DESIGN AND OPERATING PROBLEMS ON THE GLENDO DAM HIGH HEAD OUTLET WORKS STILLING BASIN

by

M. A. Jabara and W. E. Wagner, Engineers,
Office of Assistant Commissioner and Chief Engineer
Bureau of Reclamation
Denver, Colorado

A paper to be presented at the
1961 Annual Convention,
American Society of Civil Engineers,
New York City, October 16–20, 1961

DESIGN AND OPERATING PROBLEMS ON THE
GLENDO DAM HIGH HEAD OUTLET WORKS STILLING BASIN

by M. A. Jabara, F. ASCE1/ and W. E. Wagner, F. ASCE2/

SYNOPSIS

This paper describes the special laboratory and field hydraulic tests conducted to reduce cavitational damage to the Glendo Dam stilling basin walls, chute blocks, and baffle blocks. Also discussed are design considerations and problems encountered in the operation of the stilling basin which are largely attributable to the relatively low level tunnel dictated by diversion requirements and the basin foundation conditions. The paper includes a description of the prototype's irregular behavior and subsequent modifications made to correct the operational deficiencies.

INTRODUCTION

The Glendo Unit, located on the North Platte River in southeast Wyoming, is an important integral part of the Bureau of Reclamation's Missouri River Basin Project. The unit consists of the Glendo Dam, Reservoir, and Powerplant; the Fremont Canyon Powerplant below Pathfinder Dam and at the backwaters of Alcova Reservoir; and the Gray Reef Dam and Reservoir (a regulating reservoir on the North Platte River below Alcova Powerplant). The Glendo Unit serves the purposes of irrigation, flood control, power generation, fish and wildlife conservation, pollution abatement and improvement of quality of municipal and industrial water supply.

The Glendo Powerplant is on the right bank of the river about 4,000 feet south of the dam. General plan of the dam and powerplant is shown in Figure 1. The outlet works, which delivers water to the powerplant and directly to the river by means of a turbine bypass, consists primarily of a tower-type intake structure; a 21-foot-diameter pressure tunnel; a 16-foot 6-inch by 21-foot fixed wheel emergency gate; a surge tank, three 7-foot 3-inch by 7-foot 9-inch guard gates with three regulating gates of the same size, all located in the control house; and a stilling basin.

This paper discusses the significant considerations in designing the outlet works stilling basin and the problems encountered when the structure was placed in operation.

DESIGN CONSIDERATIONS

The narrowness of the valley at the damsite precluded the possibility of constructing the dam along a portion of its length while diverting the river through

1/Supervising Civil Engineer, Dams Branch, Office of Assistant Commissioner and Chief Engineer, Bureau of Reclamation, Denver, Colorado
2/Supervising Hydraulic Engineer, Hydraulic Laboratory Branch, Office of Assistant Commissioner and Chief Engineer, Bureau of Reclamation, Denver, Colorado

the uncompleted section. It was therefore expected that the contractor would utilize the outlet works facilities to bypass diversion flows. Since the upstream borrow areas would be inundated by backwater during high river discharges, a large diversion capacity at low head was required to pass the summer flows. To divert the river with a minimum of upstream inundation, a low-level diversion inlet was provided. Selection of the final outlet works tunnel alinement was influenced by the course of the meandering river. Additional valuable power head was obtained with a relatively small increase in tunnel length. Some of the operational problems associated with the outlet works stilling basin to be discussed in subsequent paragraphs are significantly attributable to the diversion requirement.

The outlet works (turbine bypass) was designed to meet the following principal hydraulic requirements:

Irrigation releases--5,570 cfs at reservoir water surface elevation 4570

Flood releases--10,000 cfs at reservoir water surface elevation 4653 (bottom of the flood control pool)

Power releases--velocities in the main penstock were not to exceed 10 feet per second for a discharge of 3,440 cfs (for two 12,000-kw units).

Subsurface geologic investigations disclosed that the shale on which the powerplant and outlet works control house are founded dips sharply toward the river. The river bottom is filled with a deposit of alluvium consisting of sand and gravel. This material is quite deep and is generally loose and pervious. A conventional hydraulic jump stilling basin to accommodate the maximum calculated outlet works discharge would extend well beyond the contact between the alluvium and shale. Moreover, the upper several feet of the shale formation is weathered and unstable. The depth to firm shale at the downstream end of the basin is so great that special foundation treatment would be required at considerable if not prohibitive cost.

By reducing the length of the conventional basin approximately 15 feet the cutoff wall at the end of the basin could feasibly extend downward to firm and competent shale. Designs proceeded for a basin 66 feet wide and 72 feet long, only 2.8 times the conjugate depth, as compared to 4 to 6 times the conjugate depth required for a conventional basin. The low-level diversion inlet requirement previously mentioned dictated the placement of the regulating gates at a level relatively low to the tail water. These two unusual physical characteristics in great measure presented the basic operational difficulties described in this paper.

Previous experience demonstrates that the operational effectiveness of this type of dissipating device is greatly enhanced by deflecting the regulating gates downward approximately 24°. This permits the discharging high velocity jets to penetrate the pool. The level of the gates demanded by diversion requirements made it impracticable to deflect the gates more than 15°. A greater deflection would necessitate a deeper basin, with added cost, to provide a chute sufficiently long to effect spreading of the jet.

An appreciable saving in cost was realized in utilizing the powerplant's right tailrace training wall as the left wall of the stilling basin. All conceivable unbalanced loading conditions to which this cantilever wall may be subjected were considered in its design. The basin as initially designed and constructed is shown on Figure 2.

Hydraulic model studies conducted to confirm the basin's operating efficiency predicted in the design indicated a need for large chute blocks and baffle piers to achieve adequate dissipation of the water's energy within the unusually short basin length. It was also discovered, after a variety of chute block shapes were tested, that blocks with their upper surfaces on a relatively steep upward slope were the most effective in distributing the flow in the stilling basin.

Despite the design precautions exercised, the prototype's operational behavior presented disturbing irregularities.

OPERATIONAL PROBLEMS

When the outlet works was placed in operation at approximately 25 percent capacity in April 1958, an audible periodic thump was noted to emanate from the stilling basin. Vibrations could be felt in the basin and powerplant walls. The thumping noise could not be associated with a definite frequency or intensity. At times the baffling noise was hardly audible and occured at surprisingly predictable intervals of 10 seconds. At other times, a flurry of louder thumps would occur at intervals of 1 or 2 seconds, and could be easily heard from a distance of more than 100 feet. However, there appeared to be a reasonably direct relationship between the noise and the very measurable vibration in the cantilevered stilling basin wall. The greatest wall deflection appeared to accompany the loudest thumps. The vigorous thumping noise and vibrations persisted throughout the 1958 irrigation season. They became more pronounced in the latter part of the season when the outlet works discharge was about 5,000 cfs, or 50 percent capacity. Power was not generated at any time in this period.

In an effort to ascertain the attendant effect of the vibration on the stilling basin, the outlet works gates were closed temporarily in July to permit a skin diver to examine the flow surfaces. The inspection disclosed evidence of cavitation erosion at the beginning of the flared walls immediately downstream from the control gates, in the stoplog grooves near the end of the flared walls, and on the sides of the center chute block in Bay 3 (extreme left gate). During the remainder of the irrigation season, releases were made only through Gates 1 and 2.

In October, the basin was unwatered in preparation for a comprehensive examination of all flow surfaces. It disclosed an alarmingly extensive cavitation damage to the sides of the center chute block in each outlet bay, in the flared walls, and near the bottom of the stoplog grooves. The whirling action of the water during the time large releases were made simultaneously through only Gates 1 and 2 caused displacement of the riprap in the outlet channel. The riprap near the end of the basin, angular when placed, had become rounded due to movement with the turbulent flow. Except for the roughened floor, no cavitation erosion was observed downstream from the chute blocks. The roughened floor is believed to have been caused during the diversion of the river when abrasive materials were carried through the outlet tunnel. Examination of the left stilling basin wall, which had vibrated violently during the operation of the outlet gates, revealed no significant spalling or cracking. Representative photographs depicting the damage are shown in Figure 3.

The extensive damage to the chute blocks indicated that they were indefensible against the negative pressures which were produced as the jets impinged on their surfaces. Obviously, the elliptical corners were much too sharp to prevent cavitating pressures on the vertical sides of the blocks. Modification of the stilling basin to insure the presence of relatively high noncavitating pressures on all flow surfaces was imperative.

BASIN MODIFICATIONS

Another hydraulic model was constructed to determine the cause of cavitation and to develop the necessary corrective measures. Extensive pressure measurements were obtained on the flow surfaces of the chute blocks, baffle piers, basin floor, and training walls. Oscillograms of typical pressures on the chute blocks and baffle piers are shown in Figures 4 and 5. The upper oscillograms in each figure are for the structure as initially constructed. The lower ones are for the modified design.

The model investigation confirmed the earlier conclusion that the cavitation erosion on the original chute blocks resulted from malstreamlining. In general, the tests indicated that the original chute blocks were most effective in stabilizing the hydraulic jump, but produced the lowest pressures on the surfaces. Improved pressures were obtained by increasing the curvature of the elliptical corners. The improvement was short of the desired result. The upward slope was then eliminated, making the maximum height of the block 2 feet 9 inches. These shorter blocks caused large boils of water to form above the baffle piers, requiring a higher tail water to retain the jump within the limits of the basin. Blocks with horizontal top surfaces and with a maximum height of 4 feet 10 inches were then tested. These produced a basin performance quite similar to that with the original blocks. Tests also revealed that blocks with tapered sides which conform with the diverging flow, and the top edges streamlined with an elliptical curve having its major axis, in a direction parallel to the chute floor and five times that of its minor axis presented the most favorable results. The prototype chute blocks were modified accordingly.

Although no cavitation erosion was found on the prototype baffle piers, the model study indicated that, with the modified chute blocks, cavitation pressures would likely occur on the pier surfaces. Because of this likelihood, additional streamlining was provided for the baffle piers as shown in Figure 5B. Sufficient concrete was removed from the surfaces of the piers to provide a 6-inch minimum thickness of new concrete cover. The modified piers are thus 12 inches wider and 6 inches higher than the originals.

To eliminate future erosion in the flared walls, 3-1/2-inch structural steel offsets were installed at the upstream end of the flared walls, as shown in Figure 6. Air to the offsets was provided through a 2-1/2-inch by 10-inch opening at the base and seven 2-inch-diameter holes directly above the opening. Again, the model studies confirmed this to be the best solution to the problem.

The stoplog grooves near the end of the flared walls were filled with concrete to form a continuous surface. Metal guides to replace the grooves were placed on the downstream face of the walls.

SUBSEQUENT BASIN OPERATION

Modification of the stilling basin was completed in March 1959. The powerplant was placed in operation the following May, providing from 1 foot to 1-1/2 feet of additional tail water for the stilling basin. The outlet works discharges during April and May ranged from 3,000 to 5,000 cfs, except for 6 days when the sustained discharge approximated 7,000 cfs. No thumping noises or vibrations were reported for these releases. Test releases were conducted the following June to determine the stilling basin performance for a series of discharges. Thumping was first observed when the outlet discharge (with no flow through the powerplant) reached 7,000 cfs. It persisted throughout the remainder of the tests, including 7,500 cfs through the outlet works only, and combined outlet and powerplant flows of 7,500 cfs up to 9,100 cfs. The maximum powerplant discharge was about 2,800 cfs. Following these releases, which were made by increasing the discharge in increments of 500 cfs, the outlet works test releases (with no flow through the powerplant) were repeated with discharges decreasing from 7,500 cfs to 5,000 cfs in increments of 500 and 1,000 cfs. Thumping noises and wall vibrations were noted throughout the repeat tests.

DISCUSSION OF OPERATIONAL PROBLEMS

A possible explanation for the noises and vibration is the formation and collapse of cavitation envelopes on the flow surfaces in the vicinity of the chute blocks. It is known that cavitation envelopes collapse audibly with tremendous force. This could be transmitted to the walls through either the water or the concrete floor. However, the frequency of collapse is considerably higher than that of the noise and vibration observed. The fact that no cavitation damage was reported after the 1959 irrigation season fails to support this theory, although the basin operated only a comparatively short period of time at discharges accompanied by noises and vibration.

Another explanation for the noises and vibrations is the unsteady pressure forces on the blocks caused by variations in the separation and vortex flow patterns with and without cavitation. These variable loads on the blocks may be transmitted through the structure to the wall; or the pressure variations in eddy patterns near the trailing edge of the blocks might be transmitted to the wall and initiate the vibrations. Changes in tail water elevations affect these separation and eddy patterns, which would explain why vibrations were observed during the repeat test releases and not during the earlier tests.

Piezometer taps were placed on the left training wall in the model to measure the pressure fluctuations on the wall surface. No effort was made to represent the wall rigidity or to measure the wall vibration in the model.

The greatest pressure variation, equivalent to about 45 feet of water occurred about 3 feet downstream from the chute blocks near the basin floor. The pressure variation decreased to about 20 feet of water near the downstream end of the wall and to a few feet of water near the water surface. The magnitude of these pressure variations was sufficient to cause the wall to vibrate, particularly if the frequency of the pressure variations and the natural wall frequency coincide.

The direct source and cause of the vibration in the training wall have not been determined. The structure operated satisfactorily during the 1960 irrigation with no apparent thumping or vibration.

CONCLUSIONS

The employment of large chute blocks and baffle piers in frequently operated outlet works stilling basins should be done with prudence. They should not be wholly relied upon to contain the hydraulic jump within the limits of the basin. Their use should be considered only to improve the basin's operation, as an added precautionary feature, or when absolutely necessary because of influencing physical elements.

To defend against cavitation erosion, all edges of chute blocks and baffle piers exposed to high-velocity flows should be adequately streamlined.

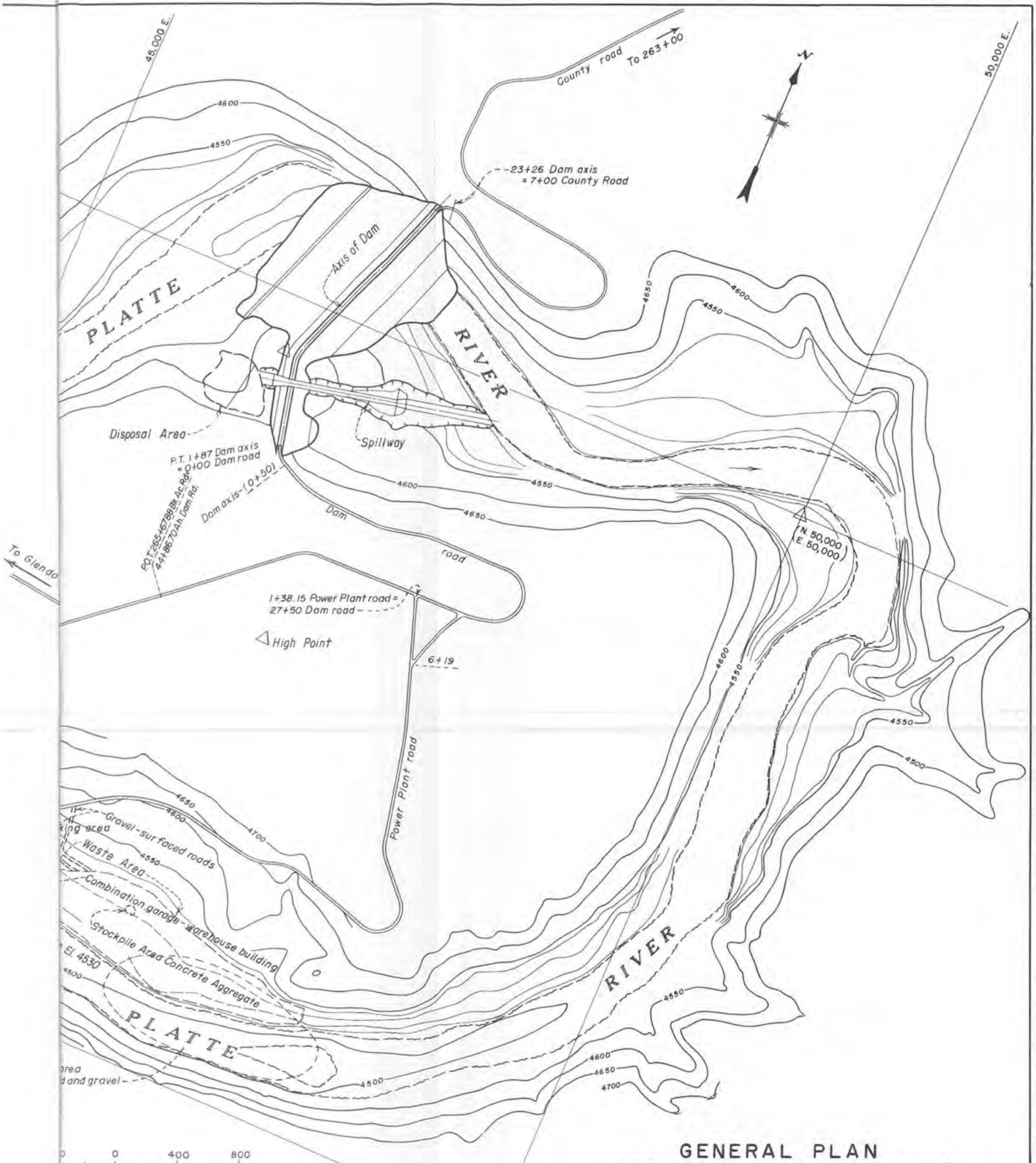
All surface irregularities which will be subjected to high-velocity flows should be eliminated.

Stoplog slots formed in concrete walls, in the path of high-velocity jets should be avoided when possible. If it becomes necessary to include such slots, their downstream corners should be offset away from the flow and the walls gradually converged back to the original alinement to insure noncavitating pressures.

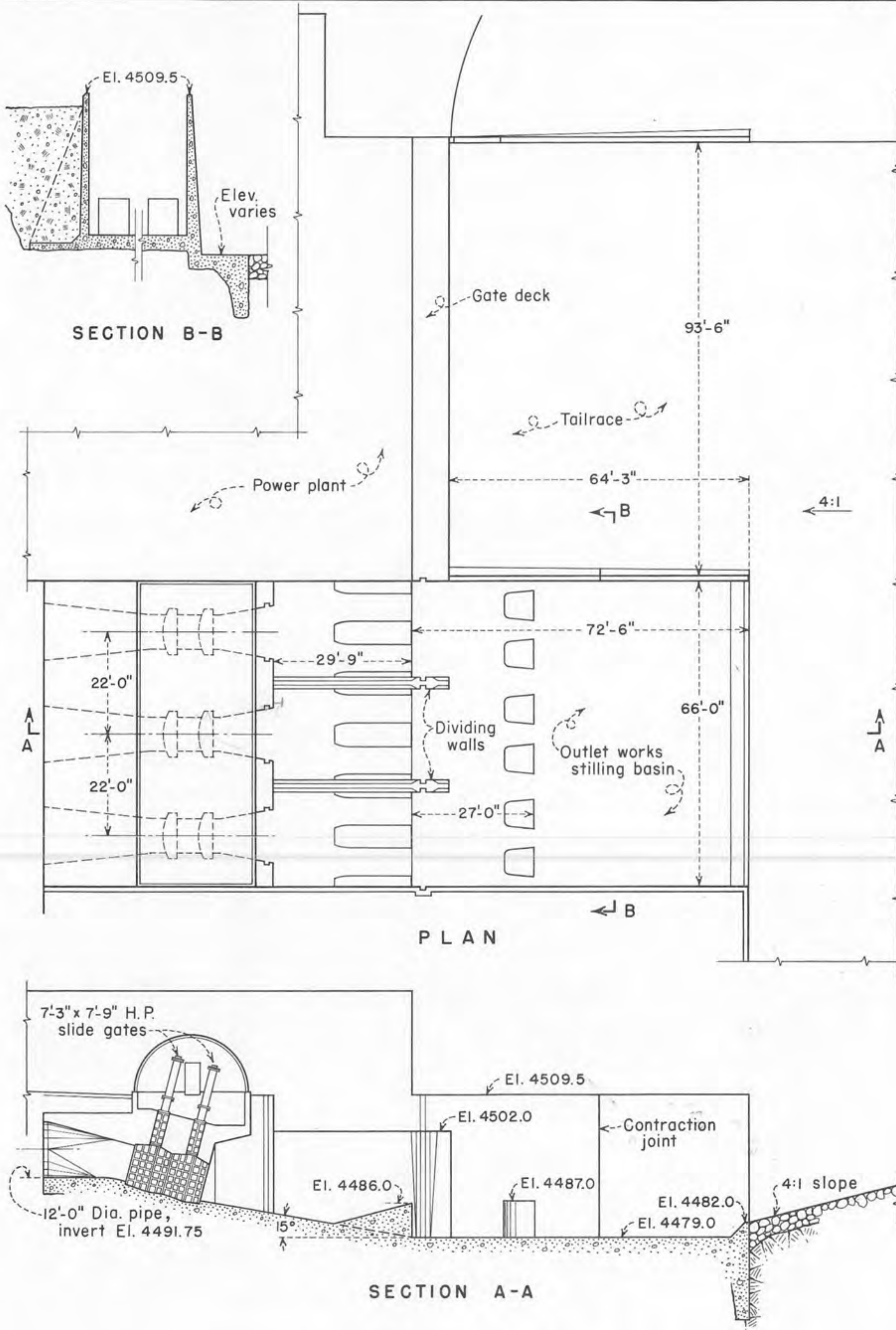
Sharp increase in divergence of training walls immediately downstream from gates producing high-velocity jets will likely result in serious cavitation erosion. This is particularly true if the jet is submerged. Changes in alinement can be accomplished by suitable rounding or by abrupt sizable offsets away from the flow, as shown in Figure 6. The admission of air may be desirable or necessary for offsets, depending upon the size of the offset.

Recent studies indicate that gates deflected downward approximately 24° permit the jets to more effectively penetrate the pool. However, the distance between the gates and the beginning of the stilling basin floor in all cases must be sufficiently long to provide lateral distribution of the water to near uniform depth.

Additional investigation will be required to determine the source and cause of the vibration in the cantilevered training wall.



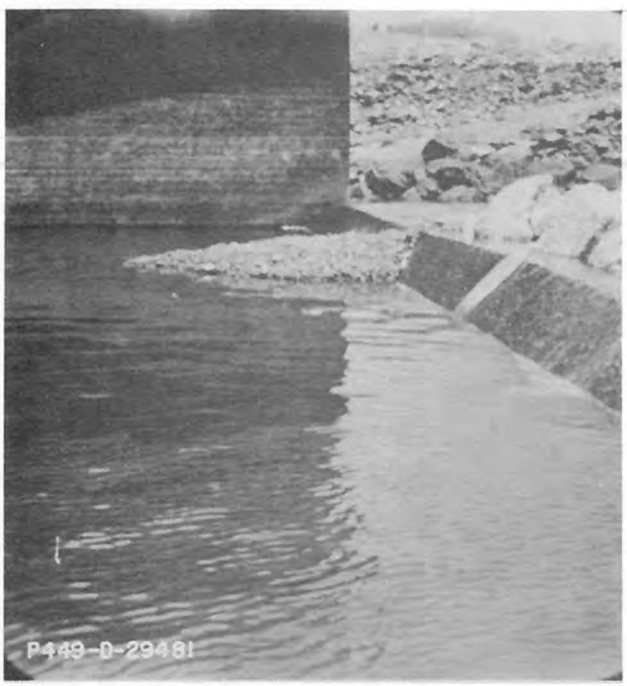
GENERAL PLAN
GLENDO DAM AND POWER PLANT



GLENDO DAM OUTLET WORKS
AS ORIGINALLY CONSTRUCTED

A. Stoplog groove on left side of Outlet No. 2.

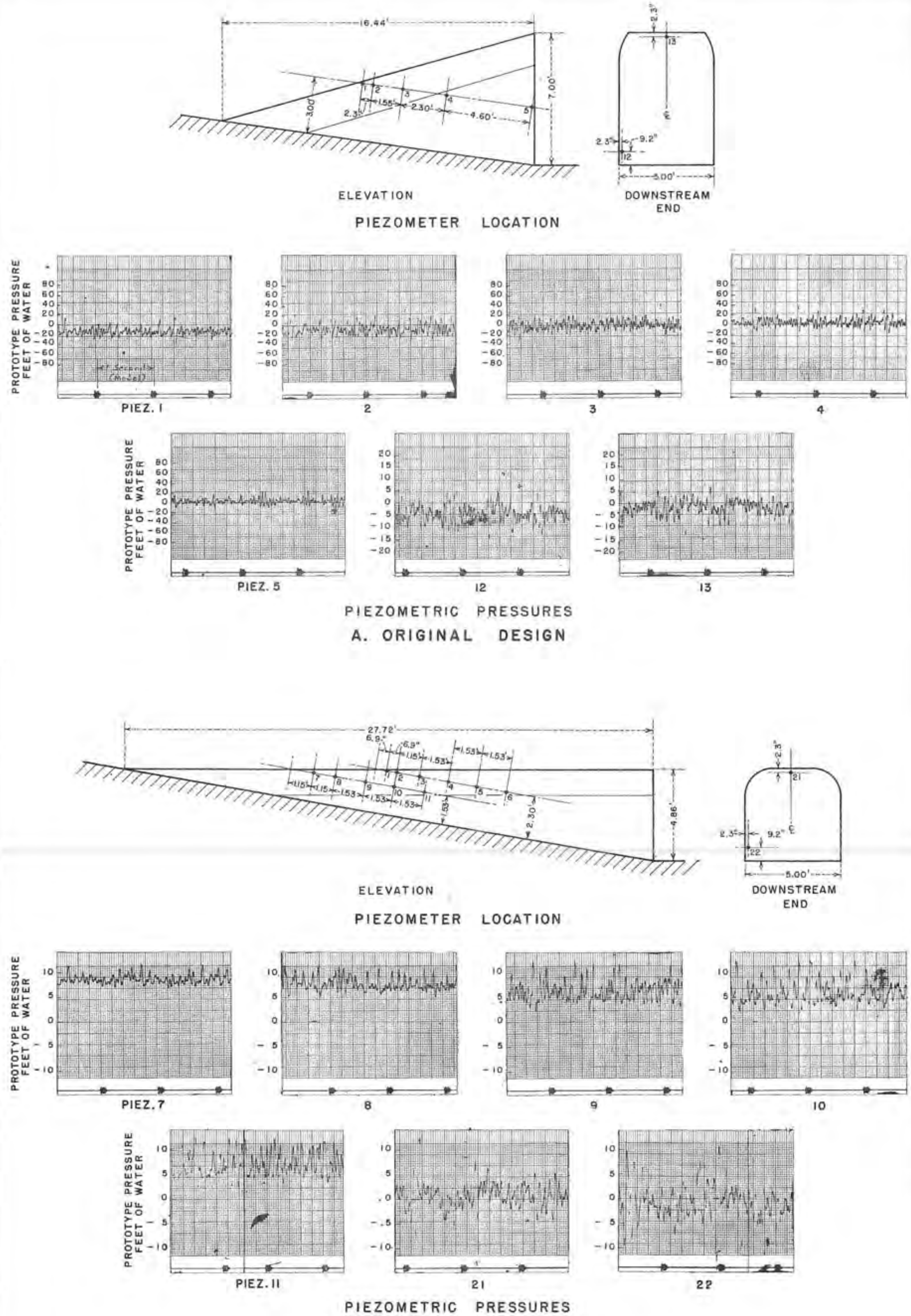
B. Left face of center chute block for Outlet No. 2.



C. View showing depression left by displaced riprap at downstream end of left stilling basin wall.

D. Right flared wall of Outlet No. 3.

GLENDO DAM OUTLET WORKS



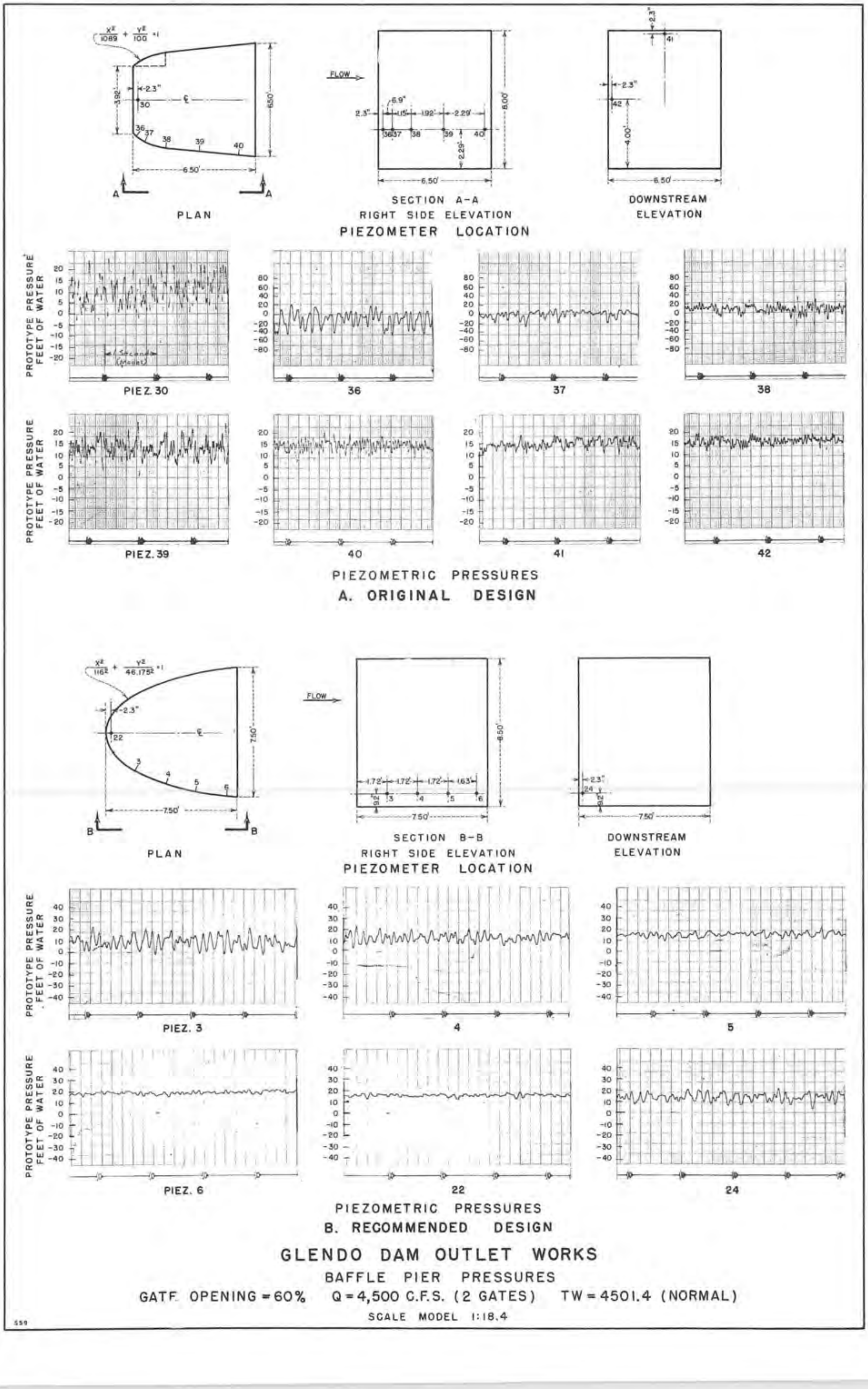
GLENDO DAM OUTLET WORKS

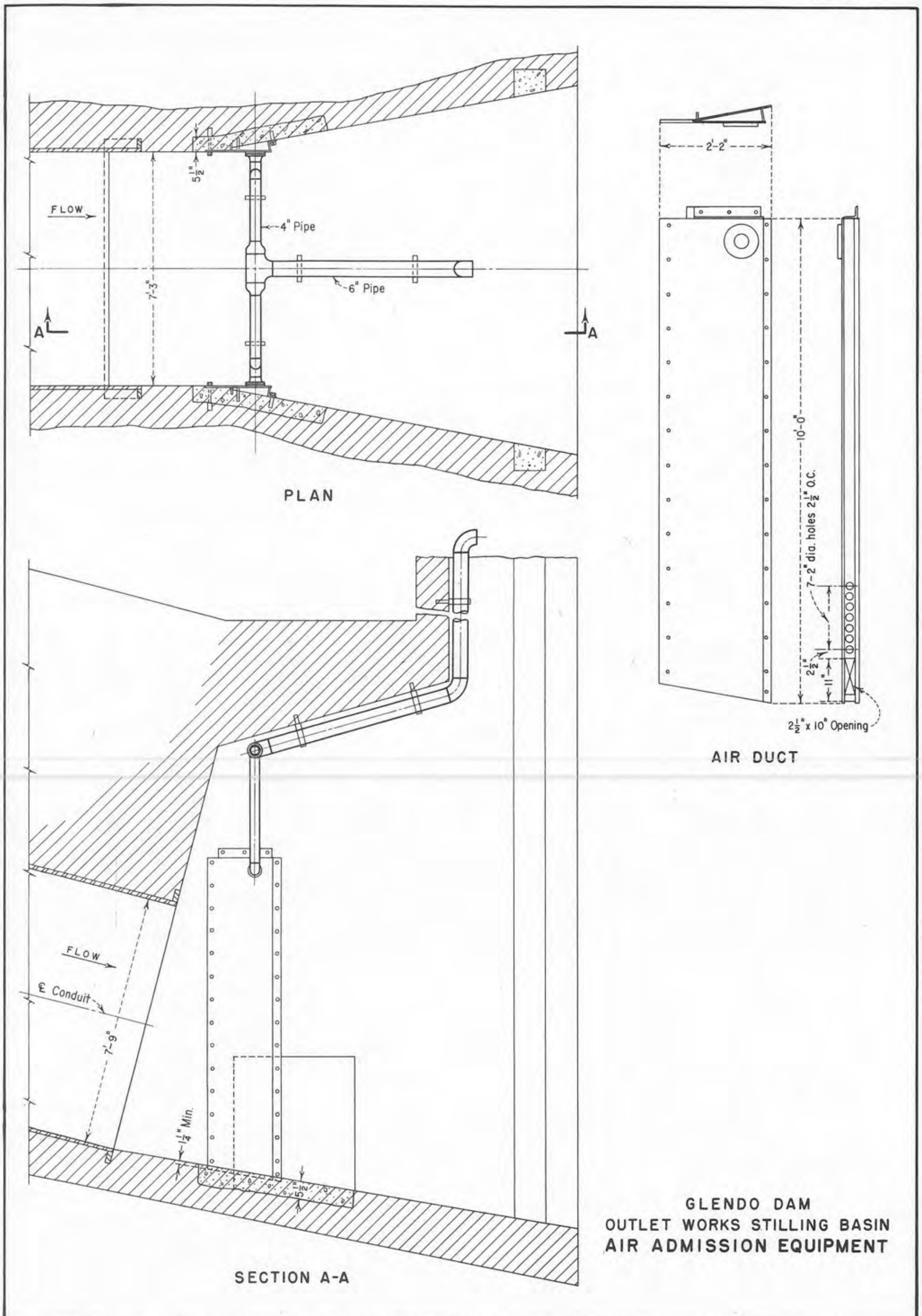
CHUTE BLOCK PRESSURES

GATE OPENING = 60% Q = 4,500 C.F.S. (2 GATES) TW = 4501.4 (NORMAL)

SCALE MODEL 1:18.4

Figure 5


FLOW
PLAN
SECTION A-A
RIGHT SIDE ELEVATION
DOWNSTREAM
ELEVATION
PIEZOMETER LOCATION
PROTOTYPE PRESSURE FEET OF WATER
PIEZ. 30
36
37
38
PIEZ. 39
40
41
42
PIEZOMETRIC PRESSURES
A. ORIGINAL DESIGN
FLOW
PLAN
SECTION B-B
RIGHT SIDE ELEVATION
DOWNSTREAM
ELEVATION
PIEZOMETER LOCATION
PROTOTYPE PRESSURE FEET OF WATER
PIEZ. 3
4
5
PIEZ. 6
22
24
PIEZOMETRIC PRESSURES
B. RECOMMENDED DESIGN
GLENDO DAM OUTLET WORKS
BAFFLE PIER PRESSURES
GATE OPENING = 60% Q = 4,500 C.F.S. (2 GATES) TW = 4501.4 (NORMAL)
SCALE MODEL 1:18.4



GLENDO DAM
OUTLET WORKS STILLING BASIN
AIR ADMISSION EQUIPMENT