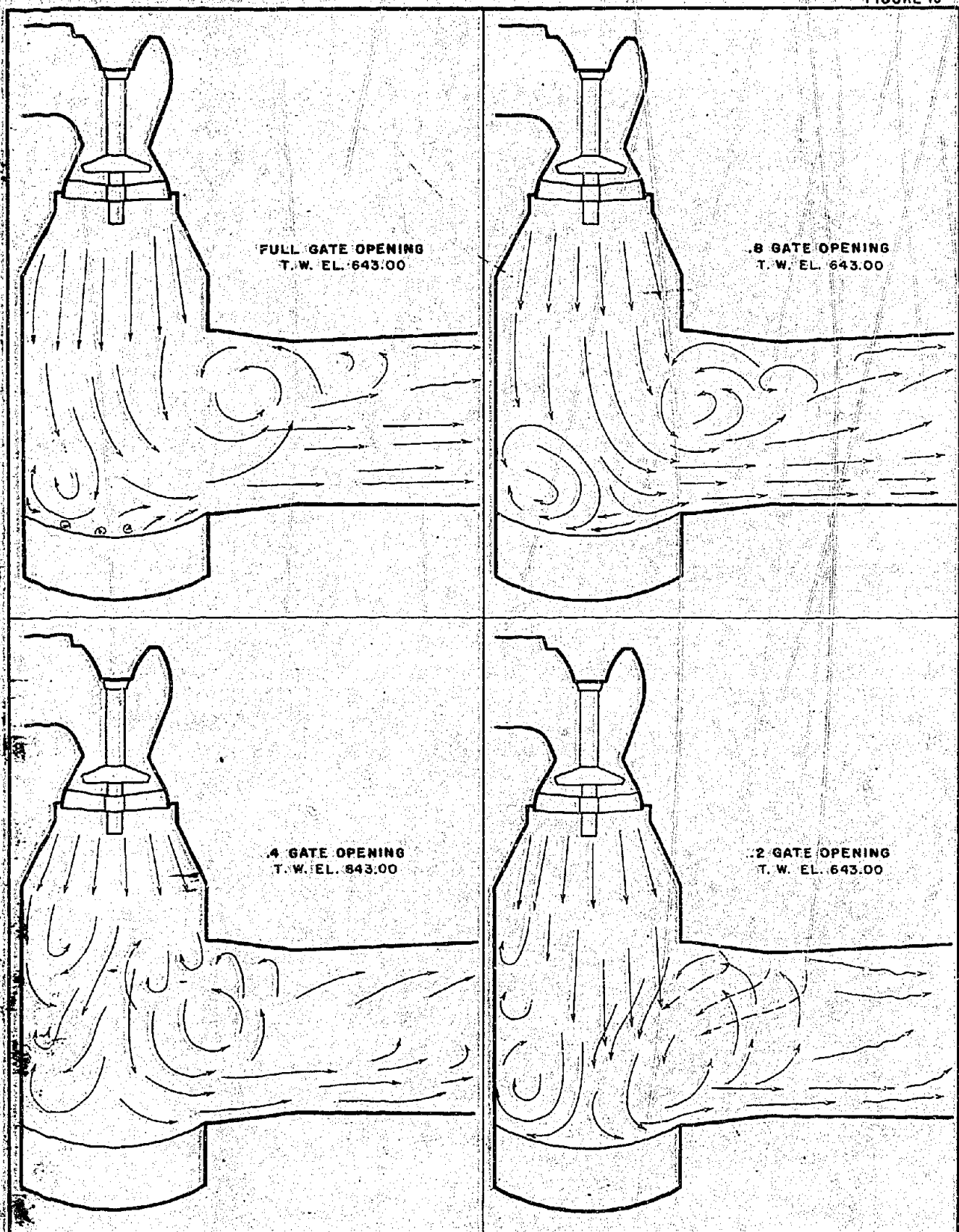
12. Test 8. In order to determine whether or not it would be possible to entirely eliminate the lower portion of the main chamber, a flat bottom was installed in the unit which was flush with the bottom of the opening to the draft tube (fig. 8). Due to the increased surge and unstable flow conditions, coupled with the observed increase in velocity on the bottom of the draft tube, this idea was immediately eliminated. Incidentally, this type of unit gave the largest average velocity in the draft tube of any plan tested.

13. Test 9. This test was made with the "bumped" bottom moved up to the same position that the flat bottom occupied in the previous test. This change reduced to a certain extent the surging and pounding of the water that existed in the main chamber during the previous test. The flow was quite unstable, as indicated by piezometers which were located in the area under the valve. There was quite evidently return flow in the area of the valve guide stem, as indicated by the positive pressures recorded at this point under high tail-water conditions, while with a low tail water slightly greater negative pressures than before recorded existed in this same area. The average velocities in the bottom of the draft tube were slightly less at both tail-water levels than those found in the previous test. From these data and observed flow conditions (fig. 19), it is not felt that this type can receive any consideration as an efficient energy destroyer.

14. General. Flow through the unit was ably guided by the vertical ribs located in the entrance chamber 180 degrees from the entrance (photograph B, plate 2). That is, the flow, as it passes the circular valve, is flowing vertically downward and not in a spiral direction as it undoubtedly would if this rib were not in place (photograph D, plate 1).

Included in tables 14 and 15 is a column headed "Coefficient of Discharge" derived from the formula $Q = CAV$, which may be written $C = Q/AV$, and since $V = \sqrt{2gh}$, we may substitute and obtain

FIGURE 19



FLOW LINES IN ENERGY ABSORBER MODEL

E.B.M.-F.T.

45-D-12138

$$C = \frac{Q}{A \times 8.03\sqrt{h}}$$

Substituting real values in the above formula, we obtain

$$C = \frac{322}{2.46 \times 8.03\sqrt{405}} = 0.810$$

which is the coefficient of discharge of the valve. This coefficient of discharge was fairly constant, varying only from 0.702 to 0.840 for the high tail water and from 0.713 to 0.859 for the low tail water. This would tend to indicate that the flow past the valve is fairly free for any valve setting and any position of the bottom; that is, there is a slight back pressure in this area.

Four piezometers were installed in the curved bottom (piezometers 8, 9, 10, and 14) to determine whether or not the impact of the jet on the bottom would be excessive. Examination of these pressures indicates a relatively small variation, ranging from 48 to 83 feet of water with a high tail water, a pressure which is not at all excessive but due almost entirely to the weight of the water. With the low tail water the range is from 30 to 45 feet of water, practically the same range but lower values, due to the lower tail-water level.

Pitot tubes were installed in the bottom of the draft tube at the quarter points as shown on section A-A, figure 9. The velocities were fairly evenly distributed across the bottom of the tube for the various valve openings. These velocities, measured along the bottom of the tube, increased as the valve opening was increased, allowing a greater discharge through the unit. The average range of velocities was from 6.50 to 36.00 feet per second, with an average velocity of 32.59 feet per second under a full valve opening for the recommended unit. The shape or position of the bottom apparently had very little effect upon the velocities in this area. A difference in velocities was noted between high and low tail water with a slight increase due to the lowering of the tail-water level.

To determine whether or not the position of the valve chamber spider arms with reference to the supply line would have any effect upon the pressures recorded on the piezometers, the valve chamber casting was rotated 90 degrees from its original position. This placed piezometer openings 5, 6, and 7 immediately below the supply line. Another set of readings was taken with the bottom in the position as tested under test 7, and the values were found to correspond to the previous readings.

Special attention was paid to the tail water as it issued

from the draft tube, and it was noted that the condition of the surface varied as the velocities in the draft tube increased, but throughout the range of tests no excessively adverse condition existed.

Positive pressures were recorded at piezometer openings 5, 6, and 7, which were located in the valve chamber face for all positions of the valves and for both high and low tail-water levels. These pressures appear to be excessively large, but upon consideration of their location and with regard to the changes which occur at this point, it is believed that the recorded pressures are indicative of the pressures that will exist in the prototype. It will be noted, upon an examination of these data, that when the tail-water level was lowered 18 feet the pressures at these three points increased on an average of 18 feet. This would tend to indicate that since these pressures in the model vary to the same ratio as the known values of the model, they may be considered as being applicable to prototype conditions.

To determine whether or not the wind chambers, as shown on figure 15, were required, piezometers were installed at these points. Three piezometers, P-11, P-12, and P-13 were installed in each valve-guide spider arm to find if negative pressures would occur there which would necessitate the use of the proposed wind chamber. It was found that under a high tail water, negative pressures existed at these three points at all valve settings except the 0.2 valve. With the low tail water, negative pressures existed at all valve settings. These negative pressures, as found in the model and translated to prototype values, are excessively high but act as a valuable indicator to the designer and undoubtedly prove the necessity of the proposed wind chamber at this point. The three openings connected together and designated as P-4 (fig. 9) were to check the proposed wind chamber above this point. With a high tail-water level it was found that negative pressures occurred only with an 0.8 and a full valve setting, while with the low tail-water level, negative values occurred under all valve settings. These results indicate that the wind chamber is required above this point or at elevation 625.25 as proposed and also that a valve must be provided with which to close the vent under certain operating conditions.

Referring to previous tests on energy absorbers, it was thought that it would be advisable to check the pressures in the area under the valve and at the end of the valve stem to determine if a high negative pressure existed which might cause cavitation in this area. Piezometers P-3 and P-2 were installed at these points. Slight constant negative pressures were found at the end of the valve stem while considerably greater pressures existed under the valve at P-3. But it is not thought that it will be necessary to provide an additional wind chamber to supply air to these points, but that the air

chamber furnished to aerate the guide spider will also aerate this area under the valve.

15. Flow lines. Included with this report is a set of drawings (figures 16, 17, and 19) which show the observed flow through the model with three positions of the "bumped" bottom and a tail-water elevation 643.00. On figure 19 are shown the flow lines with a tail-water elevation of 625.00. On the same figure is shown a comparison of the flow lines between the two tail-water levels, with an 0.6 valve opening. These flow lines were carefully drawn by Mr. E. B. Moses and represent the direction of travel of the water through the unit in the dissipation of its kinetic energy. Although these flow lines do not follow exactly the direction predicted, they represent the change of flow direction necessary to accomplish this dissipation of energy.

Cylindrical Type with Circular Exit

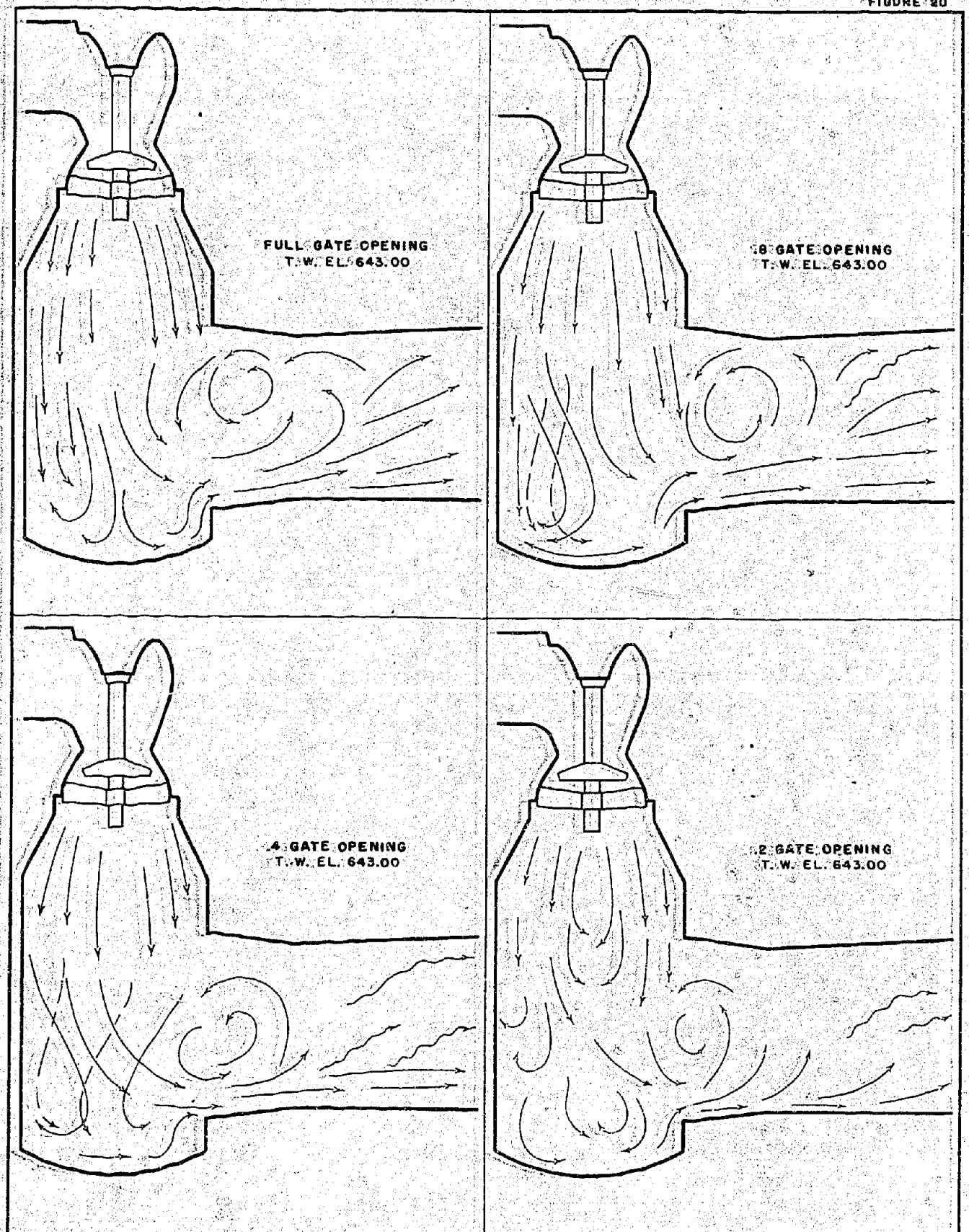
16. Test 10. The average velocities near the bottom of the draft tube taken from the two sets of data show a range in velocities of from 8.31 to 35.71 feet per second between 0.2 and full valve opening with a high tail water. With the lower tail water this range is very nearly identical, with a minimum of 7.89 to a maximum of 35.51 feet per second. The velocities are not excessive, although they are higher than those recorded from the previous model, and, due to the fact that they appear to be more evenly distributed throughout the tube, it is believed that this type will be entirely satisfactory.

The observed flow throughout the model under the different valve openings at the high tail-water level has been carefully sketched and is reproduced on figure 20. A complete record of this test was made by use of the slow-motion moving-picture camera and is available for study.

The explanation of the term "coefficient of discharge" or "coefficient of loss," which are identical, has already been made. From the data taken on this model the coefficient was computed and can be found on table 16. In order to further qualify these data, additional runs were made under heads ranging from 300 to 475 feet. This coefficient was then computed (table 17) and plotted to give an average "loss" curve under the two tail-water levels (figures 21 and 22).

From these data the following deductions may be made: (1) The main vertical chamber of the unit has again given satisfactory performance with the shortened chamber; (2) the circular type of exit, although indicating slightly higher discharge values, is also quite

FIGURE 20



FLOW LINES IN ENERGY ABSORBER MODEL

E.B.M.-F.T.

45-D-12139

TABLE 16

PROTOTYPE VALUES FROM MODEL DATA TAKEN AT POINTS SHOWN ON FIGURE 9

CONDITIONS				COEF. OF LOSS "C"	VELOCITY FT./SEC.			PRESSURES - FEET OF WATER												
VALVE OPENING	HEAD FEET	TAIL-WATER ELEV.	QUANTITY SECOND-FEET		V_L	V_M	V_R	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14
TEST No. 10-B.D. RUN 11-15																				
.2	408.0	642.8	353.5	.838	10.88	9.78	7.78	2.42	-11.62	11.68	18.20	19.26	18.40	45.20	45.20	45.00	-12.14	3.56	-13.86	46.50
.4	408.0	642.3	712.0	.881	15.65	16.08	14.84	2.52	-11.62	5.18	49.10	27.02	32.40	47.40	47.40	47.40	-12.64	- 3.54	- 41.46	47.70
.6	408.2	642.9	1082.0	.849	22.12	23.27	21.84	2.72	-11.72	0.98	121.70	59.02	54.76	51.66	52.10	51.30	-12.98	- 8.94	- 68.86	51.00
.8	407.6	641.7	1467.0	.828	30.55	30.41	28.83	2.92	-11.62	- 3.46	156.70	87.42	78.94	55.50	56.50	70.10	-13.54	-15.64	- 94.92	56.20
1.0	400.4	641.9	1748.0	.790	36.70	36.39	34.99	3.12	-11.52	- 7.42	160.86	129.08	108.10	61.70	63.50	62.40	-16.54	-18.54	-124.58	63.00
TEST No. 10-B.D. RUN 16-20																				
.2	402.2	624.8	353.5	.893	8.02	8.02	8.02	1.62	-12.66	- 6.32	- 0.10	1.72	0.40	27.30	27.10	26.90	-13.24	- 13.44	- 31.66	27.40
.4	408.6	624.8	707.0	.856	14.71	15.35	15.02	1.82	-12.72	-12.62	31.00	19.12	14.40	29.50	29.50	29.10	-20.14	-21.14	- 58.86	30.00
.6	413.2	624.7	1084.0	.845	22.56	20.05	21.84	1.92	-12.72	-17.52	102.20	40.52	36.30	33.50	33.90	32.90	-26.34	-27.74	- 97.44	33.44
.8	410.2	625.0	1438.0	.820	29.49	29.93	28.16	2.12	-12.62	-20.42	140.04	69.72	60.80	38.30	39.50	39.40	-31.14	- 32.54	-114.24	39.10
1.0	405.8	624.4	1716.0	.770	36.77	35.26	34.42	- 24.38	-12.72	-23.02	145.86	109.08	86.10	43.30	45.10	46.10	-35.34	-36.34	-145.52	44.08
TEST No. 10-B.D. RUN 21-25																				
.2	410.0	642.9	336.5	.841	7.36	8.03	8.03	10.22	19.68	11.58	17.20	17.92	17.04	44.70	44.70	44.60	5.36	5.06	-11.46	45.40
.4	408.0	642.9	696.5	.843	14.27	15.55	14.58	5.22	15.68	5.58	42.60	35.42	31.20	47.20	47.20	47.30	- 1.74	- 2.54	- 38.86	47.90
.6	408.2	643.1	1053.5	.826	21.54	22.70	21.54	1.02	13.08	1.18	118.70	56.32	52.76	51.10	51.70	51.10	- 7.44	- 6.84	- 66.36	51.80
.8	407.2	642.9	1395.4	.799	28.72	29.38	28.49	- 2.08	7.28	- 2.82	154.20	82.92	77.60	55.70	56.80	56.00	-12.24	-13.64	- 97.10	56.80
1.0	406.2	643.2	1692.9	.759	36.51	35.17	34.52	- 4.18	3.58	- 4.72	162.54	124.92	105.60	61.50	62.20	62.40	-15.54	-16.44	-119.68	62.80
TEST No. 10-B.D. RUN 26-30																				
.2	403.8	623.6	331.1	.834	7.61	8.03	7.61	- 8.68	-15.32	- 7.42	- 2.40	- 0.88	- 2.00	25.70	25.60	25.40	-13.94	-14.14	- 30.46	26.00
.4	409.2	625.3	675.7	.817	14.80	15.01	14.13	-12.48	-15.22	-12.22	24.60	17.12	12.60	29.30	29.70	29.30	-19.04	-20.04	- 72.90	28.80
.6	409.6	624.8	1045.7	.819	22.27	24.34	21.54	-17.48	-15.32	-17.02	98.36	37.92	34.40	32.80	33.30	32.40	-25.84	-27.24	- 92.48	33.40
.8	409.6	625.2	1386.8	.792	29.49	29.49	28.39	-20.58	-15.12	-20.32	137.54	66.92	59.40	38.00	39.50	38.30	-29.94	-31.74	-114.24	39.20
1.0	415.0	625.2	1720.7	.763	36.77	35.89	33.95	-23.28	-15.02	-23.72	149.20	109.92	89.76	43.50	45.90	44.30	-34.34	-35.44	-141.44	45.10

45-D-12130

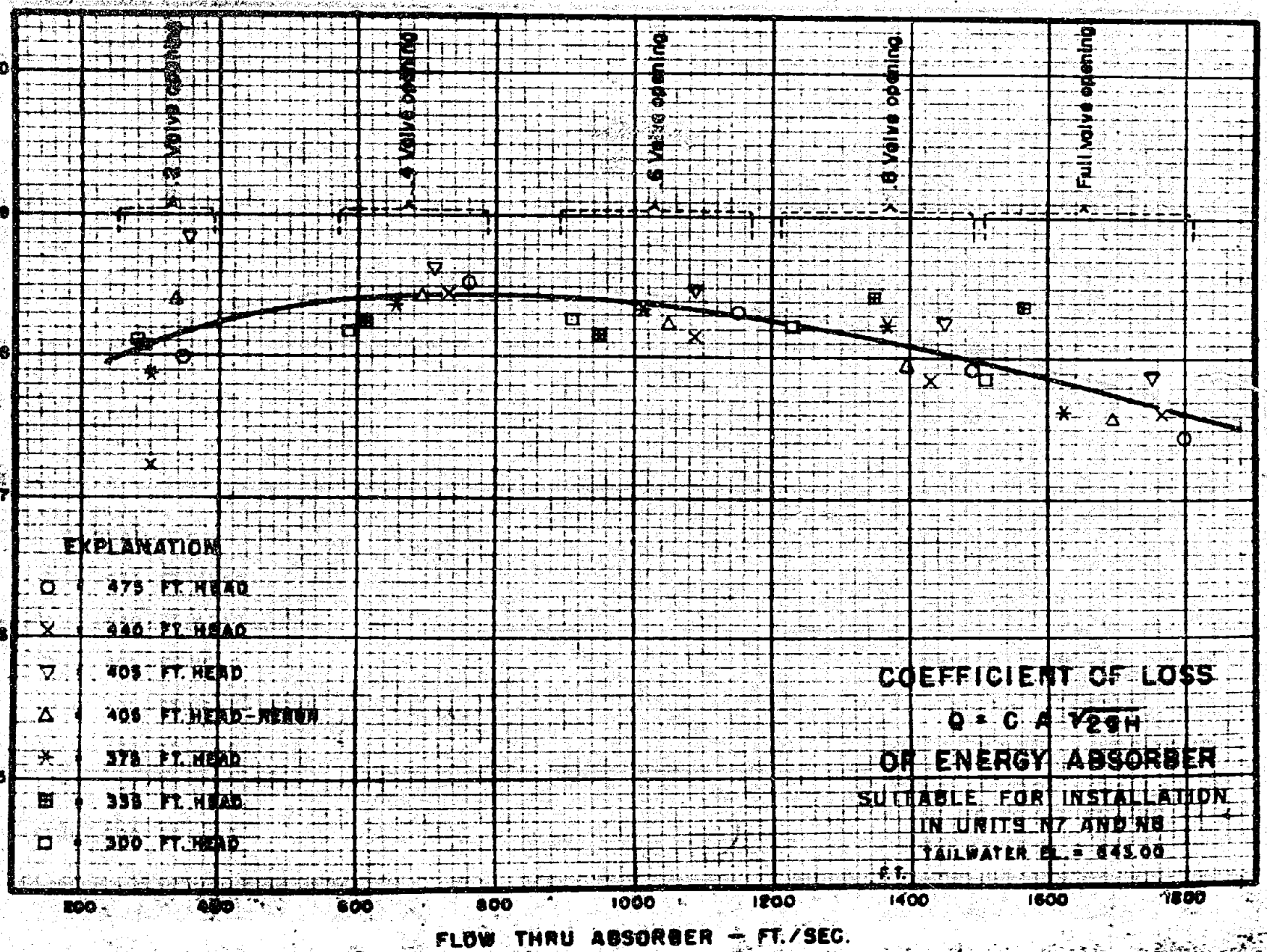

COEFFICIENT OF LOSS
Q = C A √2gH
OF ENERGY ABSORBER
SUITABLE FOR INSTALLATION
IN UNITS N7 AND N8
TAILWATER EL. = 845.00
EXPLANATION
475 FT. HEAD
440 FT. HEAD
405 FT. HEAD
405 FT. HEAD-NEWUN
375 FT. HEAD
335 FT. HEAD
300 FT. HEAD
Full Valve opening
COEFFICIENT C'
FLOW THRU ABSORBER — FT./SEC.
200
400
600
800
1000
1200
1400
1600
1800
.5
.6
.7
.8
.9
1.0

FIGURE 21

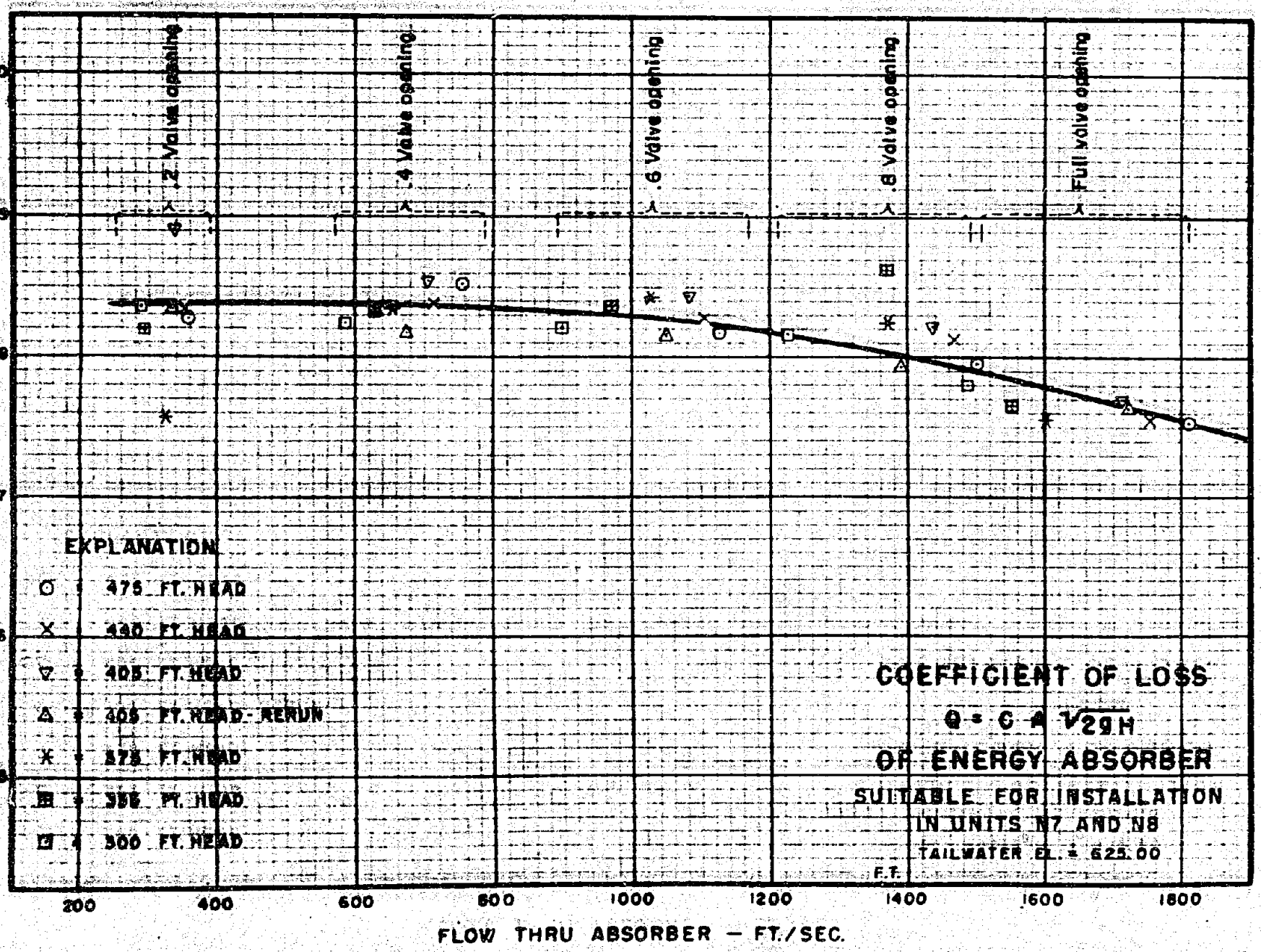


FIGURE 22

45-D-12486

TABLE 17

COEFFICIENT OF LOSS FOR ENERGY ABSORBER SUITABLE FOR INSTALLATION IN UNITS N7 AND N8

PROTOTYPE VALUES FROM MODEL DATA									
VALVE OPENING	AREA OF OPENING	HEAD FT.	QUANTITY SEC./FT.	COEF. OF LOSS "C"	VALVE OPENING	AREA OF OPENING	HEAD FT.	QUANTITY SEC./FT.	COEF. OF LOSS "C"
TAILWATER ELEVATION 643.00					TAILWATER ELEVATION 625.00				
.2	2.46	475.2	344.7	.800	.2	2.46	480.2	359.5	.829
.4	5.09	475.0	759.4	.853	.4	5.09	473.6	757.6	.852
.6	7.86	480.0	1155.6	.836	.6	7.86	474.4	1126.0	.819
.8	10.78	471.8	1469.7	.792	.8	10.78	475.6	1500.0	.795
1.0	13.78	474.6	1796.2	.747	1.0	13.78	474.6	1812.0	.752
.2	2.46	441.2	299.5	.722	.2	2.46	443.6	347.4	.835
.4	5.09	440.8	727.8	.848	.4	5.09	439.4	717.0	.838
.6	7.86	440.4	1085.6	.819	.6	7.86	444.5	1101.7	.828
.8	10.78	441.2	1426.0	.796	.8	10.78	435.8	1457.7	.812
1.0	13.78	441.0	1767.7	.761	1.0	13.78	437.2	1750.7	.756
.2	2.46	410.0	336.5	.841	.2	2.46	403.8	331.1	.834
.4	5.09	408.0	696.5	.844	.4	5.09	409.2	675.7	.817
.6	7.86	408.2	1053.5	.826	.6	7.86	409.6	1045.7	.819
.8	10.78	407.2	1395.4	.799	.8	10.78	409.6	1386.8	.792
1.0	13.78	406.2	1692.9	.759	1.0	13.78	415.0	1720.7	.763
.2	2.46	*406.0	* 353.5	*.888	.2	2.46	*402.2	* 353.5	*.893
.4	5.09	*409.0	* 712.0	*.861	.4	5.09	*408.6	* 707.0	*.856
.6	7.86	*408.2	*1082.0	*.850	.6	7.86	*413.2	*1084.0	*.845
.8	10.78	*407.6	*1447.0	*.829	.8	10.78	*410.2	*1438.0	*.820
1.0	13.78	*400.4	*1748.0	*.790	1.0	13.78	*405.8	*1716.0	*.770
.2	2.46	307.4	299.3	.787	.2	2.46	369.2	320.4	.758
.4	5.09	365.4	655.5	.839	.4	5.09	367.8	655.5	.837
.6	7.86	369.8	1014.0	.835	.6	7.86	368.4	1022.0	.843
.8	10.78	367.2	1365.0	.825	.8	10.78	367.2	1369.3	.823
1.0	13.78	371.1	1621.0	.761	1.0	13.78	367.4	1600.6	.755
.2	2.46	332.2	291.6	.809	.2	2.46	335.0	296.5	.820
.4	5.09	334.6	615.2	.824	.4	5.09	336.6	625.1	.833
.6	7.86	334.4	944.6	.818	.6	7.86	335.6	967.3	.838
.8	10.78	337.0	1343.2	.845	.8	10.78	336.2	1369.3	.862
1.0	13.78	335.0	1561.8	.839	1.0	13.78	334.0	1549.7	.766
.2	2.46	302.6	279.1	.813	.2	2.46	300.4	286.1	.836
.4	5.09	298.2	582.0	.819	.4	5.09	299.4	582.0	.823
.6	7.86	301.4	906.3	.828	.6	7.86	299.4	897.4	.821
.8	10.78	298.2	1227.0	.821	.8	10.78	300.0	1227.1	.819
1.0	13.78	298.8	1508.7	.788	1.0	13.78	296.2	1486.8	.760

* RERUNS

46-D-12131

satisfactory. The wind chambers as designed for the previous model are also proved desirable at these points and their installation is recommended. The "coefficient of loss" as determined from the data is indicative of the energy dissipation and may be considered as a high, constant value. Upon the merits of these data and the visual observations made during the tests, it is believed that this type of energy dissipator will give satisfactory results.

The energy absorber tested was not used in the final designs for the power plant installation as the contractor had developed an improved design, based on extensive laboratory tests, using prototype pressures which indicated superior performance.

SUMMARY OF FIELD REPORTS AND TESTS

Field Tests of N-1 to N-4 Type of Relief Valve and Energy Absorber

As an addition to this memorandum, there is presented a brief resume of the field reports and tests made on the energy absorbers designed for units N-1 to N-4, N-5, and N-6.

Due to the fact that unit N-1 as originally designed, installed, and tested was not satisfactory, as previously stated, and was rejected by the Bureau of Reclamation, the first part of this field report deals with the redesigned energy absorber, except that the steel throat liner has been added. This liner extends from the valve seat down through the old-type bowl to a point slightly above the lower air inlet. This part of the design is shown on figures 14 and 23 which were a part of the later tests.

The project reports by letter dated June 27, 1938, that, "The preliminary tests made since the installation of the steel-plate cylinder from the throat liner through the bowl of the old energy absorber were very satisfactory. The valve was opened in increments up to an opening of about 14 inches, the maximum possible, with the turbine gates blocked at 25 percent.

"Except for a very slight roughness at very small openings, it was very quiet throughout the entire range of the test. There was very little indication of cavitation. There was some 'bouncing' of the water and air in the tailrace close to the wall; but the tailrace generally was not greatly agitated.

"Admission of air through the 10-inch inlet had little effect; and operation was quiet without it. The air inlet at the valve throat ring took air, but the one below did not."

The following tabulation shows the results of tests on the valve, as prepared by Mr. Jessop of S. Morgan Smith Company:

Boulder Project Pressure Regulator, Unit N-1

The load-off-test tabulations are as follows:

Percent Load	Kilo-watts	Gate Opening	Plunger Opening	Closing Time	Pressure Rise	
25	20,800	0.27	3-7/16"	24.0 sec.	11.5'	By S.M.S. strip gage
50	43,550	0.44	6-11/16"	36.5 sec.	9.0	
75	59,400	0.55	8-3/4"	55.0 sec.	16.0'	
100	79,500	0.75	11-11/16"	77.0 sec.	9.0'	
100	81,600	0.76	12-3/16"	-	9.0'	

Lake elevation 1169
Tail-water elevation 646
Static head 523
Effective head ..... 513 at 82,000 kilowatts

Plunger Opening	Turbine Discharge	Regulator Discharge	Percent Turbine Discharge
3-7/16"	750 c.f.s.	700 c.f.s.	93.4
6-11/16"	1,420 c.f.s.	1,110 c.f.s.	78.3
8-3/4"	1,795 c.f.s.	1,470 c.f.s.	82.0
11-11/16"	2,350 c.f.s.	1,850 c.f.s.	78.8
12-3/16"	2,370 c.f.s.	1,910 c.f.s.	80.7

Under date of July 22, 1938, Mr. Jossop reported that, "On the night of July 5-6, a second and official test was run . . . The regulator operated very smoothly, and the load-off tests are especially good . . . Please note that the tabulation shows the pressures in feet head and that, from the readings, there is to be deducted the static head to find the correct increase in pressure due to the flow through the absorber . . . Theoretical considerations, confirmed by piezometer readings 16, 33, and 34, lead to the conclusion that very high negative pressures can occur only in the renewable throat liner close to the valve seat and that, passing downward from this point, these negative pressures are rapidly reduced." (Table 18) Figure 23 shows the location of these piezometer openings.

On November 5, 1938, the project reported the final tests (table 19) as follows: "The synchronous bypass test of the relief valve has been completed and the energy absorber and valve parts examined after the tests.

"The performance of the complete relief-valve and energy-absorber unit was very satisfactory. There was no pounding, vibration, or cavitation of any large amount. The tailrace was not very rough at any valve opening."

It was also reported that, "From the data obtained and the observations made during the complete test, it is the opinion that the valve is now satisfactory for service.

"The relief valve itself can be considered exceptionally quiet throughout the whole range of travel. Some noise or pounding was observed at times in the 625 gallery; yet, for the whole, it can be said that this was purely a transmittal of the continuous pounding in the N-1 turbine draft tube.

BOULDER DAM POWER PL

PRELIMINARY TEST WITH PLATE ST

℄ GAGE = 630.75 — 646.25

No.	TIME	VALVE OPENING	LEAD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1		7/16																								
2		1"																	0							
3		1 9/16																	-1'							
4	A.M. 12:44	2 1/8	2 7/16																-2'							
5	1:38	3 1/8	3 7/8																-3'							
6	1:41	4 1/4	4 9/16																-4'							
7	1:43	5 3/8	5 5/8																-7'							
8	1:51	6 3/8	6 5/8																-5'							
9	1:54	7 7/16	7 3/4																-8'							
10	2:02	8 1/2	8 3/4																-9'							
11	2:07	9 5/8	9 7/8																-5'							
12	2:15	10 5/8	10 7/8																-9'							
13	2:25	11 11/16	11 7/8																-10'							
14	2:32	14	14 3/16																-13'							
																			-16'							
																			-16'							
																			-10'							
																			-21'							
																			-18'							
																			-20							

These fluctuations slow and irregular

OFFICIAL TEST WITH PLATE STEE

No.	TIME	VALVE OPENING	LEAD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	P.M.	0																	-0.5		190					
1	11:41	1 1/2	1 13/16																-1		197					
2	11:55	3	3 5/16																-4							
	A.M.																							These fluctuat		
3	12:05	4 5/8	4 7/8	23 46	25 51	28 51	35 76	35 81	23 58	25 55	28 51	16 65	28 69	30 76	18 51	7 28	11 28	18 28	-1 -4		205	120 160	7 10	20 23	40 55	
4	12:48	6 1/4	6 1/2																0 -6		220					
5	12:58	7 13/16	8 1/16																-1 -7		235					
6	1:03	9 3/16	9 3/8	40 90	50 110	40 120	40 160	60 150	40 100	40 90	50 120	40 130	40 120	50 130	40 90	15 40	10 45	20 40	-1 -7		245	190 210	75 85	190 210	12	
7	1:29	10 3/4	10 15/16																-2 -7		255					
8	1:38	12	12 1/4																-3 -6		265					
9	1:44	13 1/2	13 11/16	60 120	60 130	40 130	60 150	60 150	40 100	50 120	40 170	40 150	30 160	70 150	50 130	10 50	20 50	20 50	-3		275	0	0	0	0	

All of these fluctuations in pressure were slow and irregular at all valve strokes

NOTE - After test this piezometer line to throat

BOULDER DAM POWER PLANT

PRELIMINARY TEST WITH PLATE STEEL LINER

10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	LAKE EL.	T.W. EL.
						→ 646.25 ←					℄ GAGE = 647.5 →											646.0	← ℄ GAGE = 630.75 →				647.5 ←			
																													1161.3	646.8
						0																							"	"
						-1'																							"	"
						-2'																							"	"
						-3'																							"	"
						-4' -7'																							"	"
						-5' -8'																							"	"
						-5' -9'																							"	"
						-5' -9'																							"	"
						-[illegible] -10'																							"	"
						-4' -13'																							"	"
						-6' -16'																							"	"
						-10' -21'																							"	"
						-18' -20'																							"	"

These fluctuations slow and irregular

OFFICIAL TEST WITH PLATE STEEL LINER

STATIC

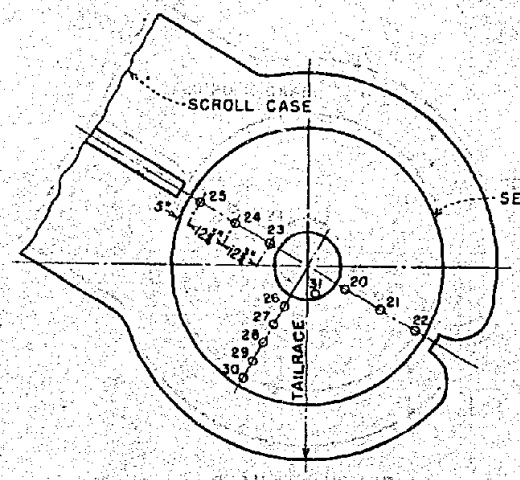
10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	LAKE EL.	T.W. EL.
																							16.4	16.4	16.4	16.4				
						-0.5			190													490							1169.4	646.0
						-1 -4			197													490							"	"
[illegible]	30 76	18 51	7 28	11 28	18 28	-1 -4			205	120 160	7 10	20 23	40 55	0	26 28	110 120	—	1	-1	0	-31	495	1	-0.6	28 35	9 18		-31	"	"
						0 -6			220													495							"	"
						-1 -7			235													495							"	"
[illegible]	50 130	40 90	15 40	10 45	20 40	-1 -7			245	190 210	75 85	190 210	12	3 4	-1	140 170	8	25 35	-1	140 150	-25	495	8	46	30	30		-32	"	"
						-2 -7			255													495							"	"
						-3 -6			265													495							"	"
[illegible]	70 150	50 130	10 50	20 50	20 50	-3			275	0	0	0	0	0	0	0	0	0	0	0	-25	495	14	—	40 50	40		-32	"	"

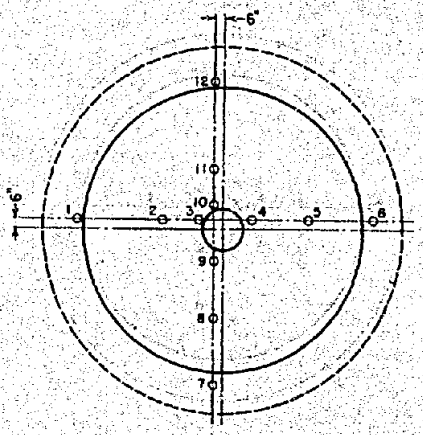
These fluctuations in pressure were slow and irregular

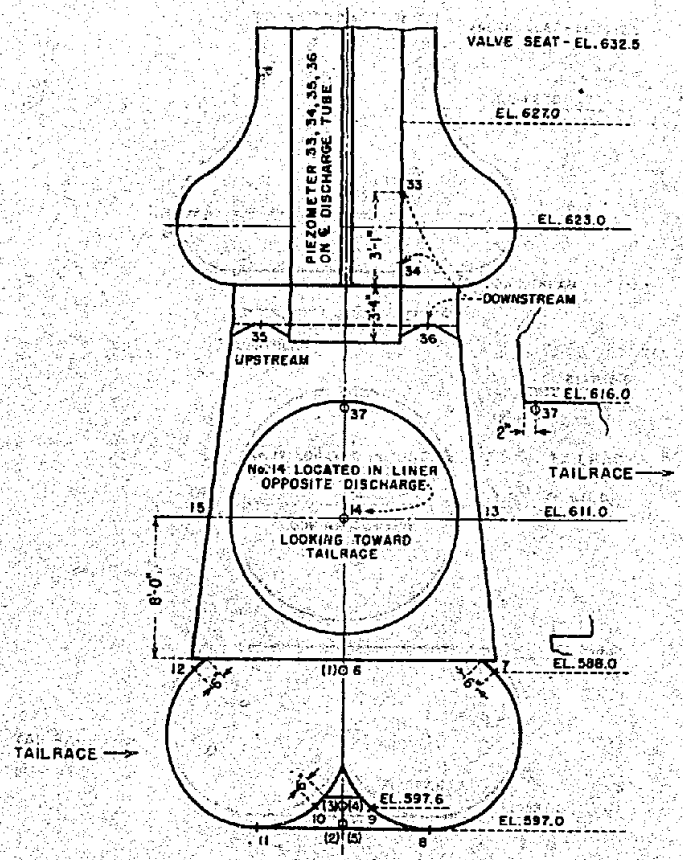
...ator of all value strokes

NOTE:- After test this piezometer line to throat ring was found broken. This gage was therefore measuring pressure in 12" air vent pipe.

CO







No. 16 - TO SMALL DIAMETER THROAT RING.
No. 17 - TO 12" AIR LINE AT GATE VALVE.
No. 18 - TO 14" AIR LINE AT GATE VALVE.
No. 19 - OPERATING CHAMBER PRESSURE.
No. 32 - PRESSURE IN 3" LINE TO CONTROL VALVE.
No. 38 - PRESSURE INSIDE VALVE BODY.

BOULDER DAM ENERGY ABSORBER

LOCATION OF PIEZOMETERS FOR FIELD TEST DATA SHOWN ON TABLE

COPIED W.A.H. 1-12-39

FIGURE 23

45-D-1248

TABLE 19

BOULDER POWER PLANT

SYNCHRONOUS BY-PASS TEST

TEST No. 2 — UNIT No. N-1-R-V

DATE.....NOVEMBER 2, 1938 — OBSERVERS.....HAUGSE-McDONALD

TIME	RUN NO.	TAIL RACE ELEV.	FOREBAY ELEV.	OPERATING CHAMBER PRESSURE (FEET)	SCROLL CASE PRESSURE (FEET)	LOWER MANHOLE TRAP DOOR PRESSURE (FEET)	LOWER MANHOLE COVER PLATE PRESSURE (FEET)	MEGAWATTS	TURBINE GATE	RELIEF VALVE (IN.)	BUTTERFLY MANOMETER LEFT LEG	BUTTERFLY MANOMETER RIGHT LEG	Q ACROSS B.V.	FLOW METER	REMARKS
4:00 A.M.	1	646.09	1171.28	—	—	—	—	82.5	77	—	—	—	—	2200	
4:30	1	646.28	1171.23	240	—	21-30	12	20	29	—	5.90	12.10	2170	1100	Air between doors only 12" vent open.
5:00	1	646.28	1171.25	240	—	21-35	12	22	29	—	5.90	12.10	2170	1100	
5:30	1	646.38	1171.27	240	—	21-35	12	22	29	7 1/16	5.90	12.10	2170	1100	
6:00	1	646.41	1171.27	240	—	—	—	22	29	7 1/16	5.90	12.10	2170	1100	
6:15	2	—	—	250	—	17-35	12	12	20	8 13/16	6.10	11.90	2120	1325	Slight pounding at intervals or 625.5
6:30	2	646.59	1171.23	250	—	20-35	12	12	20	8 13/16	6.10	11.90	2120	1300	Explosions in turbine draft tube.
7:00	2	647.79	1171.26	250	—	19-30	5-15	12	20	8 13/16	6.10	11.90	2120	1315	
7:30	2	646.45	1171.26	250	505	19-30	5-15	12	20	8 13/16	6.10	11.80	2090	1275	
8:00	2	646.28	1171.27	250	505	20-30	5-15	12	20	8 13/16	6.00	11.80	2120	1225	
8:15	3	646.29	1171.27	225	505	20-30	7-12	31	36	6 5/32	5.60	12.20	2240	1145	Unit quiet in 625 gallery.
8:30	3	646.31	1171.26	225	505	20-30	7-12	31	36	6 5/32	5.60	12.10	2230	1125	
9:00	3	646.40	1171.26	225	505	20-35	7-12	31	36	6 5/32	5.60	12.10	2230	1125	
9:30	3	646.54	1171.25	225	505	20-35	7-12	31	36	6 5/32	5.50	12.10	2240	1140	
10:00	3	646.55	1171.24	225	505	—	—	31	36	6 5/32	5.55	12.05	2230	1130	
10:20	4	646.44	1171.23	215	508	22-35	11-13	40	44	4 1/4	5.40	12.10	2280	1330	Turbine noise predominates
11:00	4	646.39	1171.23	215	510	22-35	11-13	42	44.5	4 13/16	5.30	12.10	2280	1340	
11:30	4	646.45	1171.23	215	510	—	—	42	44.5	4 13/16	5.25	12.05	2280	1350	
1:00 P.M.	5	646.15	1171.19	200	510	25-30	11-13	55	53.5	3 1/4	5.00	12.00	2350	1625	Admission free or compressed air through 2 1/4" travel indicator pipe did no good
1:30	5	646.15	1171.19	200	510	20-30	11-13	55.5	53.5	3 1/4	4.90	11.90	2350	1640	
2:00	5	646.08	1171.20	200	510	25-35	10-12	55	53.5	3 1/4	4.90	11.90	2350	1625	
2:30	5	646.15	1171.19	200	510	25-35	10-12	55	53.5	3 1/4	4.80	11.80	2350	1625	
3:00	5	646.15	1171.19	200	510	25-35	10-12	55	53.5	3 1/4	4.70	11.90	2375	1650	
3:15	6	646.00	1171.18	190	510	25-35	10-12	65	61	1 7/8	4.60	11.90	2240	1850	Pilot valve stem jumps 7/16"
4:15	6	646.00	1171.20	190	510	25-35	10-12	65	61	1 7/8	4.50	11.70	2240	1850	
5:00	6	646.03	1171.18	190	510+	25-35	10-12	65	61	1 7/8	4.45	11.65	2240	1850	
5:15	7	646.03	1171.18	180	510	25-35	10-12	75	70.5	0 1/32	4.50	11.60	2330	2050	Compressed air relieved pilot valve chatter.
5:55	8	646.54	1171.16	510	510	27	12	82+	79	0	4.15	11.90	2420	2245	
6:15	9	646.55	1171.17	185	510	—	—	70	65+	1 7/8	4.25	11.65	2370	1950	
6:30	9	—	—	185	510	26-35	12	70	65	1 7/8	4.30	11.50	2340	1950	
7:00	9	646.63	1171.17	185	510	26-35	12-13	70	65+	1 7/8	4.20	11.50	2350	1950	
7:30	9	646.53	1171.17	185	510	—	—	70	65	1 7/8	4.20	11.40	2340	1940	
7:45	10	—	—	195	510	26-35	11-14	60	57.5	2 3/4	4.15	11.35	2340	1750	
8:00	10	646.69	1171.17	195	510	26-35	13	60	57+	2 3/4	4.10	11.30	2340	1750	
8:30	10	646.56	1171.16	195	510	—	—	60	57+	2 3/4	4.05	11.25	2340	1725	
9:00	10	646.61	1171.15	195	510	26-35	13	60	57+	2 3/4	3.95	11.20	2350	1740	
9:30	10	646.46	1171.14	195	510	22-35	13	60	57	2 3/4	3.85	11.15	2360	1750	
9:42	11	646.42	1171.14	200	510	—	—	50	50.5	3 3/4	3.95	10.95	2310	1525	
10:00	11	646.37	1171.15	200	510	22-35	13	50	50.5	3 3/4+	3.90	10.90	2310	1525	
10:30	11	647.05	1171.18	200	510	—	—	50	50.5	3 3/4	3.90	10.80	2290	1525	
10:40	12	647.47	1171.15	215	515	18-35	12-13	41	43-	5 5/16	3.90	10.75	2280	1300	
11:00	12	647.58	1171.15	215	515	15-35	12-13	41	43-	5 5/16	3.90	10.65	2260	1300	
11:15	13	647.50	1171.15	235	515	15-35	12	25	31	7 5/16	4.10	10.40	2190	1075	
11:37	14	—	—	280	520	15-40	10	-8 TO +12	0	12 5/16	4.65	9.75	1970	225-75	Unit motoring
12:00 A.M.	15	647.70	1171.11	245	520	—	—	15	23	8 5/8	4.20	10.10	2150	1100	
12:30	15	647.11	1171.12	250	520	15-35	5-15	15	23	8 5/8	4.20	10.10	2150	1100	
1:05	16	646.02	1171.12	260	520	10-40	5-15	1	9	11 3/32	4.45	9.85	2050	700	Some light explosions in draft tube
1:30	16	645.78	1171.12	265	520	10-40	0-20	1	9	11 3/32	4.40	9.90	2040	700	On lower door mostly 15"-27"
2:00	16	645.77	1171.12	265	520	10-40	0-20	1	9	11 3/32	4.35	9.85	2040	690	On hatch mostly 5"-10"
2:30	16	645.75	1171.12	265	520	10-40	0-20	1	9	11 3/32	4.40	9.90	2040	700	Turbine draft tube explosions not so loud as usual but more.
3:00	16	645.82	1171.12	265	520	—	—	1	9	11 3/32	4.35	9.85	2040	725	
3:30	16	645.85	1171.10	265	520	10-40	0-20	1	9	11 3/32	4.40	9.90	2040	700	
4:30	16	645.81	1171.11	265	520	10-40	0-20	1	9	11 3/32	4.40	9.90	2040	640	
5:00	16	645.74	1171.09	265	520	10-40	0-20	1	9	11 3/32	4.40	9.90	2040	700	
5:20	16	—	—	265	520	—	—	1	9	11 3/32	4.35	9.85	2040	700	
5:30	17	645.87	1171.01	340	530	—	—	—	—	17 7/8	4.25	10.00	2090	900	

SCROLL CASE GAGE AT ELEV. 648 APPROX.

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HYD-561

"In reference to run no. 8 at full load to run no. 14 at no load and the unit motoring that the discharge through the valve is well within the 80 percent called for.

"Inspection of the draft tube and energy absorber after the test showed everything to be in good shape. The trap door to the manway to the draft tube was perfectly tight. Inspection of the acorn valve failed to reveal any sign of wear whatsoever."

"In general, the valve performed in a satisfactory manner and was found in good condition upon inspection subsequent to the test. The man door was uninjured. The acorn restricting valve did not show any cavitation. The operating pressure in the top of the valve was steadier than during any other test so far conducted. The noise was not objectionable, often less than that made by the turbine."

After this test, the valve was left in service.

Field Tests of N-5 and N-6 Type of Relief Valve and Energy Absorber

The data shown on table 20 were taken from the field test on unit N-6, which is identical to unit N-5 relief valve and energy absorber. This type of energy absorber is shown on figure 1. The difference between it and the type used for units N-1 to N-4 is shown by a comparison of figures 1 and 2. These test data have been analyzed by Mr. Ray S. Quick, Chief Engineer for the Pelton Water Wheel Company, in curve form and are presented on figure 24.

The project reports, by memorandum dated September 16, 1938, that, "The whole series of tests indicated that the valve would operate satisfactorily; therefore, it was allowed to remain in regular service from and after the conclusion of the test."

The data presented on table 21 were taken from the Gibson report of October 1938 and are part of the test made on the relief valve and energy absorber of unit N-6.

BOULDER DAM POWER PLANT

FIELD DATA FROM SYNCHRONOUS BY-PASS TEST ON UNIT N-6

RUN NO.	TIME	MERCURY MANOMETER DEFLECTIONS ACROSS BUTTERFLY VALVE				QUANTITY SEC. FT.	NET HEAD DEAD WT. TESTER #/□ 649.15	FOREBAY ELEV. FEET	TAILBAY ELEV. FEET	LOAD REJECTED M.W.	GATE OPENING %	VALVE OPENING INCHES
		INCHES OF HG LEFT	INCHES OF HG RIGHT	INCHES OF HG DIFF.	$\sqrt{\text{INS. HG.}}$ / $\sqrt{\text{DIFF.}}$							
	9-6-38											
1	9:30 P.M.	11.40	6.40	5.06	2.236	1960	224	1171.64	646.75	76	59	—
2	10:30	11.20	6.70	4.50	2.122	1860	221	1171.64	646.90	0	.06	12 3/4
3	10:35	11.10	6.70	4.40	2.100	1830	221	1171.64	646.90	0	.045	13
4	3:30 A.M.	11.35	6.55	4.80	2.190	1890	221	1171.68	646.13	8	12	11 11/32
5	4:30	11.40	6.43	4.97	2.230	1925	221	1171.68	646.04	17	185	9 5/8
6	6:35	11.47	6.37	5.10	2.259	1945	220	1171.70	646.26	25	24	8 1/4
7	8:30	11.52	6.30	5.22	2.285	1960	220	1171.70	646.80	33	30	7
8	10:30	11.15	6.62	4.53	2.128	1840	220.5	1171.72	646.65	1	.07	12 1/2
9	11:15	11.40	6.50	4.90	2.213	1930	220.5	1171.72	646.60	17	18.5	9 1/2
10	11:35	11.40	6.34	5.06	2.249	1920	220	1171.72	647.13	24.8	24	9 1/8
11	11:50	11.54	6.20	5.34	2.310	1995	220	1171.72	647.23	43.0	36	5 1/4
12	1:50 P.M.	11.54	6.16	5.38	2.319	2005	220	1171.74	646.90	52.3	42	3 31/32
13	3.50	11.56	6.16	5.40	2.324	2015	220	1171.76	646.75	61.5	48	2 9/16
14	5.50	11.48	6.22	5.26	2.294	1980	220	1171.76	646.77	67.7	52	1 9/16
15	8.00	11.52	6.32	5.20	2.280	1985	220	1171.78	646.93	68.0	52	1 9/16
16	9 25	11.50	6.32	5.18	2.276	1975	220	1171.80	646.90	70.0	54	1 3/16

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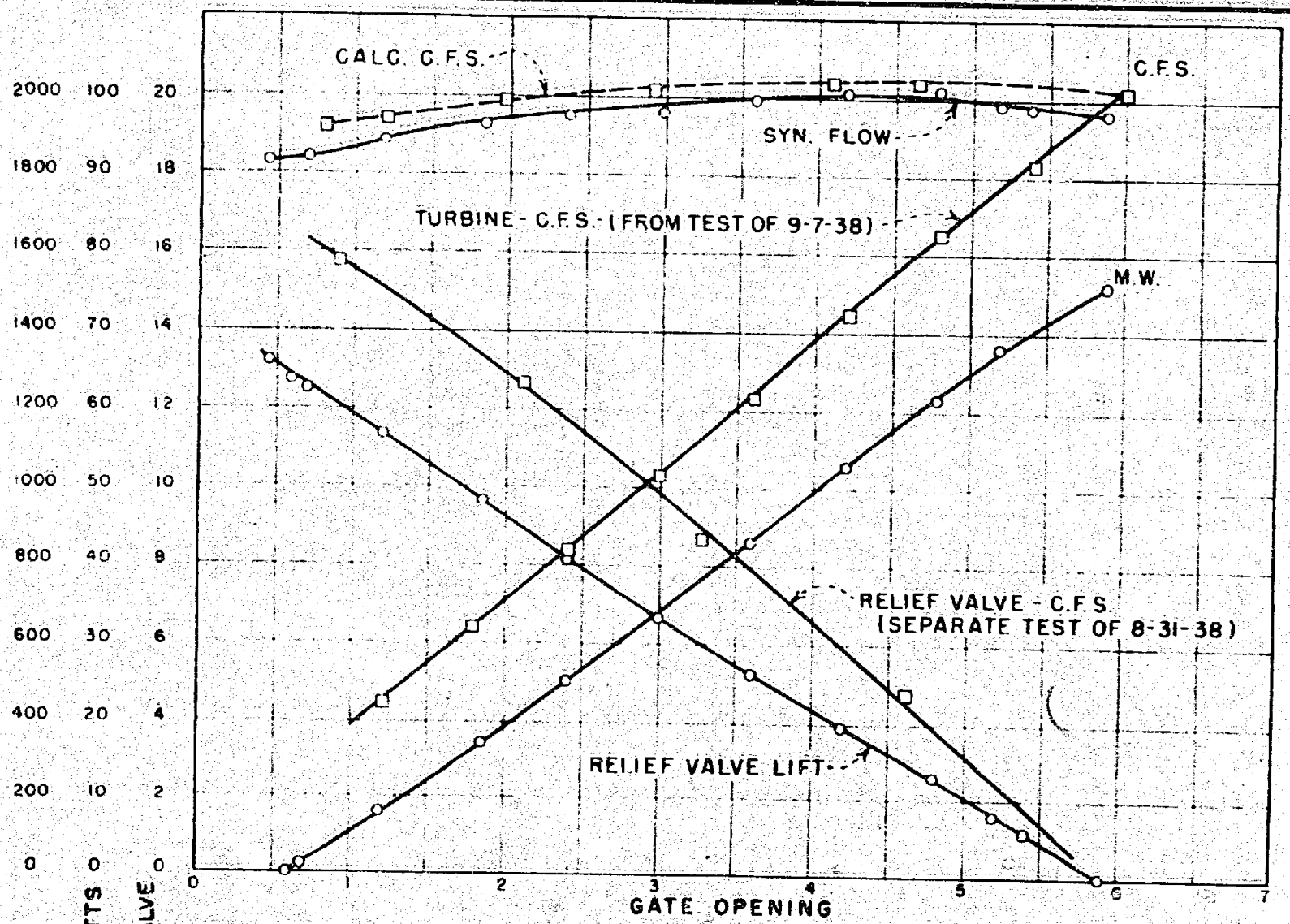
TABLE 20

99

45-D-1250



PERFORMANCE TEST OF N-6
(AT ACTUAL TEST HEADS) SEPT. 1938
BOULDER R.S.Q. 9-8-38

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FIGURE 24

45-D-12 488

TABLE 21 - TEST OF RELIEF VALVE N-6

October 12, 1938

Run No.	Valve Opening Inches	Net Head Feet	Discharge Second-feet	For net head = 610 feet Ratio of Heads	Discharge Second-feet
1	0.00	523.53	0	0.9742	0
2	1.56	523.68	222	0.9740	219
3	3.00	523.93	432	0.9734	426
4	4.53	524.50	655	0.9724	646
5	6.03	522.93	860	0.9753	849
6	7.50	523.95	1,064	0.9734	1,050
7	9.00	522.68	1,244	0.9757	1,229
8	10.50	522.47	1,393	0.9761	1,376
9	12.00	522.72	1,577	0.9757	1,558
10	13.50	521.40	1,698	0.9781	1,679
11	15.00	522.65	1,841	0.9758	1,819
12	0.00	523.49	0	0.9742	0

Finally, in every important instance the models operating at reduced head have given true indication of the performance of the prototype, and conclusions arrived at were verified by tests in the contractor's shop on models using prototype velocities. No progress was made toward a satisfactory solution of the problem of excessive cavitation until a model was made at the project which indicated the correct approach to a solution of the trouble being caused by a reversal of flow up to the valve seat.