UNITED STATES
DEPARTMENT OF THE INTERIOR
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HYDRAULIC MODEL STUDIES OF YELLOWTAIL DAM SPILLWAY--MISSOURI RIVER BASIN PROJECT, MONTANA (FINAL STUDIES)

Report No. Hyd-483

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Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
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HYD 483

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ABSTRACT

Model studies were conducted to develop the hydraulic design of the approach channel, intake structure, tunnel transition section, inclined tunnel, vertical bend, tunnel trajectory, combination stilling basin-flip bucket, and the stream channel protection. Reshaping the approach channel improved the flow pattern. Approach channel construction limitations were recommended. The center pier in the transition section was altered to improve flow conditions in the inclined tunnel. The tunnel trajectory extending to the combination stilling basin-flip bucket was modified to eliminate severe subatmospheric pressures. A combination stilling basin-flip bucket was developed to still a minimum of 12,000 cfs and to flip a jet downstream for flows up to 92,000 cfs. This basin satisfactorily discharged the anticipated maximum diversion flow of 31,000 cfs. A vent was installed in the crown of the tunnel to prevent the tunnel from filling when discharging diversion flows up to 20,000 cfs. A stoplog storage facility at the downstream end of the stilling basin-flip bucket, was developed to prevent the stored logs from being dislodged by the spillway flow. Riprap protection for the left bank of the stream channel downstream from the basin was determined. The amount of tailwater drawdown at the powerplant and outlet works resulting from the operation of the spillway flip bucket was determined.

DESCRIPTORS--*Spillways/outlet works/diversion works/tunnels/ *flip buckets/*stilling basins/intake structures/radial gates/piers/ bends/discharge coefficients/roughness coefficients/tunnel hydraulics/ hydraulic similitude/transducers/piezometers/jets/riprap/streamflow/diversion tunnels/tailrace/*hydraulic models/bank protection/ computer programming/hydraulic jumps

IDENTIFIERS--Subatmospheric pressures/approach channels/tunnel transitions/tunnel trajectories

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HYDRAULIC MODEL STUDIES OF YELLOWTAIL DAM SPILLWAY--MISSOURI RIVER BASIN PROJECT, MONTANA (FINAL STUDIES)

PURPOSE

The studies were conducted to develop the hydraulic design of the spillway approach channel, the intake structure, the tunnel transition section, the inclined tunnel, the vertical bend, the horizontal tunnel, the tunnel trajectory, the combination stilling basin-flip bucket, and the stream channel protection. Diversion flows through the spillway stilling basin were also investigated.

CONCLUSIONS

1. The general concept of the preliminary design was satisfactory.

2. Reshaping the approach channel improved the flow pattern and reduced the amount of excavation, Figures 17 and 18.

3. Spoil from approach channel excavation should be leveled to elevation 3547, Figures 19 and 20.

4. The spillway will discharge the design flow of 92,000 cfs (cubic feet per second) at approximately design reservoir elevation of 3660. Discharge curves for gate controlled flow and for free flow are shown in Figure 24.

5. The center pier in the transition section was modified to reduce the fin of water extending downstream from the pier; otherwise, the flow through the tunnel transition section, inclined tunnel, vertical bend, and straight tunnel was satisfactory, Figures 25 and 27.

6. The tunnel trajectory leading to the combination stilling basin-flip bucket was modified to eliminate severe subatmospheric pressures along the tunnel invert.

7. A combination stilling basin-flip bucket was developed to still flows up to at least 12,000 cfs, and to flip flows greater than 12,000 cfs into the river channel, Figures 40, 42, and 43. The basin satisfactorily discharges the anticipated maximum diversion flow of 31,000 cfs, Figures 55 and 57.

8. An air vent was installed in the crown of the tunnel trajectory near the point of curvature to prevent the tunnel from filling when discharging diversion flows up to 20,000 cfs, Figure 55.

9. A stoplog storage facility was developed at the downstream end of the stilling basin-flip bucket to prevent the stored logs from being dislodged by the spillway flow, Figures 48 and 49.

10. The extent of riprap needed for protection of the left bank of the stream channel downstream from the spillway stilling basin for spillway flows up to 12,000 cfs was determined, Figure 51.

11. The tailwater drawdown at the powerplant and outlet works, Figures 53 and 54, as caused by operation of the spillway was measured. It was determined that insufficient tailwater would exist for operation of the outlet works when the powerplant is not operating and the spillway flow exceeds about 20,000 cfs.

ACKNOWLEDGMENT

The final plans evolved from this study were developed through the cooperation of the staffs of the Dams Branch, Mechanical Branch and the Hydraulics Branch during the period October 1960 through May 1962. Laboratory photography was by W. M. Batts, Office Services Branch.

INTRODUCTION

Yellowtail Dam is the principal feature of the Yellowtail Unit of the Lower Bighorn Division of the Missouri River Basin Project. It is located on the Bighorn River about 45 miles southwest of Hardin, Montana, Figure 1. The dam is a concrete arch structure about 1,400 feet long and 525 feet high, Figures 2 and 3. The principal hydraulic features are the tunnel spillway, the river outlet works, and the powerplant.

The spillway, Figures 2 and 3, consists of an approach channel, a radial gate-controlled intake structure, a concrete-lined tunnel, a combination stilling basin-flip bucket, and a short discharge channel to the river. The approach channel floor, Figure 4, is at elevation 3580, 13 feet below the spillway crest and 80 feet below maximum reservoir elevation. The intake structure, Figure 5, consists of two radial gate-controlled sections converging into a single tunnel. The tunnel, Figure 6, curves downward through a transition section to a 55° slope. The transition changes the tunnel shape from an arch roof rectangular section at the entrance portal to a circular section. The sloped tunnel tapers from 40 feet 6 inches to 32 feet in diameter at the beginning of the vertical bend. The vertical bend has an invert radius of 290 feet. The tunnel leaves the vertical bend on a slope of 0.004, and the tunnel diameter remains at 32 feet to the exit portal at the stilling basin, 1201.53 feet downstream from the P.T. of the bend. Approximately 155 feet upstream from the exit portal the tunnel bends downward 15.51 feet along an invert radius of 815 feet to the stilling basin floor.

The exit portal is 1,733 feet downstream from the crest and 250 feet upstream from the end sill of the stilling basin, Figure 7. The basin floor is at elevation 3140 or 453 feet below the spillway crest. The stilling basin has a semicircular bottom the same diameter as the tunnel, Figure 8. The combination stilling basin-flip bucket is designed as a hydraulic jump energy dissipator for flows up to at least 12,000 cfs and then acts as a flip bucket in projecting flows greater than 12,000 cfs into the downstream river channel. A stoplog storage facility is located at the downstream end of the basin for storage of the downstream bulkhead, Figure 9.

During construction of the dam, the near horizontal portion of the tunnel downstream from the vertical bend will be part of the diversion tunnel, Figure 3. During diversion the basin may be required to discharge as much as 31,000 cfs from approximately reservoir elevation 3280.

The powerplant and river outlet works, Figures 2 and 3, are located at the toe of the dam approximately 1,000 feet upstream from the spillway stilling basin. The powerplant accommodates four 62,500-kw (kilowatts) generating units, and the outlet works includes two 84-inch hollow-jet valves discharging into a stilling basin along the right side of the powerplant.

The capacities of the outlet works and powerplant are 5,000 and 3,000 cfs, respectively. These flows, together with 12,000 cfs from the spillway, provide a flood capacity of 20,000 cfs that can be discharged without using the spillway stilling basin as a flip bucket. The capacity of the spillway using the stilling basin as a flip bucket is 92,000 cfs.

Model studies for the outlet works are described in Hydraulics Branch Report No. Hyd-482.1/ Studies of the preliminary spillway and outlet works in which the hydraulic requirements were different than in the present study, are discussed in Hydraulics Branch Report No. Hyd-414.2/

Dimensions of the hydraulic features are listed in Table 1 for both English and metric units.

THE MODEL

Scope

The model, Figures 10 and 11, was a 1:49.95 scale reproduction of the spillway including the immediate reservoir area surrounding the approach channel, and a reach of river channel extending approximately 2,800 feet downstream from the powerplant. Although hydraulic studies of the river outlet works and the powerplant were not conducted in this model, flows from these structures were represented in the river channel.

Hydraulic Losses

The model was geometrically similar to the preliminary design of the prototype except for the length and vertical drop of the near horizontal tunnel downstream from the vertical bend. Head losses due to friction in the model are usually greater, proportionately, than those indicated by the model scale because model surfaces sufficiently smooth to represent scaled prototype surfaces do not exist. Therefore, to maintain the scaled velocity of the flow entering the stilling basin, it was necessary to either increase the slope or reduce the horizontal length of the tunnel. Since geometric similitude at the vertical bend was desired, the tunnel length was reduced in this study.

The required reduction in tunnel length was determined for flows of 12,000 and 92,000 cfs by computing the velocity and depth of flow throughout the tunnel to the point of curvature of the vertical curve leading to the stilling basin for both model and prototype tunnels, Figure 12. The equivalent prototype velocities in the model were computed using a model roughness coefficient "n" of 0.008 in the Manning's equation. This is equivalent to approximately 0.015 in the prototype. A value of 0.014 was used for the prototype computations.

1/Hyd-482, "Hydraulic Model Studies of Yellowtail Dam Outlet Works (Final Studies)," by T. J. Rhone.
2/Hyd-414, "Hydraulic Model Studies of Yellowtail Dam Spillway and Outlet Works (Preliminary Studies)," by G. L. Beichley.

These depths and velocities were initially computed manually and later confirmed by means of an electronic digital computer program, Appendix A.

For 92,000 cfs, in the prototype the velocity and flow depth were computed to be 137.5 feet per second and 24.5 feet, respectively. For 12,000 cfs the computed values were 82.5 feet per second and 7.5 feet, respectively. In the model, for both 92,000 and 12,000 cfs, equivalent prototype velocity was reached approximately 310 prototype feet upstream from the P.C., Figure 12; therefore, the model was shortened an equivalent amount, 6.26 feet.

Reservoir

The reservoir area was contained in a 12- by 12-foot head box which allowed reproduction of the topography along the left bank of the reservoir for approximately 500 feet upstream from the spillway intake structure, Figure 13. Topography in the reservoir area was molded of concrete mortar placed on metal lath which had been nailed over wooden templates shaped to the ground surface contours. The surface was given a rough finish to simulate the natural topography of the prototype. Excavated cut surfaces were given a smooth finish. A 6-inch-wide rock baffle was installed along the right-hand and upstream sides of the box to quiet the reservoir water supply.

The reservoir water surface elevation was measured by means of a hook gage mounted in a well on the side of the head box. The well was connected to a piezometer tap located in the floor of the box near the right side of the baffle where the velocity of approach was negligible.

Intake Structure

The spillway crest was molded of concrete screeded to sheet metal templates. The sidewalls, center pier, and radial gates of the intake structure were constructed of No. 16-gage sheet metal. Piezometers were installed in the spillway crest and consisted of 1/16-inch-inside-diameter brass tubes soldered at right angles to the profile shape and filed flush.

Tunnel

The spillway tunnel from the intake structure to the stilling basin, Figure 11, was constructed of transparent plastic. The center pier in the intake structure was constructed of sheet metal and sugar pine. Plastic piezometers having a 1/16-inch-inside diameter were inserted along the invert of the tunnel transition section. The uniform diameter tunnel downstream from the vertical bend was made from commercial extruded plastic pipe. The inside diameter of this pipe governed the scale of the model.

Combination Stilling Basin-flip Bucket

The circular bottom of the spillway stilling basin-flip bucket extending from the tunnel portal to the horizontal invert of the basin was molded in concrete. The remainder of the basin was constructed of sheet metal. Piezometers made from 1/16-inch-inside-diameter brass tubing were installed in the basin walls, along the invert and along the lip of the flip bucket.

Powerplant and Outlet Works

The downstream face of the powerplant, the weir, and the outlet works stilling basin were constructed of wood, Figure 14. The 84-inch hollow-jet valves were simulated by use of 2-inch model hollow-jet valves. These valves were not to geometric scale but since the outlet works basin was not being tested in this study, the valve size was not important.

Stream Channel

The banks of the stream channel, Figure 10, were molded of concrete in the same manner as the reservoir area. The riverbed below elevation 3180 and the left bank immediately downstream from the stilling basin were initially constructed of gravel and sand for erosion studies, and later covered with a layer of concrete. Tailwater staff gages were installed at the powerplant and at stations 1, 300 and 2, 800 feet downstream from the powerplant.

Water Supply

Water was supplied to the model from the laboratory's permanent supply system. For preliminary studies of the spillway stilling basin-flip bucket, the water supply was pumped directly to the tunnel downstream from the vertical bend. This made it possible to study the stilling basin for diversion flows while other parts of the model were under construction. The depth and velocity of flow at the exit portal of the tunnel were controlled by means of a slide gate installed approximately 600 feet from the portal. Water was supplied to the powerplant and outlet works through a separate piping system shown in Figure 15.

THE INVESTIGATION

The investigation was concerned with flow conditions in the spillway approach channel, the intake structure, the tunnel transition section, the inclined tunnel, the vertical bend, the near horizontal tunnel, the tunnel trajectory to the stilling basin, the combination stilling basin-flip bucket, and the river channel. The river channel studies were conducted with and without the powerplant and outlet works operating in conjunction with the spillway.

Spillway Approach

Preliminary.--Flow through the preliminary spillway approach channel in general was satisfactory, Figure 16A. However, at the design flow of 92,000 cfs, minor disturbances occurred around the 90° wingwalls at the intake structure and around the nose of the right bank.

Modifications.--Straight 45° wingwalls at the intake structure were installed and tested, but proved to cause more disturbance than the preliminary curved walls. Since the disturbances at the 90° wingwalls were minor, no further testing of wingwalls were conducted and the preliminary wingwall was accepted for prototype use.

In an effort to reduce the excavation requirements, the approach channel widths of other structures that had been modeled were analyzed to determine a feasible approach channel velocity. In the preliminary Yellowtail Dam spillway model studies2/, the design flow was 173,000 cfs and the average velocity was computed to be approximately 11 feet per second at the approach channel entrance and approximately 15 feet per second near the intake structure. In the Glen Canyon Dam spillway, the average velocity for the design flow of 138,000 cfs was measured in the model to be equivalent to approximately 8-1/2 feet per second at the approach channel entrance and approximately 15-1/2 feet per second near the intake structure.

Based on this analysis, the width at the entrance to the approach channel was reduced from approximately 140 to 120 feet. This reduced width produced a computed average velocity of approximately 9-1/2 feet per second at the entrance to the approach channel and approximately 13 feet per second near the intake for the design flow of 92,000 cfs. Flow through this narrow approach channel, was very smooth except for increased disturbances around the nose of the right bank, Figures 16B and C.

Recommended.--The narrow approach channel was chosen for prototype use, Figure 4. Minor modifications, including a long radius of curvature around the nose of the right bank and a 2:1 downward slope at the upstream end of the approach channel floor, were included in the recommended design. A natural depression in the prototype topography passed through the right bank of the approach channel, Figure 18. However, the model tests showed that this depression did not contribute materially to any disturbance in the flow.

Flow conditions in the recommended design were very good for all discharges, Figures 17 and 18. However, some minor disturbances still occurred along the right bank. By means of dye streamers it was determined that these disturbances were caused by flow currents originating deep in the reservoir and rising to the water surface along the nose of the right bank.

2/ibid.

Prototype construction.--During prototype construction, the excavated material from the approach channel was bulldozed over the cliff at the entrance to the approach channel, Figure 19. When the approach channel was completed, this loose material extended to the elevation of the approach channel floor. It was feared that it might be carried into tunnel by the spillway flow and abrade the concrete tunnel lining. Therefore, the amount and location of this loose material were measured in the prototype and represented in the model using white sand, 0.2 millimeter in diameter, Figure 20A. This sand closely represented the scaled size of the prototype material.

Tests initially were conducted with the loose material graded to the same elevation as the approach channel floor, elevation 3580. Tests indicated that at maximum discharge, the top of this loose material would be carried into the approach channel and over the crest of the spillway into the tunnel, Figure 20A.

The top of the spoil was lowered to elevation 3563 for a second test, Figure 20B. Material near the nose of the right bank, where velocities were comparatively high, was still carried into the tunnel by the design discharge.

A third test was made with the material leveled to elevation 3547, Figure 20C. For this test, the material near the nose of the right bank was moved but was not carried into the approach channel. These tests indicated that the loose material should be leveled at least to elevation 3547.

Intake Structure

General appearance.--The intake structure, Figure 5, discharged all flows in a very satisfactory manner, Figure 21. The water surface was as smooth as could be expected. Water surface profiles along each wall and each side of the center pier were well below the gate pins for maximum design flow, Figure 22.

Pressures.--Pressures were measured along the crest profile near the training wall where the crest curvature was the greatest and along the centerline of one bay. All pressures were near atmospheric or above for the design flow and for 12,000 cfs discharging from maximum reservoir elevation through a 5-foot gate opening, Figure 23. The lowest pressures were recorded at the piezometers located on the centerline crest profile for a gate-controlled flow of 12,000 cfs.

Spillway capacity.--The discharge capacity of the spillway was determined for both uncontrolled and gate-controlled flows. The results are plotted in Figure 24. The design flow of 92,000 cfs was discharged at approximately design reservoir elevation 3660.

The free discharge coefficients were computed for the data points using the equation, $Q = CLH^{3/2}$, where Q is the discharge, L is the crest length of both bays, H is the difference in elevation between reservoir water surface and crest, and C is the coefficient. The results are plotted in Figure 24. For the design flow of 92, 000 cfs, the coefficient was approximately 3. 34 which was very close to the design value.

Transition Section

Flow characteristics.--The preliminary transition between the gate section and the circular tunnel performed very well and required no modifications, Figure 25. The preliminary center pier shown in Figure 26 was not completely satisfactory in that an air pocket and a large fin of water formed downstream from the pier. The fin was objectionable because it impinged upon the crown of the inclined tunnel, possibly resulting in excessive air entrainment in the prototype flow. Bulking of the flow, due to the air entrainment, might crowd the tunnel and hinder the normal passage of air required for the proper ventilation of free flow. Although the problem did not appear to be serious even at the design discharge, several modified piers were tested to eliminate or reduce the magnitude of this fin.

Due to the nonsymmetrical approach channel, a ridge of water also occurred along the right wall of the transition. This ridge of water fluctuated as indicated in Figure 25, but did not spin over the crown of the tunnel.

Pier modifications.--The preliminary pier, Figure 26, was lengthened from 57. 53 to 102. 5 feet and tapered to nearly a knife edge at the downstream end. The air pocket was eliminated and the fin was greatly reduced with this modification; however, a thin layer of water climbed the tunnel sidewalls and folded over much like the center fin that had formed with the shorter pier. Apparently, the longer center pier crowded the flow to the sides. This water added to the ridge of water already occurring along the right wall and made the fin larger on the right wall than on the left wall.

For the second trial, the pier was shortened to 45 feet, the minimum length required for structural support of the tunnel roof. The short pier intensified the fin which struck the crown of the tunnel at a discharge of 70, 000 cfs, or about 15, 000 cfs less than observed with the preliminary pier.

Next, the pier was lengthened 25 feet at the water surface for design flow. Below the water surface, the length of the extension was reduced to zero at the invert along a concave path.

This modification eliminated the formation of an air pocket at the end of the pier and provided excellent flow conditions for all discharges. The fin was nearly eliminated and the water surface at the walls of the tunnel was lowered. However, a piezometer installed on the floor of the tunnel near the corner of the end of the pier showed subatmospheric pressures equal to about 10 feet of water. Air vents were drilled in the end of the extension to relieve the low pressure, after which the air pocket and the fin of water again formed.

Recommended pier.--Other slight variations were tested with minor degrees of improvement before arriving at an acceptable pier design. The pier recommended for the prototype was the 45-foot-long pier with the downstream end extended to a line normal to the invert as shown in Figure 6. This modification did not eliminate the fin, Figure 25, but reduced the size of the air pocket and, in turn, the size of the fin.

Pressures.--A low-pressure area in the transition was detected as shown in Figure 26; however, the minimum observed pressure was no more than 5 feet of water below atmospheric and occurred only for maximum design flow. Pressures approached atmospheric as the discharge was decreased.

Inclined Tunnel, Vertical Bend, and Horizontal Tunnel

Flow characteristics.--The tunnel design is shown in Figure 6. With the reduction in the magnitude of the fin, as discussed in the preceding section, the flow through the inclined tunnel, vertical bend, and horizontal tunnel was excellent at all discharges, Figure 27. There was very little tendency for the flow to climb the walls of the tunnel downstream from the bend, indicating that bend radius was ample.

Pressures.--Pressures recorded along the invert of the inclined tunnel and vertical bend were well above atmospheric for maximum design flow, Figure 28. Piezometers 64 and 65 show the magnitude of the force on the invert of the vertical bend.

Preliminary Stilling Basin-flip Bucket

Test procedures.--The initial investigation of the tunnel trajectory and combination stilling basin-flip bucket was made with the water supplied directly to the nearly horizontal portion of the tunnel. A slide gate was installed 600 feet (12-foot model) upstream from the P. C. of the tunnel trajectory to control the depth and, therefore, the velocity of flow in accordance with the computed depths and velocities shown in Figure 29.

The combination stilling basin-flip bucket, Figure 30, is designed to act as a hydraulic jump stilling basin for flows up to 12,000 cfs, with the powerplant and outlet works discharging an additional 8, 000 cfs, thus providing a total discharge of 20, 000 cfs. Based upon the preliminary tailwater curves that were prepared specifically for the model study, Figure 31, the tailwater elevation for 20, 000 cfs could vary about 4 feet, depending upon the amount of storage behind the afterbay dam 2 miles downstream from the stilling basin. Spillway flows in excess of the maximum stilling basin flow will sweep the hydraulic jump from the basin, thus converting the basin to a flip bucket.

Flow characteristics.--The preliminary combination stilling basin-flip bucket is shown discharging 12, 000 cfs at maximum tailwater elevation in Figure 32A. Surges occurred at the upstream end of the basin. These were due to the rather flat slope at which the flow entered the basin. Occasionally these surges filled the tunnel at the exit portal. The hydraulic jump occupied the upstream portion of the basin indicating that the basin was longer than necessary.

The basin was capable of stilling approximately 25 percent more than the 12, 000 cfs requirement before the hydraulic jump swept from the bucket for the minimum anticipated tailwater elevation. This observation was another indication that the basin was longer than necessary. Therefore, it was estimated that the 330-foot-long basin could be shortened approximately 25 percent or 75 feet.

The basin performing as a flip bucket is shown discharging the maximum flow of 92, 000 cfs in Figures 32B and C. All discharges from the flip bucket produced jets that were quite uniform and well positioned in the stream channel.

Channel erosion.--The canyon walls were covered with a considerable amount of talus. It was planned to remove all such material including much of the overburden immediately downstream from the basin. The amount of excavation or the location of rock contours was not known at the time of these preliminary tests; therefore, the model left bank was initially installed as a loose gravel slope. Later the rock contours were installed in concrete and the amount of riprap required for protection of the overburden for stilling basin flows up to 12, 000 cfs was determined.

For flip bucket flows, a considerable amount of erosion occurred in the loose rock of the model riverbed as shown for 92, 000 cfs in Figure 33. However, the prototype streambed is much more stable than loose rock and erosion to this extent is not expected. Considering the extremely infrequent operation as a flip bucket, it was considered desirable to allow the jet to erode and, if necessary, clean the prototype channel after each occurrence. The elevation of the deposited material was of more concern than the eroded hole, since the bar formed by the deposited material would dam the channel and raise the tailwater elevation at the powerplant and outlet works. This would reduce the efficiency of both. The amount of material in the bar and thus the amount of channel cleaning necessary would depend upon the size of the eroded hole and the amount of material washed from the canyon walls. This could not be determined in the model study.

Flip bucket pressures.--Pressures measured in the flip bucket of the basin are recorded in Figure 34. The pressures varied from about 105 feet above atmospheric to 5 feet below atmospheric and are similar to those found in other structures.3/

Modification of the Stilling Basin-flip Bucket

Flow characteristics.--As a result of the preliminary tests, the basin length was shortened 75 feet from 330 feet to 255 feet; the floor and bucket lip elevations were not changed. Tests indicated that this shorter basin was deeper or longer than it need be since 12,000 cfs swept from the basin at a tailwater well below the minimum elevation of 3186 when the powerplant and outlet works were operating.

Next, the basin floor was raised 5 feet to elevation 3145. With this arrangement, the jump for 12,000 cfs swept out at tailwater elevation 3181; and at minimum tailwater elevation 3186 the basin was capable of stilling about 13,300 cfs before sweepout. Thus, this basin provided a safety factor of 5 feet of tailwater depth or a discharge safety factor of about 1,300 cfs above the 12,000 cfs, Test 1, Figure 35.

The basin was shortened further to 200 feet with the basin floor at elevation 3145 and the bucket lip remaining at elevation 3170. The hydraulic jump for 12,000 cfs was swept from this basin arrangement at tailwater elevation 3186, thus, just barely satisfying the design requirement.

Flip bucket flows from this basin produced rather ragged jets for certain discharges. Therefore, the flip bucket portion of the basin was altered several times in attempts to improve the jet and to provide sweepout for 12,000 cfs at a lower tailwater.

Changing the bucket radius from 150 to 138 feet and leaving the lip of the bucket at elevation 3170 improved the jet appearance but did not lower the sweepout tailwater elevation below elevation 3186 for 12,000 cfs, Test 4, Figure 35. However, increasing the length of this basin from 200 to 220 feet and leaving the basin floor at elevation 3145 lowered the sweepout tailwater 2 feet to elevation 3184 and increased the basin stilling capacity to about 12,500 cfs at

3/ASCE Transactions, Volume 126, Part I, 1961, Paper No. 3236, "Improved Tunnel-Spillway Flip Buckets," by T. J. Rhone and A. J. Peterka.

tailwater elevation 3186, Test 5, Figure 35. Therefore, a 220-foot long basin with the floor at elevation 3145 and a 138-foot radius flip bucket with the lip of the bucket at elevation 3170 was tentatively accepted until it could be further tested with the tunnel flow originating in the model reservoir.

Preliminary Tunnel Trajectory

Test procedure. --The preliminary tunnel trajectory shown in Figure 30 was designed for the average flow velocity for 92,000 cfs and tested with the tentatively accepted basin described above. During these tests the tunnel flow depths and velocity were controlled by the model slide gate.

Flow characteristics. --The flow distribution was poor near the tunnel portal at the downstream end of the trajectory particularly for the higher flows. The water surface at this point was much higher on the centerline than at the sides of the tunnel.

Pressures. --Subatmospheric pressures recorded along the trajectory, Figure 36, also indicated that the curvature of the trajectory was too rapid. For the maximum flow of 92,000 cfs, pressures were approximately 25 feet of water below atmospheric near Piezometer 4 on the trajectory centerline. Other flows down to 23,000 cfs also produced pressures below atmospheric at this point.

To be sure that the proximity of the slide gate control was not affecting the pressures or the flow distribution, the slide gate was moved upstream a distance equivalent to approximately 900 prototype feet. Tests with the gate at both locations produced approximately the same flow distribution and pressures.

Recommended Tunnel Trajectory

Description. --A velocity profile for maximum discharge was measured at the point of curvature of the trajectory, Figure 37. Using the maximum measured velocity of 158 feet per second, a new parabolical trajectory was computed. The parabolical curve was then very closely approximated by an 815-foot-radius arc for the recommended trajectory, Figure 6. This trajectory continued from the portal to the basin floor, Figure 7. At the time of these tests the basin floor was at elevation 3145. This trajectory to the portal was 27.03 feet longer than the preliminary trajectory. The length of the trajectory from the tunnel portal to basin floor corresponded closely to the 0.234 tangent slope in the preliminary design.

Flow characteristics. --This longer trajectory improved the flow distribution at the tunnel portal by providing a more level water surface, Figure 38. As a result the appearance of the flip bucket jets was improved.

Pressures.--The pressure gradients along the invert of the recommended trajectory were greater than atmospheric except for a short length in the vicinity of Piezometer 4 which was 6 feet of water below atmospheric for maximum flow, Figure 40.

Pressures also were measured with the source of flow controlled by the slide gate and again later in the model study with the source at the model reservoir for comparison, Figures 38A and B. In general, the agreement between pressures measured when the flow was controlled by the two methods was quite good. However, for flows less than 46,000 cfs the pressures were lower for reservoir-controlled flows, indicating higher velocities through the tunnel than when controlled by the slide gate. This would affect the stilling basin sweepout tests.

Modified Stilling Basin-flip Bucket

Flow characteristics.--The tentative stilling basin-flip bucket developed using flows controlled by the slide gate was 220 feet long with the invert at elevation 3145. After changing the flow source to the model reservoir, the hydraulic jump swept out of the basin with the tailwater at Station 28+00 at approximately elevation 3189, for 12,000 cfs discharging from reservoir elevation 3657, Test 6, Figure 35. This tailwater was about 5 feet higher than the sweepout tailwater with the preliminary trajectory and with the flow controlled by the slide gate. This tailwater was also 3 feet above minimum tailwater elevation 3186. Thus, the velocity of flow entering the basin was very critical in determining the tailwater elevation at which sweepout would occur.

Recommended Stilling Basin-flip Bucket

Stilling basin flow characteristics.--The basin was lengthened to 250 feet and the invert of the basin floor lowered 5 feet to elevation 3140 for the prototype design, Figures 7 and 8. For 12,000 cfs the jump remained in the basin for tailwater as low as elevation 3183, and at elevation 3186 the hydraulic jump remained in the basin for flows up to about 12,800 cfs, Test 7, Figure 35. With no flow through the powerplant and outlet works, the jump for 12,000 cfs will be swept from the basin at tailwater elevation 3186. However, this is not an anticipated operating condition.

Water surface profiles along the basin walls are shown in Figure 41 for 12,000 cfs with minimum and maximum tailwaters. The appearance of the flow in the basin for 12,000 cfs is shown in Figure 40.

Flip bucket flow characteristics.--Flip bucket flows from the recommended stilling basin-flip bucket with and without the powerplant discharging are shown in Figures 42 and 43, respectively. With the powerplant discharging, the tailwater under the jet was above bucket lip elevation 3170. For this condition the center of the underside of the jet was pulled downward, presenting a ragged appearance. This condition also existed for small flip bucket flows without the powerplant and outlet works operating because the smaller jets did not lower the water surface under the jet to below lip elevation, Figure 43A. For flip bucket flows greater than 23,000 cfs the water surface at the bucket lip was about 1.5 feet lower than at Station 13+00 in the adjacent stream channel.

The jet was well positioned in the river channel and was quite compact for the small flows and for the large flows. For intermediate flows near one-half design capacity, the jet was somewhat ragged as it left the flip bucket, Figure 44A. Jet measurements are recorded in Figure 45.

Water surface profiles, shown photographically in Figure 44 and graphically in Figure 41, were not uniform in cross section from one side of the basin-flip bucket to the other. However, due to the shortening of the model tunnel that was made to correct for friction head loss, the cross-sectional flow distribution in the prototype basin would likely be different than was observed in the model. The profiles were obtained to aid in the structural design of the basin walls and in determining the location of the drains through the left wall. The drains were to be located above the water surface of any high-velocity flow to prevent possible cavitation erosion damage to the concrete.

Stilling basin-flip bucket pressures.--Pressures were measured in the stilling basin-flip bucket by use of water manometers for discharges of 12,000, 46,000, and 92,000 cfs, Figure 46. These pressure measurements were made to aid the designers in the structural design of the training walls, to determine pressure distribution on the flip bucket, and to detect any subatmospheric pressures that might cause cavitation erosion. Pressure distribution on the flip bucket was similar to that recorded for other structures previously tested in the laboratory.3/ Slightly subatmospheric pressures were detected on the downstream face of the bucket lip, but in general the pressures were well above atmospheric.

To obtain data for use in the design of the training walls, selected piezometers in the maximum pressure areas near Stations 22+98.12 and 24+47.12 were used to measure instantaneous dynamic pressure fluctuations, Figure 47. The pressure measurements were made using pressure transducers and a six-channel direct-writing oscillograph. A typical pressure fluctuation diagram taken from the direct-writing oscillograph is shown in Figure 47. Approximately 99 percent of the time the fluctuation of the instantaneous pressure above or below the average was less than 10 percent of the average pressure. Occasionally the fluctuation at some piezometers reached 30 percent. The average water manometer pressure plus 10 percent was used in the design of the walls.

3/ ibid.

Stoplog storage facility.--When it becomes necessary to unwater the basin, stoplogs will be used to provide a bulkhead at the downstream end of the basin. When not in use, the stoplogs will be stored by spanning the basin from the top of one training wall to the other, Figure 9. There will be six stoplogs; each will be 18 inches wide by 3 feet 8 inches deep made up of three 18 WF 96 beams and will weigh 11,200 pounds.

Tests were conducted using model logs to determine how high above the flow and how far upstream the logs should be stored to prevent the flow from striking the logs. The model logs were constructed of wood and were geometrically dimensioned. One log was loaded with nails to provide the correct model weight.

For small flows and for large flows, the jet did not impinge on the logs when they were stored at the downstream end of the basin at normal training wall elevation 3204. However, for intermediate flows, Figure 48A, large particles of water separating from the jet impinged upon the logs and sometimes dislodged them. Therefore, it was necessary to develop a facility that would store the stoplogs and provide a walkway a safe distance above the jet.

The weighted log was tested at various elevations and distances from the end of the basin to determine the desired location of the downstream log. It was decided to place the downstream log at the minimum recommended distance from the downstream end of the basin wall and 11 feet 5 inches above normal training wall elevation 3204, Figure 49. Even here, particles of water from the flow sometimes wobbled the logs and dislodged the walkway grating, Figure 48. Therefore, full length guides are to be provided for log storage to prevent the logs from dislodging, and the walkway gratings are to be securely fastened.

Channel erosion.--The banks of the river channel downstream from the stilling basin consist of a considerable amount of a talus type of overburden that could quite easily be washed into the stream channel. The overburden will be removed to bedrock downstream from the spillway stilling basin to provide a discharge channel into the river, Figure 2. About 163 feet downstream from the end of the basin the bedrock angles to the left so that it was necessary to extend the left bank of the discharge channel through the overburden. Riprap will be used to protect this portion of the bank from washing into the channel for spillway flows up to 12,000 cfs.

Erosion tests of the left bank were made using sand to represent the overburden and gravel up to three-fourths inch in diameter to represent the riprap. A discharge of 12, 000 cfs with the highest anticipated tailwater elevation for 20, 000 cfs provided the severest conditions for bank erosion. Waves overtopping the layer of riprap which was initially installed to elevation 3195, Figure 50, collapsed the upstream end of the riprap during a 1-hour (model) test.

These tests indicated that the top layer of riprap should extend to elevation 3205 at the upstream end and slope downward to elevation 3195 at the downstream end of the riprap slope, Figure 51. The tests also indicated that the upstream end should be reinforced with an extra-thick layer of riprap. A 4-hour model erosion test with this arrangement produced practically no movement of riprap for the most severe operating condition, Figure 51.

Tailwater conditions.--Tailwater conditions at the powerplant, outlet works, and spillway stilling basin were investigated for various flow conditions. The tailwater elevation was controlled approximately 1, 500 feet downstream from the spillway stilling basin at river Station 28+00 in accordance with the values shown on Figure 31. For flows up to 36, 000 cfs a minimum and maximum tailwater elevation was anticipated depending upon the amount of storage in the afterbay dam 2 miles downstream. For flows greater than 36, 000 cfs the afterbay dam will wash out and the tailwater elevation at Station 28+00 will depend upon the extent of the failure.

Tailwater elevations in the model were first checked with those anticipated in the prototype for a flow of 8, 000 cfs from the powerplant and outlet works with no flow from the spillway. For maximum anticipated tailwater elevation at Station 28+00, the tailwater at the powerplant and at Station 13+00 were approximately 0.2 foot higher than shown in Figure 31. For minimum anticipated tailwater at Station 28+00, the water surface elevations at the powerplant and at Station 13+00 were approximately 1 foot higher than shown in Figure 31.

When the spillway is discharging 12, 000 cfs in addition to 8, 000 cfs from the powerplant and outlet works, the total flow at Station 28+00 is 20, 000 cfs. This operating condition at the powerplant, outlet works, and spillway stilling basin, is shown in Figure 52 for the anticipated minimum and maximum tailwater elevations at river Station 28+00. The tailwater elevations at Station 13+00 and the powerplant were approximately 1 foot below those shown in Figure 31 for both minimum and maximum elevations.

When the spillway flow was increased to approximately 12, 800 cfs in addition to 8, 000 cfs from the powerplant and outlet works, the jump swept from the basin with minimum tailwater at Station 28+00, Figure 35, and the tailwater elevation at Station 13+00 and the powerplant was drawn down approximately 5 feet to elevation 3182. With maximum tailwater at Station 28+00, which is approximately 4 feet higher than minimum tailwater, the flow swept from the basin at approximately 13,800 cfs and the tailwater elevations at Station 13+00 and the powerplant were drawn down to approximately elevation 3186, Figure 53.

Increasing the spillway flow to 23,000 cfs while maintaining the powerplant and outlet works at 8,000 cfs lowered the tailwater elevations at the powerplant and at Station 13+00 to approximately 3178.5 and 3177.5, respectively, Figures 53 and 54. Increasing the spillway flow or changing the tailwater elevation at Station 28+00 in accordance with whether or not the afterbay dam was washed out did not appreciably affect the tailwater elevation at Station 13+00 or the powerplant.

Closing the powerplant, leaving 5,000 cfs through the outlet works, lowered the tailwater at the powerplant and Station 13+00 to elevations 3176.5 and 3175.5, respectively, Figures 53 and 54. This is 1 foot below the minimum tailwater elevation for which 5,000 cfs through the outlet works was designed.[1] Therefore, the outlet works should not be operated at maximum design flow while the spillway is discharging approximately 23,000 cfs or more, unless the powerplant is operating.

When the outlet works was closed, leaving only 3,000 cfs through the powerplant and at least 23,000 cfs through the spillway, the tailwater at the powerplant and Station 13+00 was lowered to approximately elevations 3175 and 3174, respectively, Figures 42, 53 and 54. Closing both powerplant and outlet works lowered the tailwater elevation at both the powerplant and at Station 13+00 to approximately elevations 3171.7 and 3171.3, respectively, Figures 43, 53, and 54.

After completion of the model study the afterbay dam was designed for a reservoir storage capacity of 3,150 acre-feet at water surface elevation 3192. Therefore, the tailwater curves shown in Figure 31, will not be valid. However, operation of the afterbay dam is such that the gates will be opened completely before the riverflow reaches 20,000 cfs. With the afterbay dam gates open and for flows near 20,000 cfs, the tailwater at Stations 28+00, 13+00 and the powerplant, will be approximately as shown on Figure 31 for the 2,700-acre-foot afterbay dam. The hydraulic design of the stilling basin was based upon this tailwater elevation, as well as the minimum tailwater and therefore is a satisfactory design.

If the material removed from the riverbed or from the channel banks by erosion is deposited in the river channel, the tailwater elevation at the powerplant will be higher than those elevations shown in Figures 53 and 54. Tests conducted with an erodible bed, Figure 33, showed that a bar of eroded material would be deposited to elevation 3195 in the river channel. Tailwater elevations in the powerplant tailrace for this condition, are shown in the following table:

1/ibid.

Spillway discharge cfs	Outlet works and powerplant discharge cfs	Total discharge cfs	Tailwater at elevation downstream river gage Station 28+00	Tailwater elevation at powerplant
38,000	8,000	46,000	3195.5	3184
61,000	8,000	69,000	3200.5	3188
84,000	8,000	92,000	3202.0	3188

A further test was made to determine the highest possible water surface at the powerplant. To obtain this information the spillway gates were suddenly closed while the powerplant and outlet works were discharging 8,000 cfs and while the spillway was discharging 92,000 cfs. With the bar deposited to elevation 3195 in the river channel, a wave traveled upstream and reached elevation 3194 at the powerplant. With no bar, the wave reached elevation 3189. This information was used to determine to what elevation protection against flooding should be provided at the powerplant.

Diversion flows.--Before connecting the model reservoir to the horizontal tunnel, the modified basin that had been developed at that time and the recommended trajectory were tested for diversion flows of 20,000 and 31,000 cfs, Figure 55. Minimum tailwater elevations as shown in Figure 31 at Station 28+00 for both flows were used in the test since the afterbay dam would not be in existence during the diversion period.

For 20,000 cfs, the flow in the tunnel trajectory was expected to be about 21.4 feet deep, and flowing at a velocity of about 35 feet per second. For 31,000 cfs, the flow depth was expected to be 25.3 feet and the velocity about 46 feet per second. These depths were controlled by the slide gate in the model tunnel.

For 20,000 cfs, the position of the toe of the jump fluctuated within the tunnel near the portal exit. The hydraulic jump sealed the portal part time and eventually evacuated the air and filled the tunnel. Similar conditions existed for 31,000 cfs, but the tunnel filled more rapidly.

These flow conditions suggested that the tunnel be vented, and a 12-inch air vent was located in the crown of the tunnel at the point of curvature of the tunnel trajectory. With this vent, the tunnel flowed a little more than one-half full for 20,000 cfs, Figure 55. For 31,000 cfs, the tunnel flowed full to the air vent and was partially full from the air vent to the portal. The exact discharge for which the tunnel upstream of the vent filled was not determined. The stilling basin performance was satisfactory for both flows, Figure 55.

Water surface profiles along the training walls of the basin are recorded in Figure 56. Pressures along the invert of the tunnel trajectory, Figure 40A, were above atmospheric.

After completion of the diversion flow studies, the model reservoir and remainder of the spillway tunnel was installed for further development of the stilling basin. The recommended basin was 30 feet longer and 5 feet deeper than the one tested for diversion flows and the air vent was located downstream from the P. C. of the tunnel trajectory. It was believed that these changes would not adversely affect the operation of the basin for diversion flows but that the tunnel might fill at a lower discharge since the air vent was located at a lower elevation.

During construction of the dam and before completion of the right wall of the prototype stilling basin, the structure was required to operate, Figure 57. A peak flow of 25,500 cfs was satisfactorily diverted through the structure. The model operation of the modified basin at a similar flow as shown for the prototype in Figure 57 is shown in Figures 55A and C.

APPENDIX A
by D. L. King

Electronic Digital Computer Program to Determine Water Surface Profiles by the Standard Step Method

The subject computer program was developed primarily for determining water surface profiles for supercritical flow in scale models of hydraulic structures, such as tunnel or chute spillways or canals, but is equally applicable to investigation of prototype structures.

The program is written in the FORTRAN II (FORmula TRANslation) language for an IBM 7090 computer (see Program Listing) and can be used for rectangular, trapezoidal, circular or compound (such as the Yellowtail Spillway type of rectangular to circular transition) sections. The program has been used on a large solid state computer located at the National Bureau of Standards in Boulder, Colorado.

The water surface profiles are computed by the standard step method which consists of solving Manning's flow equation $V = \frac{1.49}{n} R^{2/3} S^{1/2}$, where V is the mean velocity in feet per second, n is the coefficient of roughness, R is the hydraulic radius in feet, and S is the slope of the energy gradient. In this method the distance between stations is known and the correct depth at each station is determined in the computations.

The computation is carried forward in a series of steps as shown in the flow chart, Figure 1, beginning with a known depth of flow (such as critical depth) at the first station. The depth of flow is used in the computation to obtain the area, velocity, velocity head, and hydraulic radius. Manning's equation can then be solved for the slope of the energy line, S. The loss in head due to friction is then computed by multiplying S by the length of reach. The program also contains provisions for computation of additional losses due to transitions or bends and losses accrued prior to the beginning station. The vertical component of the depth, the velocity head, and the friction head losses are summed to determine the total head. This value is compared to the total head at the first station (or reservoir elevation where applicable). If the two values do not compare within specified limits, a new depth is assumed and the steps are repeated.

The program increments the depth in intervals of 0.1 foot until the correct total head value has been passed. The increment is then changed to 0.001 foot and changed in sign so that the computation proceeds in the opposite direction until the correct value of total head has again been passed. The program then performs a test to see if the current depth or the depth used in the previous step results in a total head nearer to the prescribed value. The appropriate depth is then printed along with the station, invert elevation, velocity, and total head.

A sample of the data sheet and the printed results follow Figure 1.

FORTRAN II SOURCE STATEMENTS FOR ELECTRONIC DIGITAL COMPUTER PROGRAM TO COMPUTE WATER SURFACE PROFILES BY THE STANDARD STEP METHOD

Bureau of Reclamation, Denver, Colorado

```
    1 FORMAT (9F8.0)
    2 FORMAT (2F8.3)
    3 FORMAT (I4)
    5 FORMAT (F9.3,9X,F8.3,10X,F8.3,10X,F8.3,10X,F8.3)
    6 S=0.0
      V=0.0
      K=0
      TOTAL=0.0
      DX=0.0
      READ INPUT TAPE 5,1,Q,RESEL,DN,SUM,CN
      WRITE OUTPUT TAPE 6,4,Q,RESEL,DN,SUM,CN
    4 0FORMAT(1H1,3H Q=,F10.3,5X,8H RES EL=,F8.3,5X,15H INITIAL DEPTH=,F6
     1.3,5X,16H INITIAL LOSSES=,F6.3,3H N=,F5.3)
      READ INPUT TAPE 5,3,N
      WRITE OUTPUT TAPE 6,55
   55 0FORMAT (1H0, 80H STATION          INVERT ELEV              DEPTH
     1    VELOCITY           TOTAL HEAD)
   56 FORMAT (1H0,31H DO LOOP LIMIT HAS BEEN REACHED)
    7 SAVE=STA
      STORE=S
      STORE1=ELINV
      SUMMA=SUM
      HIDE1=HV
      L=0
      DX=0.0
      ADD=0.1
      IF (K-3) 31,30,31
C       FIRST STATION
   30 WRITE OUTPUT TAPE 6,5,STA,ELINV,DN,V,TOTAL
   31 READ INPUT TAPE 5,3,I
C       I DENOTES SHAPE OF CROSS SECTION
      K=K+1
      IF (I-1) 101,102,103
C       RECTANGULAR OR TRAPEZOIDAL CHANNELS
  101 READ INPUT TAPE 5,1,STA,ELINV,W,SB,SS
      READ INPUT TAPE 5,1,TLF,BLF,BENDR,BENDA
      K=K+2
   82 DO 70 J=1,1000
      IF (J-1000) 83,84,84
   83 IF (I-1) 104,105,106
   84 WRITE OUTPUT TAPE 6,56
      GO TO 83
  104 AKEEP=DN
      L=L+1
      DN=DN+DX
      IF (DN) 32,32,33
   32 DN=AKEEP
      DX=DX/10.0
      DN=DN+DX
   33 A=W*DN+SS*DN*DN
      HR=A/(W+2.0*SQRTF(DN*DN+((SS*DN)*(SS*DN))))
```

Note: Variables used in the program are defined following this listing.

```
      GO TO 52
C        CIRCULAR CONDUITS
  102 READ INPUT TAPE 5,1,STA,ELINV,SB,R
      READ INPUT TAPE 5,1,TLF,BLF,BENDR,BENDA
      K=K+2
      GO TO 82
  105 AKEEP=DN
      L=L+1
      DN=DN+DX
      IF (DN) 34,34,35
   34 DN=AKEEP
      DX=DX/10.0
      DN=DN+DX
   35 IF (DN-R) 90,91,92
C        LESS THAN HALF FULL
   90 ROOT=SQRTF(R*R-(R-DN)*(R-DN))
      TERM=ROOT/(R-DN)
      ANGLE=ATANF(TERM)
      A=((R*R)*ANGLE)-((R-DN)*ROOT)
      HR=A/(R*2.0*ANGLE)
      GO TO 52
C        EXACTLY HALF FULL
   91 A=(3.1416*R*R)/2.0
      HR=R/2.0
      GO TO 52
C        GREATER THAN HALF FULL
   92 ROOT=SQRTF(R*R-(DN-R)*(DN-R))
      TERM=ROOT/(DN-R)
      ANGLE=ATANF(TERM)
      A=(3.1416*R*R)-((R*R*ANGLE)-((DN-R)*ROOT))
      HR=A/((2.0*3.1416*R)-(R*2.0*ANGLE))
      GO TO 52
C        CIRCULAR TO RECTANGULAR TRANSITIONS
  103 READ INPUT TAPE 5,1,STA,ELINV,SB,R,ELC,EL1,W,R1,T
      READ INPUT TAPE 5,1,TLF,BLF,BENDR,BENDA
      K=K+2
      GO TO 82
  106 AKEEP=DN
      L=L+1
      DN=DN+DX
   38 IF (DN) 36,36,37
   36 DN=AKEEP
      DX=DX/10.0
      DN=DN+DX
      GO TO 38
   37 DIFF=DN-(EL1-ELINV)
      DIFF1=DN-(ELC-ELINV)
      DIFF2=EL1-ELC
      IF (DIFF) 50,50,51
C        EQUAL TO OR LESS THAN THE DEPTH OF THE RECTANGULAR SECTION
   50 IF (DN-R1) 61,60,60
   60 A=W*DN-2.0*(R1*R1-(3.1416*R1*R1/4.0))-T*DN
```

```
      IF (T) 11,63,64
   63 HR=A/(W-2.0*R1+2.0*(DN-R1)+3.1416*R1)
      GO TO 52
   64 HR=A/(W-2.0*R1+2.0*(DN-R1)+3.1416*R1-T+2.0*DN)
      GO TO 52
   61 ROOT=SQRTF(R1*R1-(R1-DN)*(R1-DN))
      TERM=ROOT/(R1-DN)
      ANGLE=ATANF(TERM)
      A1=(R1*R1*ANGLE)-(R1-DN)*ROOT
      A=(W-2.0*R1)*DN+A1-T*DN
      IF (T) 11,65,66
   65 HR=A/(W-2.0*R1+2.0*R1*ANGLE)
      GO TO 52
   66 HR=A/(W-2.0*R1+2.0*R1*ANGLE-T+2.0*DN)
      GO TO 52
C       GREATER THAN THE DEPTH OF THE RECTANGULAR SECTION
   51 ROOT1=SQRTF(R*R-DIFF1*DIFF1)
      TERM1=ROOT1/DIFF1
      ANGLE1=ATANF(TERM1)
      A1=(3.1416*R*R/2.0)-(R*R*ANGLE1-DIFF1*ROOT1)
      ROOT2=SQRTF(R*R-DIFF2*DIFF2)
      TERM2=ROOT2/DIFF2
      ANGLE2=ATANF(TERM2)
      A2=(3.1416*R*R/2.0)-(R*R*ANGLE2-DIFF2*ROOT2)
      A=A1-A2+W*(EL1-ELINV)-2.0*(R1*R1-(3.1416*R1*R1/4.0))-T*DN
      IF (T) 11,67,68
   670HR=A/(((ANGLE2*R)-(ANGLE1*R))*2.0+W-2.0*R1+2.0*(EL1-ELINV-R1)+
     13.1416*R1)
      GO TO 52
   680HR=A/(((ANGLE2*R)-(ANGLE1*R))*2.0+W-2.0*R1+2.0*(EL1-ELINV-R1)+
     13.1416*R1-T+2.0*DN)
   52 HIDE=V
      V=Q/A
      HV=V*V/64.4
      HT=TLF*ABSF(HV-HIDE1)
      HB=BLF*(HV+HIDE1)/2.0
      S=(CN*CN*V*V)/(2.2082*(HR**1.3333))
      IF (STORE) 11,7,9
    9 AVGS=(STORE+S)/2.0
      IF (BENDR) 11,71,72
   71 RUN=SQRTF((STA-SAVE)*(STA-SAVE)+(STORE1-ELINV)*(STORE1-ELINV))
      GO TO 73
   72 RUN=BENDR*BENDA
   73 HF=RUN*AVGS
      SUM=HF+HT+HB+SUMMA
      CHECK=TOTAL
      D=DN/SQRTF(1.0+SB*SB)
      TOTAL=ELINV+D+HV+SUM
      IF (RESEL-TOTAL) 12,100,14
   12 IF (L-1) 11,13,17
   13 DX=ADD
      GO TO 17
```

```
14 IF (L-1) 11,15,17
15 DX=-ADD
17 IF (DX) 18,11,19
18 IF (RESEL-TOTAL) 21,100,70
19 IF (RESEL-TOTAL) 70,100,21
21 IF (ADD-0.1) 20,23,11
23 ADD=0.001
   L=0
   GO TO 82
20 ONE=TOTAL-RESEL
   TWO=RESEL-CHECK
   IF (ONE-TWO) 100,100,120
100 WRITE OUTPUT TAPE 6,5,STA,ELINV,DN,V,TOTAL
   IF (K-N) 7,80,11
120 WRITE OUTPUT TAPE 6,5,STA,ELINV,AKEEP,HIDE,CHECK
   IF (K-N) 7,80,11
70 CONTINUE
80 GO TO 6
11 WRITE OUTPUT TAPE 6,2,STA,DN
88 IF (K-N) 8,6,6
 8 READ INPUT TAPE 5,1,STA
   K=K+1
   GO TO 88
   END(1,0,0,0,0,0,1,0,0,0,0,0,0,0,0)
```

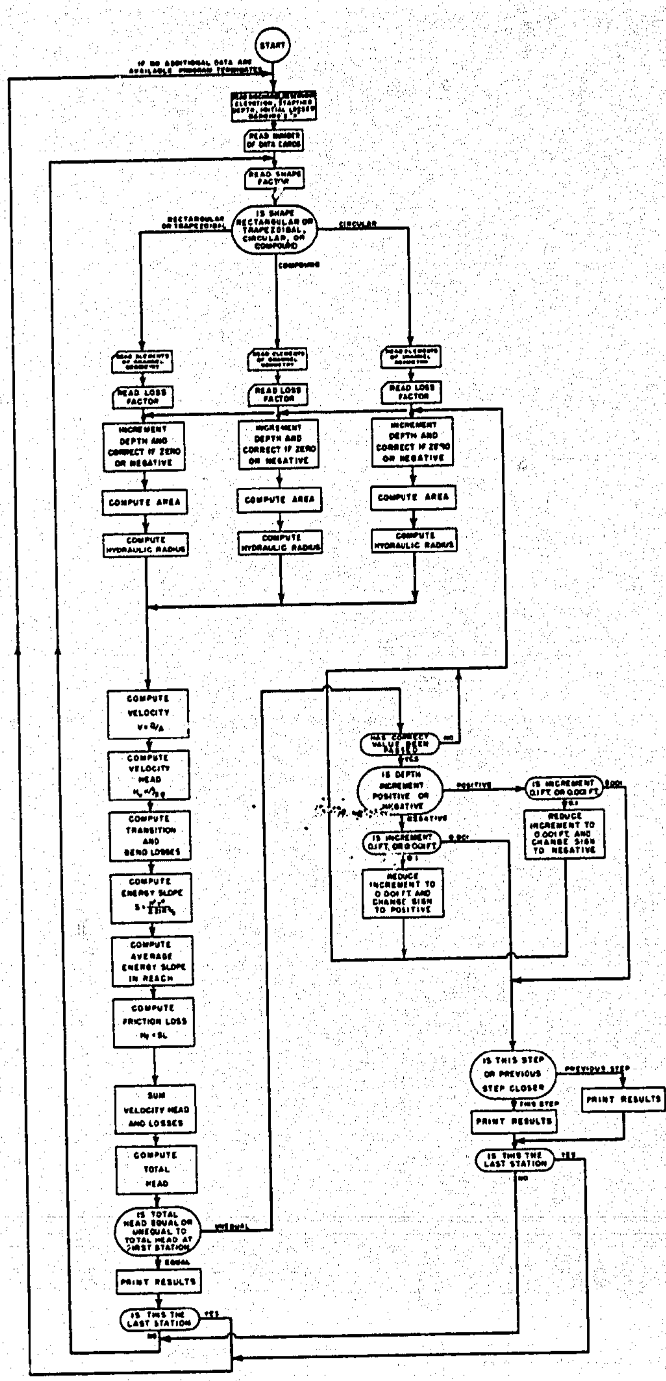
ELECTRONIC DIGITAL COMPUTER PROGRAM TO COMPUTE WATER SURFACE PROFILES BY THE STANDARD STEP METHOD

Definition of Variables Used in Program

A1 and A2	--subareas of compound transition section
ADD	--depth increment
AKEEP	--depth of flow normal to bottom alternate path of computation (dependent on direction from which correct solution is being approached)
ANGLE1 and ANGLE2	--angles used in computation of A1 and A2
ANGLE	--angle used in computation of area for very small depths in compound transition section
A	--area of flow
AVGS	--average slope of energy gradient
BENDA	--central angle of channel or conduit bend
BENDR	--radius of channel or conduit bend
BLF	--bend loss factor
CHECK	--value of total head, alternate path of computation
CN	--Manning's roughness coefficient
DIFF1, DIFF2, and DIFF	--used in comparison of depth of flow in compound transition section with conduit geometry characteristics to determine appropriate methods of computing area of flow
DN	--depth of flow normal to bottom
D	--vertical depth of flow
DX	--depth increment, determined by value of ADD

EL1	--elevation of top of vertical sides in compound transition section
ELC	--elevation of center of circular portion in compound transition section
ELINV	--elevation of channel or conduit bottom or invert
HB	--bend loss
HF	--friction loss
HIDF1	--velocity head, alternate path of computation
HIDE	--velocity of flow, alternate path of computation
HR	--hydraulic radius
HT	--transition loss
HV	--velocity head
I	--conduit or channel shape factor
J	--loop counter
K	--counter for number of cards read
L	--counter for number of stations processed
N	--number of data cards
ONE	--difference between computed and actual total head
Q	--discharge rate
R1	--radius of bottom corner rounding, compound transition section
RESEL	--reservoir elevation or elevation of total head line

ROOT1, ROOT2, and ROOT	--square root extractions used in area computation for compound transition section
R	--radius of circular portion of compound transition section or circular conduit
RUN	--length of reach between stations
SAVE	--value of previous station for use in determination of RUN
SB	--bottom slope
S	--slope of energy gradient
SS	--side slopes for trapezodial channel
STA	--station
STORE1	--invert elevation for previous station for use in determination of RUN
STORE	--slope of energy gradient for previous station, used in determination of AVGS
SUMMA	--accumulated sum of friction loss
SUM	--summation of head losses at a given station
TERM1, TERM2, and TERM	--used in area computation for compound transition section
TLF	--transition loss factor
TOTAL	--elevation of total head line at a given station
T	--width of dividing pier in compound transition section
TWO	--difference between computed and actual total head, alternate path of computation
V	--velocity of flow
W	--bottom width



FLOW CHART FOR DIGITAL COMPUTER SOLUTION OF WATER SURFACE PROFILES BY THE STANDARD STEP METHOD

BUREAU OF RECLAMATION

LABORATORY PUNCH CARD DATA

USE / COLORED CARDS	PROBLEM	Water Surface Profile Calculations	JOB NO.
	DETAIL	Prototype Tunnel	#
	FEATURE	Yellowtail Dam Spillway	RETURN TO
	PROJECT	Missouri River Basin	ROOM BLDG. PHONE

1–8	9–16	17–24	25–32	33–40	41–48	49–56	57–64	65–72	73–80
Q	RESEL	DN	SUM	CN					
12000.0	3657.0	3.64	0.0	0.014					
N									
36									
I					SAMPLE DATA SHEET				
2									
	The format of this card varies according to the channel shape.								
STA	ELINV	SB	R	ELC	EL1	W	R1	T	
545.0	3584.9	0.3852	34.333	3605.567	3622.9	59.276	0.0	9.0	
TIF	BLF	BENDR	BENDA						
0.0	0.0	0.0	0.0						
	Each subsequent station includes an "I" card, a "STA" card, and a "TIF" card.								

REMARKS

BY   DATE   CHECKED   SHEET   OF

EXAMPLE OF PRINTED RESULTS

Q = 12000.000

N = 0.014
RESERVOIR ELEVATION = 3657.000

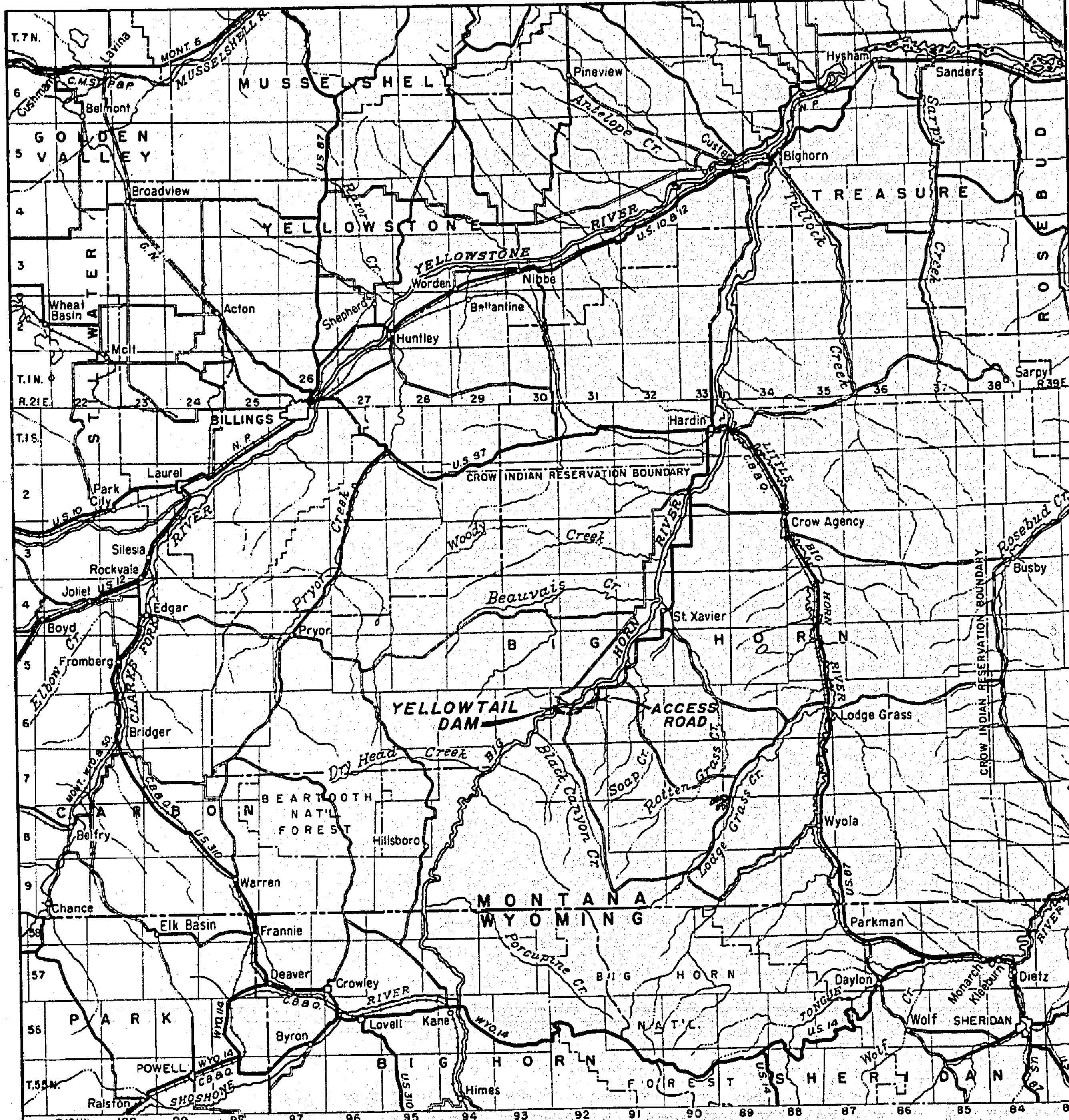
PRECOMPUTED LOSSES = 0.0
STARTING DEPTH = 3.640

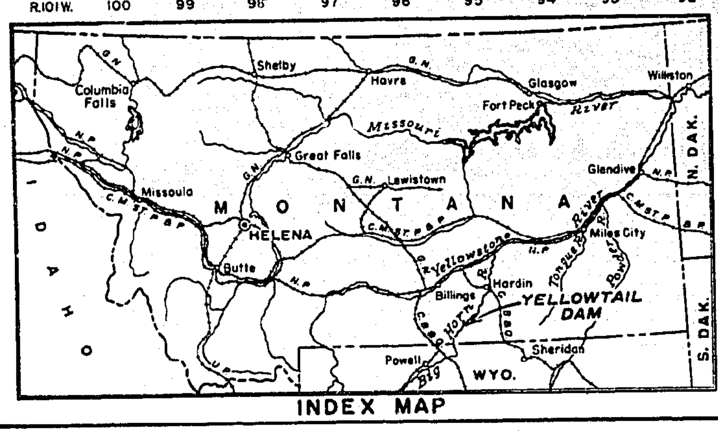
STATION	INVERT ELEV	DEPTH	VELOCITY	TOTAL HEAD
545.000	3584.900	3.640	65.572	0.
590.000	3560.600	4.471	74.599	3656.982
650.000	3503.000	6.389	92.060	3657.026
722.500	3399.400	5.668	116.381	3657.104
795.080	3299.060	5.426	132.856	3657.118
896.190	3204.850	5.167	142.580	3657.117
1031.470	3175.400	5.318	136.768	3657.061
1331.470	3174.200	5.976	115.618	3656.964
1631.470	3173.000	6.616	99.941	3657.013
1831.470	3172.200	7.032	91.621	3656.977
2031.470	3171.400	7.442	84.536	3657.014
2271.500	3155.700	7.559	82.688	3656.995

Table 1

DIMENSIONS OF HYDRAULIC FEATURES

Feature	English units	Metric units
Height of Dam	520 feet	158.50 meters
Length of Dam at Crest	1,450 feet	5,442 meters
Reservoir Area	17,960 acres	72 square kilometers
Storage Capacity	1,427,840 acre-feet	1.761 cubic kilometers
Spillway Design Capacity (Flip Bucket)	92,000 cfs	2,603 cubic meters per second
Head on Spillway Crest at Design Discharge	67 feet	20.42 meters
Radial Gates	25 x 64.4 feet	7.62 x 19.63 meters
Drop from Spillway Crest to Tunnel Invert P.T. of Vertical Bend	417.6 feet	127.28 meters
Drop (Spillway Crest to Basin Floor)	453 feet	138.07 meters
Diameter of Tunnel Spillway	40.5 feet to 32 feet	12.34 meters to 9.75 meters
Vertical Bend Invert Radius	290 feet	88.39 meters
Flip Bucket Radius	138 feet	42.06 meters
Crest Station to Exit Portal	1,733 feet	528.22 meters
P.T. of Vertical Bend to Exit Portal	1201.53 feet	366.23 meters
Basin Length (Portal to End Sill)	250 feet	76.20 meters
Spillway Basin Capacity	12,000 cfs	339 cubic meters per second
Diversion Design Capacity	31,000 cfs	877 cubic meters per second
Outlet Works Capacity	5,000 cfs	141 cubic meters per second
Powerplant Capacity	3,000 cfs	85 cubic meters per second
Spillway Stilling Basin, Outlet Works, and Powerplant Combined Capacity	20,000 cfs	566 cubic meters per second
Hollow-jet Valve Diameter	84 inches	2.13 meters
Spillway Downstream from Powerplant	1,300 feet (approx)	396 meters (approx)
Tailwater Control Station Downstream from Powerplant	2,800 feet	853 meters





INDEX MAP

SCALE OF MILES

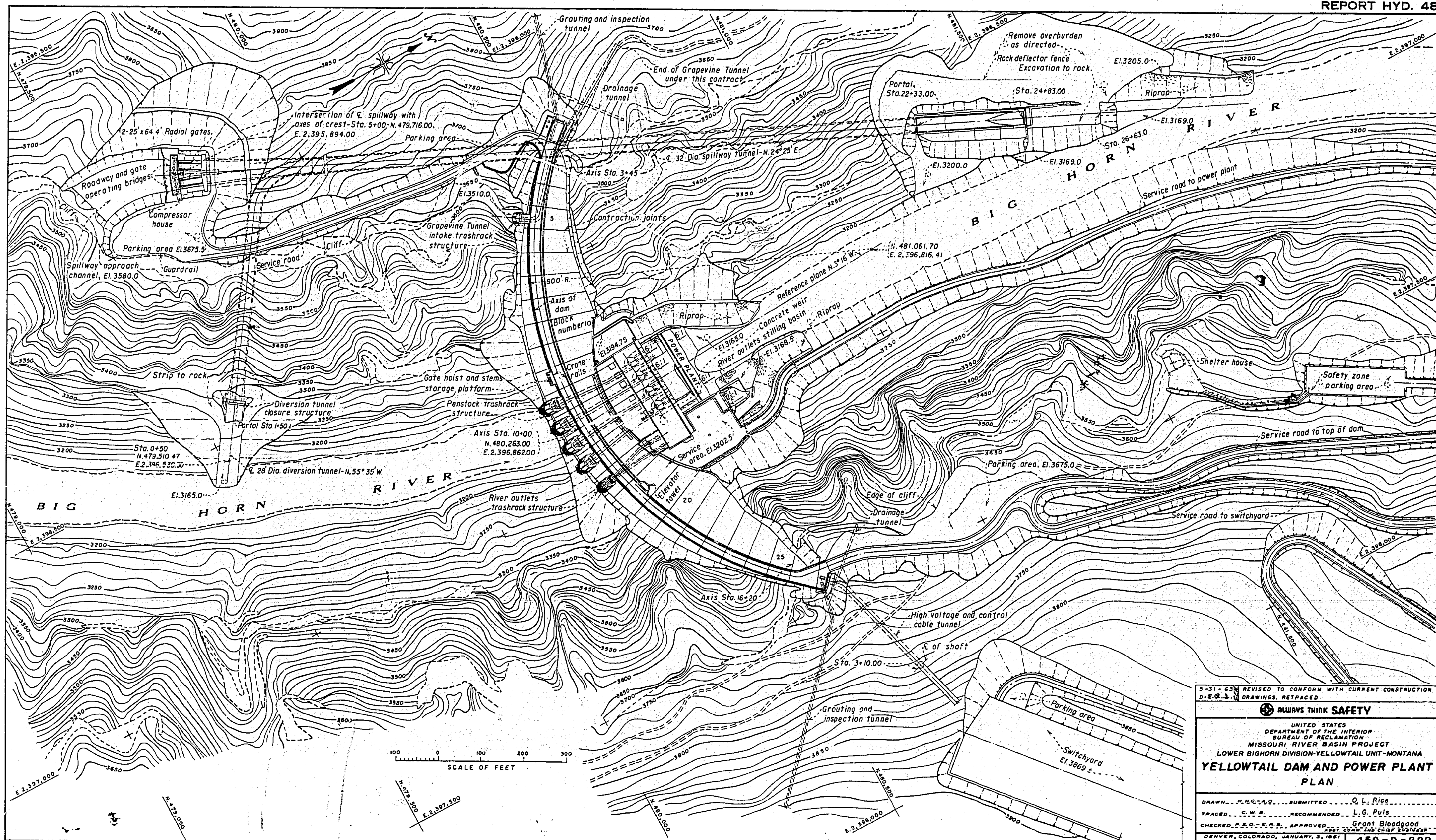
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
LOWER BIGHORN DIVISION-YELLOWTAIL UNIT-MONTANA

YELLOWTAIL DAM AND POWER PLANT
LOCATION MAP

DRAWN A.E.S. SUBMITTED O. L. Rice
TRACED C.M.A. RECOMMENDED [signature]
CHECKED [initials] APPROVED Grant Bloodgood ASSOC. CHIEF ENGINEER

DENVER, COLORADO, NOV. 21, 1955 | 459-D-129

FIGURE 2
REPORT HYD. 483



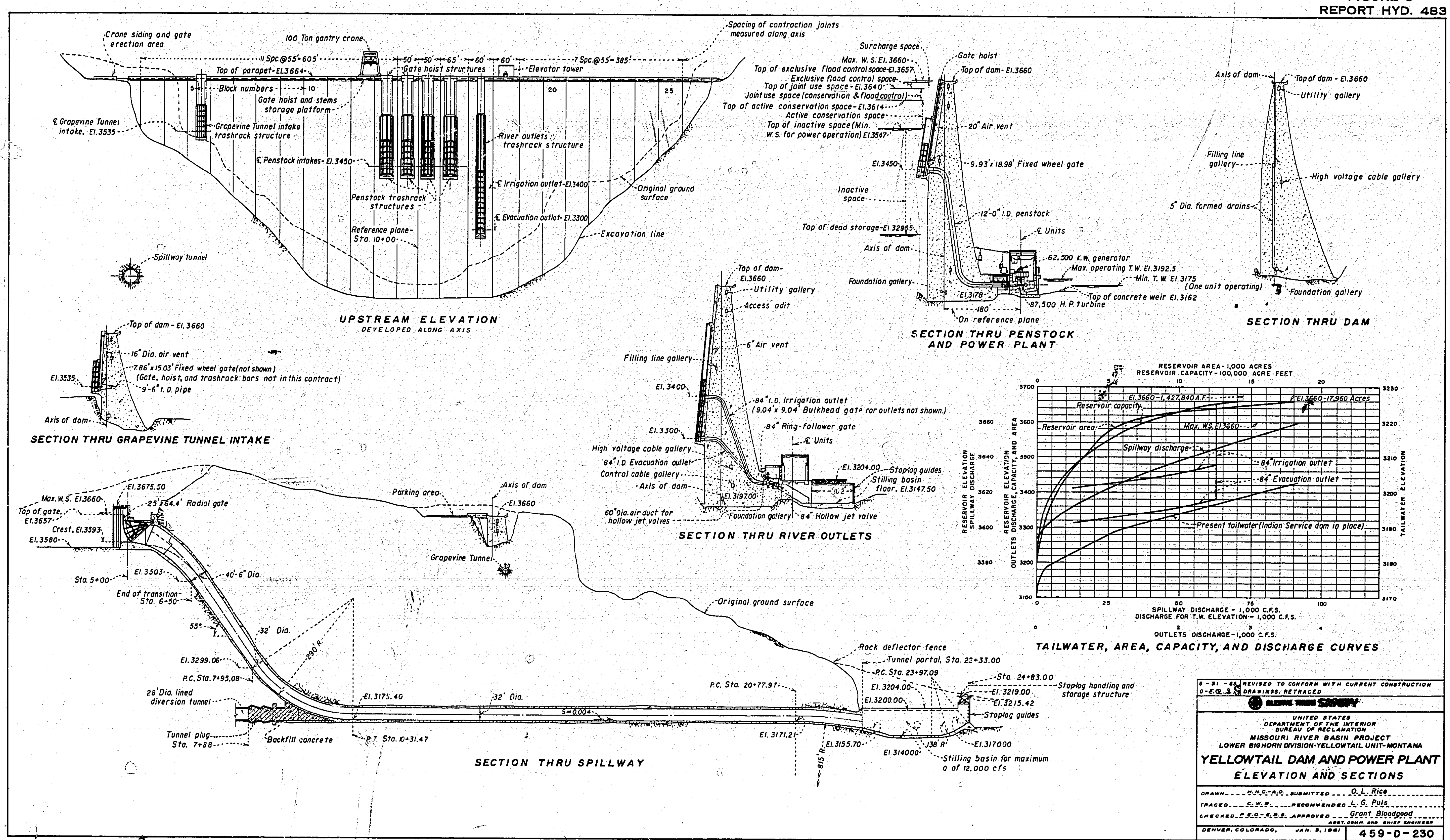

UPSTREAM ELEVATION
DEVELOPED ALONG AXIS
Crane siding and gate erection area.
100 Ton gantry crane
Spacing of contraction joints measured along axis
11 Spc.@55'=605'
50' 50' 65' 60' 60'
7 Spc.@55'=385'
Top of parapet-El.3664
Gate hoist structures
Elevator tower
Block numbers
5
10
20
25
Gate hoist and stems storage platform
℄ Grapevine Tunnel intake, El.3535
Grapevine Tunnel intake trashrack structure
River outlets trashrack structure
℄ Penstock intakes-El.3450
℄ Irrigation outlet-El.3400
Original ground surface
Penstock trashrack structures
℄ Evacuation outlet-El.3300
Reference plane-Sta. 10+00
Excavation line
Spillway tunnel
SECTION THRU GRAPEVINE TUNNEL INTAKE
Top of dam-El.3660
16" Dia. air vent
7.86'x15.03' Fixed wheel gate(not shown)
(Gate, hoist, and trashrack bars not in this contract)
El.3535
9'-6" I.D. pipe
Axis of dam
SECTION THRU PENSTOCK AND POWER PLANT
Surcharge space
Max. W.S. El.3660
Gate hoist
Top of exclusive flood control space-El.3657
Top of dam-El.3660
Exclusive flood control space
Top of joint use space-El.3640
Joint use space (conservation & flood control)
Top of active conservation space-El.3614
Active conservation space
Top of inactive space (Min. W.S. for power operation) El.3547
20" Air vent
El.3450
9.93'x18.98' Fixed wheel gate
Inactive space
12'-0" I.D. penstock
Top of dead storage-El.3296.5
℄ Units
Axis of dam
62,500 K.W. generator
Max. operating T.W. El.3192.5
Foundation gallery
Min. T.W. El.3175
(One unit operating)
El.3178
Top of concrete weir El.3162
180'
87,500 H.P. turbine
On reference plane
SECTION THRU DAM
Axis of dam
Top of dam-El.3660
Utility gallery
Filling line gallery
High voltage cable gallery
5" Dia. formed drains
Foundation gallery
SECTION THRU RIVER OUTLETS
Top of dam-El.3660
Utility gallery
Access adit
6" Air vent
Filling line gallery
El.3400
84" I.D. Irrigation outlet
(9.04'x9.04' Bulkhead gate for outlets not shown.)
84" Ring-follower gate
El.3300
℄ Units
High voltage cable gallery
84" I.D. Evacuation outlet
El.3204.00
Stop-log guides
Control cable gallery
Stilling basin floor, El.3147.50
Axis of dam
El.3197.00
60" Dia. air duct for hollow jet valves
Foundation gallery
84" Hollow jet valve
TAILWATER, AREA, CAPACITY, AND DISCHARGE CURVES
RESERVOIR AREA-1,000 ACRES
RESERVOIR CAPACITY-100,000 ACRE FEET
El.3660-1,427,840 A.F.
El.3660-17,960 Acres
Reservoir capacity
Reservoir area
Max. W.S. El.3660
Spillway discharge
84" Irrigation outlet
84" Evacuation outlet
Present tailwater (Indian Service dam in place)
RESERVOIR ELEVATION SPILLWAY DISCHARGE
RESERVOIR ELEVATION OUTLETS DISCHARGE, CAPACITY, AND AREA
TAILWATER ELEVATION
SPILLWAY DISCHARGE-1,000 C.F.S.
DISCHARGE FOR T.W. ELEVATION-1,000 C.F.S.
OUTLETS DISCHARGE-1,000 C.F.S.
SECTION THRU SPILLWAY
Max. W.S. El.3660
El.3675.50
25'x64.4' Radial gate
Top of gate, El.3657
Crest, El.3593
El.3580
Parking area
Axis of dam
El.3660
Grapevine Tunnel
Sta. 5+00
El.3503
40'-6" Dia.
End of transition-Sta. 6+50
Original ground surface
55°
32' Dia.
290'R.
El.3299.06
P.C. Sta. 7+95.08
28' Dia. lined diversion tunnel
El.3175.40
32' Dia.
S=0.004
Tunnel plug-Sta. 7+88
Backfill concrete
P.T. Sta. 10+31.47
Rock deflector fence
Tunnel portal, Sta. 22+33.00
P.C. Sta. 23+97.09
P.C. Sta. 20+77.97
Sta. 24+83.00
El.3204.00
Stop-log handling and storage structure
El.3219.00
El.3200.00
El.3215.42
Stop-log guides
El.3171.21
El.3155.70
El.3170.00
El.3140.00
138'R.
815'R.
Stilling basin for maximum Q of 12,000 cfs
REVISED TO CONFORM WITH CURRENT CONSTRUCTION
DRAWINGS. RETRACED
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
LOWER BIGHORN DIVISION-YELLOWTAIL UNIT-MONTANA
YELLOWTAIL DAM AND POWER PLANT
ELEVATION AND SECTIONS
SUBMITTED O. L. Rice
RECOMMENDED L. G. Puls
APPROVED Grant Bloodgood
ASST. COMM. AND CHIEF ENGINEER
DENVER, COLORADO, JAN. 3, 1961
459-D-230

FIGURE 4
REPORT HYD. 483

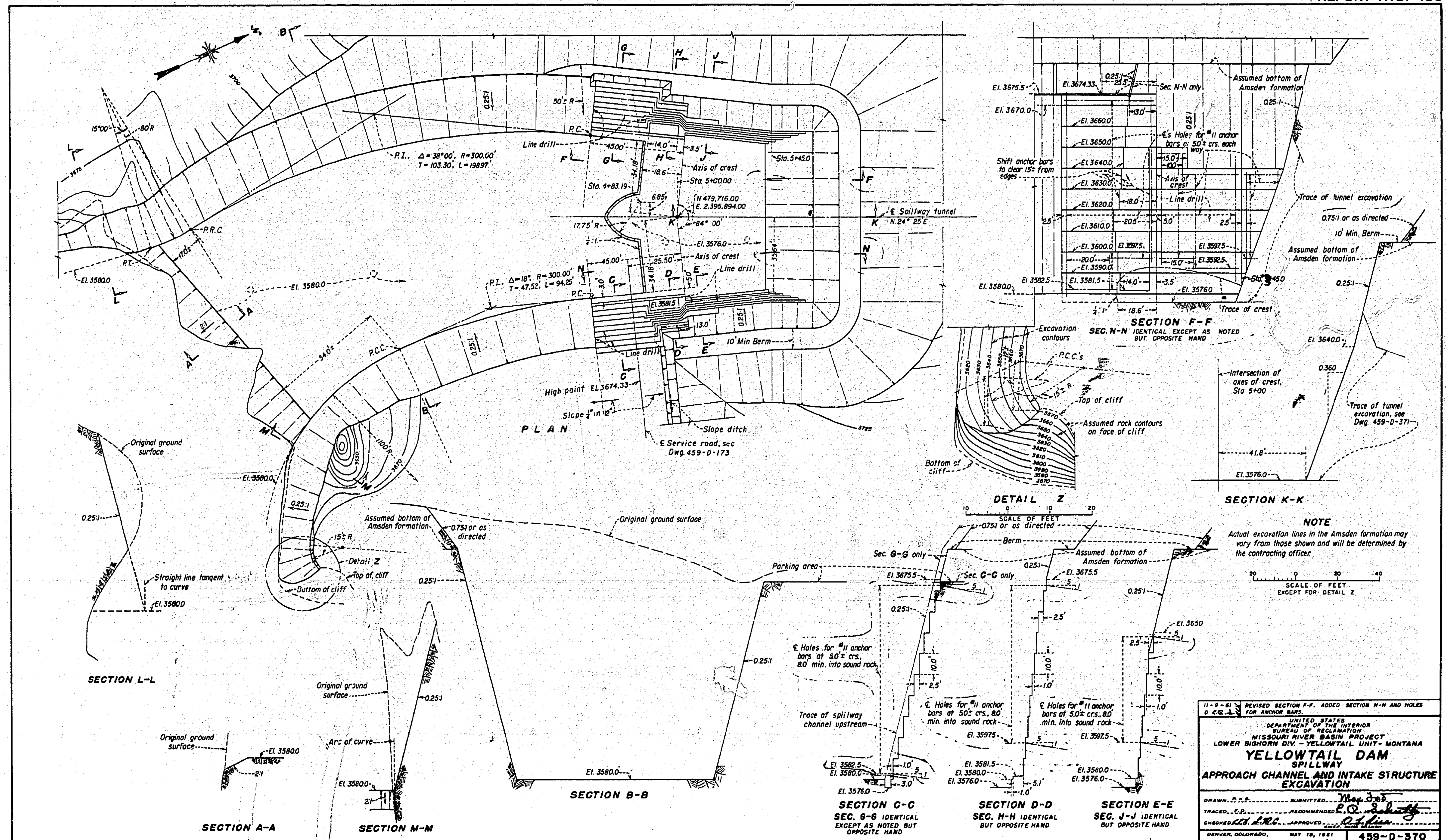


FIGURE 5
REPORT HYD. 483

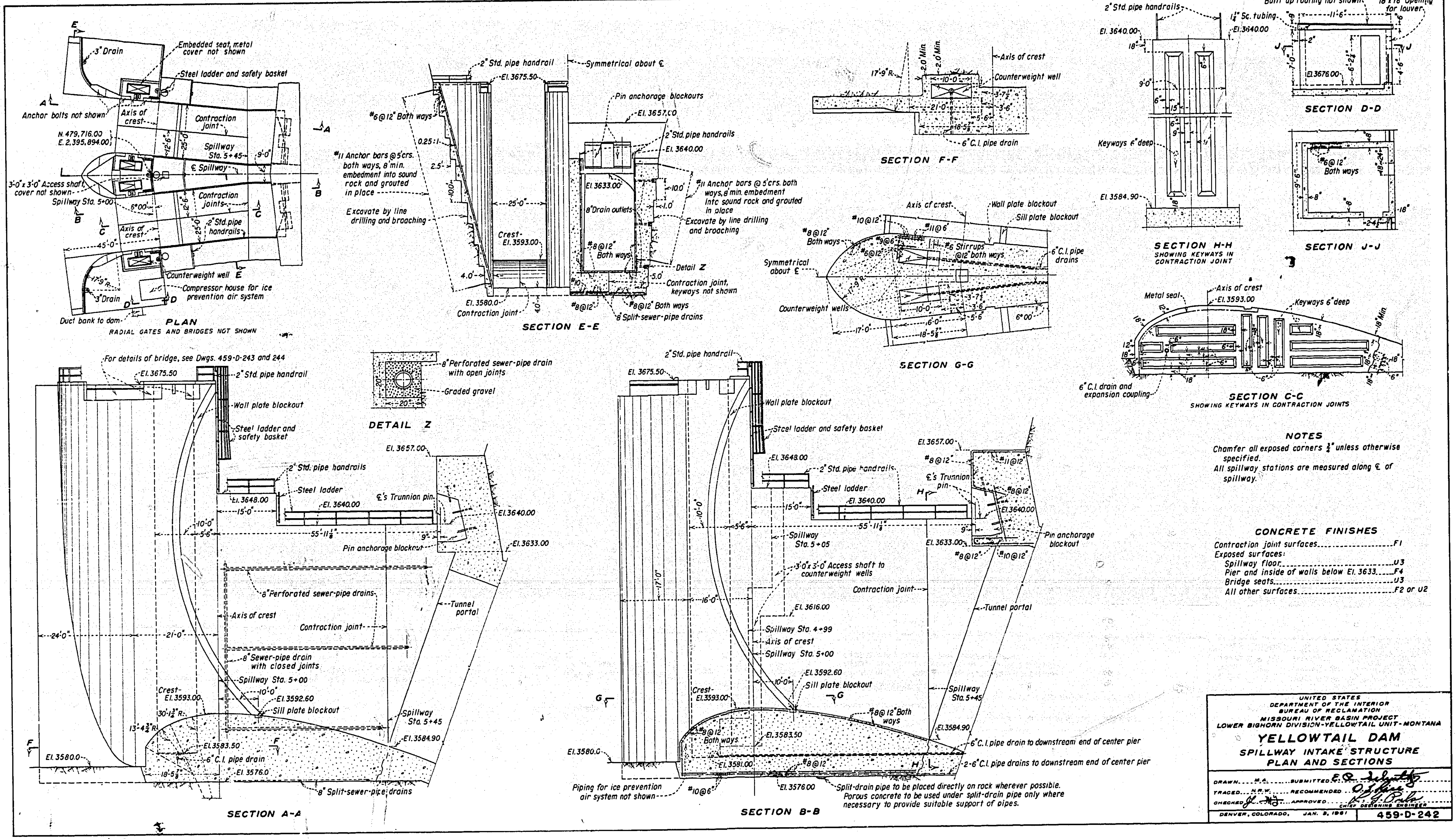
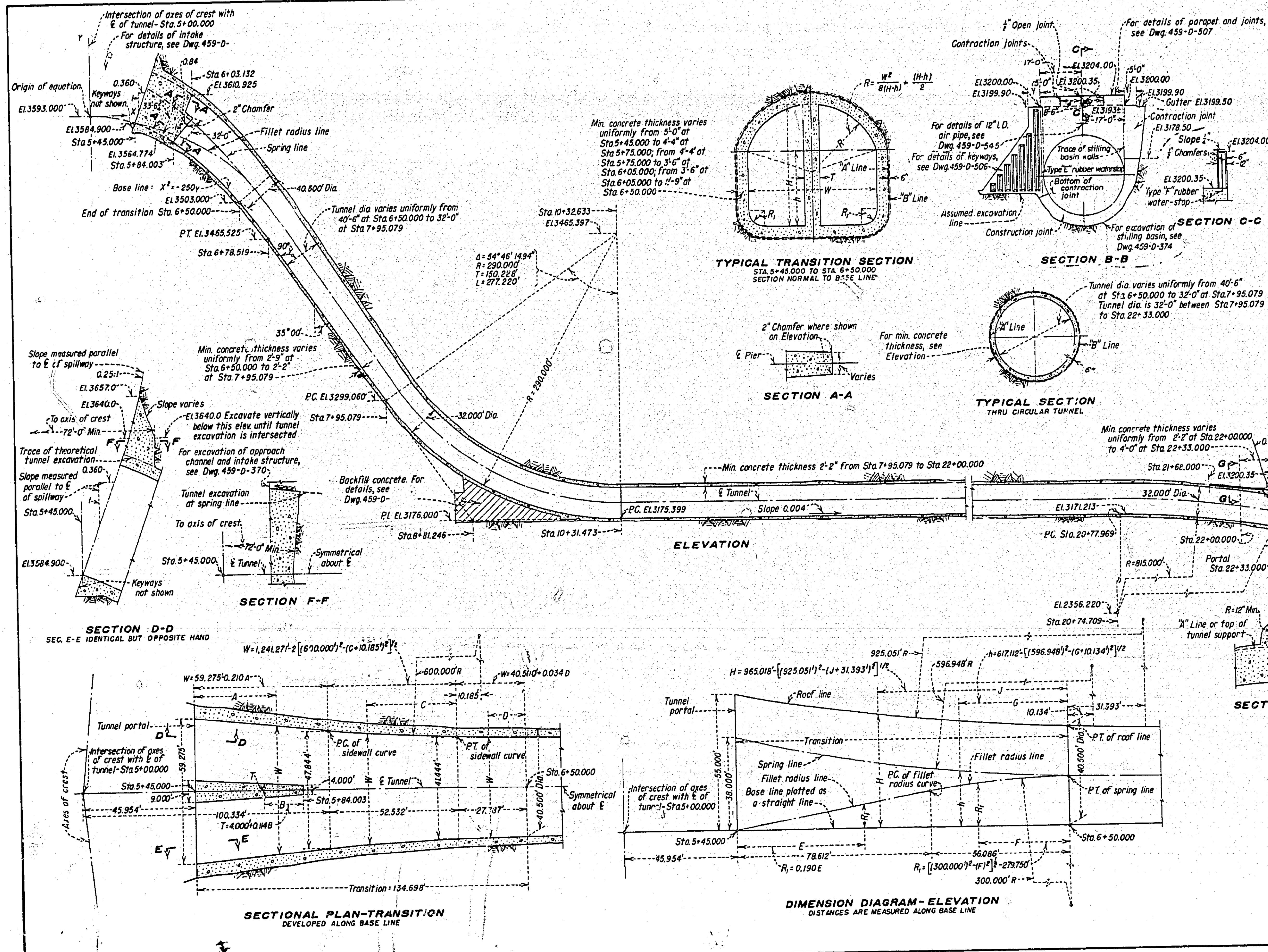


FIGURE 6
REPORT HYD. 483



BASE LINE		ROOF LINE		ELEMENTS OF TRANSITION SECTIONS					
STATION	ELEVATION	STATION	ELEVATION	H	h	W	R	R_1	T
5+45.000	3584.900	5+63.630	3636.649	55'-0"	38'-0"	59'-3 3/4"	34'-4"	0	9'-0"
5+48.745	3583.496	5+68.466	3634.066	54'-3 7/8"	37'-0 7/16"	58'-5 7/16"	33'-4 1/4"	9 1/8"	8'-6 1/2"
5+52.453	3581.995	5+73.184	3631.398	53'-6 7/16"	36'-0 11/16"	57'-7 1/8"	32'-5 1/8"	18 1/4"	8'-1 1/16"
5+56.122	3580.401	5+77.786	3628.652	52'-10 1/16"	35'-1 7/16"	56'-9 1/16"	31'-6 7/16"	2'-3 7/8"	7'-7 7/8"
5+59.751	3578.719	5+82.274	3625.837	52'-2 1/16"	34'-2 7/16"	55'-10 7/8"	30'-8 9/16"	3'-0 7/16"	7'-2 1/16"
5+63.339	3576.951	5+86.652	3622.959	51'-6 5/16"	33'-4 3/8"	55'-0 7/8"	29'-11 1/16"	3'-9 1/8"	6'-8 7/16"
5+66.887	3575.105	5+90.923	3620.024	50'-11 3/4"	32'-6 1/4"	54'-2 3/4"	29'-2"	4'-6 7/16"	6'-3 1/4"
5+70.393	3573.179	5+95.090	3617.035	50'-4"	31'-8 1/2"	53'-4 1/16"	28'-5 3/16"	5'-3 13/16"	5'-9 13/16"
5+73.857	3571.180	5+99.158	3614.001	49'-8 7/8"	30'-11 1/16"	52'-6 9/16"	27'-9 1/16"	6'-1 1/16"	5'-4 3/8"
5+77.281	3569.111	6+03.132	3610.925	49'-1 7/16"	30'-2"	51'-8 1/2"	27'-1 1/8"	6'-10 7/16"	4'-10 7/8"
5+80.662	3566.975	6+07.014	3607.812	48'-7 3/16"	29'-5 7/16"	50'-10 7/8"	26'-5 1/2"	7'-7 3/8"	4'-5 7/16"
5+84.003	3564.774	6+10.809	3604.663	48'-0 1/16"	28'-8 1/8"	50'-0 5/16"	25'-10 1/4"	8'-4 1/2"	4'-0"
5+87.302	3562.513	6+14.521	3601.485	47'-6 1/16"	28'-0 3/16"	49'-2 1/4"	25'-3 3/16"	9'-1 3/8"	
5+90.561	3560.195	6+18.153	3598.280	47'-0 7/8"	27'-5 1/8"	48'-4 1/8"	24'-8 1/16"	9'-10 7/8"	
5+93.781	3557.821	6+21.712	3595.050	46'-6 1/2"	26'-9 3/4"	47'-6 1/8"	24'-2"	10'-7 1/8"	
5+96.961	3555.394	6+25.196	3591.797	46'-0 7/8"	26'-2 11/16"	46'-8 3/8"	23'-8"	11'-5"	
6+00.102	3552.918	6+28.617	3588.525	45'-7 7/16"	25'-7 13/16"	45'-11 3/4"	23'-2 3/8"	12'-2 1/8"	
6+03.206	3550.395	6+31.973	3585.237	45'-2 7/16"	25'-1 9/16"	45'-3 9/16"	22'-9 13/16"	12'-11 7/16"	
6+06.271	3547.826	6+35.266	3581.931	44'-9 3/16"	24'-7 1/2"	44'-8"	22'-5 7/16"	13'-8 7/16"	
6+09.301	3545.213	6+38.504	3578.611	44'-4 3/8"	24'-1 3/4"	44'-1 1/16"	22'-1 1/2"	14'-5 7/16"	
6+12.294	3542.560	6+41.687	3575.278	43'-11 3/4"	23'-8 3/16"	43'-6 5/16"	21'-10 1/16"	15'-2 3/8"	
6+15.252	3539.868	6+44.818	3571.935	43'-7 3/8"	23'-3 1/4"	43'-1 3/16"	21'-7"	15'-11 1/4"	
6+18.176	3537.138	6+47.902	3568.580	43'-3 1/4"	22'-10 1/2"	42'-8 3/16"	21'-4 3/8"	16'-7 1/8"	
6+21.066	3534.372	6+50.939	3565.216	42'-11 1/4"	22'-6 1/16"	42'-3 1/8"	21'-2 1/16"	17'-2 3/8"	
6+23.923	3531.573	6+53.934	3561.845	42'-7 1/2"	22'-2 [illegible]	42'-0 1/8"	21'-0 3/16"	17'-8 13/16"	
6+26.747	3528.741	6+56.887	3558.465	42'-4"	21'-10 7/16"	41'-9 1/16"	20'-10 3/8"	18'-2 13/16"	
6+29.540	3525.877	6+59.802	3555.078	42'-0 7/8"	21'-6 3/4"	41'-6 11/16"	20'-9 7/8"	18'-8 1/8"	
6+32.303	3522.984	6+62.682	3551.686	41'-9 1/2"	21'-3 7/8"	41'-4 7/8"	20'-8 1/16"	19'-0 11/16"	
6+35.035	3520.063	6+65.526	3548.288	41'-6 3/4"	21'-0 5/16"	41'-3 1/4"	20'-7 3/8"	19'-4 11/16"	
6+37.737	3517.114	6+68.338	3544.885	41'-3 7/8"	20'-10 5/16"	41'-1 7/8"	20'-6 7/16"	19'-8"	
6+40.411	3514.139	6+71.121	3541.519	41'-1 3/8"	20'-8 3/16"	41'-0"	20'-6"	19'-10 11/16"	
6+43.057	3511.139	6+73.837	3538.110	40'-11 1/8"	20'-6 3/16"	40'-10 3/8"	20'-5 3/16"	20'-0 1/16"	
6+45.675	3508.115	6+76.602	3534.652	40'-9"	20'-4 7/16"	40'-8 3/4"	20'-4 3/8"	20'-2 1/8"	
6+48.267	3505.068	6+79.304	3531.235	40'-7 1/8"	20'-3 3/8"	40'-7 1/8"	20'-3 5/16"	20'-2 7/8"	
6+50.000	3503.000	6+81.115	3528.929	40'-6"	20'-3"	40'-6"	20'-3"	20'-3"	

TRANSITION DATA
STA. 5+45.000 TO STA. 6+50.000-SECTIONS NORMAL TO BASE LINE

CONCRETE REQUIREMENTS

FINISHES
- Tunnel below ℄ or spring line ---------- F4 or U3
- Tunnel below ℄ from Sta. 7+90 to Sta. 10+35 ---------- F4 with special finish or U3
- All other surfaces ---------- F2 or U2
- Contraction joint surfaces ---------- F1

STRENGTH

Design of concrete is based on a compressive strength of not less than 3000 lbs. per sq. inch at 28 days

NOTES

Reinforcement required but not shown
Chamfer all exposed corners 3/4" unless otherwise specified
"A" Line is line of minimum concrete thickness

REFERENCE DRAWINGS

SPILLWAY-
- TUNNEL SUPPORTS ---------- 459-D-372
- TUNNEL-GROUTING AND DRAINAGE DETAILS ---------- 459-D-373

7-19-62	REVISED TO CONFORM TO STILLING BASIN DRAWINGS
7-28-61	TRACED. ADDED PARAPET JOINTS

THIS DRAWING SUPERSEDES DWG. 459-D-241 IN PART

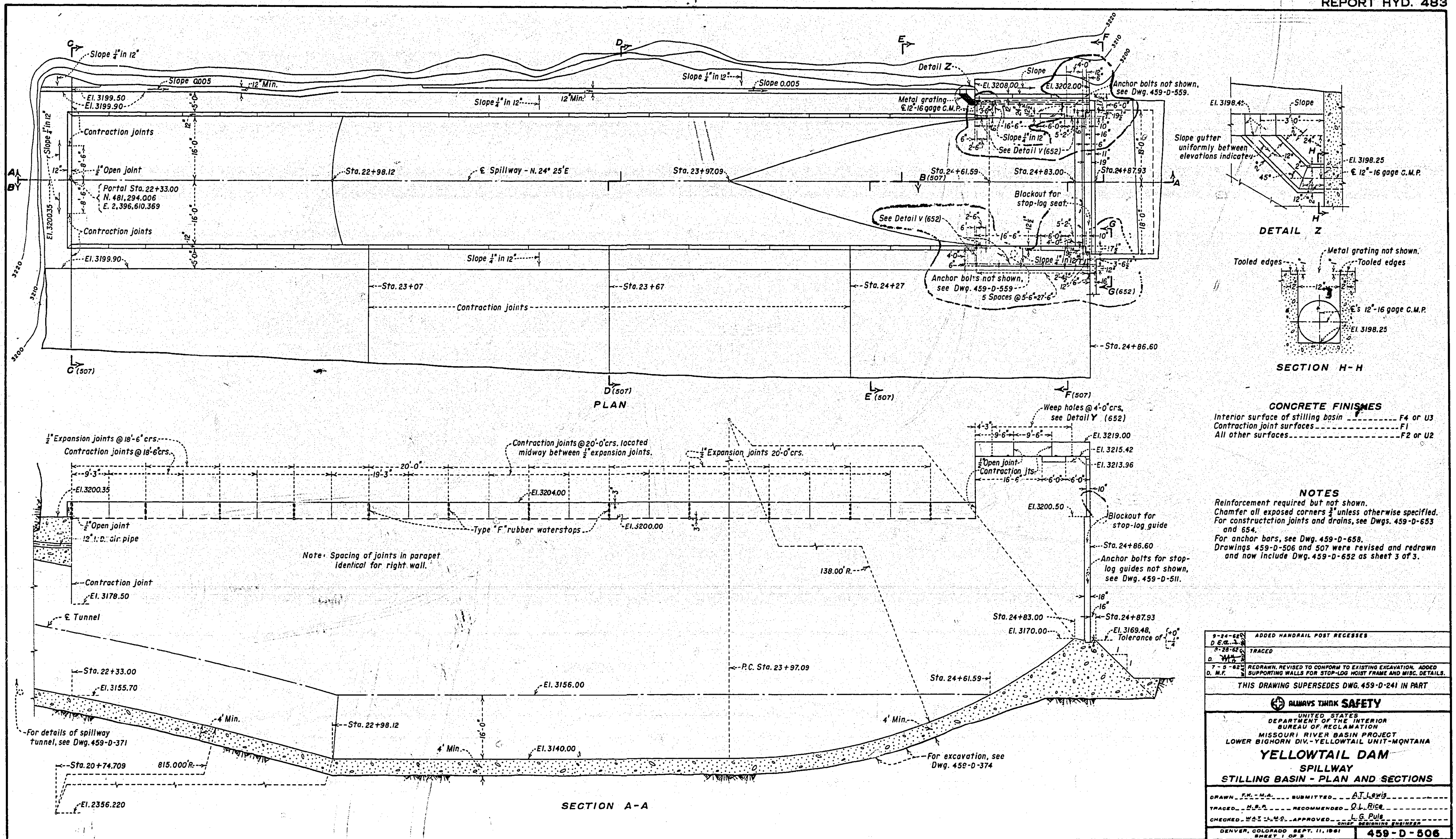
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
LOWER BIGHORN DIV.-YELLOWTAIL UNIT-MONTANA

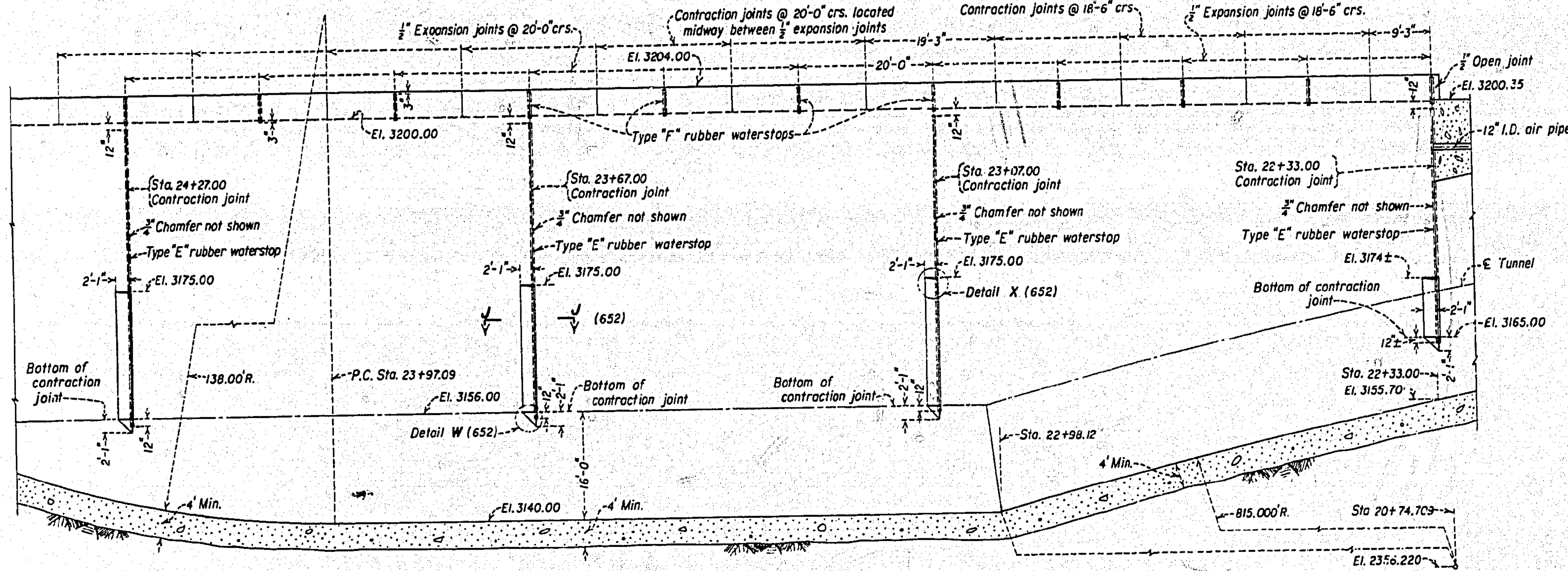
YELLOWTAIL DAM
SPILLWAY
TUNNEL-EXCAVATION AND LINING DETAILS

DRAWN M.A. SUBMITTED Max Ford
TRACED W.A.P. RECOMMENDED E. R. Schultz
CHECKED C.E.H.-L.M.G. APPROVED R. T. Larsen, ACT. CHIEF, DAMS BRANCH

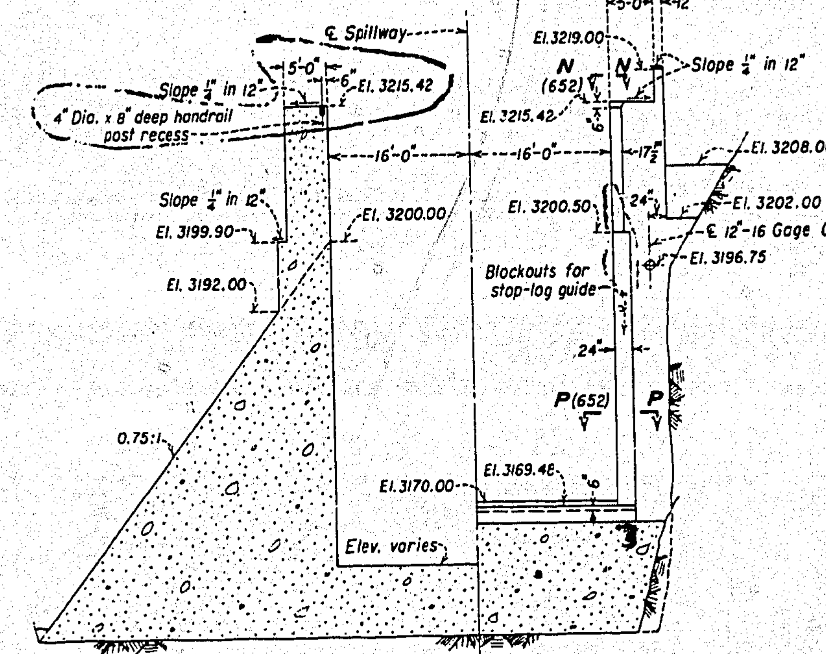
DENVER, COLORADO, JUNE 2, 1961 — 459-D-371

FIGURE 7
REPORT HYD. 483





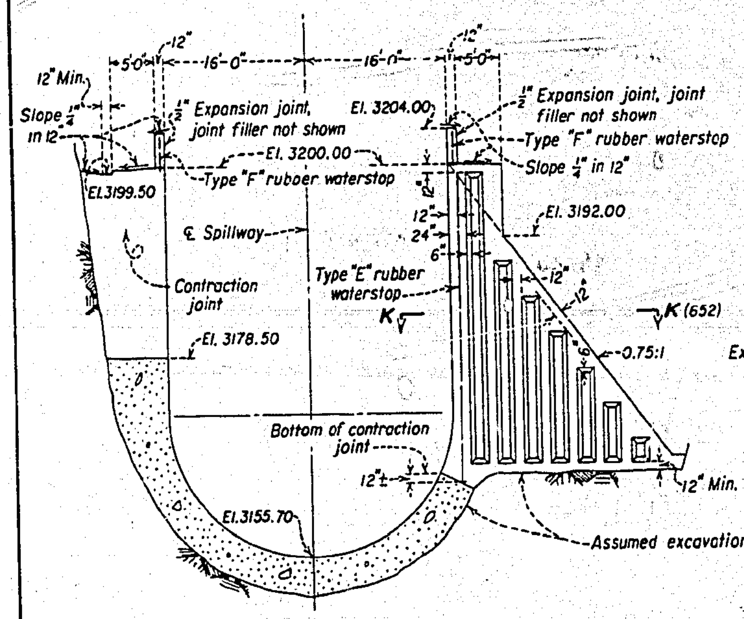
SECTION B-B(506)



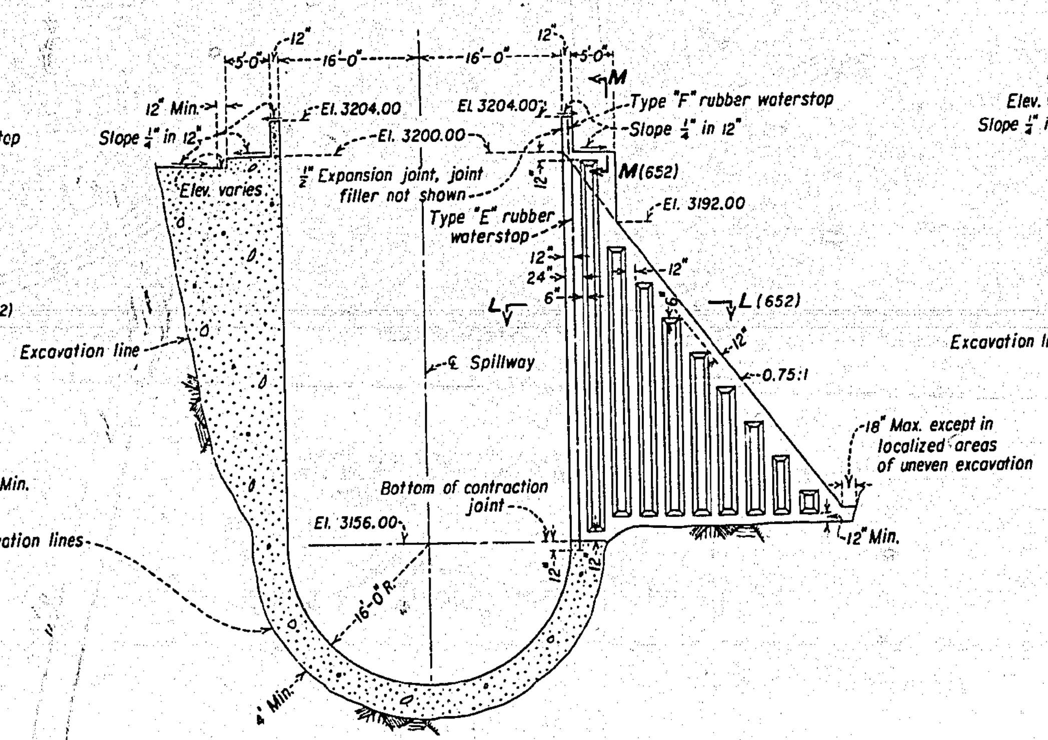
SECTION F-F(506)

TRANSITION DATA

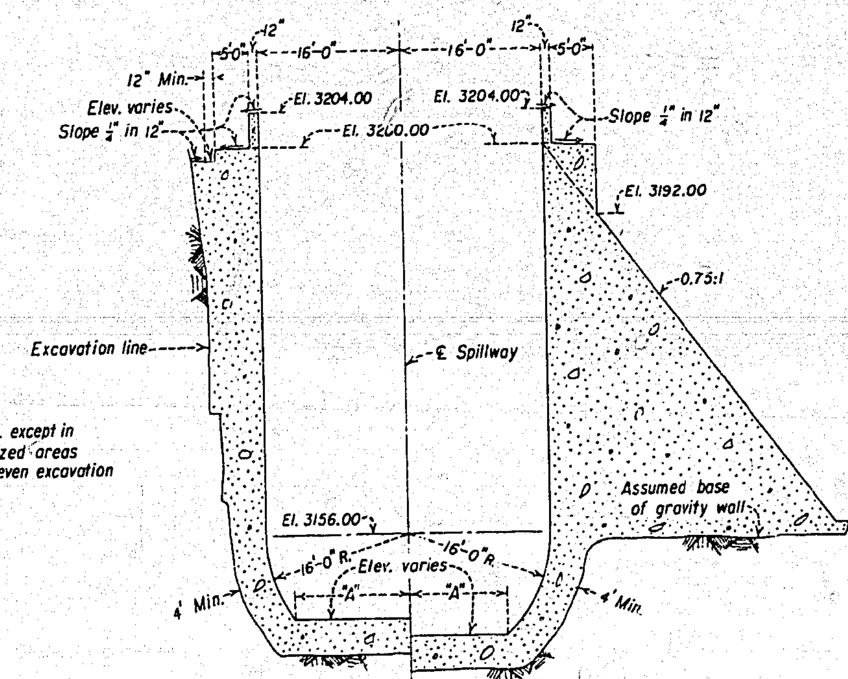
STATION	ELEVATION	"A"
23+97.09	3140.00	0
24+00	3140.03	11⅞"
24+04	3140.17	2'-4⅛"
24+08	3140.43	3'-8¼"
24+12	3140.81	5'-0¼"
24+16	3141.30	6'-3⅞"
24+20	3141.91	7'-7⅛"
24+24	3142.65	8'-9¾"
24+28	3143.51	9'-11⅞"
24+32	3144.49	11'-1⅜"
24+36	3145.60	12'-1⅞"
24+40	3146.84	13'-1⅜"
24+44	3148.22	13'-11¾"
24+48	3149.73	14'-8⅝"
24+52	3151.39	15'-3⅞"
24+56	3153.20	15'-9"
24+60	3155.17	15'-11¾"
24+61.59	3156.00	16'-0"



SECTION C-C(506)



SECTION D-D(506)
(KEYWAYS TYPICAL FOR CONTRACTION JOINTS AT STA. 23+07 AND STA. 24+27)



SECTION E-E(506)

NOTE

For concrete finishes and notes, see Dwg. 459-D-506.

9-24-62 D. E.G.L.	ADDED HANDRAIL POST RECESS.
8-28-62 D.	TRACED.
7-5-62 D. M.F. W.A.T.	REDRAWN. REVISED TO CONFORM TO EXISTING EXCAVATION. ADDED SUPPORTING WALLS FOR STOP-LOG HOIST FRAME AND MISCELLANEOUS DETAILS.

THIS DRAWING SUPERSEDES DWG. 459-D-241 IN PART

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
LOWER BIGHORN DIV.-YELLOWTAIL UNIT-MONTANA

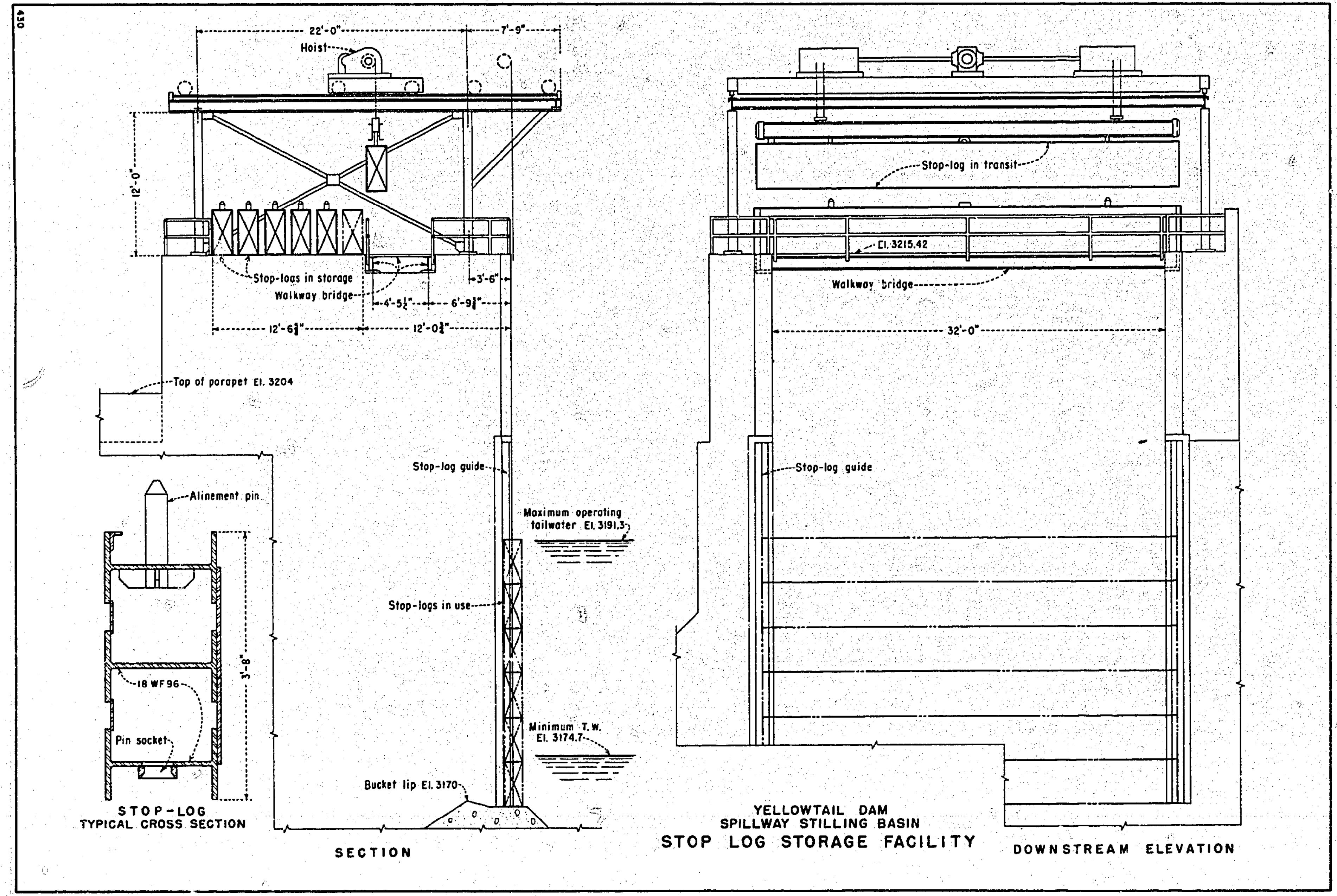
YELLOWTAIL DAM
SPILLWAY

STILLING BASIN-PLAN AND SECTIONS

DRAWN M.A.-F.K. SUBMITTED A.T. Lewis
TRACED J.L. RECOMMENDED O.L. Rice
CHECKED W.A.T.-L.M.C. APPROVED L.G. Puls
CHIEF DESIGNING ENGINEER

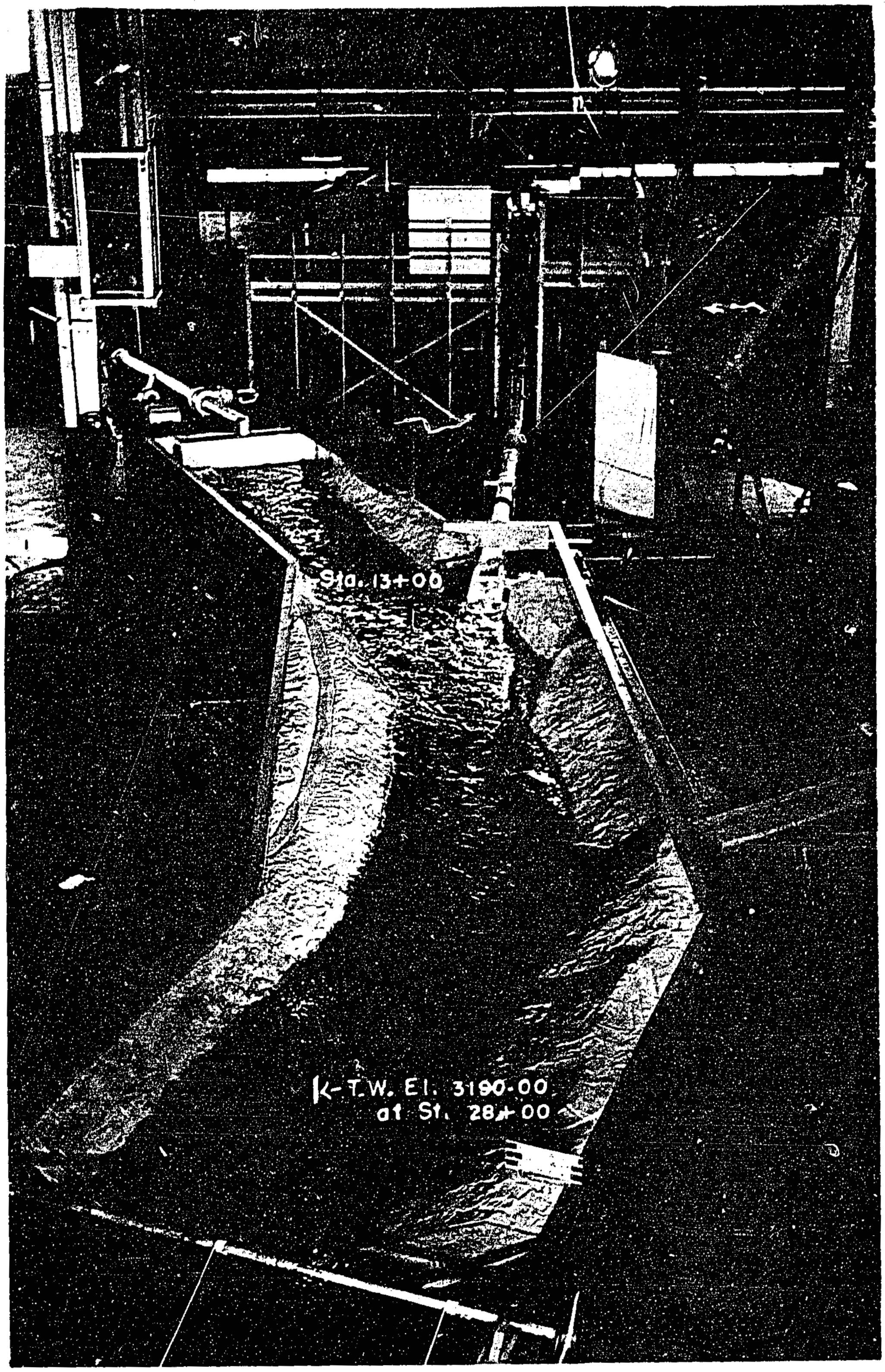
DENVER, COLORADO, SEPT. 11, 1961
SHEET 2 OF 3

459-D-507



YELLOWTAIL DAM
SPILLWAY STILLING BASIN
STOP LOG STORAGE FACILITY

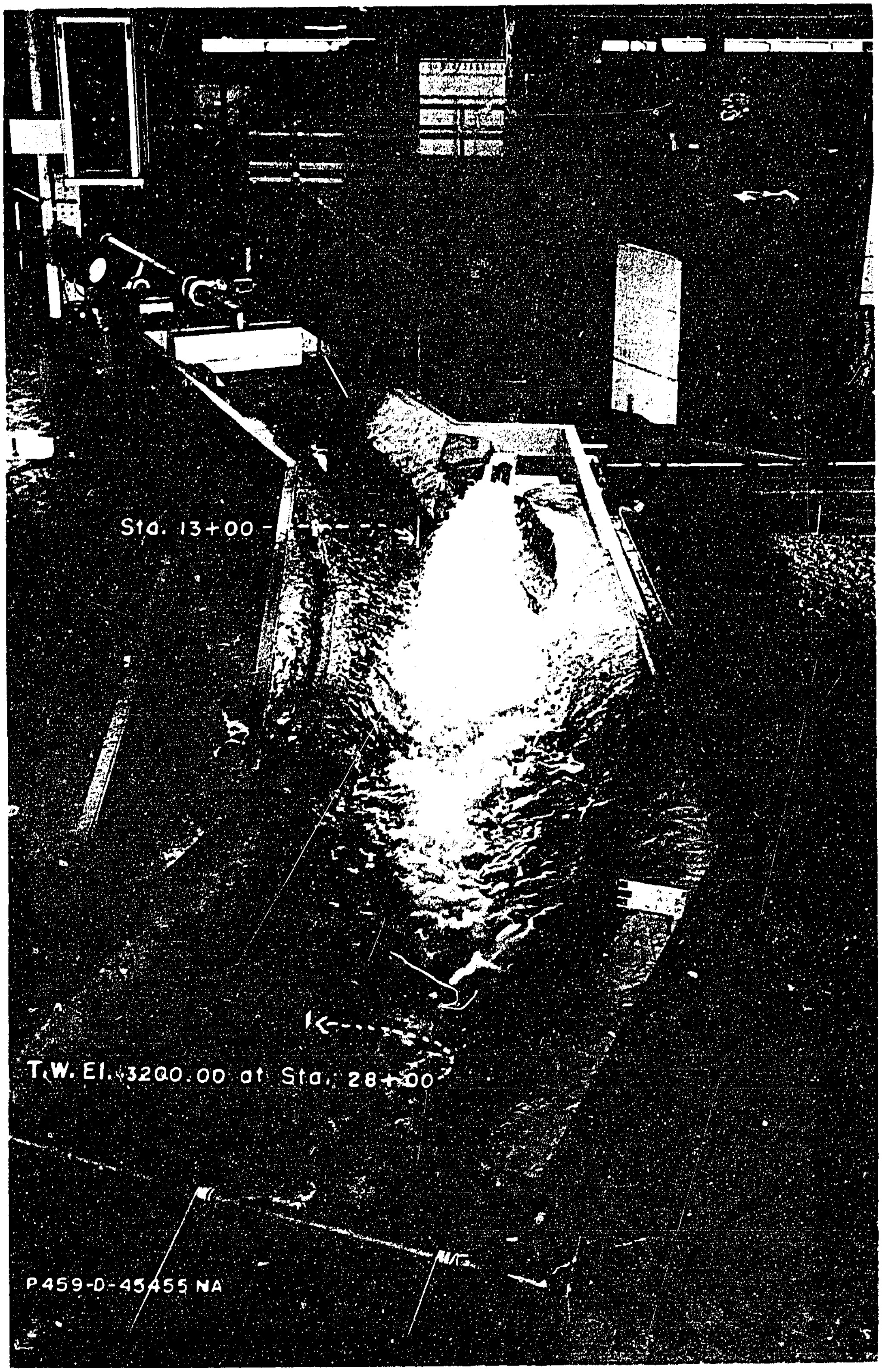
FIGURE 9
REPORT HYD. 483



Spillway 12,000 cfs powerplant and outlet works 8,000 cfs.

YELLOWTAIL DAM SPILLWAY

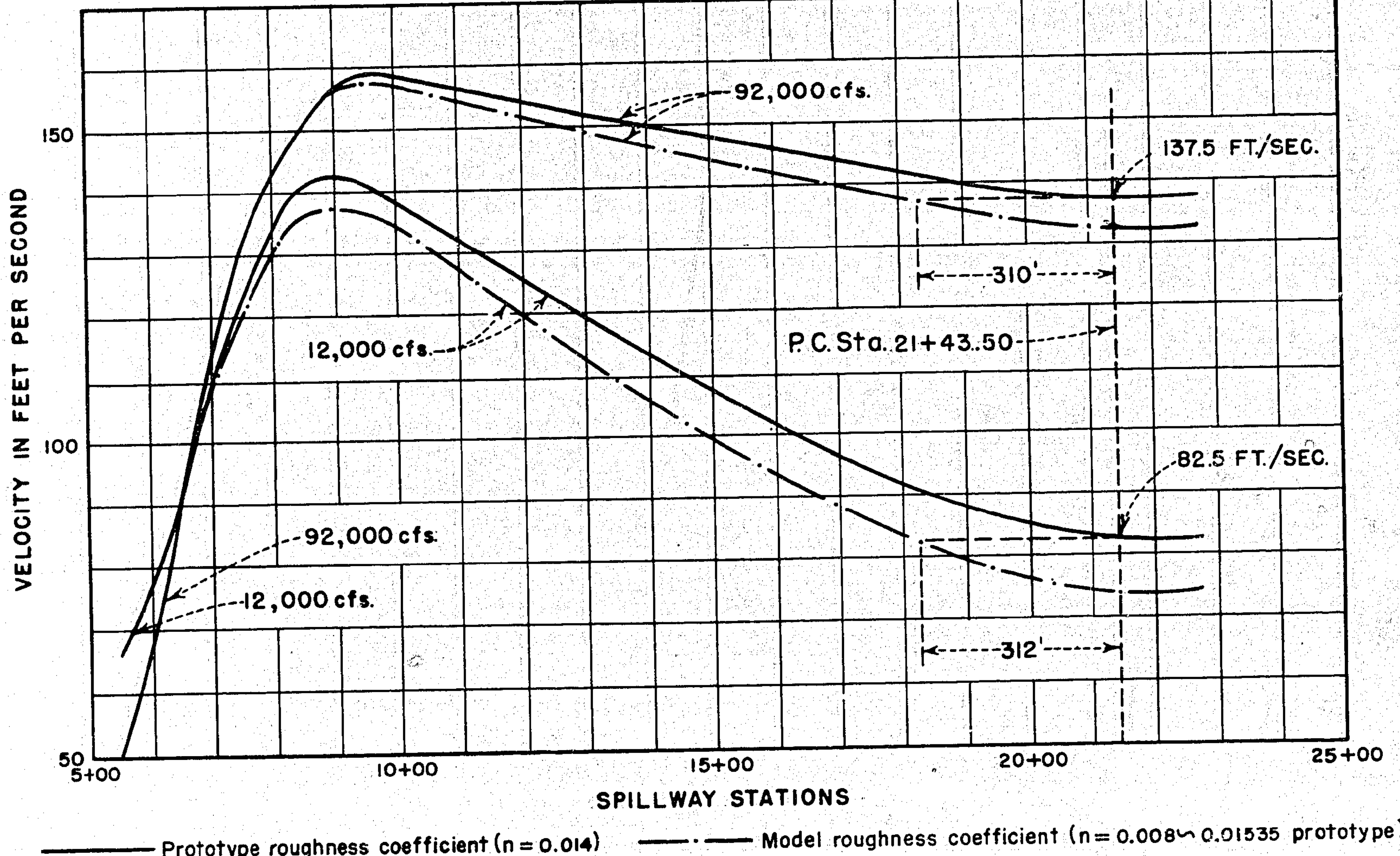
20,000 cfs in the 1:49.95 scale model



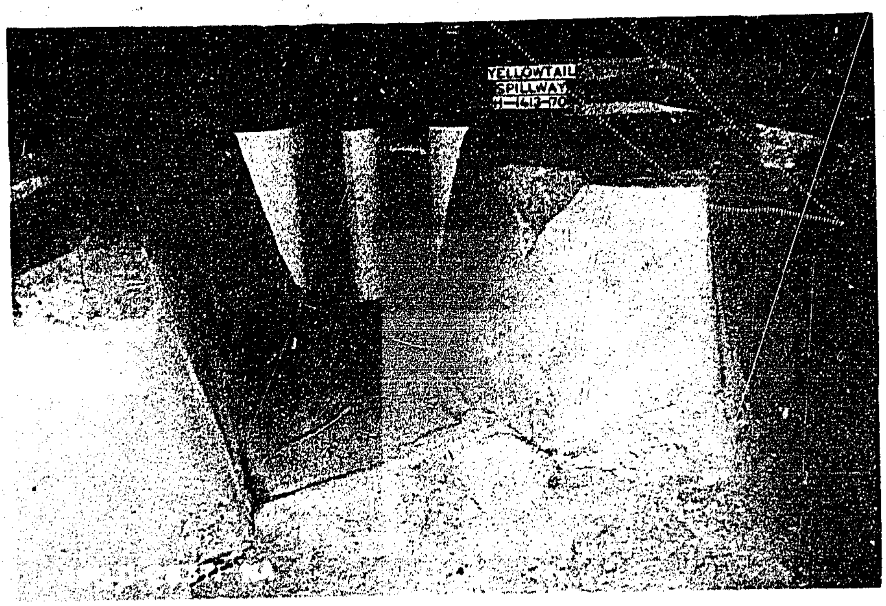
No flow from the powerplant and outlet works.

YELLOWTAIL DAM SPILLWAY

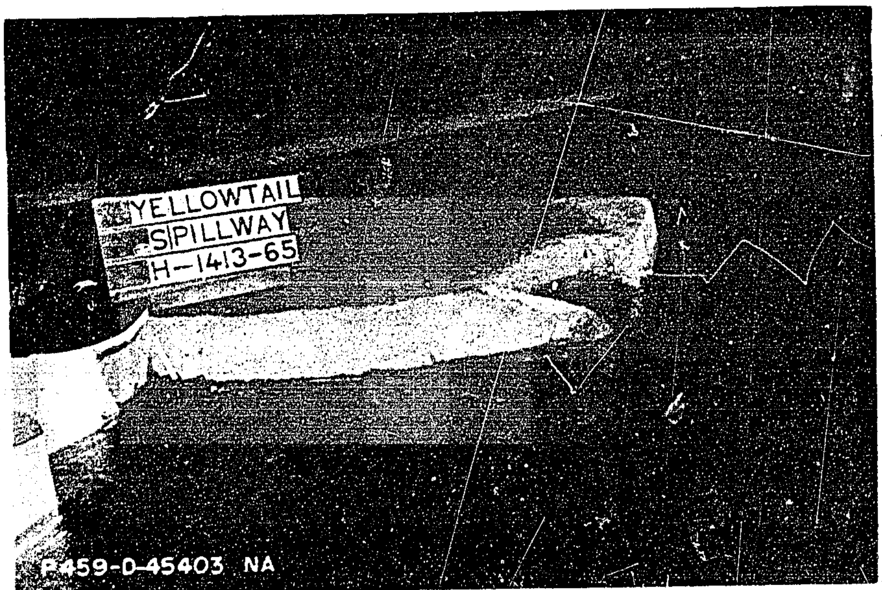
92,000 cfs in the 1:49.95 scale model



YELLOWTAIL DAM SPILLWAY
COMPUTED TUNNEL VELOCITIES
(BY COMPUTER PROGRAMMING)
1:49.95 SCALE MODEL



A. Approach channel and intake structure.



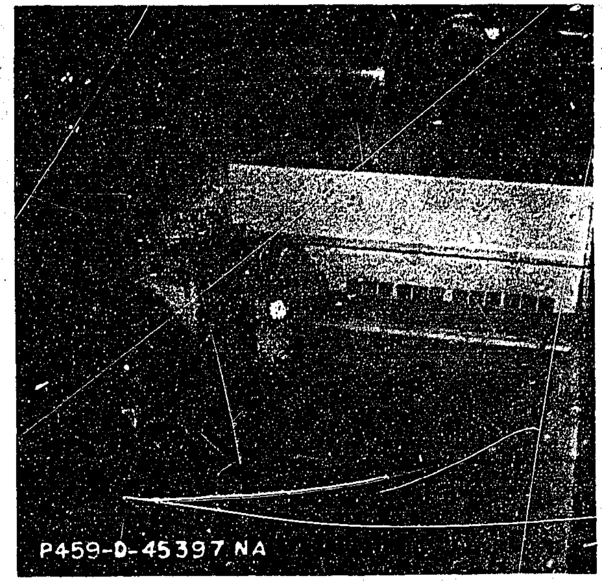
B. 92,000 cfs in the approach channel.

YELLOWTAIL DAM SPILLWAY

Reservoir area near intake structure
1:49.95 scale model

A. Center pier in tunnel transistion section.

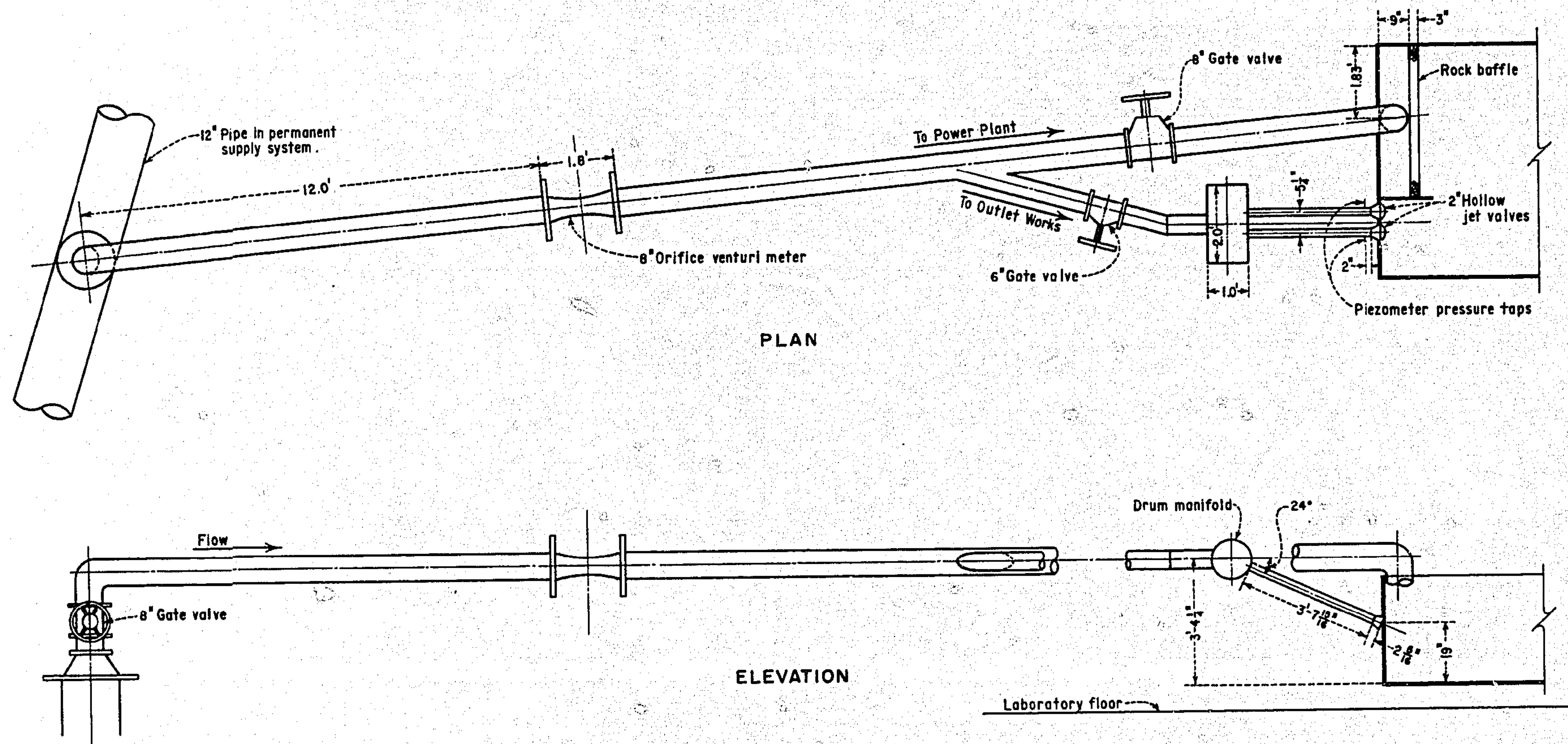
B. Stilling basin and stream channel.



C. Outlet works and powerplant.

YELLOWTAIL DAM SPILLWAY

Tunnel spillway, stilling basin, and powerplant area
1:49.95 scale model



YELLOWTAIL DAM SPILLWAY
POWER PLANT AND OUTLET WORKS SUPPLY LINES
1: 49.95 SCALE MODEL

FIGURE 15
REPORT HYD. 483

A. 92,000 cfs in the preliminary approach channel (140 feet wide).

B. 92,000 cfs in the modified approach channel (120 feet wide).

C. Same as B.

YELLOWTAIL DAM SPILLWAY

Flow in the preliminary and modified approach channel
1:49.95 scale model

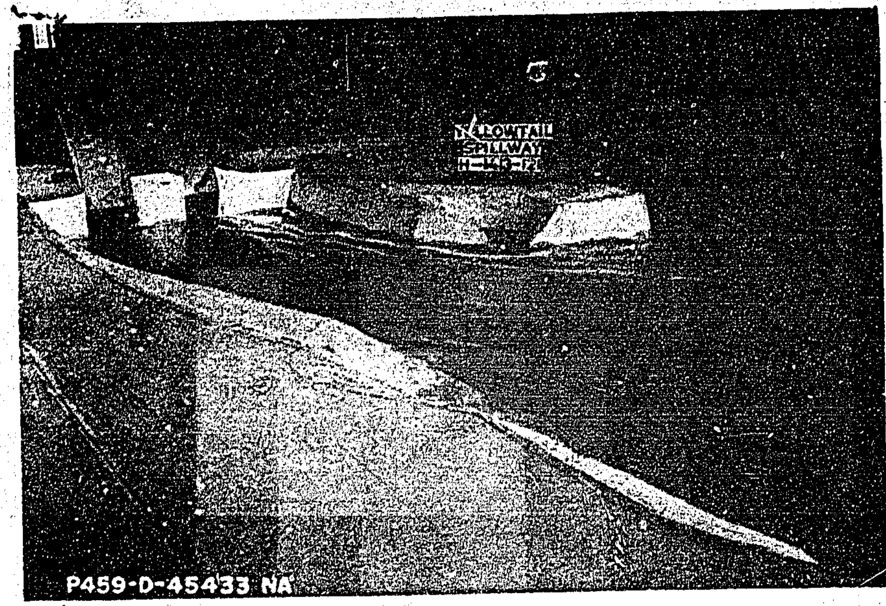
A. 23,000 cfs

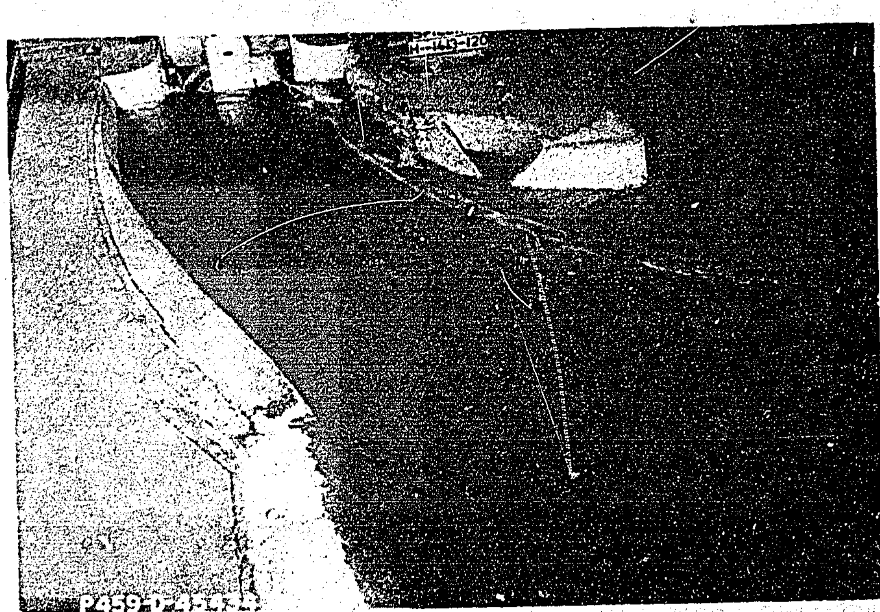
B. 46,000 cfs

C. 69,000 cfs

YELLOWTAIL DAM SPILLWAY

Flow in the recommended approach channel
1:49.95 scale model

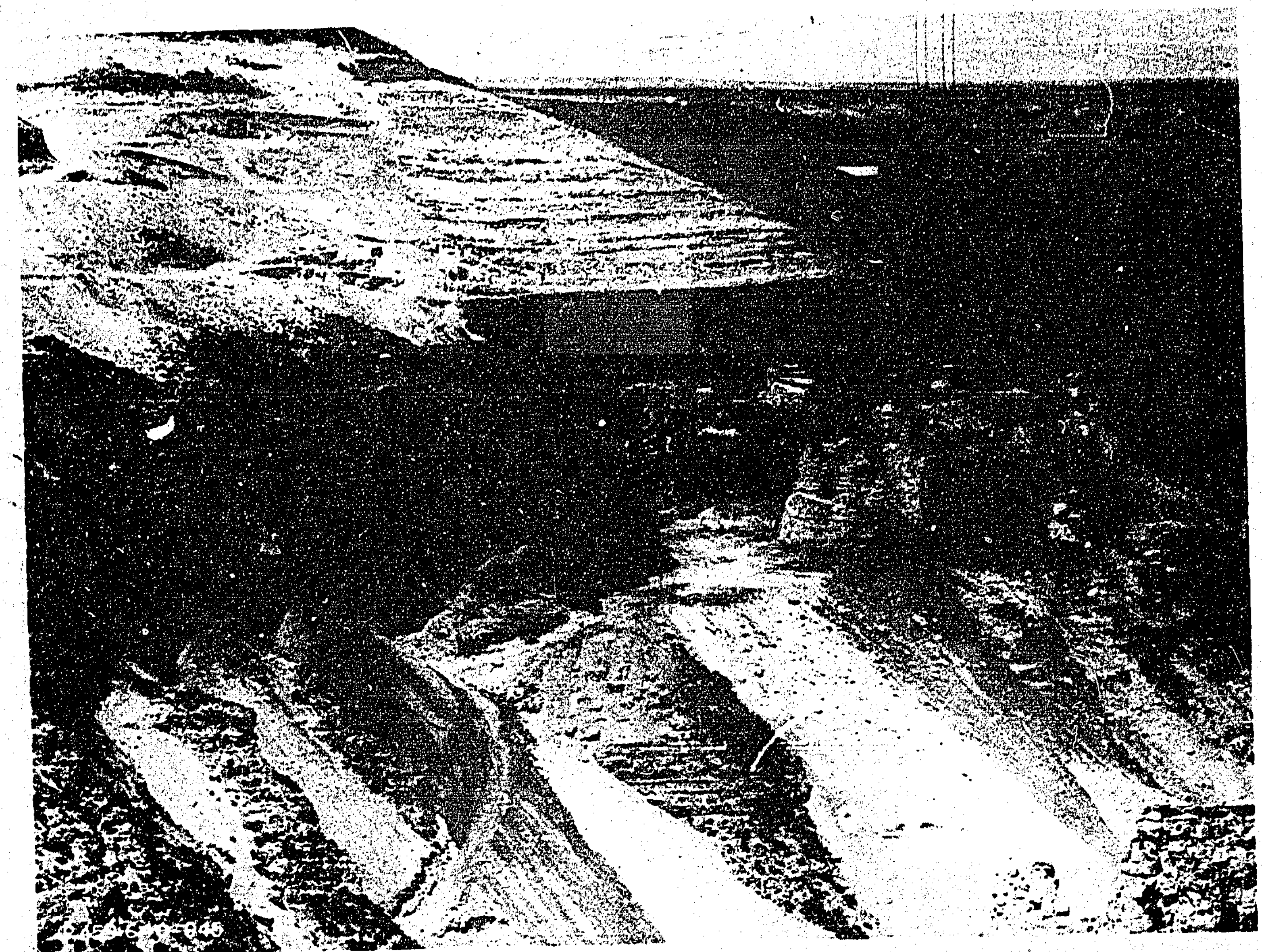




Discharge = 92,000 cfs

YELLOWTAIL DAM SPILLWAY

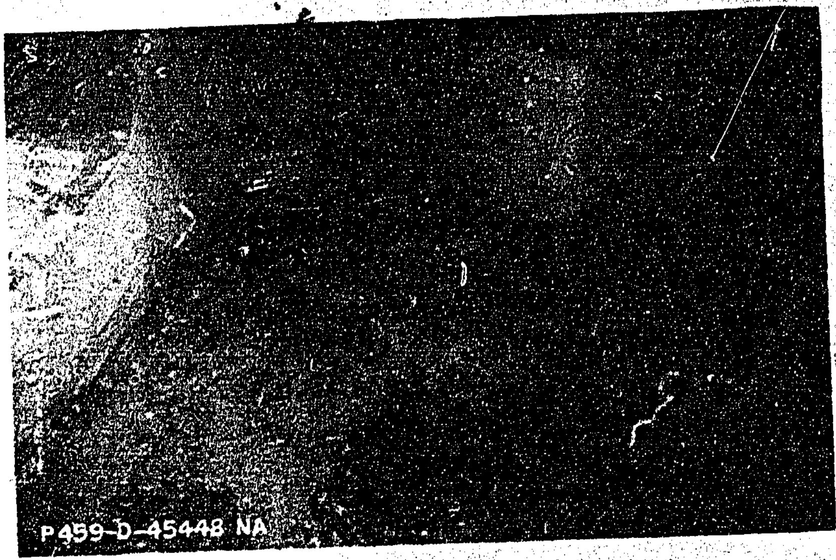
Flow in the recommended approach channel
1:49.95 scale model



YELLOWTAIL DAM SPILLWAY

Prototype approach channel excavation in progress

Figure 20
Report Hyd-483



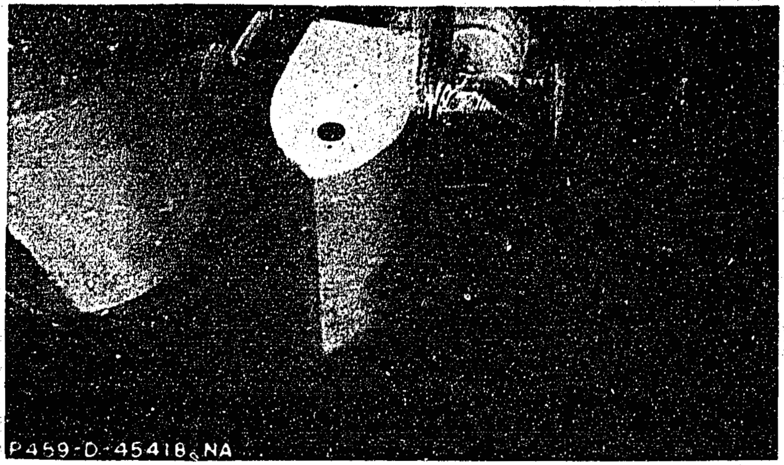
A. Movement of the waste material placed at elevation 3580, caused by 92,000 cfs discharging in the model for 2 hours.

B. Same as A except waste material was originally placed at elevation 3563.

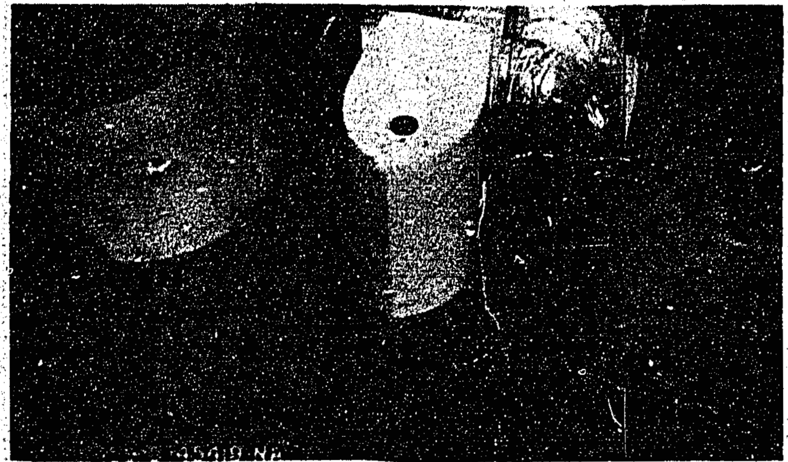
C. Same as A except waste material was originally placed at elevation 3547.

YELLOWTAIL DAM SPILLWAY

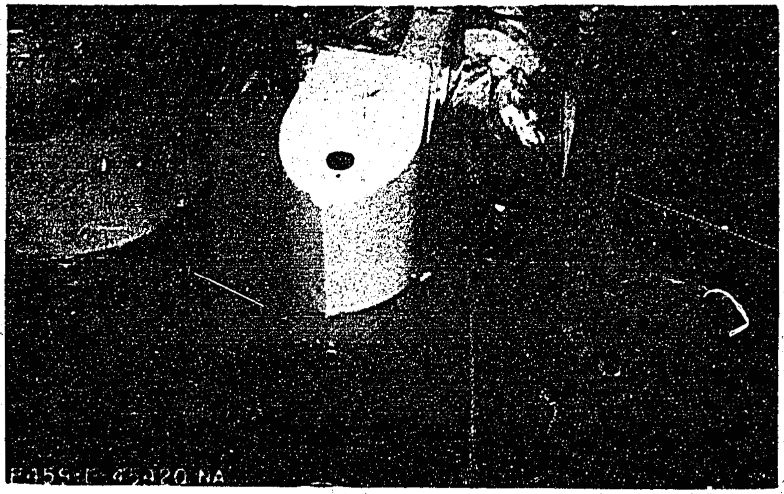
Approach channel waste material movement tests
1:49.95 scale model



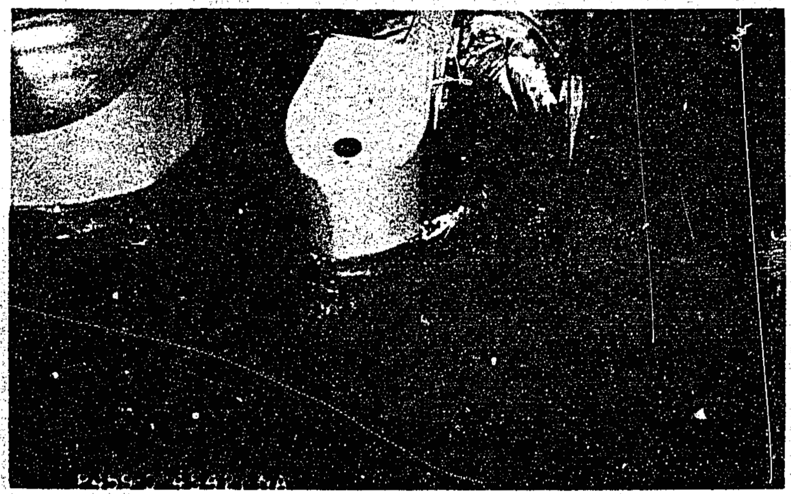
A. 23,000 cfs



B. 46,000 cfs



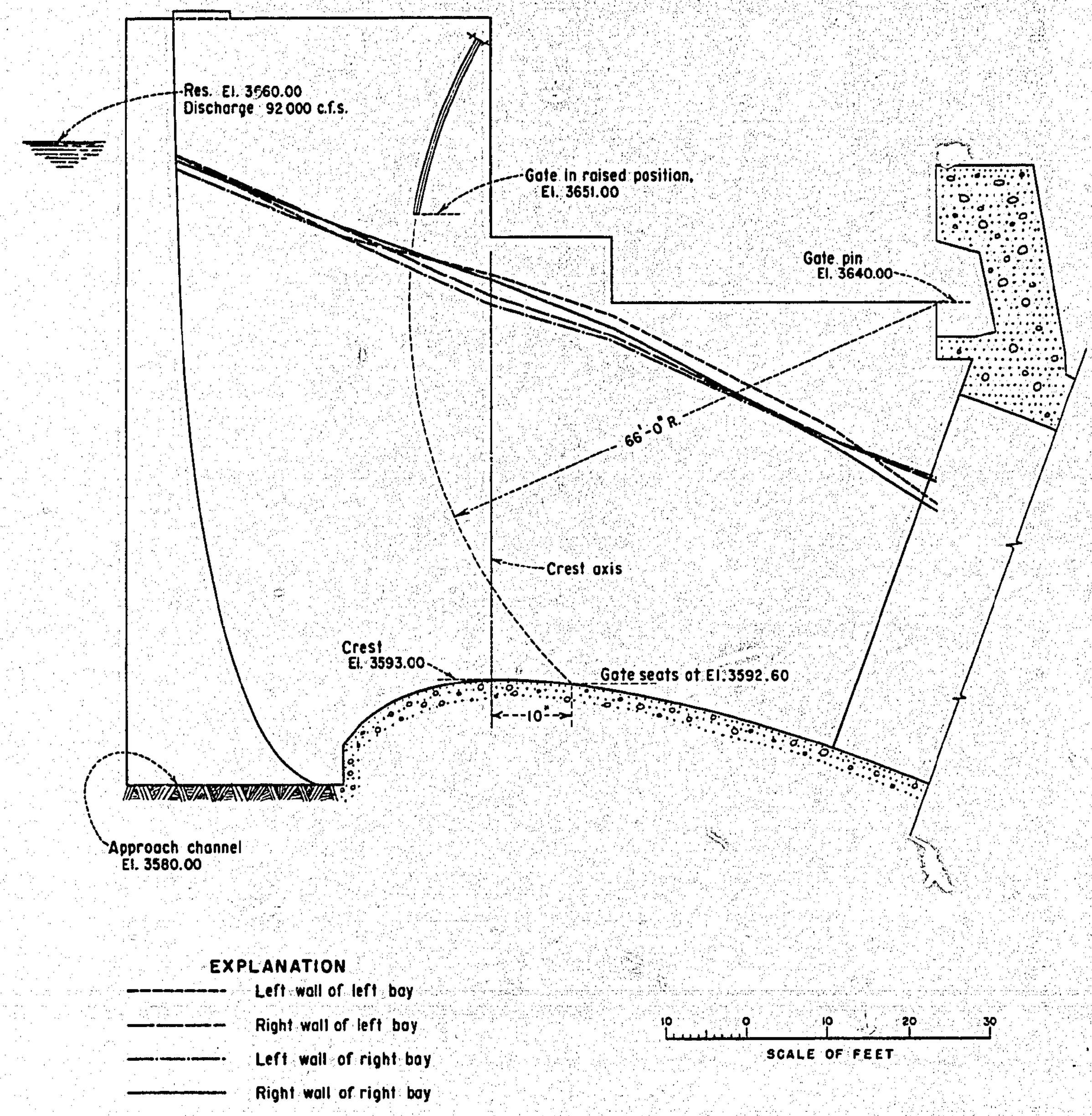
C. 69,000 cfs



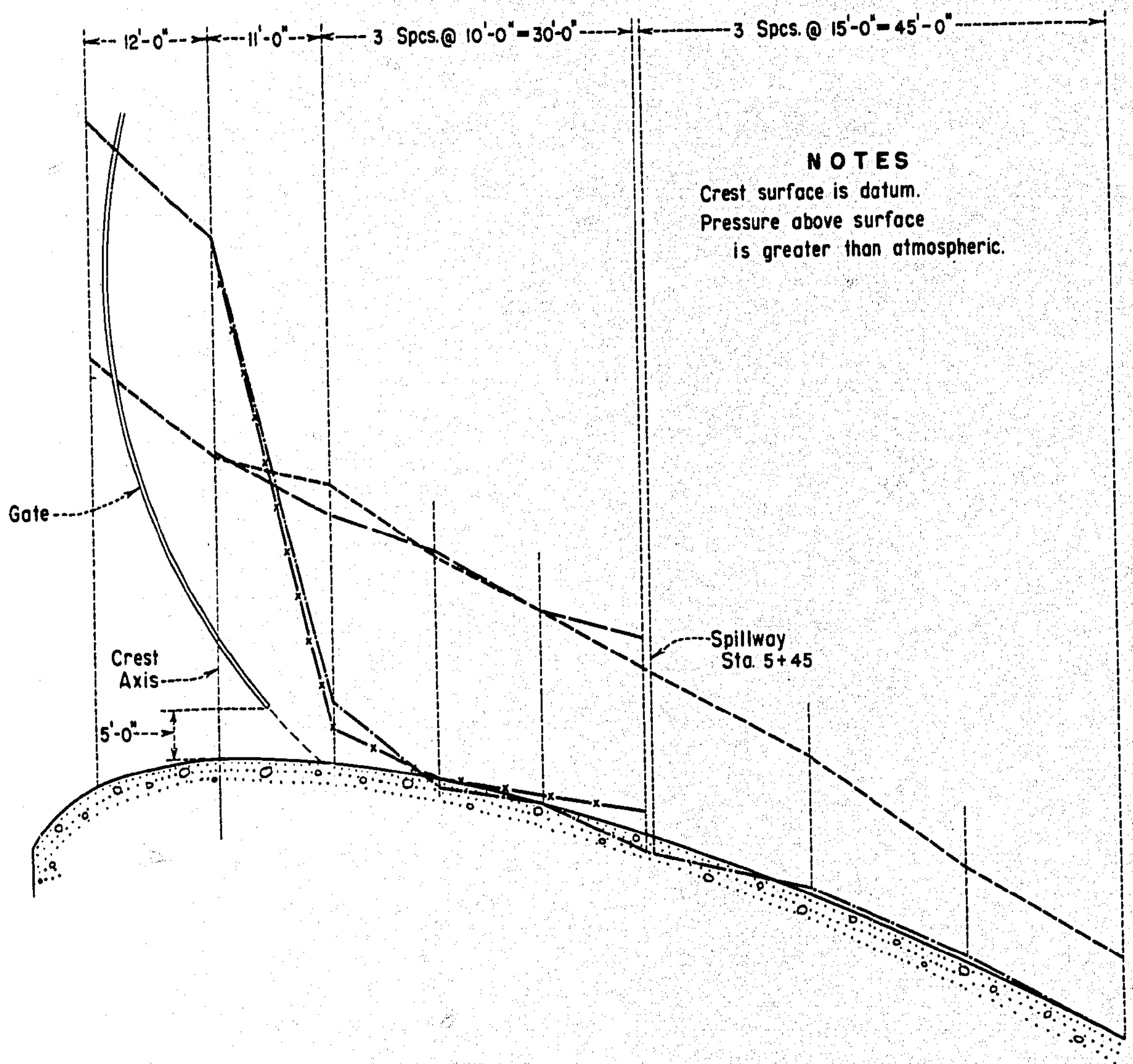
D. 92,000 cfs

YELLOWTAIL DAM SPILLWAY

Flow in the intake structure
1:49.95 scale model



YELLOWTAIL DAM SPILLWAY
WATER SURFACE PROFILES IN INTAKE STRUCTURE
1:49.95 SCALE MODEL



EXPLANATION

—·—·— Center line crest pressures, Q= 12000 C.F.S., 5'-0" gate opening.

—x—x— Crest pressures at wall, Q= 12 000 C.F.S., 5'-0" gate opening.

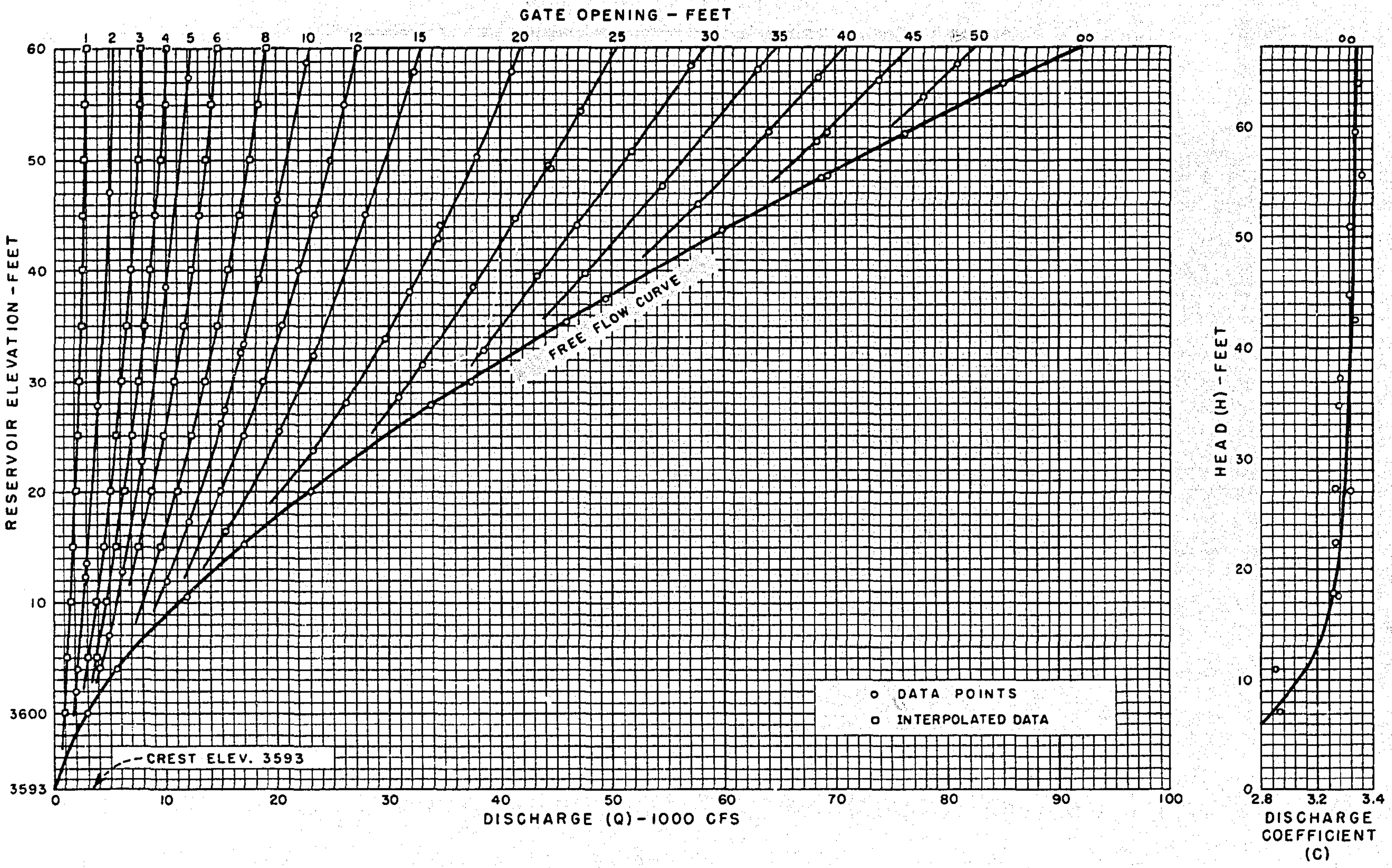
- - - - Center line crest pressures, Q= 92000 C.F.S.

—— —— Crest pressures at wall, Q= 92000 C.F.S.

YELLOWTAIL DAM SPILLWAY

CREST PRESSURES IN INTAKE STRUCTURE

1:49.95 SCALE MODEL



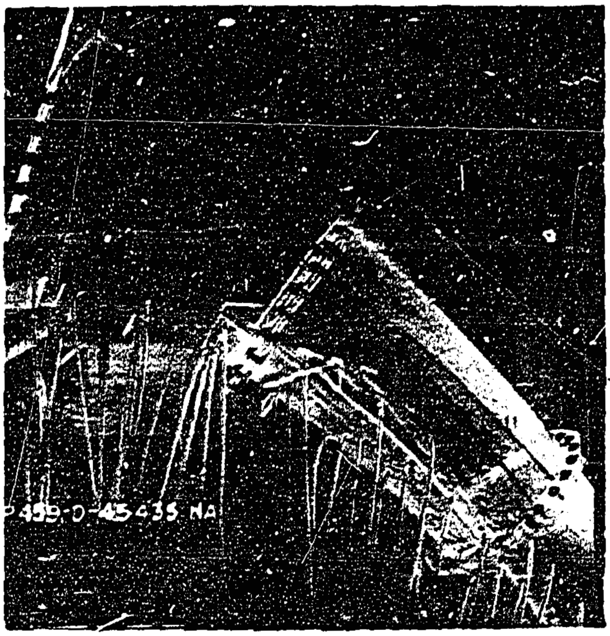
YELLOWTAIL DAM SPILLWAY

DISCHARGE CAPACITY AND COEFFICIENT CURVES FOR RECOMMENDED DESIGN

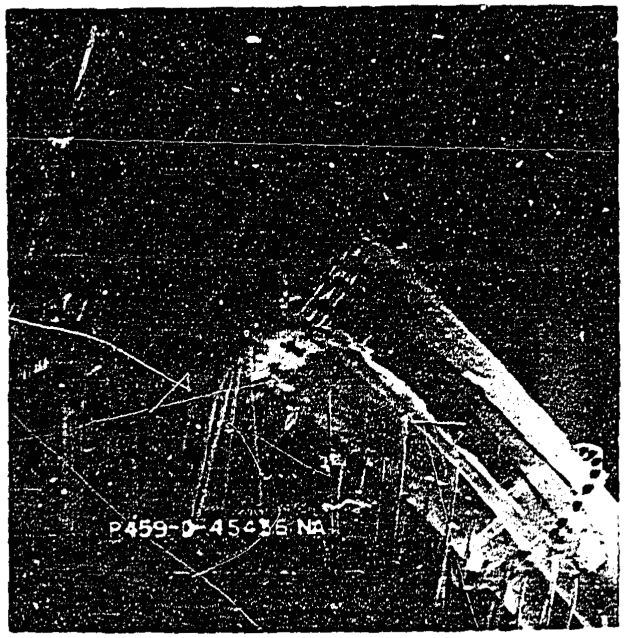
1:49.95 SCALE MODEL

$Q = CLH^{3/2}$, where L is the crest length of both bays.

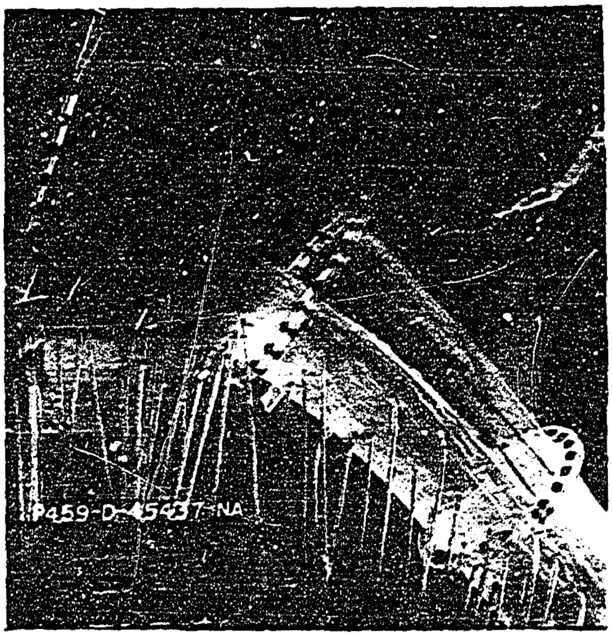
FIGURE 24
REPORT HYD. 483



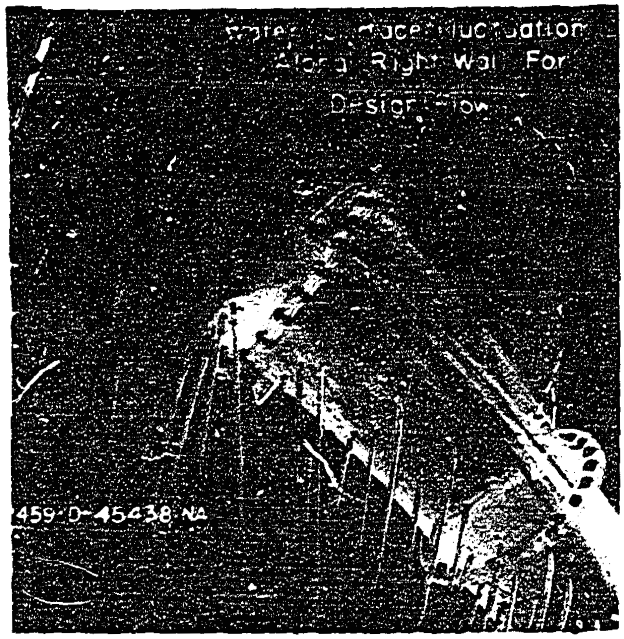
A. 23,000 cfs



B. 46,000 cfs



C. 69,000 cfs

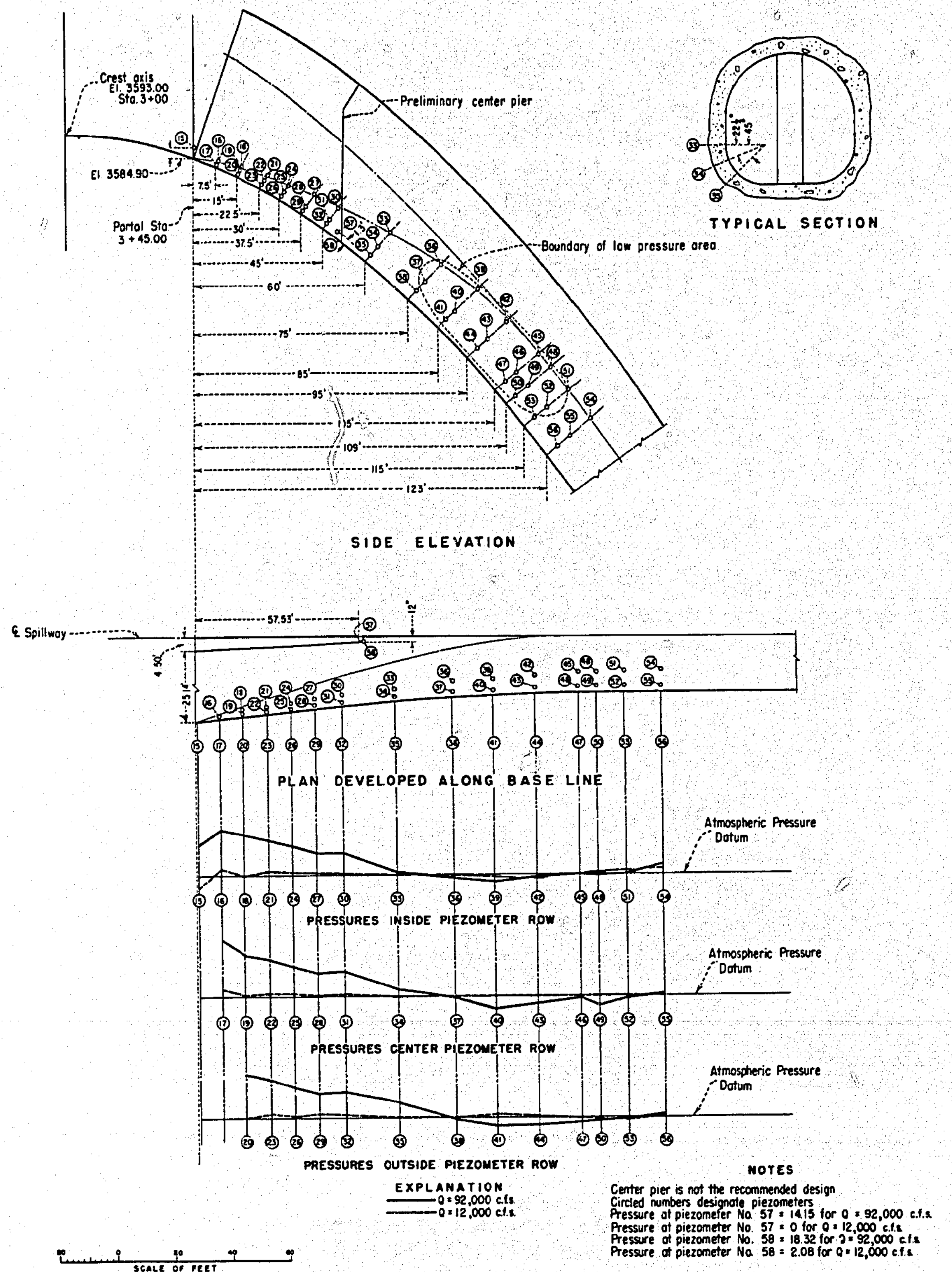


D. 92,000 cfs

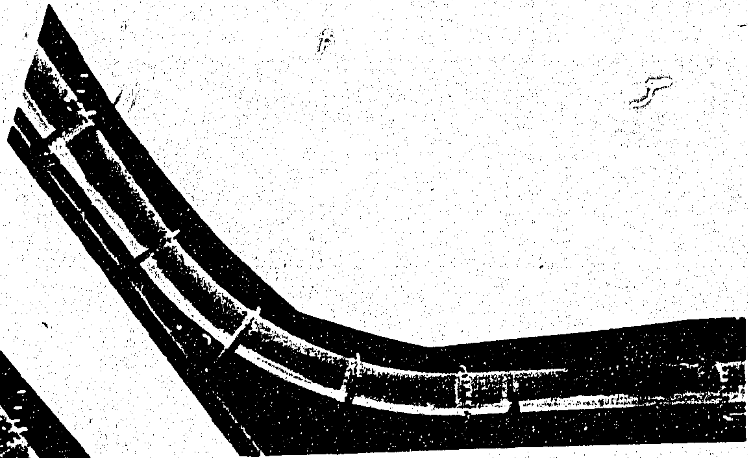
Note: A fin of water occurs downstream from center pier.

YELLOWTAIL DAM SPILLWAY

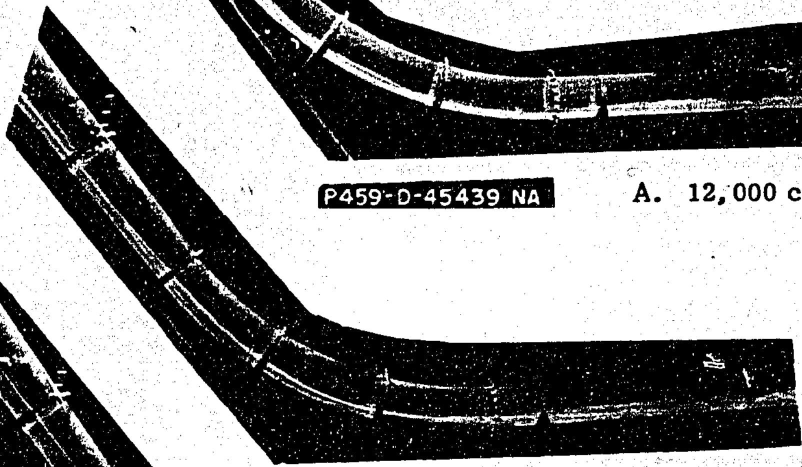
Flow in the tunnel transition
1:49.95 scale model



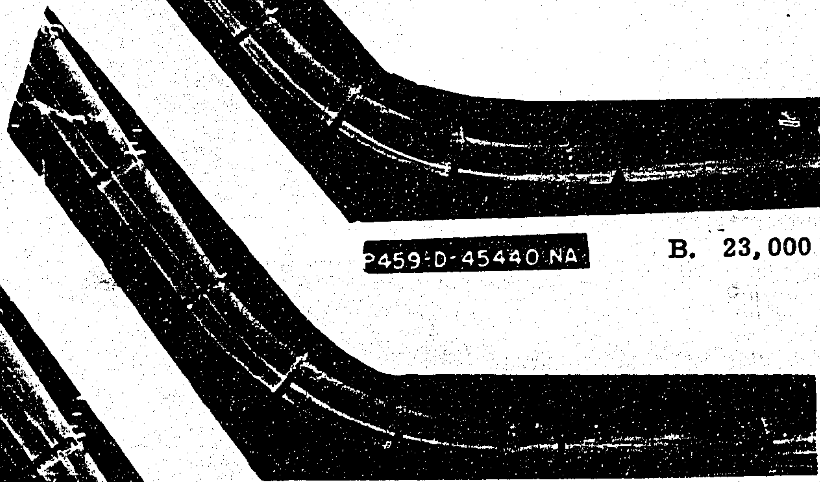
YELLOWTAIL DAM SPILLWAY
PRESSURES IN THE TUNNEL TRANSITION
1:49.95 SCALE MODEL



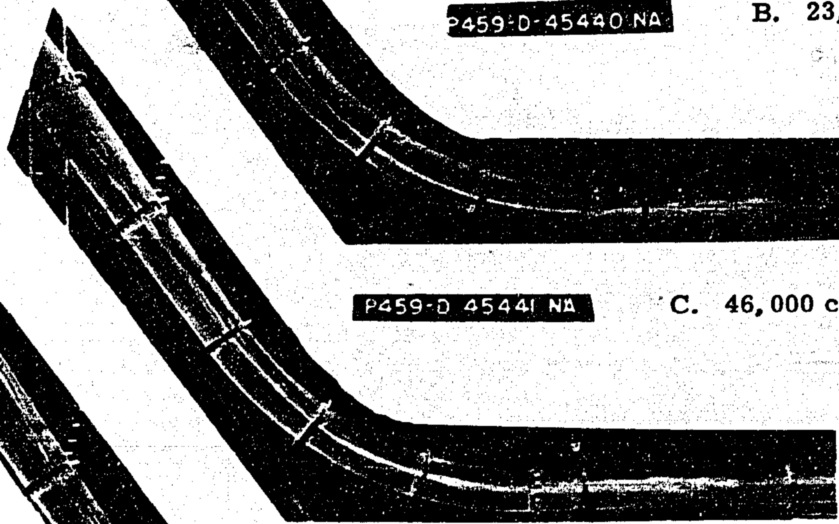
A. 12,000 cfs



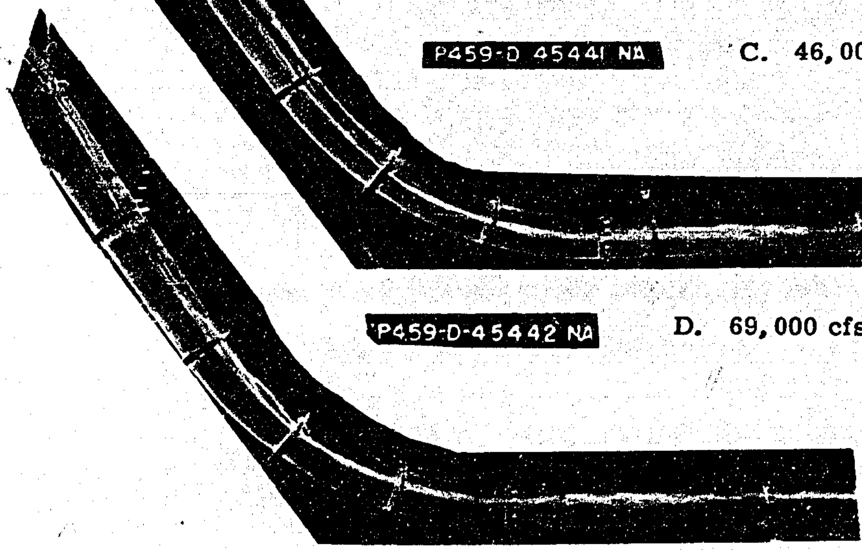
B. 23,000 cfs



C. 46,000 cfs



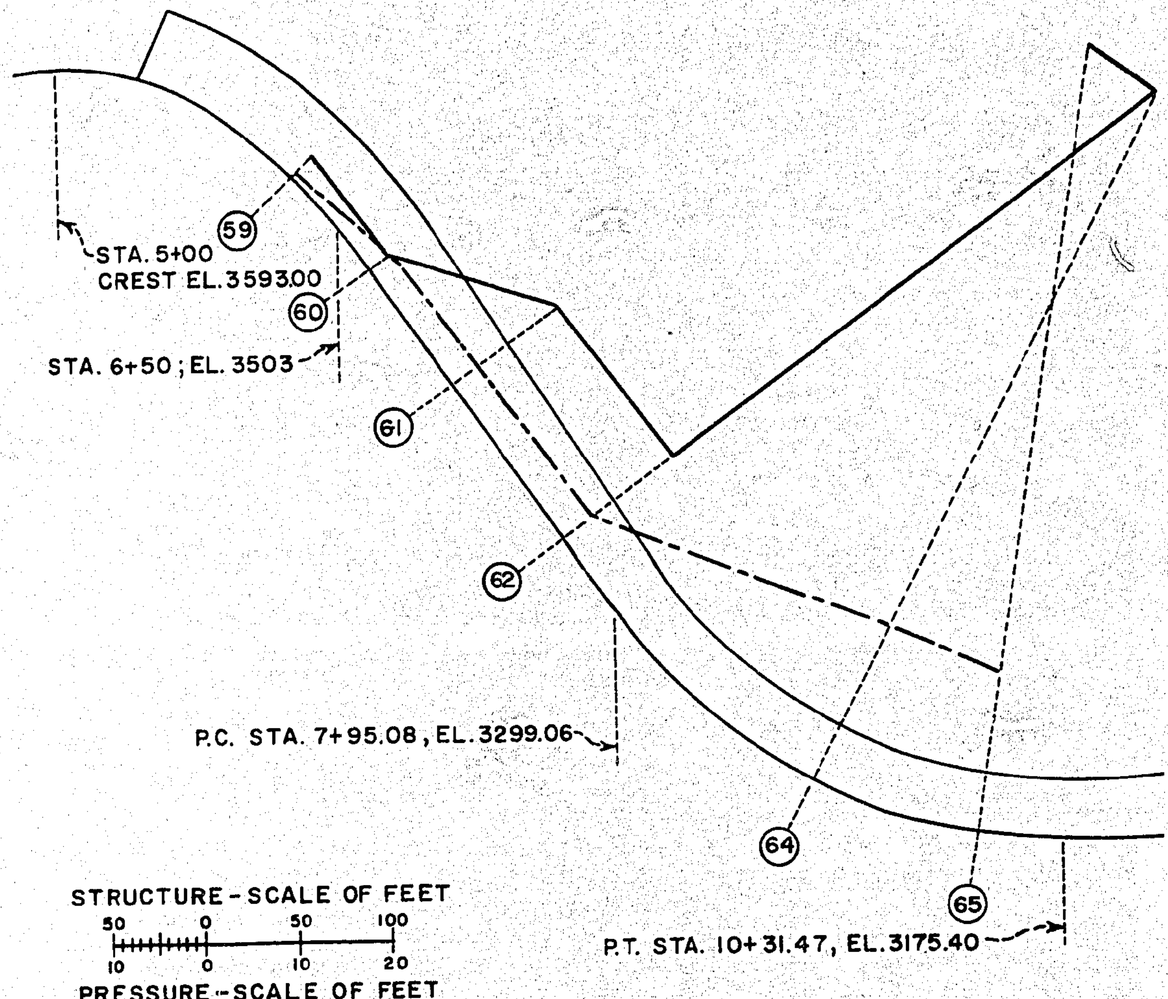
D. 69,000 cfs



E. 92,000 cfs

YELLOWTAIL DAM SPILLWAY

Flow in the inclined tunnel and vertical bend
1:49.95 scale model



EXPLANATION

——————— 92,000 c.f.s.

– — – — – — 12,000 c.f.s.

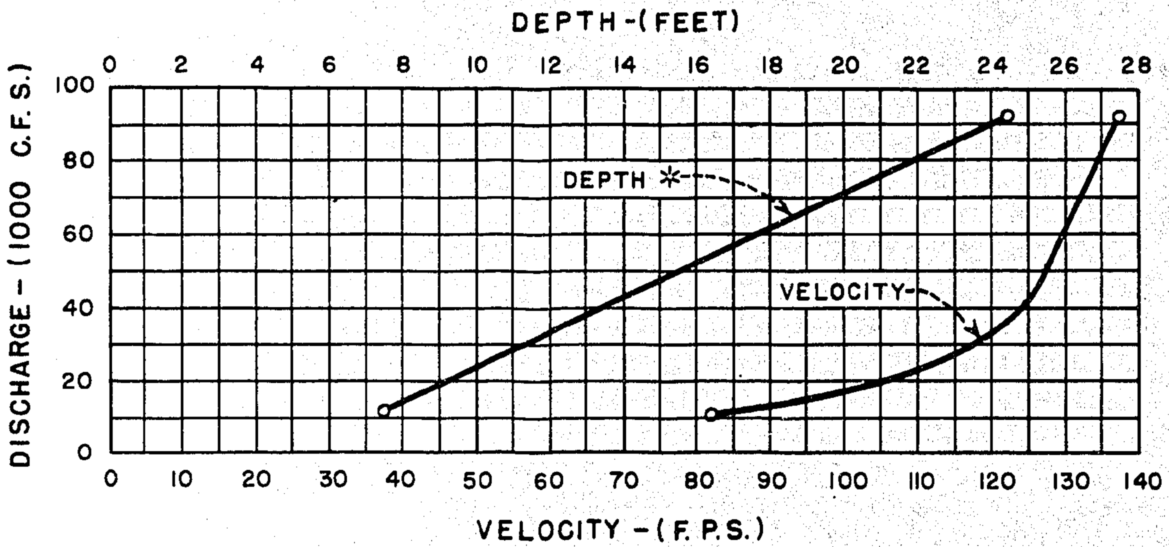
NOTES

Circled numbers designate piezometers.
Tunnel Invert is zero pressure datum.

YELLOWTAIL DAM SPILLWAY

PRESSURE IN THE INCLINED
TUNNEL AND VERTICAL BEND

1: 49.95 SCALE MODEL



o - Computed at P.C. of Tunnel Trajectory (Sta. 21+43.50) See Figure 12

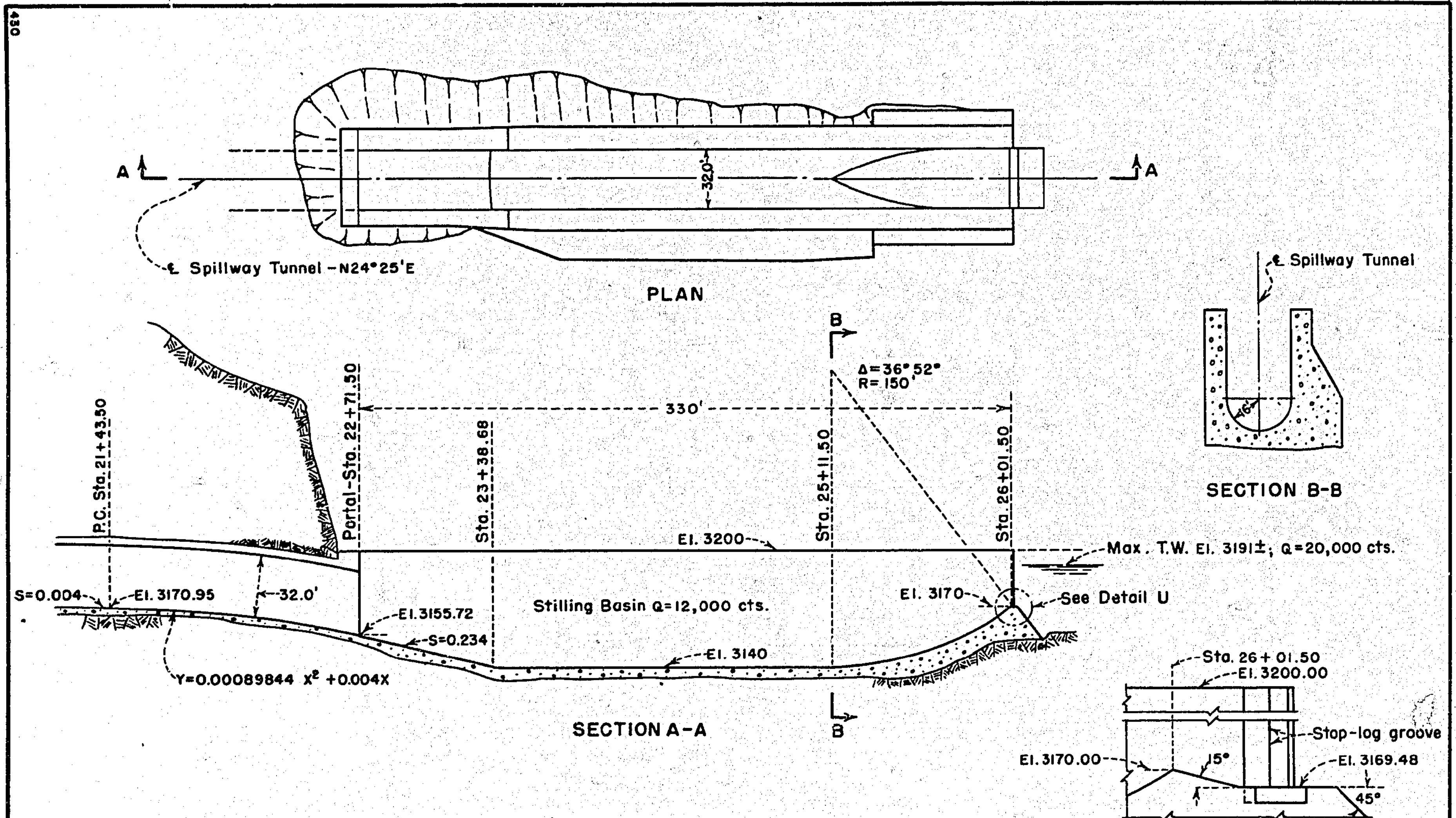
*- Assumed to be a straight line relation

DISCHARGE IN C.F.S.	TOTAL HEAD IN FEET	* DEPTH IN FEET	VELOCITY IN FEET/SEC.	VELOCITY HEAD IN FEET	% HEAD LOSS	FROUDE NO.
92,000	489.05	24.5	137.5	293.6	35.0	4.90
69,000	489.05	19.5	132.0	271.0	40.7	5.26
46,000	489.05	14.7	126.5	248.4	46.2	5.79
23,000	489.05	9.8	110.1	188.2	59.5	6.20
12,000	489.05	7.6	82.5	105.7	76.8	5.29

* Depth at invert. The Froude number computed here is based on invert depth.

YELLOWTAIL DAM SPILLWAY

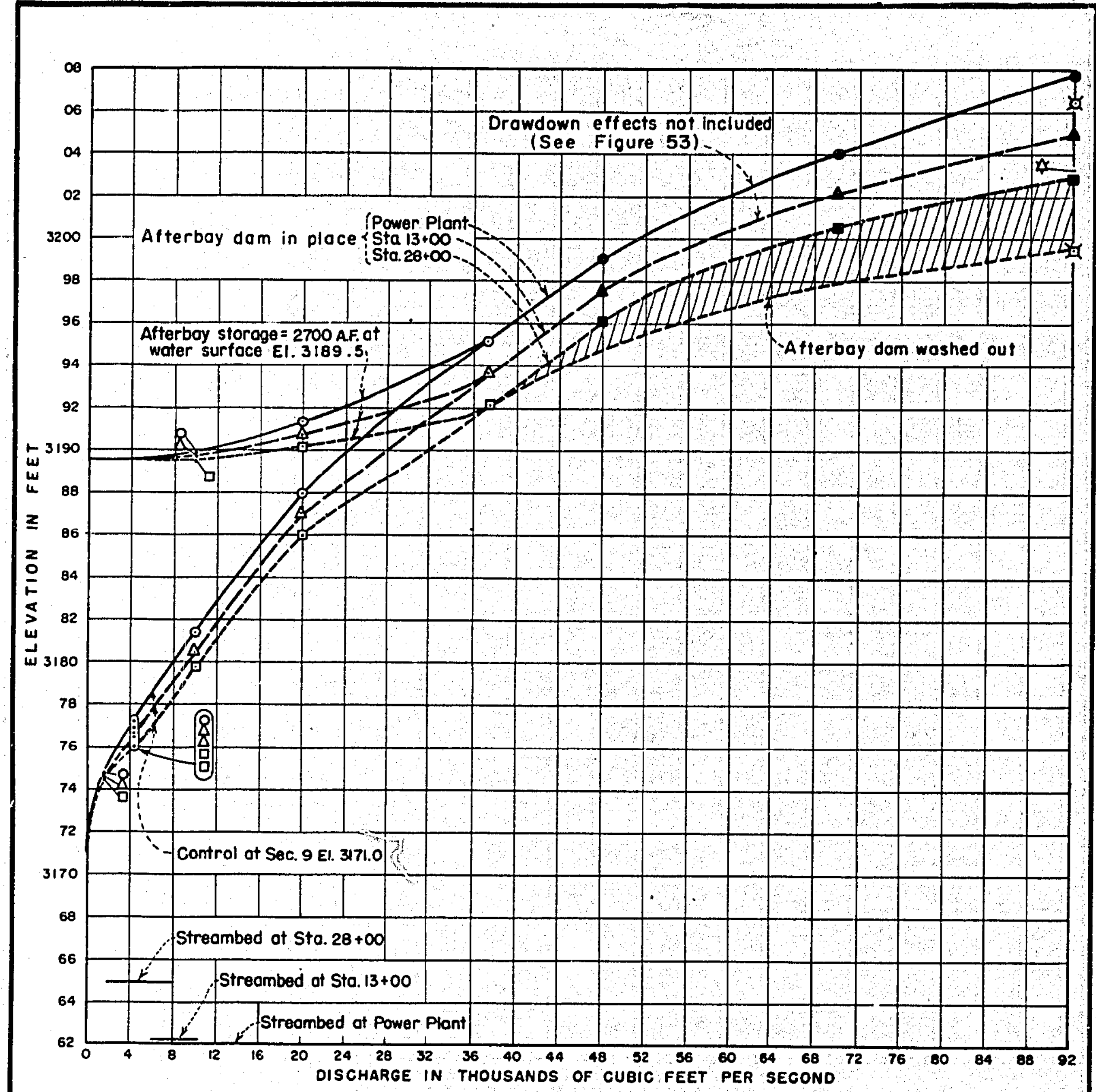
VELOCITY AND FLOW DEPTH AT TUNNEL TRAJECTORY P.C. STA. 21+43.50



YELLOWTAIL DAM SPILLWAY

PRELIMINARY TUNNEL TRAJECTORY AND STILLING BASIN - FLIP BUCKET

FIGURE 30
REPORT HYD. 483



EXPLANATION

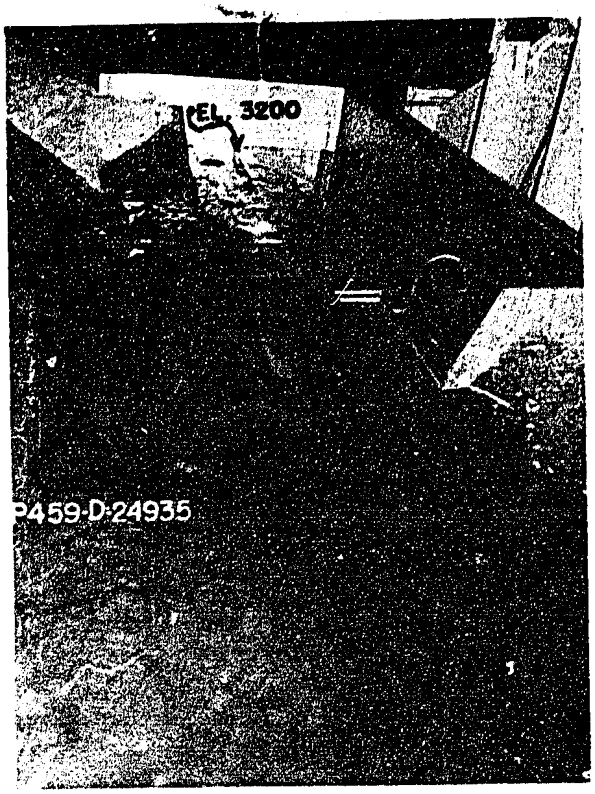
● ▲ ■ Water surface at top of Afterbay dam (El. 3194.5) or above.

Afterbay dam assumed washed out.

○ Δ □ Minimum and maximum water surfaces.

YELLOWTAIL DAM SPILLWAY

PRELIMINARY TAILWATER CURVES
FOR MODEL STUDIES



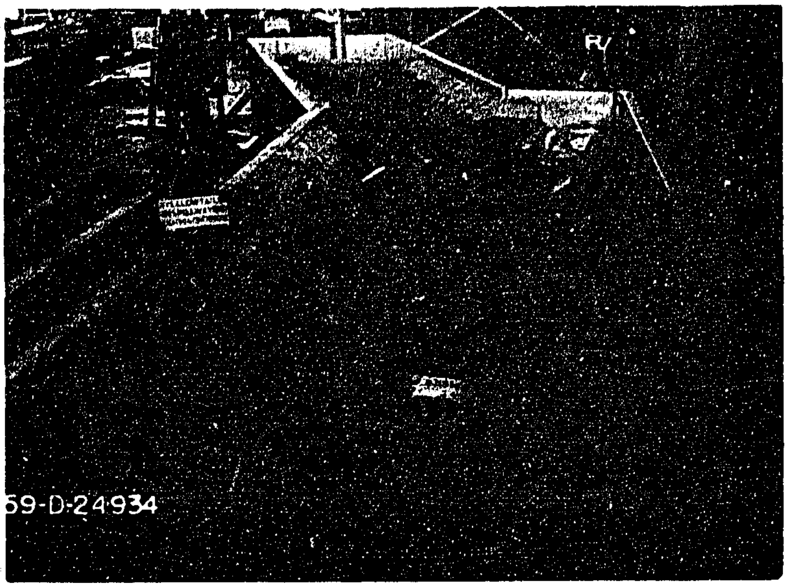
A. 12,000 cfs--No powerhouse or outlet works flow; tailwater elevation 3190.7 at staff gage.

B. 92,000 cfs--Erodible gravel bed; normal tailwater.

C. Same as B.

YELLOWTAIL DAM SPILLWAY

Flow in the preliminary stilling basin--flip bucket
1:49.95 scale model



A. Deposition of eroded material to elevation 3195.

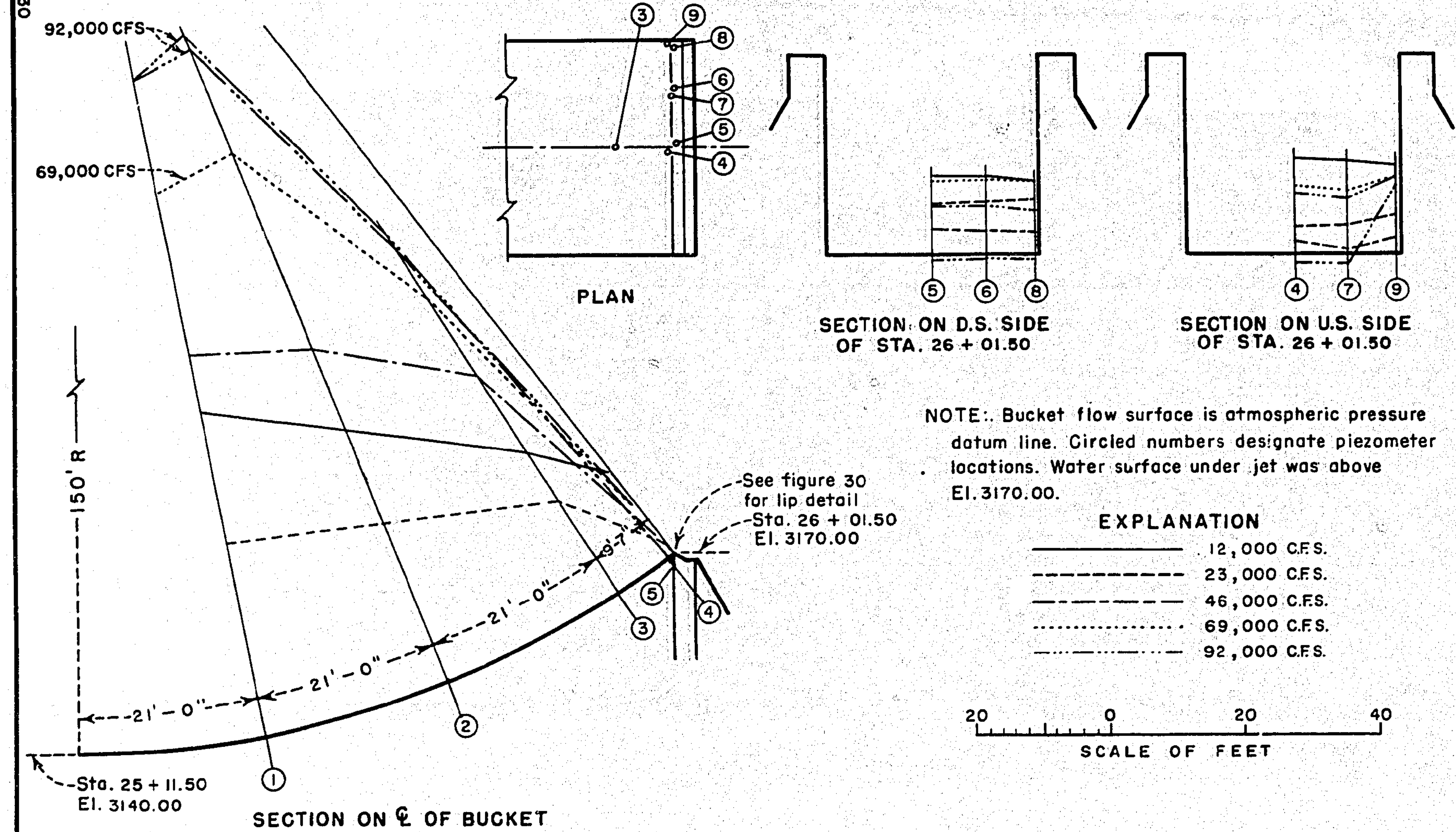
B. Erosion to elevation 3120.

Note: Erosion after discharging 92,000 cfs for approximately 1 hour (model time).

YELLOWTAIL DAM SPILLWAY

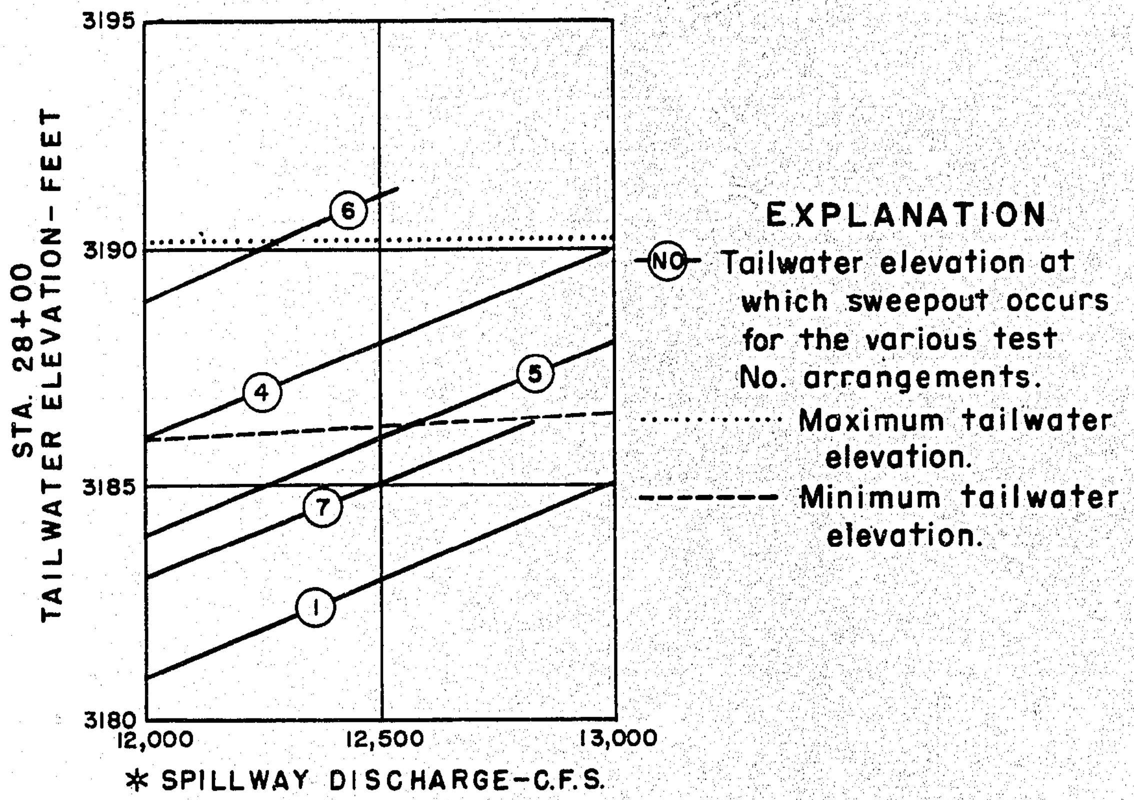
Channel erosion test
1:49.95 scale model

430



YELLOWTAIL DAM SPILLWAY
PRESSURES IN PRELIMINARY BUCKET
1:49.95 SCALE MODEL

FIGURE 34
REPORT HYD. 483



TEST NO.

- (1) 255 foot basin, invert EL. 3145, lip El. 3170, 150 foot radius bucket
- (4) 200 foot basin, invert EL. 3145, lip El. 3170, 138 foot radius bucket
- (5) 220 foot basin, invert EL. 3145, lip El. 3170, 138 foot radius bucket
- ** (6) 220 foot basin, invert EL. 3145, lip El. 3170, 138 foot radius bucket
- ** (7) 250 foot basin, invert EL. 3140, lip El. 3170, 138 foot radius bucket

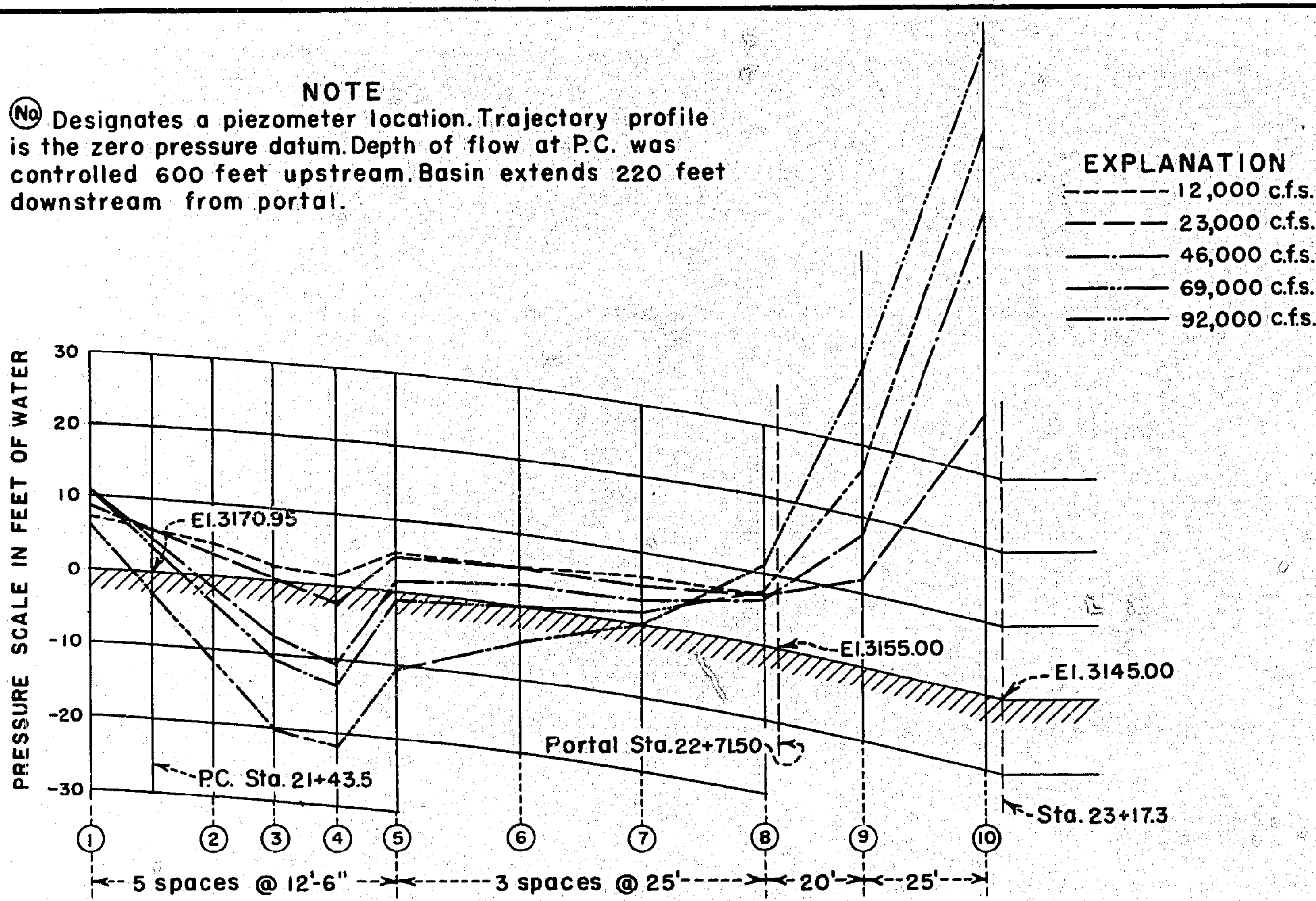
** Test (7) is for recommended design. Recommended design tests and test (6) were conducted using flow source from the model reservoir which produced sweepout at about 5 foot higher tailwater than when flow source was from the slide gate control as used for tests (1) through (5)

* Spillway discharge is in addition to 8,000 CFS from the power plant and outlet works.

YELLOWTAIL DAM SPILLWAY

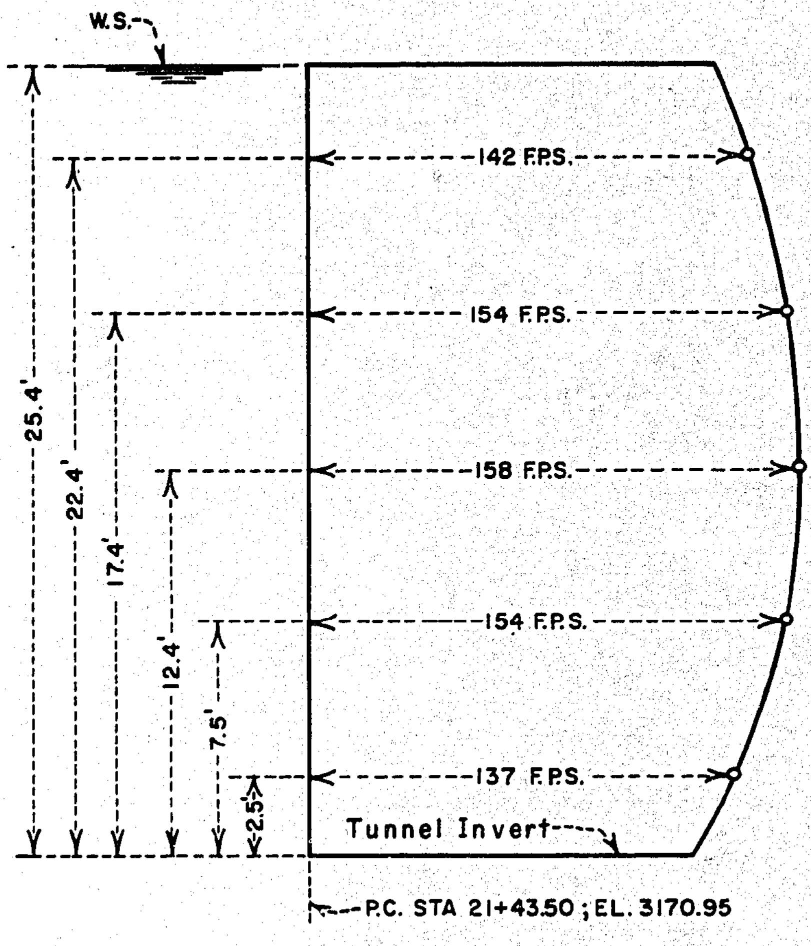
SWEEPOUT TESTS

1:49.95 SCALE MODEL

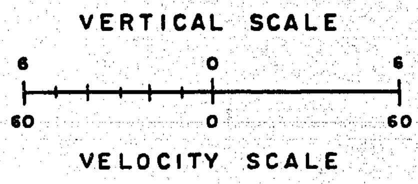


YELLOWTAIL DAM SPILLWAY
PRESSURES IN THE PRELIMINARY TUNNEL TRAJECTORY
1:49.95 SCALE MODEL

FIGURE 36
REPORT HYD. 483



Velocity Profile on ℄ of 32 Foot Diameter Tunnel at P.C. Sta. 21+43.50 in the preliminary design (See Figure 30)



NOTE
Depth of flow is controlled by slide gate in horizontal tunnel.

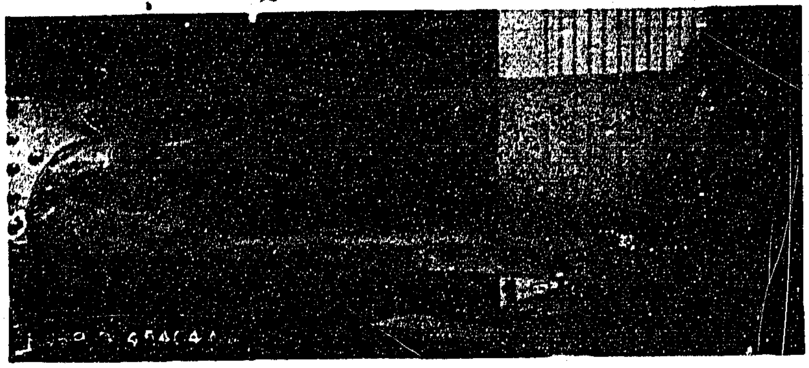
YELLOWTAIL DAM SPILLWAY

VELOCITY PROFILE AT STA. 21 + 43.50 FOR 92,000 CFS.

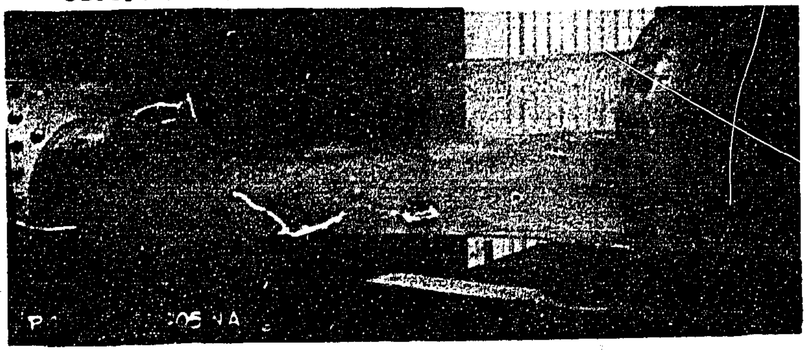
1:49.95 SCALE MODEL

Figure 38
Report Hyd-483

Notes: The stilling basin extended 220 feet downstream from portal and its floor was at elevation 3145. This was not the final recommended basin. Flow velocity is controlled by slide gate in horizontal tunnel.

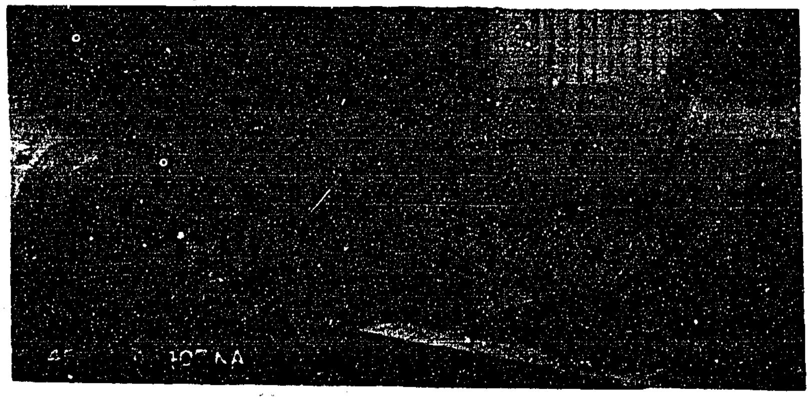


A. 12,000 cfs, tailwater elevation 3190.7 at Station 28+00.



B. 46,000 cfs

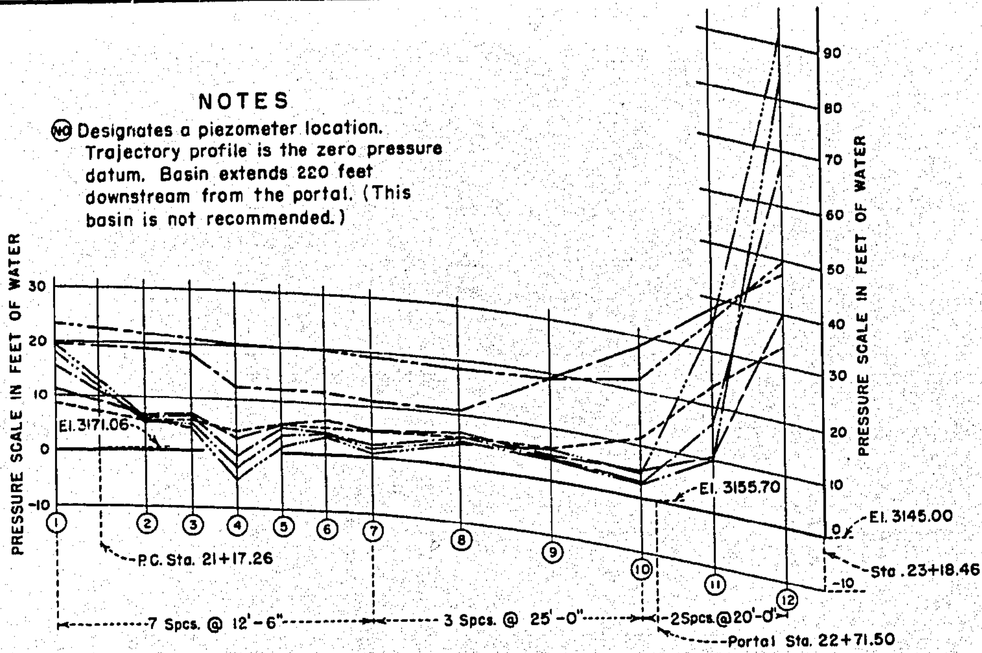
C. 69,000 cfs



D. 92,000 cfs

YELLOWTAIL DAM SPILLWAY

Flow in the recommended tunnel trajectory
1:49.95 scale model

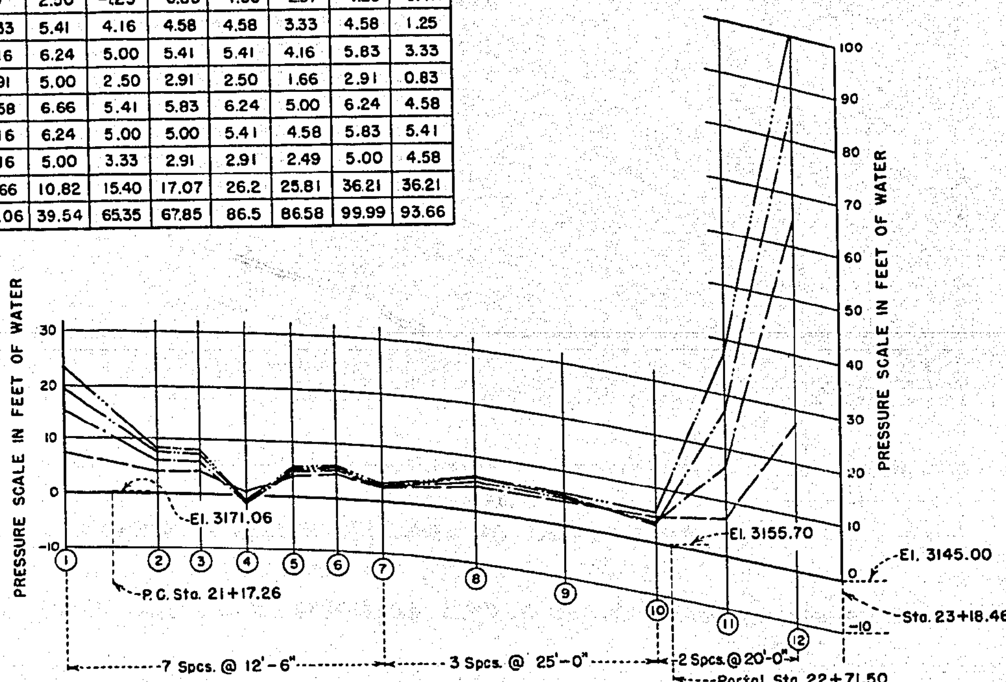


A. DEPTH OF FLOW AT P.C. WAS CONTROLLED BY A SLIDE GATE 1500 FEET UPSTREAM

PIEZOMETER PRESSURES								
PIEZ. NO.	23,000 cfs.		46,000 cfs.		69,000 cfs.		92,000 cfs.	
	B	A	B	A	B	A	B	A
1	7.49	11.66	15.40	15.82	19.56	18.32	23.31	19.55
2	3.75	6.66	5.83	6.66	7.49	5.41	8.32	5.83
3	3.75	6.66	5.83	6.24	7.08	5.41	7.91	4.16
4	0	2.50	-1.25	-0.83	-1.66	-2.91	-1.25	-5.41
5	3.33	5.41	4.16	4.58	4.58	3.33	4.58	1.25
6	4.16	6.24	5.00	5.41	5.41	4.16	5.83	3.33
7	2.91	5.00	2.50	2.91	2.50	1.66	2.91	0.83
8	4.58	6.66	5.41	5.83	6.24	5.00	6.24	4.58
9	4.16	6.24	5.00	5.00	5.41	4.58	5.83	5.41
10	4.16	5.00	3.33	2.91	2.91	2.49	5.00	4.58
11	6.66	10.82	15.40	17.07	26.2	25.81	36.21	36.21
12	27.06	39.54	65.35	67.85	86.5	86.58	99.99	93.66

EXPLANATION

- 20,000 cfs. Diversion flow.
- 31,000 cfs. Diversion flow.
- 12,000 cfs. Res. El. 3560.
- 23,000 cfs. Free flow.
- 46,000 cfs. Free flow.
- 69,000 cfs. Free flow.
- 92,000 cfs. Free flow.



B. DEPTH OF FLOW AT P.C. WAS CONTROLLED BY THE MODEL RESERVOIR

YELLOWTAIL DAM SPILLWAY

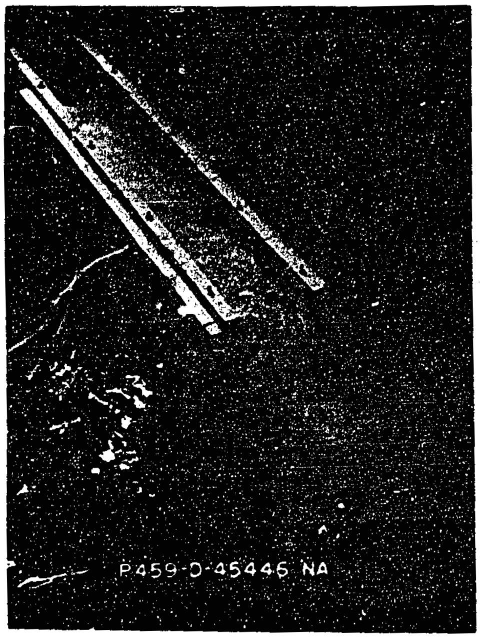
PRESSURES IN THE RECOMMENDED TUNNEL TRAJECTORY

1:49.95 SCALE MODEL

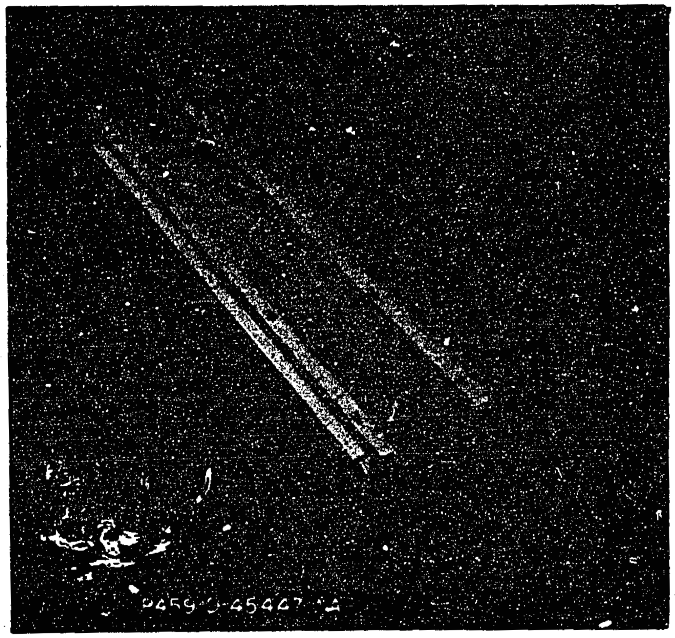
430

A. 12, 000 cfs, tailwater elevation 3186.

B. 12, 000 cfs, tailwater elevation 3190.



C. 12, 000 cfs, tailwater elevation 3186.

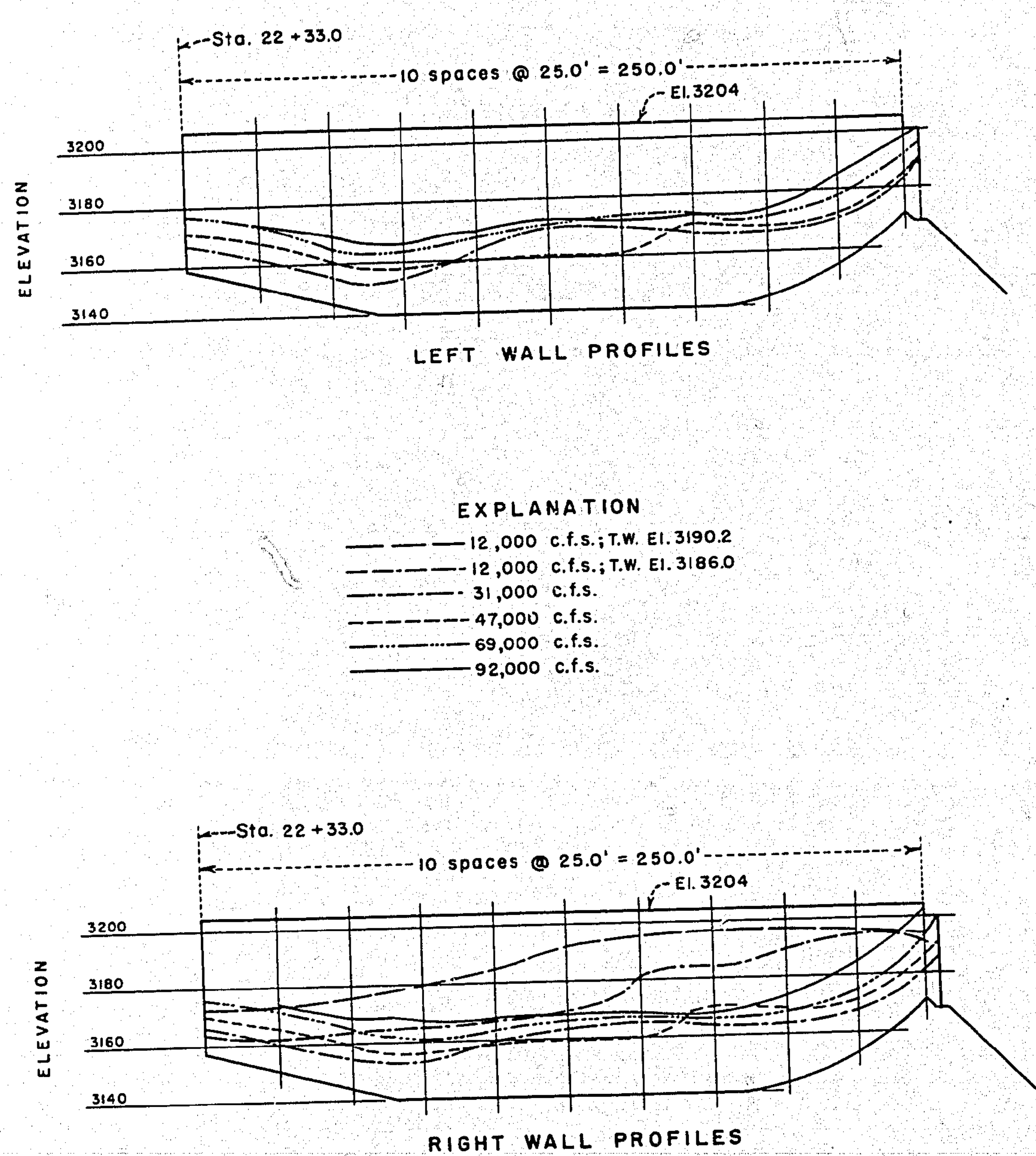


D. 12, 000 cfs, tailwater elevation 3190.

Note: An additional 8, 000 cfs is being discharged through the powerplant and outlet works. See Figures 7 and 8 for recommended basin dimensions.

YELLOWTAIL DAM SPILLWAY

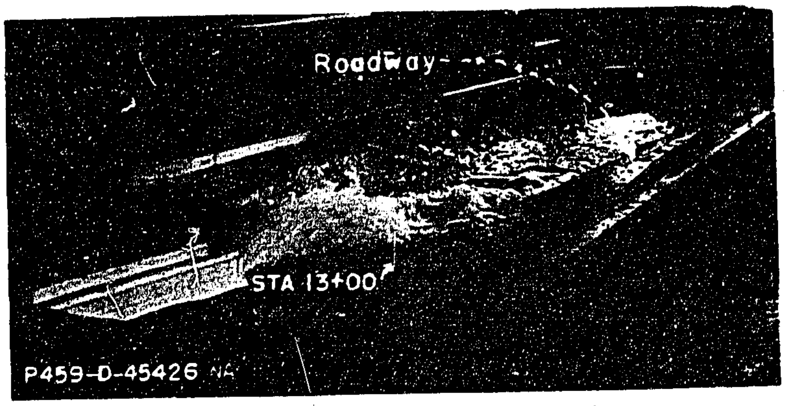
Flow in the recommended tunnel trajectory and stilling basin 1:49, 95 scale model



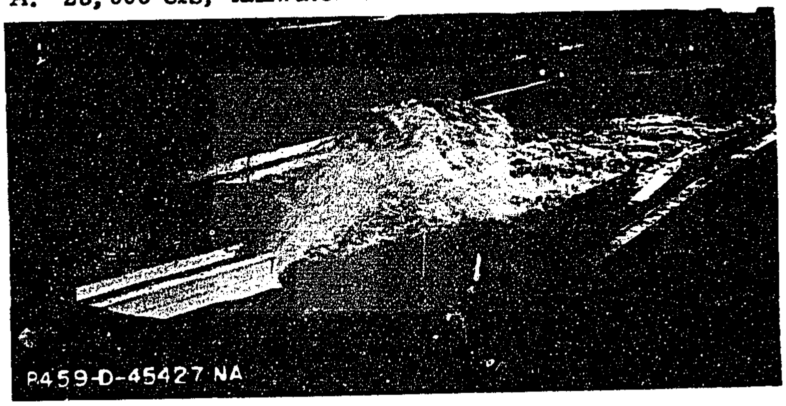
YELLOWTAIL DAM SPILLWAY

WATER SURFACE PROFILES IN THE RECOMMENDED BASIN AND FLIP BUCKET

1:49.95 SCALE MODEL

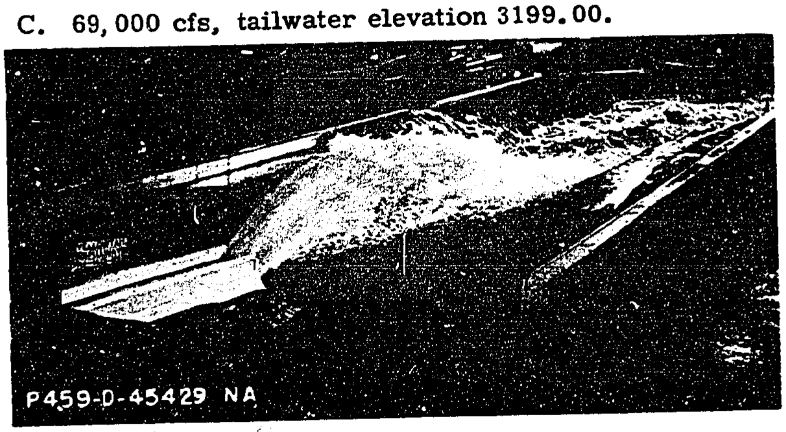


A. 23,000 cfs, tailwater elevation 3188.00.



B. 46,000 cfs, tailwater elevation 3195.00.

C. 69,000 cfs, tailwater elevation 3199.00.

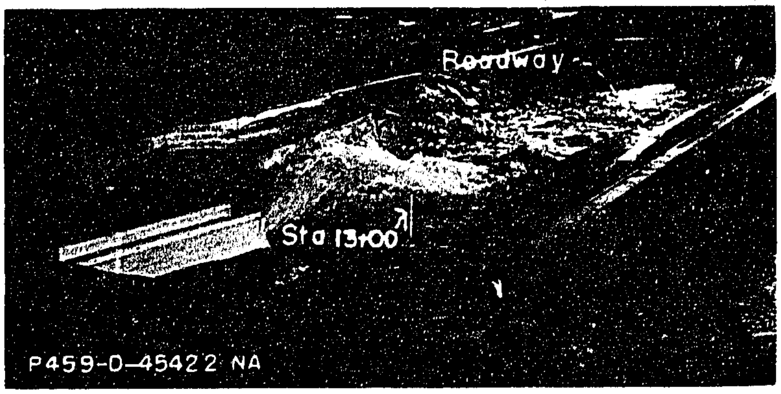


D. 92,000 cfs, tailwater elevation 3200.00.

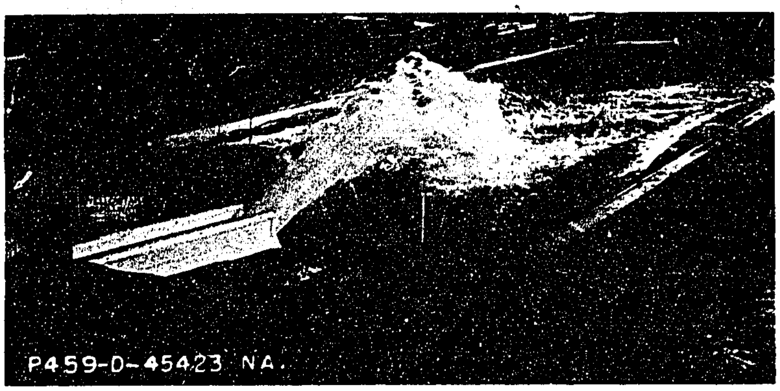
Notes: Powerplant was discharging an additional 3,000 cfs. Tailwater elevation was regulated at Station 28+00. For all flows the tailwater at Station 13+00 was at approximately elevation 3174.

YELLOWTAIL DAM SPILLWAY

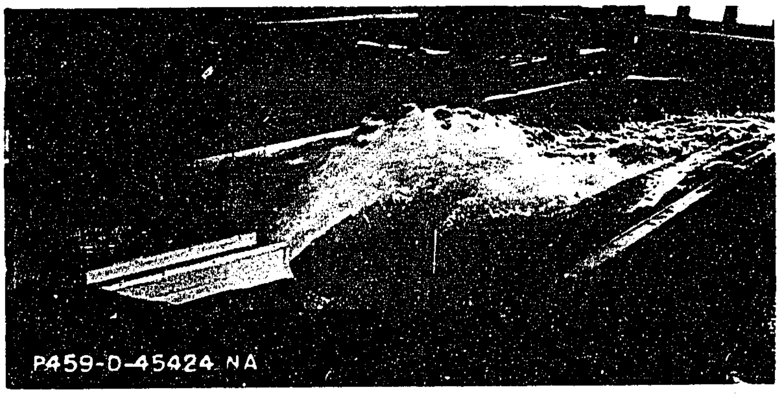
Flow from the recommended flip bucket
1:49.95 scale model



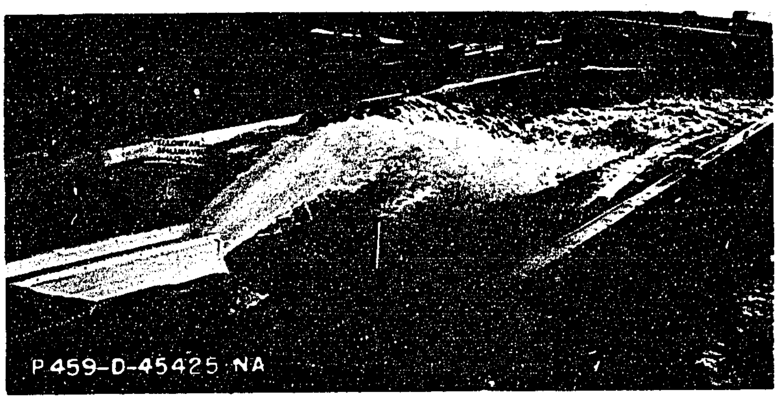
A. 23,000 cfs, tailwater elevation 3187.50.



B. 46,000 cfs, tailwater elevation 3194.50.



C. 69,000 cfs, tailwater elevation 3199.00.



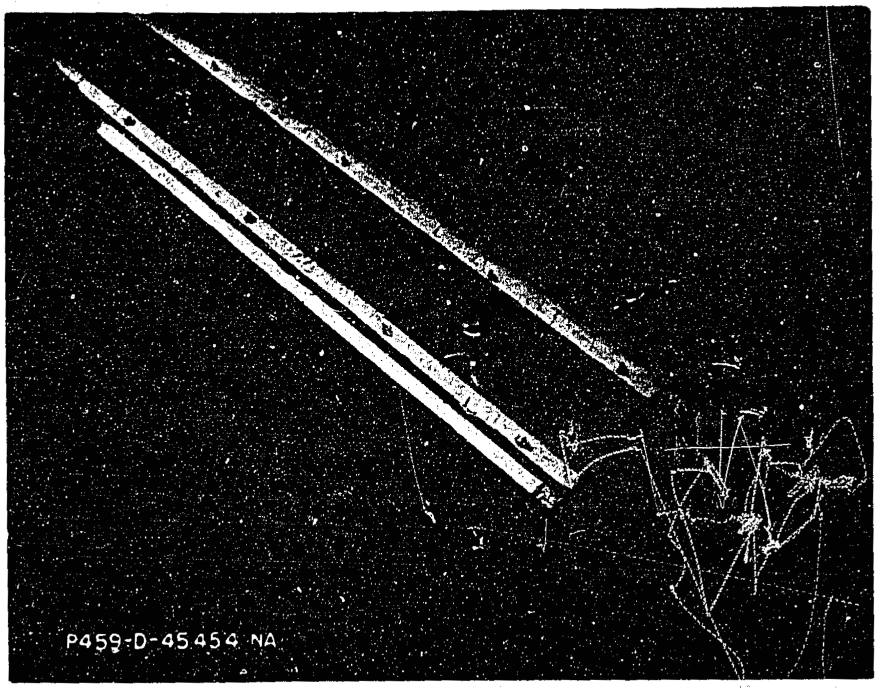
D. 92,000 cfs, tailwater elevation 3200.00.

Notes: Powerplant and outlet works were not discharging. Tailwater elevation was regulated at Station 28+00. For all flows the tailwater at Station 13+00 was at approximately elevation 3171.3.

YELLOWTAIL DAM SPILLWAY

Flow from the recommended flip bucket
1:49.95 scale model

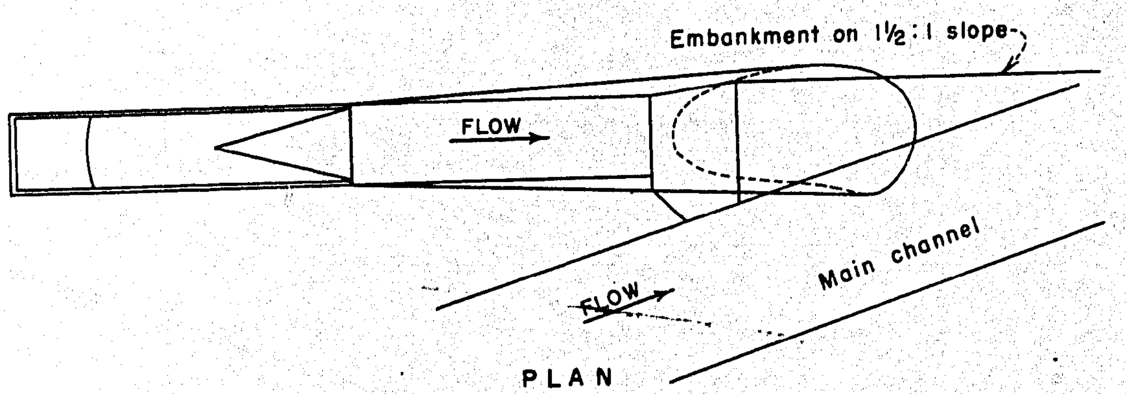
A. 46,000 cfs, uncontrolled gate flow.



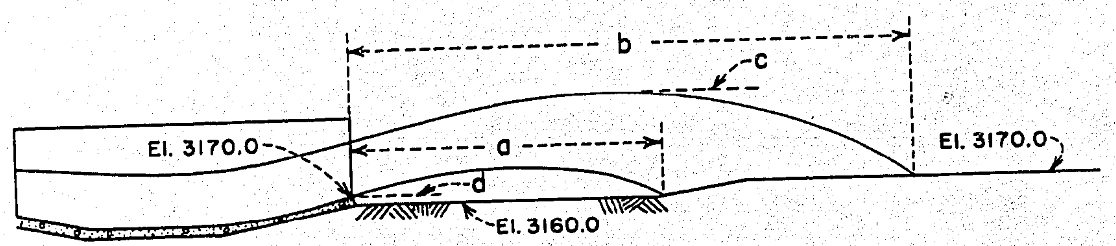
B. 92,000 cfs.

YELLOWTAIL DAM SPILLWAY

Flow through the recommended stilling basin--flip bucket
1:49.95 scale model



PLAN



PROFILE

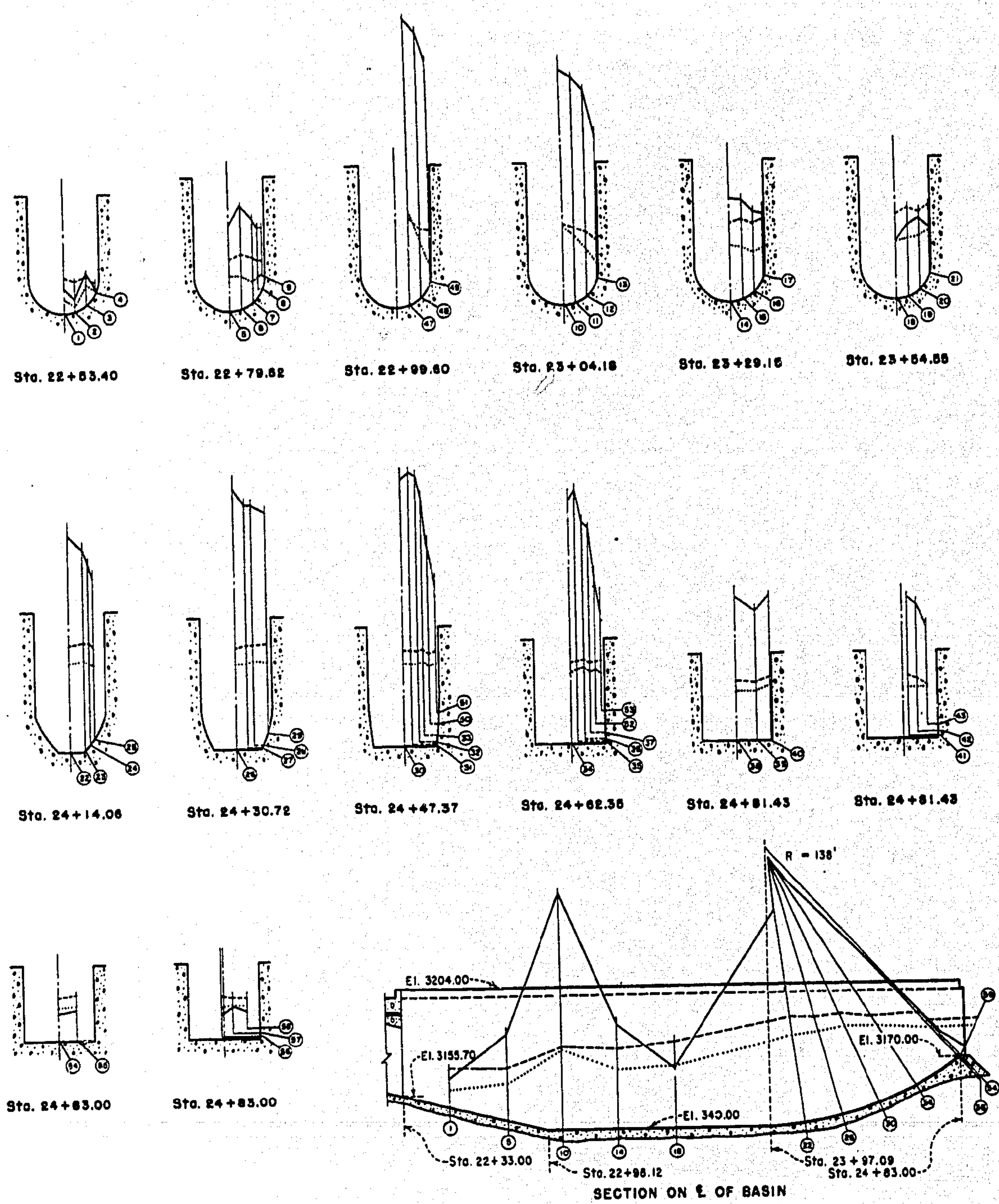
Q	a	b	c	d
¼ MAX.	258	341	3241	3170
½ MAX.	383	500	3295	3170
¾ MAX.	425	525	3287	3170
FULL MAX.	478	540	3287	3170

All dimensions are in feet.
Max. Q = 92,000 cfs

a. Minimum length of jet projection lower nappe
b. Maximum length of jet projection upper nappe
c. Maximum elevation of upper nappe
d. Tailwater elevation

YELLOWTAIL DAM SPILLWAY
JET DIMENSIONS IN THE RECOMMENDED DESIGN
1:49.95 SCALE MODEL

FIGURE 46
REPORT HYD. 483



DISCHARGE (CFS)	TAILWATER ELEVATION		PRESSURE		
	AT POWERPLANT	AT SPILLWAY	PIEZ. #54	PIEZ. #55	PIEZ. #56
92,000*	3181.5	3181.5	20.0	6.5	16.6
92,000	3177.8	3176.0	10.0	2.0	14.0
92,000	DRY	DRY	8.0	-2.85	6.5
46,000	3184.6	3182.5	16.0	12.0	15.5
46,000	3177.9	3173.5	11.0	4.0	10.0
46,000	DRY	DRY	5.6	-1.28	3.0

*INCLUDES POWERPLANT DISCHARGE OF 3,000 C.F.S.

NOTES

(50) Designates piezometer location.
Elevation of piezometer openings is atmospheric pressure datum.

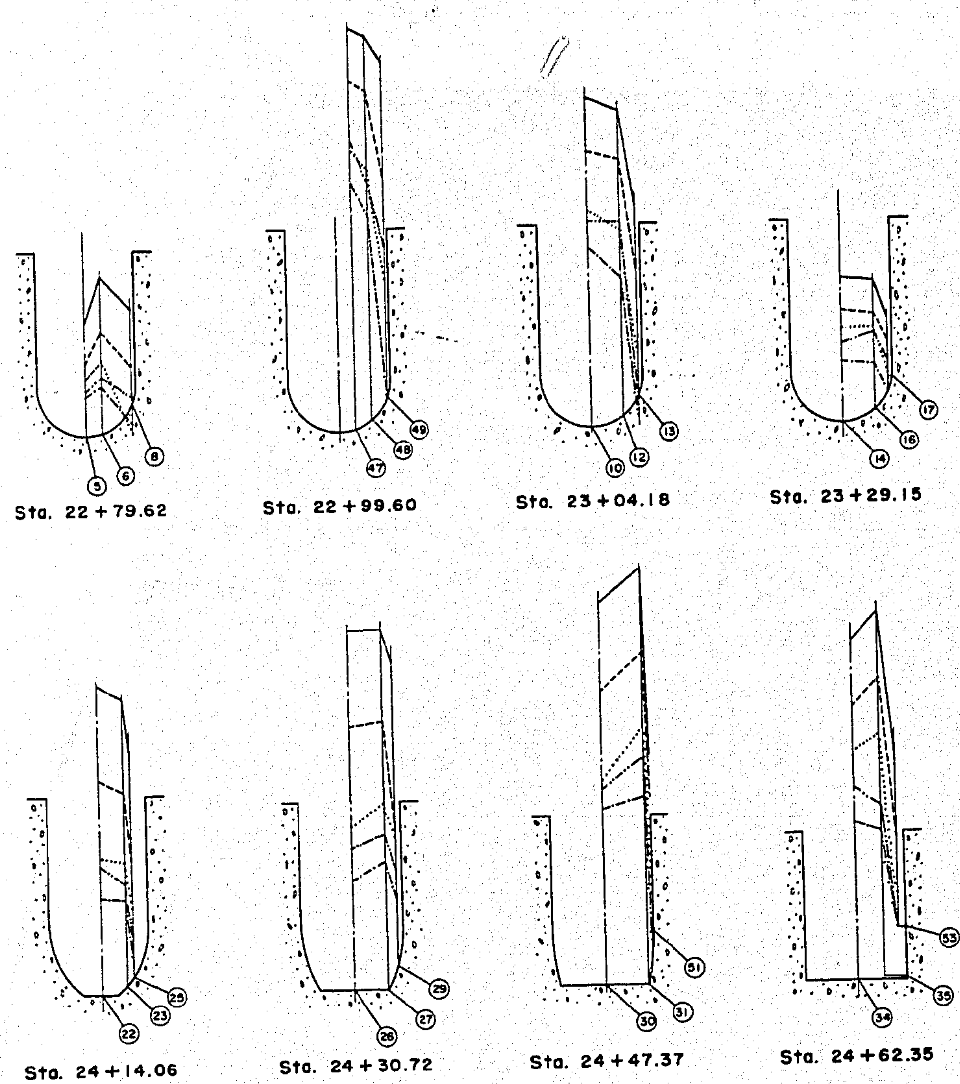
30 0 30 60 90
PRESSURE SCALE IN PROTOTYPE
FEET OF WATER

EXPLANATION

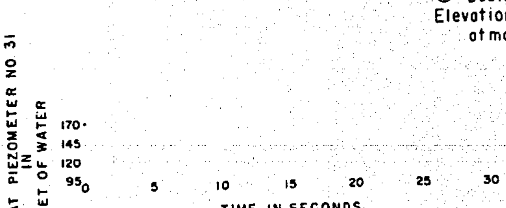
——— 92,000 C.F.S. T.W. El. 3203 AT STA. 28+00
- - - - 12,000 C.F.S. T.W. El. 3186 AT STA. 28+00
.... 12,000 C.F.S. T.W. El. 3190.2 AT STA. 28+00

YELLOWTAIL DAM SPILLWAY
PRESSURES IN RECOMMENDED BASIN AND FLIP BUCKET
1:49.95 SCALE MODEL

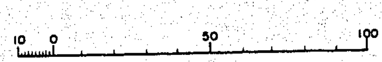
430



(NO) Designates piezometer location. Elevation of piezometer openings is atmospheric pressure datum.



INSTANTANEOUS PRESSURE DIAGRAM FOR 92,000 C.F.S.



PRESSURE SCALE IN PROTOTYPE FEET OF WATER

NOTE

For 99% of the time, the pressure fluctuation above or below average in the instantaneous pressure diagram is less than 10% of the average.

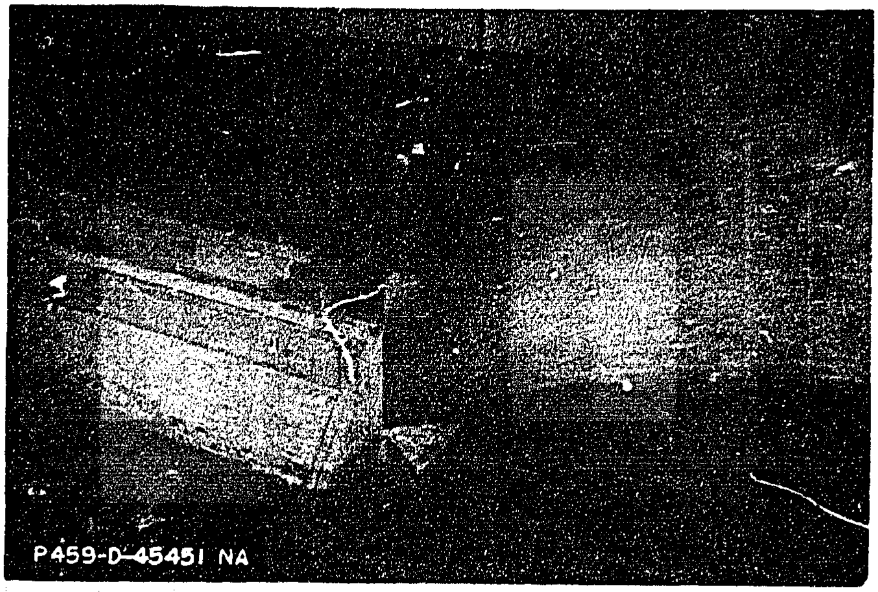
EXPLANATION

Line	Discharge	
···········	DISCHARGE = 47,000 CFS.	AVERAGE INSTANTANEOUS PRESSURE
– – – – –	DISCHARGE = 67,000 CFS.	AVERAGE INSTANTANEOUS PRESSURE
————	DISCHARGE = 92,000 CFS.	AVERAGE INSTANTANEOUS PRESSURE
–·–·–·–	DISCHARGE = 31,000 CFS	AVERAGE INSTANTANEOUS PRESSURE
–··–··–	DISCHARGE = 31,000 CFS.	(AVERAGE MAXIMUM INSTANTANEOUS PRESSURE)

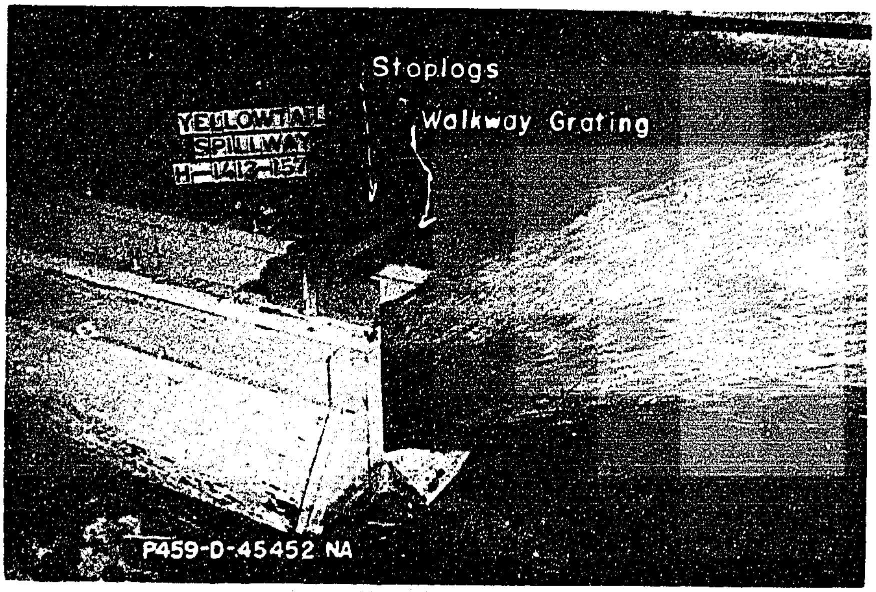
YELLOWTAIL DAM SPILLWAY

INSTANTANEOUS PRESSURES IN THE STILLING BASIN-FLIP BUCKET

1:49.95 SCALE MODEL



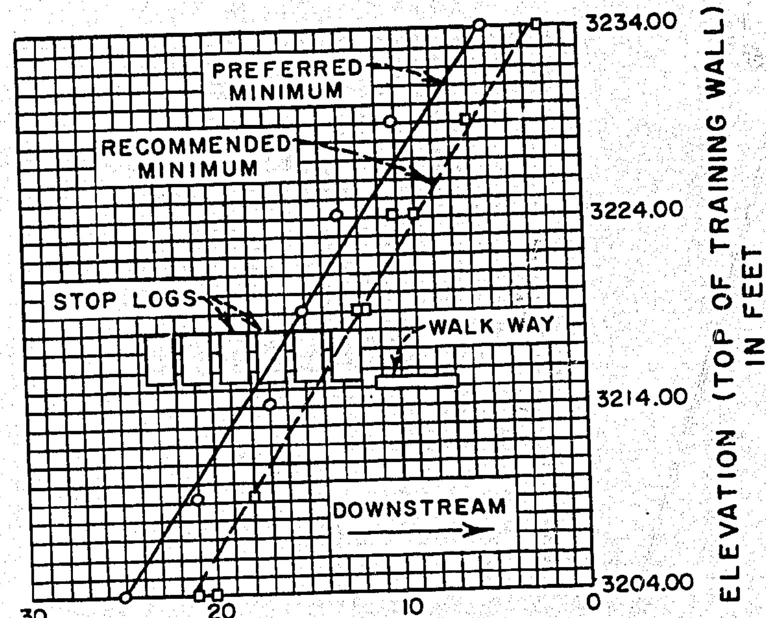
A. 45,000 cfs--25-foot gate opening. Note the walkway grating has been dislodged by the flow.



B. 92,000 cfs.

YELLOWTAIL DAM SPILLWAY

Flow under the stoplog storage facility
1:49.95 scale model



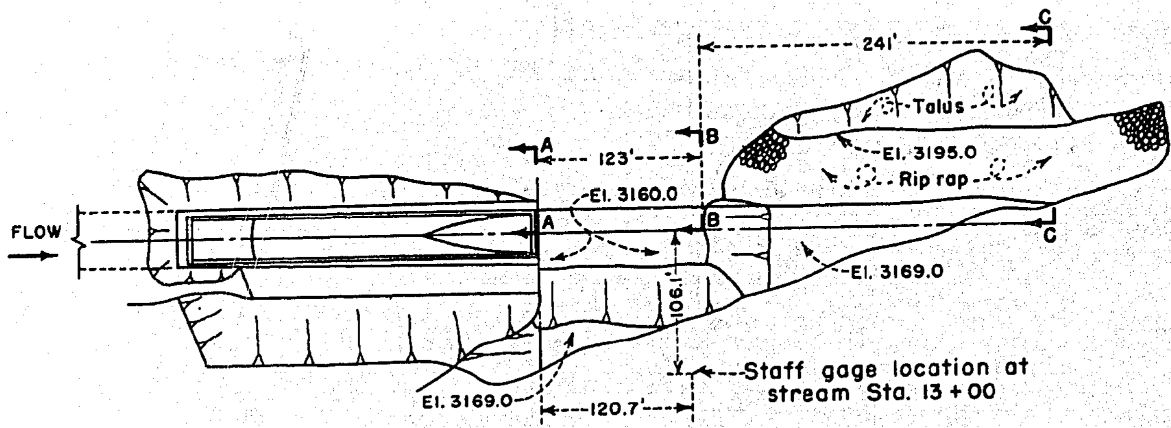
EXPLANATION

□ Logs wobbled but did not move downstream (46,000 cfs)
○ Logs did not wobble (46,000 cfs)

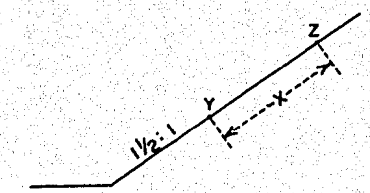
NOTES

For stilling basin flows, logs will be placed as shown.
For flip bucket flow the three downstream logs will be placed on top of the three upstream logs and walkway grating will be removed.

YELLOWTAIL DAM SPILLWAY
STOPLOG STORAGE LOCATION TESTS
1:49.95 SCALE MODEL



PLAN



SECTIONS AA, BB, CC

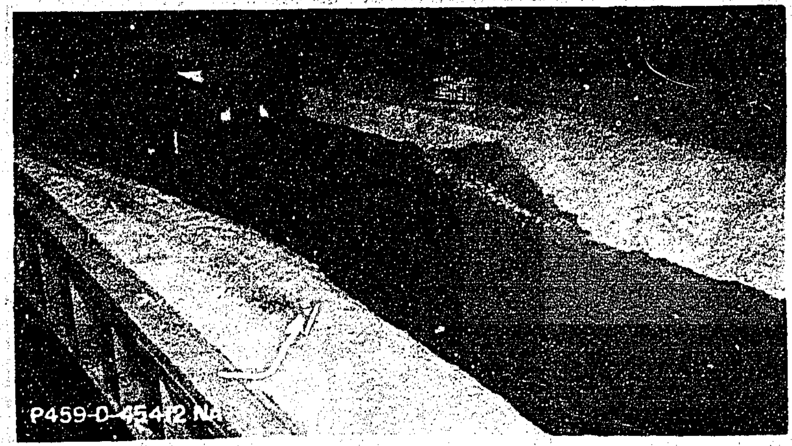
SECTION	SPILLWAY DISCHARGE C.F.S.	P.H. AND O.W. DISCHARGE C.F.S.	T.W. EL. AT STREAM STA. 28 + 00	MAX. WAVE EL. POINT Z FT.	MIN. WAVE EL. POINT Y FT.	WAVE TRAVEL DISTANCE X FT.	MAX. WAVE EL. AT STREAM GAGE STA. 13 + 00	MIN. WAVE EL. AT STREAM GAGE STA. 13 + 00
A – A	12,000	8,000	3190.2	3209	3184	46	3195	3188
B – B	12,000	8,000	3190.2	3202	3186	29	3195	3188
C – C	12,000	8,000	3190.2	3199	3188	21	3195	3188
A – A	12,000	8,000	3186.0	3200	3180	38	3191	3186
B – B	12,000	8,000	3186.0	3199	3183	29	3191	3186
C – C	12,000	8,000	3186.0	3196	3184	21	3191	3186

YELLOWTAIL DAM SPILLWAY

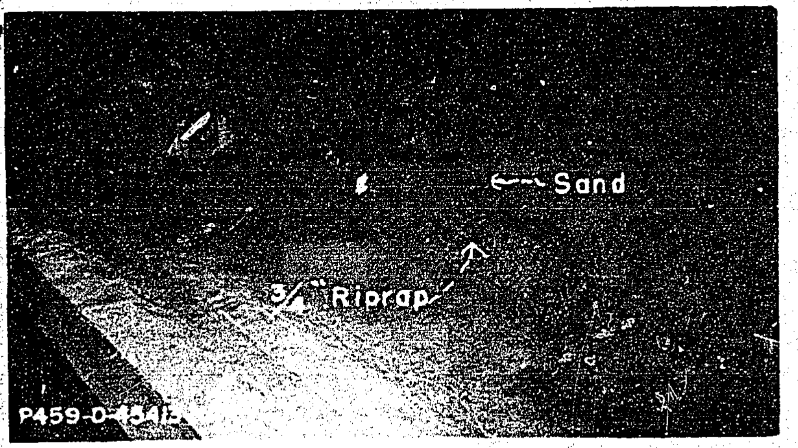
WAVE HEIGHTS DOWNSTREAM FROM STILLING BASIN

1:49.95 SCALE MODEL

A. Spillway--12,000 cfs, powerplant and outlets--8,000 cfs, tailwater elevation 3186 at Station 28+00.



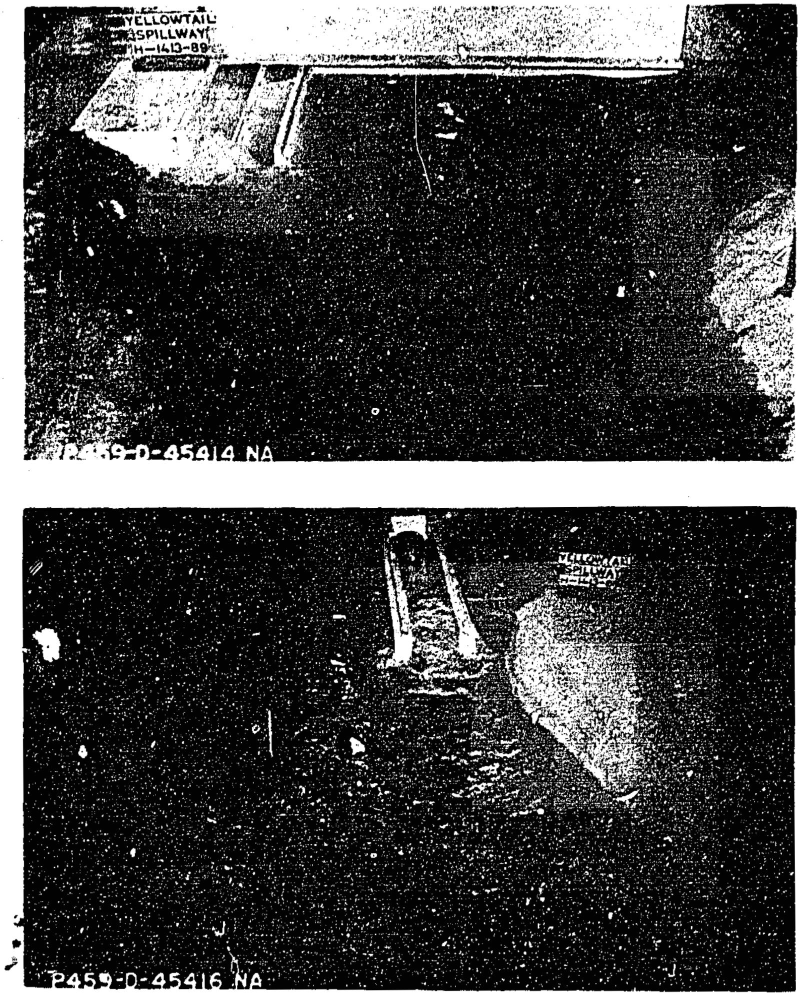
B. Spillway--12,000 cfs, powerplant and outlets--8,000 cfs, tailwater elevation 3190 at Station 28+00.



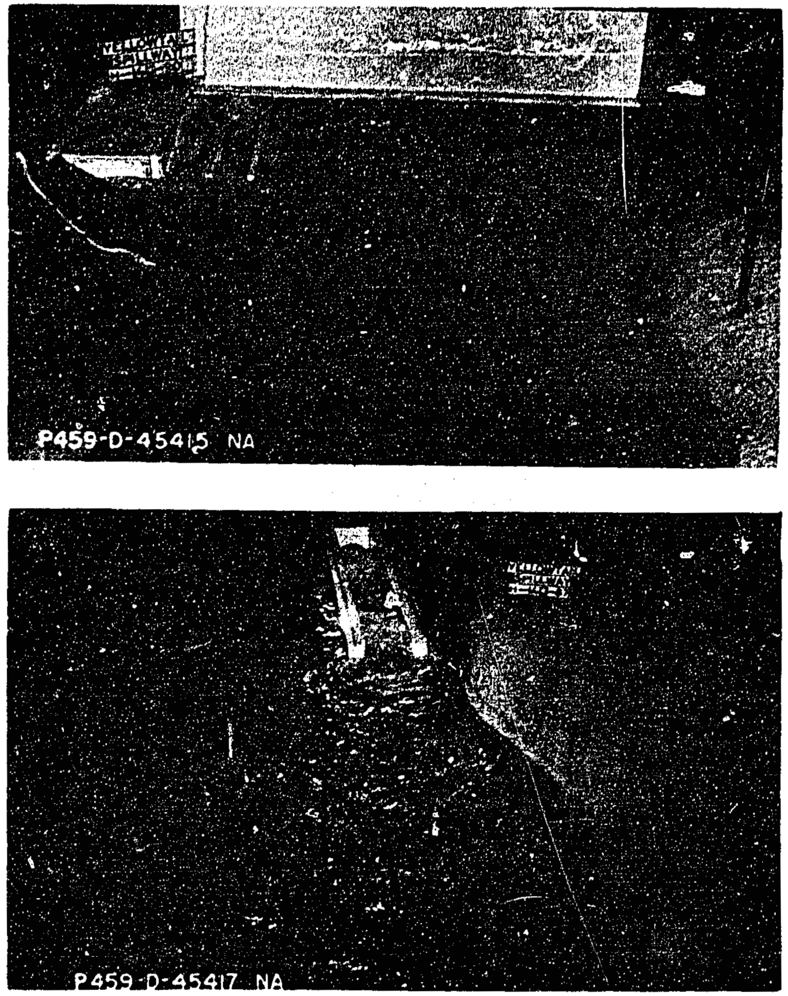
C. Erosion after 4-hour model test for discharge conditions shown in B. above.

YELLOWTAIL DAM SPILLWAY

Erosion test with recommended riprap
1:49.95 scale model



A. Tailwater elevation 3186 at Station 28+00.

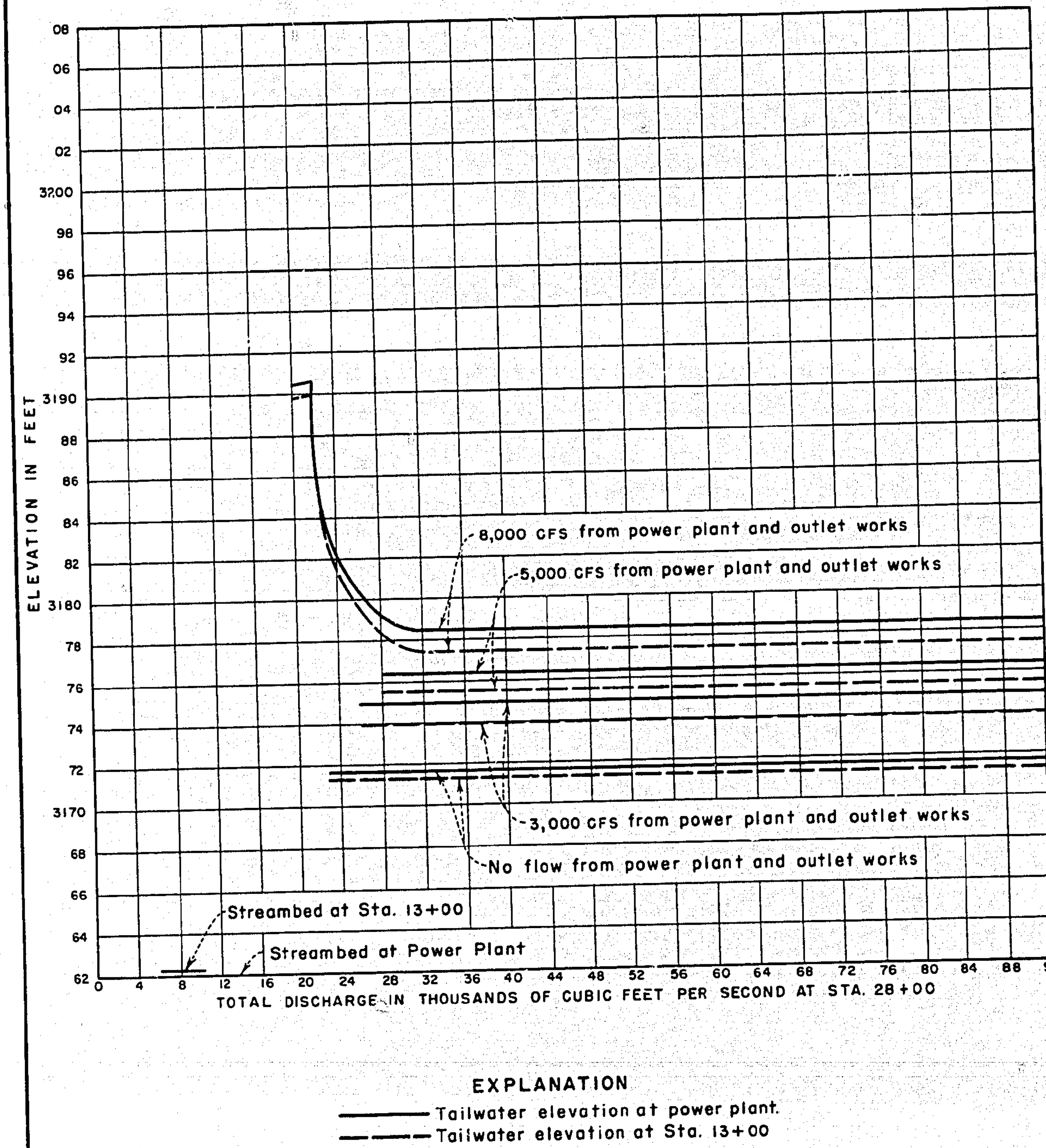


B. Tailwater elevation 3190 at Station 28+00.

Note: Spillway 12,000 cfs, powerplant 3,000 cfs, and outlet works 5,000 cfs.

YELLOWTAIL DAM SPILLWAY

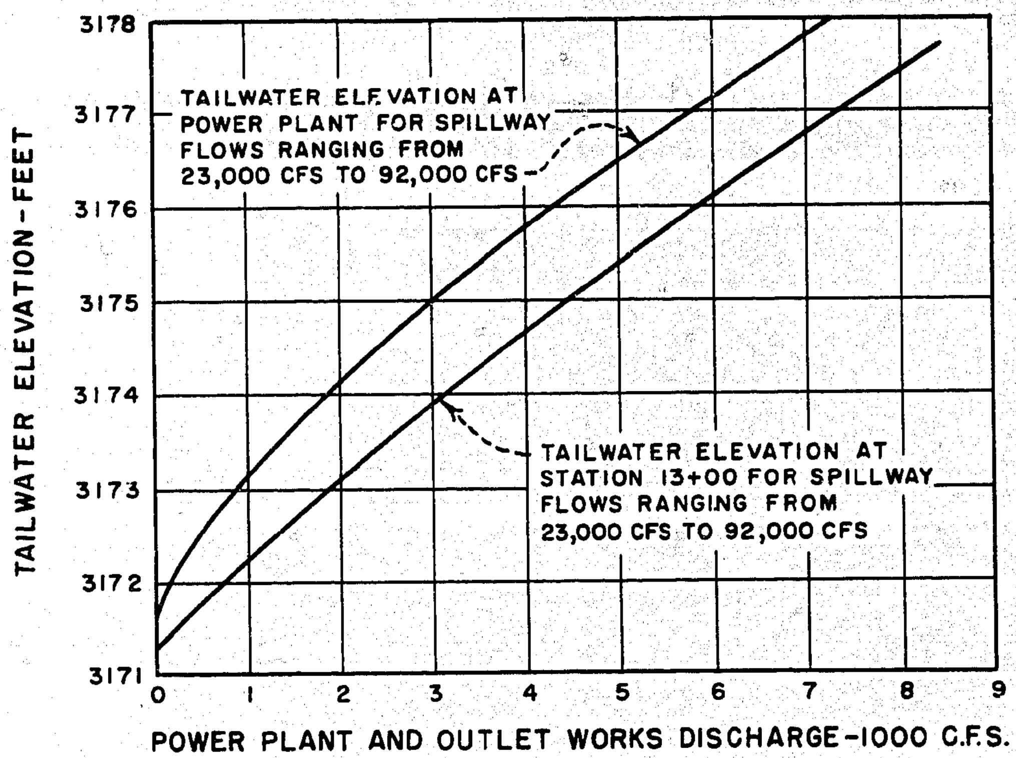
Tailwater conditions at the powerplant outlet works and spillway
1:49.95 scale model



YELLOWTAIL DAM SPILLWAY

TAILWATER DRAWDOWN

DUE TO OPERATION OF THE FLIP BUCKET



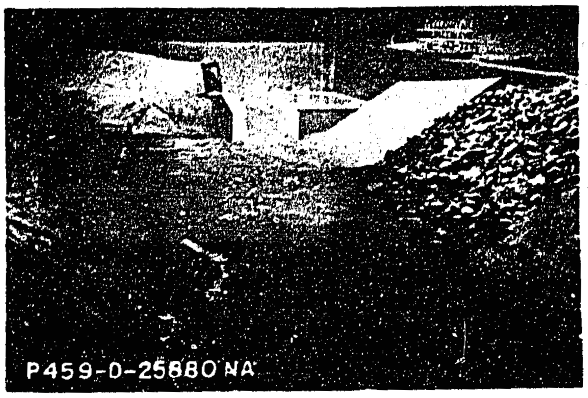
NOTE

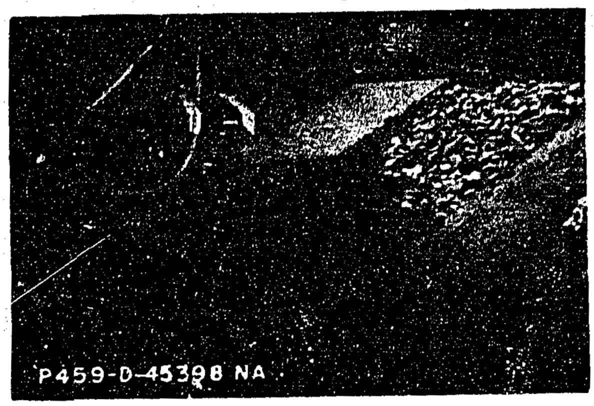
Tailwater elevation was controlled at river Sta. 28+00 in accordance with Figure 31. Varying the tailwater at Sta. 28+00 in accordance with whether or not afterbay dam is assumed to be washed out did not appreciably affect the tailwater elevation at the Power Plant or at Sta. 13+00 near spillway stilling basin. (See Figures 42 and 43)

YELLOWTAIL DAM SPILLWAY

TAILWATER ELEVATION

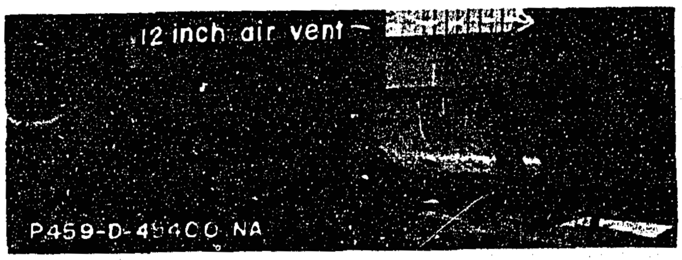
1:49.95 SCALE MODEL



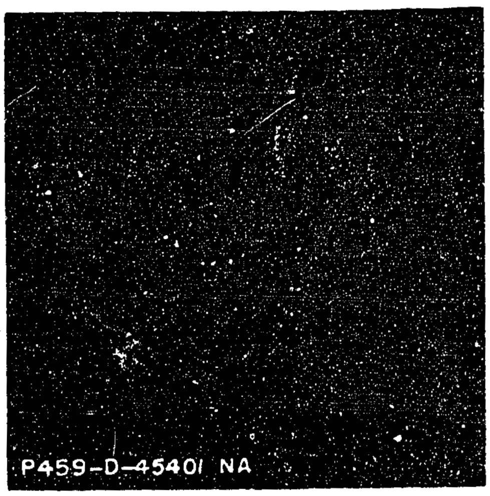


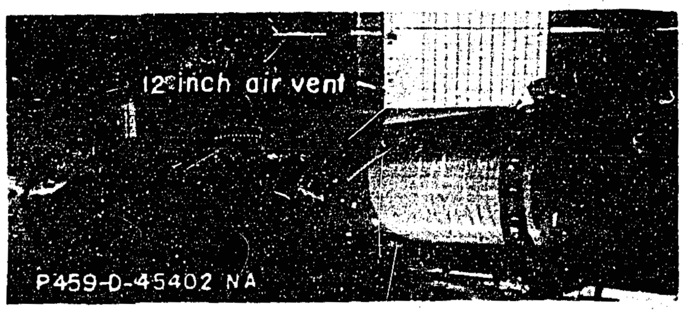
A. Modified basin 220 feet long, invert at elevation 3145, discharging 20,000 cfs, tailwater elevation 3186 at Station 28+00.

B. Discharge = 31,000 cfs, tailwater elevation 3189.8 at Station 28+00.



C. and D. Recommended tunnel trajectory with air vent and the modified basin discharging 20,000 cfs. Position of toe of jump fluctuates from portal to about 25 feet upstream.

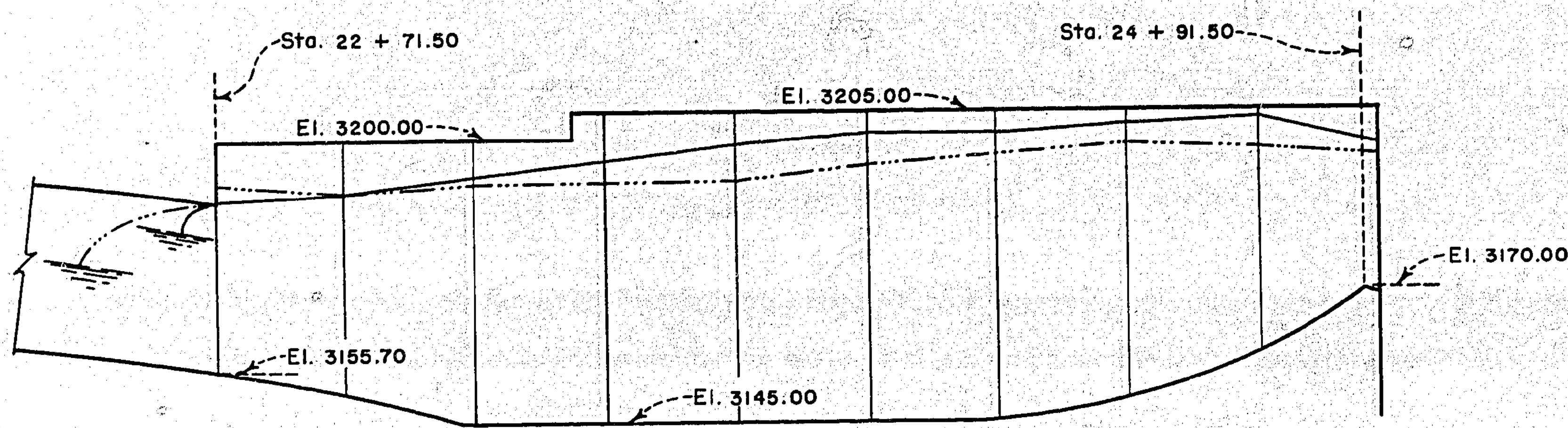




E. and F. Discharge = 31,000 cfs.

YELLOWTAIL DAM SPILLWAY

Diversion flows in the recommended tunnel trajectory
and modified basin
1:49.95 scale model



EXPLANATION

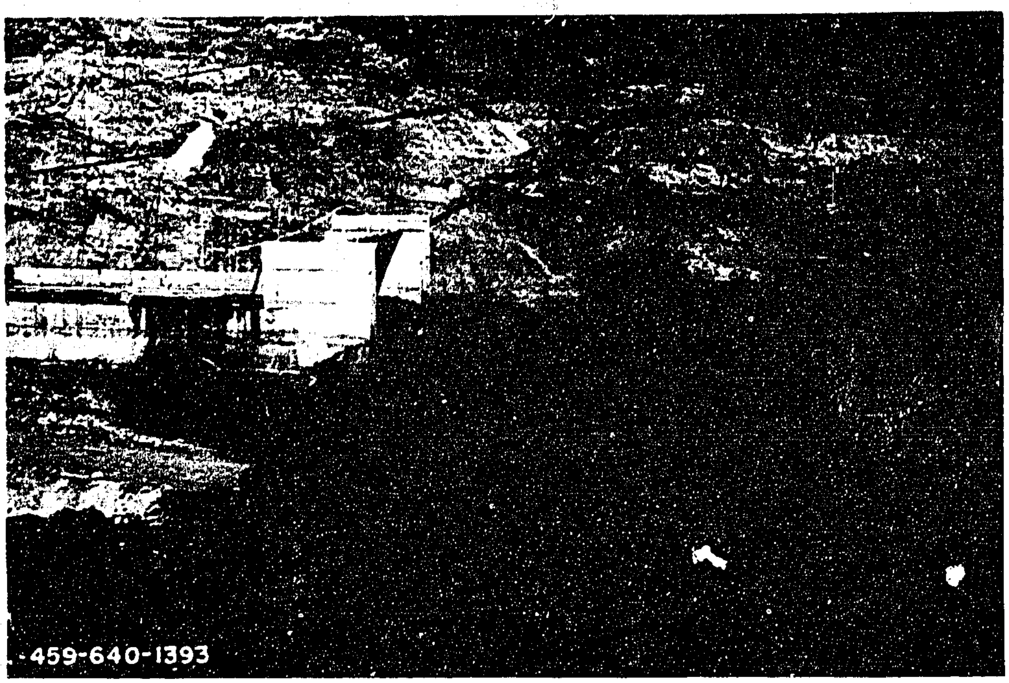
20,000 cfs., Tailwater El. 3185.6 at Power Plant.
31,000 cfs., Tailwater El. 3189.0 at Power Plant.

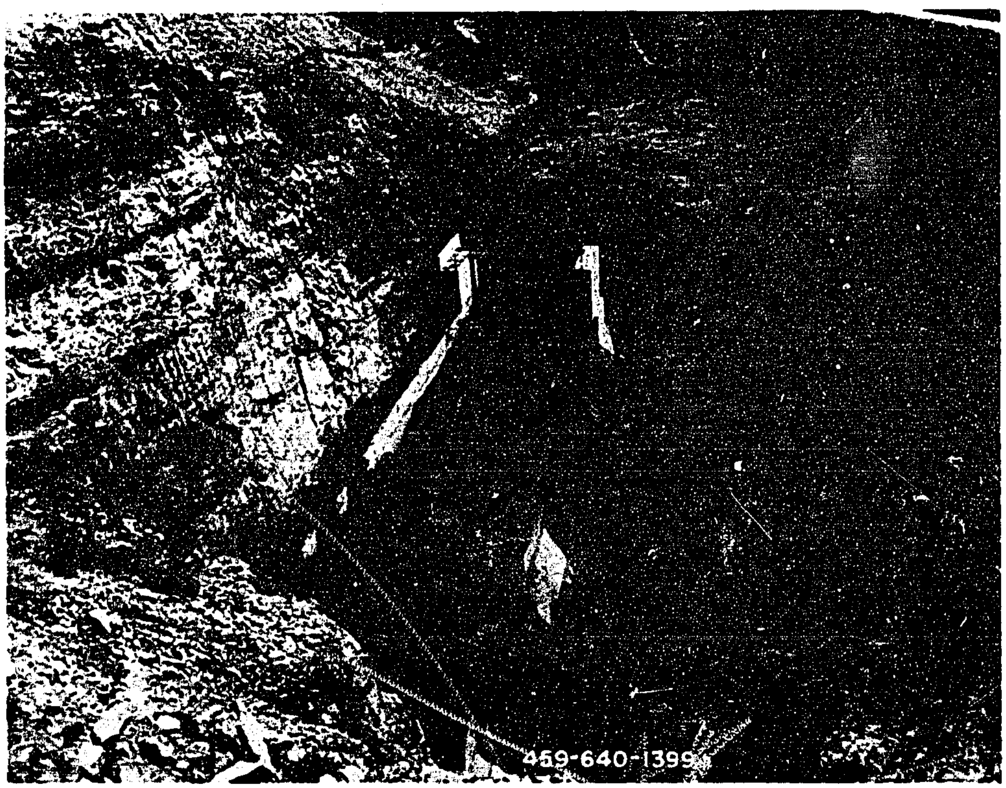
NOTE

The recommended tunnel trajectory with air vent was used with this modified basin.

YELLOWTAIL DAM SPILLWAY
DIVERSION FLOW PROFILES IN MODIFIED STILLING BASIN
1:49.95 SCALE MODEL

FIGURE 56
REPORT HYD. 483





Compare with Figures 55A and C.

YELLOWTAIL DAM SPILLWAY

Diversion flow of 20,000 cfs in the prototype basin

7-1750
(10-64)

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 an 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

GPO 845-237

ABSTRACT

Model studies were conducted to develop the hydraulic design of the approach channel, intake structure, tunnel transition section, inclined tunnel, vertical bend, tunnel trajectory, combination stilling basin-flip bucket, and the stream channel protection. Reshaping the approach channel improved the flow pattern. Approach channel construction limitations were recommended. The center pier in the transition section was altered to improve flow conditions in the inclined tunnel. The tunnel trajectory extending to the combination stilling basin-flip bucket was modified to eliminate severe subatmospheric pressures. A combination stilling basin-flip bucket was developed to still a minimum of 12,000 cfs and to flip a jet downstream for flows up to 92,000 cfs. This basin satisfactorily discharged the anticipated maximum diversion flow of 31,000 cfs. A vent was installed in the crown of the tunnel to prevent the tunnel from filling when discharging diversion flows up to 20,000 cfs. A stoplog storage facility at the downstream end of the stilling basin-flip bucket, was developed to prevent the stored logs from being dislodged by the spillway flow. Riprap protection for the left bank of the stream channel downstream from the basin was determined. The amount of tailwater drawdown at the powerplant and outlet works resulting from the operation of the spillway flip bucket was determined.

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Laboratory Report, Bureau of Reclamation, Denver, 38 p, 57 fig, 1 tab, 3 ref, append, 1964

DESCRIPTORS--*Spillways/outlet works/diversion works/tunnels/*flip buckets/*stilling basins/intake structures/radial gates/piers/bends/discharge coefficients/roughness coefficients/tunnel hydraulics/hydraulic similitude/transducers/piezometers/jets/riprap/streamflow/diversion tunnels/tailrace/*hydraulic models/bank protection/computer programming/hydraulic jumps

IDENTIFIERS--Subatmospheric pressures/approach channels/tunnel transitions/tunnel trajectories

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