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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF PORTAGE MOUNTAIN DEVELOPMENT LOW-LEVEL OUTLET WORKS BRITISH COLUMBIA, CANADA

Hydraulics Branch Report No. Hyd-562

DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

June 30, 1966

UNITED STATES
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IN REPLY
REFER TO: D-293

June 30, 1966

General Manager
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Sir:

I am pleased to submit Hydraulics Branch Report No. Hyd-562 which constitutes our final report on studies conducted on the low-level outlet works of Portage Mountain Dam. I believe you will find this report interesting and informative, and that it will satisfy the requirements of your office for a comprehensive discussion of the extensive test program.

Very truly yours,

B. P. Bellport
Chief Engineer

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ABSTRACT

Studies on a 1:14 scale model of the low level outlet works of Portage Mountain Development show the fixed-cone valve-ring deflector combination provides a relatively simple and effective device for flow control and energy dissipation. The ring deflector contributes significantly to energy dissipation. Baffle piers downstream from the deflector and a weir at the downstream tunnel portal can be added later to improve energy dissipation if necessary. The extent of the steel-lined section required downstream of the valves was determined. High fluctuating pressures were measured on the wall of the liner in the impingement area of the jet and on the upstream face of the ring deflector at the crown and invert. Pressures on the lip of the deflector were slightly subatmospheric. No uniform simultaneous peaking of pressures at widely separated areas occurred on the deflector ring. A recirculating air supply tunnel was developed to provide near atmospheric pressures within the cone-shaped jet as well as upstream of the jet at the valves. Nonsymmetrical operation of the valves is not recommended. The design discharge of 10, 000 cfs per tunnel at reservoir elevation 2125 was verified by the model operation.

DESCRIPTORS-- *outlet works/ diversion tunnels/ conduits/ tunnel plugs/ hydraulic structures/ *hydraulic models/ hydraulic jumps/ stilling basins/ *air demand/ head losses/ discharge measurement/ energy losses/ backwater profiles/ steel linings/ weir crests/ baffles/ vapor pressures/ cavitation/ *energy dissipation/ water surface/ erosion/ tunnel linings/ oscillographs/ transducers/ laboratory tests
IDENTIFIERS-- *jet flow gates/ tunnel transitions/ fixed-cone valves/ ring deflectors/ subatmospheric pressures/ Portage Mtn Dvlpmt, Can/ bell-mouthed entrances/ British Columbia, Canada

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Office of Chief Engineer
Division of Research
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Laboratory Report No. Hyd-562
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HYDRAULIC MODEL STUDIES OF PORTAGE MOUNTAIN DEVELOPMENT LOW-LEVEL OUTLET WORKS BRITISH COLUMBIA, CANADA

PURPOSE

This study was undertaken to develop a satisfactory method of dissipating the energy of the high-velocity flow in the low-level outlet works, and to determine the hydraulic flow characteristics of the structure.

CONCLUSIONS

1. In the preliminary design hydraulic jumps formed in the baffled area and in the tunnel for discharges obtained at reservoir elevations up to 2000. Above reservoir elevation 2000 the jump in the baffled area swept out and shooting flow with large turbulent boils or waves was present, Figures 10 and 11.

2. Additional baffle piers improved the energy dissipation, but did not force a hydraulic jump in the baffled area. A 14-foot-high weir at the downstream tunnel portal was necessary to provide sufficient tailwater to retain a hydraulic jump in the baffled area, Figure 14.

3. A 43-foot-diameter barrel replacing the preliminary 40-foot-diameter barrel and an off-center position for the air inlet made no significant changes in the energy dissipation or air demand. However, a slight instability or flutter in the jet emerging from the deflector ring was noticed. Reducing the height of the ring deflector from 6 to 4-1/2 feet stabilized the jet and slightly increased the air demand.

4. A 15-foot-high weir at the portal provided sufficient tailwater for a good hydraulic jump and smooth flow conditions with the larger barrel, smaller deflector, and with the number of baffle piers reduced from 15 to 8.

INTRODUCTION

Portage Mountain damsite is located in the Peace River Canyon in northern British Columbia 480 miles north of Vancouver and 80 miles west of Dawson Creek. The nearest community is Hudson Hope, approximately 11 air miles from the site. The nearest center of communication is Fort St. John, approximately 55 air miles east of the site. The map of the catchment area (Figure 1) shows some of the above-mentioned geographical locations.

The general arrangement of the development is shown in Figure 2. The zoned earthfill dam has a 6,700-foot-long crest at elevation 2230 and rises 600 feet above the riverbed. A radial gate controlled spillway is located on the right abutment. An underground powerplant is in the left abutment upstream of the diversion tunnel outlets. Diversion of the Peace River during construction of the dam will be effected by means of three 48-foot-diameter horseshoe-shaped concrete-lined tunnels located in the right abutment. Ultimately, the diversion tunnels will be plugged and two will be converted to serve as low-level outlets during and after the reservoir filling period. The third tunnel will serve for access to the remaining two by means of transverse tunnel connections, Figure 3.

The low-level outlets will be placed in the tunnel plugs and are designed to control the reservoir level and to provide minimum flows in the Peace River during the initial reservoir filling; after completion of the dam their function will be reduced to standby duty as emergency outlets.

The diversion works include the intake approach channel; the three 48-foot-diameter, concrete-lined, horseshoe-shaped diversion tunnels together with their intakes; outlet transitions; and outlet channels, as shown in Figure 3. The intake approach channel, located in the right bank of the river about 1,800 feet upstream from the axis of the dam, is divided into three separate channels by shoulders of rock left in situ.

THE MODELS

Two models were used in the study. The first was built to develop an outlet works using jet-flow gates for flow control; and the second was used for the development of an outlet scheme utilizing fixed-cone valves (Howell-Bunger type). Fixed-cone valves were adopted for the prototype installation and the development of an adequate energy dissipator is the subject of this report. The scheme utilizing the jet-flow gates is discussed briefly in the appendix.

The model for the fixed-cone valve scheme (Figure 4) was a 1:14 scale reproduction of a portion of Diversion Tunnel 2 from the tunnel plug to a point 472 feet downstream of the plug. The model included about 58 percent of the true length of the 84-inch outlet conduits through the tunnel plug. The bellmouth entrances were studied and found to be satisfactory in the initial model, and were not rebuilt for the second model but were represented by cone-shaped transitions. The shortened tunnels and cone-shaped transitions were provided to insure that the head at the valves would equal or exceed the equivalent prototype head. The two Howell-Bunger valves were constructed from brass; one valve was available in the laboratory and the second was built from the same plans. These valves had four vanes supporting the center dispersion cone. Information received near the end of the studies revealed that the prototype valves would probably have six vanes. It is believed that this difference will cause only minor variations in the flow pattern.

The model was initially operated with air supplied directly from the atmosphere through a 12-foot-diameter air inlet located in the tunnel directly above the valves. However, before any extensive air demand measurements were made, the complete 12-foot-diameter recirculating air tunnel was installed as shown in Figure 4. Three different sized circular orifices were used in the air tunnel to measure the air demand.

Flow was supplied to the model by means of the laboratory's permanent pumping system; discharges were measured by calibrated Venturi meters permanently installed in the laboratory supply system. The operating head (or reservoir elevation) was measured one tunnel diameter upstream from the plug by means of a differential mercury manometer. Flow depths in the downstream tunnel were controlled by an adjustable tailgate at the downstream end of the model tunnel and were measured by a staff gage at Station 13+67, approximately 401 feet downstream from the tunnel plug.

THE INVESTIGATION

Introduction

The investigation was primarily concerned with dissipating the energy in the flow from the outlet works control valves. Studies of the flow characteristics in the bellmouthed conduit entrances were conducted in the model of the jet-flow gates (see Appendix).

Principally, the studies were conducted with both valves discharging simultaneously at maximum capacity of approximately 5, 000 and 5, 500 cfs each at reservoir elevations 2125 and 2225. However, investigations were also made with partial valve openings for flows as low as 2, 500 cfs per valve at reservoir elevation 2125, and with fully open valves operating at all reservoir elevations ranging from 1, 700 to 2, 200 feet. Single-valve operation was also studied.

Tests on the 1:24 scale model using the jet-flow gate control had indicated that an extensive stilling basin would be necessary to effectively dissipate the flow energy, or that a major portion of the diversion tunnel should be reinforced with a thicker concrete lining. Therefore, the jet-flow gates were abandoned and a second scheme utilizing fixed-cone (Howell-Bunger type) valves with a ring deflector similar to the design for the Oroville Dam outlet works1/ was adopted. This arrangement permitted energy dissipation to be effected in a relatively short distance between the valves and a ring deflector in a steel-lined barrel section.

Preliminary Design

Description. --Two 84-inch fixed-cone valves discharged into the diversion tunnel from two 84-inch-diameter conduits that passed through the tunnel plug. The conduits were 3.5 feet above centerline of the diversion tunnel and were spaced 19 feet apart. A 40-foot-diameter reinforced concrete barrel lined with steel plate extended for a distance of 63 feet downstream from the tunnel plug, Figure 5. The lower half of the liner extended downstream for an additional 31 feet, and a quarter segment on the invert another 65 feet.

A 4.5-foot-high ring deflector was located 42 feet downstream from the tunnel plug and two rows of five baffle blocks each were located 80 and 145 feet downstream from the plug. The baffle blocks extended to a height of 11.5 feet above the tunnel invert.

Operating conditions. --The tests were made under the following operating conditions:

Tailwater conditions	Reservoir elevations	Valve opening
Curve A (Figure 6)	1690-1770	Fully open only
	1770-2000	Fully open down to 2,500 cfs/valve
	2000-2125	Fully open to close
Curve B (Figure 6)	1690-1770	Fully open only
	1770-2000	Fully open down to 2,500 cfs/valve

Curve A represented completed project conditions when the invert at the tunnel outlet portal, elevation 1640, controlled the upstream tailwater level. Since only a portion of the tunnel was reproduced in the

1/"Hydraulic Model Studies of the River Outlet Works at Oroville Dam - California Department of Water Resources - State of California," Report No. Hyd-508, D. Colgate.

model, stage-discharge relationships (backwater curves) in the tunnel upstream to Station 13+67 were computed for this type of control, Figure 6. Backwater curves obtained from the computations indicated that the slope of the tunnel was supercritical and a hydraulic jump would form downstream from the 40-foot-diameter liner. Therefore, Curve A provided a shooting flow tailwater condition downstream from the liner.

Curve B represented high tailwater conditions estimated to exist in the river during a temporary construction phase when the river channel was partially blocked. The tailwater elevation at Station 13+67 in the tunnel was assumed to be level with that in the river channel for this condition, Figure 6.

Discharge capacity. --For the initial model operation, the discharge capacity of the valves was determined for 25-, 50-, 75-, and 100-percent gate openings and related to the reservoir elevation measured in the model tunnel upstream of the tunnel plug, Figure 7. These capacities were expected to be slightly greater than would occur in the prototype since all of the head loss was not represented in the model. In the initial studies, 10, 300 cfs was discharged at reservoir elevation 2125 with the gates fully open. In the final capacity tests, with the computed operating head measured 1 diameter upstream of the valves, the discharge proved to be 10, 000 cfs.

Flow characteristics. --For tailwater Curve A, Figure 6, two hydraulic jumps occurred in the tunnel downstream from the deflector ring for all test discharges obtained at reservoir elevations up to 2000, Figures 8, 9, and 10. One jump occurred in the baffled area in the 40-foot-diameter liner and the other in the 48-foot-diameter horseshoe tunnel.

At reservoir elevation 2125 with the valves fully open, discharging about 10, 300 cfs, the jump occurred only in the tunnel. The jump in the baffled area swept out and a large boil or surge occurred over each of the two sets of five baffle piers, Figure 11. Similar conditions occurred with the valves 50 percent open and discharging approximately 7, 100 cfs at reservoir elevation 2125.

For tailwater Curve B, Figure 6, a hydraulic jump formed in the baffled area of the 40-foot liner and tranquil flow existed in the downstream tunnel with the valves fully open and reservoir elevations 1690 to 1770, and for flows of 5, 000 to 8, 600 cfs at various valve openings and reservoir elevations ranging from 1770 to 2000 feet. The energy dissipation was quite satisfactory, Figures 8, 9, and 10. It was not anticipated that the outlet works would discharge at reservoir elevations above 2000 with Curve B tailwater; therefore, higher reservoir elevations were not tested in the model.

Air demand. --The air demand at the valves in the 40-foot-diameter barrel liner was measured initially with air supplied directly from outside the tunnel, and later with the air supplied through a recirculating tunnel as previously described. No significant differences in the quantity of airflow could be detected from either source of supply.

A maximum air velocity of 300 feet per second is normally used as a design criterion to keep below the "whistling" range. The head differential required to create an air velocity of 300 feet per second is about 1.5 feet of water. Assuming an entrance, line, and exit head loss in the air duct of 0.5 foot, a maximum subatmospheric pressure of 2 feet of water was permissible in the tunnel around the valves. The air demand was approximately 7,000 cfs for valve openings of 50-, 75-, and 100-percent when the pressures at the valves was about 2 feet of water below atmospheric, Figure 12. Tailwater elevation did not affect the air demand unless the tailwater was extremely high, such as tailwater elevation 1675, and then only a very negligible amount.

Based on a maximum air demand of 7,000 cfs, a 6-foot-diameter flat-bottom horseshoe tunnel would provide sufficient area for a velocity of about 220 feet per second. Since the accurate prediction of prototype air demand by the use of scaled models has not been proven, it was desirable to provide a sufficiently large tunnel to maintain the air velocity well below the "whistling" velocity of 300 feet per second. Therefore, a 10-foot-diameter flat-bottom horseshoe tunnel was chosen which provided a theoretical velocity of less than 80 feet per second when the airflow was 7,000 cfs.

The inlet to the recirculating air tunnel appeared to be sufficiently far downstream to prevent splash and spray at the baffle blocks from entering the air tunnel or interfering with the intake of air.

A curtain wall extending from the water surface to the crown of the tunnel was installed at the downstream end of the model to simulate a prototype curtain at the portal that might be used to prevent extremely cold outside air from entering the tunnel. This curtain slightly reduced the air demand.

Second Design

New design requirements. --At this stage of the investigation, the design criteria were modified such that the outlet works might be required to operate with the valves fully open at reservoir elevation 2225, or 100 feet higher than originally specified. In addition, tailwater Curve B in Figure 6 was eliminated as an operating condition.

Description. --Twenty-four different arrangements of the baffle piers and ring deflector were tested in arriving at the arrangement of the second design shown in Figure 13. The design was essentially the same as the preliminary design except that five additional baffle piers were installed and the baffle piers in the upstream row were rearranged.

Flow characteristics. --At reservoir elevations 2125 and 2225 with the valves fully open, this arrangement provided considerable energy dissipation with a minimum amount of splash and high boils for the Curve A tailwater operating conditions. However, the additional blocks failed to create a hydraulic jump and shooting flow existed in the baffled area.

Tailwater requirements. --Tests were made to determine the tailwater depth required at Station 13+67 to bring the toe of the hydraulic jump to three locations in the tunnel: (1) the downstream side of the downstream row of baffles; (2) just upstream of the downstream row of baffles; and (3) at the downstream end of the half liner, Figure 14. These tests were conducted with gate openings of 35-, 50-, 75-, and 100-percent for a range of reservoir elevations from 1690 to 2225.

Computations based on these tailwater tests indicated that a 14-foot-high, unobstructed weir at the tunnel portal, with its crest at elevation 1654, would provide sufficient tailwater depth to maintain the toe of the jump upstream of the downstream row of baffles, Figure 14.

Third Design

Description. --The diameter of the barrel liner at the downstream end of the plug was increased from 40 to 43 feet for structural reasons. The elevation and spacing of the fixed-cone valves were not changed. The cross-sectional height of the ring deflector was increased from 4.5 to 6 feet, while maintaining the inside diameter at 31 feet. The upstream toe of the ring deflector was located at the same station as in the preliminary design. The number, height, and location of the baffles were not altered.

The 12-foot-diameter air vent with its inlet at the same tunnel station, was rotated to a position 45° to the right of the tunnel crown, and terminated in an 8- by 10-foot rectangular duct tangent to the tunnel crown at the valve chamber.

Flow characteristics and tailwater depth requirements. --There was no significant difference in energy dissipation or tailwater depth requirements from those observed in the second design. The principal difference in the flow conditions was a slight instability or flutter of the flow emerging from the ring deflector.

Air demand. --Neither the larger barrel liner nor the relocation of the air tunnel inlet caused significant change in air demand over the preliminary design.

Fourth Design

Description.--Approximately 18 modifications to the third design, including different arrangements of baffle piers, ring deflector size and location, and valve spacing, were tested in arriving at the fourth design. As a result of these tests and other design considerations, four major changes were adopted, as follows, Figure 15:

a. A 15-foot-high weir (not shown in Figure 15) was proposed at the downstream tunnel portal.

b. The number of baffle piers was reduced from 15 to 8.

c. The cross-sectional height of the ring deflector was reduced from 6 to 4.5 feet, thereby increasing the inside diameter of the ring from 31 to 34 feet.

d. The spacing between the valves was increased from 19 to 21.5 feet for structural reasons: the elevation was not changed.

e. The air vent supply tunnel was relocated to a position directly above the tunnel crown.

Flow characteristics.--The deeper tailwater provided by the 15-foot-high weir at the portal, Figure 16, maintained the hydraulic jump in the baffled area and eliminated the need for the large number of baffle piers that were required in previous arrangements. However, eight baffle piers, five in the downstream row and three in the upstream row, were still used primarily to stabilize the hydraulic jump. The hydraulic jump was a little farther downstream with the fewer number of baffle piers. However, a good hydraulic jump formed in the baffled area with a fairly smooth water surface in the downstream tunnel, particularly with the valves discharging fully open at reservoir elevation 2125. Discharges at reservoir elevation 2225 caused considerable turbulence, but the operation was believed to be satisfactory for this infrequent operating condition.

The reduction in the height of the ring deflector improved the stability of the jet and reduced the flutter, and small spurts of water from the jet only occasionally splashed against the walls of the tunnel. However, due to the smaller obstruction offered by the deflector, the hydraulic jump formed a little farther downstream in the tunnel.

Tailwater depth requirements.--Tailwater elevations necessary to maintain the hydraulic jump at three different locations in the baffled area were determined from the model, for 50-, 75-, and 100-percent valve openings. Tailwater elevations were determined (1) with the toe of the hydraulic jump just upstream of the downstream row of five baffles,

(2) with the toe of the jump near the upstream end of the upstream baffles, and (3) with the toe of the jump near the 43-foot-diameter barrel.

The tailwater depth required to maintain the jump at the first location was the minimum to prevent a jump from forming downstream from the baffled area; any tailwater elevation that equaled or exceeded this minimum requirement provided satisfactory flow conditions in the baffled area and in the downstream tunnel. Tailwater depths required to place the jump at the second location were preferred, inasmuch as these depths provided a large margin of safety that would permit these depths to be reduced, or exceeded, by approximately 3 or 4 feet and still hold the jump in the baffled area. The pool that formed beneath the valves never submerged the valves with the jump at any of the three locations.

Water surface fluctuations at Station 13+67 in the tunnel were recorded for the minimum tailwater elevations, Figure 16. The maximum fluctuation from peak to trough was approximately 4.5 feet with the valves fully open at reservoir elevation 2225. The amplitude of the fluctuation for any specific discharge did not vary noticeably with tailwater depth.

Pressures. --Pressures on the baffle piers were recorded for the design tailwater, assuming the use of the proposed 15-foot weir, and for no tailwater, assuming no weir at the portal and no hydraulic jump in the baffled area.

Piezometer locations and water manometer pressures are shown in Figures 17 and 18. Neither tailwater elevation nor discharge had any significant effect on the pressures observed on the upstream baffle when the valves were discharging at reservoir elevation 2125 or greater, Figure 17. However, on the sides and top of the downstream baffle the pressures were lower with no tailwater than with the design tailwater. Lower pressures also were observed for either tailwater condition when the reservoir was increased from elevation 2125 to 2225.

The lowest pressures on the upstream baffle occurred near the elliptical upstream corners on the baffle 5.75 feet above the floor. The lowest pressures on the downstream baffle were also observed at the elliptical corners but were near the bottom of the baffle. The lowest observed pressures were about 8 feet of water below atmospheric on both upstream and downstream baffles.

A representative group of the more critical pressures that indicated low subatmospheric, high impact, or large fluctuations in pressure were further evaluated using pressure transducers and a direct writing oscillograph. The dynamic pressures interpreted from these oscillograph recordings are tabulated in Figure 19 and some are plotted in Figure 20 for comparison with the water manometer pressures.

The maximum and minimum dynamic pressures recorded in Figure 19 were chosen so that the pressure was within these limits at least 95 percent of the time. For example, Figure 20 shows that the dynamic pressure at Piezometer No. 10 fluctuates from 5 feet of water above atmospheric to 17 feet below atmospheric, or a range of 22 feet, as compared to a range of about 2 feet as measured by the water manometer. Extreme maximum and minimum pressures were also recorded to show the extremes to which the dynamic pressures occasionally fluctuated, Figures 19 and 20. The extreme fluctuations for Piezometer No. 10 were from 30 feet of water above atmospheric to vapor pressure. The frequency of dynamic pressure fluctuations and the number of these fluctuations that reached or exceeded the maximum and minimum pressure limits, including hesitations and minor reversals in the pressure trace, were recorded, Figure 19. Only a small percent of the fluctuations reached or exceeded the limits; for example, at Piezometer No. 10, for a discharge of 10, 300 cfs with either high or low tailwater, the average number of fluctuations was 8 per second while the average number that reached or exceeded the maximum and minimum limits was 1. 2 per second. Pressures that reached the vapor pressure at any piezometer occurred less than 1 percent of the operating time.

Air demand. --The smaller ring deflector approximately doubled the subatmospheric pressure in the valve chamber, which increased the air demand. However, for a chamber pressure of 2 feet of water, below atmospheric, the maximum air demand only increased from about 7, 000 cfs to about 9, 000 cfs. At 100- and 50-percent valve openings, the air demand increased to approximately 8, 000 cfs, Figure 21.

The larger air demand increased the computed velocity in the 10-foot horseshoe tunnel from about 80 to 100 feet per second, which is still well below the 300 feet per second limit recommended for design purposes.

Other Design Modifications

Tests were also made with the valves raised 14.75 inches to 4.73 feet above the tunnel centerline and, at the same time, with the valve spacing reduced from 21. 5 to 19. 43 feet. This arrangement provided a more stable jet emerging from the ring deflector and a good hydraulic jump. (This arrangement was tested prior to increasing the inside diameter of the ring deflector; subsequent tests indicated that the larger inside diameter ring deflector also stabilized the jet, making it unnecessary to raise the valves.) Tailwater depths under the valves were greater with the valves in the higher position. Air demand was slightly more than in the third design but slightly less than in the fourth design.

Cone-shaped fillets placed under the valves, Figures 22 and 23, similar to those used at Dokan Dam in Iraq, proved to be of no value. The fillets increased the instability of the jet emerging from the ring deflector, particularly when used with the smaller inside diameter ring deflector. The fillets prevented the pool of water from forming under the valves, and appeared to increase the force of the jet striking the lower half of the ring deflector, causing the jet leaving the ring to spurt intermittently upward and impinge on the crown of the tunnel. Since the ring deflector prevented the formation of a pool of water that might submerge the valves at high tailwater, fillets for this purpose at Portage Mountain were unnecessary. The air demand was not significantly changed by the fillets.

Final Model Design

General.--A review of the operating history of the project indicated that the prototype tunnels had discharged river diversion flow at velocities up to 55 feet per second with no apparent damage to the original tunnel lining. It was conceivable that the baffle piers and portal weir of Design 4 could be eliminated in the final design if velocities in the outlet works flows did not exceed this value. Therefore, tests were made to determine the flow characteristics without the baffle piers or ring deflector. From these tests it was concluded that the fixed-cone valve-ring deflector combination without baffle piers provided a relatively simple and effective low-level outlet device for flow control and energy dissipation. Under the maximum gross head at Portage Mountain Dam, and with full open valves discharging about 11,000 cfs per tunnel, the energy would be dissipated approximately as follows:

In tunnel and conduits upstream of valves	120 feet
From valves to a point 100 feet downstream of ring deflector.	390 feet
In low energy jump in tunnel	15 feet
	525 feet

Assuming a 25-foot flow depth in the tunnel, the total remaining energy would be about 27 feet.

Flow characteristics.--Flow depths were measured, and the velocity and energy in the flow computed at Station 13+67 assuming no weir control at the downstream portal. The measurements were made with and without the baffles and also with and without the ring deflector, Figure 24.

With the baffles and ring deflector removed, and operating with the valves 100-percent open at reservoir elevation 2125, the portion of the jet emerging from the crown of the barrel liner followed a trajectory which reached the invert about 200 feet downstream of the valves, i.e., beneath the air-circulating tunnel inlet, Figure 25. From this point the extremely turbulent flow shot downstream at a velocity estimated at over 70 feet per second, or considerably higher than the velocities realized during the diversion flows (accurate measurement of the model water depth and velocity was difficult because of the turbulence and fluctuating water surface). The total energy head at this velocity and flow depth exceeds 80 feet and the jump would be swept from the tunnel. This test showed conclusively that the ring deflector was essential to intercept the jet flowing along the walls of the barrel liner, to deflect it inward on itself, and to direct it downward toward the tunnel invert.

With the baffles removed and the ring deflector in place the velocity downstream was only 45 feet per second for valves fully open discharging 11,300 cfs. The corresponding energy head was about 39 feet, as compared to the gross head of 550 feet. Under these conditions, a low energy jump, with downstream depth about 25 feet, formed in the tunnel.

With all eight baffles in place in addition to the ring deflector, the velocity was reduced to approximately 38 feet per second for both valves fully open discharging 11,300 cfs. The total energy head was about 32 feet as compared to 39 feet with the baffles removed.

As a result of these tests it was concluded that the ring deflector was essential in reducing the velocity and energy in the flow but that the baffles did not significantly increase the energy dissipation. It was also concluded that formation of the hydraulic jump in the steel-lined section was not necessary and therefore, the 15-foot-high weir at the tunnel portal could be omitted. However, after the reservoir filling period, the tunnel inverts should be inspected for damage and the need for portal weirs and baffle piers should be reassessed at that time.

Tailwater requirements.--The tests, as discussed above, showed that the baffle piers and portal weirs were unnecessary for satisfactory energy dissipation, and that a low-energy jump will form in the downstream tunnel. However, should tunnel damage occur as the result of the low-energy jump, a weir crest at the tunnel portal could be installed to provide sufficient tailwater to move the jump location to the lined section. The tailwater depth at Station 13+67 required to accomplish this without the addition of baffles is shown in Figure 26 for two different jump locations. If at that time it is also decided to use eight baffles arranged as shown in Figure 15, the tailwater depth requirements are shown in Figure 16.

Water surface profiles.--Water surface profiles through the lined section downstream from the ring deflector were obtained for 11,000 cfs to determine the necessary length and height of the 43-foot-diameter liner, Figure 27. The tests showed that the 65-foot-long quarter liner along the invert should be replaced with a 52-foot-long liner in the lower half of the tunnel.

A long sloping fillet diverging from the end of the 43-foot-diameter half liner to the 48-foot-diameter horseshoe tunnel was considered but not tested. The velocity of the downstream end of the liner was estimated to be 40 feet per second; it was believed that adverse pressures would be more likely to occur with a fillet than with the offset at the end of the liner. Abrasion damage at the offset is not likely since debris is not expected to be present in the flow. It is important that all foreign material be removed from the tunnel before the outlets are placed in operation.

Final Design Operation

The final design evolved from this series of tests resulted in a simple and effective energy dissipating system consisting of the 4.5-foot-high ring deflector in the 43-foot-diameter barrel liner and an 83-foot-long semicircular extension of the liner along the invert downstream from the deflector, Figures 28 and 29; the baffle piers and portal weir were eliminated.

Flow conditions in this structure were satisfactory over the full range of discharges and reservoir elevations, Figures 30 to 33.

Pressures.--Pressures on the walls of the barrel liner, and on the ring deflector were recorded during operation with full open valves discharging 10,300 and 11,500 cfs. Data were obtained first by means of water manometers, Figures 34 and 35. Piezometers No. 2 and 3 in the liner were located in the impingement area of the jet from the left valve. Piezometer No. 1 located immediately upstream of the impingement area, and Piezometers No. 4, 5, and 6 were on the downstream side. Piezometer No. 7 was located in an impingement area of a fin of water caused by one of the structural ribs on the valve cone.

The geometry of the impingement areas and to some extent the magnitude of the pressures were not truly represented in the model, inasmuch as there were only four structural ribs in the model valves as compared to six in the prototype. However, the piezometers were located in areas of maximum impact pressures, and the maximum recorded pressures can be used as a guide for prototype design purposes.

The pressure at Piezometer No. 2 for the two discharges averaged approximately 133 and 161 feet of water, respectively, and fluctuated tremendously as discussed later. The pressure at Piezometer No. 3 was about 90 feet less than at No. 2 and the pressure at Piezometer No. 7 was much less than at either of these two, Figure 34. Just upstream from the impingement area at Piezometer No. 1 and downstream at Piezometers No. 4, 5, and 6, pressures were near atmospheric.

Pressures on the upstream side of the ring deflector were highest near the base of the deflector at the crown and invert of the barrel liner, Figure 35, and fluctuated considerably. At Piezometer No. 1 (nearest the crown) the average pressures were approximately 112 feet and 86 feet of water for discharges of 11, 500 and 10, 300 cfs, respectively.

The average pressure at Piezometer No. 15, near the upstream edge of the horizontal lip of the ring deflector on the invert, was slightly below atmospheric and fluctuated to as much as 7 feet of water below atmospheric at 11, 500 cfs. Pressures on the downstream side of the ring deflector were atmospheric or above.

A representative group of the more critical pressure readings that indicated low subatmospheric, high impact, or large fluctuations in pressure on the ring deflector and walls of the liner were further evaluated using pressure transducers and a direct writing oscillograph. The dynamic pressures interpreted from these oscillograph recordings are tabulated in Figure 36.

The dynamic maximum and minimum pressures tabulated in Figure 36 were not exceeded more than 5 percent of the time. Extreme maximum and minimum pressures are also tabulated to show the extremes to which the dynamic pressures occasionally fluctuated. It is believed that the maximum and minimum limits chosen are conservative.

For comparison of the dynamic pressure fluctuation with the water manometer pressure fluctuation the following two examples are cited: at Piezometer No. 15 on the lip of the ring deflector at the tunnel invert, the dynamic pressure fluctuated from about 22 feet of water below atmospheric to 14 feet above, with extremes as low as vapor pressure and as high as 44 feet above atmospheric; the water manometer measurement had shown fluctuations from atmospheric pressure to 7 feet below atmospheric. At Piezometer No. 2 in the jet impingement area on the wall liner, the dynamic pressure fluctuation ranged from 28 feet of water to approximately 378 feet of water above atmospheric for 11, 500 cfs with extremes from 30 feet below atmospheric to 476 feet above atmospheric compared to a maximum water manometer fluctuation of about 70 feet of water. This wide fluctuation in pressure at Piezometer No. 2 possibly is due in part to a quiver or movement in the location of the impingement area of the jet on the model walls. The reason for the quiver is not known.

The frequency of the dynamic pressure fluctuations, and the frequency at which these fluctuations reached or exceeded the maximum and minimum dynamic pressure limits, including hesitations and minor reversals in the pressure trace, are tabulated in Figure 36. Only a small percentage of the fluctuations reached or exceeded the limits. For example, at Piezometer No. 2 in the jet impingement area on the wall, the average number of fluctuations per second was about 15 and the average number reaching either limit ranged from 0.9 to 3.2 for discharges of 10,300 and 11,500 cfs.

The high-frequency dynamic pressure vibrations could easily be felt on the 1/4-inch-thick plastic wall of the model barrel liner upstream of the ring deflector. A much lower frequency vibration could be seen and felt on any part of the model tunnel downstream from the ring deflector. Dynamic pressures were recorded simultaneously at eight piezometers shown in Figure 37 to determine if simultaneous peaking of the pressures occurred. Six of the piezometers were at two different cross section locations in the ring deflector; the seventh was a probe extending through the wall of the barrel liner into the interior of the hollow cone-shaped jet; and the eighth piezometer was located in the wall of the barrel liner upstream of the jet. The latter two piezometers measured the ambient pressure in the hollow portion of the cone jet and in the valve chamber rather than waterflow pressure.

These simultaneous recordings were obtained for discharges with the valves fully open for reservoir elevations 1800, 1900, 2000, 2125, and 2225. There appeared to be no uniform simultaneous peaking of the pressures, except for some uniformity noted at adjacent piezometers in the same cross section of the ring deflector. Oscillograph recordings obtained during operation at reservoir elevations 2125 and 2225 are shown on Figures 38 and 39.

It was noted that the average pressure at Piezometer No. 15, located on the horizontal lip of the ring deflector at the invert, was near atmospheric but that at reservoir elevation 1900 to elevation 2125, the dynamic pressure fluctuated sometimes to vapor pressure. This was also true in previous test data discussed above and recorded in Figure 36. This was due to a fluctuating submergence of the piezometer by the backwater pool under the jet from the ring deflector, which was greatest at reservoir elevations 1900 to 2000. At reservoir elevations 1800 and 2225 the piezometer was open to the atmosphere nearly 100 percent of the time.

To prevent these low, fluctuating pressures, the top surface of the ring deflector should be redesigned to provide a sharp edge as shown in the alternate designs in Figure 40. Although these proposed modifications were not tested, the square corner and offset will prevent the jet from clinging to the top surface of the ring deflector.

The recording charts of Figures 38 and 39 do not show the rapid frequency of pressure fluctuations which existed at Piezometers No. 20, 21, and 22 located on the ring deflector near the horizontal centerline. This was due to the extra long copper leads between these piezometers and the transducers attenuating the pressure fluctuations.

Reference is made to Harrold's paper2/ in which he cited the Corps of Engineers as having concluded from model and prototype comparison tests that vapor pressure existing 25 percent of the operating time could be tolerated for infrequent operation. At Piezometers No. 2, 14, and 15, Figure 36, pressures as low as the vapor pressure occurred only about 1 percent of the operating time.

Air demand. --Air demand was the same as that required for the fourth design, Figure 21.

Further observations were made using a pressure probe to the interior of the jet and the wall piezometer in the valve chamber. The dynamic pressure measurements disclosed that the pressure within the jet and in the valve chamber upstream of the jet were nearly identical, Figures 38 and 39. Pressure measurements were also made in the interior of the jet near the valves, about halfway between the valves and deflector ring, and just upstream from the deflector ring. The pressures of these three points were nearly identical, indicating that the interiors of the jets were well aerated.

One valve operation. --Flow appearance with one valve open and the other closed was unsatisfactory. The jet from the ring deflector impinged upon the side of the tunnel opposite the operating valve in an area extending partly above the top of the half liner, Figure 41. The flow oscillated from side to side throughout the tunnel, and the toe of the jump was on a diagonal line across the tunnel because of the nonuniform flow distribution.

Complete aeration of the downstream side of the ring deflector lip at about 35° up from the invert was not evident. However, pressure measurements at this point on the lip of the ring deflector showed the pressure to be atmospheric for one valve discharging at all reservoir

2/Harrold, J. C., "Experience of the Corps of Engineers," Transactions of the American Society of Civil Engineers, Paper No. 2225, Vol. 112, 1947.

elevations. The recommended alternate modifications of the ring deflector lip (Figure 40) should provide adequate aeration of the downstream side of the ring deflector. Nonsymmetrical operation of the valves is not recommended, except for emergency releases.

Discharge capacity.--To verify the expected prototype capacities the discharge measurements were related to the total head (measured pressure head plus computed velocity head), observed one valve diameter upstream of the valves, Figure 42. Computed head losses from the reservoir to this point are also shown in Figure 42. A friction factor of 0.0096 for new smooth butt-welded pipe3/ was assumed in computing the friction loss in the tunnel plug conduits, and an entrance loss of 0.10 velocity head in the pipe was assumed at the bellmouth entrance to the conduits. This total head loss plus the measured pressure head and the computed velocity head provides the anticipated capacity curves shown in Figure 43. These computations and the model verified that approximately 10,000 cfs will be discharged from two fully open valves at reservoir elevation 2125. At reservoir elevation 2225 the full open gates will discharge approximately 11,100 cfs.

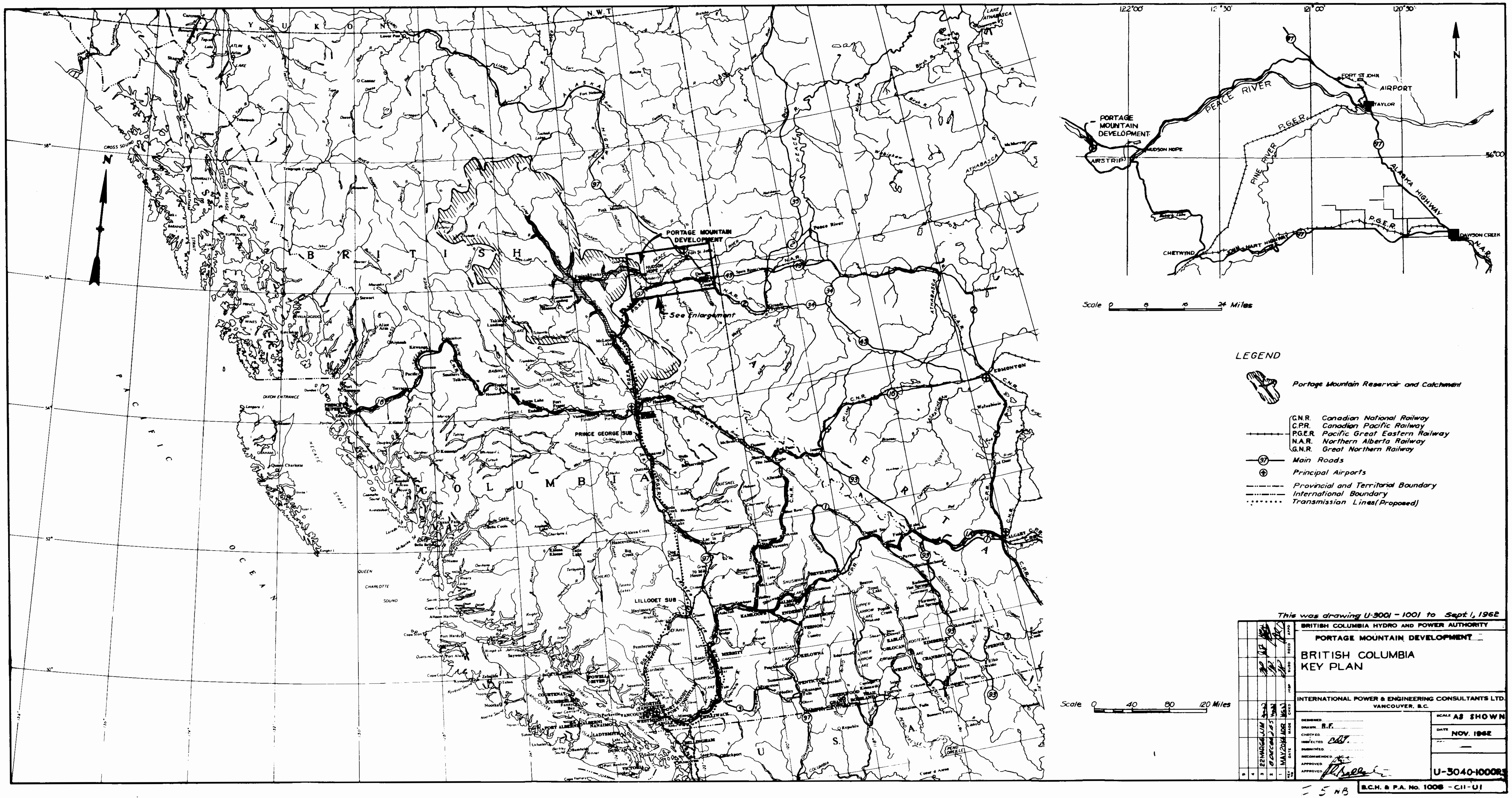
3/Engineering Monograph No. 7, "Friction Factors for Large Conduits Flowing Full," U.S. Department of the Interior, Bureau of Reclamation.

Table 1

DIMENSIONS OF HYDRAULIC FEATURES

Feature	English units	Metric units
Height of dam	600 feet	183.00 meters
Length of dam at crest	6,700 feet	2,042.00 meters
Diversion tunnel length (approximate)	2,700 feet	823.00 meters
Diversion tunnel length downstream from tunnel plug (approximate)	1,600 feet	488.00 meters
Diversion tunnel diameter	48 feet	14.63 meters
Tunnel plug length	200 feet	60.96 meters
Fixed-cone valve diameter	84 inches	2.13 meters
Outlet works design capacity	10,000 cubic feet per second per tunnel	283.2 cubic meters per second per tunnel

FIGURE 1
REPORT HYD-562



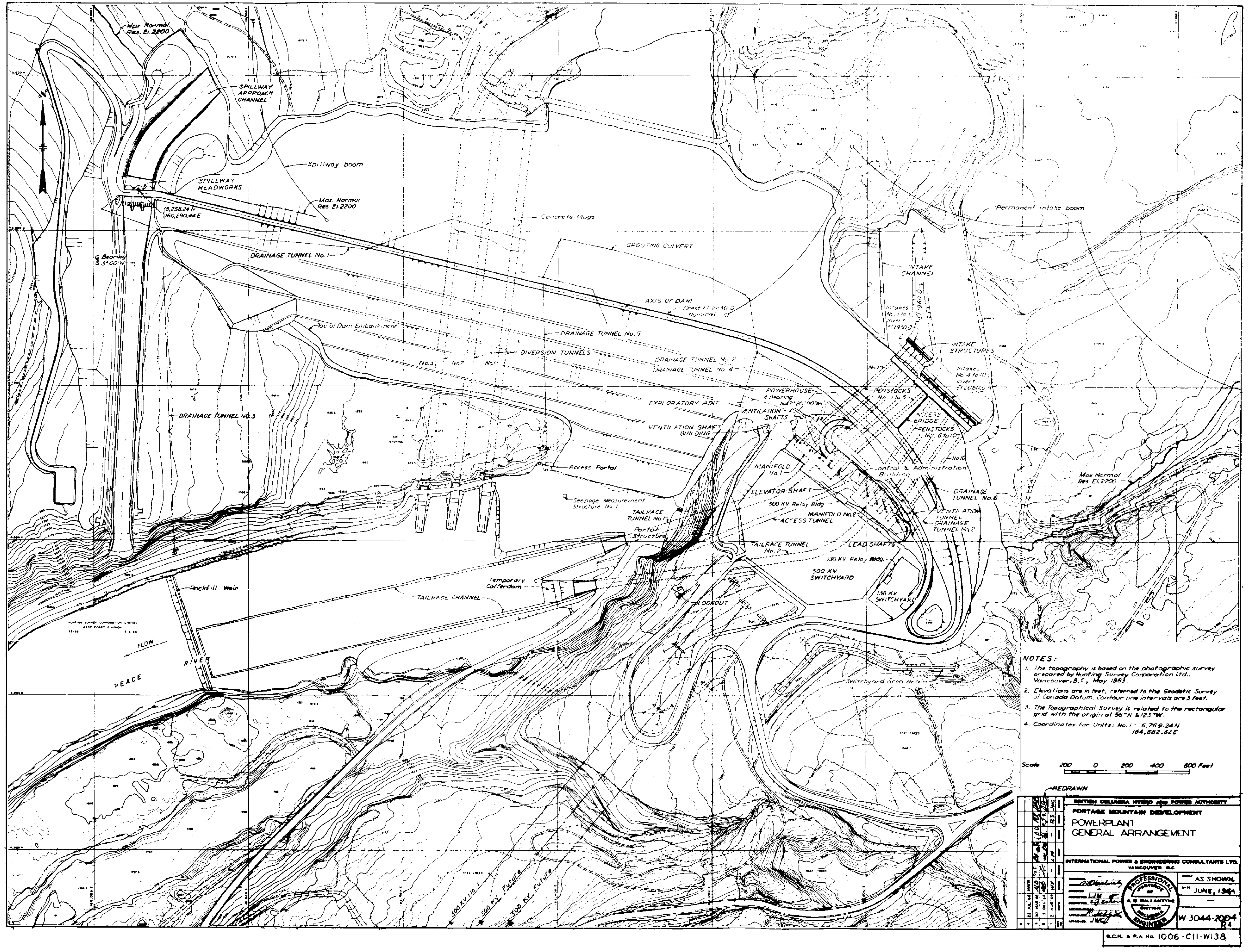
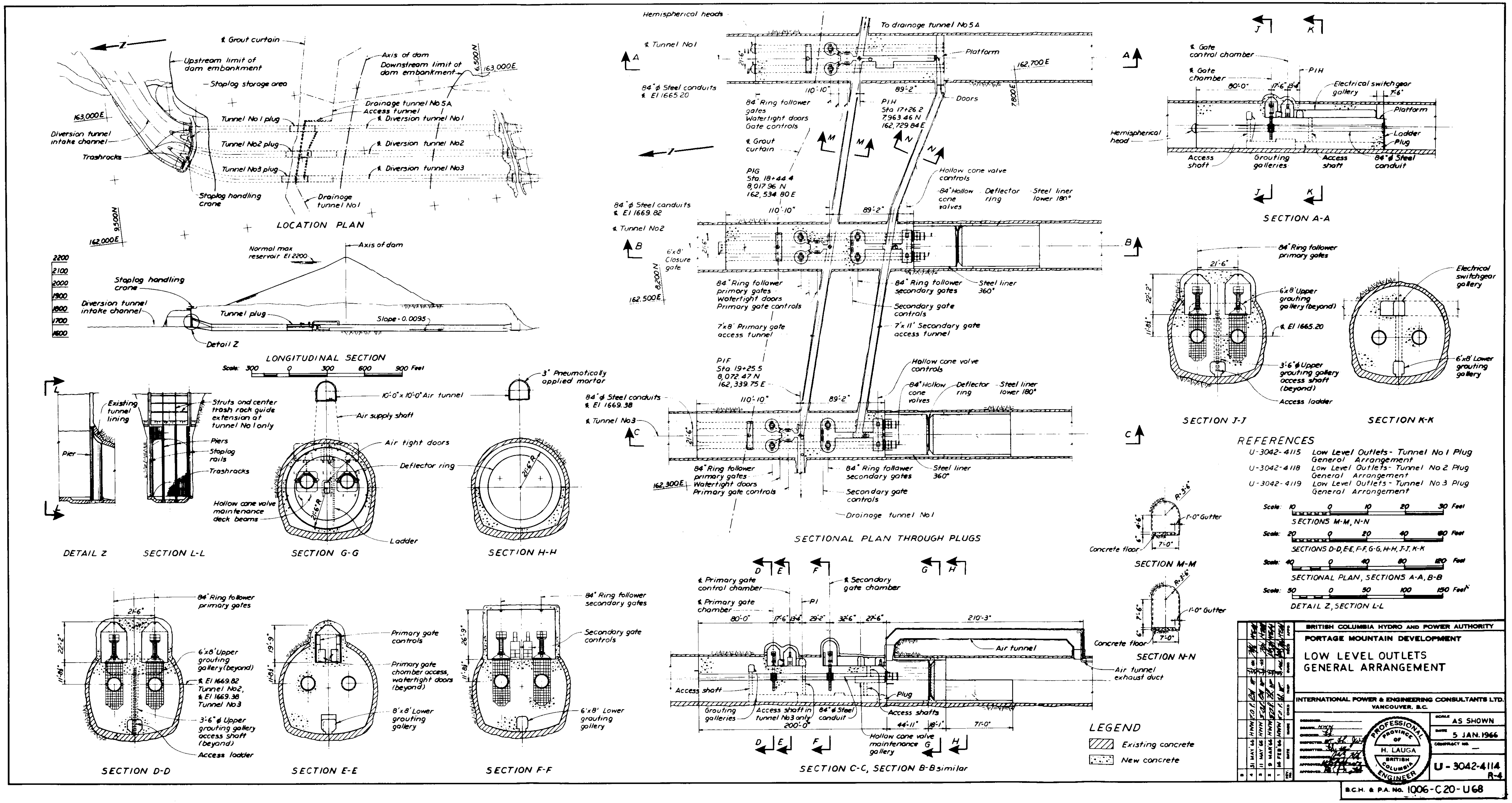
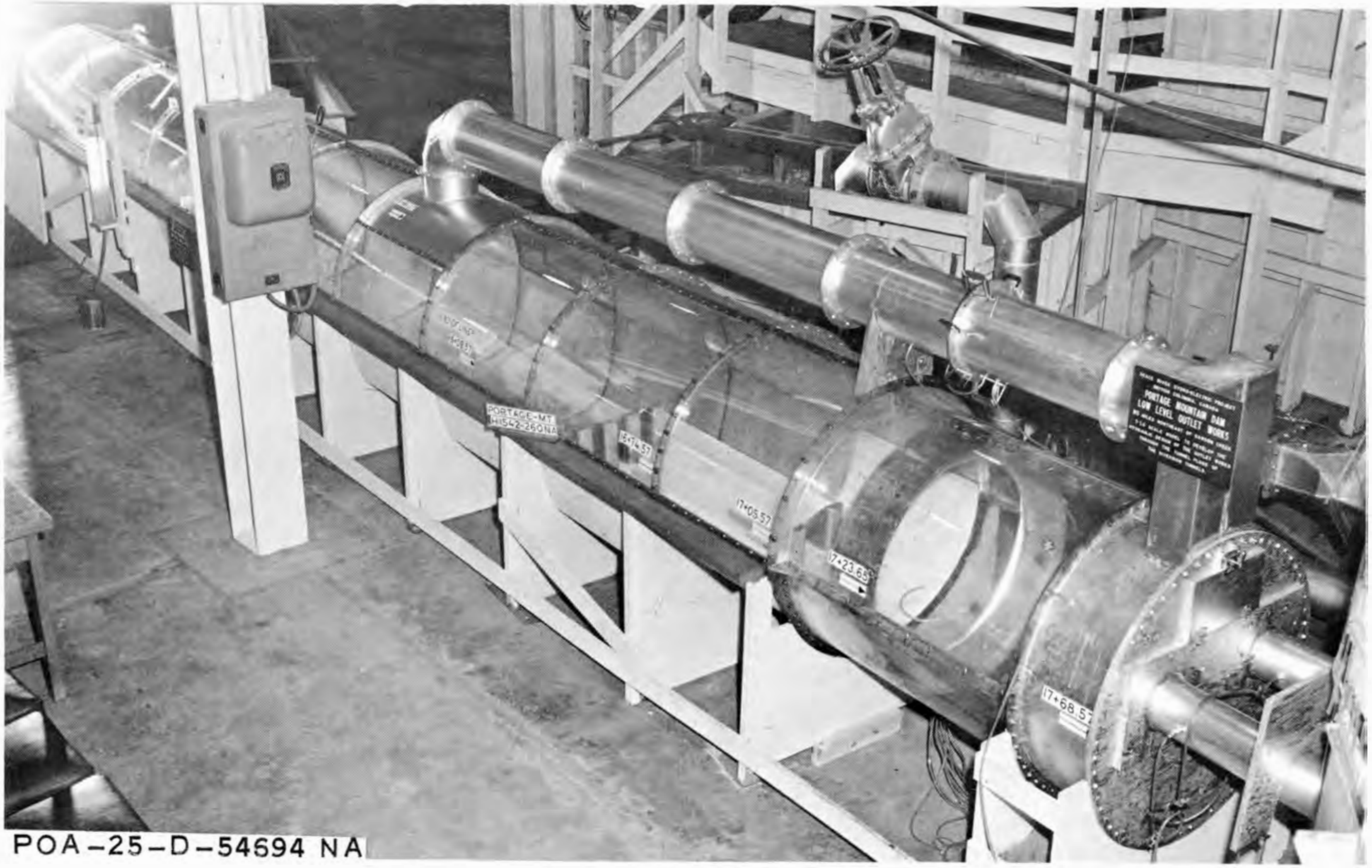

Max. Normal Res. El. 2200
SPILLWAY APPROACH CHANNEL
Spillway boom
SPILLWAY HEADWORKS
Max. Normal Res. El. 2200
16,258.24 N
160,290.44 E
Concrete Plugs
GROUTING CULVERT
Permanent intake boom
℄ Bearing S 3°00' W
DRAINAGE TUNNEL No. 1
INTAKE CHANNEL
AXIS OF DAM
Crest El. 2230.0 Nominal
Toe of Dam Embankment
DRAINAGE TUNNEL No. 5
INTAKE STRUCTURES
No. 3
No. 2
No. 1
DIVERSION TUNNELS
DRAINAGE TUNNEL No. 2
DRAINAGE TUNNEL No. 4
POWERHOUSE ℄ Bearing N 47°26' 00" W
PENSTOCKS No. 1 to 5
EXPLORATORY ADIT
VENTILATION SHAFTS
ACCESS BRIDGE
PENSTOCKS No. 6 to 10
DRAINAGE TUNNEL No. 3
VENTILATION SHAFT BUILDING
MANIFOLD No. 1
Control & Administration Building
Access Portal
Max. Normal Res. El. 2200
ELEVATOR SHAFT
DRAINAGE TUNNEL No. 6
500 KV Relay Bldg.
Seepage Measurement Structure No. 1
TAILRACE TUNNEL No. 1
MANIFOLD No. 2
ACCESS TUNNEL
VENTILATION TUNNEL
DRAINAGE TUNNEL No. 2
Portal Structure
TAILRACE TUNNEL No. 2
LEAD SHAFTS
138 KV Relay Bldg.
500 KV SWITCHYARD
Temporary Cofferdam
Rockfill Weir
TAILRACE CHANNEL
LOOKOUT
138 KV SWITCHYARD
FLOW
PEACE RIVER
Switchyard area drain
500 KV No. 1
500 KV Future
500 KV Future
NOTES:
1. The topography is based on the photographic survey prepared by Hunting Survey Corporation Ltd., Vancouver, B.C., May 1963.
2. Elevations are in feet, referred to the Geodetic Survey of Canada Datum. Contour line intervals are 5 feet.
3. The Topographical Survey is related to the rectangular grid with the origin at 56°N & 123°W.
4. Coordinates for Units: No. 1 - 6,769.24 N 164,682.62 E
Scale 200 0 200 400 600 Feet
REDRAWN
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY
PORTAGE MOUNTAIN DEVELOPMENT
POWERPLANT
GENERAL ARRANGEMENT
INTERNATIONAL POWER & ENGINEERING CONSULTANTS LTD.
VANCOUVER, B.C.
PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
A. G. BALLANTYNE
AS SHOWN
JUNE, 1964
W 3044-2004
R4
B.C.H. & P.A. No. 1006-C11-W138

FIGURE 3
REPORT HYD-562

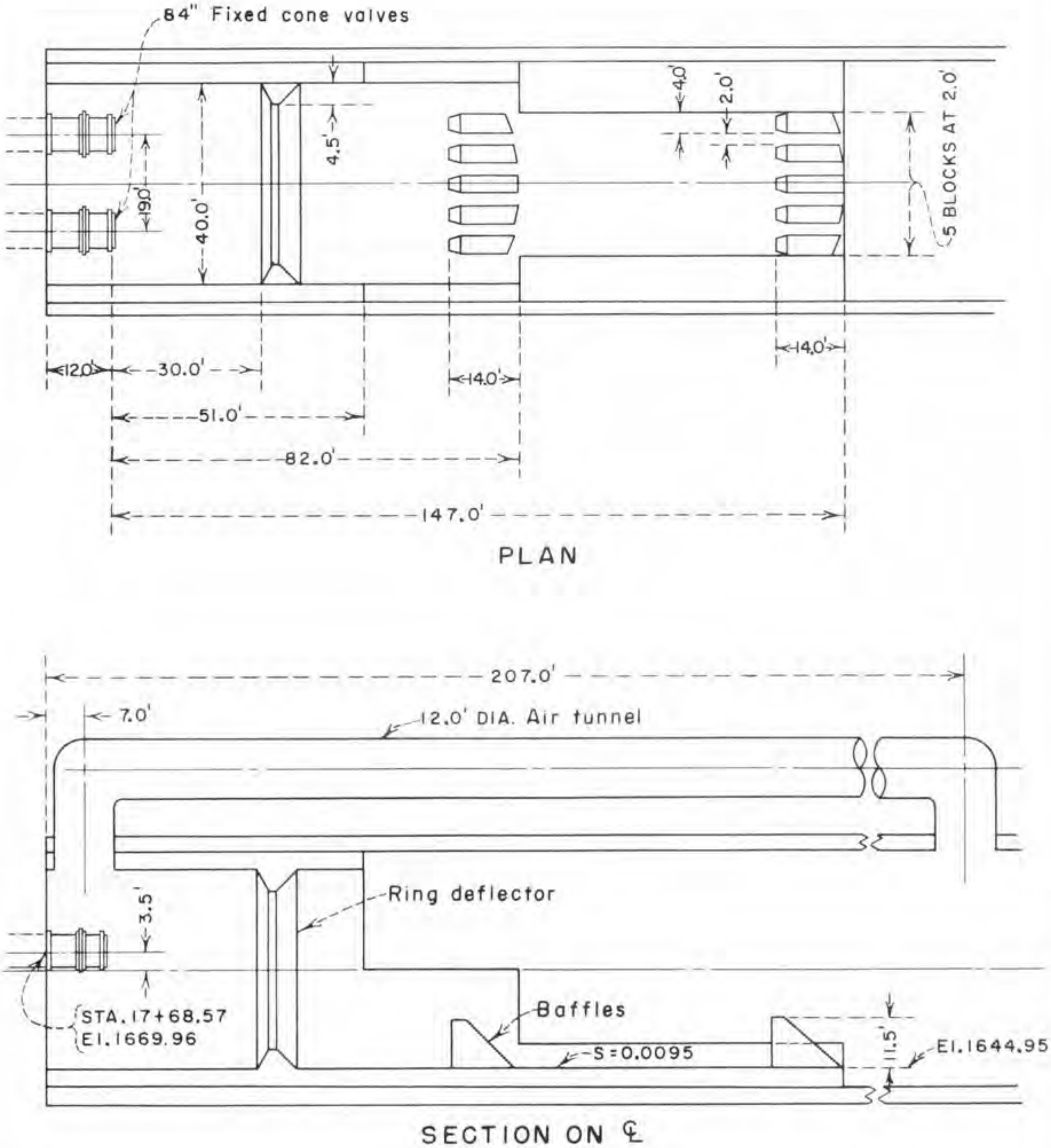




Looking downstream

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
1:14 SCALE MODEL

FIGURE 5
REPORT HYD-562

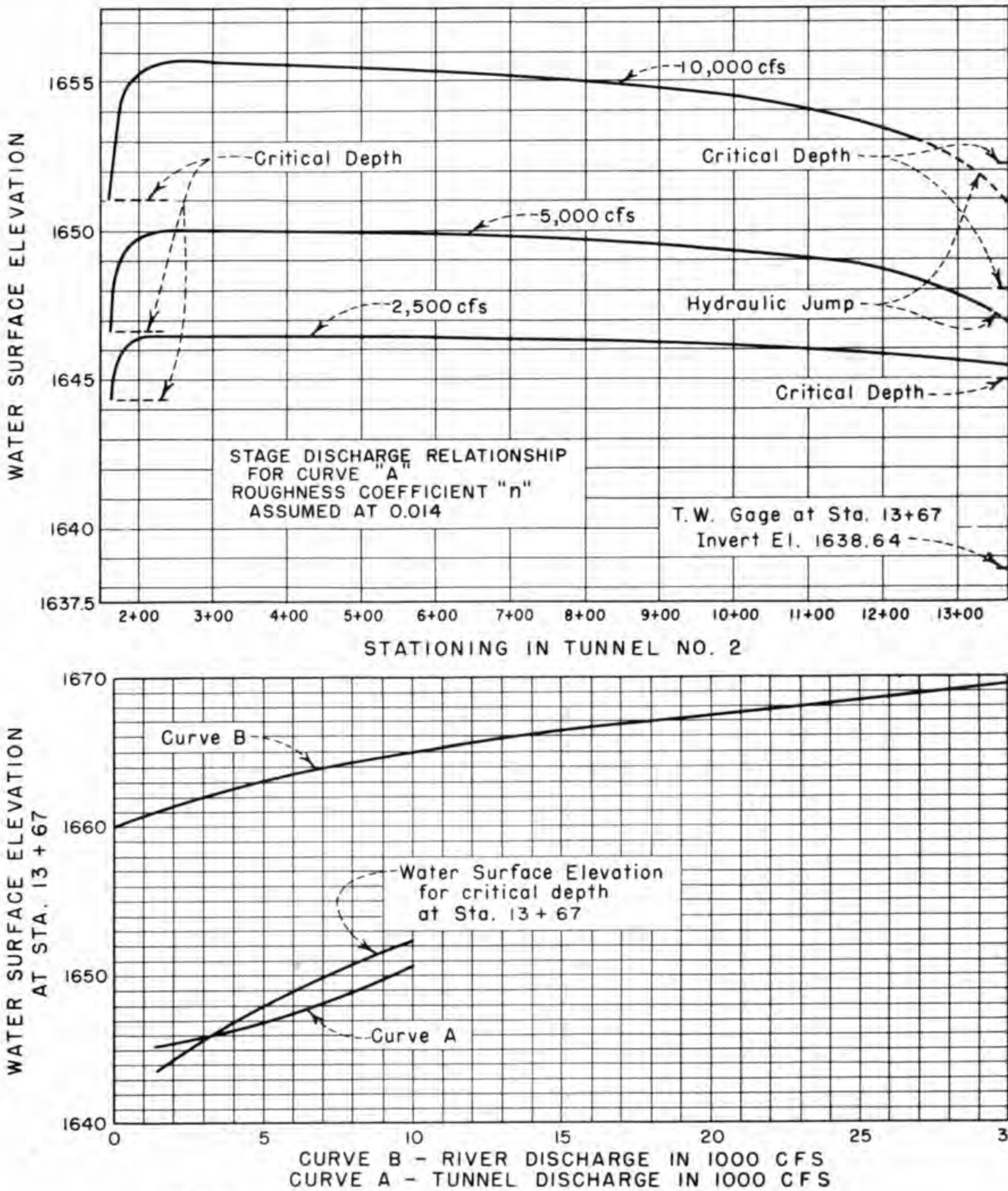


PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

PRELIMINARY DESIGN

1:14 SCALE MODEL

693

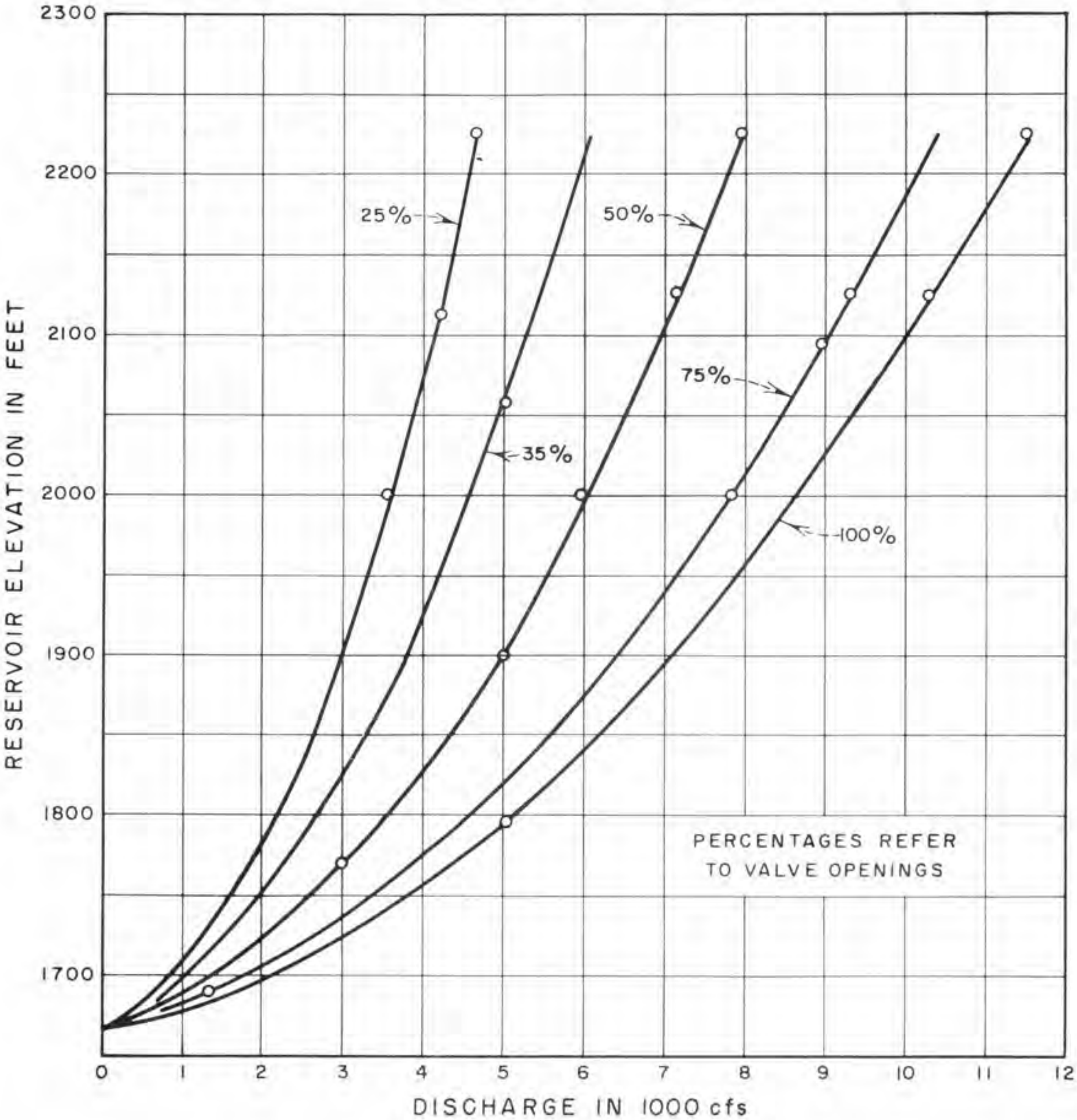


NOTE: CURVE A. TAILWATER IS ESTIMATED AT STA. 13+67 FROM WATER SURFACE PROFILES ABOVE.
CURVE B. TAILWATER IS ESTIMATED AT STA. 13+67 TO BE SAME AS IN RIVER CHANNEL AT PORTAL.

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

COMPUTED WATER SURFACE

1 : 14 SCALE MODEL

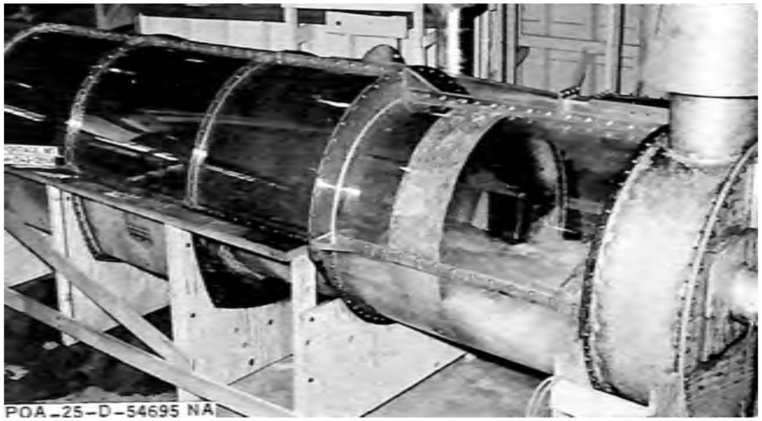


NOTE: For final calibration see Figures 42 and 43
℄ of valve at El. 1669.96

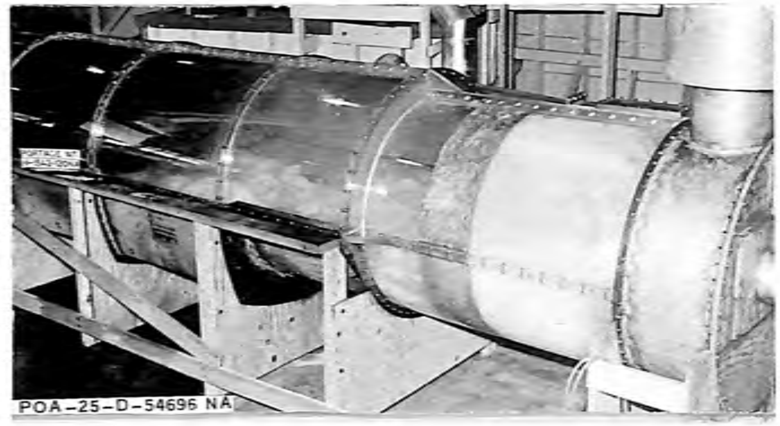
PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

PRELIMINARY DISCHARGE CAPACITY CURVES
TWO 84 - INCH FIXED CONE VALVES

1 : 14 SCALE MODEL

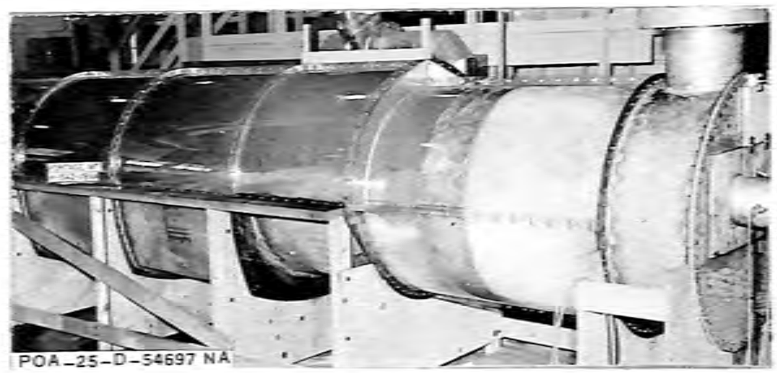


T.W. El. 1645.2 (Curve A) Q = 2,000 cfs
Reservoir El. 1690



T.W. El. 1646.5 (Curve A) Q = 4,300 cfs
Reservoir El. 1770

T.W. El. 1662.8 (Curve B) Q = 4,300 cfs
Reservoir El. 1770



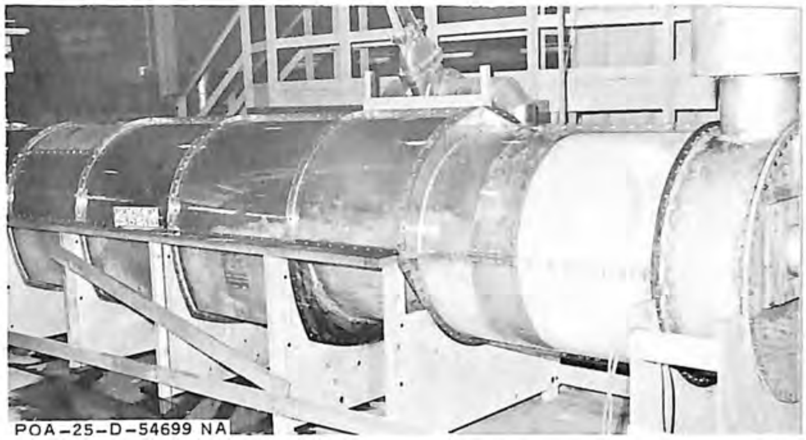
T.W. El. 1669.0 (Curve B assuming total riverflow Q = 28,000 cfs) Q = 4,300 cfs
Reservoir El. 1770

Note: T.W. Elevations are set at Station 13+67

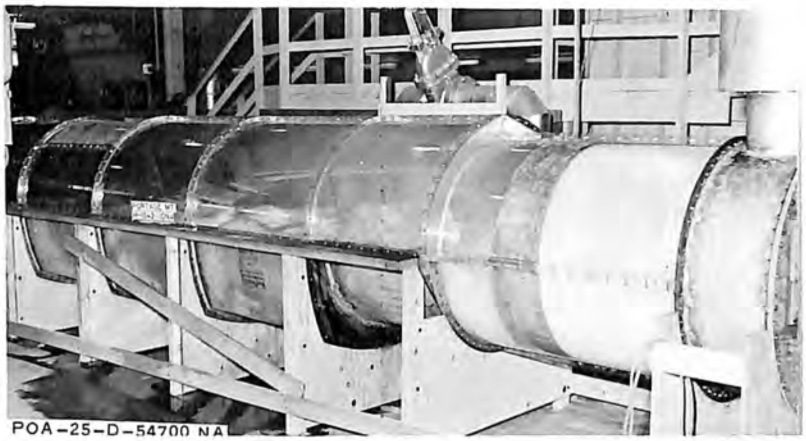
PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
PRELIMINARY DESIGN--TWO-VALVE OPERATION 100 PERCENT OPEN
1:14 SCALE MODEL

Figure 8
Report No. Hyd-562

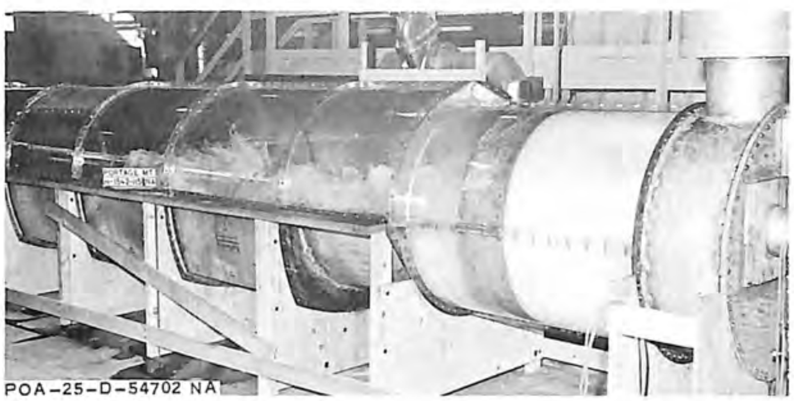
Note: T. W. elevations are set at Station 13+67



T. W. El. 1647.0 (Curve A)



T. W. El. 1662.8 (Curve B)

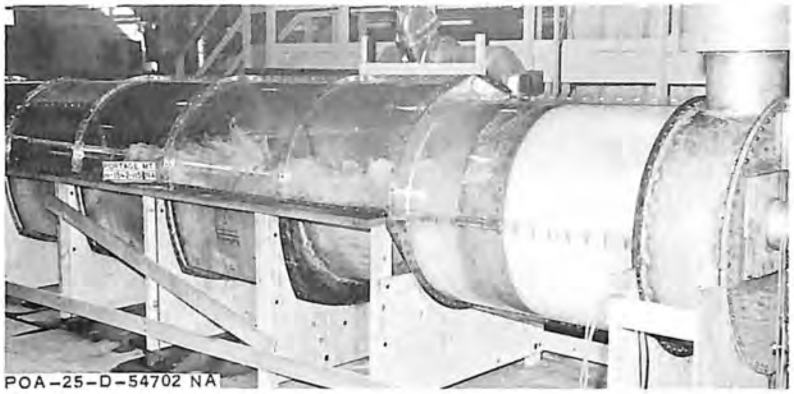


T. W. El. 1669.0 (Curve B assuming total river discharge = 28,000 cfs)

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
PRELIMINARY DESIGN--TWO-VALVE OPERATION 50 PERCENT OPEN
5,000 CFS--RESERVOIR ELEVATION 1900
1:14 SCALE MODEL

Figure 10
Report No. Hyd-562

Note: T. W. elevations are set at Station 13+67



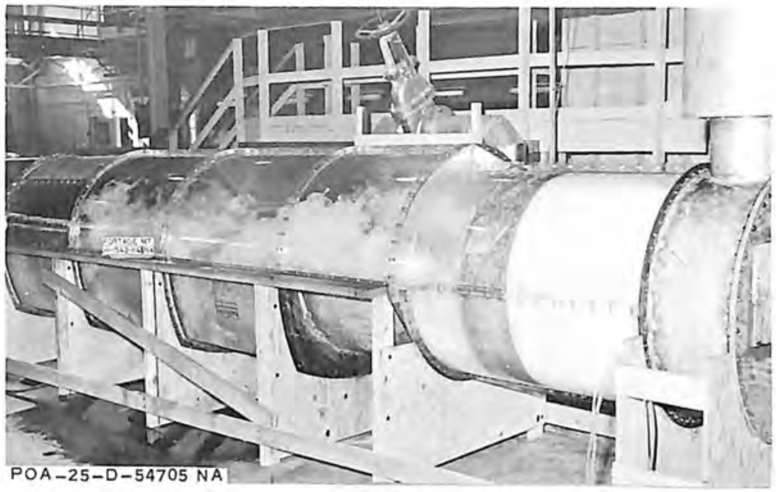
T. W. El. 1649.4 (Curve A)

T. W. El. 1664.5 (Curve B)

T. W. El. 1669.0 (Curve B assuming total river discharge = 28,000 cfs)

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
PRELIMINARY DESIGN--TWO-VALVE OPERATION 100 PERCENT OPEN
8,600 CFS--RESERVOIR ELEVATION 2000
1:14 SCALE MODEL

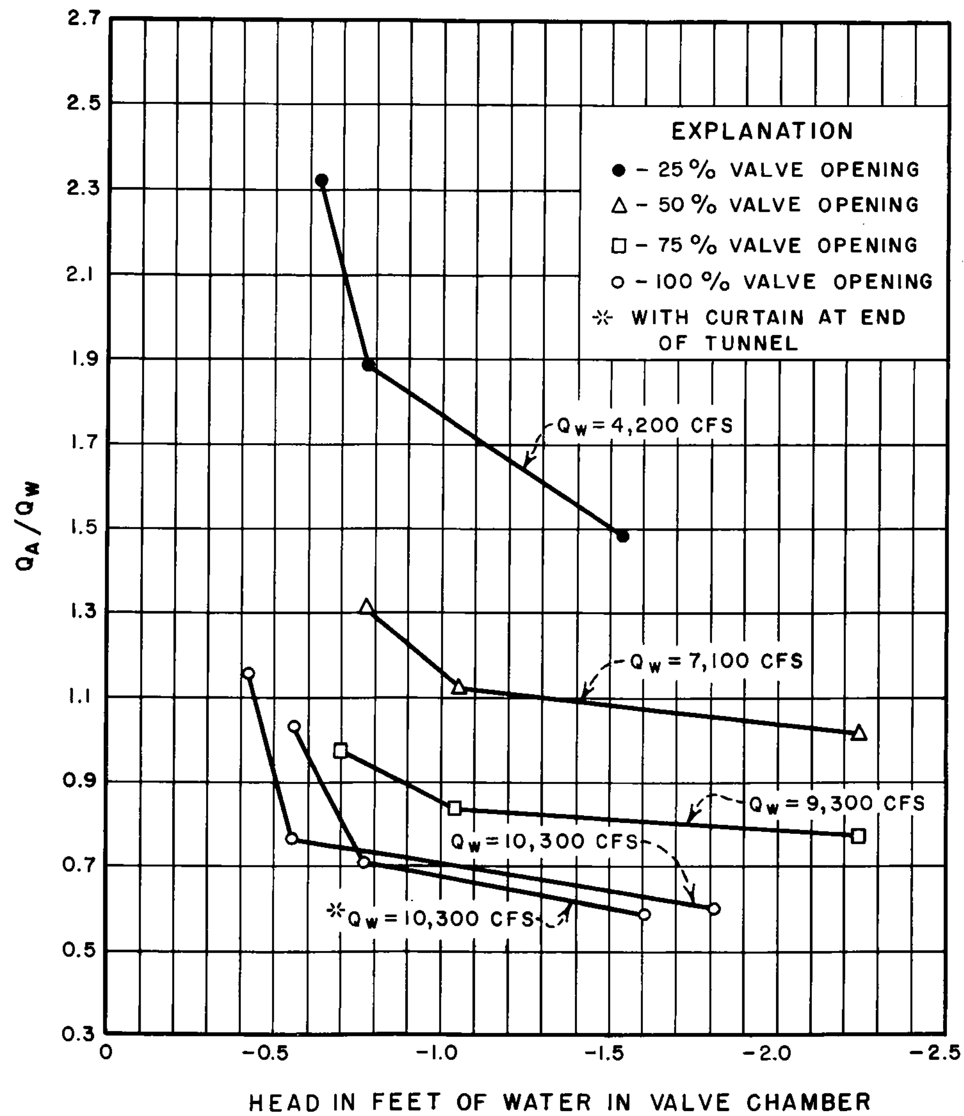
Note: T.W. elevations are set at Station 13+67



Valves 100 percent open
Q = 10,300 cfs
T.W. El. 1651.0 (Curve A)

Valves 50 percent open
Q = 7,100 cfs
T.W. El. 1648.2 (Curve A)

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
PRELIMINARY DESIGN--RESERVOIR ELEVATION 2125
1:14 SCALE MODEL



Q_A = QUANTITY OF AIR IN CFS

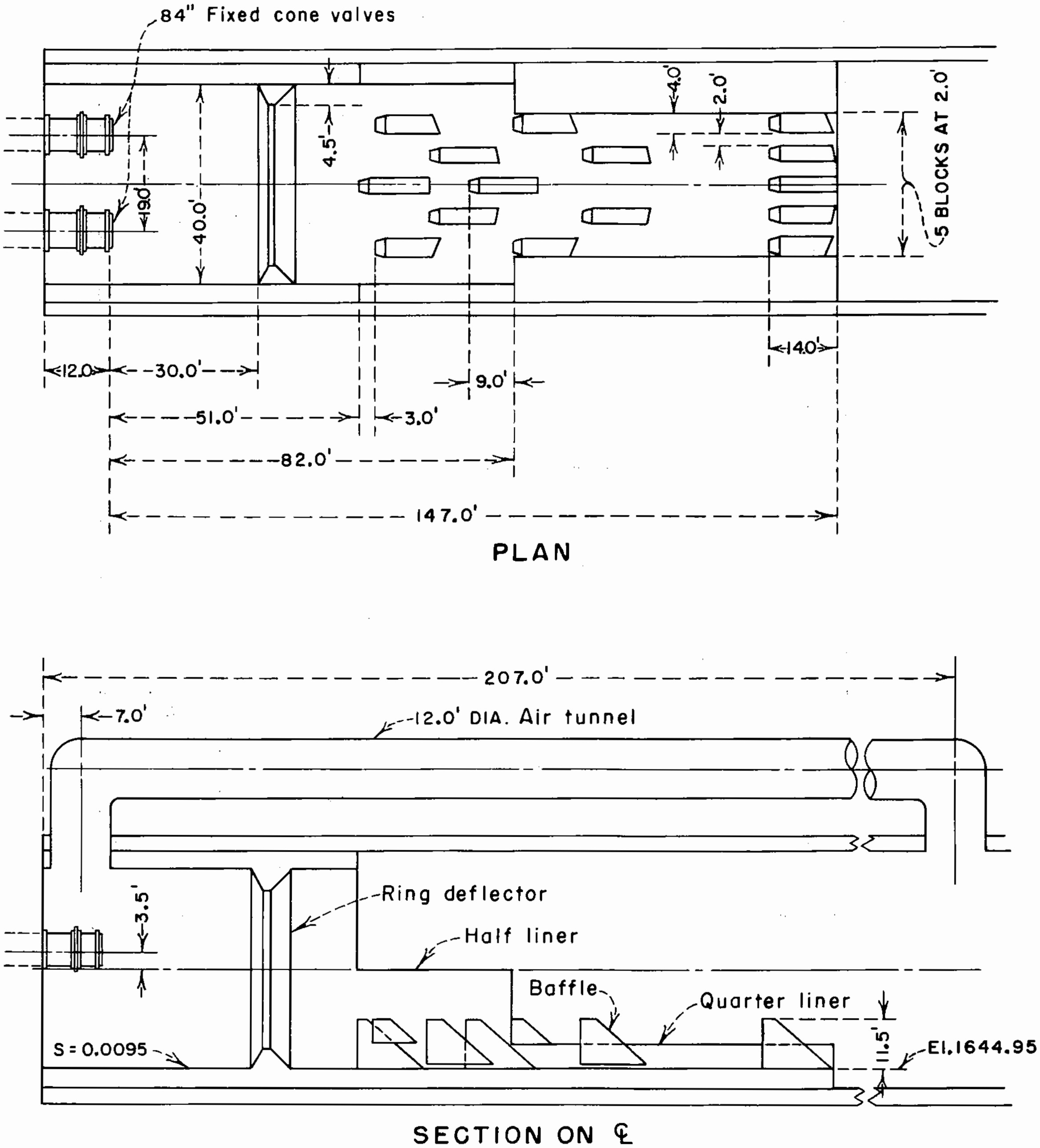
Q_W = QUANTITY OF WATER IN CFS

ZERO HEAD IS ATMOSPHERIC PRESSURE

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

AIR DEMAND - PRELIMINARY DESIGN

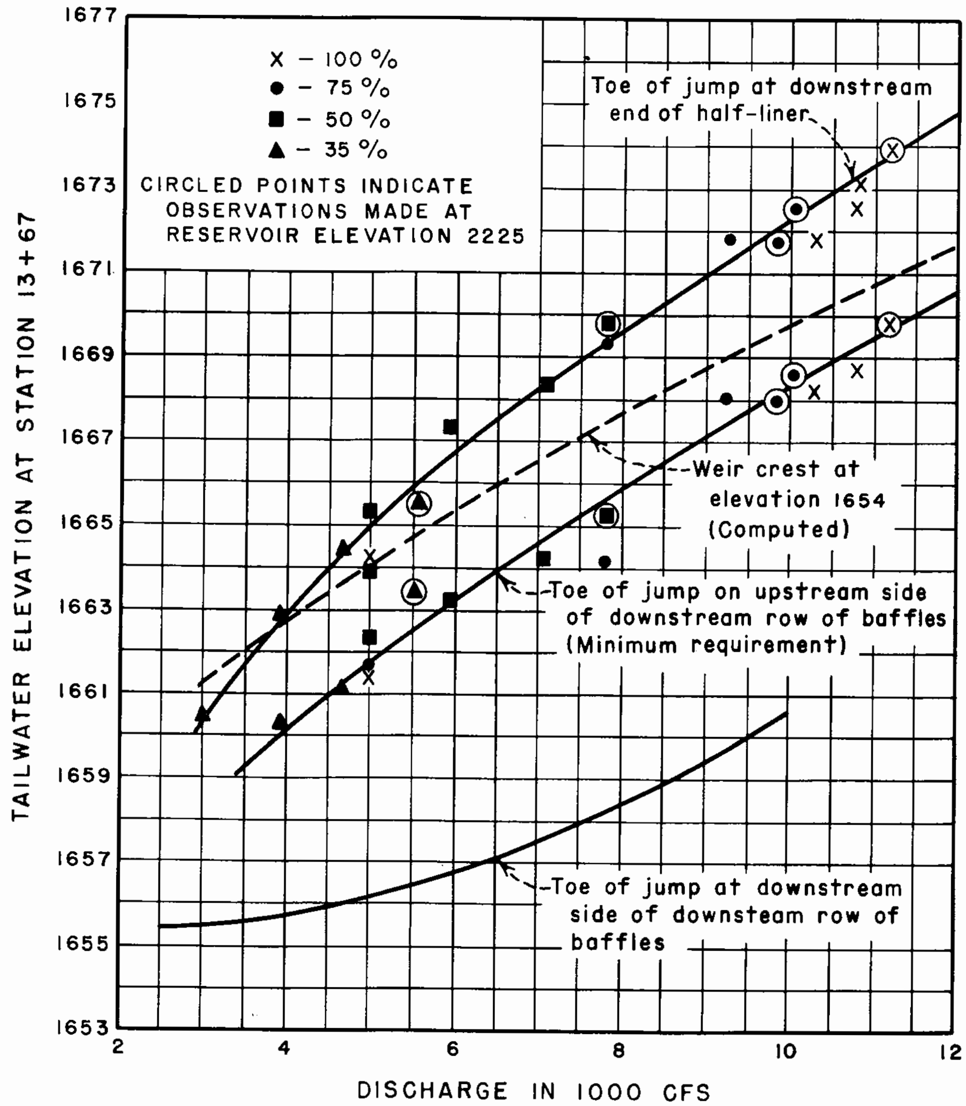
1 : 14 SCALE MODEL



PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

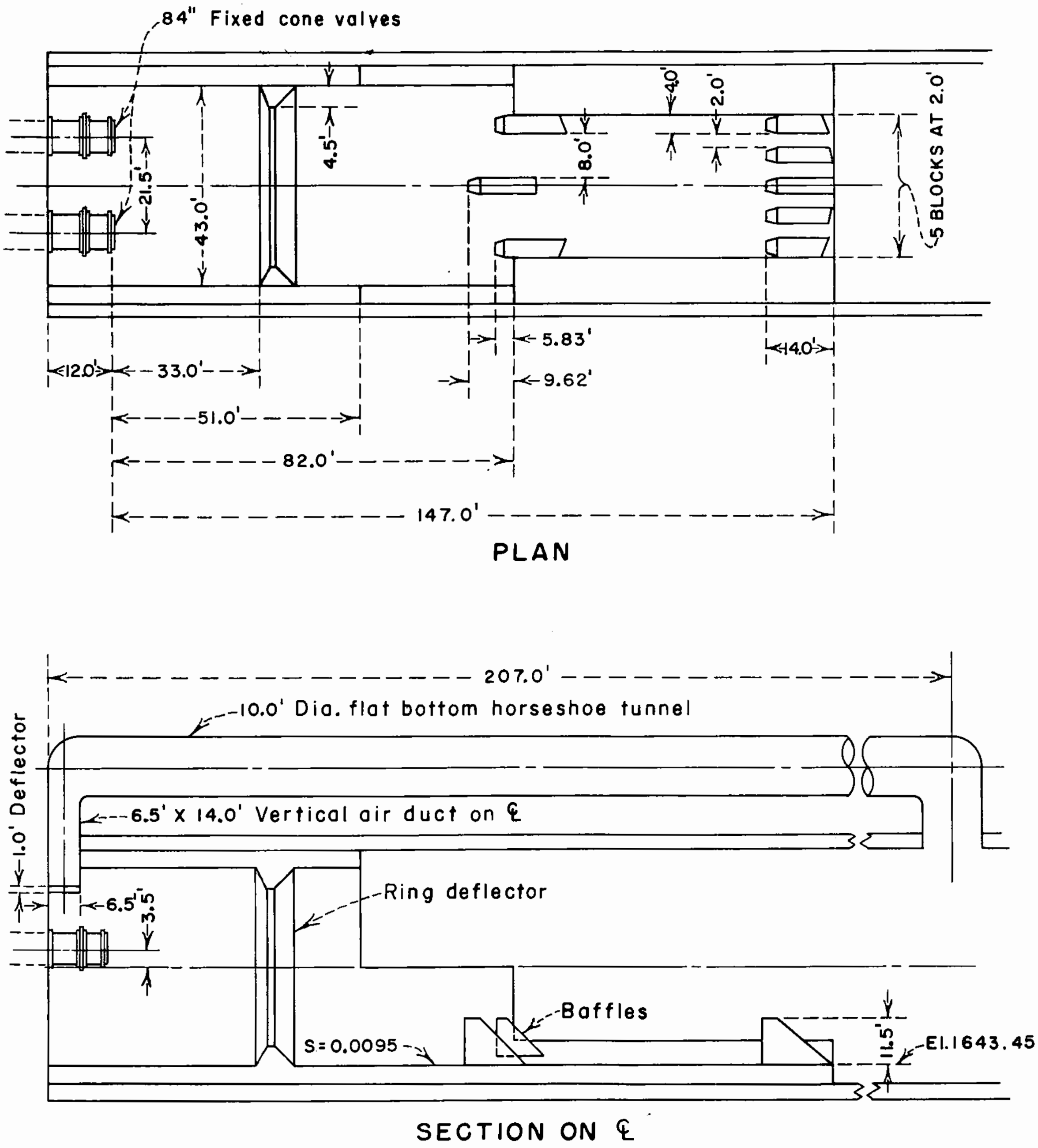
BAFFLE PIER ARRANGEMENT
SECOND DESIGN

1 : 14 SCALE MODEL



NOTE:
Model arrangement as shown in Figure 13

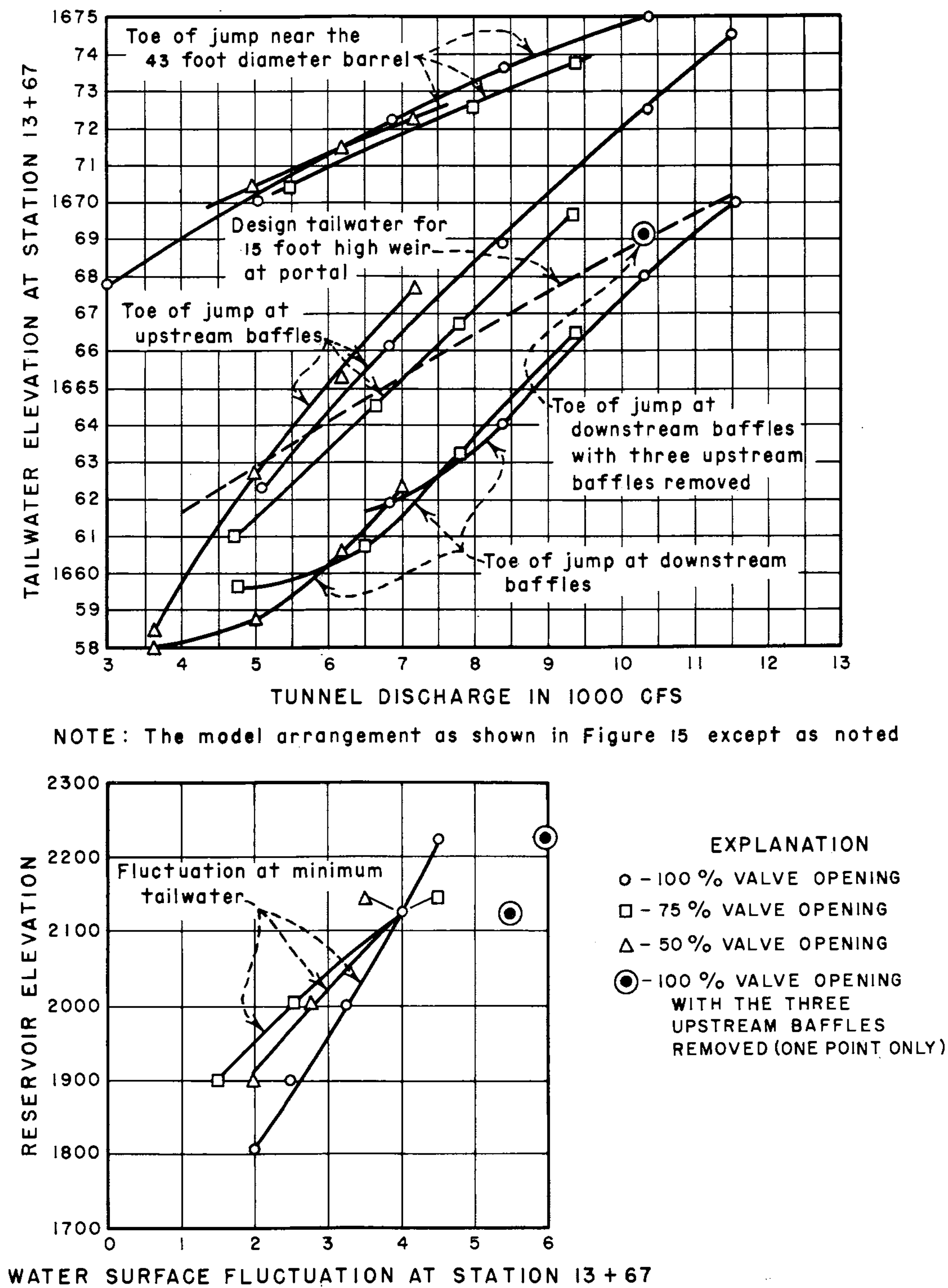
PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
TAILWATER REQUIREMENTS
SECOND DESIGN
1 : 14 SCALE MODEL



PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

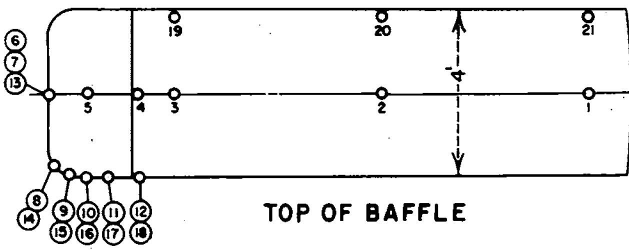
BAFFLE PIER ARRANGEMENT
FOURTH DESIGN

1 : 14 SCALE MODEL

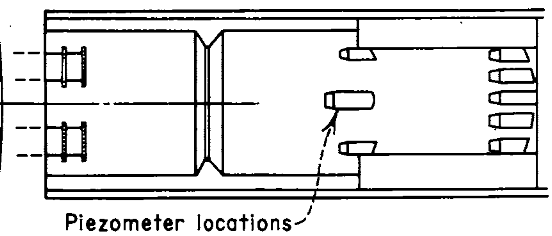


NOTE: The model arrangement as shown in Figure 15 except as noted

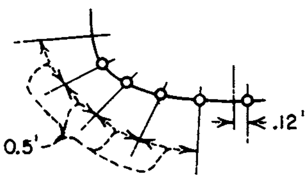
PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
TAILWATER REQUIREMENTS
1 : 14 SCALE MODEL



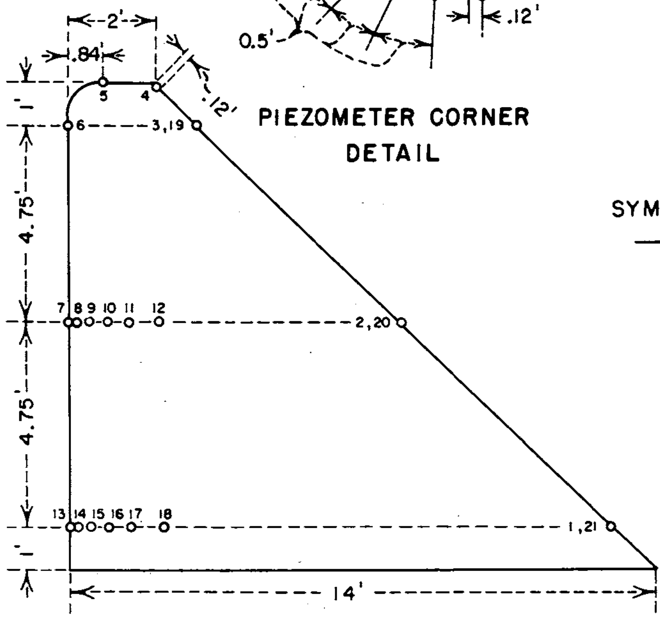
TOP OF BAFFLE



PLAN VIEW



PIEZOMETER CORNER DETAIL



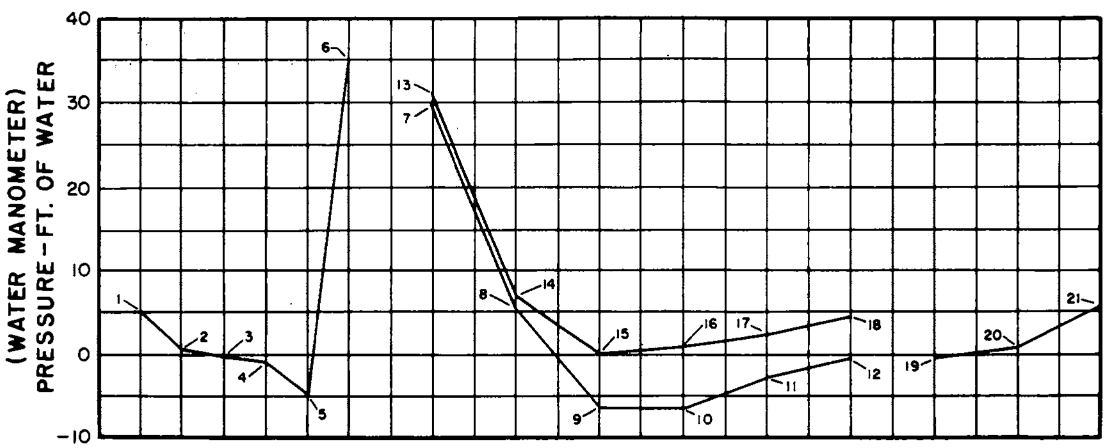
SIDE OF BAFFLE

EXPLANATION

SYMBOL	DISCHARGE	T.W. ELEVATION
——	10,300 CFS	1657 AND 1669

NOTES

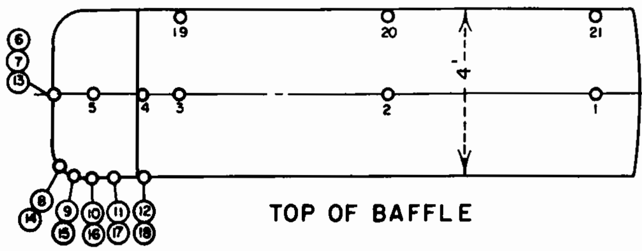
Valves 100% open
Numbers designate piezometers



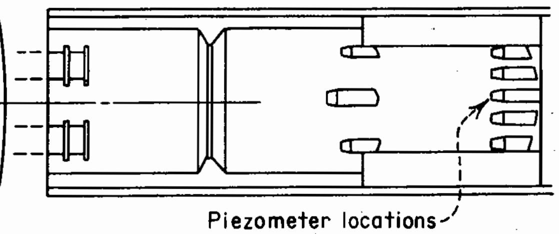
PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

UPSTREAM BAFFLE PIER
PIEZOMETERS AND PRESSURES

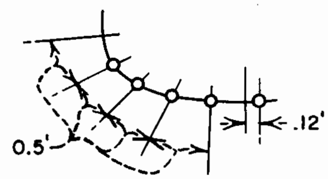
1 : 14 SCALE MODEL



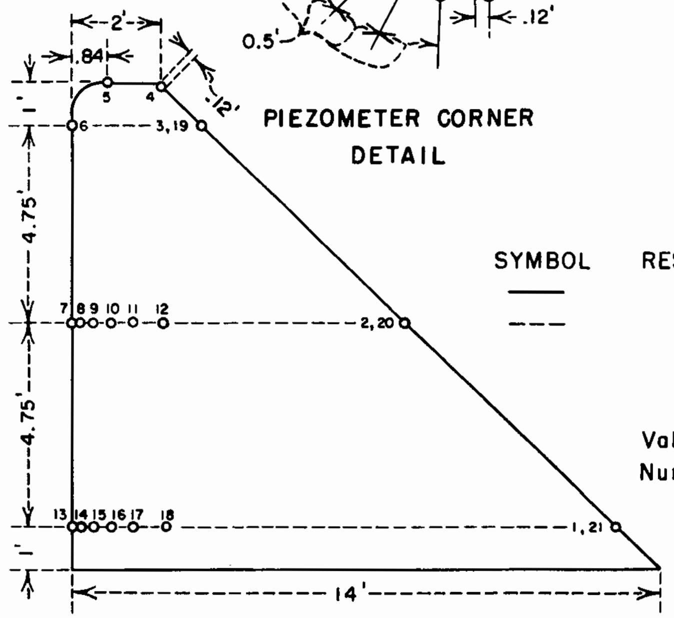
TOP OF BAFFLE



PLAN VIEW



PIEZOMETER CORNER DETAIL



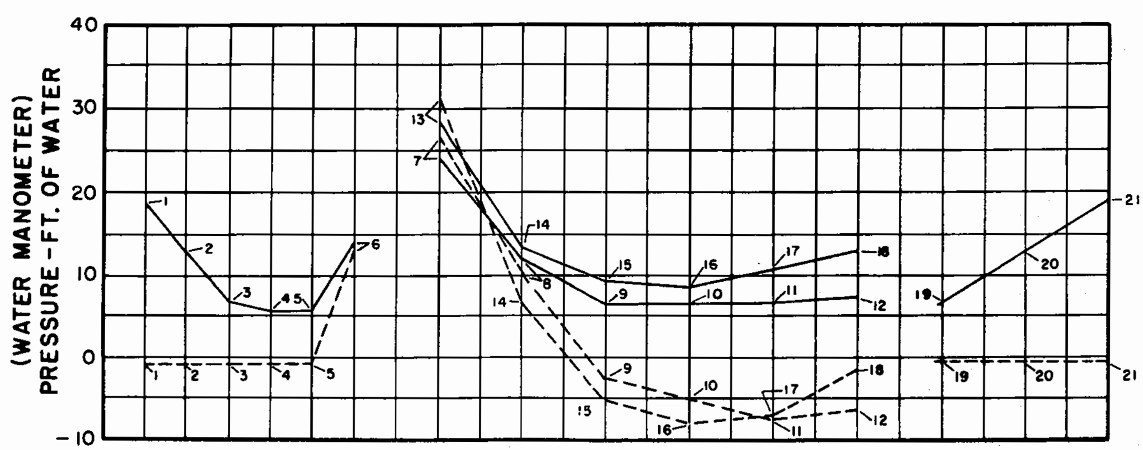
SIDE OF BAFFLE

EXPLANATION

SYMBOL	RESERVOIR EL.	DISCHARGE	T.W. EL.
———	2150	10,300 CFS	1669
– – –	2150	10,300 CFS	1657

NOTES

Valves 100% open
Numbers designate piezometers



PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

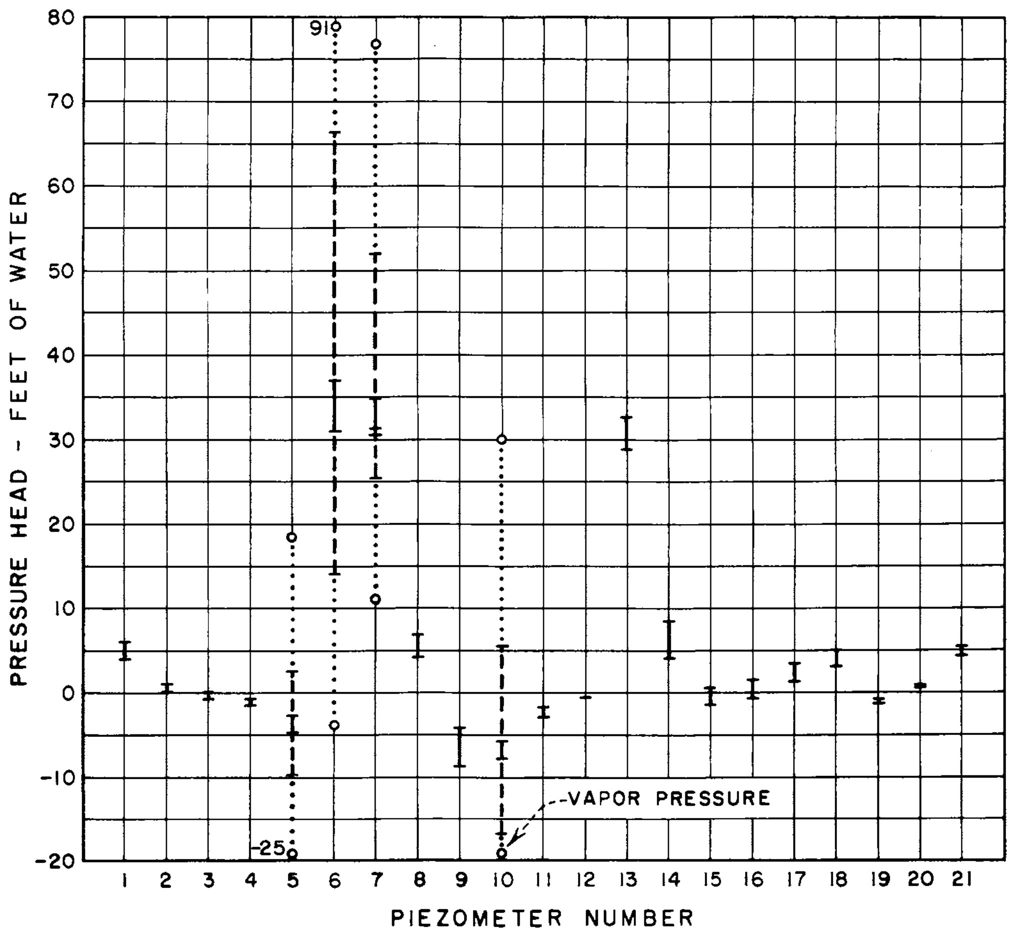
DOWNSTREAM BAFFLE PIER
PIEZOMETERS AND PRESSURES

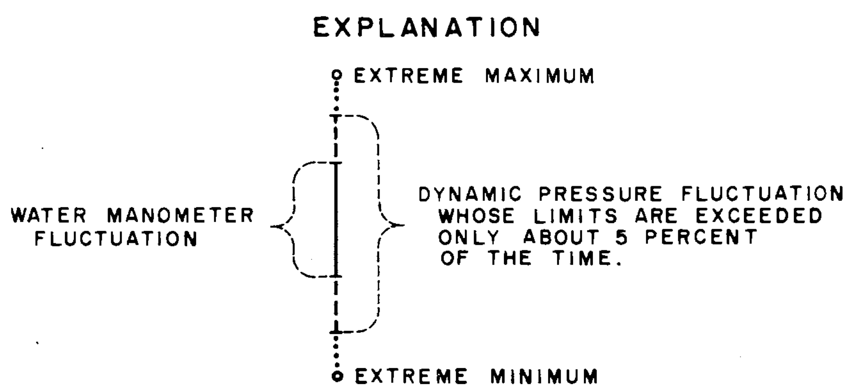
1 : 14 SCALE MODEL

Discharge in cfs	T.W. el in ft	Piezometer No.	Pressures in feet of water					No. of pressure fluctuations/second		
			Ex min***	Min	Avg	Max	Ex max***	Average No.	Avg. No. reaching Max press	Avg. No. reaching Min press
10,300	1657-69	5*	-25	-10	-3	3	19	12	2.9	2.2
10,300	1657-69	6*	-4	14	35	67	91	5	1.6	2.0
10,300	1657-69	7*	11	25	36	52	77	9	0.8	1.3
10,300	1657-69	10*	VP	-17	-6	5	30	8	1.2	1.2
11,500	1658-70	5*	-29	-11	-3	1	24	12	2.9	2.5
11,500	1658-70	6*	-10	14	37	56	98	6	2.2	0.7
11,500	1658-70	7*	12	28	39	56	85	10	0.4	0.8
11,500	1658-70	10*	VP	-21	-7	7	38	9	0.9	0.8
10,300	1669	5**	0	4	7	11	15	9	0.3	2.2
10,300	1669	6**	3	8	13	20	34	2	0.3	0.5
10,300	1669	13**	17	21	27	35	45	7	0.3	0.1
10,300	1669	14**	-14	3	14	25	31	7	0.8	1.1
10,300	1669	16**	-6	3	11	20	28	9	0.3	0.5
10,300	1657	5**	-1	0	1	3	4	11	2.2	5.3
10,300	1657	6**	-1	4	13	25	35	2	0.3	0.3
10,300	1657	13**	18	22	29	41	60	6	0.3	0.5
10,300	1657	14**	VP	-11	8	25	42	7	0.3	0.3
10,300	1657	16**	-28	-15	-7	3	14	10	0.7	0.3
11,500	1670	5**	-7	0	4	8	14	10	1.3	2.9
11,500	1670	6**	0	4	13	27	41	2	0.3	0.3
11,500	1670	13**	21	25	32	41	57	7	1.1	0.1
11,500	1670	14**	-17	-3	14	21	39	6	0.5	0.5
11,500	1670	16**	-15	-7	4	14	21	10	0.5	0.7
11,500	1658	5**	-4	-1	1	3	4	13	2.4	3.2
11,500	1658	6**	-4	4	17	31	46	3	1.9	1.3
11,500	1658	13**	21	25	34	43	63	6	1.2	0.5
11,500	1658	14**	-28	-8	8	28	42	7	0.5	0.1
11,500	1658	16**	-29	-18	-7	3	13	10	0.7	0.5

*Upstream baffle.
**Downstream baffle.
***Extreme maximum or minimum.
Zero pressure is atmospheric.
VP = vapor pressure.

PORTAGE MOUNTAIN DEVELOPMENT
Low-level Outlet Works
Dynamic Pressures on Baffle Piers
1:14 Scale Model



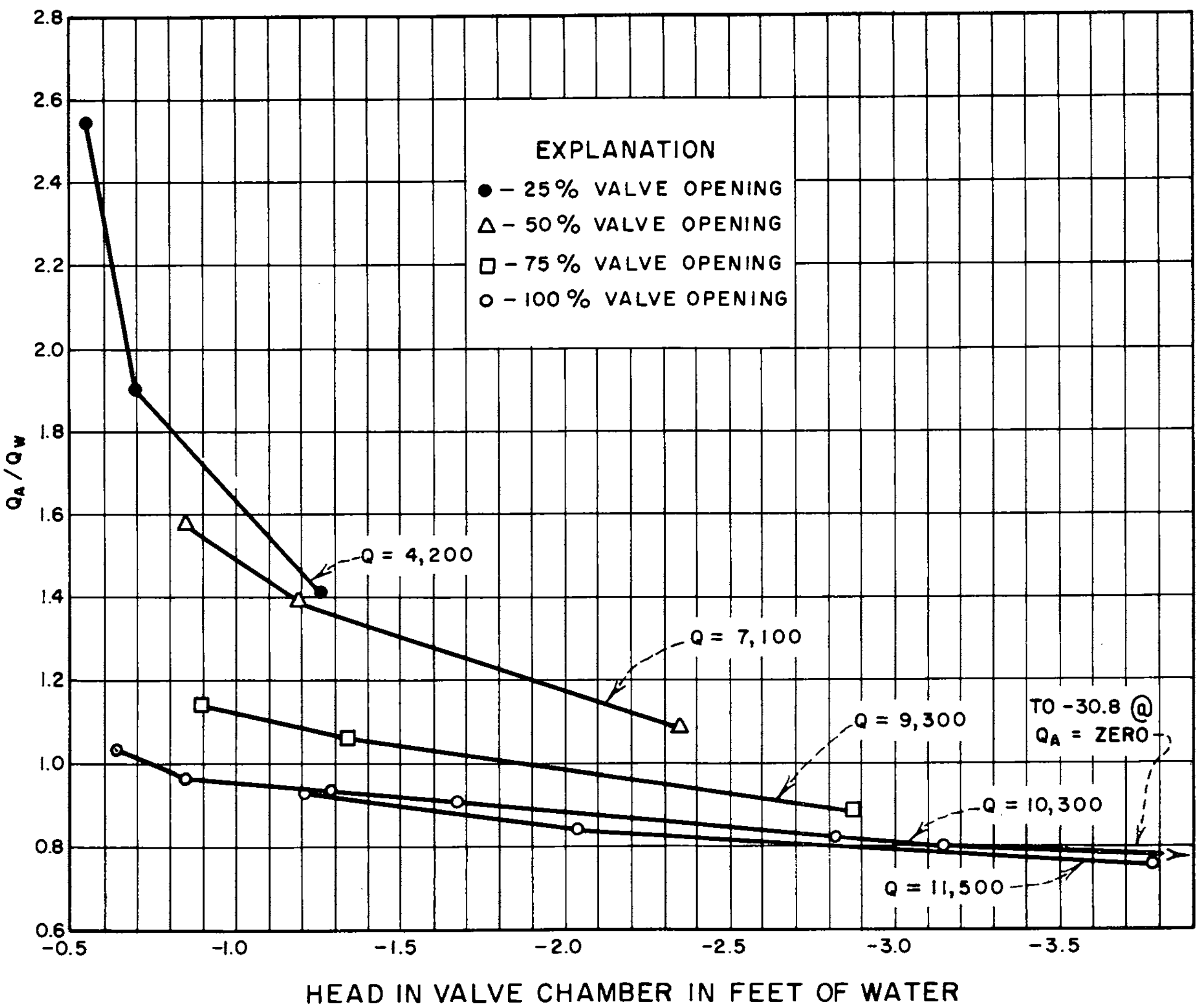


NOTES: PRESSURES NOT AFFECTED BY TAILWATER.
VALVES FULLY OPEN.

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

UPSTREAM BAFFLE PIER PRESSURE FLUCTUATIONS
10,300 CFS -- VALVES FULLY OPEN

1 : 14 SCALE MODEL



NOTE: THE MODEL ARRANGEMENT INCLUDED A 6.5 X 14.0 FOOT AIR TUNNEL OUTLET AT CROWN OF 43 FOOT DIAMETER BARREL.

Q_A = QUANTITY OF AIR IN CFS

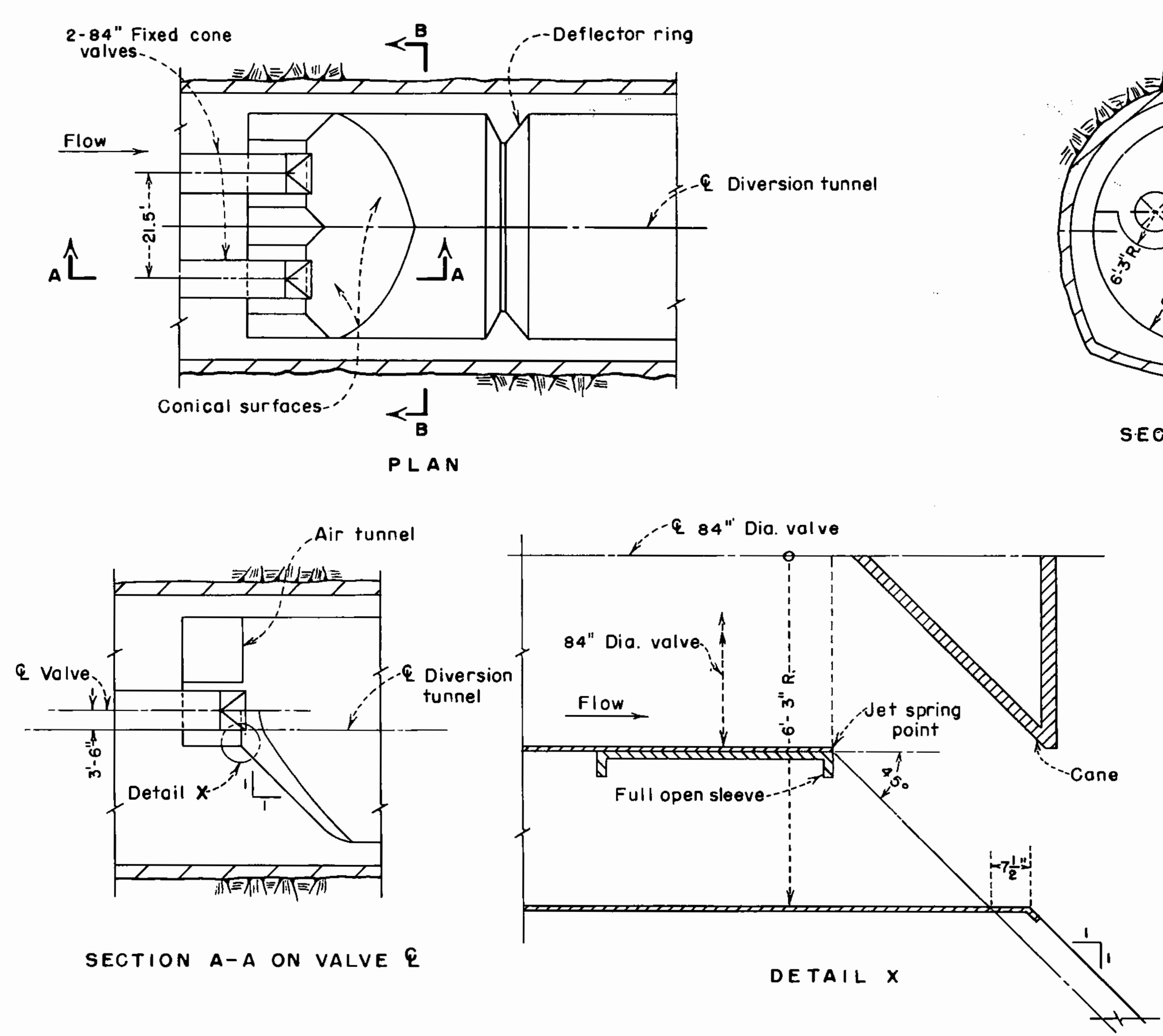
Q_W = QUANTITY OF WATER IN CFS

ZERO HEAD IS ATMOSPHERIC PRESSURE

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

AIR DEMAND - FOURTH AND FINAL DESIGNS

1 : 14 SCALE MODEL

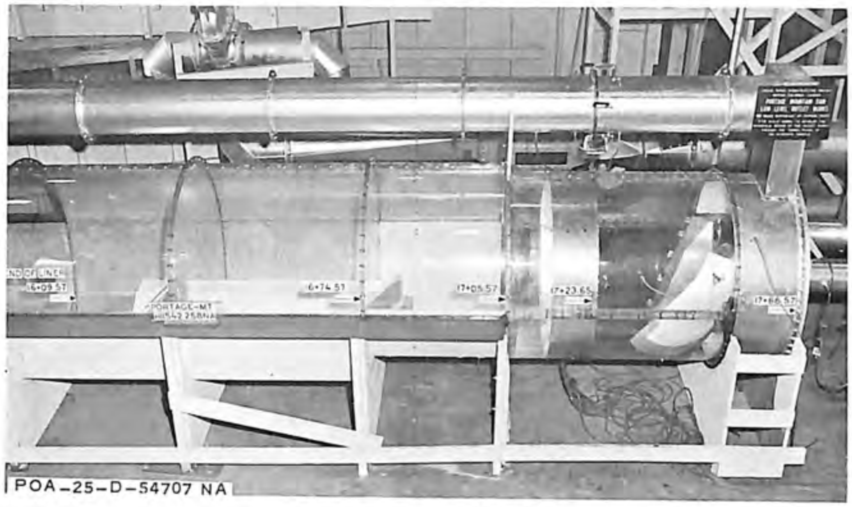


PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
PROPOSED DOKAN FILLET

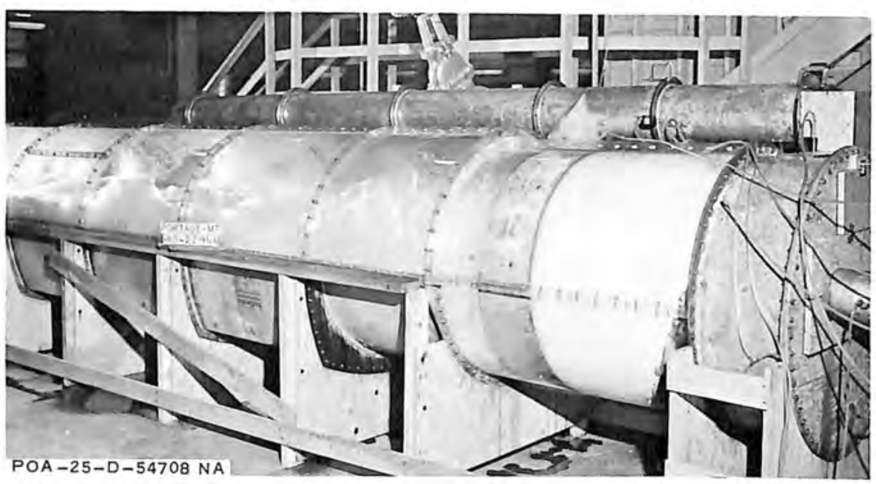
FIGURE 22
REPORT HYD-562

693

Figure 23
Report No. Hyd-562



A. Dokan fillet installed



B. Reservoir El. 2125, 10,000 cfs
T.W. El. 1669.2

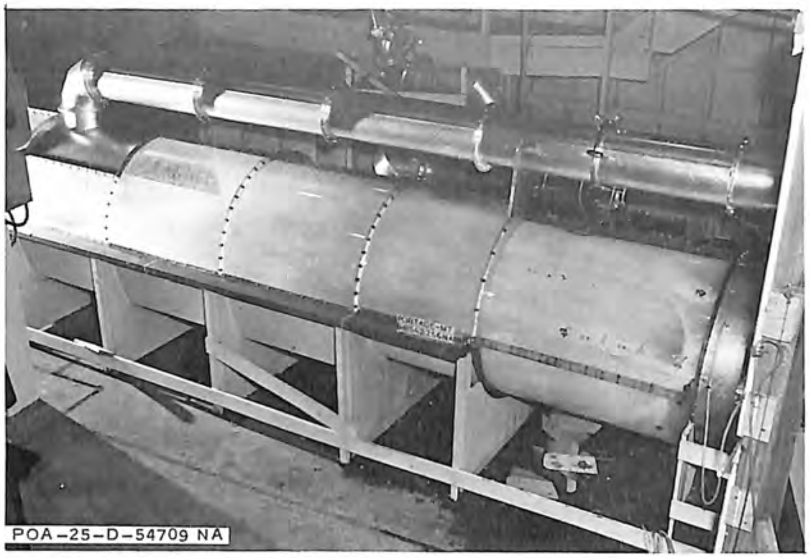
PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
OPERATION WITH DOKAN FILLET
1:14 SCALE MODEL

Number and arrangement of baffles	Tunnel discharge* (cfs)	Mean velocity at Sta 13+67 (ft/sec)	Conjugate Depths for Hydraulic Jump		Total energy at Sta 13+67 ($h_v + d_1$) (ft)
			d_1 (measured at Sta 13+67) (ft)	d_2 Computed (ft)	
Fourth Design, 2 rows of baffles 8 total	11, 300	38.6	8.6	23.5	31.7
	10, 300	36.5	8.4	21.2	29.1
Upstream row removed	11, 300	40.0	8.4	24.2	33.3
Five baffles in down-stream row	10, 300	37.7	8.2	21.7	30.3
All baffles removed	11, 300	45.2	7.6	26.0	39.3
	10, 300	42.9	7.4	23.5	36.0
Ring deflector and baffles removed	10, 300	71.5	About 5.0	31.0 (jump swept out of tunnel)	84.5

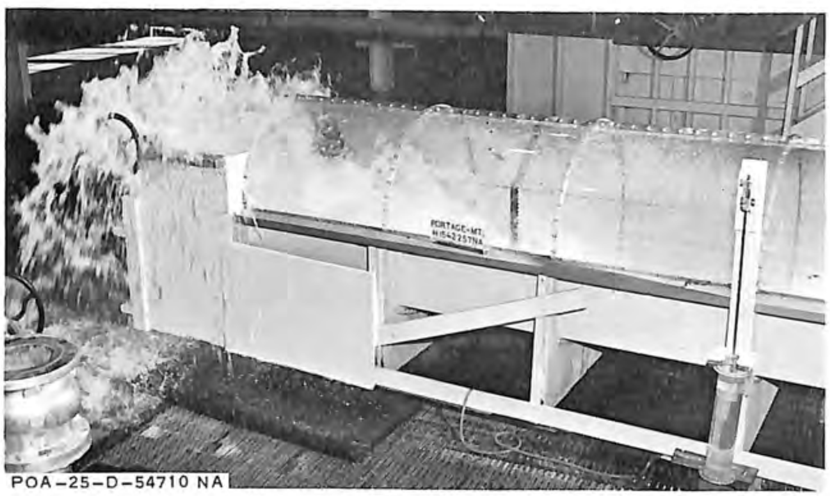
*Valves fully open

PORTAGE MOUNTAIN DEVELOPMENT
Low-level Outlet Works
Flow Energy at Sta 13+67
1:14 Scale Model

Figure 25
Report No. Hyd-562



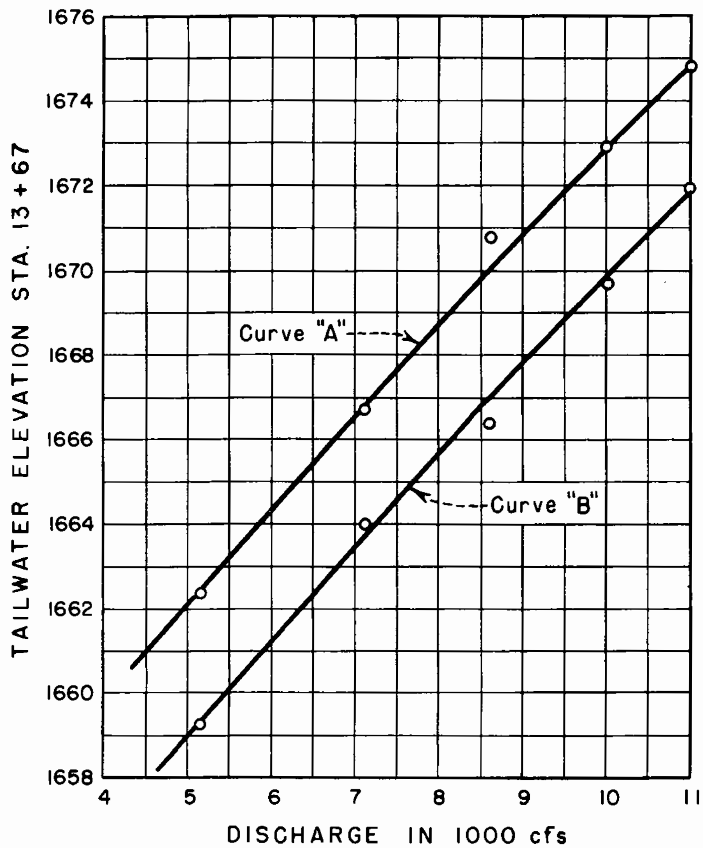
A. Jet trajectory from barrel liner extends beyond entrance to overhead air tunnel.



B. Flow sweeps out of tunnel.

RESERVOIR ELEVATION 2125, Q = 10,000 cfs
NO PORTAL WEIR

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
OPERATION WITH RING DEFLECTOR AND BAFFLES REMOVED
1:14 SCALE MODEL



EXPLANATION

Curve "A" is the tailwater required to maintain the toe of jump at Sta. 16+78

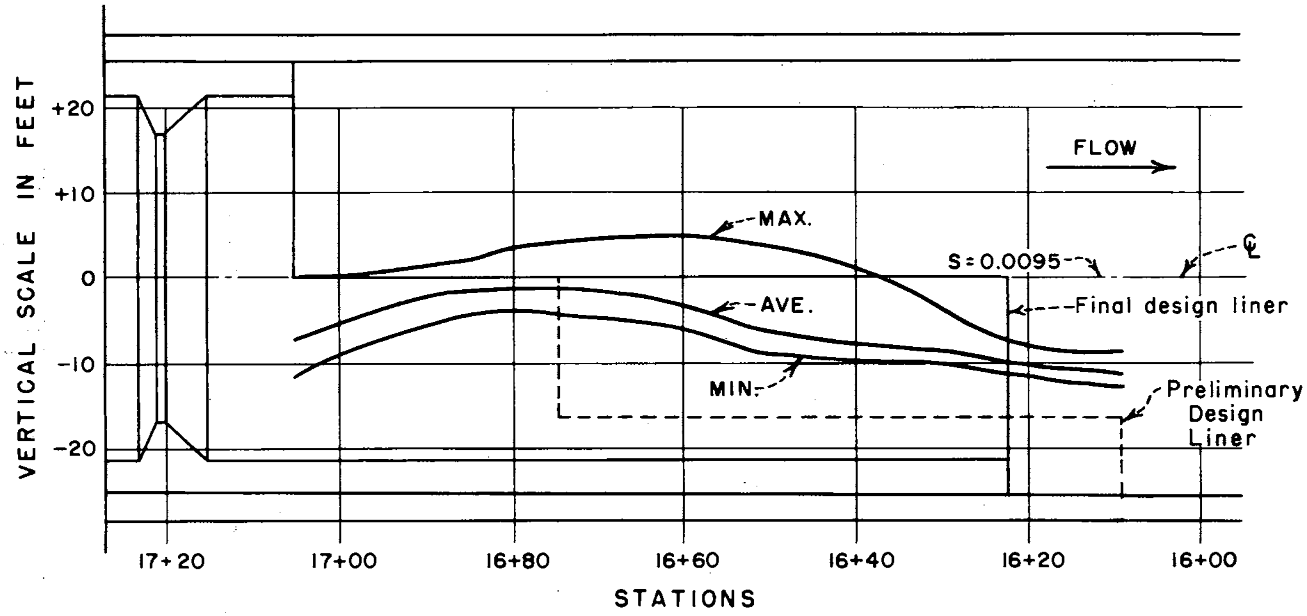
Curve "B" is the tailwater required to maintain the toe of jump at Sta. 16+36

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

TAILWATER REQUIREMENTS FOR A HYDRAULIC JUMP
FINAL DESIGN

1 : 14 SCALE MODEL

VALVES FULLY OPEN DISCHARGING 11,100 CFS



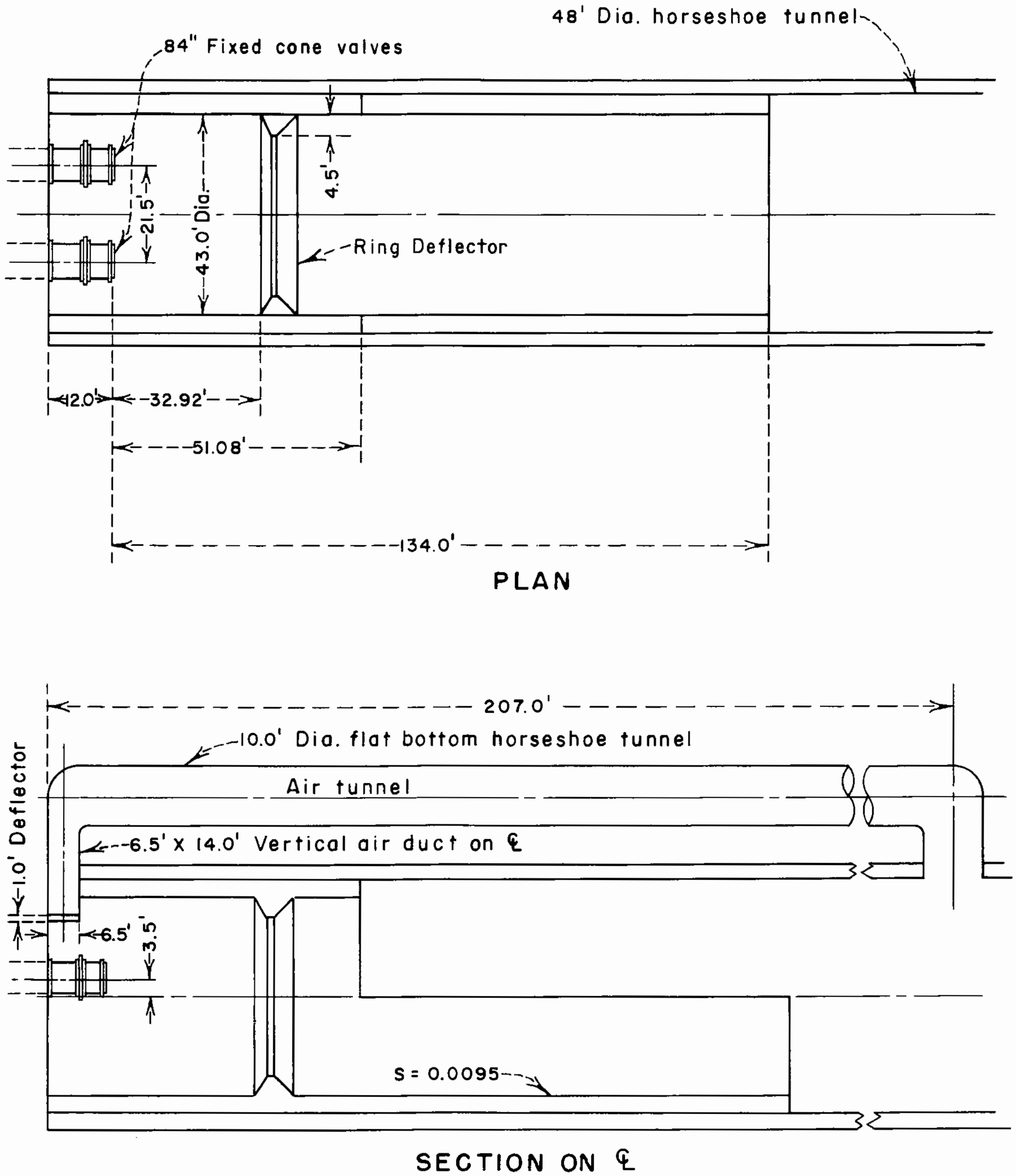
EXPLANATION

Ave. - Average impingement profile of the main flow.
Max. - Average maximum profile of waves and spray.
Min. - Average minimum profile of the main flow.

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

WATER SURFACE PROFILE THROUGH THE LINED SECTION

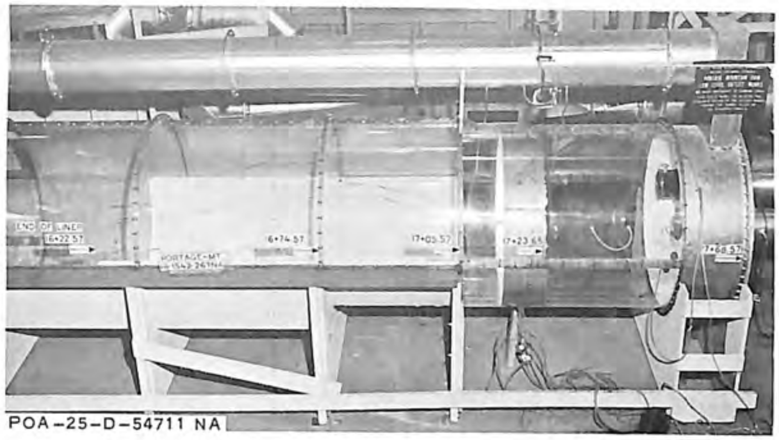
1 : 14 SCALE MODEL



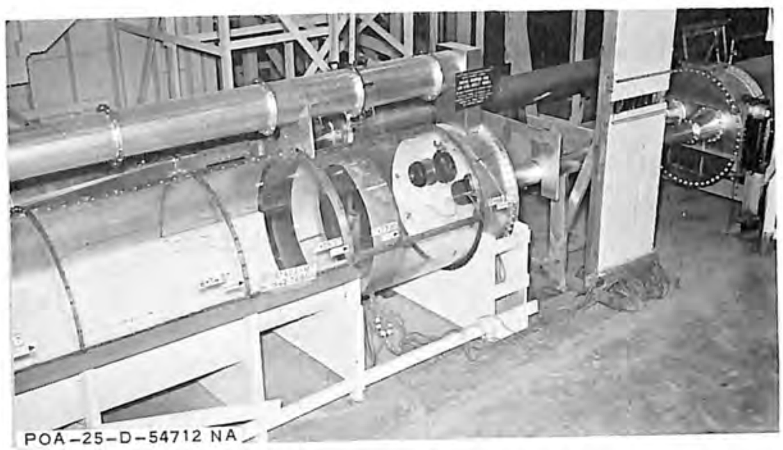
PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

FINAL DESIGN

1 : 14 SCALE MODEL



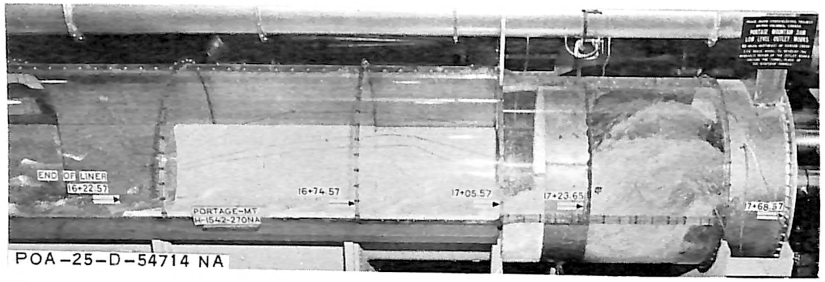
Side view of lined section



Angle view of lined section

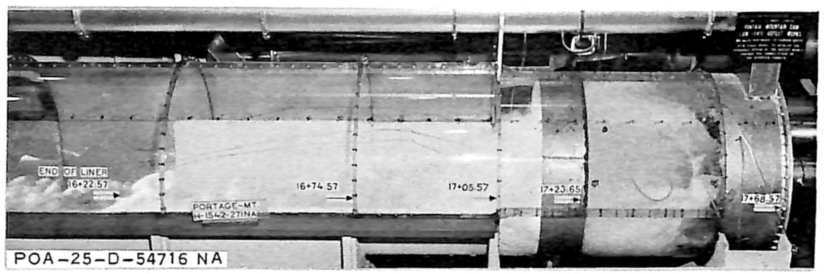
Looking upstream

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
FINAL DESIGN (MODEL)
1:14 SCALE MODEL

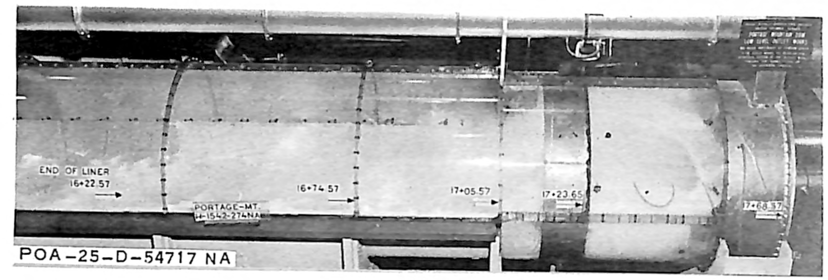


RESERVOIR ELEVATION 1700, Discharge 2, 500 cfs

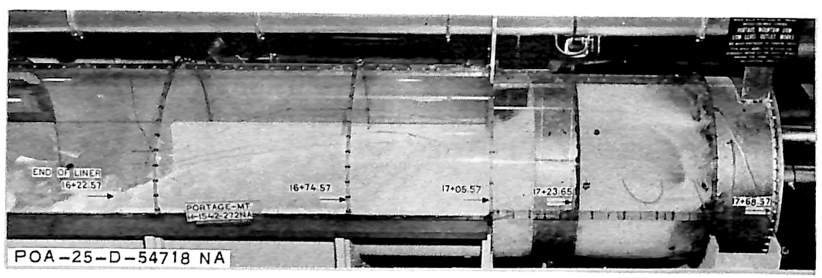
RESERVOIR ELEVATION 2000, Discharge 8, 500 cfs



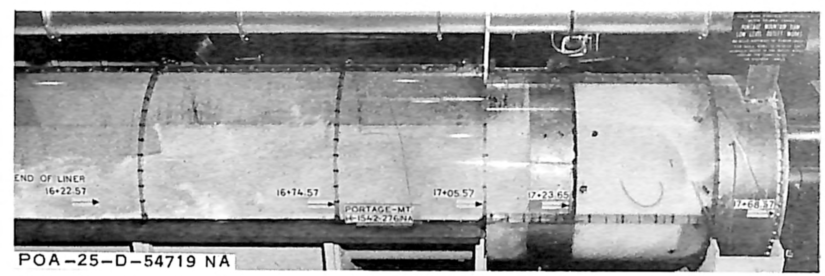
RESERVOIR ELEVATION 1780, Discharge 4, 900 cfs



RESERVOIR ELEVATION 2125, Discharge 10, 000 cfs



RESERVOIR ELEVATION 1900, Discharge 7, 100 cfs

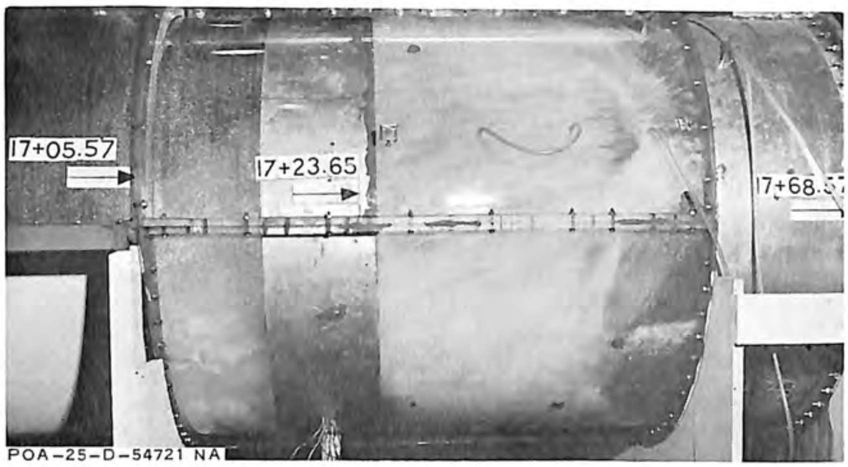


RESERVOIR ELEVATION 2225, Discharge 11, 100 cfs

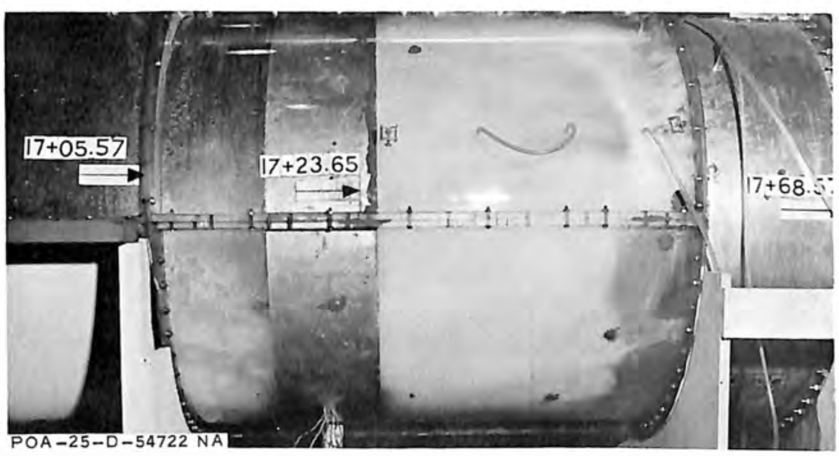
Note: Valves fully open

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
FINAL DESIGN
DISCHARGE THROUGH THE LINED SECTION

RESERVOIR ELEVATION 1700, Discharge 2,500 cfs



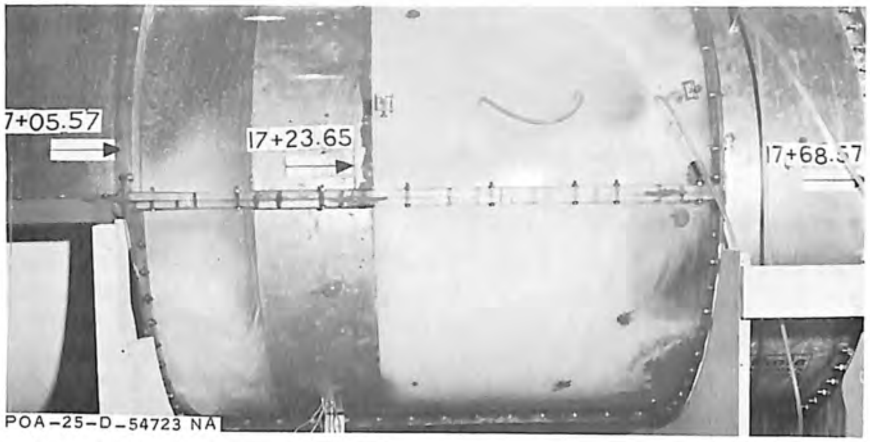
RESERVOIR ELEVATION 1780, Discharge 4,900 cfs



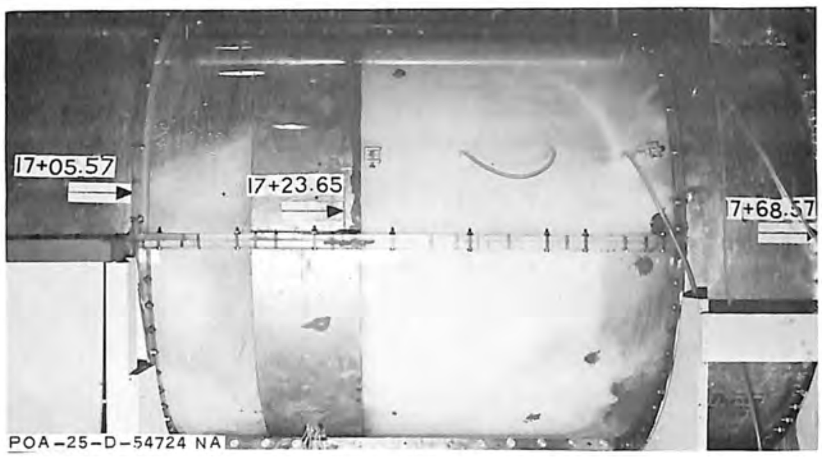
RESERVOIR ELEVATION 1900, Discharge 7,100 cfs

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
FINAL DESIGN
DISCHARGE THROUGH THE BARREL LINER
1:14 SCALE MODEL

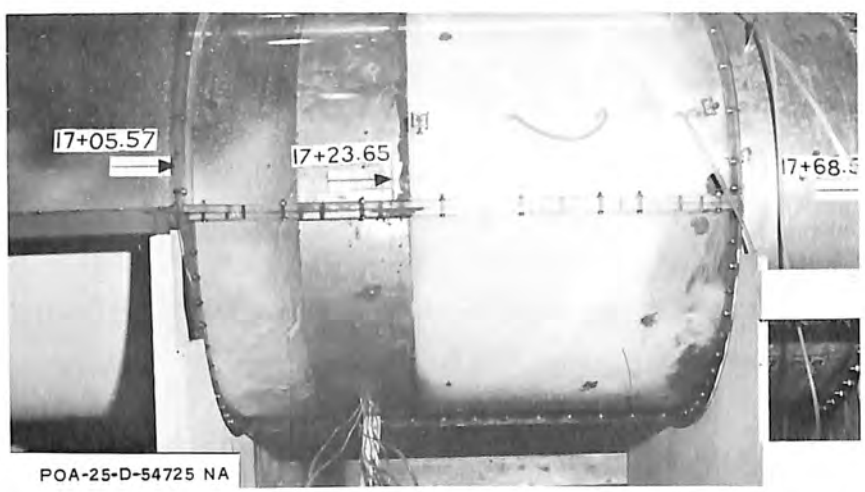
Figure 32
Report No. Hyd-562



RESERVOIR ELEVATION 2000, Discharge 8,500 cfs



RESERVOIR ELEVATION 2125, Discharge 10,000 cfs



RESERVOIR ELEVATION 2225, Discharge 11,100 cfs

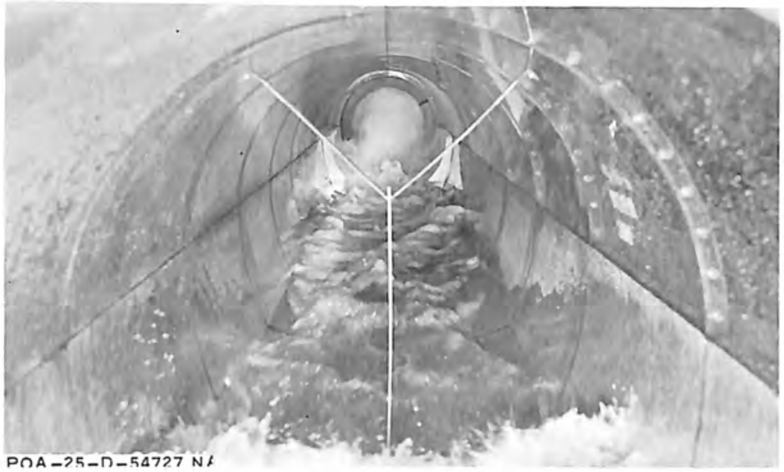
Note:
Valves fully open

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
FINAL DESIGN
DISCHARGE THROUGH THE BARREL LINER
1:14 SCALE MODEL

Figure 33
Report No. Hyd-562

Flow through lined section

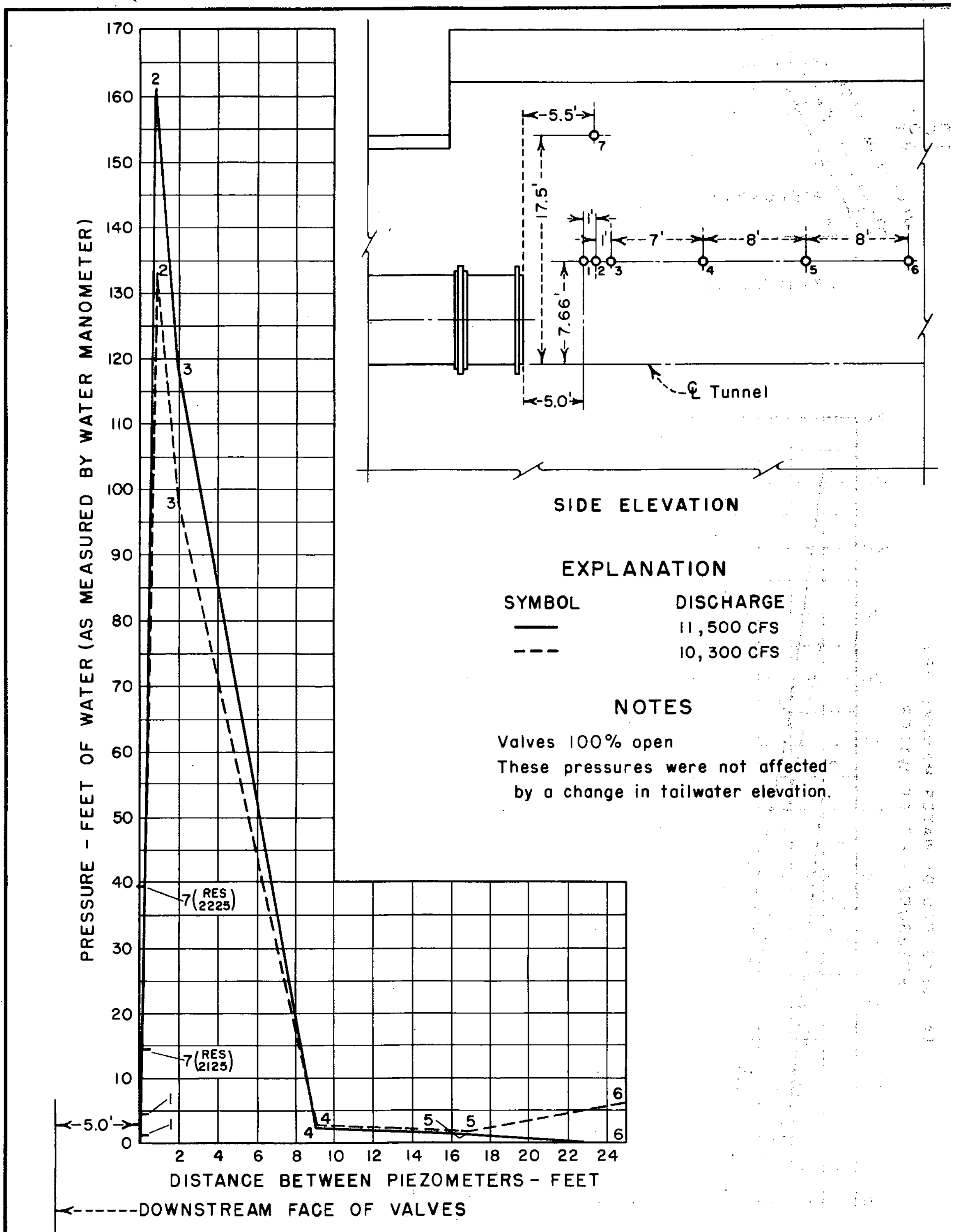
Note:
Valves about
30 percent open.



Looking upstream

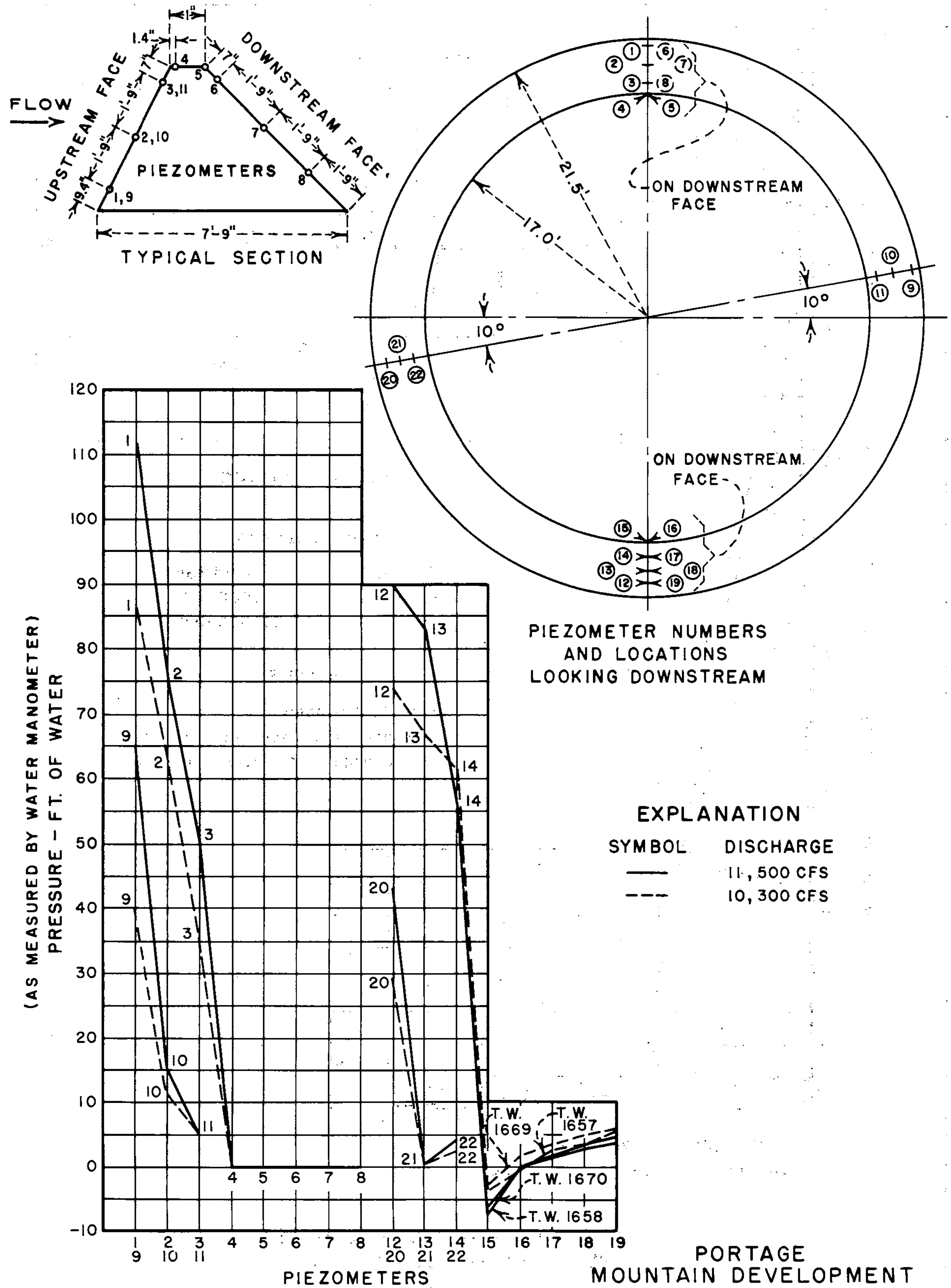
Flow through barrel liner

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
FINAL DESIGN
RESERVOIR ELEVATION 2125, DISCHARGE 5,000 CFS
1:14 SCALE MODEL



PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

LINER WALL
PIEZOMETERS AND PRESSURES
1 : 14 SCALE MODEL



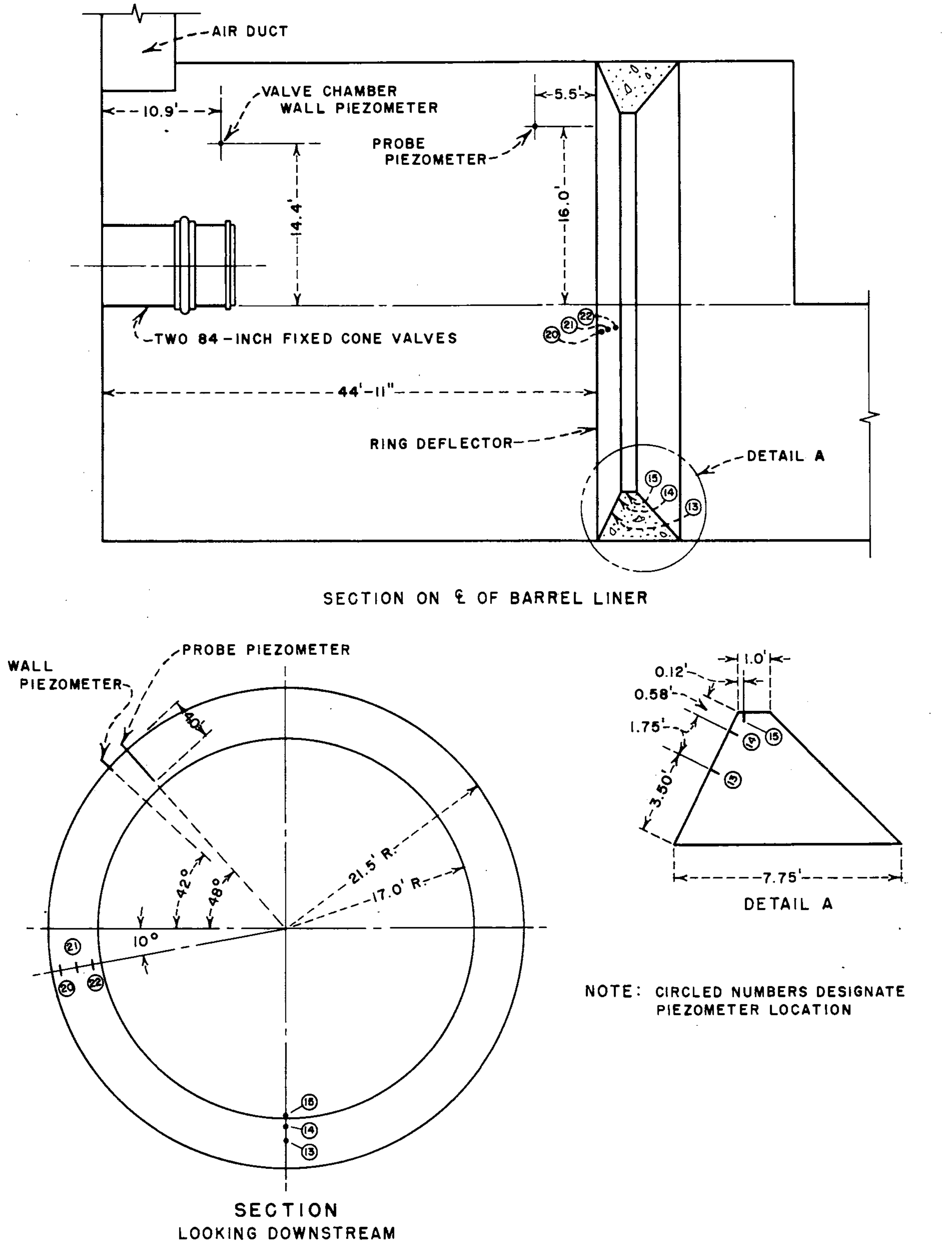
PORTAGE
MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
RING DEFLECTOR
PIEZOMETERS AND PRESSURES
1 : 14 SCALE MODEL

Discharge in cfs	T. W. el in ft	Piezometers	Pressures in feet of water: Ex min***	Min	Avg	Max	Ex max***	No. of pressure fluctuations/second: Average No.	Avg No. reaching max press	Avg No. reaching min press
10,300	1657 & 1669	1*	-12	-4	3	11	49	19	3.9	3.9
10,300	1657 & 1669	2*	VP	-10	130	310	430	15	2.7	0.9
10,300	1657 & 1669	3*	7	58	112	210	322	19	5.8	4.0
10,300	1657 & 1669	4*	-5	-3	2	7	10	25	--	--
10,300	1657 & 1669	5*	-10	-3	1	6	24	19	1.6	2.2
10,300	1657 & 1669	6*	-6	0	4	12	39	16	2.4	2.0
11,500	1658 & 1670	1*	-17	-6	2	14	49	17	4.8	3.5
11,500	1658 & 1670	2*	-30	28	196	378	476	14	3.2	2.3
11,500	1658 & 1670	3*	-7	56	126	224	350	18	3.7	2.4
11,500	1658 & 1670	4*	-10	-1	3	7	15	25	2.5	2.9
11,500	1658 & 1670	5*	-11	-3	1	6	24	19	3.3	2.5
11,500	1658 & 1670	6*	-6	0	6	14	42	15	3.7	2.3
10,300	1669 & 1657	12**	0	28	77	140	220	13	1.7	1.0
10,300	1669 & 1657	13**	0	24	70	133	160	7	0.6	0.5
10,300	1669 & 1657	14**	-28	7	47	94	160	12	2.9	2.9
10,300	1669 & 1657	15**	VP	-22	2	14	44	5	1.1	0.7
11,500	1670 & 1658	12**	-7	35	91	175	250	12	2.0	1.7
11,500	1670 & 1658	13**	-7	35	84	160	225	7	0.8	1.0
11,500	1670 & 1658	14**	VP	0	66	150	230	12	2.3	1.6
11,500	1670 & 1658	15**	VP	-30	-7	17	39	6	1.1	0.8

*Piezometers in wall of liner.
**Piezometers in ring deflector.
***Extreme maximum or minimum.
Zero pressure is atmospheric.
VP = vapor pressure.

PORTAGE MOUNTAIN DEVELOPMENT
Low-level Outlet Works
Dynamic Pressures in Barrel Liner and Deflector Ring
1:14 Scale Model

Figure 36
Report No. Hyd-562



PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

BARREL LINER PIEZOMETER LOCATIONS

1 : 14 SCALE MODEL

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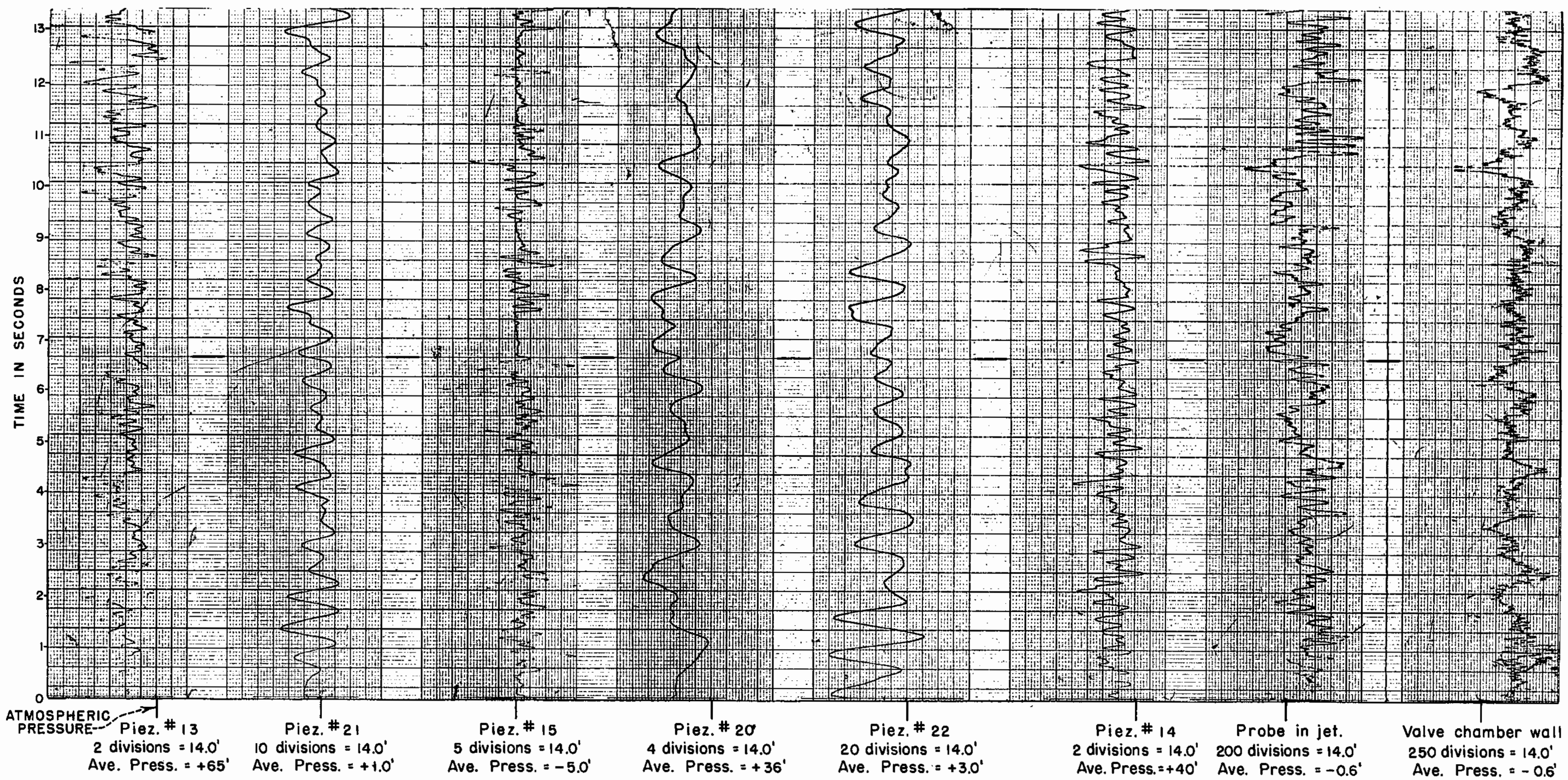


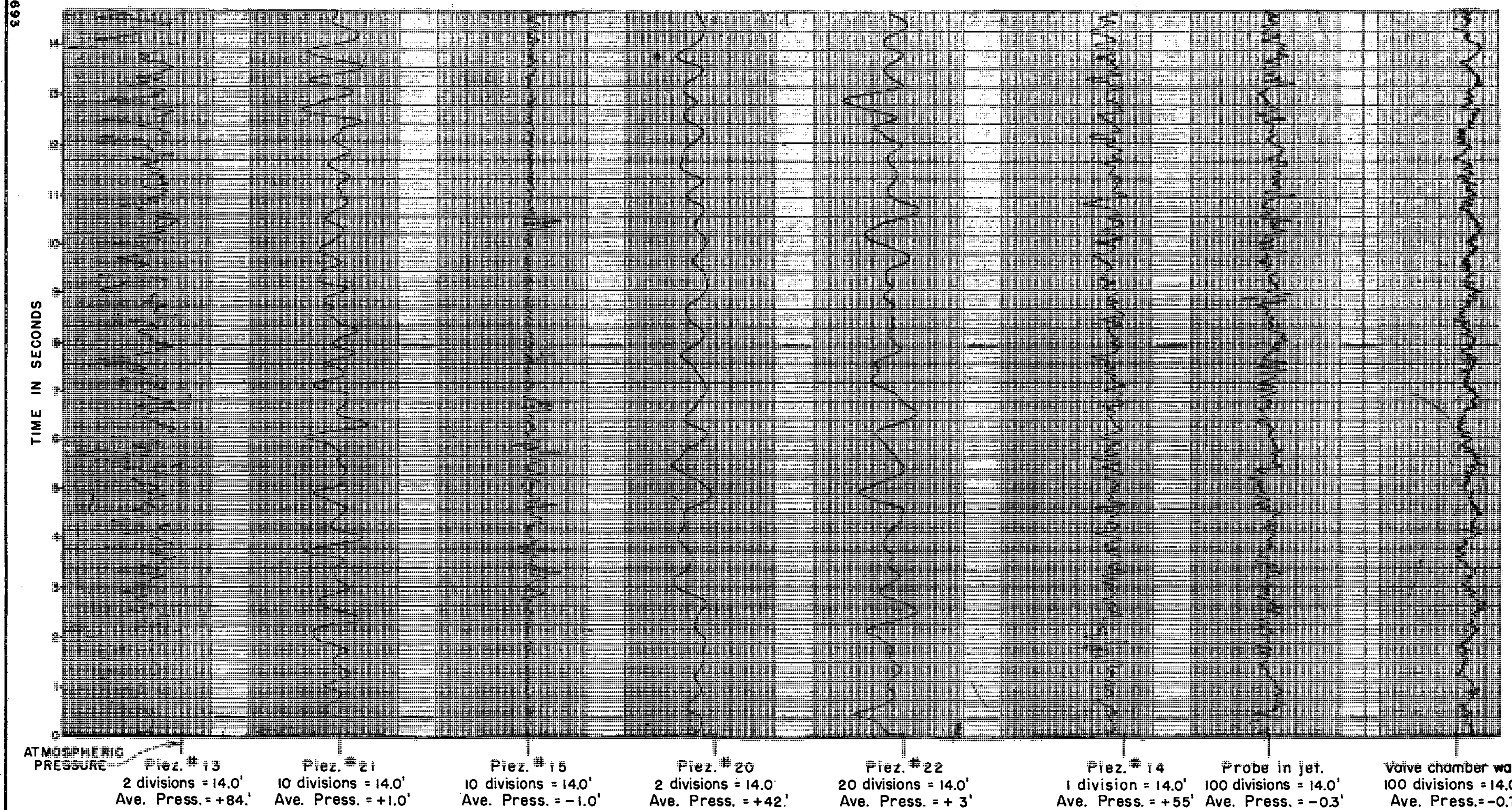
For explanation, see Figure 37

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

SIMULTANEOUS DYNAMIC PRESSURES - VALVES FULLY OPEN - RESERVOIR ELEVATION 2125

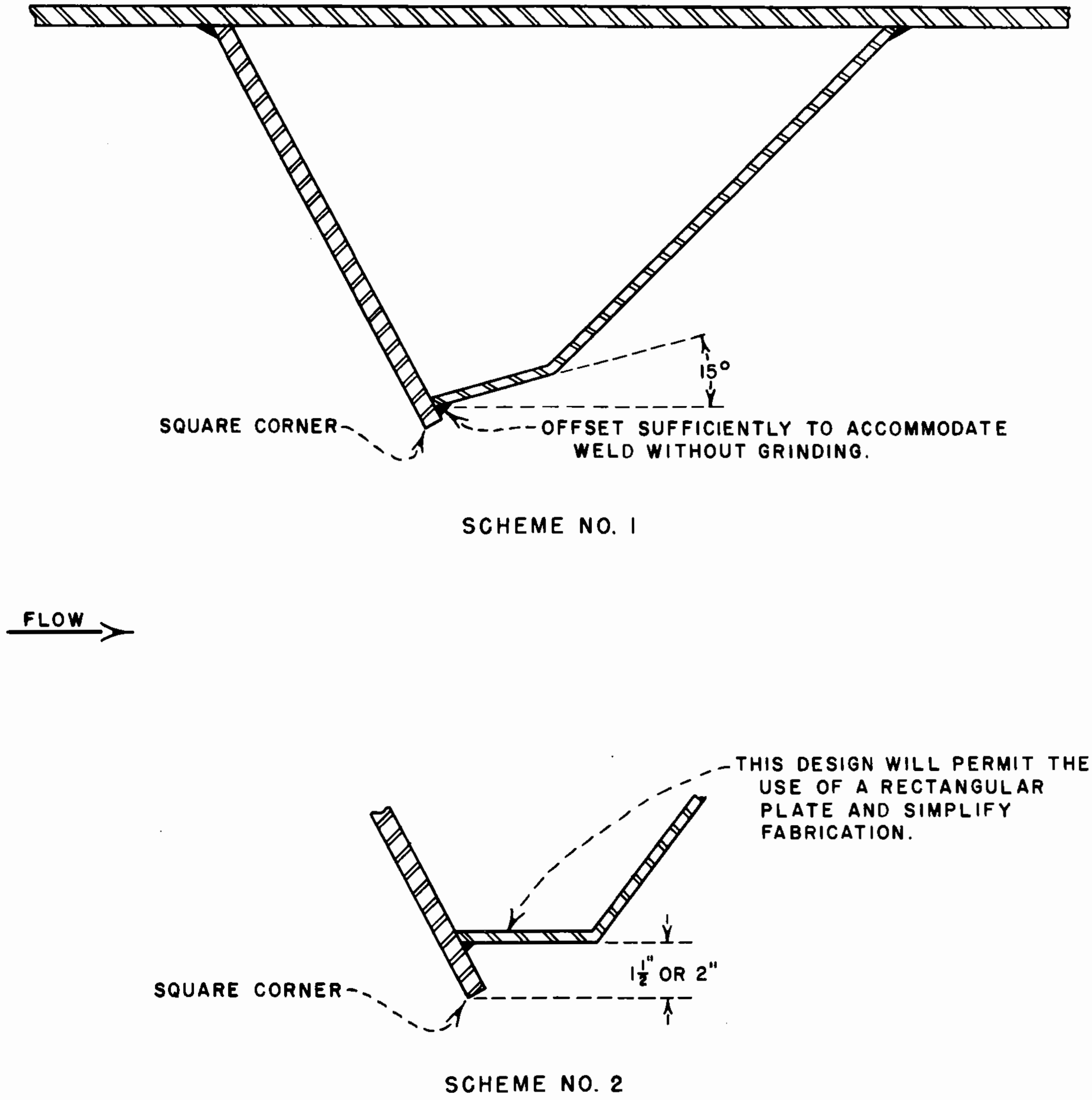
1 : 14 SCALE MODEL

FIGURE 38
REPORT HYD 562



For explanation, see Figure 37

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
SIMULTANEOUS DYNAMIC PRESSURES — VALVES FULLY OPEN — RESERVOIR ELEVATION 2225
1 : 14 SCALE MODEL



PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

PROPOSED MODIFICATIONS TO RING DEFLECTOR

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Figure 41
Report No. Hyd-562

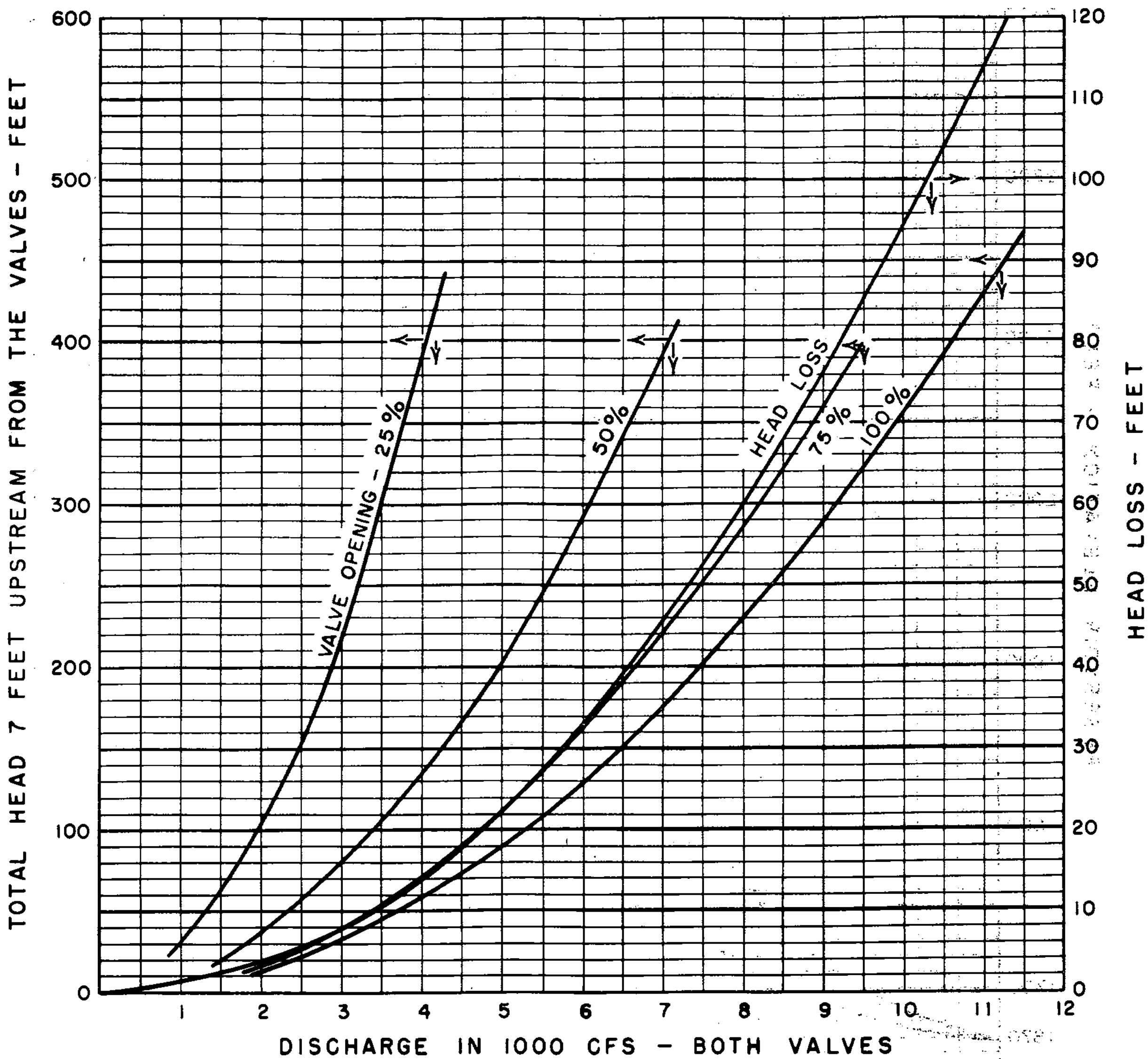
Note:
Right valve
fully open.
Left valve closed.
Discharge 5,000 cfs.

Flow through lined section

Looking upstream

Flow through barrel liner

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
FINAL DESIGN
RESERVOIR ELEVATION 2125--ONE-VALVE OPERATION
1:14 SCALE MODEL



NOTATION: HEAD LOSS FROM DIVERSION TUNNEL ONE DIAMETER UPSTREAM OF PLUG TO CONDUIT ONE DIAMETER UPSTREAM OF VALVE = ENTRANCE LOSS + CONDUIT FRICTION LOSS.

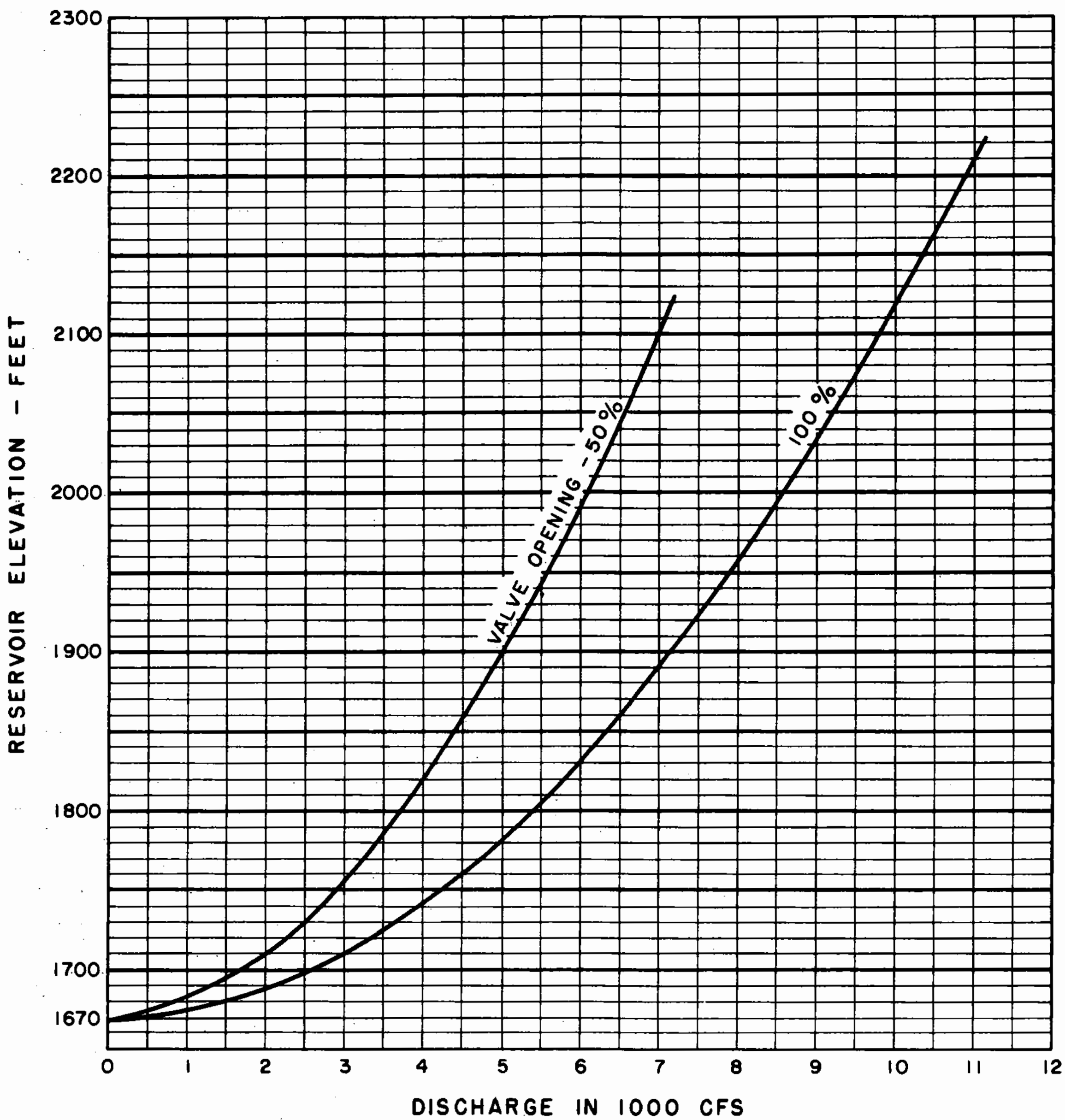
FRICTION LOSS = $f\,(L/D)(V^2/2g)$

ENTRANCE LOSS = $0.1\,(V^2/2g)$

WHERE f = 0.0096
L = 200.00
D = 7.00
V = VELOCITY IN CONDUIT

℄ VALVES AT ELEVATION 1669.96

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS
DISCHARGE AND HEAD LOSS CURVES
1 : 14 SCALE MODEL



Reservoir Elevation is equal to
Total Head @ valves plus H_L from valves to reservoir

PORTAGE MOUNTAIN DEVELOPMENT
LOW LEVEL OUTLET WORKS

DISCHARGE CAPACITY CURVES
TWO 84 - INCH FIXED CONE VALVES

1 : 14 SCALE MODEL

APPENDIX

Studies to Develop an Energy Dissipator for Jet-flow Gates

Purpose

The purpose of this phase of the model study was to develop the hydraulic design of Portage Mountain Development low-level outlet works utilizing two 84-inch jet-flow gates in each of two diversion tunnels.

Summary

The above-atmospheric pressures obtained at all operating conditions showed that the shape of the bellmouth entrances was satisfactory. Head losses through the model bellmouth entrances and conduits down to the valves closely represented the computed prototype losses. The discharge coefficient of the jet-flow gates was 0.83 for 100-percent opening. The size of the air vents to the gate slots and downstream conduit was increased from two 24-inch-diameter conduits to one 42-inch-diameter conduit; the maximum air demand was found to be about 2,000 cfs per gate, resulting in a velocity of about 210 feet per second through the 42-inch conduits. The steel liner downstream from the face of the tunnel plug should be lengthened several hundred feet.

A stilling basin 300 feet long with the floor 26 feet below the tunnel invert was required to adequately still the flow. In addition to the basin, a 9-foot-high weir was needed at the downstream portal to provide sufficient tailwater depth for the hydraulic jump; the weir height cannot exceed 9 feet to avoid surges from the hydraulic jump sealing the tunnel. The tunnel must be free of debris to avoid erosion of the concrete by abrasive action of material in the hydraulic jump.

INTRODUCTION

The initial investigations were concerned with developing an energy dissipator when the outlet works flow was controlled by jet-flow gates. Flow characteristics in the bellmouth entrances, the jet-flow gates, tunnel plugs, and the downstream portal were also studied, Figures 1 and 2.

Tests were made with both jet-flow gates simultaneously discharging the maximum capacity of approximately 10,000 and 11,000 cfs at reservoir elevations 2125 and 2225, respectively. Tests were also performed with the gates partially open for flows as low as 5,000 cfs at reservoir elevation 2125 and with the gates fully open for reservoir elevations ranging from 1,700 to 2,200 feet. One valve operation was also studied.

THE MODEL

The model was a 1:24 scale reproduction of Diversion Tunnel 2 extending from 288 feet upstream of the tunnel plug down to and including the outlet portal.

The bellmouth entrances to the two conduits through the tunnel plug were machined out of clear plastic; the conduits between the bellmouths and the jet-flow gates were 3-1/2-inch-diameter sheet metal pipes. The jet-flow gates were constructed of brass, and the conduits downstream from the gates to the downstream end of the tunnel plug were 4-inch-diameter clear plastic pipes.

The 48-foot-diameter horseshoe tunnel downstream from the plug had a sheet metal invert and a clear plastic semicircular top.

The model diversion tunnel was shortened about 23 percent to provide flow velocity similitude between the model and prototype at the exit portal. This correction was based on estimated Manning's roughness coefficients (n) of 0.009 for sheet metal and 0.012 for concrete.

The operating head on the gates was measured 1-tunnel diameter upstream from the plug and flow was regulated by simultaneously adjusting the opening of the jet-flow gates and the discharge.

Tailwater elevation was controlled by means of an adjustable gate at the end of the tail box and was measured by a staff gage located in the downstream end of the discharge channel.

THE INVESTIGATION

The Bellmouth Entrances

Previous studies1/ have shown that the bellmouth entrances to the conduits in the plug should be located a minimum distance away from the boundaries of the diversion tunnels and properly spaced to prevent subatmospheric pressures from occurring on the bellmouth

1/Bureau of Reclamation Hydraulic Laboratory Report Hyd-470, "Aerodynamic Model Studies of the Outlet Works Intake Structure for Twin Buttes Dam, San Angelo Project, Texas," by D. Colgate.

surfaces. Twenty piezometers were installed on one of the model bellmouths (five each on the crown, invert, and two sides) to confirm these criteria. These piezometers showed that the bellmouth pressures were above atmospheric and therefore satisfactory during operation with both gates either partially or fully opened (Fig. 3). Similarly, all pressures were satisfactory with one gate fully closed.

The pressure data, expressed as a dimensionless pressure factor, $\frac{\Delta h}{h_v}$, are given in Figure 4. Δ_h equals the piezometric pressure referred to the conduit centerline minus the conduit centerline pressure 53.82 feet downstream from the bellmouth, and h_v equals the velocity head $\frac{V^2}{2g}$ in the conduit.

In the final design, the bellmouths were placed higher in the plug to provide a rock trap in the diversion tunnel and to steepen the angle of flow from the conduits into a proposed stilling basin. Since the bellmouths were no closer to the tunnel boundary than in the preliminary design, the pressure measurements were not repeated.

The head loss from the diversion tunnel to a point 1-pipe diameter upstream from the gate valves was measured for 2,500 cfs per valve at reservoir elevations 2100 and 2200 and for 5,000 cfs at reservoir elevation 2100. These measurements indicated that the model loss closely represented the computed prototype losses and varied from about 0.12- to 0.18 $\frac{V^2}{2g}$.

Jet-flow Gates

The Portage Mountain 84-inch jet-flow gates were patterned after the gates used for the Trinity Dam auxiliary outlet works2/, Figure 5. Coefficients of discharge computed from the model discharge capacity calibration data, Figure 6, were almost identical to those determined for the Trinity jet-flow gates.

Pressures in the 8-foot-diameter conduit were slightly subatmospheric immediately downstream from the gate slot for the operating

2/Bureau of Reclamation Hydraulic Laboratory Report Hyd-472, "Hydraulic Model Studies of the Trinity Dam Auxiliary Outlet Works Jet-Flow Gate, Central Valley Project, California," by W. P. Simmons, Jr.

condition of 2,500 cfs per gate at reservoir elevation 2100. Pressures 40° from the invert were about 2 feet below atmospheric compared to about 5 feet below atmospheric at the invert piezometers in this region. However, these low-pressure areas appeared to be in an area where the jet had not yet expanded to fill the conduit and were probably due to lack of sufficient air supply from the vents rather than from the flowing water. For 5,000 cfs per gate at reservoir elevation 2100, the subatmospheric pressures were approximately 10 feet below atmospheric both at the invert and 40° from the invert, and the subatmospheric pressure region appeared to extend more than 1 diameter downstream from the gates. These pressures also appeared to be in the vented area rather than in the area where the flow was in contact with the boundaries; therefore, additional piezometers were installed farther downstream to determine the pressure pattern in the region of flow contact with the walls.

The additional piezometers showed that as the gates were opened, the point of impact of the jet moved downstream. Upstream of the impact area, pressures were below atmospheric; in the impact area the pressures were well above atmospheric; and downstream from the impact area the pressures were near atmospheric.

The size of the air vent was increased from two 24-inch-diameter conduits to one 42-inch-diameter conduit to alleviate the low pressures in the conduit downstream from the gate slots. The increased air supply reduced the instantaneous minimum subatmospheric pressure from 24 feet of water below atmospheric to only 5 feet below atmospheric.

Air demand measurements showed that the airflow increased with increase in head or with increase in gate opening. In general, the ratio of airflow to waterflow increased as the gate opening decreased or as the head increased. These data agreed with the Trinity Dam jet-flow gate test data.

Maximum air demand was approximately 2,000 cfs per conduit supplied through one 42-inch-diameter air duct into the air chamber. Velocity of the air through the duct would be approximately 210 feet per second which is below the recommended maximum limit of 300 feet per second.

Flow Downstream from the Tunnel Plug

In the preliminary design, the conduits were to be placed no closer than 12 inches from the walls of the 42-foot-diameter steel liner, Figure 1. The 150-foot-long liner was installed in the model horseshoe tunnel so that it was tangent to a point on the outside wall of the conduit portals, and an offset existed between the conduits and the liner on either side of the point of tangency. Piezometers were installed in this area, and the pressures did not exceed 3 to 4 feet of water below atmospheric. The jets were not submerged for the design flow of 5,000 cfs or for an emergency flow of 10,000 cfs, Figure 7.

The steel liner extended 150 feet downstream from the conduit portals and formed a vertical offset between the liner and tunnel wall. Although the liner extended beyond the impingement area of the jets, the velocity of the flow at the end of the liner was almost as high as at the conduit portal. Some of the flow backed up and submerged the undernappe of the jet at the offset which could introduce adverse pressure conditions. Therefore, it was felt that a long transition section should be placed between the liner and the horseshoe tunnel or that the liner should be extended farther downstream.

An alternative to lengthening the steel liner was to construct a stilling basin immediately downstream from the tunnel plug to dissipate the energy of the flow leaving the conduits. The model was modified to include a stilling basin and all further investigations were directed toward developing a satisfactory basin.

Stilling Basin in Tunnel

The initial stilling basin development tests were with the tunnel plug conduits placed on an 8° 30' slope discharging into a basin 40 feet wide by 343 feet long with its floor 21.5 feet below the centerline of the conduits, Figure 8. Since the computed tailwater depth at Station 11+20 (assuming critical depth at the portal Station 1+87) indicated insufficient depth to maintain the hydraulic jump within the basin at any discharge, a weir was required at or near the tunnel portal to provide sufficient d_2 or tailwater depth.

The weir height was adjusted so that the basin performed well for flows up to and including the design flow of 5,000 cfs at reservoir elevation 2100; the surging and waves that developed in the hydraulic jump for 5,000 cfs were not excessive and did not reach tunnel crown. However, the basin appeared to be longer and wider than necessary. With the same weir settings and operating at low reservoir elevations with the gates 100 percent open, the flow submerged the conduit portals at the downstream face of the tunnel plug. Although submerged operation appeared satisfactory, poor flow conditions existed during the transition zone from unsubmerged flow to submerged flow.

The inverts of the conduit portals were raised 9 feet to prevent the submergence during operation at low reservoir levels. In addition to elevating the portals, the conduits were placed 1 foot closer together and the basin was narrowed from 40 to 38 feet. The narrower basin performed well for flows up to and including the design flow of 5,000 cfs at reservoir elevation 2100. Although the conduit portals were not submerged at lower reservoir elevations, occasionally the flow from both conduits veered to one side or the other and flowed downstream along one of the side walls. Flow returning upstream along the opposite side wall nearly submerged the portal near that wall. However, the flow was sufficiently stable to be considered a satisfactory operating condition for the short time that the reservoir would be discharging at reservoir elevations below 2100.

For emergency operating conditions with either one gate operation or both gates fully open operating at maximum reservoir elevation, the performance was acceptable. However, the surging in the flow through the tunnel increased with discharge until, at 10,000 cfs, the tunnel occasionally filled. The surges did not fill the tunnel for 9,000 cfs at about reservoir elevation 2000, although waves from one side or the other sometimes reached the crown.

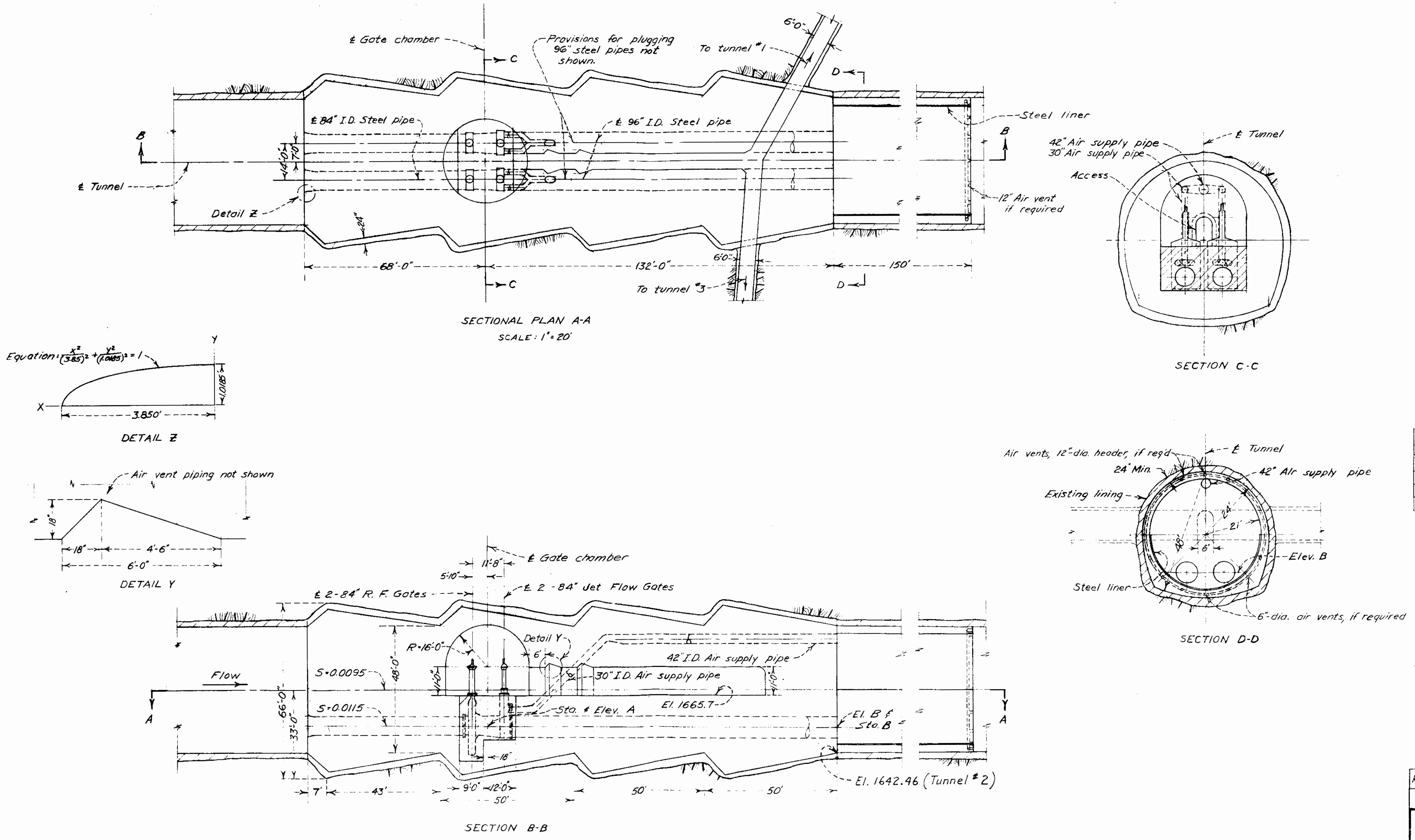
Data were obtained for this basin to determine how variation in weir height affected hydraulic characteristics of the tunnel such as the location of the jump, jump sweepout, depth of flow at the face of the tunnel plug, depth of flow in tunnel at the downstream end of basin, surges at the portal and tunnel vibration, and audible choking as caused by the surges.

These tests showed that the surges filled the tunnel near the downstream portal causing an audible belching and tunnel vibration when the weir was sufficiently high to prevent the jump from sweeping out of the basin. Based on these tests, the basin floor was lowered 11 feet to elevation 1616, the sloping apron lengthened to 190 feet, and the basin length was reduced to 300 feet to maintain the same overall length, Figure 9.

The same data obtained on the revised basin determined that the weir crest should not be higher than elevation 1649 and that the basin floor should be placed at elevation 1616. The hydraulic performance of the revised basin was very satisfactory at 5,000 cfs and acceptable at a discharge of 10,000 cfs, Figure 10. The surges at the portal occasionally came close to sealing the tunnel at flows of 10,000 and 11,000 cfs, but the audible belching effect did not occur.

At this stage in the investigation, it was decided to use fixed-cone (Howell-Bunger) valves to control the flow through the low-level outlet works and the studies on the jet-flow-gate-controlled scheme were abandoned. The decision to change the type of control was brought about by several considerations including (1) the extremely high cost and difficulties involved in the excavation and construction of stilling basins in the existing diversion tunnels, and (2) the inherent danger of placing a hydraulic jump stilling basin in the tunnel directly under the dam embankment.

This concluded the testing of the 1:24 scale model of the scheme utilizing the jet-flow gates, and the model was rebuilt for studies of the new design.



	Tunnel No.2	Tunnel No.3
℄ Gate Chamber	19+00.57	19+76.37
Sta. A	19+00.73	19+76.53
El. A	1653.58	1653.09
Sta. B	17+68.57	18+44.37
El. B	1652.06	1651.57

NOTES

Grouting details not shown.

Rev. 5-31-66 Elev., 1642.46 at Sta B, Tunnel #2, added GLB.

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TECHNICAL ASSISTANCE PROGRAM
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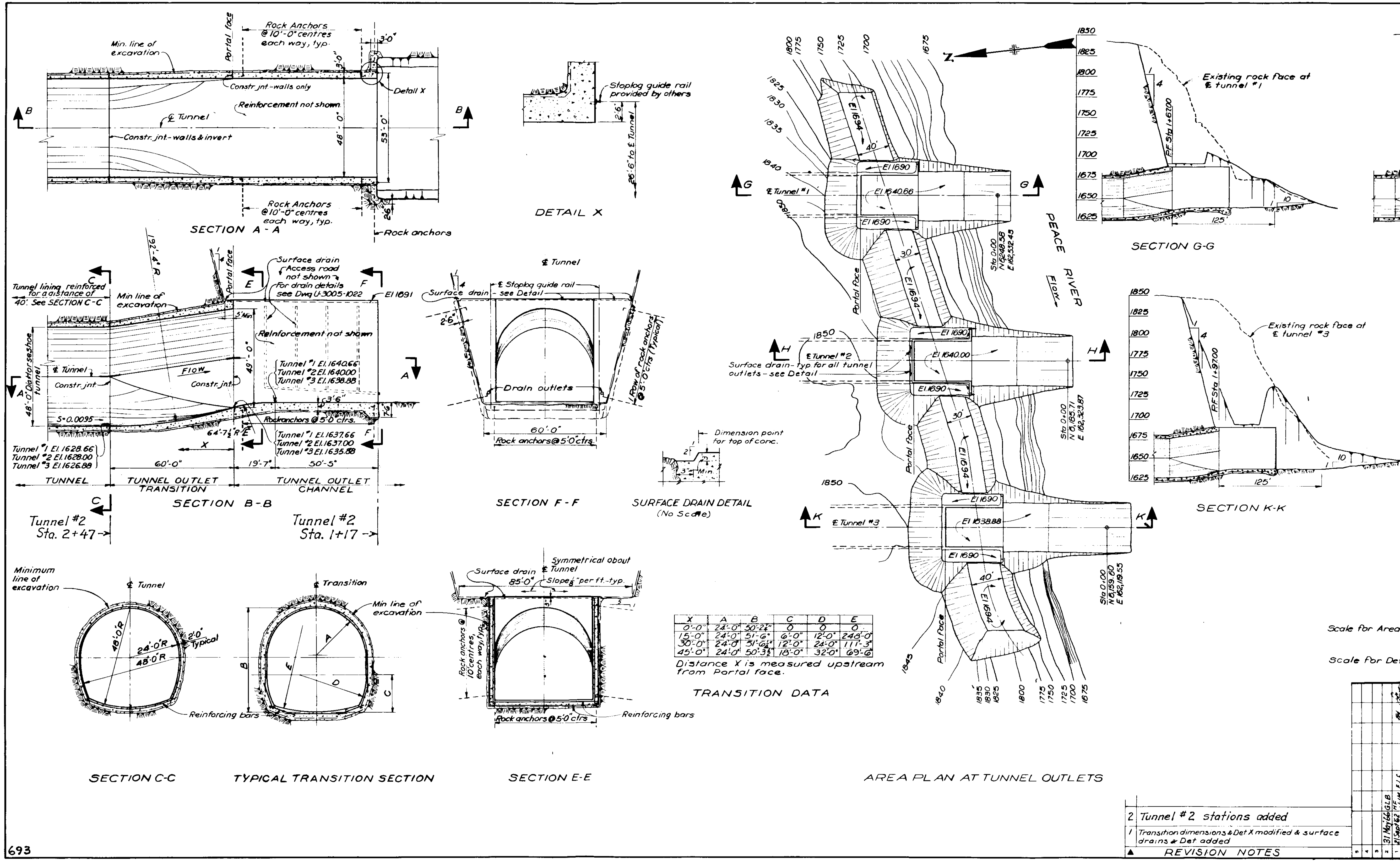
PORTAGE MTN. DAM
OUTLET WORKS
GATE CHAMBER

DRAWN R.E.F. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED

DENVER, COLO. JAN. 29, 1965 OA-25-1



TRANSITION DATA

X	A	B	C	D	E
0'-0"	24'-0"	50'-2¼"	0	0	0
15'-0"	24'-0"	51'-6"	6'-0"	12'-0"	248'-0"
30'-0"	24'-0"	51'-6¼"	12'-0"	24'-0"	111'-3"
45'-0"	24'-0"	50'-3½"	18'-0"	32'-0"	69'-6"

Distance X is measured upstream from Portal face.

NOTES

1. All concrete shown on this drawing shall be Class A 2, (5000 psi) see Specification.
2. No grouting behind concrete shall be carried out until concrete has cured for a minimum of 28 days.
3. All rock anchors shown on this drawing shall be made from No 11 reinforcing bars grouted into 2-inch dia holes drilled to a minimum depth of 10 feet into sound rock.
4. All exposed coal and shale seams on the outlet channel and powerhouse access road excavated faces to be covered with a ½ inch layer of pneumatically applied mortar as soon as possible after excavation to protect against loss of moisture.
5. Sides of outlet channel and powerhouse access road to be excavated to slopes of 4 vertical to 1 horizontal.
6. For references see Dwg U-3005-1020
7. Abbreviations:
   P.F. = Portal face
8. For details of rock anchors see Reinforcement Dwg. U-3042-4022

REFERENCE

U-3005-1020 General Arrangement

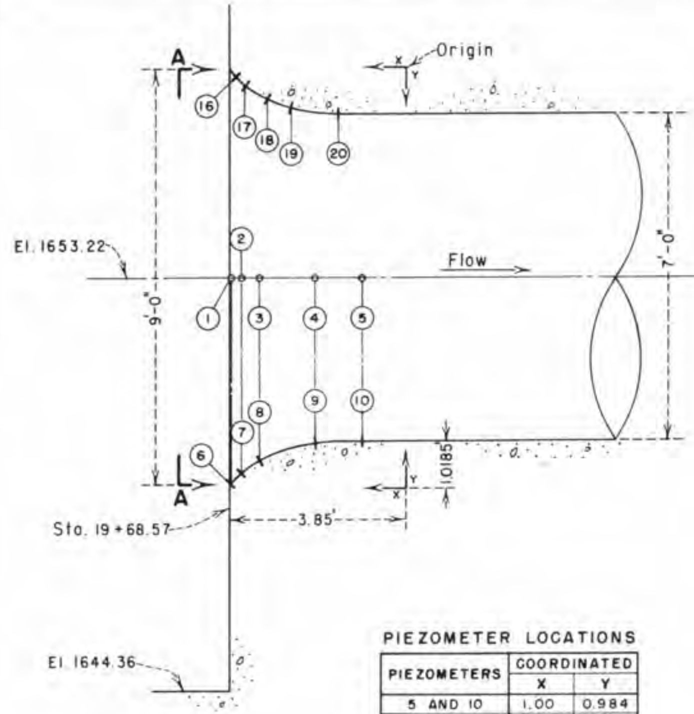
Rev	Revision Notes
2	Tunnel #2 stations added
1	Transition dimensions & Det X modified & surface drains & Det added

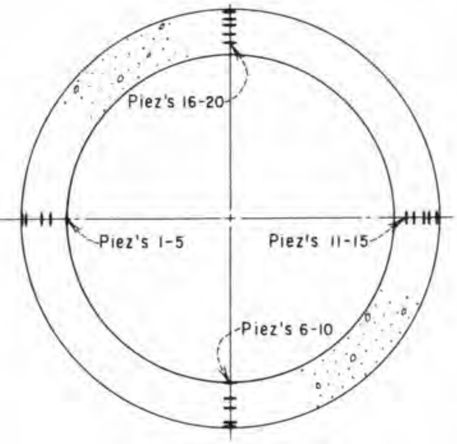
BRITISH COLUMBIA ELECTRIC COMPANY LIMITED
PORTAGE MOUNTAIN DIVERSION TUNNELS

TUNNEL OUTLETS
PLAN & SECTIONS

INTERNATIONAL POWER & ENGINEERING CONSULTANTS LTD.
VANCOUVER, B.C.

Scale: AS SHOWN
Date: DEC 1961
Contract No 3
U-3005-1023 R1

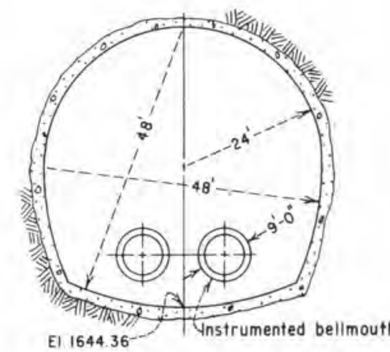




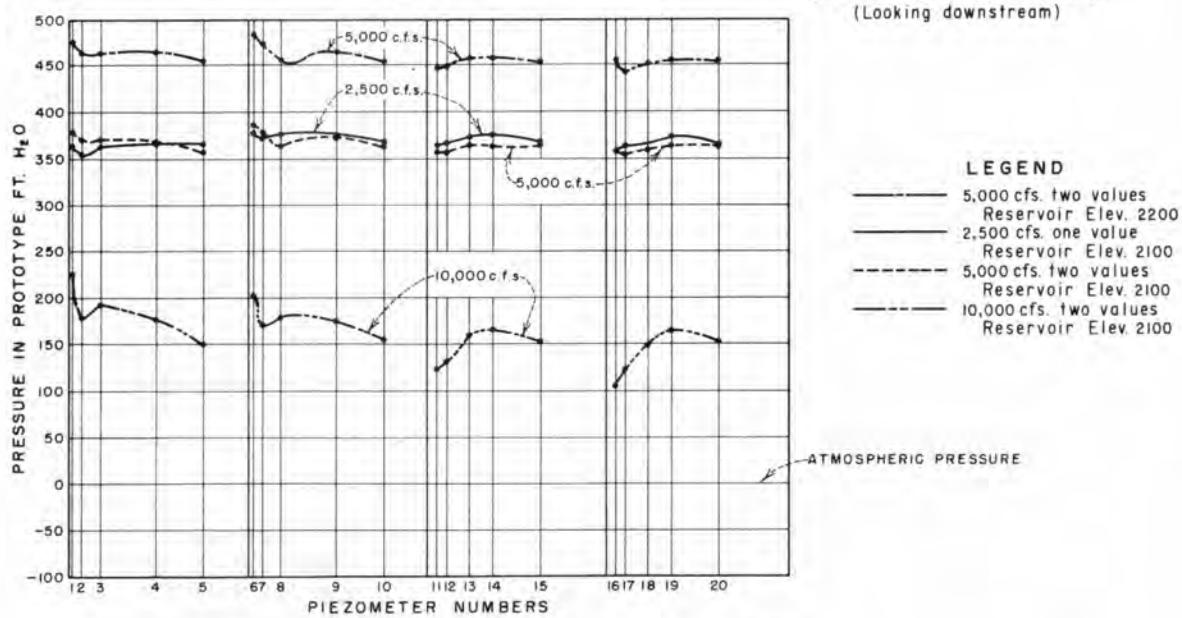
SECTION A-A

PIEZOMETER LOCATIONS

PIEZOMETERS	COORDINATED X	COORDINATED Y
5 AND 10	1.00	0.984
4 AND 9	2.00	0.870
3 AND 8	3.20	0.566
2 AND 7	3.60	0.360
1 AND 6	3.80	0.156
15 AND 20	1.50	0.944
14 AND 19	2.50	0.776
13 AND 18	3.00	0.638
12 AND 17	3.50	0.424
11 AND 16	3.70	0.280



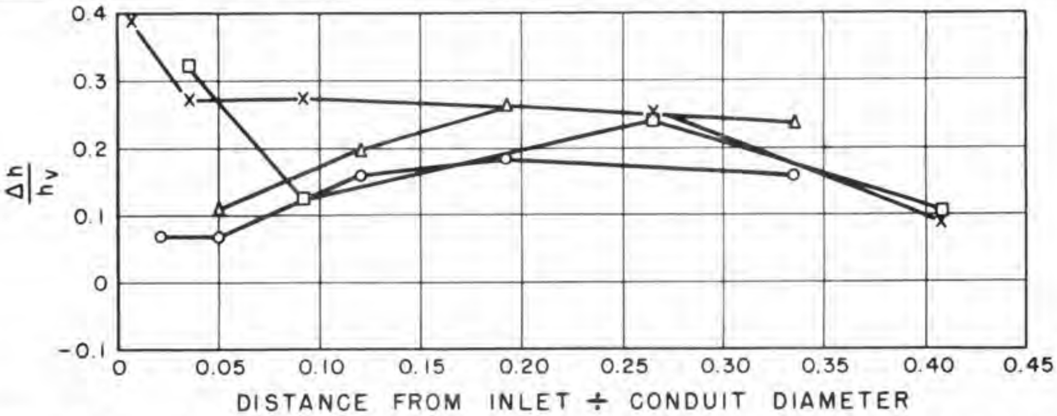
LOCATION DIAGRAM
(Looking downstream)



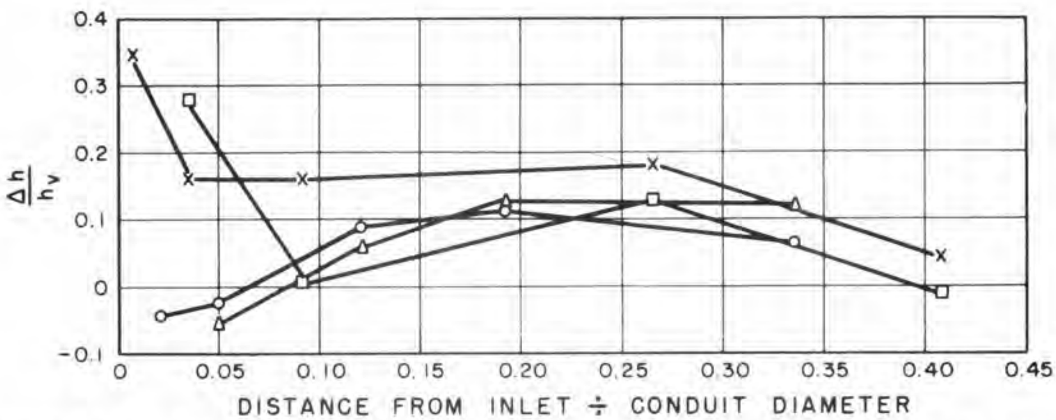
PORTAGE MOUNTAIN DAM

OUTLET WORKS
BELLMOUTH PRESSURES

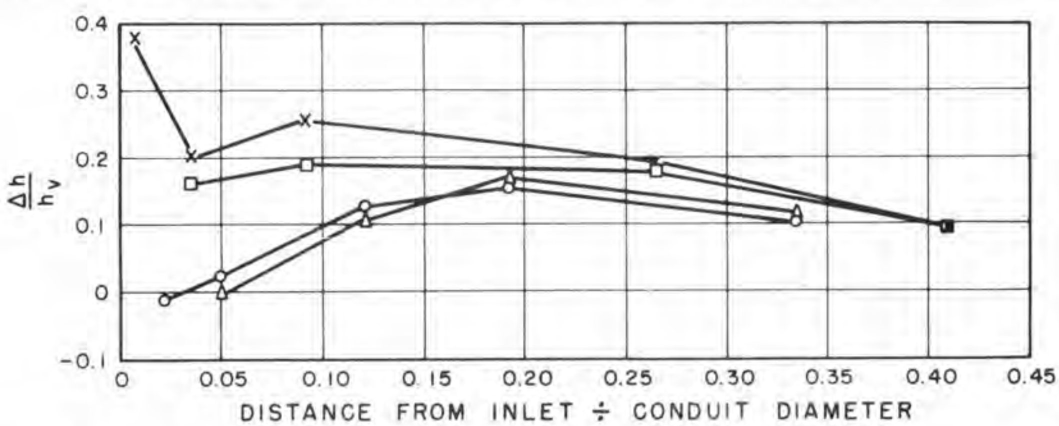
1 : 24 SCALE MODEL



DISCHARGE = 5,000 CFS, RES. EL. 2100 FT., BOTH GATES EQUALLY OPEN



DISCHARGE = 5,000 CFS, RES. EL. 2200 FT., BOTH GATES EQUALLY OPEN



DISCHARGE = 10,000 CFS, RES. EL. 2100 FT., BOTH GATES EQUALLY OPEN

NOTES

Δh = PIEZOMETER PRESSURE REFERRED TO ℄ MINUS CONDUIT PRESSURE 53.82 FT. DOWNSTREAM OF BELLMOUTH.

h_v = VELOCITY HEAD IN CONDUIT.

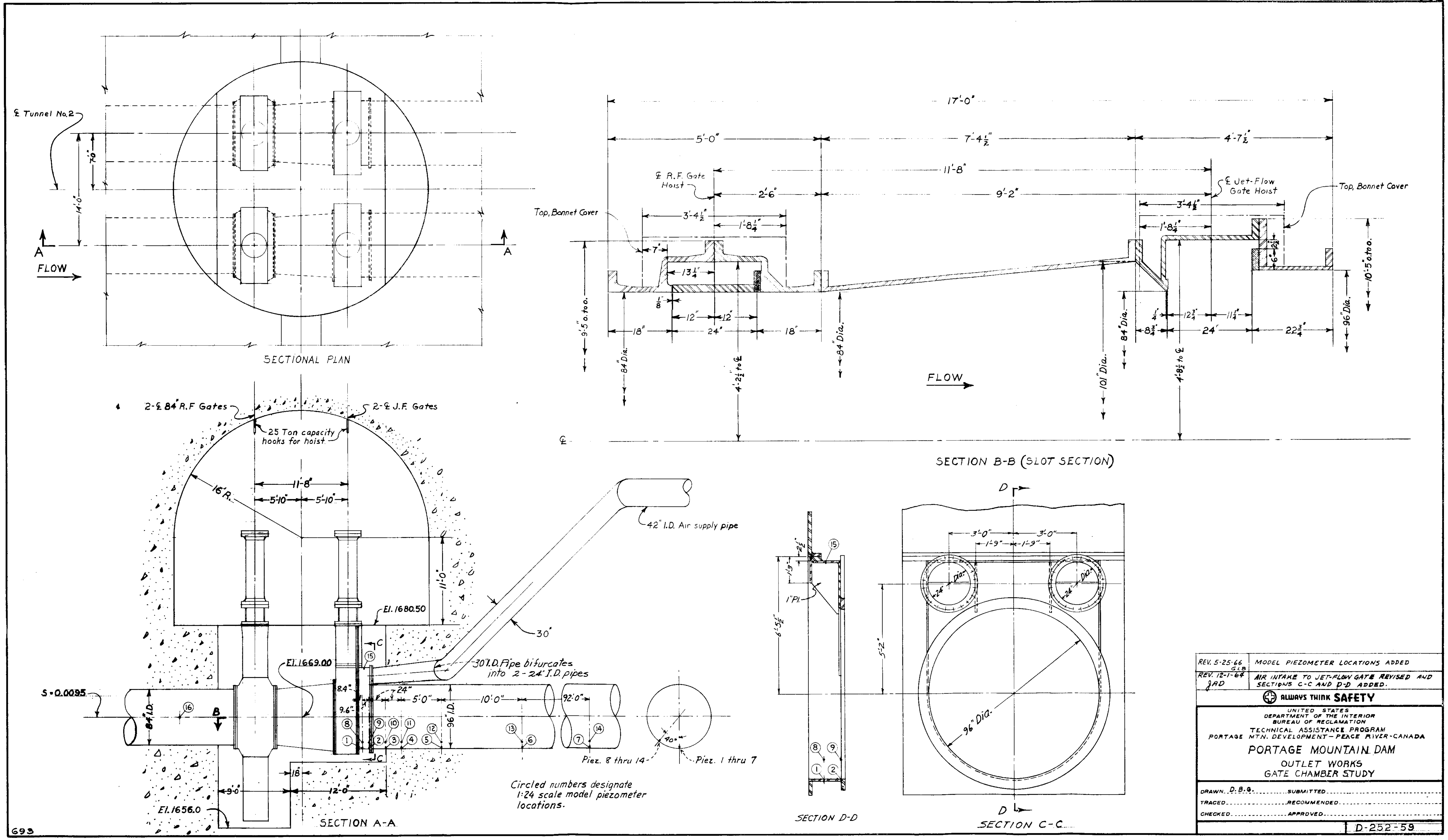
EXPLANATION

x = PIEZOMETER NO. 1 - 5
□ = PIEZOMETER NO. 7 - 10
o = PIEZOMETER NO. 11 - 15
Δ = PIEZOMETER NO. 17 - 20

PORTAGE MOUNTAIN DAM
OUTLET WORKS

PRESSURE FACTORS FOR BELLMOUTHS

1 : 24 SCALE MODEL


SECTIONAL PLAN
℄ Tunnel No. 2
FLOW
SECTION B-B (SLOT SECTION)
℄ R.F. Gate Hoist
℄ Jet-Flow Gate Hoist
Top, Bonnet Cover
17'-0"
5'-0"
7'-4½"
4'-7½"
11'-8"
2'-6"
9'-2"
84" Dia.
101" Dia.
96" Dia.
SECTION A-A
2-℄ 84" R.F. Gates
2-℄ J.F. Gates
25 Ton capacity hooks for hoist
16' R.
El. 1680.50
El. 1669.00
El. 1656.0
S = 0.0095
42" I.D. Air supply pipe
30"
30" I.D. Pipe bifurcates into 2-24" I.D. pipes
Piez. 8 thru 14
Piez. 1 thru 7
Circled numbers designate 1:24 scale model piezometer locations.
SECTION D-D
SECTION C-C
REV. 5-25-66 MODEL PIEZOMETER LOCATIONS ADDED
REV. 12-1-64 AIR INTAKE TO JET-FLOW GATE REVISED AND SECTIONS C-C AND D-D ADDED.
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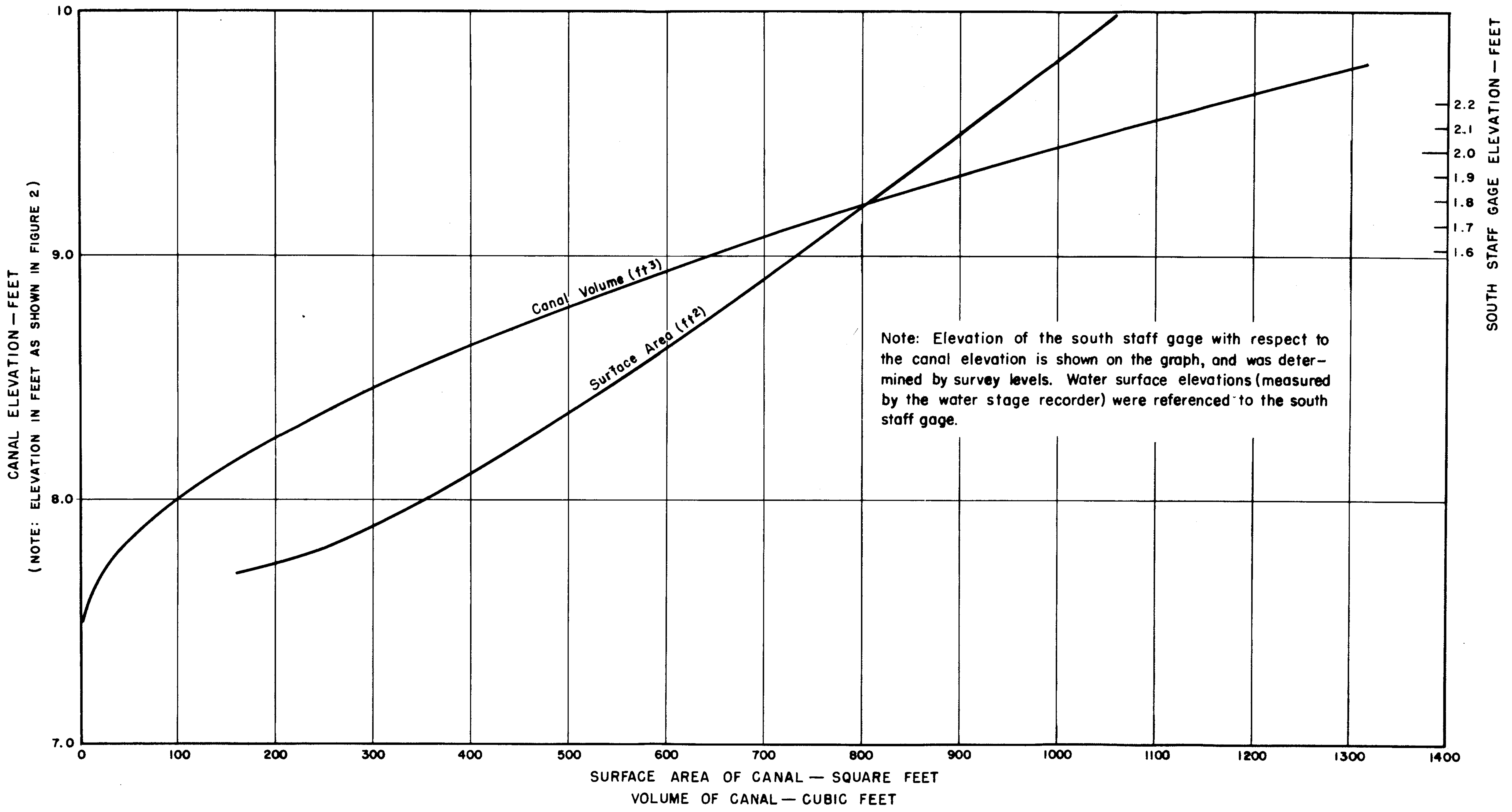
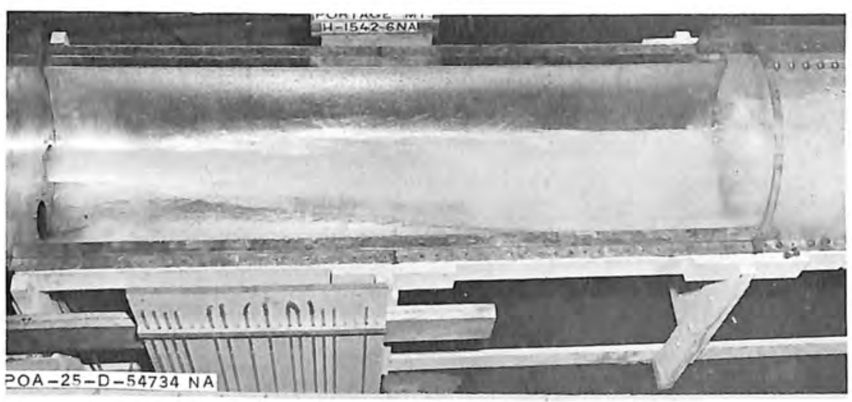
PORTAGE MOUNTAIN DAM
OUTLET WORKS
GATE CHAMBER STUDY
DRAWN D.B.G. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED
D-252-59
693



ELEVATION - SEEPAGE AREA AND CANAL VOLUME

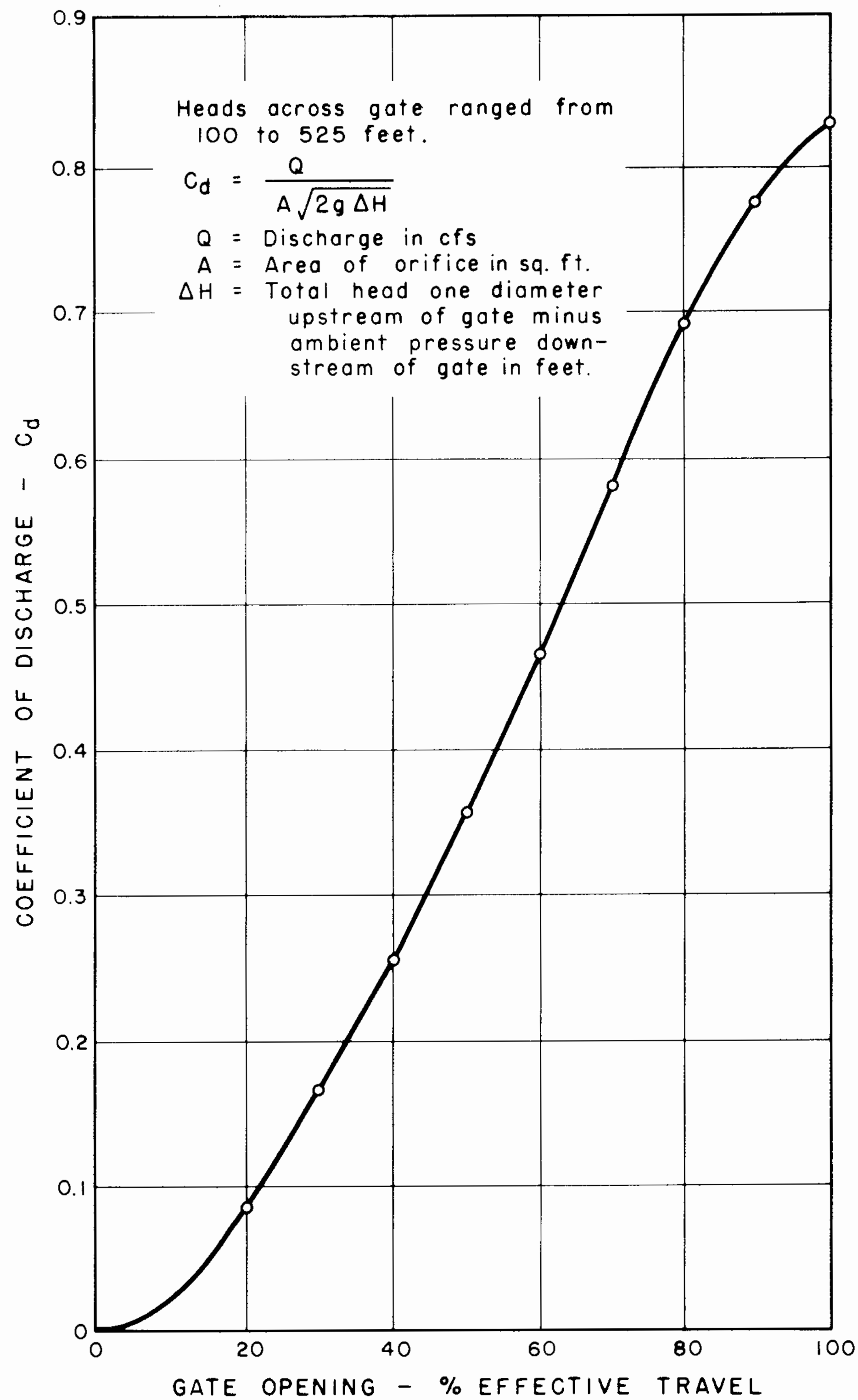
A. Both gates discharging 5,000 cfs
Reservoir El. 2100. Looking downstream.

B. Both gates discharging 5,000 cfs
Reservoir El. 2100. Looking downstream.



C. Left gate discharging 2,500 cfs
Reservoir El. 2100.

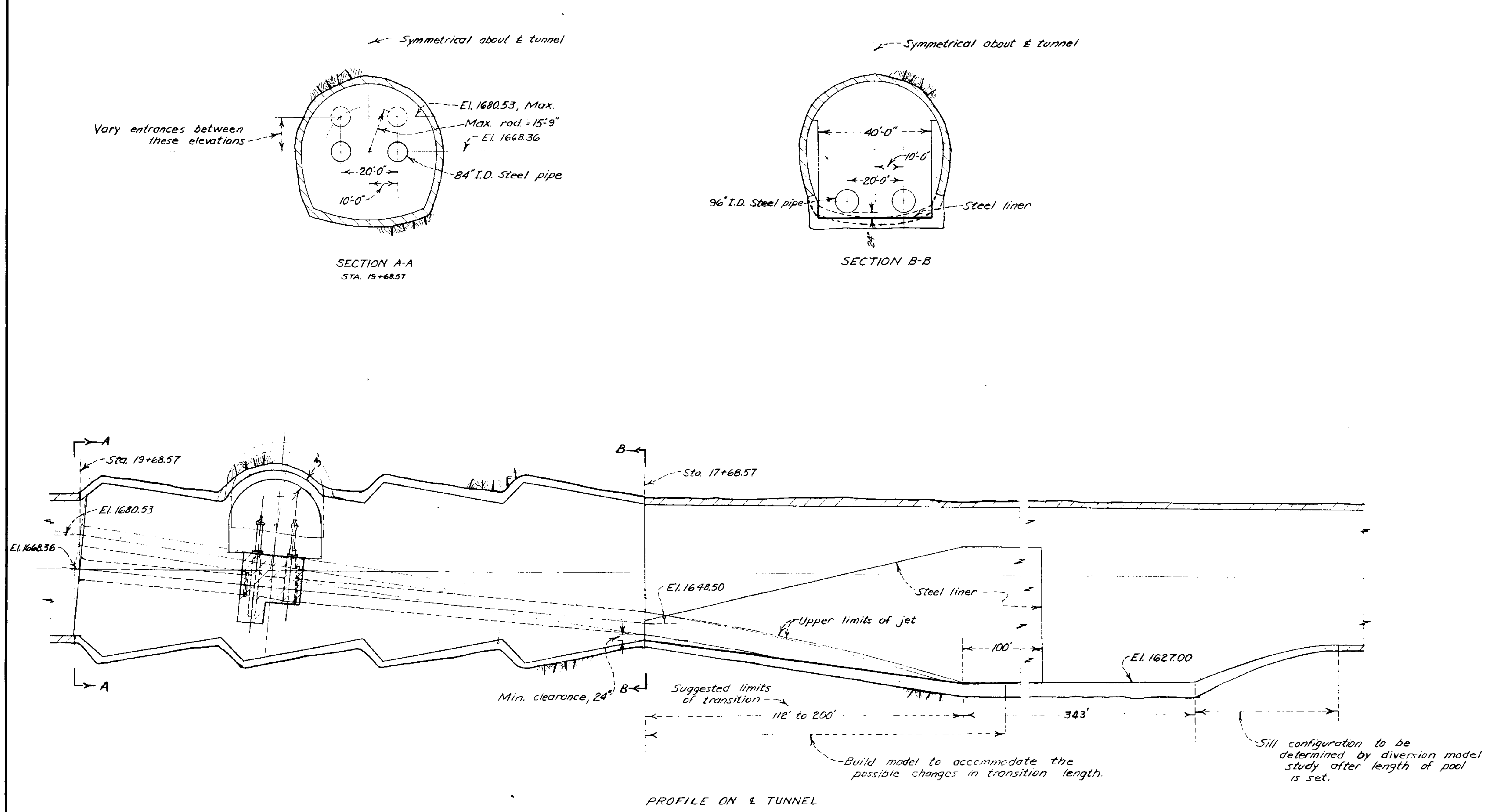
PORTAGE MOUNTAIN DAM
OUTLET WORKS
FLOW IN PRELIMINARY DESIGN
1:24 SCALE MODEL



PORTAGE MOUNTAIN DAM
OUTLET WORKS

COEFFICIENT OF DISCHARGE -- 84-INCH JET FLOW GATE

1 : 24 SCALE MODEL



NOTE

Stations and elevations refer to tunnel #2.

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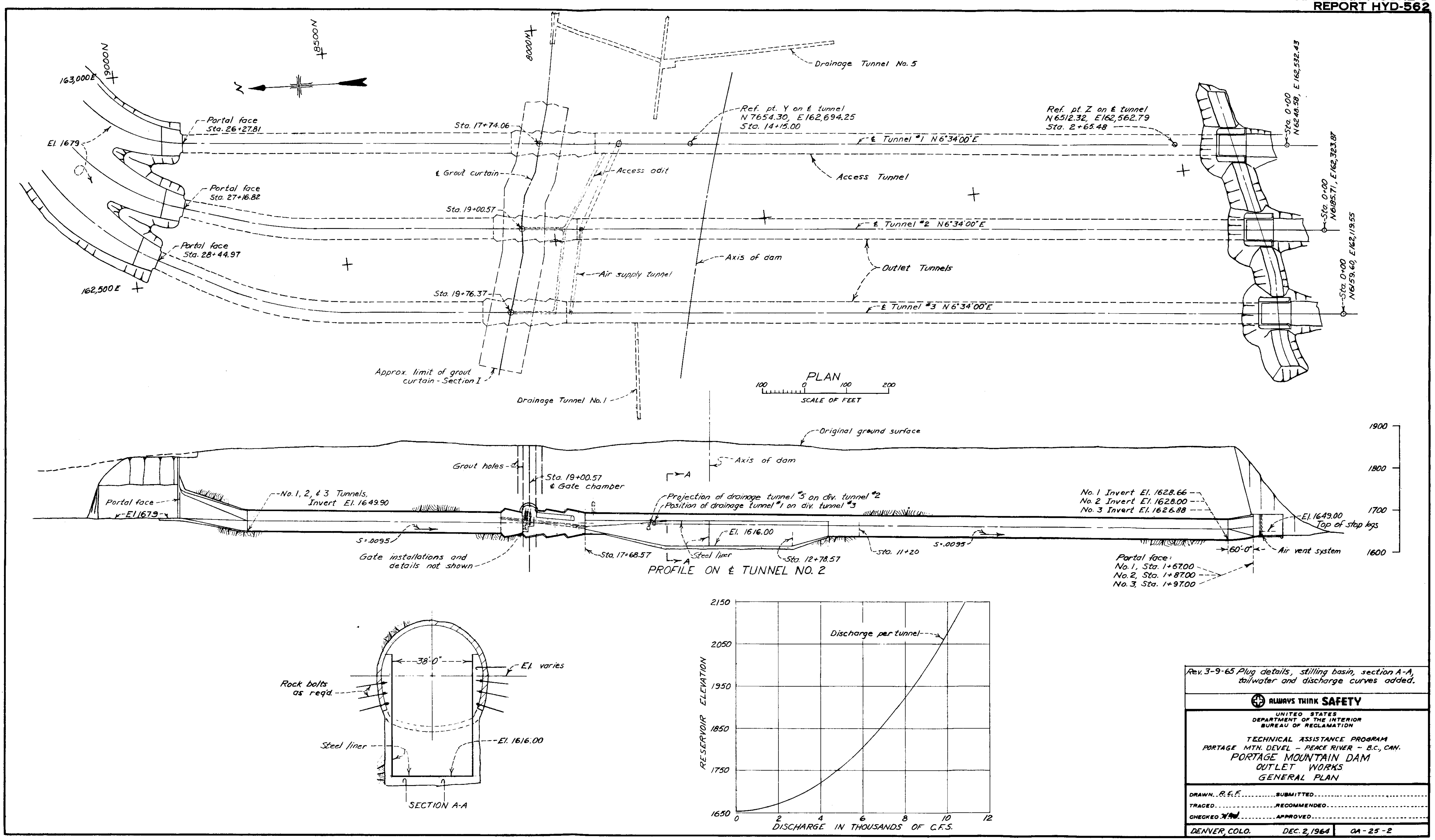
PORTAGE MOUNTAIN DAM
OUTLET WORKS
MODEL STUDY - SCHEME H

DRAWN. R.L.E. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED
DENVER, COLO. MARCH 17, 1965 OA-25-4


Drainage Tunnel No. 5
Ref. pt. Y on ℄ tunnel
N 7654.30, E 162,694.25
Sta. 14+15.00
Ref. pt. Z on ℄ tunnel
N 6512.32, E162,562.79
Sta. 2+65.48
Portal face
Sta. 26+27.81
Sta. 17+74.06
El. 1679
℄ Tunnel #1 N 6°34'00" E
Access adit
Access Tunnel
℄ Grout curtain
Portal face
Sta. 27+16.82
Sta. 19+00.57
℄ Tunnel #2 N 6°34'00" E
Portal face
Sta. 28+44.97
Axis of dam
Air supply tunnel
Outlet Tunnels
163,000 E
162,500 E
Sta. 19+76.37
℄ Tunnel #3 N 6°34'00" E
Approx. limit of grout curtain - Section I
Drainage Tunnel No. 1
Sta. 0+00 N 6248.58, E 162,532.43
Sta. 0+00 N 6185.71, E 162,323.87
Sta. 0+00 N 6159.60, E 162,119.55
PLAN
SCALE OF FEET
Original ground surface
Axis of dam
Grout holes
Sta. 19+00.57
℄ Gate chamber
Portal face
El 1679
No. 1, 2, & 3 Tunnels, Invert El. 1649.90
S=.0095
Gate installations and details not shown
Projection of drainage tunnel #5 on div. tunnel #2
Position of drainage tunnel #1 on div. tunnel #3
El. 1616.00
Steel liner
Sta. 17+68.57
Sta. 12+78.57
Sta. 11+20
S=.0095
No. 1 Invert El. 1628.66
No. 2 Invert El. 1628.00
No. 3 Invert El. 1626.88
El. 1649.00 Top of stop logs
60'-0"
Air vent system
Portal face:
No. 1, Sta. 1+67.00
No. 2, Sta. 1+87.00
No. 3, Sta. 1+97.00
PROFILE ON ℄ TUNNEL NO. 2
1900
1800
1700
1600
38'-0"
El. varies
Rock bolts as req'd.
Steel liner
El. 1616.00
SECTION A-A
Discharge per tunnel
RESERVOIR ELEVATION
DISCHARGE IN THOUSANDS OF C.F.S.
Rev. 3-9-65 Plug details, stilling basin, section A-A, tailwater and discharge curves added.
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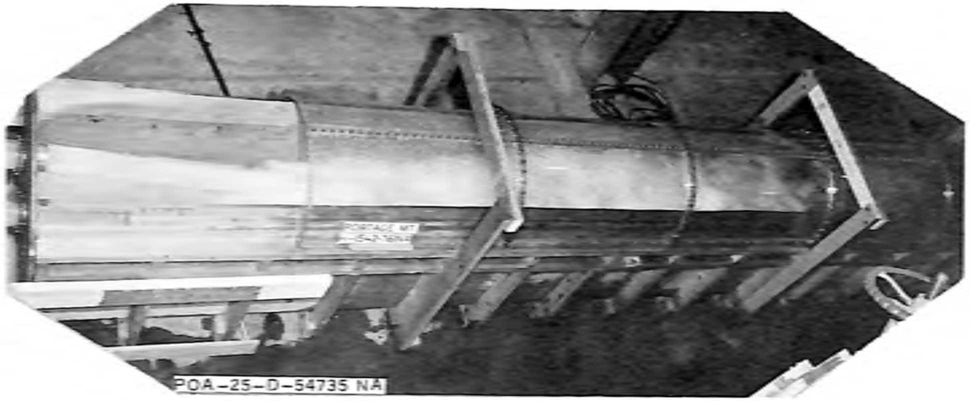
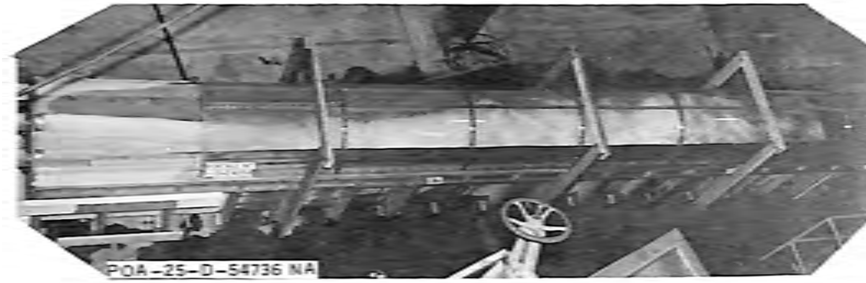
PORTAGE MOUNTAIN DAM
OUTLET WORKS
GENERAL PLAN
DRAWN R.E.F.
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
DENVER, COLO.
DEC. 2, 1964
OA-25-2





Flow at upstream end of tunnel

5,000 cfs, Reservoir El. 2100

10,100 cfs, Reservoir El. 2100

Flow at downstream tunnel portal

PORTAGE MOUNTAIN DAM
OUTLET WORKS
STILLING BASIN OPERATION WITH BOTH GATES DISCHARGING
1:24 SCALE MODEL

Appendix Figure 10
Report No. Hyd-562

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

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ABSTRACT

Studies on a 1:14 scale model of the low level outlet works of Portage Mountain Development show the fixed-cone valve-ring deflector combination provides a relatively simple and effective device for flow control and energy dissipation. The ring deflector contributes significantly to energy dissipation. Baffle piers downstream from the deflector and a weir at the downstream tunnel portal can be added later to improve energy dissipation if necessary. The extent of the steel-lined section required downstream of the valves was determined. High fluctuating pressures were measured on the wall of the liner in the impingement area of the jet and on the upstream face of the ring deflector at the crown and invert. Pressures on the lip of the deflector were slightly subatmospheric. No uniform simultaneous peaking of pressures at widely separated areas occurred on the deflector ring. A recirculating air supply tunnel was developed to provide near atmospheric pressures within the cone-shaped jet as well as upstream of the jet at the valves. Nonsymmetrical operation of the valves is not recommended. The design discharge of 10,000 cfs per tunnel at reservoir elevation 2125 was verified by the model operation.

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Hyd-562
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USBR Lab Rept Hyd-562, Hyd Br, June 30, 1966. Bureau of Reclamation, Denver, 80 p, 1 tab, 52 fig, 5 ref, append

DESCRIPTORS-- *outlet works/ diversion tunnels/ conduits/ tunnel plugs/ hydraulic structures/ *hydraulic models/ hydraulic jumps/ stilling basins/ *air demand/ head losses/ discharge measurement/ energy losses/ backwater profiles/ steel linings/ weir crests/ baffles/ vapor pressures/ cavitation/ *energy dissipation/ water surface/ erosion/ tunnel linings/ oscillographs/ transducers/ laboratory tests
IDENTIFIERS-- *jet flow gates/ tunnel transitions/ fixed-cone valves/ ring deflectors/ subatmospheric pressures/ Portage Mtn Dvlpmt, Can/ bell-mouthed entrances/ British Columbia, Canada

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