PAP 120

PAP 120

PAP 120

Form DFC-11
(7-52)
Bureau of Reclamation

INFORMATIONAL ROUTING

AUTHOR

GPO 845867

Memorandum

Denver, Colorado
February 9, 1959

To: Chief Designing Engineer

From: Chief, Division of Engineering Laboratories

Subject: Interim report of hydraulic model studies, Glendo Dam Outlet Works

This report is submitted to discuss the more important problems encountered in developing cavitation-free chute blocks and baffle piers for the subject outlet works and to finalize and record the decisions made thus far to eliminate the cavitation erosion on the flow surfaces.

The Model

The studies were conducted on a 1:18.4 scale model of the outlet works and downstream river channel, Figure 1. Because of fund and time limitations, only one of the three bays was made operative. An existing gate was installed in Bay 1, and the flow conditions for three-bay operation were represented by extending the dividing wall between Bays 1 and 2 to the sill at the end of the basin, thus forming a line of symmetry at the left edge of Bay 1. Sweep-out data obtained from the one-bay model check reasonably close the operation of the prototype and the results of the previous model study with three bays. Therefore, this isolated one-bay model was considered adequate to study the pressure conditions along the flow surfaces and the sweep-out characteristics of the stilling basin.

Flared Walls

To eliminate the cavitation-erosion in the flared walls immediately downstream from the gates, it was proposed prior to the model studies that air admission equipment be installed at each flared wall as shown in Figure 2. Tests were conducted both with and without the proposed venting system installed in the model. With the structure as originally constructed (no air vents), average pressures equivalent to 30 feet of water below atmospheric were observed at piezometers placed immediately downstream from the start of the flared walls and 9 and 36 inches prototype above the chute floor. When the air admission equipment was installed, the minimum average pressure as measured by water manometers was 5 feet below atmospheric just downstream from the air vent, and the instantaneous minimum pressure as measured by pressure cell was 12 feet below atmospheric. The vents took air at all gate openings and discharges; however, the demand for air was greater when the jet from the gate was submerged. The observed pressures are above the cavitation range, and the proposed venting system is considered adequate to eliminate the cavitation-erosion along the flared walls.

Two piezometers were installed in the vicinity of the stoplog slots where cavitation-erosion also occurred at Glendo. Preliminary tests on the model have indicated no cavitation pressures at these piezometers. Additional piezometers will be placed in the vicinity of the slot to pinpoint the cause of the cavitation in this region. However, the modifications to the field structure include filling the existing slots with concrete, forming a continuous surface along the flared walls which will eliminate any cavitation tendencies at the slots.

Chute Blocks

Average pressures observed on the original chute block indicated cavitation would occur near the spring point of the elliptical curve at gate openings above 50 percent and reservoir elevation 4653 feet (top of flood storage), Figure 3. No instantaneous pressures were recorded because the average pressure was obviously in the cavitation range.

In developing a satisfactory chute block for the basin, it was desirable that two design requirements be met: (1) the block surface must be free of cavitation and (2) the effectiveness of the stilling basin should not be impaired. In general, these two requirements oppose each other; that is, additional curvature on the sides of the blocks is normally needed to raise the pressures, and increased curvature reduces the effectiveness of the block in deflecting the high velocity jet and stabilizing the hydraulic jump.

Seven chute-block designs were tested and varied in height (2.9 to 7 feet), in width (5 to 7 feet), in slope of the block top, and in curvature of the sides of the block.

In general, the tests showed that the original block (7 feet high with upward slope) was best in stabilizing the hydraulic jump but gave the lowest pressures on the block surfaces. Improved pressures were obtained by increasing the curvature of the sides of the original block, but the improvement was insufficient to assure cavitation-free surfaces on the block. The upward slope was then removed from the original block, making a block about 2.9 feet high; this shorter block caused large boils of water to form above the baffle piers and more tail water was required to hold the jump in the basin. Next, a block with horizontal top and 4 feet 7 inches in height was tested, and the basin performance was similar to that with the original block installed.

The preliminary tests indicated that the chute block should be at least 4-1/2 feet in height, but the test results were inconclusive in establishing that a block with an upward slope gave a better jump than one with a horizontal top. Therefore, it was decided to develop a block with a horizontal top and a height such that the top of the block intersected the chute floor at a point 2 feet downstream from the contraction joint at Station 30+46, Figure 1. Tests of several variations of this basic design were conducted, including blocks with parallel sides, tapered sides to conform with the diverging flow, and with widths of 5 and 7 feet. The test results indicated little preference among the various shapes as far as jump performance was concerned. Although no pressure tests were conducted on the various shapes, a block with tapered sides was chosen for detailed pressure tests since a flow surface more nearly parallel to or encroaching on the flow lines generally requires less streamlining than one flaring away from the direction of flow.

The sides of the tapered block (Chute Block 5) were streamlined with a 5:1 elliptical curve in the direction of flow (parallel to the chute floor) and equipped with piezometers as shown in Figure 4. Pressure observations recorded for 25 to 100 percent gate openings, reservoir elevation 4653 and actual tail water are also shown in Figure 4. The lowest average pressure observed on the block was 5 feet of water below atmospheric at Piezometer 21 located on the downstream end of the block. About 4-1/2 feet below atmospheric at 83 percent gate opening was the lowest average pressure observed on the sides of the block. The lowest instantaneous pressure occurred at 50 percent gate opening and reached about 10 feet below atmospheric at Piezometer 4 on the side of the block. It is interesting that the lowest average pressure occurred at 83 percent gate opening while the lowest instantaneous pressure was observed at 50 percent gate opening. This apparent inconsistency was due to the position of the hydraulic jump in the basin; at 83 percent gate opening, the jump was practically swept from the basin, and the chute block was free of backwater from the jump; at 50 percent gate opening the jump roller extended upstream completely covering the chute block, and the surges inherent in a jump roller caused large pressure fluctuations on the block. Tests are now being conducted to determine the effect of additional tail water on the average and instantaneous pressures at all gate openings.

On the basis of the above tests, Chute Block No. 5, was chosen for construction in the field.

Baffle Piers

Average pressures observed on the original design indicated that cavitation would also occur on the baffle piers at gate openings above 50 percent and reservoir elevation of 4653 feet, Figure 5. The Glendo basin operated at gate openings of about 60 percent over a considerable period of time during the 1958 irrigation season at reservoir elevations between approximately 4595 and 4625 feet and no cavitation-erosion on the prototype baffle piers was reported. The model indicated that minimum pressures on the baffle piers will occur at 83 percent gate opening, and cavitation will probably occur at 60 percent gate opening and reservoir elevation 4653 feet. The fact that no cavitation-erosion was noted on the prototype baffle piers was probably due to the lower than maximum operating heads and the large amount of entrained air in the jump.

As a result of the above studies, it was evident that additional streamlining of the baffle piers was required to insure cavitation-free piers at near-maximum gate openings and operating heads.

Six baffle pier designs were tested, Figure 6. Average pressures in or near the cavitation range were observed on Piers 1 (original), 2 and 3. Tests on these piers indicated that the lowest pressures occurred on the pier sides next to the training wall and the dividing wall; considerably higher pressures were observed on the sides next to the center line of the bay.

For structural reasons and ease of construction, the designers suggested that the shape of the existing pier be modified by placing a minimum of 6 inches of new reinforced concrete on the exposed pier surfaces, thus making the new block 12 inches wider and longer and 6 inches higher than the original pier. Increasing the width and height of the piers had the effect of offering more resistance to the flow and permitted excessive streamlining of the pier without sacrificing its efficiency.

The minimum average pressure observed on Pier 4 was 23 feet below atmospheric at 75 percent gate opening, Figure 7, and occurred on the elliptical curve near the upstream nose, indicating that still more streamlining was needed in the vicinity of the pier nose.

Extreme streamlining of the sides was provided on Piers 5 and 6, Figure 6. The pressures observed on Piers 5 and 6 are shown in Figures 8 and 9, respectively. Considerable improvement in the pressures on the piers was noted:

Pier No.	Minimum av pressure	Minimum instant pressure
1, 2, 3	-30 ft	Not obtained
4	-23 ft	Not obtained
5	-10 ft	-26 ft
6	0	-17 ft

The above table clearly indicates the preference of Pier 6 over the other test piers as far as pressures were concerned. Also, the basin performance, which is discussed later, was similar when either Pier 5 or Pier 6 was installed.

Based on the above test results, Pier 6 was chosen for field construction.

Basin Performance

The basin performance with the various test blocks and piers installed was evaluated primarily by recording the tail water elevation when the jump "swept" from the basin. "Jump sweepout" in this study is the same as that used in the original 1:24 model and is defined as the tail water elevation at which the entering flow broke through the tail water and was deflected upward at the baffle piers, Figure 10.

Sweepout curves for various chute block and baffle pier designs are shown in Figure 11 and 12. The uppermost curve is the tail water used in originally designing the outlet works basin. Tail water elevations observed last summer at Glendo, however, showed that the actual tail water was about 1 foot below the computed curve used in design. Therefore, the actual tail water curve is the normal tail water referred to in this report.

In comparing the sweepout curves obtained from the current 1:18.4 model and the original 1:24 model, the results check reasonably close for the right gate operating singly and three gates operating at 100 percent gate opening with decreasing reservoir head. (A comparison for two gates operating fully open cannot be made because sweepout conditions for two gates cannot be represented in a one-bay model). However, with constant reservoir at elevation 4653 feet and three gates operating, the sweepout curves from the two models are considerably different. The data from both models have been rechecked, and no apparent reason for the discrepancy has been found. The sweepout curve from the original model for three gates operating at constant reservoir level is believed in error, and the curve from the current model was used in defining the sweepout characteristics of the basin.

The effect of air vents and streamlining of the chute blocks on the sweepout characteristics of the basin is shown in Figure 11, for different discharges and reservoir elevation 4669 feet. The sweepout curve for the original structure is about 6 inches below the actual or normal tail water curve for discharges between 10,000 and 12,000 cfs. When the air vents were installed with the original chute blocks and baffle piers, the jump swept from the basin at a slightly higher tail water elevation; thus, some of the safety against sweepout was lost in the original structure by installing the air vents. Additional safety against sweepout was lost when the original chute block was replaced with Chute Block 5, and the jump will sweepout at 75 percent gate opening (discharge--9,500 cfs) and normal tail water, Figure 11.

The effect of streamlining the baffle piers is shown in Figure 12. The sweepout curves indicate that additional safety against sweepout was lost by streamlining the baffle piers. With either Pier 5 or 6 installed, the jump swept out at about 9,000 second-feet and approximately 0.4 foot of additional tail water above normal was needed at the maximum discharge of 10,000 second-feet. A direct comparison between Figures 11 and 12 cannot be made, because the sweepout curves in Figure 11 were obtained using reservoir elevation 4669 while the curves in Figure 12 were obtained with the reservoir at elevation 4653 feet.

From the above discussion and Figures 11 and 12, it is apparent that all proposed modifications to the basin have the effect of causing the jump to sweepout at a higher tail water elevation. Since the actual tail water is already about 1 foot lower than the tail water used in designing the structure, it is imperative that additional tail water be provided for satisfactory stilling-basin operation at discharges above approximately 8,000 second-feet. From the tests made thus far, it appears that a minimum of 18 inches of additional tail water is required for the basin to operate satisfactorily at the maximum design discharge of 10,000 second-feet. Additional studies are being conducted to determine the minimum tail water required for the structure.

Tail water elevations used in the sweepout studies were those resulting from flow through the outlet works with no flow through the powerplant. When the powerplant is operating at its capacity of 3,400 cfs, about 18 inches of additional tail water will be available at the outlet works. Limited scour tests have indicated that the basin modifications will not cause greater displacement of riprap in the outlet channel.

A scour test at 83 percent gate opening (discharge=10,000 cfs), and tail water elevation 4505.2 which is 1-1/2 feet above actual tail water, Figure 10, showed that scour conditions to be similar to that observed in the prototype when the basin was unwatered.

<u>Training Wall Vibration</u>

The model studies have not disclosed any source of the thumping noise and related vibrations in the training walls of the Glendo basin other than cavitation on the chute blocks. Studies of pressures on the training walls have been limited because of the pressing need for developing satisfactory shapes for the chute blocks and baffle piers. Tests thus far, however, have given no indication that the vibration in the left wall is caused by turbulence and surges in the basin. Field reports on the operation of the Glendo basin have indicated that the wall vibration is directly associated with the audible thumps or pounding in the basin. Assuming that the thumping was caused by the collapse of cavitation envelopes originating on the sides of the chute blocks where cavitation actually occurred, it follows that the thumping will be eliminated when the proper streamlining of the chute blocks is accomplished by the installation of Chute Block 5. If cavitation occurs at the flow interface immediately downstream from the chute block and independently of the block streamlining, there is no assurance from the model studies made thus far that the thumping has been eliminated.

It is the opinion of the laboratory, however, that the thumping resulted from cavitation on the sides of the blocks, and the thumping and related vibrations in the walls will be eliminated when the streamlined chute blocks are installed.

Conclusions

1. The 1:18.4 scale model of one bay was adequate to study the pressures along the flow surfaces and the sweepout conditions in the Glendo Outlet Works stilling basin.

2. The proposed air admission equipment, Figure 2, and the filling of the stoplog slots will eliminate the cavitation-erosion along the flared walls.

3. The severe cavitation on the chute blocks was caused by insufficient streamlining of the sides of the blocks. Pressure studies indicate that the installation of Chute Block 5, Figure 4, will eliminate the cavitation on the chute blocks.

4. Although no cavitation-erosion was observed on the prototype baffle piers, the study indicated that cavitation may occur on the sides of the piers at near-maximum discharges. The streamlining of Pier 6, Figure 6, is adequate to prevent cavitation on the surfaces of the baffle piers, at all discharges and operating heads.

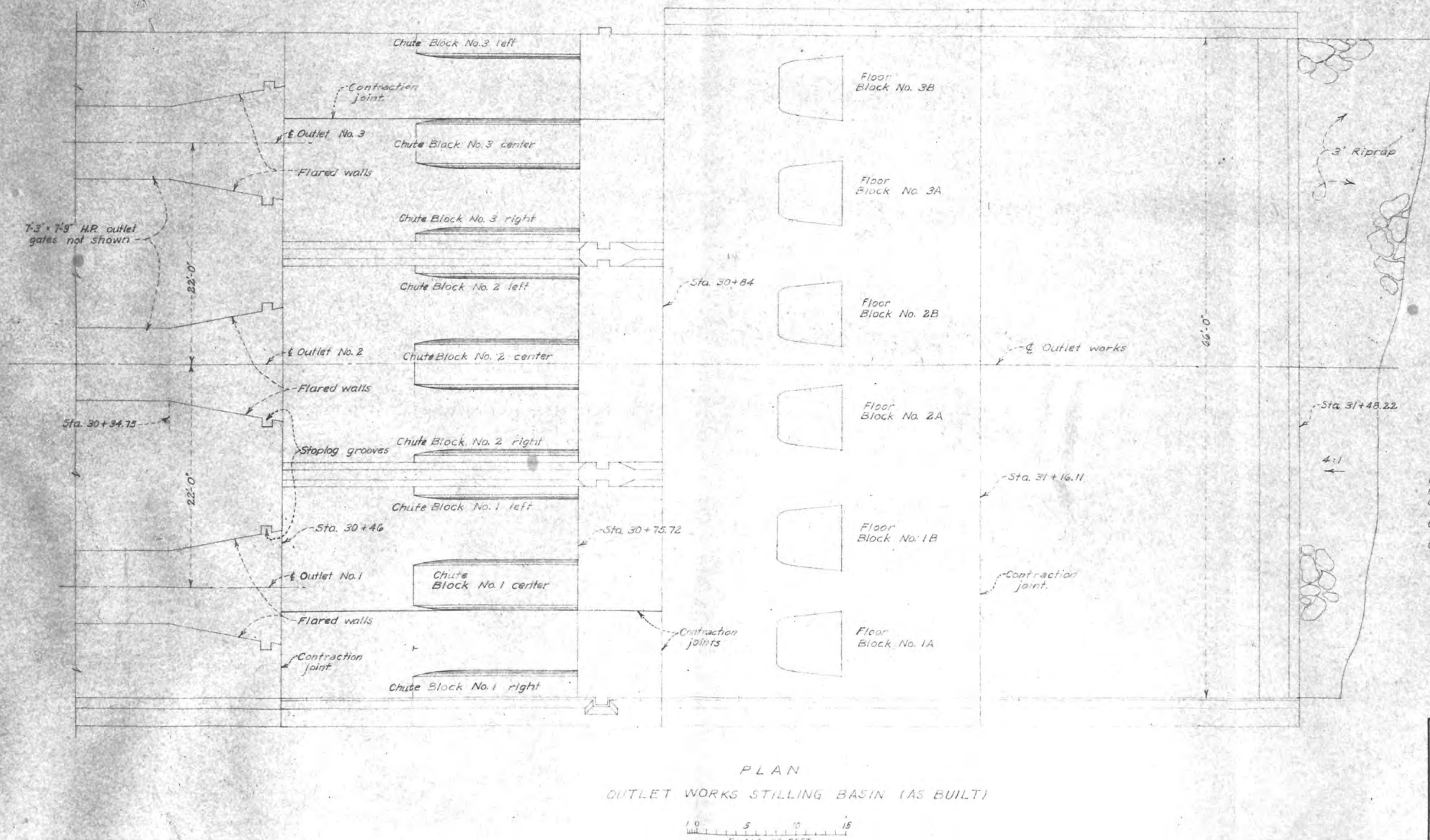
5. The installation of the air admission equipment and streamlining the chute blocks and baffle piers reduced the stability of the hydraulic jump to the point that additional tail water is required to assure satisfactory stilling-basin operation at discharges above 8,000 second-feet with no flow through the powerplant.

6. No conclusive evidence was found in the model studies to indicate that the thumping and related vibrations noted in the

prototype training walls resulted from any condition other than cavitation which occurred on the chute blocks. It is the opinion of the laboratory that the thumping resulted from this cavitation.

Copy to: 220
225
250
293 4

Figure 1



PLAN
OUTLET WORKS STILLING BASIN (AS BUILT)

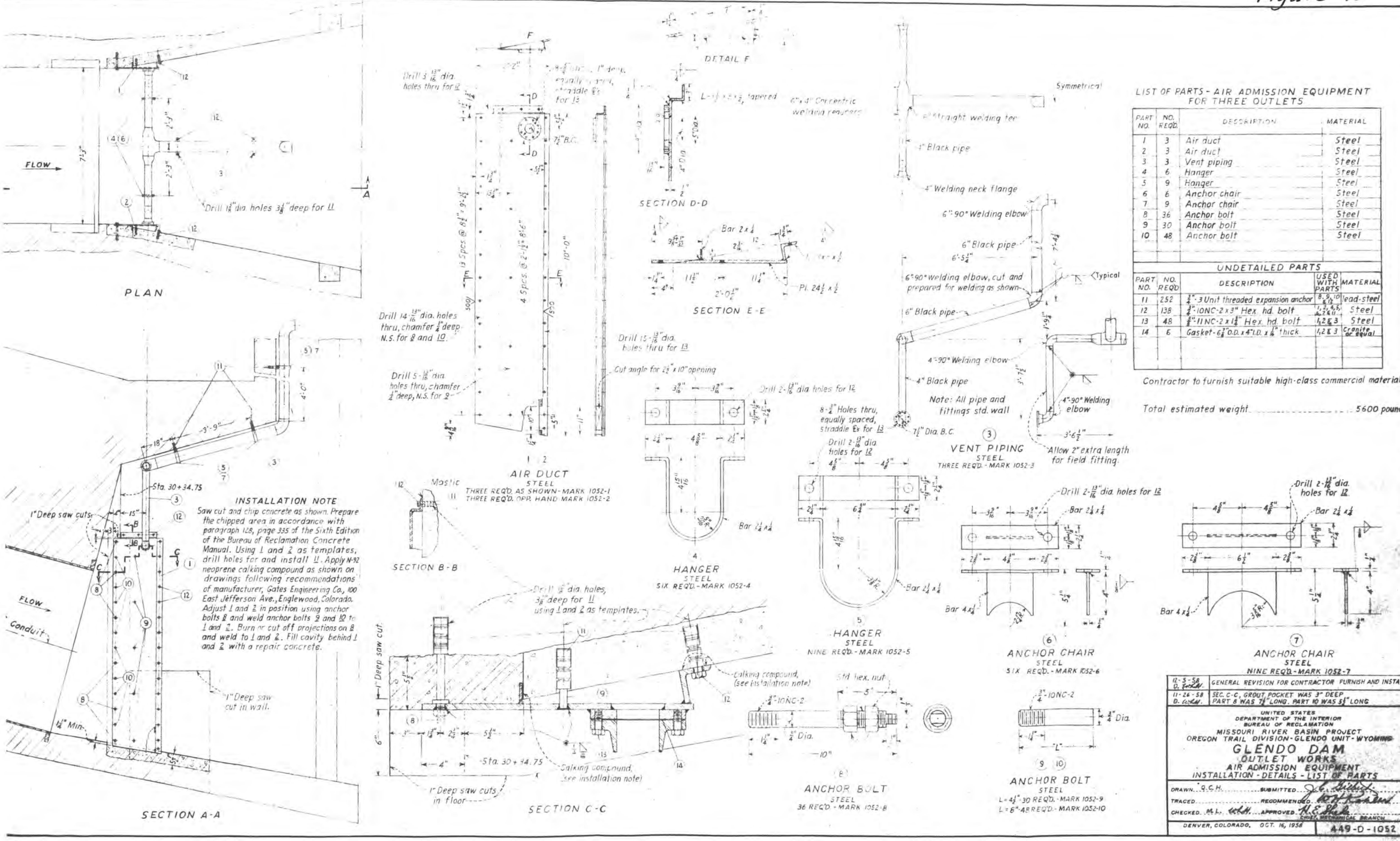
REFERENCE DRAWINGS

OUTLET WORKS CONTROL HOUSE 449-
OUTLET WORKS STILLING BASIN 449-
OUTLET WORKS REPAIR OF FLARED WALLS 449-D
OUTLET WORKS REPAIR AND FILLING OF STOP LOG GROOVES 449-D
OUTLET WORKS REPAIR OF CHUTE AND FLOOR BLOCKS 449-D

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
OREGON TRAIL DIVISION-GLENDO UNIT-WYO
GLENDO DAM
OUTLET WORKS
MODIFICATION OF STILLING BASI
KEY PLAN

DRAWN HGA SUBMITTED R.W. Whinnerah
TRACED RECOMMENDED O.L. Rice
CHECKED H.A.H. McK APPROVED
CHIEF DESIGNING E
DENVER, COLORADO, DEC. 4, 1958 449-D-1

Figure 2



LIST OF PARTS - AIR ADMISSION EQUIPMENT FOR THREE OUTLETS

PART NO.	NO. REQ'D.	DESCRIPTION	MATERIAL
1	3	Air duct	Steel
2	3	Air duct	Steel
3	3	Vent piping	Steel
4	6	Hanger	Steel
5	9	Hanger	Steel
6	6	Anchor chair	Steel
7	9	Anchor chair	Steel
8	36	Anchor bolt	Steel
9	30	Anchor bolt	Steel
10	48	Anchor bolt	Steel

UNDETAILED PARTS

PART NO.	NO. REQ'D	DESCRIPTION	USED WITH PARTS	MATERIAL
11	252	¾"-3 Unit threaded expansion anchor	8, 9, 10 & 12	lead-steel
12	138	¾"-10NC-2 x 3" Hex. hd. bolt	1, 2, 4, 5, 6, 7 & 11	Steel
13	48	⅝"-11NC-2 x 1¾" Hex. hd. bolt	1, 2 & 3	Steel
14	6	Gasket - 6⅞" O.D. x 4" I.D. x 1/16" thick	1, 2 & 3	Cranite or equal

Contractor to furnish suitable high-class commercial materials.

Total estimated weight .... 5600 pounds

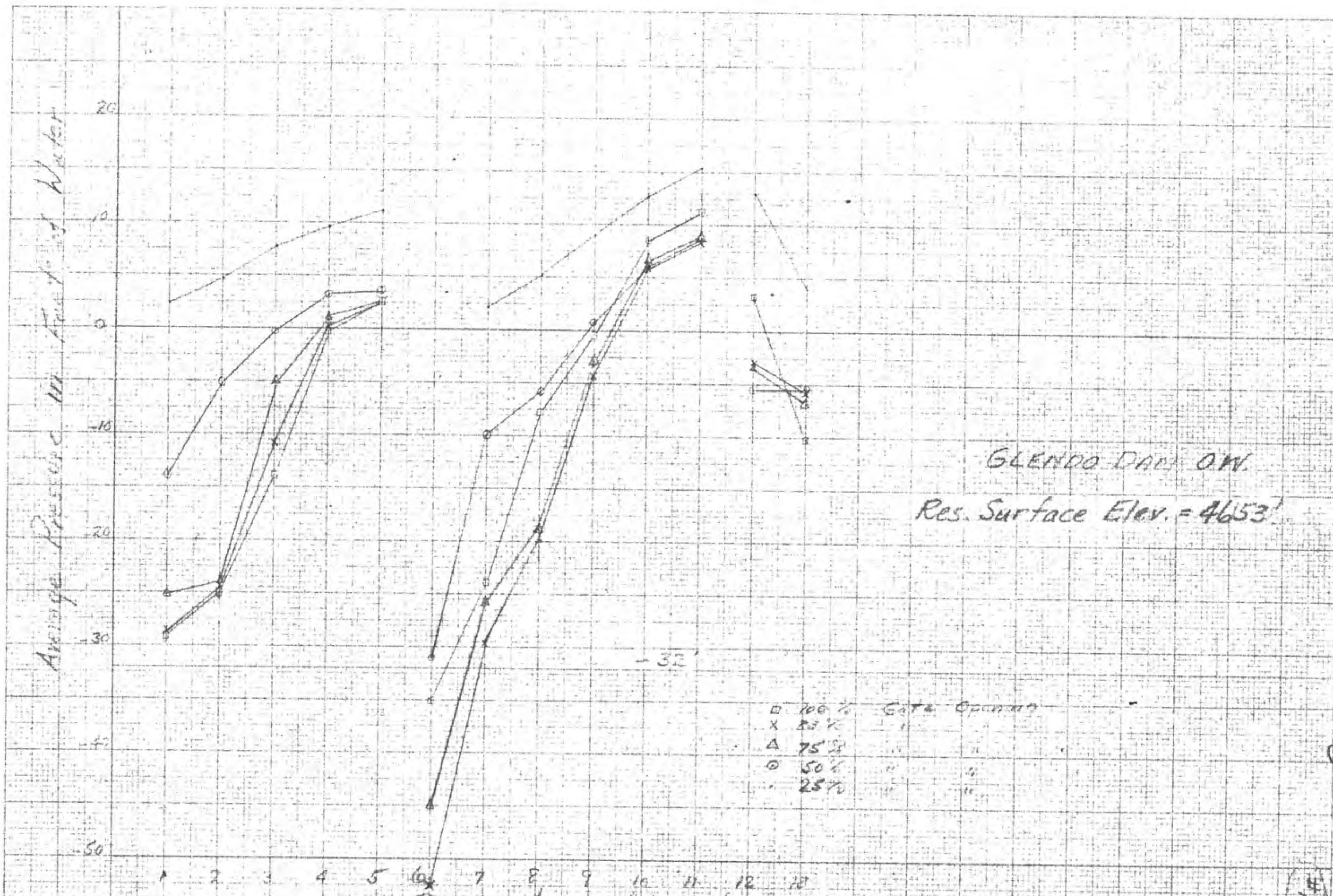
12-5-58 D.	GENERAL REVISION FOR CONTRACTOR FURNISH AND INSTALL
11-26-58 D.	SEC. C-C, GROUT POCKET WAS 3" DEEP PART 8 WAS 7½" LONG. PART 10 WAS 5½" LONG

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
OREGON TRAIL DIVISION - GLENDO UNIT - WYOMING

GLENDO DAM
OUTLET WORKS
AIR ADMISSION EQUIPMENT
INSTALLATION - DETAILS - LIST OF PARTS

DRAWN Q.C.H. SUBMITTED
TRACED RECOMMENDED
CHECKED M.L. APPROVED
CHIEF, MECHANICAL BRANCH

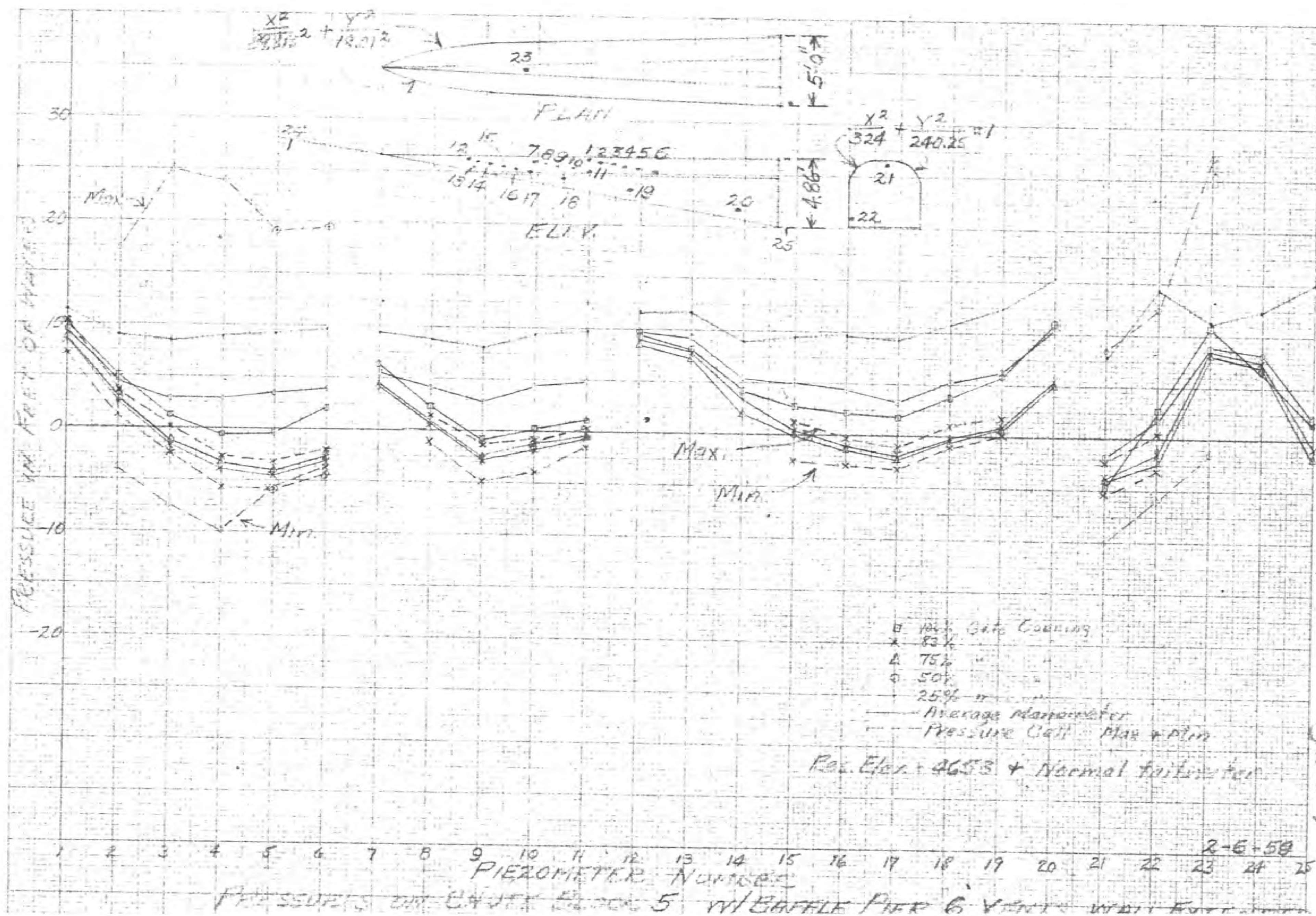
DENVER, COLORADO, OCT. 16, 1958 — 449-D-1052



Pressures on Original Chute Blocks with Original Baffle Piers

Figure 3

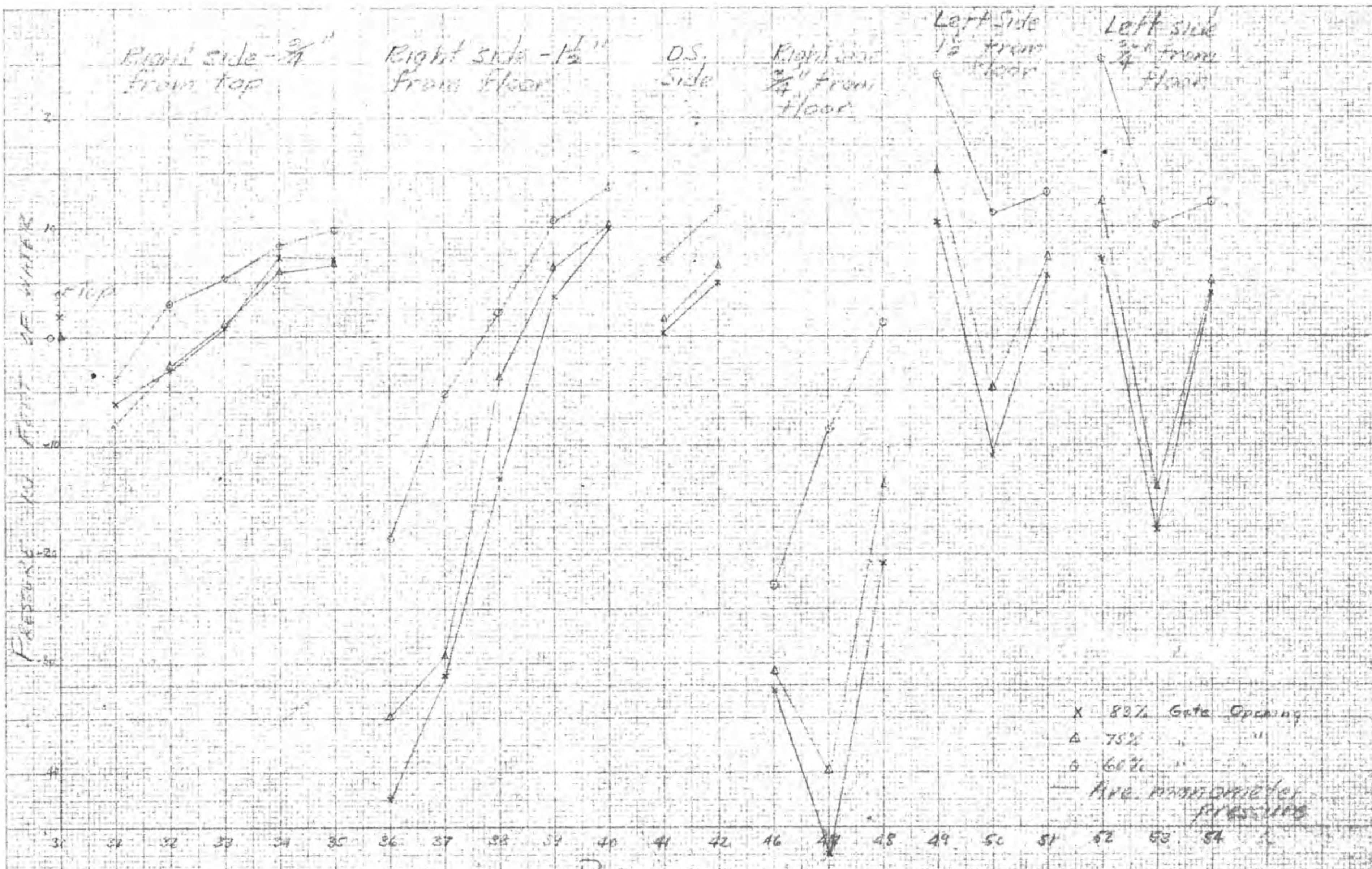
#115



PLAN
ELEV.
5'0"
4.86'
$\frac{X^2}{324}+\frac{Y^2}{240.25}=1$
Max.
Min.
Pressure in Feet of Water
Piezometer Number
100% Gate Opening
83%
75%
50%
25%
Average Manometer
Pressure Cell Max + Min
Res. Elev. 4653 + Normal Tailwater
2-6-58

Figure 4

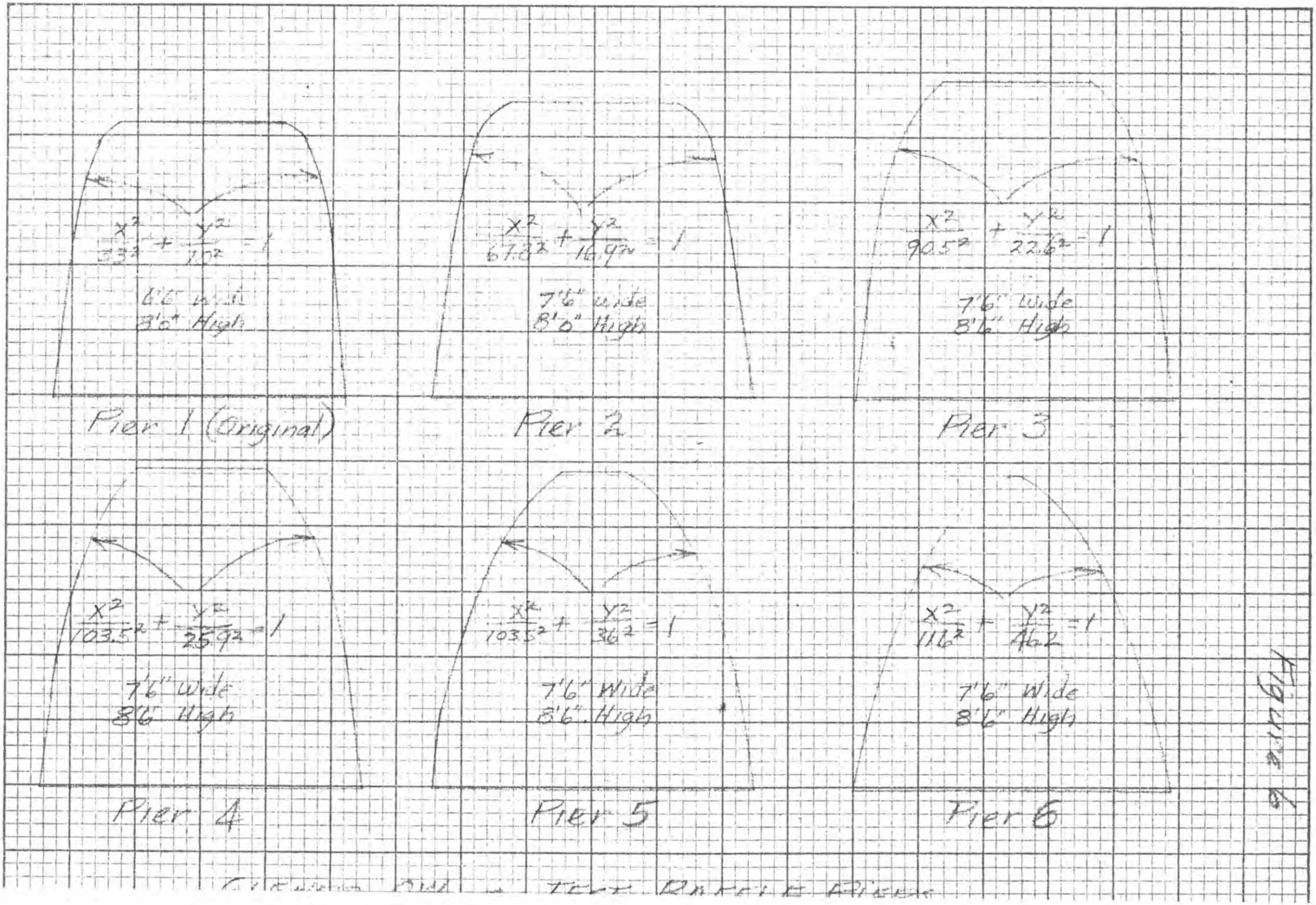
K+E 10 X 10 TO THE CM. 359-14
KEUFFEL & ESSER CO., MADE IN U.S.A.



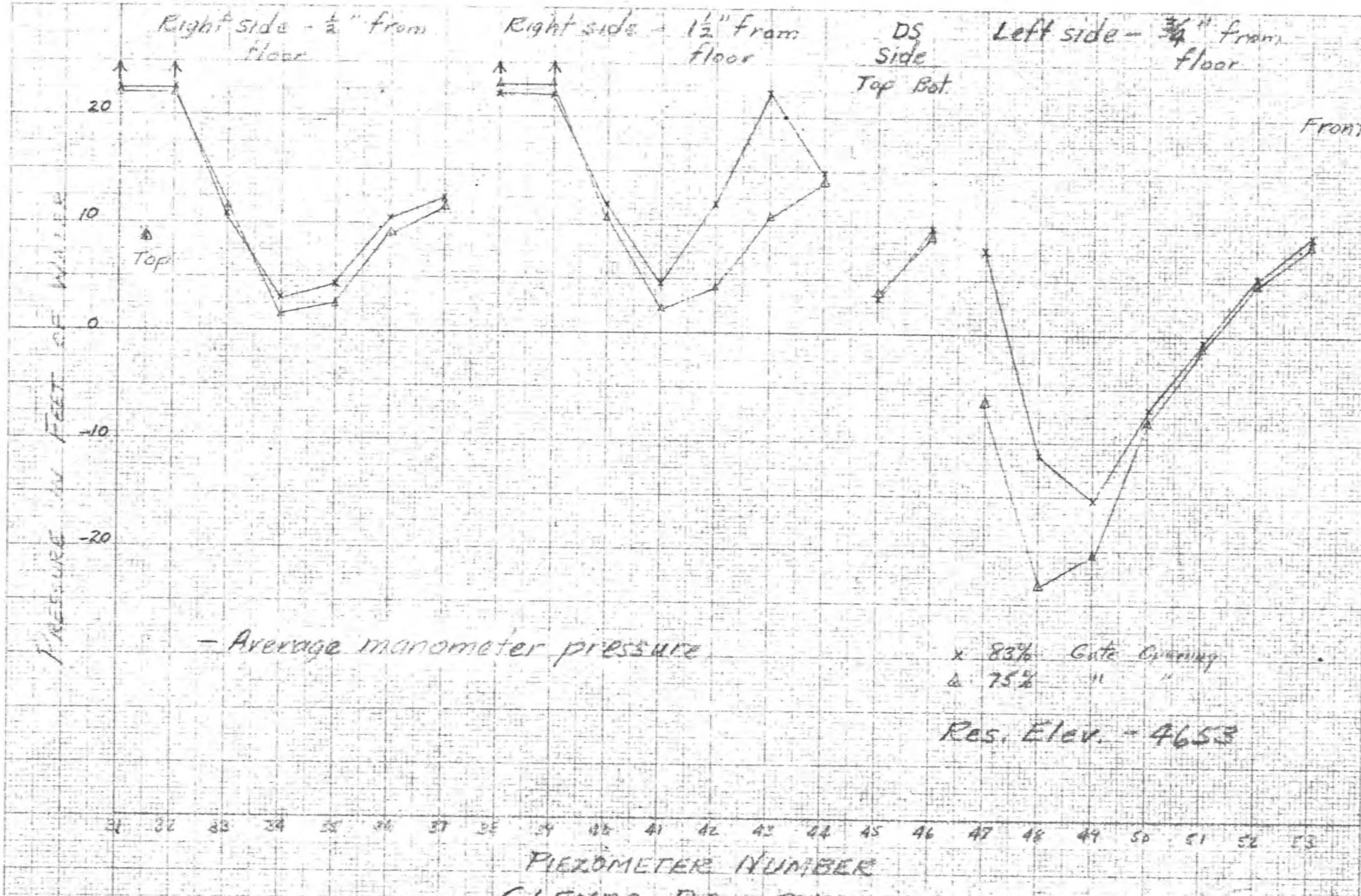
PIEZOMETER NUMBER
GLENDO DAM OUTLET WORKS
PRESSURES ON ORIGINAL BAFFLE PIER w/ ORIGINAL CHUTE BLOCK

12-30-57

Figure 6


Pier 1 (Original)
X²/67.8² + Y²/16.9² = 1
7'6" wide
8'0" High
Pier 2
X²/90.5² + Y²/22.6² = 1
7'6" Wide
8'6" High
Pier 3
X²/103.5² + Y²/25.9² = 1
7'6" Wide
8'6" High
Pier 4
X²/103.5² + Y²/36² = 1
7'6" Wide
8'6" High
Pier 5
X²/116² + Y²/46² = 1
7'6" Wide
8'6" High
Pier 6

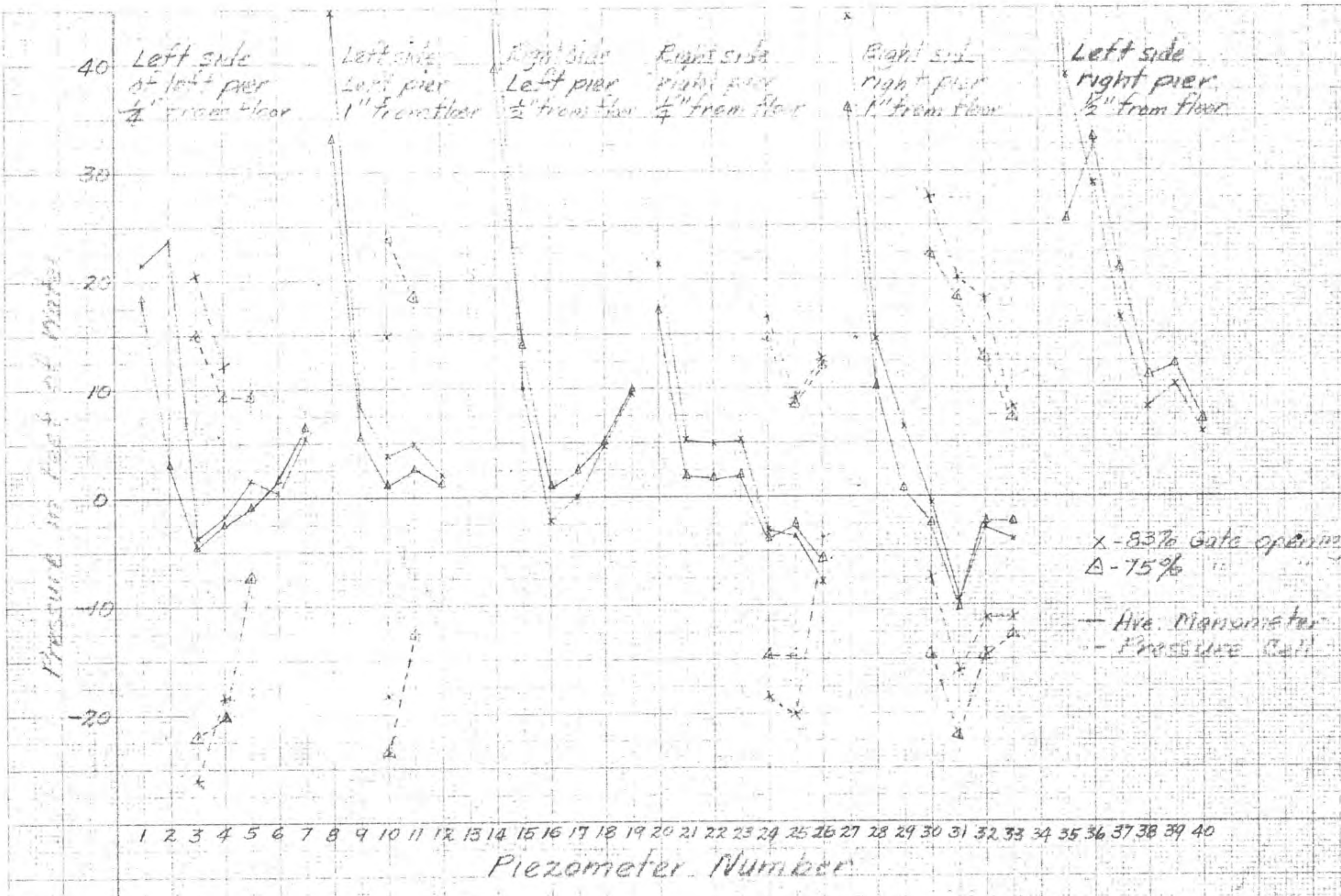
K&E 10 X 10 TO THE CM. 359-14
KEUFFEL & ESSER CO. MADE IN U.S.A.



GLENDO DAM O.W.

1-5-59

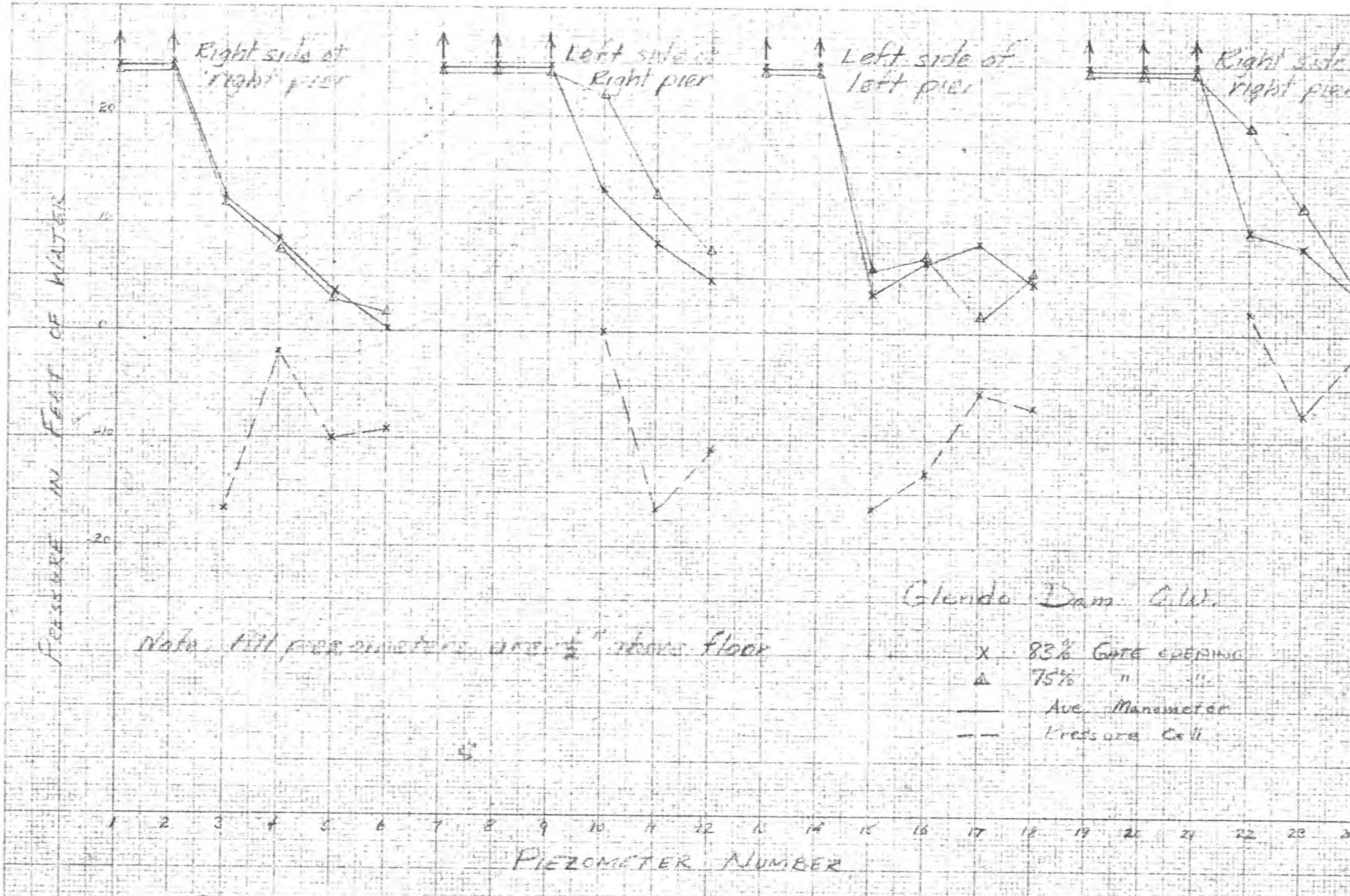
Pressures on Left Baffle Pier #4 with Chute Block #5



GLENDO OUTLET WORKS
Chute Block 5 and Baffle Pier 5
Pressures on Pier 5

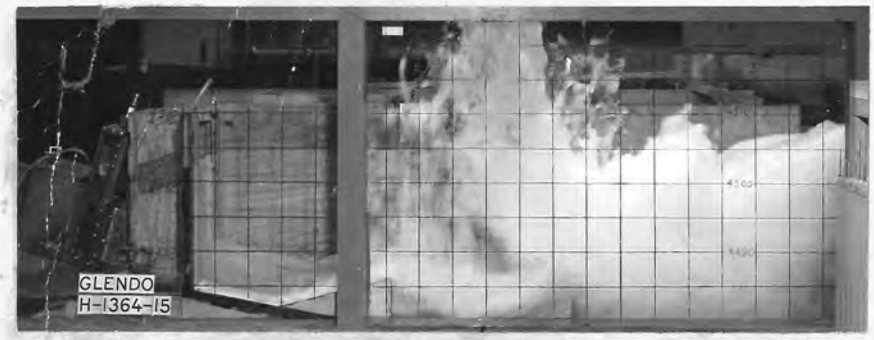
Figure 5

K+E 10 X 10 TO THE CM. 359-14
KEUFFEL & ESSER CO. MADE IN U.S.A.



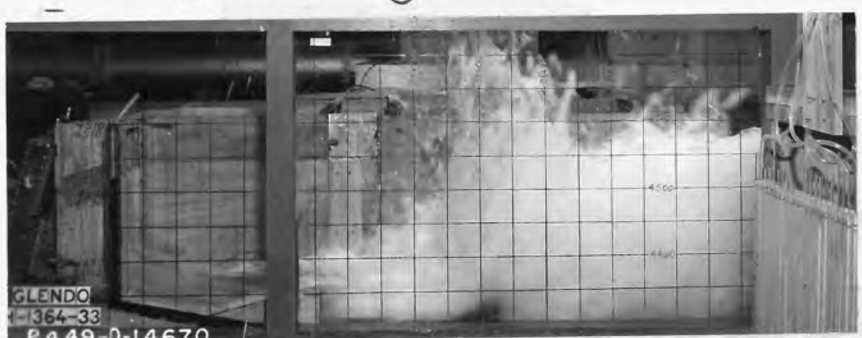
Pressures on Baffle Pier #6 with Chute Block #5

FIGURE 10

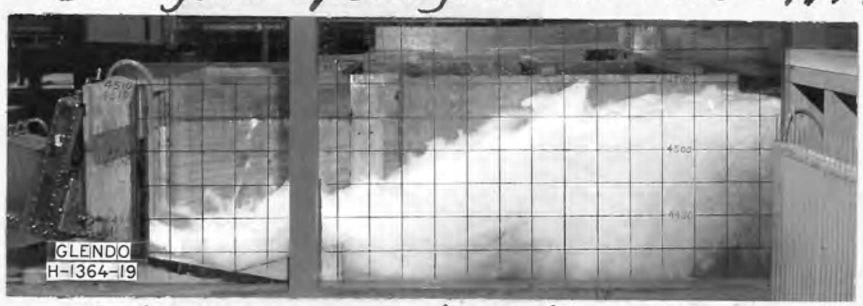


A. Chute Block 5 and Baffle Pier 5
83% gate opening. Q=10,000 cfs - N.T.W.

B. Erosion in d.s. channel after 1-hour operation
at 83% gate opening. Q=10,000 cfs. NTW + 1½ feet.

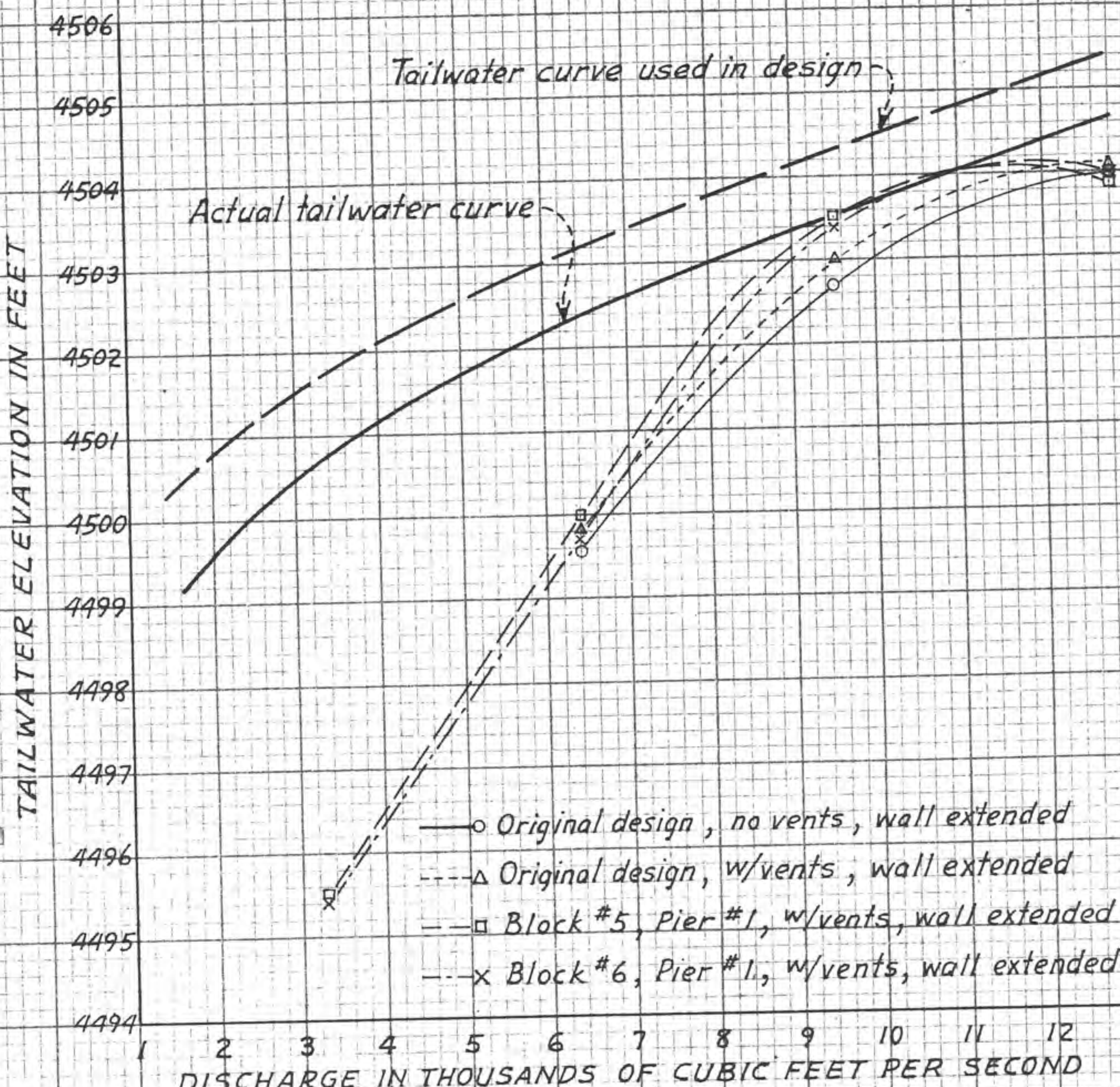


C. Chute Block 5 and Baffle Pier 6
83% gate opening. Q=10,000 cfs - NTW



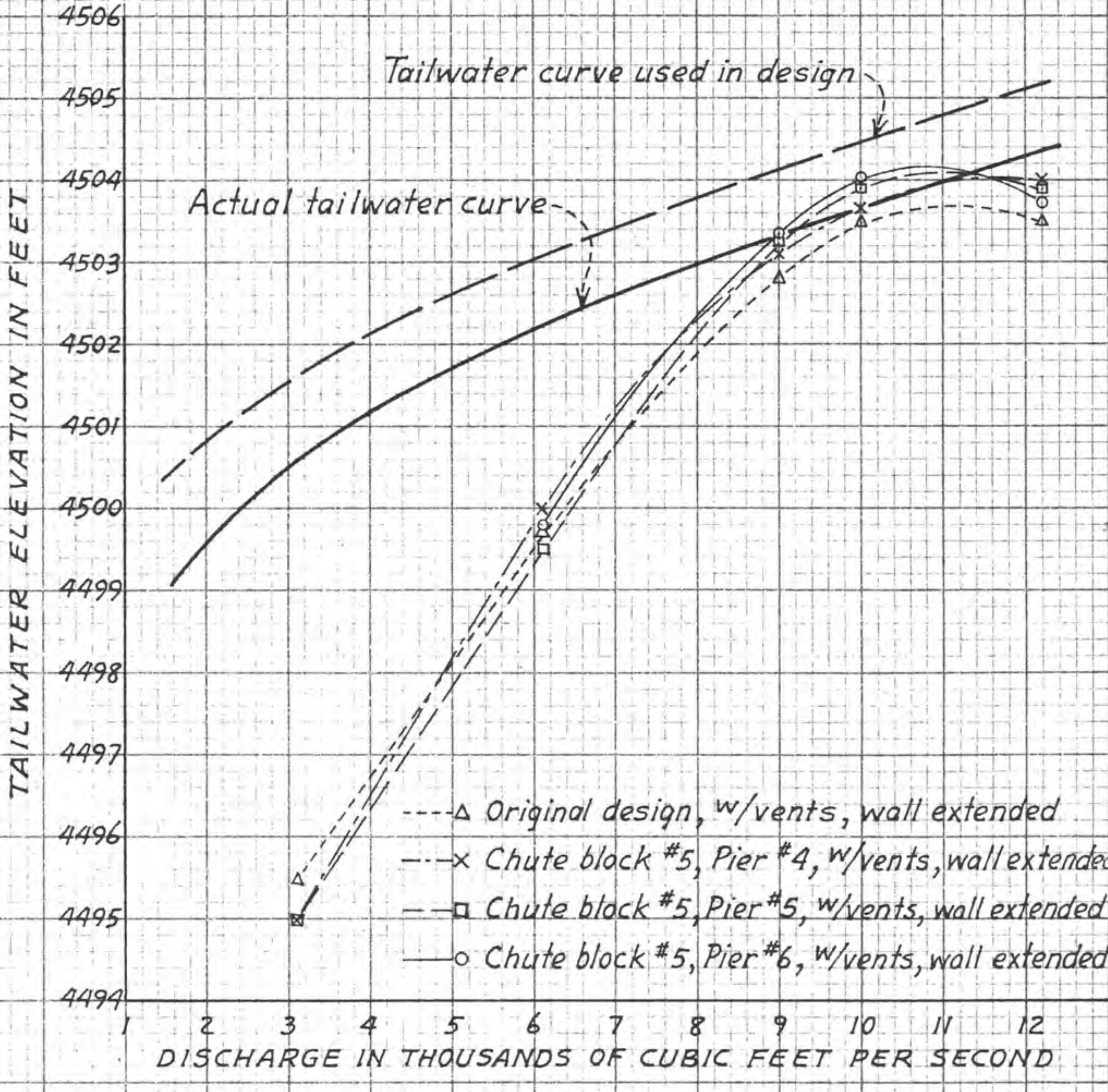
D. Chute Block 5 and Baffle Pier 6
83% gate opening. Q=10,000 cfs - NTW+1½'

GLENDO DAM OUTLET WORKS
1:18.4 Scale Model



GLENDO DAM OUTLET WORKS
TAILWATER AND JUMP SWEEP-OUT CURVES
RESERVOIR ELEVATION - 4669 FEET
1:18.4 MODEL

FIGURE 12



GLENDO DAM OUTLET WORKS

TAILWATER AND JUMP SWEEP-OUT CURVES

RESERVOIR ELEVATION - 4653 FEET

1:18.4 MODEL

559