UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF YELLOWTAIL DAM OUTLET WORKS

(Final Studies)

Hydraulics Branch Report No. Hyd-482

DIVISION OF ENGINEERING LABORATORIES

OFFICE OF ASSISTANT COMMISSIONER AND CHIEF ENGINEER
DENVER, COLORADO

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Report No. Hyd-482
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Subject: Hydraulic model studies of Yellowtail Dam Outlet Works (Final Studies)

PURPOSE

The model studies discussed in this report were conducted to develop a stilling basin that would operate satisfactorily for a higher than normal tailwater resulting from storage in a downstream conservation pool and for low tailwater when there is no storage in the pool.

CONCLUSIONS

1. The hydraulic jump swept from the preliminary stilling basin at the maximum discharge, 5,000 second-feet, and low tailwater, elevation 3177.5.

2. When the stilling basin floor was lowered 2.5 feet, the jump remained in the basin at the low tailwater and the energy dissipation was satisfactory for all flows, Figures 7, 8, and 9.

3. For the maximum discharge and with the tailwater elevation between 3183.0 and 3188.0, an occasional piece of riprap moved upstream into the basin where it rolled around with an abrasive action.

4. Retaining walls along both banks downstream from the basin training walls prevented the riprap from entering the basin. The walls also served to reduce the intensity of the wave action striking the side slopes, permitting a reduction in the size of the recommended riprap from 3-foot stones to 2-foot stones.

5. To prevent overloading the stilling basin walls during unwatering, the top of the center wall was lowered to elevation 3186.0 and the top of the left wall to elevation 3190.0. The operation of the basin was satisfactory with the lower walls, Figure 10.

INTRODUCTION

Yellowtail Dam is the principal feature of the Yellowtail Unit, Lower Bighorn Division of the Missouri River Basin Project. It is located on the Bighorn River about 45 miles southeast of Billings, Montana, Figure 1.

The dam is a concrete arch structure about 1,450 feet long and 520 feet high. The principal hydraulic features are the tunnel spillway and the river outlet works. The tunnel spillway is located in the left canyon wall and the outlet works is located near the center of the dam to the right of the powerplant, Figure 2. The model studies described herein were concerned with the river outlet works. Model studies for the spillway are discussed in Hydraulics Branch Report No. Hyd-483.

The river outlet works consists of two 84-inch hollow-jet valves discharging into a stilling basin. The intake to the right valve, the irrigation outlet, is at elevation 3400; the intake to the left valve, the evacuation outlet, is at elevation 3300. At the downstream ends of both valves, the centerlines are at elevation 3191.38. At the maximum reservoir elevation, 3657.0, the design discharge for each valve is 2,500 second-feet.

The tailwater elevation in the downstream channel is subject to wide variation due to a conservation pool and reregulating system about 6,500 feet downstream from the dam. It is possible that the tailwater elevation will vary as much as 13.8 feet for a discharge of 2,000 second-feet, depending on the operation of the conservation pool.

THE MODEL

The model, built to a geometrical scale of 1:28, included the two hollow-jet valves, the stilling basin, the powerplant afterbay and a section of the excavated channel downstream from the afterbay, Figure 3.

The 84-inch hollow-jet valves were represented by 3-inch model valves machined from brass. The stilling basin was made of wood treated to resist swelling. A plate glass panel was used for the right wall of the stilling basin so that the action of the jet penetrating the pool could be observed. The afterbay area and downstream channel were formed in river sand, so that erosion tendencies could be checked. The river sand had a median diameter of 0.8 millimeter with 90 percent between the No. 8 and No. 200 Tyler Standard Screens.

Water was distributed to the valves through a baffled manifold connected directly to the laboratory supply system. Discharges in the model were measured using calibrated venturi-meters permanently installed in the laboratory. Pressure head at each valve was measured by U-tube mercury manometers connected to a piezometer placed 1 diameter upstream from the valve. Tailwater elevations were controlled by an adjustable tailgate at the downstream end of the model; the tailwater elevation was measured on a staff gage located near the center of the channel about 3 feet upstream from the tailgate.

THE INVESTIGATION

The model investigation was concerned with flow conditions in the stilling basin, the powerplant afterbay and in the channel downstream from the afterbay.

Stilling Basin Studies

The design of the preliminary basin was based on the procedures established in Hydraulics Branch Report No. Hyd-446, "Stilling Basin for High Head Outlet Works Utilizing Hollow-Jet Valve Control." The basin was designed for 2,500 second-feet discharging through each valve at the maximum reservoir elevation. The total head at the valves was computed to be 420 feet at the left valve and 410 feet at the right valve. The preliminary basin, Figure 4, was 120 feet long and 40 feet wide with a 4-foot 4-inch-wide dividing wall along the basin centerline. The floor of the basin was at elevation 3150.0 and the tops of the left training wall and center wall were at elevation 3193.0. The top of the right side wall was at elevation 3203.25. At the upstream end of the basin the floor sloped upward to the valves on a 30° angle. Wedge-shaped blocks converged the width of the upstream part of each compartment of the basin from 17 feet 10 inches at the valves to 4 feet 10 inches at the end of the sloping floor, Figure 4. At the downstream end of the wedges, each compartment abruptly widened to 17 feet 10 inches. A 3-foot-high sill was placed across the downstream end of the basin. The upstream face of the sill was on a 2:1 slope.

Downstream from the basin, the channel sloped upward on a 2-1/2:1 slope to elevation 3168.5. The right side of the downstream channel curved to the left toward the afterbay. The right bank of the channel was on a 1-1/2:1 slope and was riprapped.

Four operating conditions at maximum and minimum tailwaters were used in evaluating the stilling basin performance:

1. Total discharge = 20,000 second-feet.

12,000 second-feet through spillway.
3,000 second-feet through powerhouse.
5,000 second-feet through outlet works.
Tailwater elevations 3188.0 and 3191.3.

2. Total discharge = 12,000 second-feet.

4,000 second-feet through spillway.
3,000 second-feet through powerhouse.
5,000 second-feet through outlet works.
Tailwater elevations 3183.0 and 3190.0.

3. Total discharge = 5,000 second-feet

5,000 second-feet through outlet works.
Tailwater elevations 3177.5 and 3186.0

4. Total discharge = 2,000 second-feet.

2,000 second-feet through outlet works.
Tailwater elevations 3175.0 and 3189.5.

To represent conditions 1, 2, and 3, the outlet works model was operated at a discharge of 5,000 second-feet and the tailwater elevation was set at one of the six values shown. To represent condition 4, the outlet works model was operated at a discharge of 2,000 second-feet and the tailwater elevation was set at one of the two values shown.

Preliminary Basin

The preliminary basin operated satisfactorily for operating conditions 1 and 2 and for the higher tailwater elevation of condition 3. However, when the tailwater was lowered to elevation 3179.0 with condition 3, the hydraulic jump swept from the basin.

To determine how much the basin floor should be lowered to retain the jump at the minimum tailwater elevation, the tailwater was initially set at elevation 3183.0 and lowered in increments of 1 foot until the jump was on the verge of sweeping out. By this method it was determined that the jump remained in the basin for tailwater elevation 3180.0 or above. This elevation was 2.5 feet higher than the minimum tailwater elevation, indicating that the basin floor should be lowered 2.5 feet. A review of the design computations for the basin, substantiated this figure by showing that the width of each compartment of the basin should have been 19.60 feet rather than 17.83 feet for the basin floor and tailwater elevations. The narrower width had been used because it was the maximum allowable due to space restrictions within the powerhouse. The 17.83-foot width is approximately 9 percent less than the theoretical width. If the theoretical sweepout depth of 26.6 feet is increased by 9 percent, the sweepout depth becomes 29.0 feet and allowing a 1.0-foot factor of safety the floor of the basin elevation 3147.5 rather than 3150.0.

Recommended Basin

For the stilling basin, the basin floor was lowered to elevation 3147.5. The 30° slope at the upstream end of the basin was extended to the new floor elevation, Figure 5. The downstream end of the basin was not lengthened; so in effect, the length of the basin was reduced by 4.33 feet. The length of the converging sections along each wall was increased to correspond to the length of the modified sloping floor, but the amount of convergence was not changed. All other dimensions of the basin were the same as those of the preliminary basin. Operation of this basin was very good. For both discharges and at all tailwater elevations, the energy dissipation was excellent. With the maximum discharge and at the minimum tailwater elevation, the hydraulic jump remained in the basin. The jump in the basin was rough but the flow in the downstream channel was very smooth.

Channel Bank Protection

To determine the size of riprap necessary to provide adequate protection against bed scour and channel bank failure, the magnitude of the waves and the flow velocities adjacent to the right bank were determined. Wave heights and flow velocities were measured at four different locations in the channel downstream from the end of the basin. The measuring stations were located about 5 feet (prototype) to the left of the contact line of the water surface and the right bank. Stations 1 through 4 were approximately 36, 82, 117, and 152 feet, respectively, downstream from the end of the stilling basin.

The direction of the surface flow at Station 1 was predominantly upstream due to the return eddy at the end of the basin. The velocity was negligible and very few measurements were made at this station. At the other three stations, measurements were made for the four operating conditions previously described.

With a discharge of 2,000 second-feet, and at both tailwater elevations, the waves were less than 1 foot high and the velocity about 3.5 feet per second at Stations 2 and 3. At Station 4, the wave heights were the same but the velocity increased to about 5.3 feet per second. For a discharge of 5,000 second-feet the maximum wave heights and velocities occurred at the minimum tailwater elevation 3177.5. For this operating condition, the waves were about 2.0 feet high at Station 2 and decreased to 1.3 feet high at Station 4. The velocity was 9.7 feet per second at Station 4. On the basis of these measurements, it was decided that the riprap protection along the right bank should consist of 3-foot rocks.

During operation at the maximum discharge through the outlet works (condition 3) and with the tailwater between elevation 3183.0 and 3188.0, the turbulent action of the flow on the riprapped side slopes downstream from the basin dislodged an occasional stone from the riprap. The roller action of the jump at the end of the basin moved these stones into the basin where they moved back and forth with considerable abrasive action. These pieces of riprap did not move out of the basin until the tailwater was lowered to approximately elevation 3180.0.

Several pieces of the riprap were numbered with paint for identification and placed on the bottom and sides of the channel. The model was operated at the critical conditions, and it was determined that most of the stones that moved into the basin came from the bottom of the channel at the end of the basin, with a few of the stones originating from the right bank of the channel.

To prevent riprap from moving into the basin, it was decided to pave with concrete any part of the upward sloping channel floor that was not excavated in sound rock, and to construct concrete retaining walls on top of the rock along both side slopes, Figure 6. On the right side slope, the retaining wall extended 80 feet downstream from the end of the basin, parallel with the bank. On the left side, the wall extended 50 feet downstream in a straight line. The tops of both walls sloped so that they were 1 foot above the riprap on the left side and 3 feet above the riprap on the right side, Sections C-C and D-D, Figure 6.

With the paved apron and retaining walls in place, no riprap moved into the basin at any discharge-tailwater combination. The retaining walls on the right side also served to reduce the intensity of the waves striking the right bank. The maximum height of the waves was approximately the same, but the frequency was reduced about 50 percent. On the basis of the reduced frequency and intensity of the waves, it was recommended that the size of the riprap be reduced to 2-foot rocks.

The performance of the recommended basin with the addition of the retaining walls in the downstream channel was excellent at all discharge-tailwater combinations, and the appearance of the flow in the powerplant afterbay and downstream channel was very good, Figures 7 and 8.

Unsymmetrical Operation

With one valve operating at maximum capacity (2,500 second-feet) and with minimum tailwater elevation 3175.5, the toe of the jump moved downstream onto the horizontal floor, Figure 9. The jump did not sweep from the basin, but extreme turbulence and considerable wave action occurred downstream from the basin; the turbulence was greater when the left valve was operating, but there was no damage to the side slopes of the downstream channel with single operation of either valve.

When the tailwater elevation was raised to 3177.0, or when the discharge was reduced to 2,000 second-feet, the jump moved upstream onto the chute and the excessive turbulence and large waves in the downstream channel were eliminated.

Stilling Basin Training Walls

When it is necessary to unwater the stilling basin for any reason, it is usually accomplished by closing the downstream end of the basin with stop logs and pumping out the water. Structural investigations disclosed that the center and left gravity walls in the stilling basin with their tops at elevation 3193 would not withstand the pressure differential if the basin were unwatered with tailwater elevation 3189.6, the maximum tailwater with the powerplant in operation and no flow through the spillway.

To determine what effect lowering these walls would have on the stilling basin performance and in the powerplant afterbay, the top of the center wall was lowered to elevation 3186.0 and the top of the left wall to elevation 3187.0.

For the maximum discharge with tailwater elevation 3191.3, water spilled from the powerhouse tailrace into the left side of the upstream end of the basin. Farther downstream in the basin, a boil formed which spilled water from the basin into the tailrace, resulting in waves of 2 to 2.5 feet in height, Figure 10A. For lower tailwater elevations, this objectionable action was somewhat reduced. When the left wall was raised to elevation 3190.0, this objectionable action was eliminated even at the higher tailwater, Figure 10B. The top of the center wall was kept at elevation 3186.0, which made it impossible to unwater the basin when the tailwater was above this elevation.

Wave measurements were obtained in the center of the tailrace at points 15 feet and about 100 feet downstream from the powerplant. Measurements were made with the maximum discharge through the outlet works and tailwater elevations 3188.0 and 3191.3. The wave heights have been related to the height of the left wall, Figure 11. The tests indicated that the waves near the powerplant would be 2.6 feet high at high tailwater and 1.8 feet high at low tailwater when the top of the wall was at elevation 3187.0. With the top of the wall at elevation 3190.0, the waves were reduced to 2.2 and 1.5 feet high, respectively. With the top of the wall at elevation 3193.0, the wave heights were 2.0 and 1.3 feet, respectively. At the downstream station, the waves with both tailwater elevations were about 1.7 feet high for the low wall and about 1.5 feet high when the top of the wall was at either of the other two elevations.

Although the wave heights increased slightly as the top of the left training wall was lowered, it was recommended that the top of the left wall should be at elevation 3190.0. The top of the center wall may be lowered to elevation 3186.0.

After the model studies had been completed, it was determined that to provide structural stability it would be necessary to place a roof across the top of the stilling basin to tie the center and side walls together. Although this modification was not tested in the model, it was approved on the basis that the invert of the roof be placed at or above elevation 3194.0, 2.7 feet above the maximum tailwater.

FIGURE 1
REPORT HYD. 482

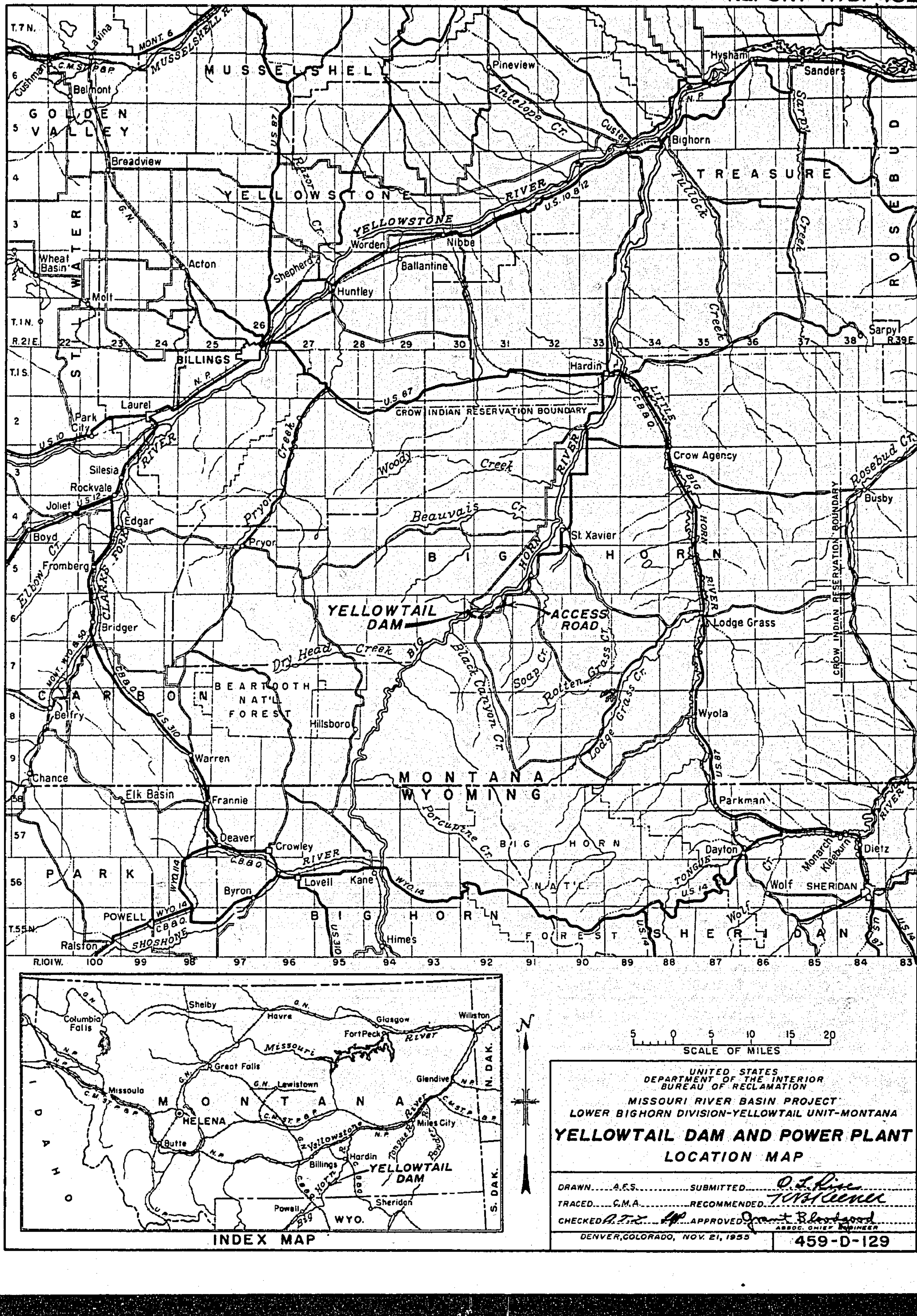
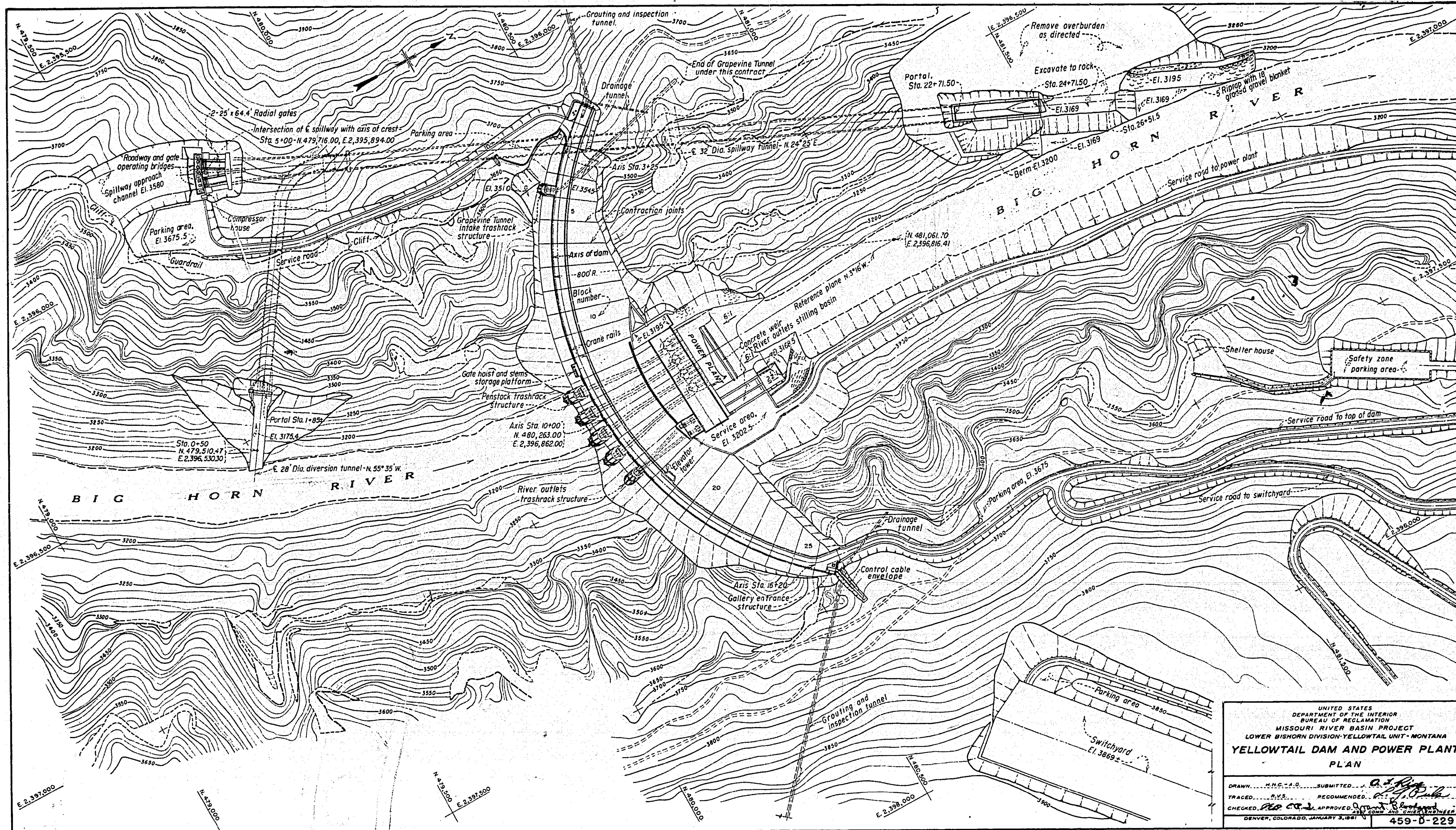
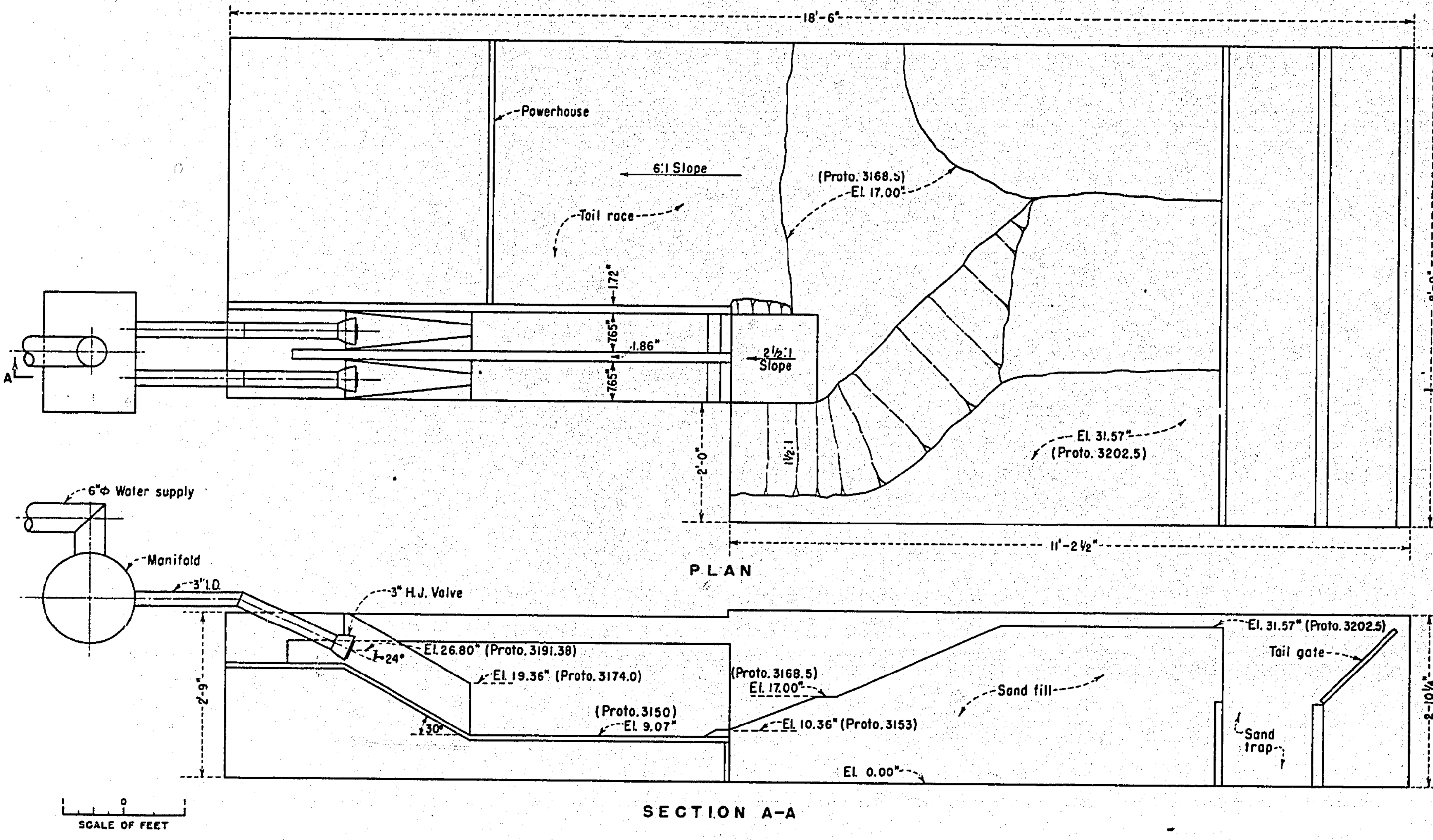


FIGURE 2
REPORT HYD. 482



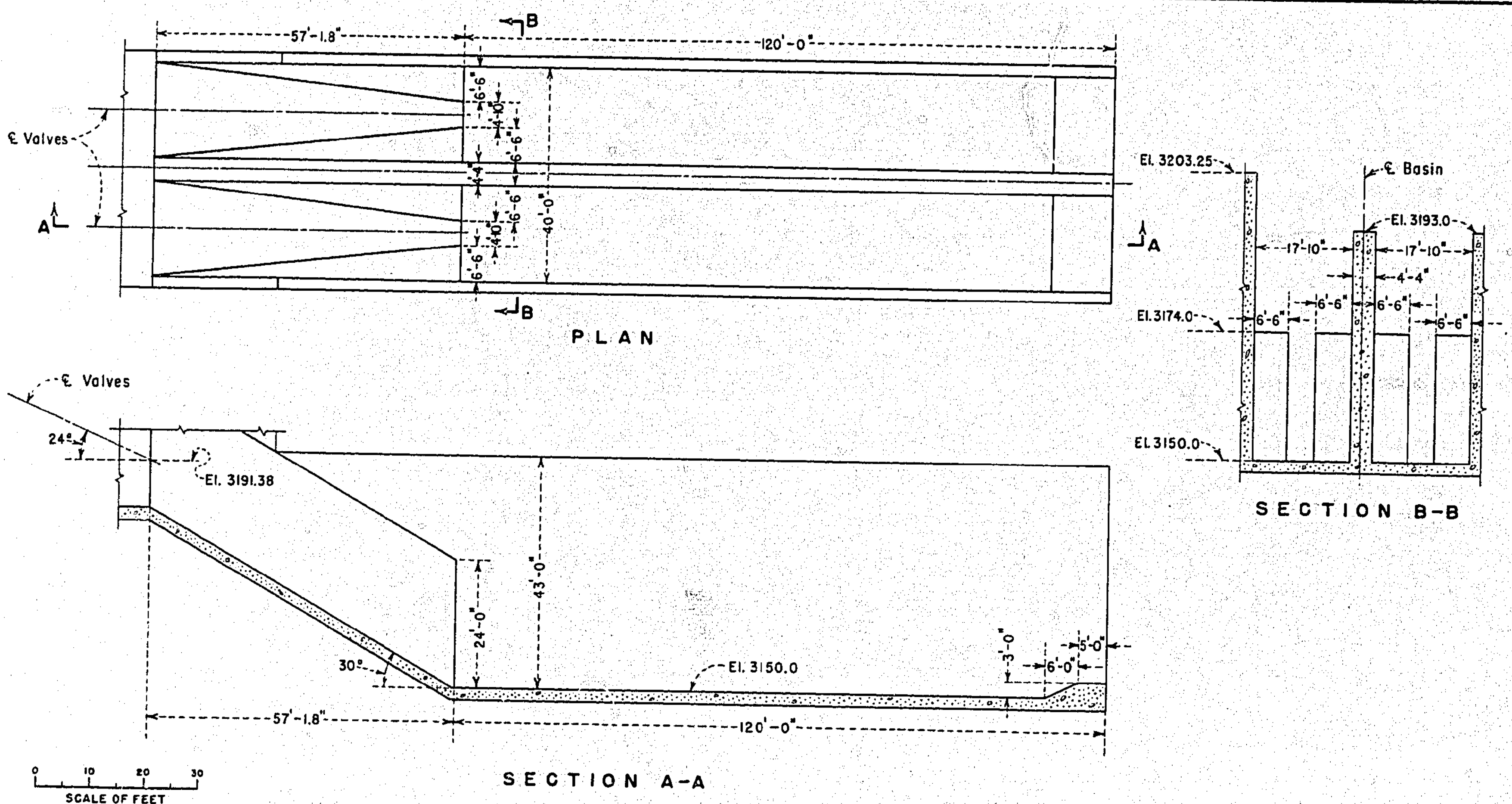


YELLOWTAIL DAM RIVER OUTLETS

1:28 SCALE MODEL STUDIES

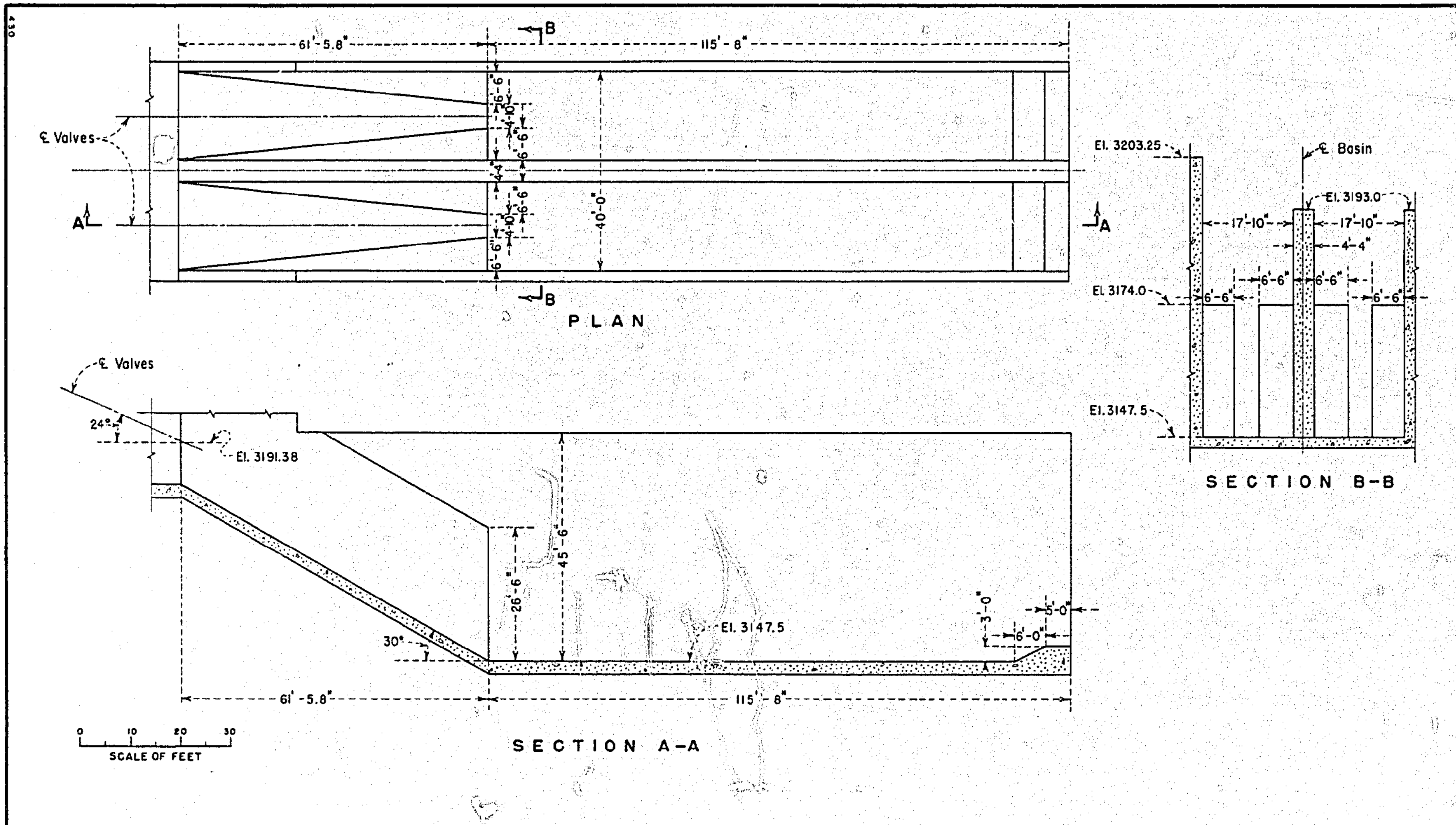
MODEL LAYOUT

FIGURE 3
REPORT HYD. 482



YELLOWTAIL DAM RIVER OUTLETS
1:28 SCALE MODEL STUDIES
PRELIMINARY STILLING BASIN

FIGURE 4
REPORT HYD 482



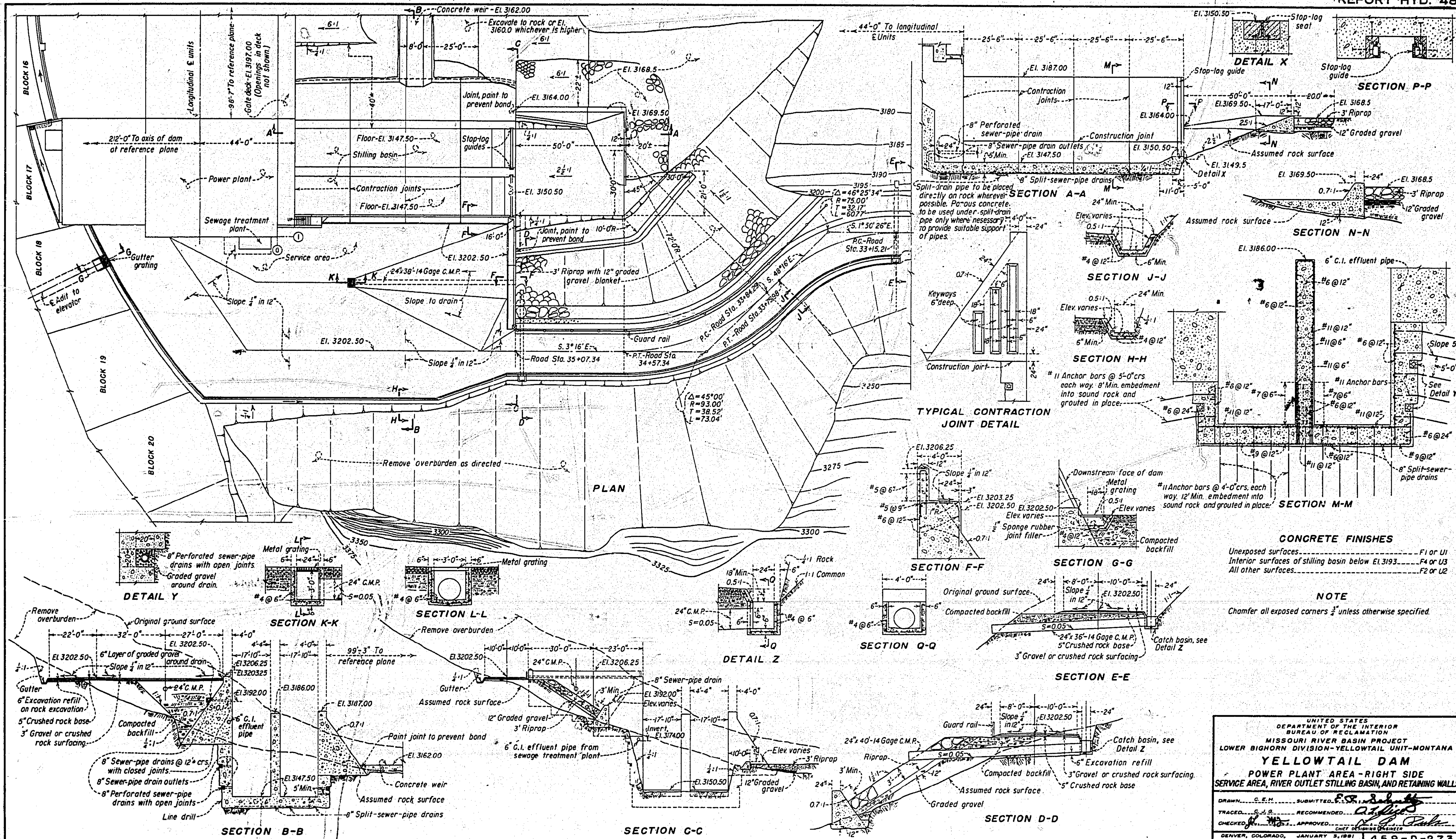
YELLOWTAIL DAM RIVER OUTLETS

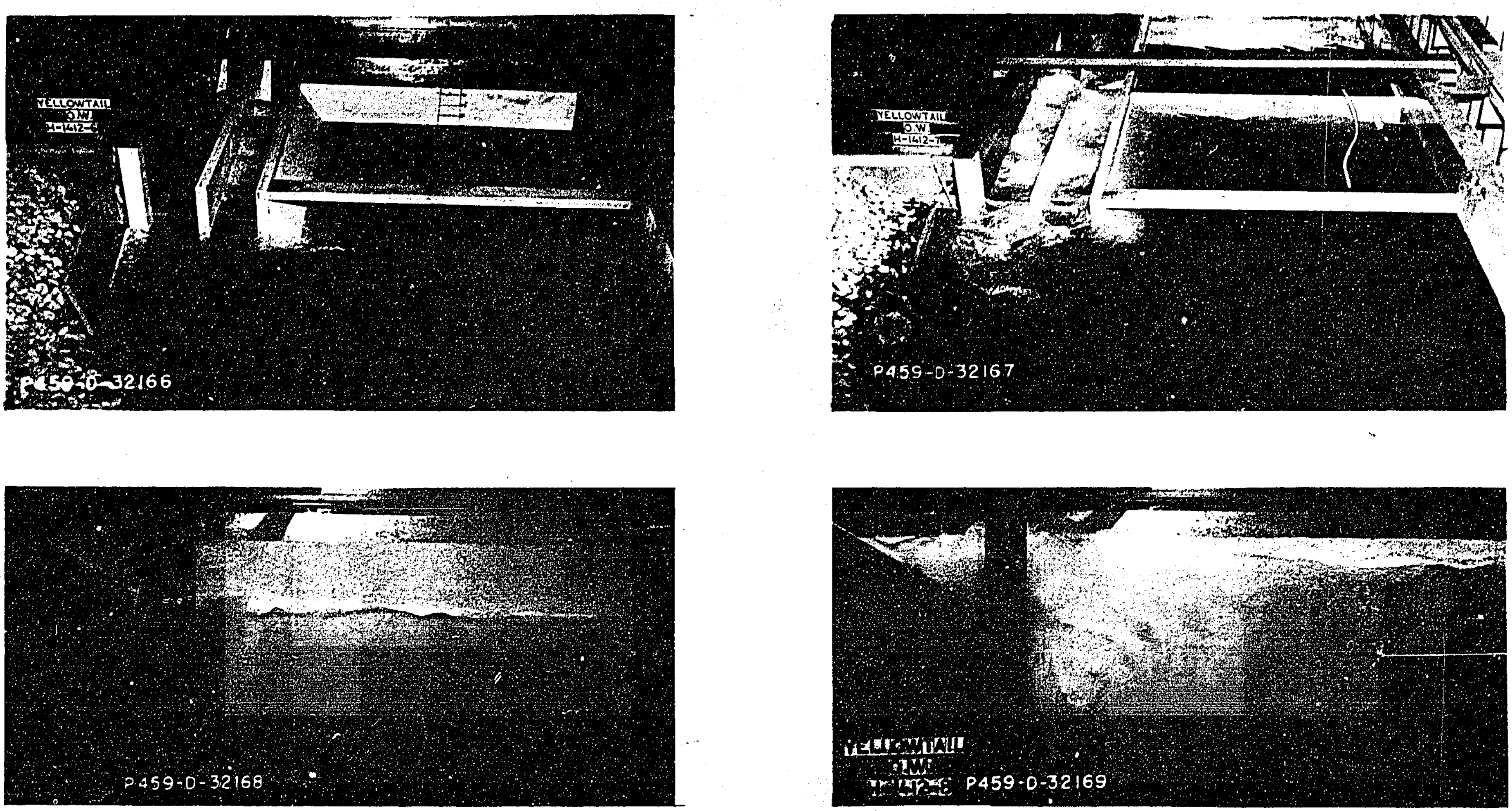
1:28 SCALE MODEL STUDIES

RECOMMENDED STILLING BASIN

FIGURE 5
REPORT HYD 482

FIGURE 6
REPORT HYD. 482

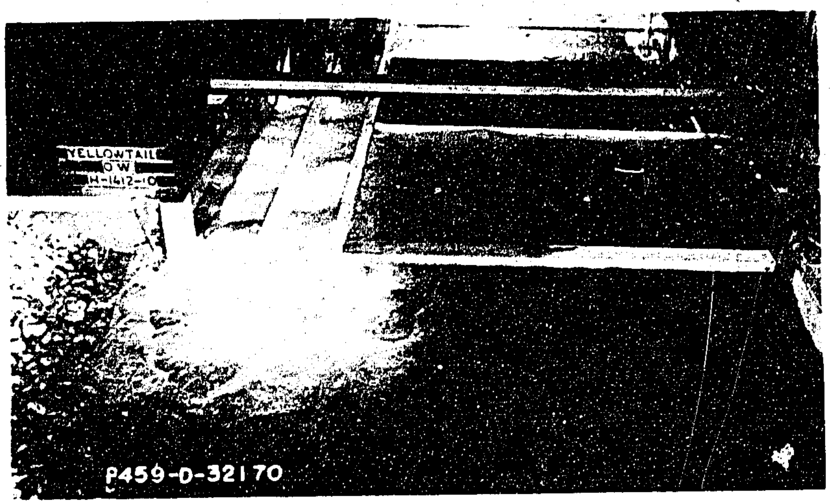


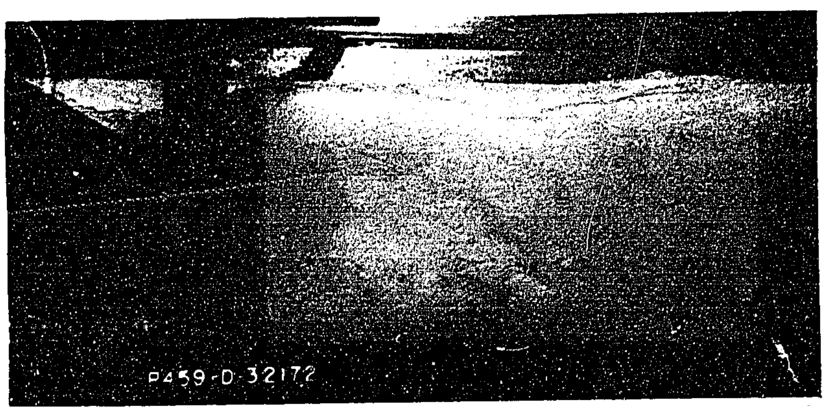


T. W. Elev. 3175.0

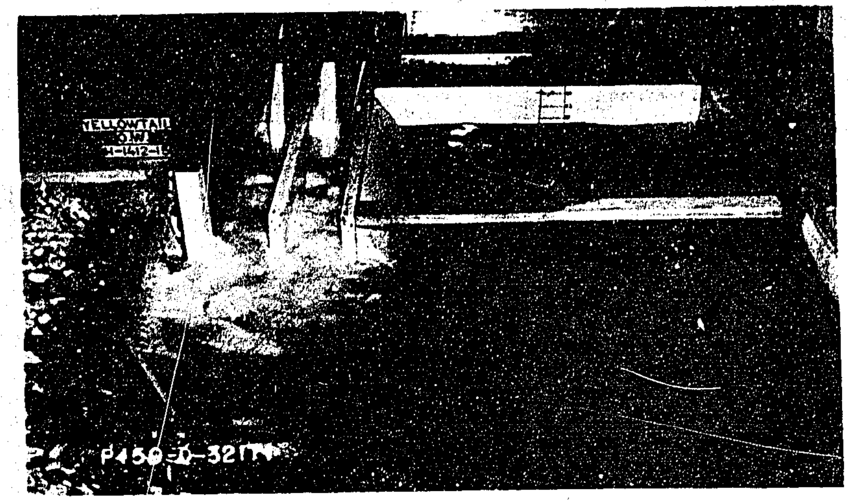
T. W. Elev. 3189.5

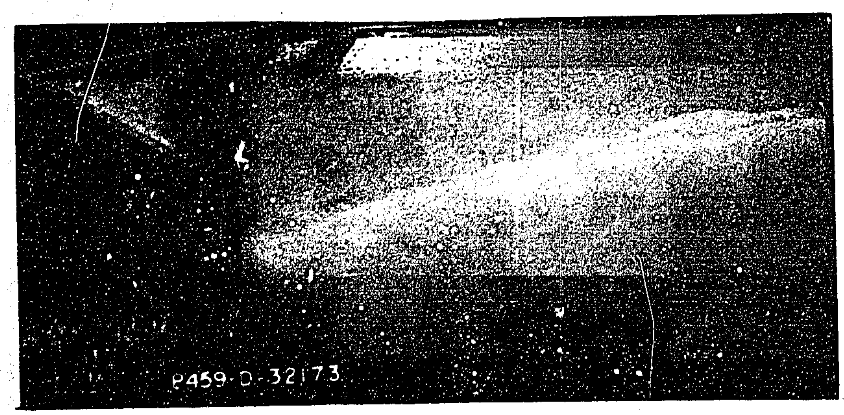
YELLOWTAIL DAM RIVER OUTLETS
1:28 Scale Model
Recommended Stilling Basin
Operation at low discharge (2,000 cfs)
(No flow through spillway or powerplant)





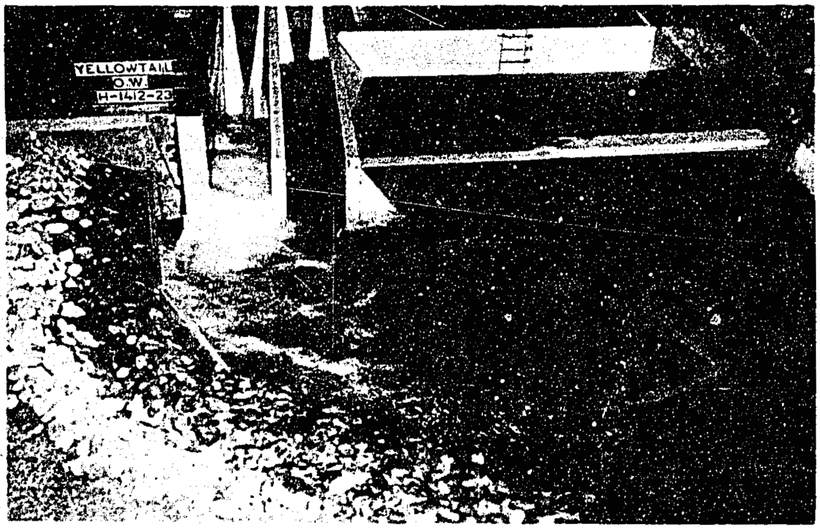
Maximum T. W. Elev. 3191.3 (3,000 cfs through powerplant and 12,000 through spillway)

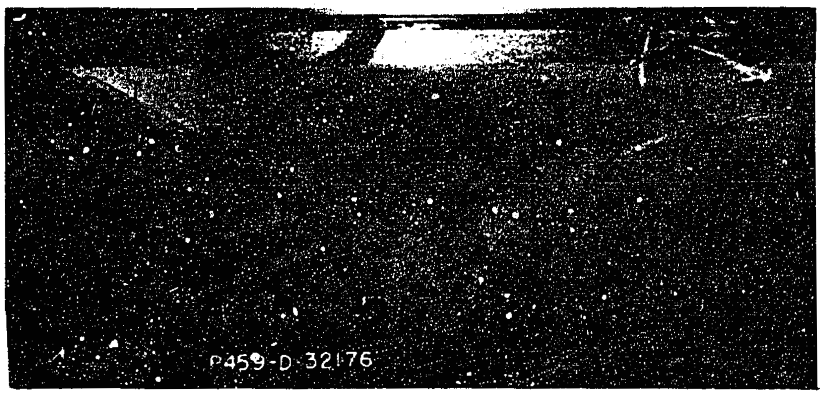




Minimum T. W. Elev. 3177.5 (No flow through spillway or powerplant)

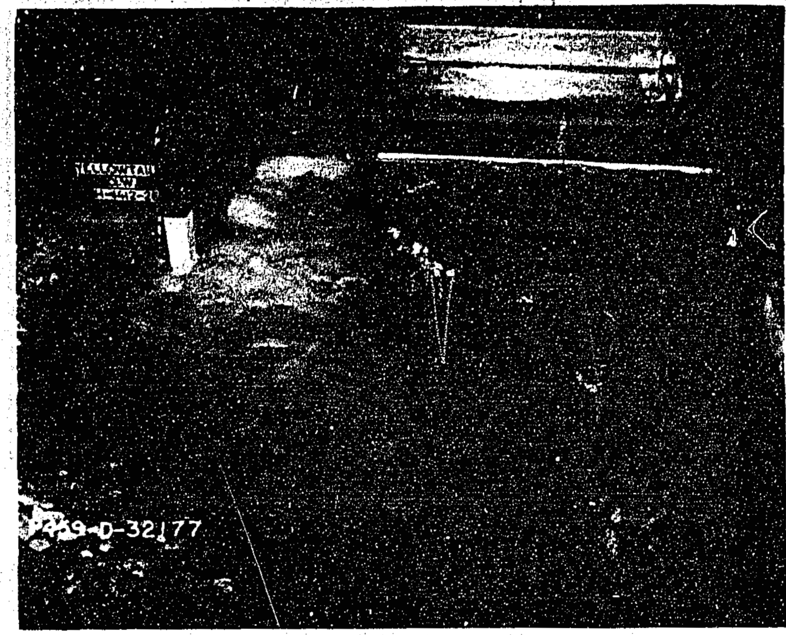
YELLOWTAIL DAM RIVER OUTLETS
1:28 Scale Model
Recommended Stilling Basin
Operation at maximum discharge (5,000 cfs)
through outlet works



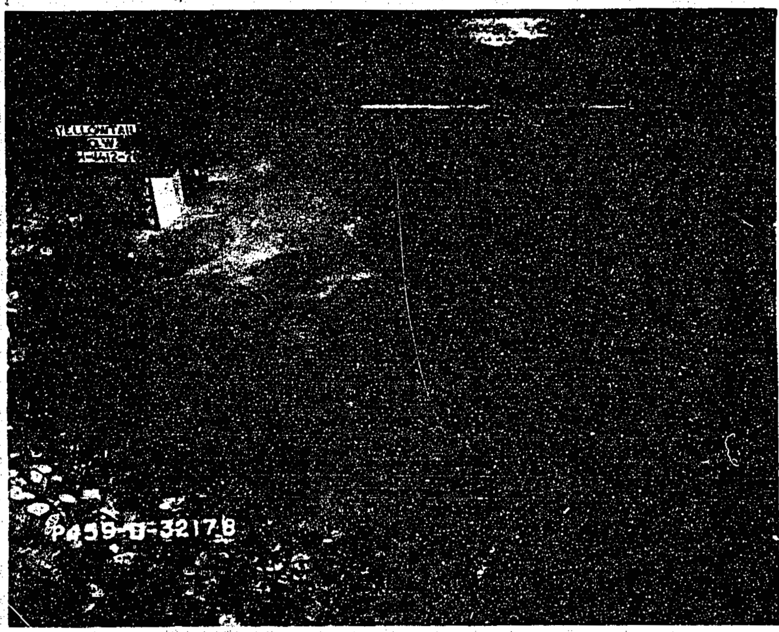


Discharge = 2, 500 cfs   T. W. Elev. = 3175. 5

YELLOWTAIL DAM RIVER OUTLETS
1:28 Scale Model
Recommended Stilling Basin
Unsymmetrical operation
No flow in powerplant or spillway



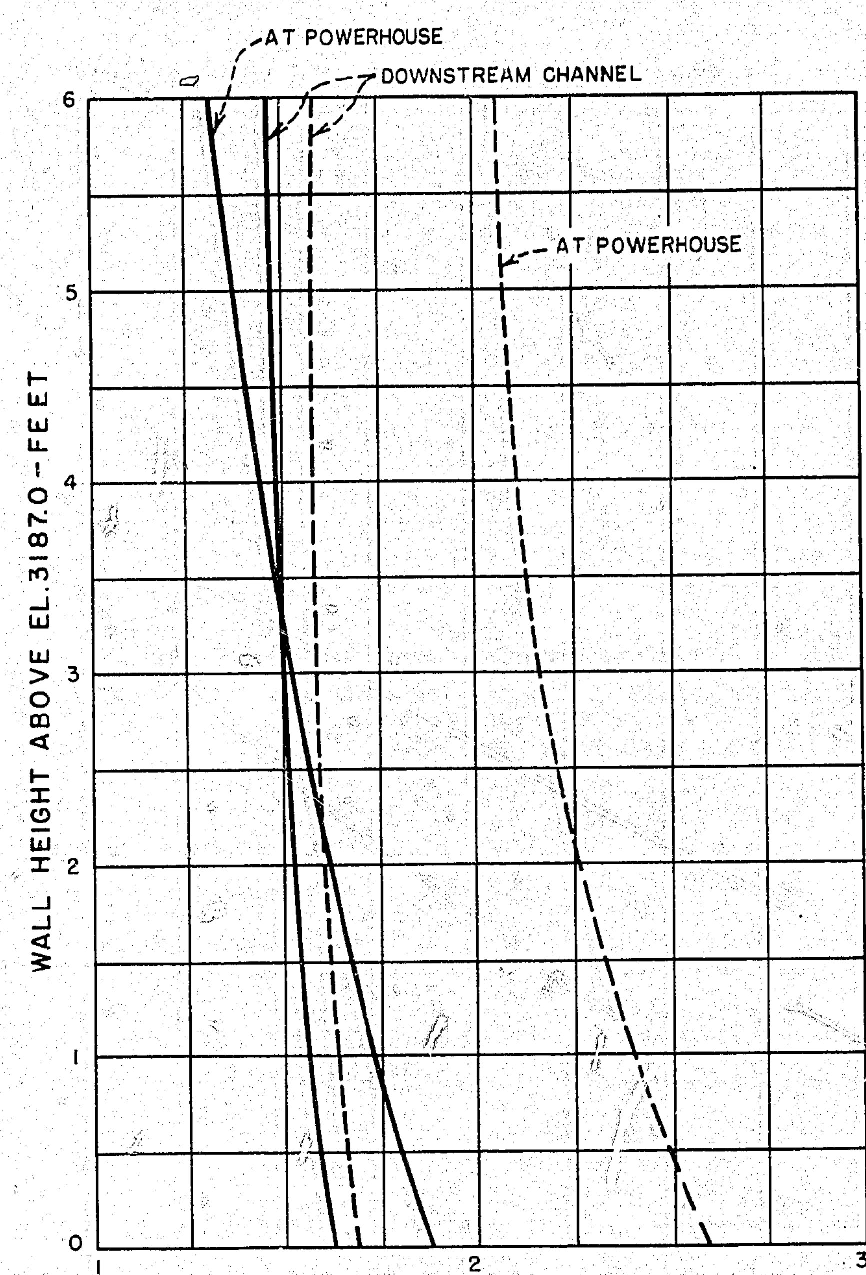
A. Top of left wall at elev. 3187.0
Top of center wall at elev. 3186.0



B. Top of left wall at elev. 3190.0
Top of center wall at elev. 3186.0

Discharge = 5,000 cfs
T. W. Elev. = 3191.3

YELLOWTAIL DAM RIVER OUTLETS
1:28 Scale Model
Flow conditions with different
training wall heights



NOTES

DISCHARGE = 2500 CFS EACH VALVE

– – – – – = T.W. EL. 3191.3

————— = T.W. EL. 3188.0

YELLOWTAIL DAM RIVER OUTLETS

1:28 SCALE MODEL STUDIES

TRAINING WALL STUDIES

WAVE HEIGHTS VS. WALL HEIGHTS