UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE SLUICEWAY AND OVERFLOW WEIR--YELLOWTAIL AFTERBAY DAM MISSOURI RIVER BASIN PROJECT, MONTANA

Report No. Hyd-523

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

April 1, 1965

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ABSTRACT

Model studies to develop hydraulic design of the sluiceway and overflow weir for Yellowtail Afterbay Dam indicated the most efficient energy dissipators for each. The sluiceway has three 10-ft-wide bays separated by 2-ft tapered piers with the flow controlled by 10- by 8-ft slide gates and energy dissipated by a hydraulic jump stilling basin. It is designed for a 4,500-cfs maximum discharge. The overflow weir includes five 30-ft-wide bays separated alternately by 4- and 2-ft piers with a maximum design discharge of 15,500 cfs. Discharge is controlled by five 30- by 13.5-ft radial gates and energy dissipated by a stilling basin. Two types of energy dissipators were investigated for each structure. For the sluiceway either a hydraulic jump basin with chute blocks and a dentated end sill (Type II basin) or a basin with chute blocks, baffle piers, and a solid end sill (Type III) would be satisfactory. Since an abutment wall forms one side of the stilling basin, it was decided to extend the apron and use the Type II basin. For the overflow weir the studies showed that a slotted bucket type energy dissipator was not satisfactory but that a Type III basin should be used. The recommended basins for both structures provided excellent energy dissipation with minor wave action and channel bed erosion. Discharge capacity and coefficient curves were prepared for both structures.

DESCRIPTORS--dentated sills/ spillways/ *stilling basins/ piers/ hydraulic jumps/ wave action/ discharge coefficients/ discharge measurement/ spillway crests/ Froude number/ hydraulic models/ hydraulic similitude/ riprap/ flow control/ turbulent flow/ training walls/ research and development/ baffles/ laboratory tests/ *energy dissipation/ *weirs/ hydraulics/ aprons/ slide gates/ model tests/ stream erosion

IDENTIFIERS--chute blocks/ sweepout/ hydraulic design/ Yellowtail Afterbay Dam/ Missouri River Basin Proj/ *sluiceways/ *slotted buckets/

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Office of Chief Engineer
Division of Research
Hydraulics Branch
Denver, Colorado
April 1, 1965

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HYDRAULIC MODEL STUDIES OF THE SLUICEWAY AND OVERFLOW WEIR--YELLOWTAIL AFTERBAY DAM MISSOURI RIVER BASIN PROJECT, MONTANA

PURPOSE

The purpose of the study was to determine the hydraulic operating characteristics of the afterbay dam sluiceway and overflow weir and to develop satisfactory stilling basins for both structures.

CONCLUSIONS

Sluiceway

1. Flow conditions in the approach, through the Type II stilling basin, and in the downstream channel were satisfactory for all discharges with all gates fully open and for maximum discharge with the gates controlling and for both low and high tailwater elevations (Figure 7).

2. The best flow conditions were with symmetrical gate operation. Unsymmetrical gate operation should be avoided.

3. During the operation of the Type II stilling basin the finer material of the downstream riverbed eroded; however, the riprap and other larger material did not move.

4. With the maximum discharge, all riverbed material that had been placed in the basin was flushed from the basin.

5. The best stilling basin operation was obtained when the piers were terminated at the chute blocks rather than extended downstream into the basin.

6. Although slightly more wave action occurred in the downstream channel, the Type III stilling basin produced nearly as efficient operation as the Type II basin (Figures 7 and 9).

7. The maximum design discharge of 4,500 cfs (cubic feet per second) was obtained at reservoir elevation 3172.5 with the gates fully open.

8. The coefficient of discharge at reservoir water surface elevation 3172.5 was 0.69 (Figure 10).

Overflow Weir

1. The slotted bucket energy dissipator caused extensive erosion of downstream bed material and riprap under all operating conditions with all modifications of dentates and end sill that were tested (Figures 16 and 18).

2. Tailwater sweepout from the bucket was possible under anticipated prototype operating conditions.

3. The best operating bucket had 12-inch spaces between dentates and a 26° end sill rise. This arrangement produced relatively minor movement of the riprap, but caused extensive water surface waves (Figure 17B).

4. Operation with a Type III stilling basin was excellent. Riverbed erosion and riprap movement was negligible. The downstream water surface was very smooth (Figure 19).

5. Riverbed material deposited within the basin was flushed out by flows near the maximum discharge.

6. The discharge at reservoir elevation 3189.5 was 17,000 cfs, or 1,500 cfs greater than the design value (Figure 21).

7. The coefficient of discharge at reservoir elevation 3189.5 was 3.60 for the sloping face.

8. Either a vertical or sloping upstream face on the weir (Figure 21) produced essentially the same coefficient of discharge.

ACKNOWLEDGMENT

The model studies were accomplished through the cooperation of the Concrete Dams Section of the Dams Branch, Division of Design, and the Hydraulics Branch, Division of Research. Model photography was by W. M. Batts, Office Services Branch.

METRIC EQUIVALENTS

A summary of metric equivalents of important quantities used in this report is included as Table 1.

INTRODUCTION

Yellowtail Afterbay Dam, located at Lime Kiln site on the Big Horn River about 2-1/4 miles downstream from Yellowtail Dam (Figure 1), is a feature of the Yellowtail Unit, Lower Big Horn Division of the Missouri River Basin Project. The structure is a concrete diversion-type dam with earth dikes at either end, rising about 50 feet above the riverbed (Figure 2). The dam includes a sluiceway, overflow weir, canal headworks, and walls for retaining the earth dikes. The total length of the dam, including the earth dikes, is 1,400 feet. The primary function of the afterbay dam is to maintain relatively uniform flows in the Big Horn River, on a daily basis at least, in order that existing downstream canals diverting from the river can continue to divert without major overhaul of existing diversion structures. The sluiceway (Figure 3) consists of three 10-foot-wide bays separated by tapered piers which are 2 feet 2 inches wide at the crest. The flow is controlled by 10- by 8-foot slide gates and the energy is dissipated by a hydraulic jump stilling basin.

The overflow weir includes five 30-foot-wide bays separated alternately by 4- and 2-foot-wide piers (Figure 12). The discharge is controlled by five 30- by 13.5-foot radial gates and energy dissipation is provided by a stilling basin.

The sluiceway is designed to carry a maximum discharge of 4,500 cfs and the overflow weir is designed for a maximum of 15,500 cfs.

During normal operation the reservoir water surface will fluctuate between elevations 3192 and 3175. It is anticipated that for flows above 10,000 cfs, the flow through the afterbay reservoir will be steady because the outlets, powerplant, and spillway at Yellowtail Dam will regulate the inflow. It is estimated that the afterbay reservoir will lower to elevation 3189.50 for the maximum design flood of 20,000 cfs (safe channel capacity). The sluiceway of the afterbay dam will operate continuously during the irrigation season; the overflow weir will operate intermittently.

THE MODELS

Two separate models were constructed consecutively in a glass-sided test flume (Figure 4). The first was a 1:24 scale model of the complete sluiceway, including slide gates, piers, stilling basin, about 60 feet of the reservoir, and 100 feet of downstream river channel (Figure 5). The model was built entirely of wood. The riverbed downstream from the sluiceway stilling basin was shaped with a mixture of sand, passed through a No. 20 sieve, and rock having a 3/4-inch average diameter.

The second model was a 1:24 scale sectional model of the overflow weir. It included two of the five bays, one 4-foot-wide intermediate pier, stilling basin, about 60 feet of the reservoir, and 100 feet of the downstream river channel. The radial gates were not included in the model. The two bays adjacent to the sluiceway were modeled because of the irregular downstream riverbed topography in this area (Figure 14); however, other bays were also simulated for some tests by altering this topography. This model was also built of wood except for the overflow weir surface which was galvanized sheet metal.

Water was supplied to the model from the permanent laboratory system and measured by volumetrically calibrated Venturi meters. The water passed through a rock baffle to quiet the turbulence. The tailwater was controlled by an adjustable tailgate.

THE INVESTIGATION

Good, efficient energy dissipators were required for both the sluiceway and spillway structures. Since riprap was to be placed downstream from the basins, it was imperative that the flow in this region be quieted so that no erosion or excessive movement of the riprap would occur. Several stilling basin designs were tested to obtain the most efficient and economical structures.

THE SLUICEWAY

Stilling Basin Investigations

The effectiveness of the stilling basin was based on the efficiency of energy dissipation within the basin as shown by visual observation of the turbulence in the jump, the location of the hydraulic jump, the downstream water surface roughness, and the streambed erosion and riprap movement which was the most important criterion. Three operating conditions were tested to evaluate the stilling basin: The first condition was with three gates fully open discharging 4,500 cfs at reservoir elevation 3174.5, and tailwater elevation 3161.5 (Figure 7); the second condition was with all three gates 63 percent open to hold the discharge to 4,500 cfs at reservoir elevation 3189.5 with tailwater elevation 3161.5; for the third condition, the discharge was also 4,500 cfs through gates open 63 percent, but the tailwater elevation was 3165.5, which assumed maximum discharge of 15,500 cfs from the spillway (Figure 6).

Preliminary Basin (Type II).--The preliminary design included a Type II hydraulic jump stilling basin. 1/ The basin was 85 feet long, contained chute blocks and a dentated end sill, and accommodated flow from all three bays. The dividing piers terminated 1 foot 10-3/4 inches downstream from the chute blocks (Figure 3).

The Type II stilling basin operated satisfactorily for flows up to and including the maximum discharge of 4,500 cfs operating under the three test conditions.

Flow downstream from the gates was smooth and well distributed across the entire width of each bay. The hydraulic jump was confined within the basin and velocities at the downstream end of the basin were low. The water surface downstream from the basin was very smooth with waves not exceeding 2 feet in height. Flow appearance was best with the first test condition. The jump was well upstream and the downstream water surface was very smooth (Figure 7A). The higher flow velocity of the second test condition moved the jump downstream, causing a higher velocity over the end sill and a rough water surface downstream from the jump (Figure 7B). The high tailwater of the third test condition moved the jump back upstream and reduced the downstream velocity (Figure 7C). There was no noticeable riverbed erosion or riprap movement at the downstream end of the basin for any of the test conditions.

Riprap material was placed in the operating basin to determine if it would sweep out or circulate within the basin and possibly damage the concrete surfaces. At maximum flow all of this material was flushed from the basin.

The model also was tested with the center bay only discharging 1,500 cfs (no flow through the outside bays), and the two outside bays discharging 1,500 cfs each at equal gate openings and no flow through the center bay. This type of operation caused some riverbed and riprap material to be drawn upstream into the inoperative bays.

The model was also tested with the piers extended 25 feet downstream from the end of the chute blocks. Although the pier extensions made very little difference for three-gate operation (Figure 8), they greatly worsened flow conditions with one- and two-gate operation. A discharge of 1,500 cfs through the center gate only produced a return current upstream along the sides of the basin and carried riprap material,

1/ "Hydraulic Design of Stilling Basins and Energy Dissipators," Engineering Monograph No. 25, U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, 1963, pp. 19-31.

as large as 2 feet in diameter, from the river channel upstream along the sides of the basin into the center flow and hurled it against the dentated end sill. With the preliminary (shorter) piers, the flow spread over the basin and greatly reduced the return flow. Thus, the preliminary dividing piers are recommended.

The Type III Basin. --Although the Type II basin provided entirely satisfactory energy dissipation, it was considered possible that this was an overconservative design. Therefore, a Type III basin, 1/ which would be less expensive to construct, was tested. The Type III basin utilizes chute blocks, baffle piers, and a solid end sill. With these appurtenances, the hydraulic jump occurs farther upstream and allows the use of a basin about 40 percent shorter than the Type II basin. The baffle piers, located about one-third of the basin length downstream from the chute blocks, are in a region of high velocity flow.

The same criteria used in testing the Type II basin was used to evaluate the Type III basin. The basin operation was nearly as efficient as the Type II basin (Figure 9). There was slightly more wave action in the downstream channel, with the waves averaging about 2 to 4 feet in height, and a small amount of erosion occurred near the basin end sill. The 25-foot pier extensions were also tested in the Type III basin. The longer piers did not affect the flow during three-gate operation but caused very poor flow conditions during one- and two-gate operation. Either basin would provide satisfactory hydraulic operation. However, design considerations called for the abutment wall of the sluiceway to be extended downstream to contain the earthfill of the dike. Since this wall also formed one side of the stilling basin, it was decided to extend the apron and use the Type II stilling basin.

Discharge Capacity

Discharge capacity and coefficient of discharge curves for the sluiceway were obtained with the model. The discharge coefficient curve, for operation with the gates fully opened with varying operating heads, is shown in Figure 10. The coefficient of discharge obtained at reservoir water surface elevation 3172.5 was about 0.69. Discharge curves for gate openings from 1 foot to fully open are shown in Figure 11. These curves should be used with reservation since the model was equipped with flat plates as slide gates rather than true representations of the prototype gates. The maximum design discharge of 4,500 cfs was obtained at reservoir elevation 3172.5, with the gates fully open.

1/Ibid pp. 33-41.

The Overflow Weir

The efficiency and flow conditions of the overflow weir and stilling basin were evaluated by tests similar to those used for the sluiceway. No gates were included in the model; thus, all tests were run with free flow over the weir. Principally, the maximum discharge through both bays, simulating maximum discharge of 15,500 cfs through all five bays, was used for the tests.

Stilling Basin Investigations

Erosion in the downstream channel was the principal criterion used in evaluating the energy dissipator and most of the overflow weir tests were made to determine the amount of riprap movement and riverbed erosion. Usually the duration of the erosion tests was 35 minutes (3-hour prototype). Although most of the tests were with maximum discharge, flows equivalent to 50 and 25 percent of maximum were also observed. Single bay operation at maximum discharge per bay was also observed. The effect of the tailwater elevation on erosion was also determined.

Preliminary Energy Dissipator.--The preliminary energy dissipator was a slotted bucket[1/] (Figure 13). The bucket had a 12-foot radius with dentates just ahead of a 16° upward sloping apron. The initial design specified 6-inch spaces between 18-inch-wide dentates. The riverbed downstream from the bucket was arranged to represent the two spillway bays adjacent to the sluiceway (Figure 14).

The preliminary bucket showed generally poor operation with rough water surface and excessive riverbed erosion. The flow was deflected upward by the dentates resulting in a high boil over the dentates, a counterclockwise roll upstream from the dentates, and a clockwise roll downstream from the dentates (Figure 15A). The clockwise roll caused a reverse flow along the channel bottom and picked up rock material and hurled it against the apron lip. The high boil caused considerable turbulence and wave action downstream from the basin. Waves were 8 feet high at the end of the pier and decreased to heights of 4 feet, at a point 35 feet downstream from the piers. Erosion was severe and resulted in the riverbed being lowered to nearly basin floor level (Figure 16B).

Sweepout of the basin at maximum discharge occurred when the tailwater was lowered 3.5 feet to about elevation 3162. Also, a 3,100-cfs discharge through one bay with no flow in the other bay produced sweepout at normal tailwater elevations. This test indicated that sweepout could easily occur when larger flows were passed through only one or

1/Ibid pp. 91-125.

two bays. As this was a possible operating condition, sweepout at these flows could not be permitted. None of the subsequent modifications to the end sill angle or tooth spacing in the bucket reduced this sweepout tendency.

Since the clockwise roll was carrying bed material against the apron lip, this tendency possibly could be eliminated if the angle at which the flow left the bucket was decreased. This design was accomplished by removing every other dentate, which left 30-inch spaces between dentates and seven dentates per bay, and allowed a greater part of the flow to leave the bucket at a flatter angle. At maximum discharge, the roll actually reversed to a strong counterclockwise direction and caused excessive flow velocity along the channel bottom downstream from the bucket. The riverbed erosion was unchanged except for a more deeply scoured area about 40 feet downstream from the basin (Figure 16C). The water surface was slightly smoother than before. Waves were 4 feet high at the downstream end of the pier and 5 feet high about 35 feet farther downstream from the piers.

In an attempt to improve the energy dissipation and reduce the wave heights, 2 more arrangements were tested. The number of dentates was increased to 10 per bay with 18-inch spaces between each dentate for the second arrangement. The third test arrangement was with 12 dentates per bay with 12-inch spaces (Figure 17A). Either arrangement reduced the size of both the clockwise and counterclockwise rolls. However, the high velocity flow continued to sweep along the bottom and caused excessive movement and erosion of riverbed and riprap material with the second arrangement. The third arrangement created an unstable condition when some of the flow shifted from one direction of roll to the other.

Generally through all of these tests the conditions which produced the least movement and erosion of riverbed and riprap material produced the greatest water surface roughness. Alterations to the dentate spacing apparently could not be made to appreciably reduce riverbed erosion.

A series of tests was made to determine the effect of different angles of rise of the bucket apron downstream from the dentates. The initial design had a rise of 16°; wedge blocks were added to this apron to create 22°, 24°, 26°, and 30° angles of rise. The third dentate arrangement of 12 dentates with 12-inch spaces between dentates was used throughout this series of tests. This arrangement was used because it produced the best compromise between riverbed erosion and water surface roughness.

The flow from the basin was deflected upward by the increased apron angles. The 22° and 24° rises did not greatly change the flow conditions and the riverbed erosion remained severe. The direction of roll was predominantly counterclockwise. The 26° apron rise greatly reduced the erosion but roughened the water surface. The main body of the flow from the bucket was deflected away from the bottom and only a small clockwise roll developed downstream from the apron lip. However, the flow left the bucket at too flat an angle to cause a very large counterclockwise roll but instead emerged as a rough water surface with considerable wave action. The 30° apron deflected the flow high enough to again split the flow into clockwise and counter-clockwise rolls (somewhat like the initial basin) and bed material was drawn up against the apron lip.

The 26° apron produced the best flow conditions; therefore it was tested more extensively. Although riverbed erosion had been reduced, the finer material still eroded rapidly and a gradual movement of the riprap and larger riverbed material persisted. A 2-hour (prototype) erosion test with this arrangement was first performed with the riverbed arranged to simulate Bays 4 and 5 adjacent to the sluiceway (Figure 18A). The flow currents first moved the finer riverbed material down the slope into the depression adjacent to the sluiceway wall. Some of this material was then carried upstream and deposited in a windrow 20 feet downstream from the bucket of Bay 5. This movement of the finer material allowed the large riprap to roll down the slope into the depression (Figure 18B). No movement of the riprap, however, could be seen in the foreground.

This erosion test was repeated with the riverbed arranged to represent any adjacent pair of Bays 1 through 4. The 4-foot-deep riprap bed which extended on a 6:1 slope for 35 feet downstream from the basin was formed from 1/2- to 1-foot-diameter rock with about 25 percent 1- to 2-foot-diameter rock (prototype). A 1-foot-thick gravel bedding was also represented in the model. During this test the gravel bedding remained stable; the finer surface material eroded out rapidly and the riprap and other large material in the riverbed was left. After this erosion process stabilized, a vigorous movement of the surface riprap continued. Since a stable bed was necessary, this riverbed movement was considered intolerable.

Type III Basin, Recommended.--The slotted bucket energy dissipator was abandoned at this time and a Type III stilling basin was constructed in its place. This basin was 42 feet long and included chute blocks, baffle piers, and a solid end sill (Figure 12).

The Type III hydraulic jump stilling basin operated satisfactorily for all flows up to and including the maximum discharge (3,100 cfs per bay). The flow was very smooth and well distributed across the entire width of the downstream riverbed with very little wave action for all discharges and all tailwater settings (Figure 19).

The hydraulic jump was confined within the basin and velocities leaving the basin were relatively uniform. Rock material placed in the basin was efficiently removed with no swirling or other damaging action. Symmetrical operation and single bay operation were equally smooth with no adverse flow conditions.

This basin was subjected to the same erosion tests and the riverbed topography arrangements were the same as described for the slotted bucket tests. After initial downstream riverbed degradation of about 2 feet, no further movement of the riprap or riverbed material was observed (Figure 20). Tests made with the dividing piers extended to the end of the basin showed no improvement in the flow conditions; therefore, the short piers were used for the structure. Because of the excellent performance of this basin, it was chosen for the prototype installation.

Discharge Capacity

The discharge capacity of the overflow weir was determined for two conditions. The first condition was with a vertical upstream face on the weir; the second condition was with a sloping upstream face on the weir (Figure 21). The triangular fillet that formed the sloping upstream face was desirable because it provided additional structural stability for the dam, and permitted better location of the drainage gallery.

The discharge capacity of the weir was essentially the same for either condition (Figure 21). Coefficients of discharge computed from the equation $Q = CLH^{3/2}$ indicated that when the head over the crest was greater than 4 feet, the vertical upstream face provided slightly higher coefficients; for heads less than 4 feet the sloping upstream face provided the higher coefficients. The discharge coefficient with the sloping approach was 3.60 at reservoir elevation 3189.5. The discharge at this reservoir elevation was 17,000 cfs, 1,500 cfs higher than the design value.

Chute Block Pressures

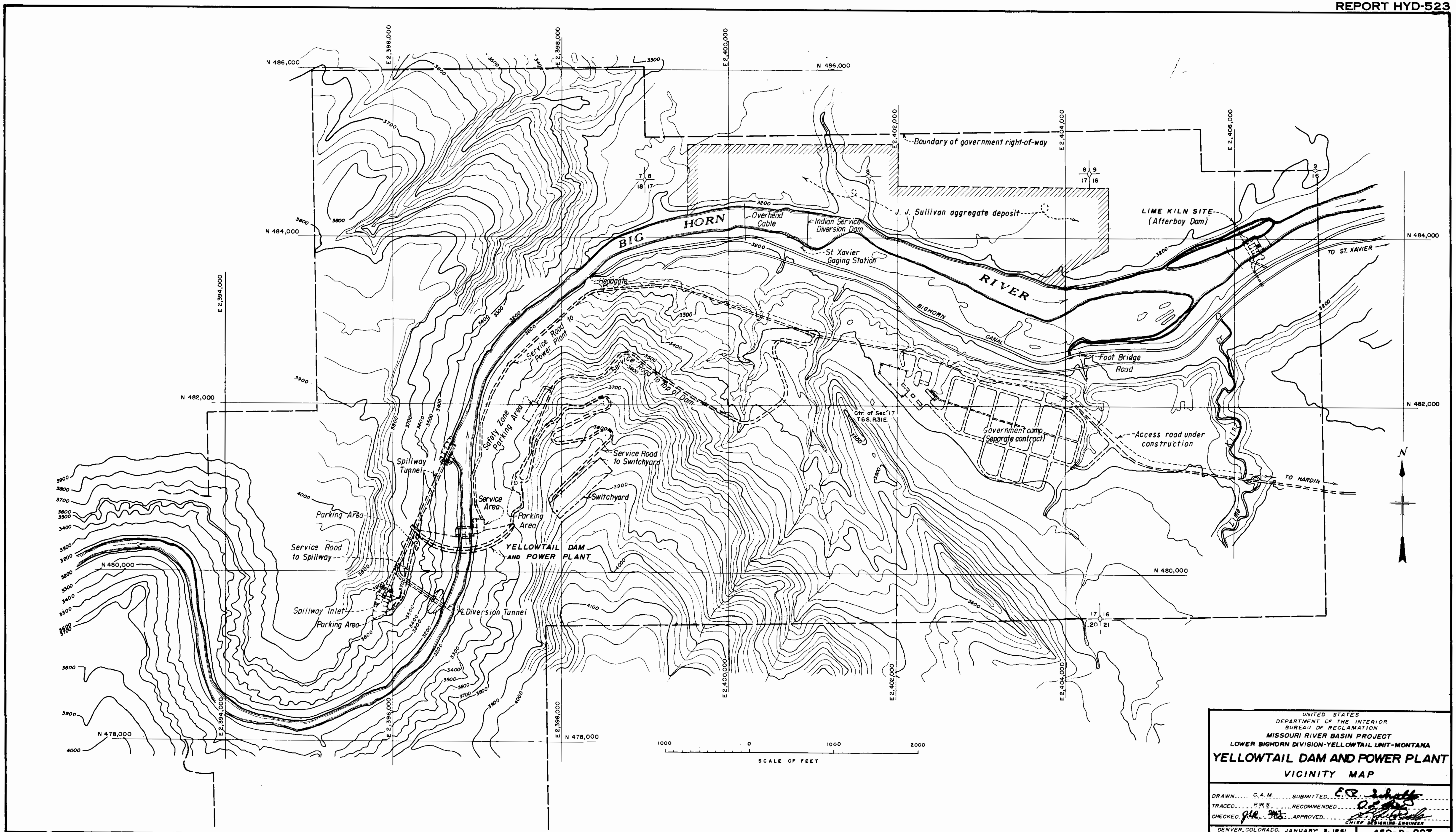
Computations were made to determine possible cavitation damage to the chute blocks in the overflow weir and sluiceway stilling basins.2/ All chute block pressures were determined to be in the positive range due to the comparatively high tailwater and low Froude numbers of 5.7 for the overflow weir and 6.2 for the sluiceway.

2/Progress Report VI Research Study on Stilling Basins Energy Dissipators--and Associated Appurtenances Section 12 Stilling Basin Chute Block Pressures (Basin II), Hyd-514, U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, 1963, pp. 1-3.

Table 1

METRIC EQUIVALENTS TO IMPORTANT QUANTITIES REFERRED TO IN THIS REPORT

Feature	English Units	Metric Units
Height of dam	56.0 feet	17.07 meters
Length of dam (total including earth dikes)	1,400 feet	426.7 meters
Volume of fill	145,000 cubic yards	110,860 cubic meters
Reservoir capacity at:		
Water surface elevation, 3192	3,150 acre-feet	3.88 million cubic meters
Water surface elevation, 3175	600 acre-feet	0.74 million cubic meters
Combined maximum design flood	20,000 cubic feet per second	566.34 cubic meters per second
Sluiceway		
Width at crest	30.0 feet	9.14 meters
Length of chute	55.1 feet	16.79 meters
Drop-crest to basin	18.0 feet	5.49 meters
Width of basin	34.3 feet	10.45 meters
Length of basin	84.9 feet	25.88 meters
Height of basin walls	33.0 feet	10.06 meters
Maximum discharge	4,500 cubic feet per second	127.43 cubic meters per second
Slide gates	10 x 8 feet	3.05 x 2.44 meters
Overflow Weir		
Width of weir	150.0 feet	45.72 meters
Length of chute	45.0 feet	13.72 meters
Drop-crest to basin	33.5 feet	10.21 meters
Width of basin	162.0 feet	49.38 meters
Length of basin	42.0 feet	12.80 meters
Maximum discharge	15,500 cubic feet per second	438.91 cubic meters per second
Radial gates	30.0 x 13.5 feet	9.14 x 4.12 meters



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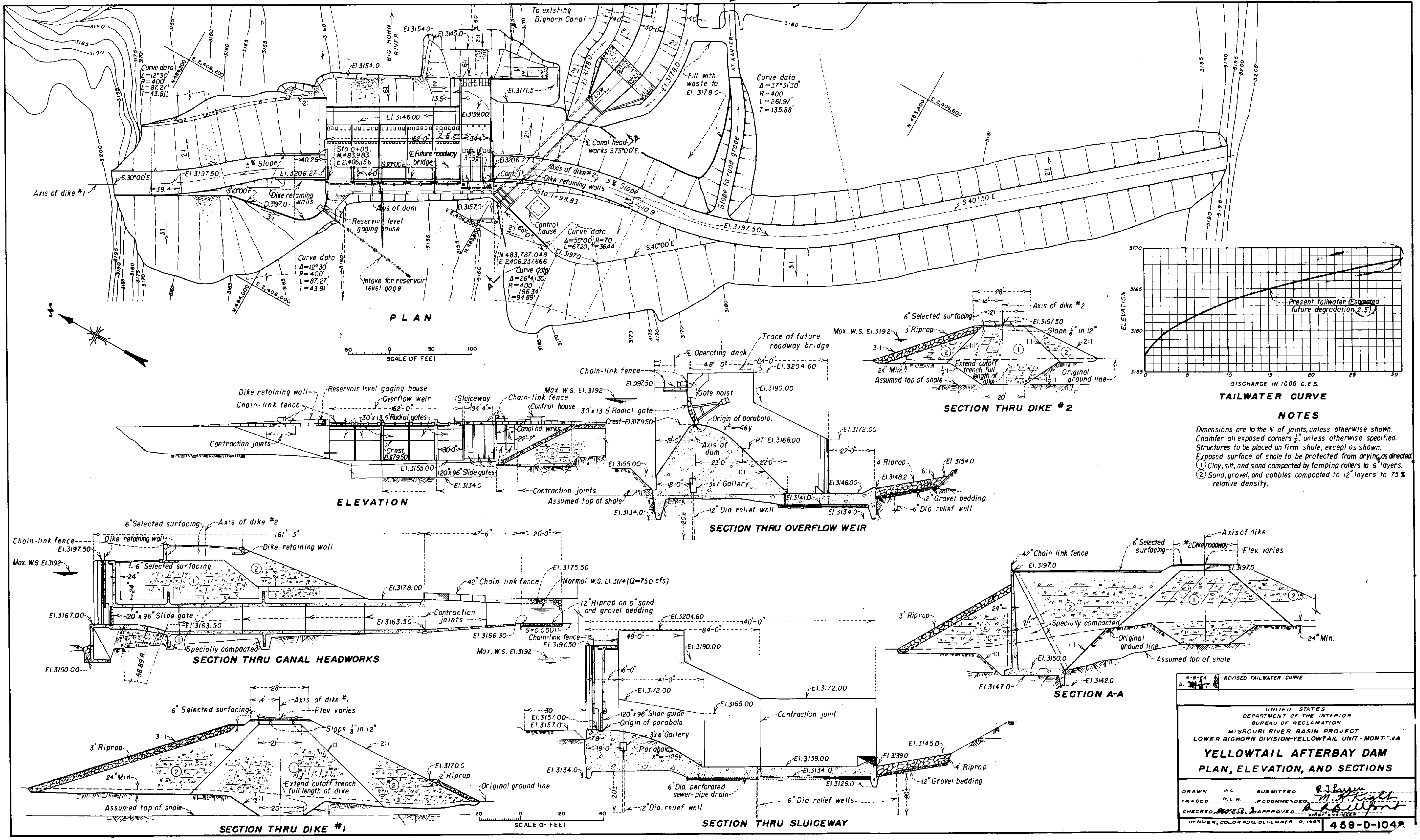
MISSOURI RIVER BASIN PROJECT
LOWER BIGHORN DIVISION-YELLOWTAIL UNIT-MONTANA

YELLOWTAIL DAM AND POWER PLANT

VICINITY MAP

DRAWN C.A.M. SUBMITTED
TRACED P.W.S. RECOMMENDED
CHECKED APPROVED
CHIEF DESIGNING ENGINEER
DENVER, COLORADO, JANUARY 3, 1961 459-D-227



NOTES

Dimensions are to the ℄ of joints, unless otherwise shown.
Chamfer all exposed corners 3/4" unless otherwise specified.
Structures to be placed on firm shale, except as shown.
Exposed surface of shale to be protected from drying, as directed.
(1) Clay, silt, and sand compacted by tamping rollers to 6" layers.
(2) Sand, gravel, and cobbles compacted to 12" layers to 75% relative density.

4-6-64 REVISED TAILWATER CURVE

UNITED STATES
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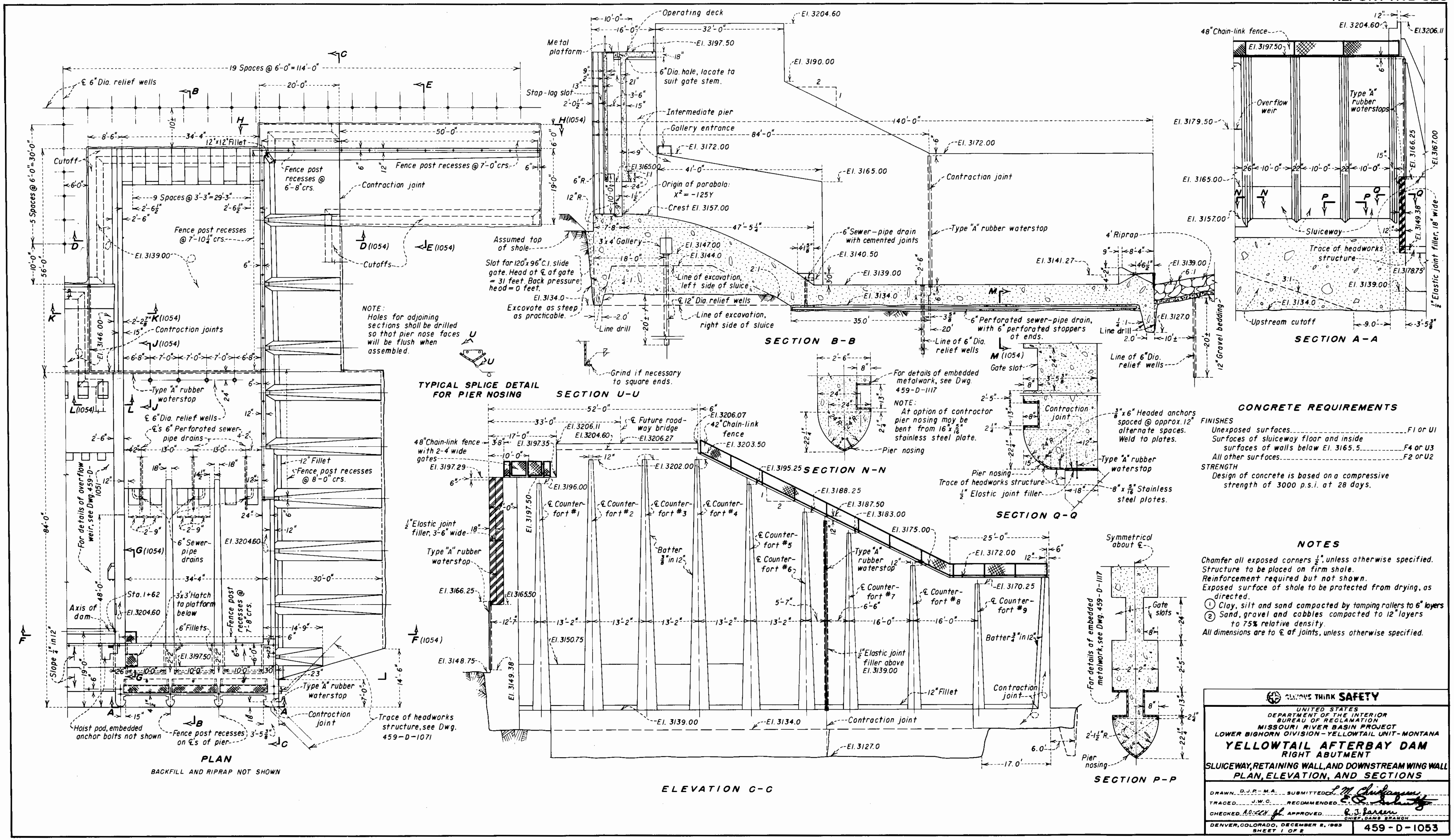
MISSOURI RIVER BASIN PROJECT
LOWER BIGHORN DIVISION-YELLOWTAIL UNIT-MONTANA

YELLOWTAIL AFTERBAY DAM
PLAN, ELEVATION, AND SECTIONS

DRAWN J.L. SUBMITTED R.J. Larsen
TRACED R.L.W. RECOMMENDED M.H. Knight
CHECKED APPROVED CHIEF ENGINEER
DENVER, COLORADO, DECEMBER 2, 1963

459-D-1048


PLAN
BACKFILL AND RIPRAP NOT SHOWN
SECTION B-B
SECTION A-A
SECTION U-U
TYPICAL SPLICE DETAIL FOR PIER NOSING
SECTION N-N
SECTION Q-Q
SECTION P-P
ELEVATION C-C
NOTE: Holes for adjoining sections shall be drilled so that pier nose faces will be flush when assembled.
CONCRETE REQUIREMENTS
FINISHES
Unexposed surfaces F1 or U1
Surfaces of sluiceway floor and inside surfaces of walls below El. 3165.5 F4 or U3
All other surfaces F2 or U2
STRENGTH
Design of concrete is based on a compressive strength of 3000 p.s.i. at 28 days.
NOTES
Chamfer all exposed corners 3/4", unless otherwise specified.
Structure to be placed on firm shale.
Reinforcement required but not shown.
Exposed surface of shale to be protected from drying, as directed.
(1) Clay, silt and sand compacted by tamping rollers to 6" layers
(2) Sand, gravel and cobbles compacted to 12" layers to 75% relative density.
All dimensions are to ℄ of joints, unless otherwise specified.
ALWAYS THINK SAFETY
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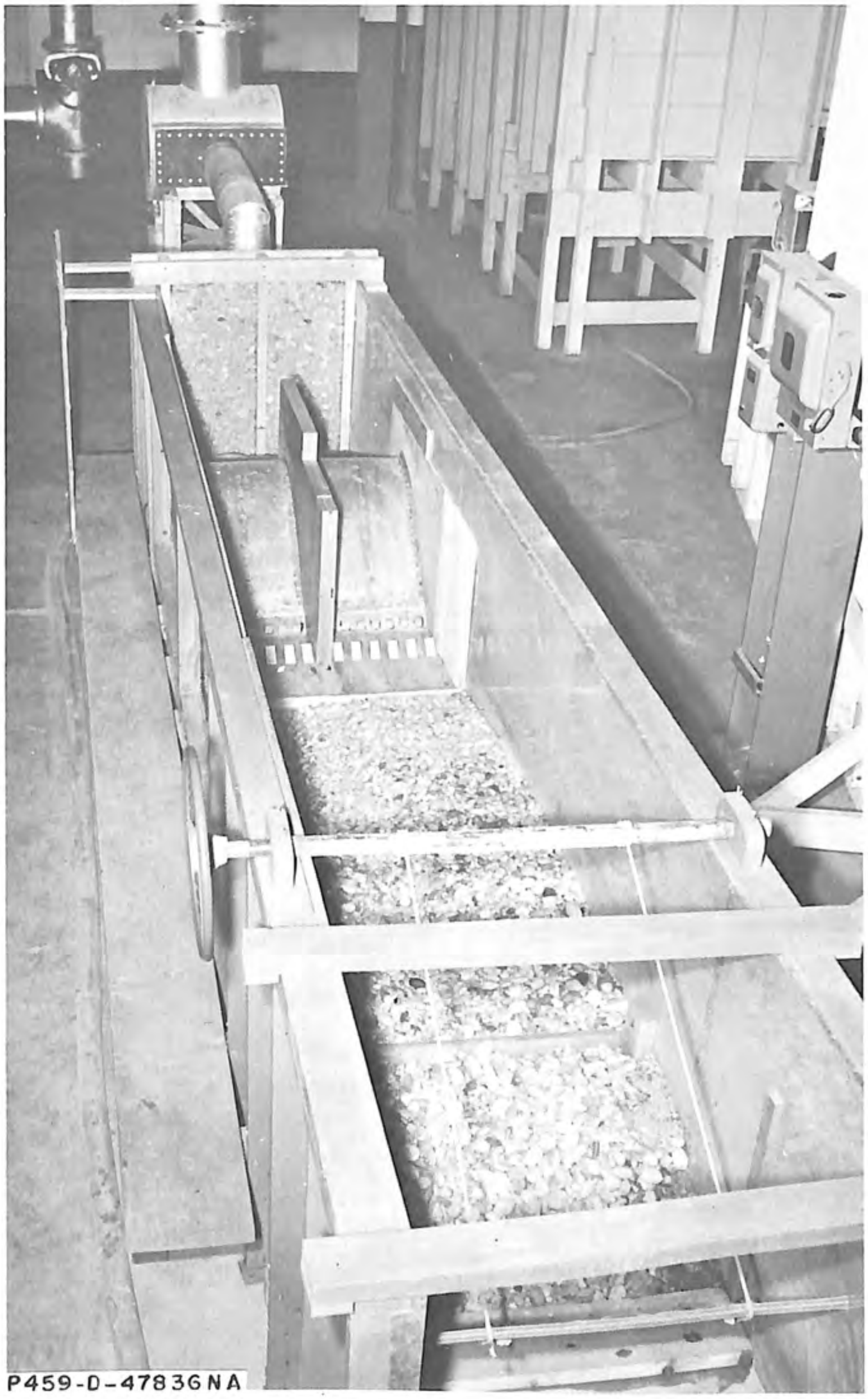
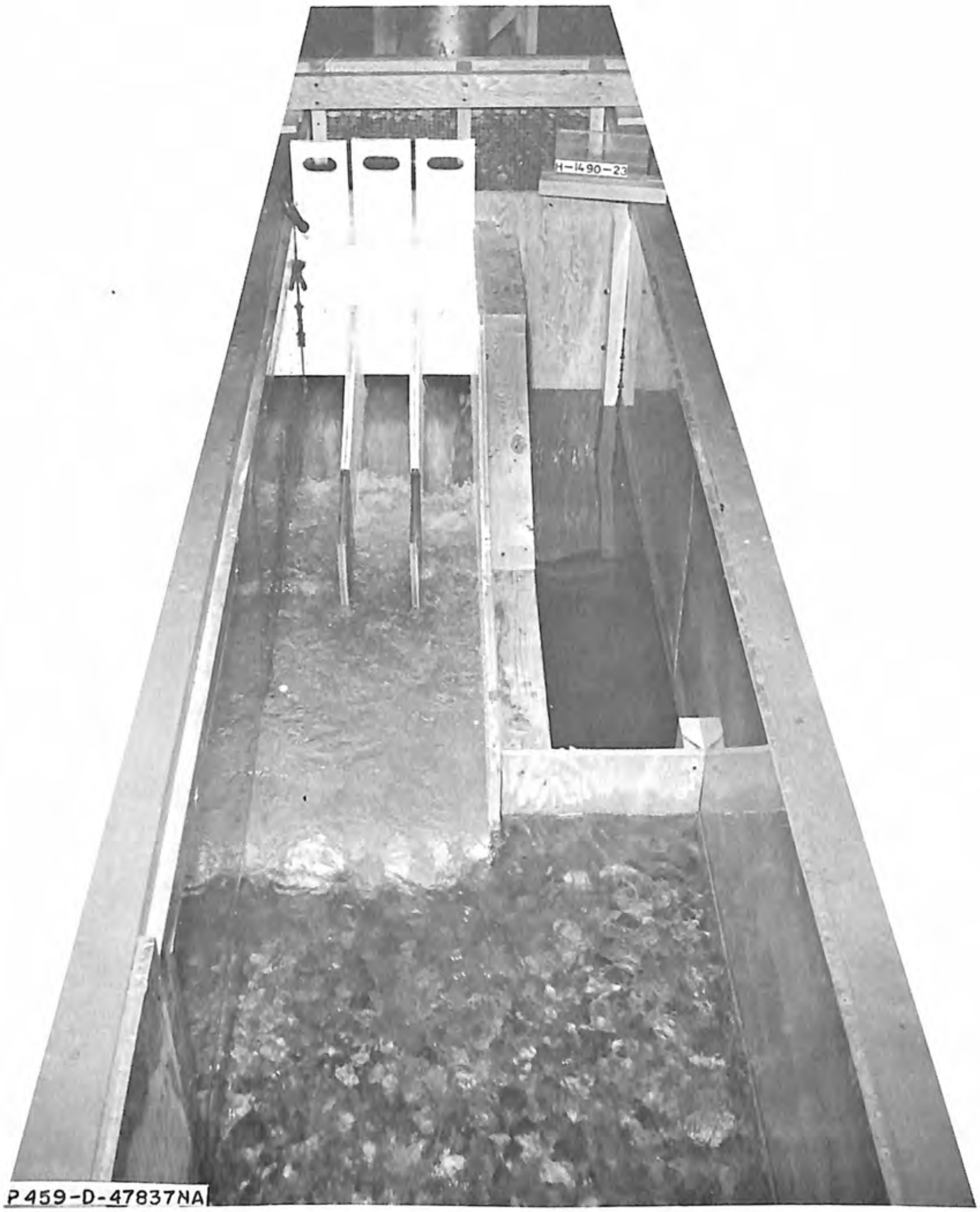
LOWER BIGHORN DIVISION - YELLOWTAIL UNIT - MONTANA
YELLOWTAIL AFTERBAY DAM
RIGHT ABUTMENT
SLUICEWAY, RETAINING WALL, AND DOWNSTREAM WING WALL
PLAN, ELEVATION, AND SECTIONS
DRAWN D.J.P.-M.A. SUBMITTED
TRACED J.W.C. RECOMMENDED
CHECKED APPROVED
CHIEF, DAMS BRANCH
DENVER, COLORADO, DECEMBER 2, 1963
SHEET 1 OF 2
459-D-1053



YELLOWTAIL AFTERBAY DAM
1:24 Scale Model

Overflow Weir

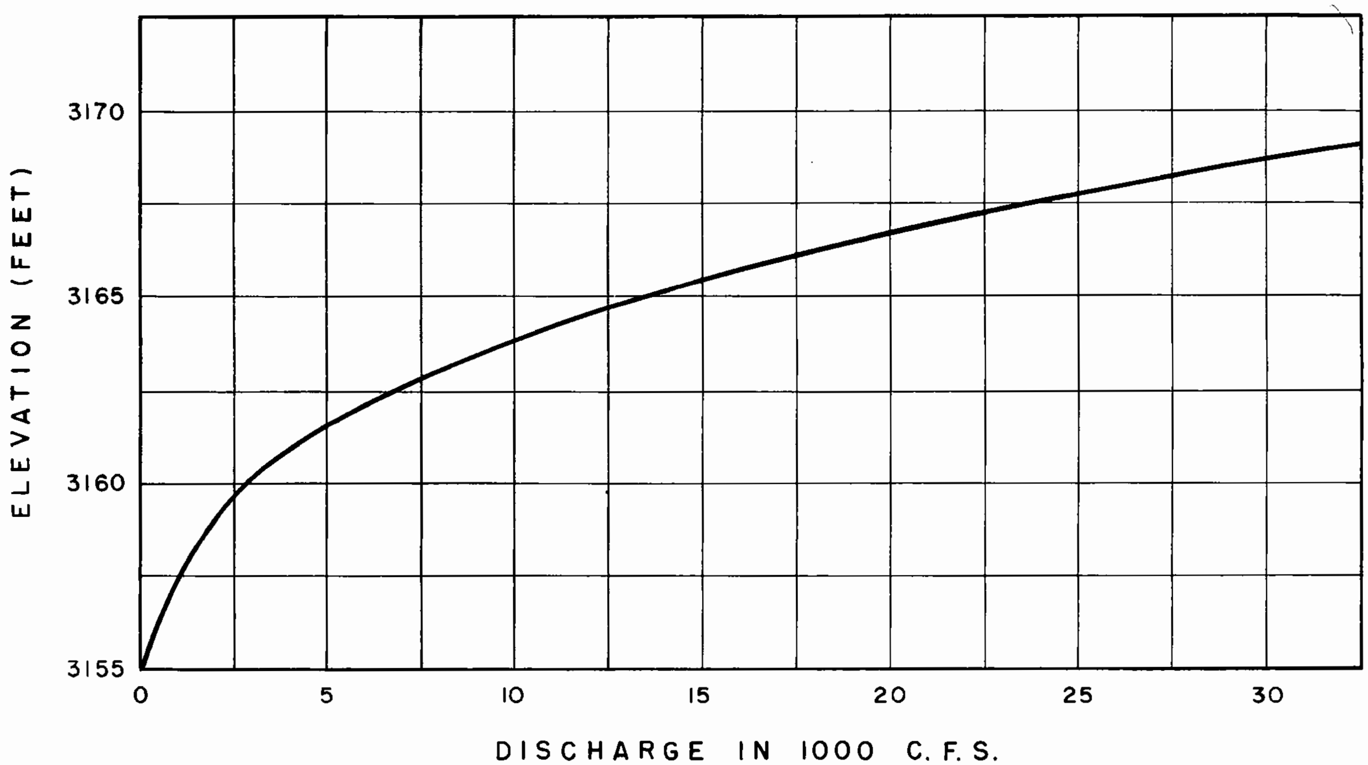
Figure 5
Report Hyd-523



YELLOWTAIL AFTERBAY DAM
1:24 Scale Model

Sluiceway

689

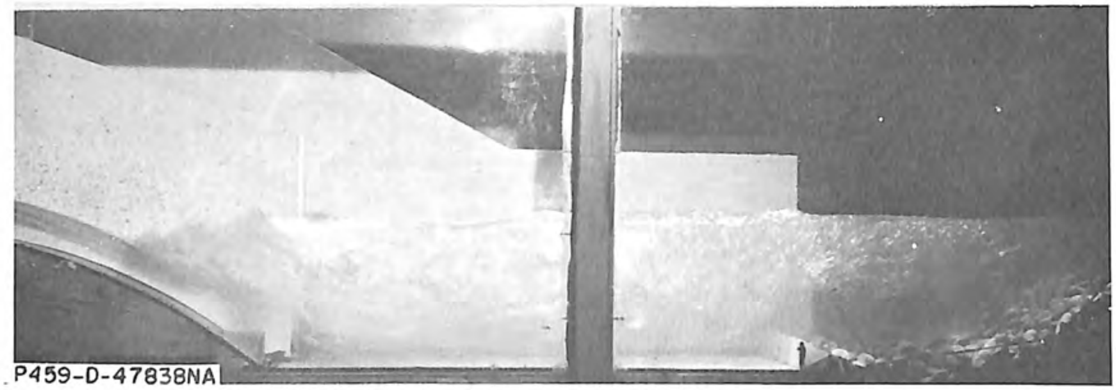


YELLOWTAIL AFTERBAY DAM

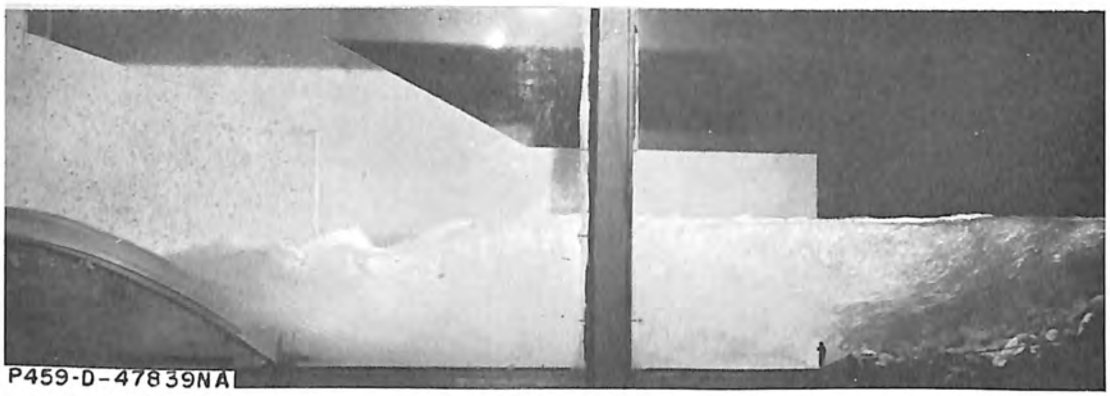
1:24 SCALE MODEL

TAILWATER CURVE
FOR MODEL STUDIES

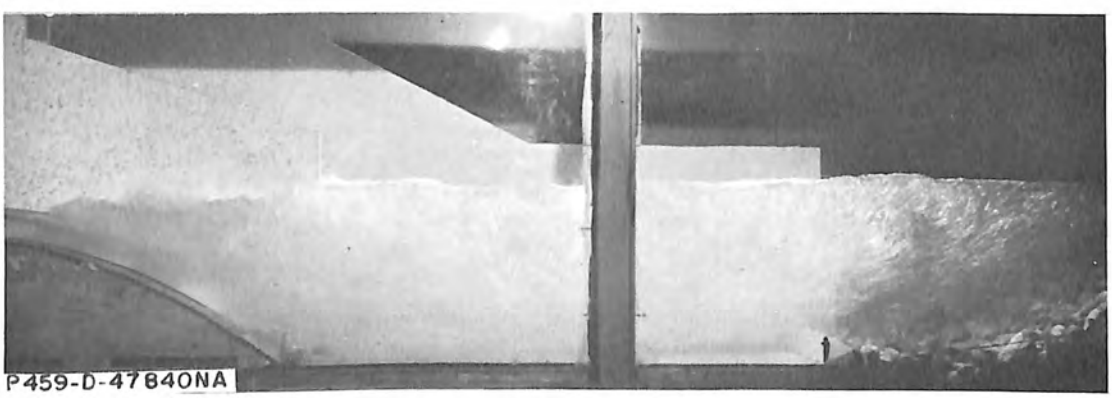
FIGURE 6
REPORT HYD-523



A. Reservoir elevation 3174.5, tailwater elevation 3161.5. All gates fully open.



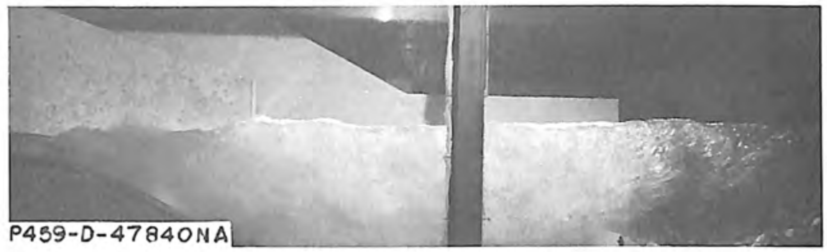
B. Reservoir elevation 3189.5, tailwater elevation 3161.5. All gates 63 percent open.



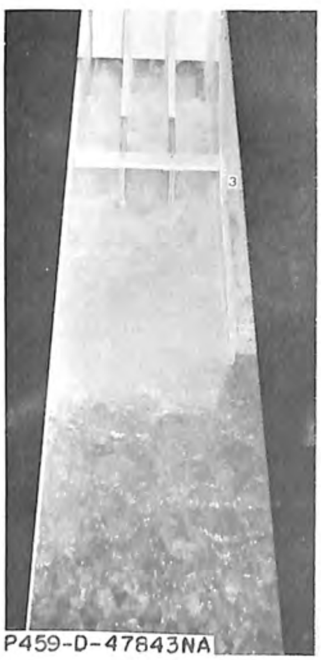
C. Reservoir elevation 3189.5, tailwater elevation 3165.5. All gates 63 percent open.

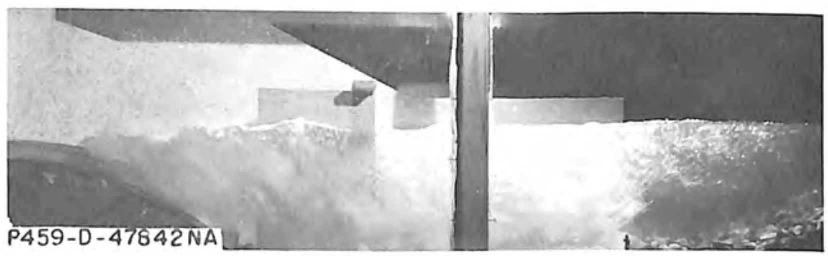
YELLOWTAIL AFTERBAY DAM
SLUICEWAY
1:24 Scale Model

Flow Conditions in the Type II Stilling Basin
(Q = 4,500 cfs)



A. Pier as initially designed.



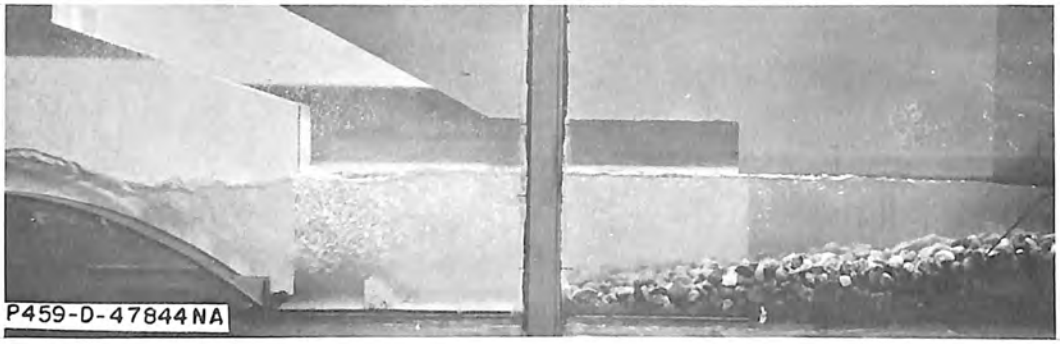


B. Pier lengthened 25 feet.

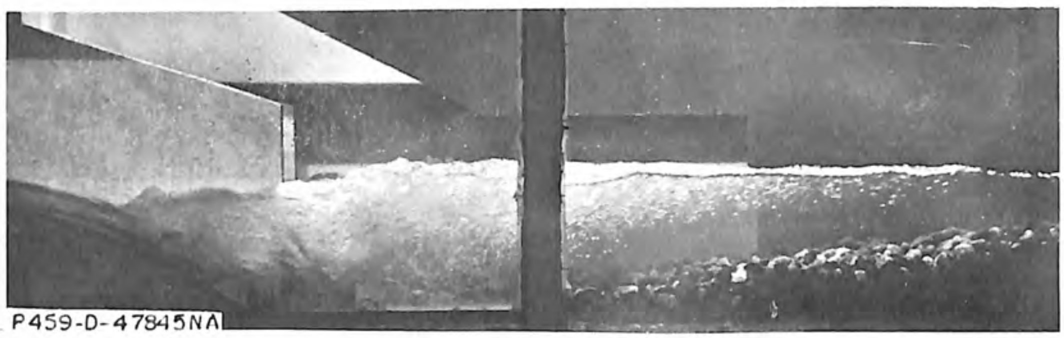
YELLOWTAIL AFTERBAY DAM
SLUICEWAY
1:24 Scale Model

Comparison of Flow With and Without
Pier Extensions for the Type II Stilling Basin
(Reservoir elevation 3189.5, Tailwater elevation 3165.5, Q = 4,500 cfs)

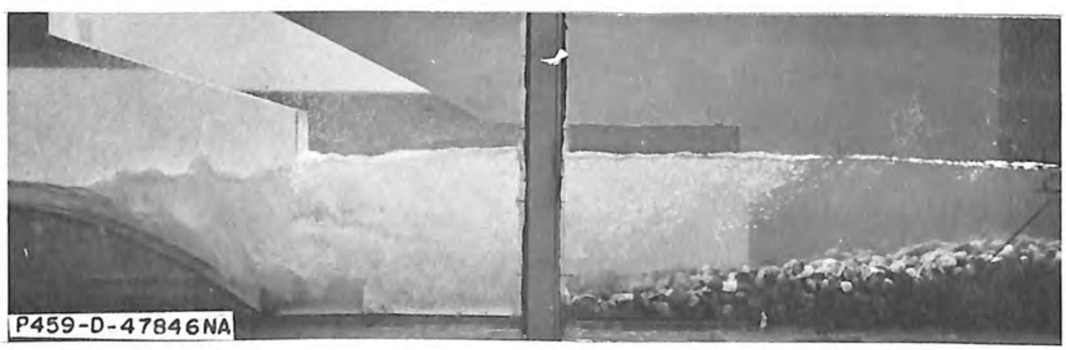
Figure 9
Report Hyd-523



A. Reservoir elevation 3174.5, tailwater elevation 3161.5. Gates full open.



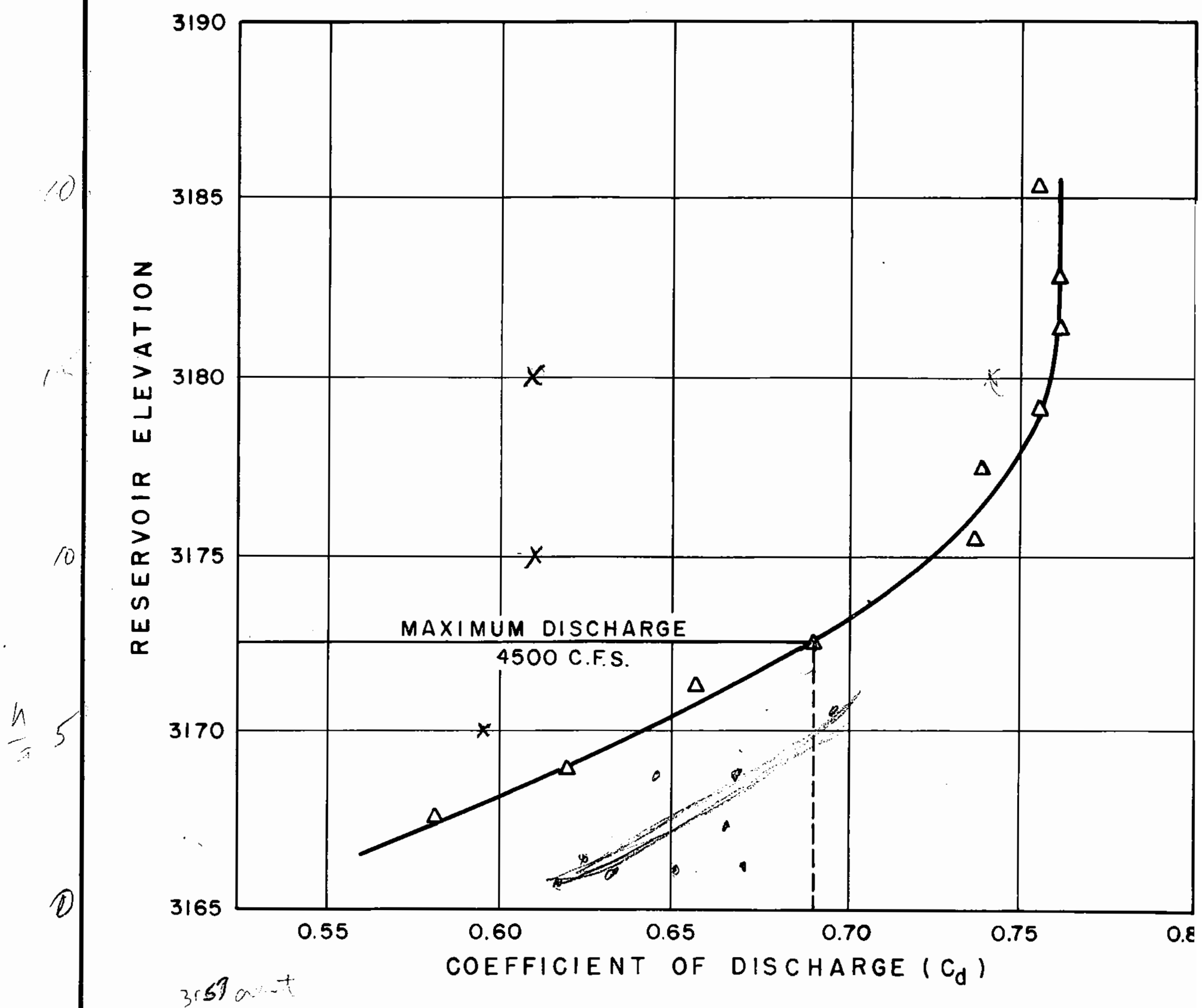
B. Reservoir elevation 3189.5, tailwater elevation 3161.5. Gates 63 percent open.



C. Reservoir elevation 3189.5, tailwater elevation 3165.5. Gates 63 percent open.

YELLOWTAIL AFTERBAY DAM
SLUICEWAY
1:24 Scale Model

Flow Conditions in the Type III
Stilling Basin (Q = 4,500 cfs)



COEFFICIENT IN:

$Q = C_d A\sqrt{2gh}$

Where Q = Discharge in C.F.S.

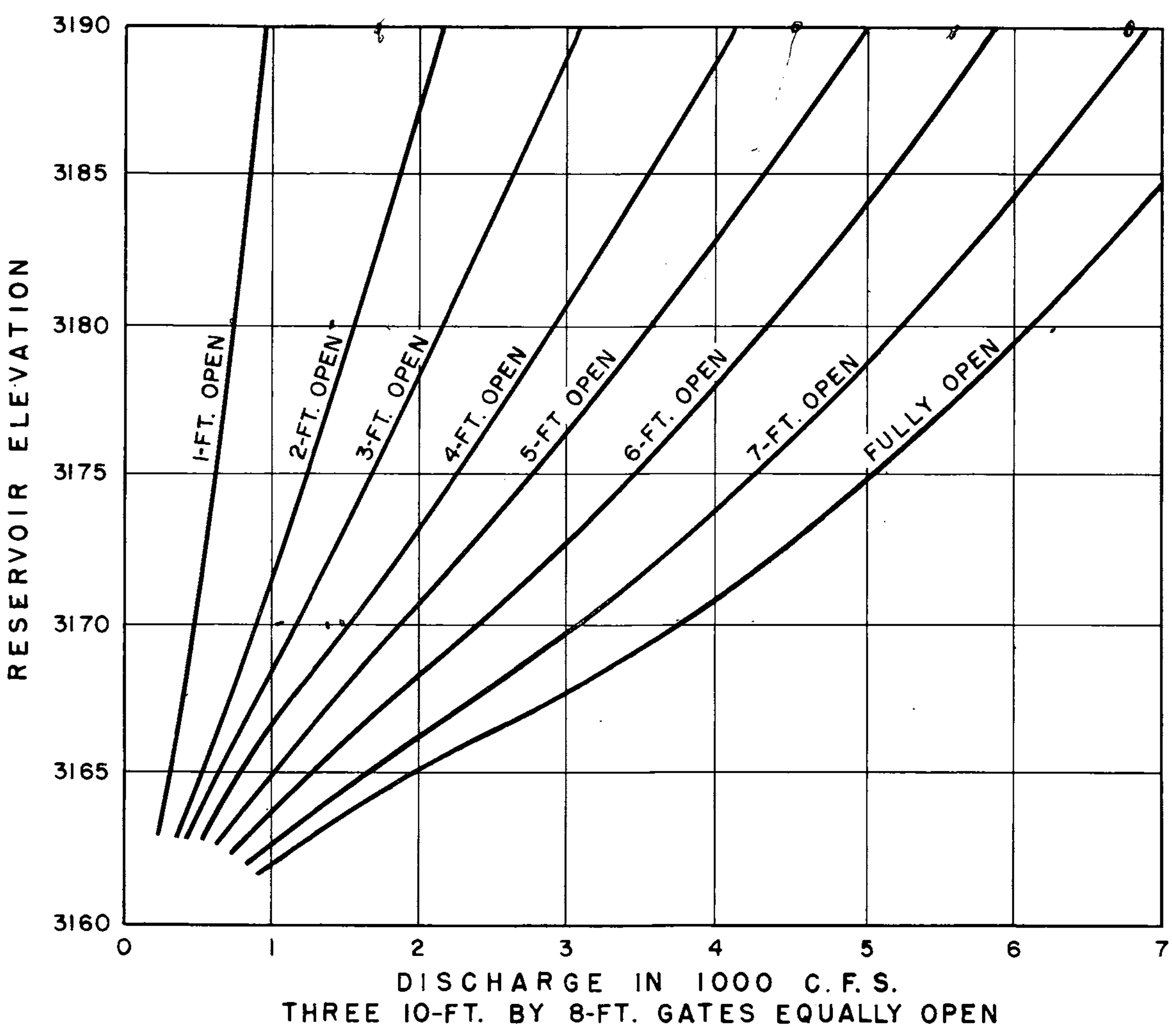
A = Area of flow through gate opening

h = Head measured from ℄ of opening (El. 3161) to water surface.

YELLOWTAIL AFTERBAY DAM
SLUICEWAY

1:24 SCALE MODEL

COEFFICIENT OF DISCHARGE
WITH GATES 100 % OPEN

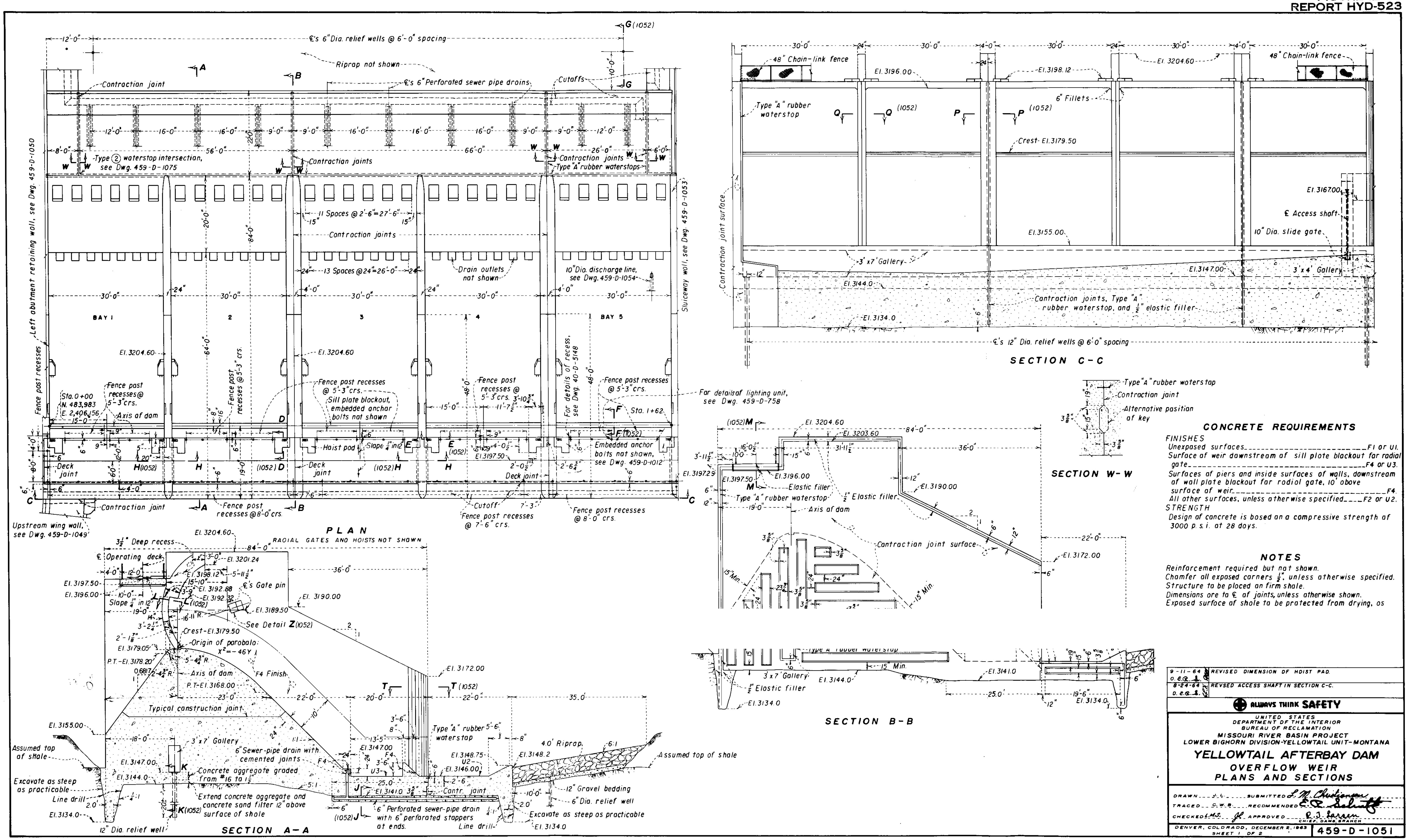


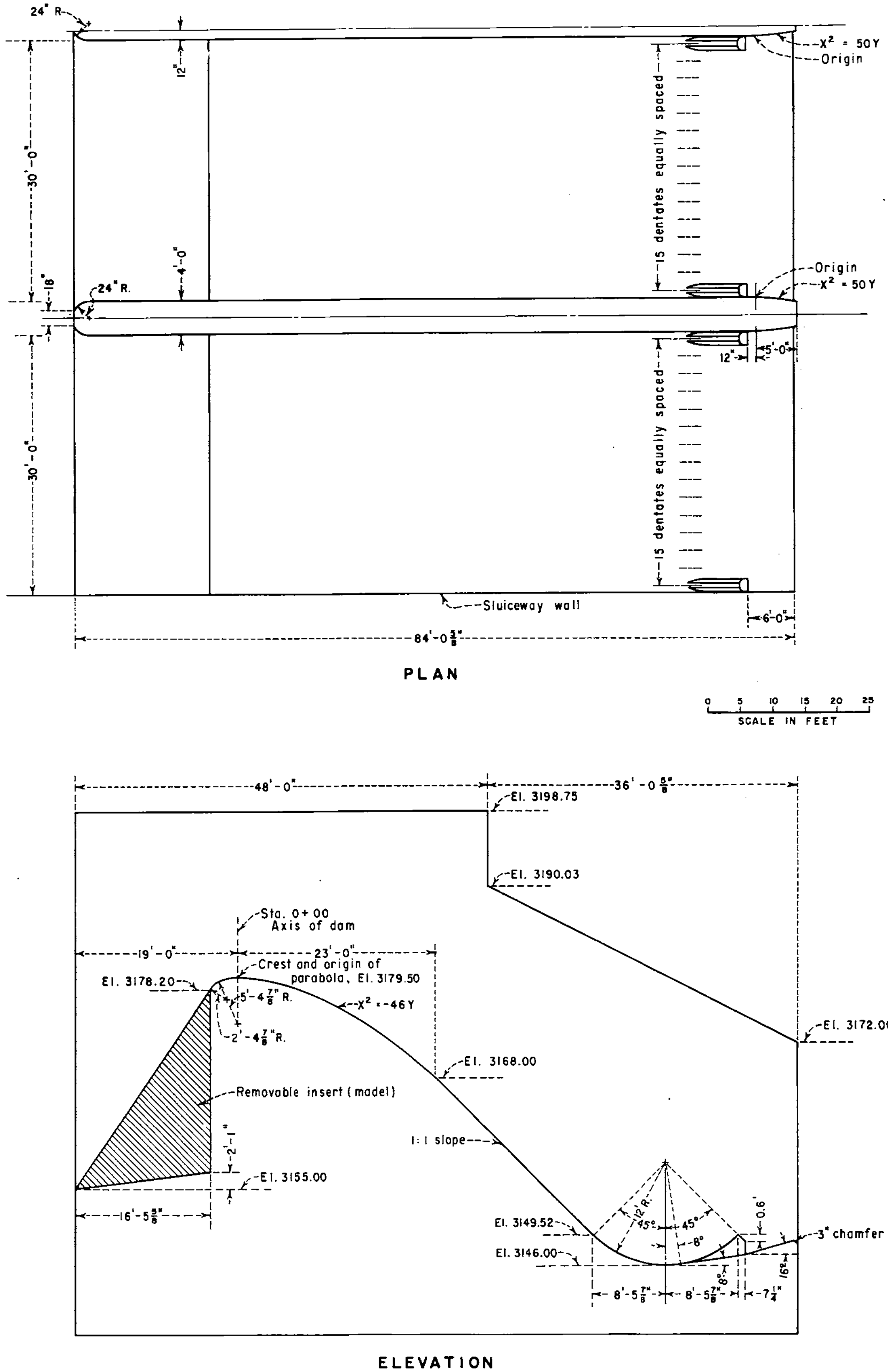
YELLOWTAIL AFTERBAY DAM
SLUICEWAY

1:24 SCALE MODEL

DISCHARGE CAPACITY

FIGURE 12
REPORT HYD-523

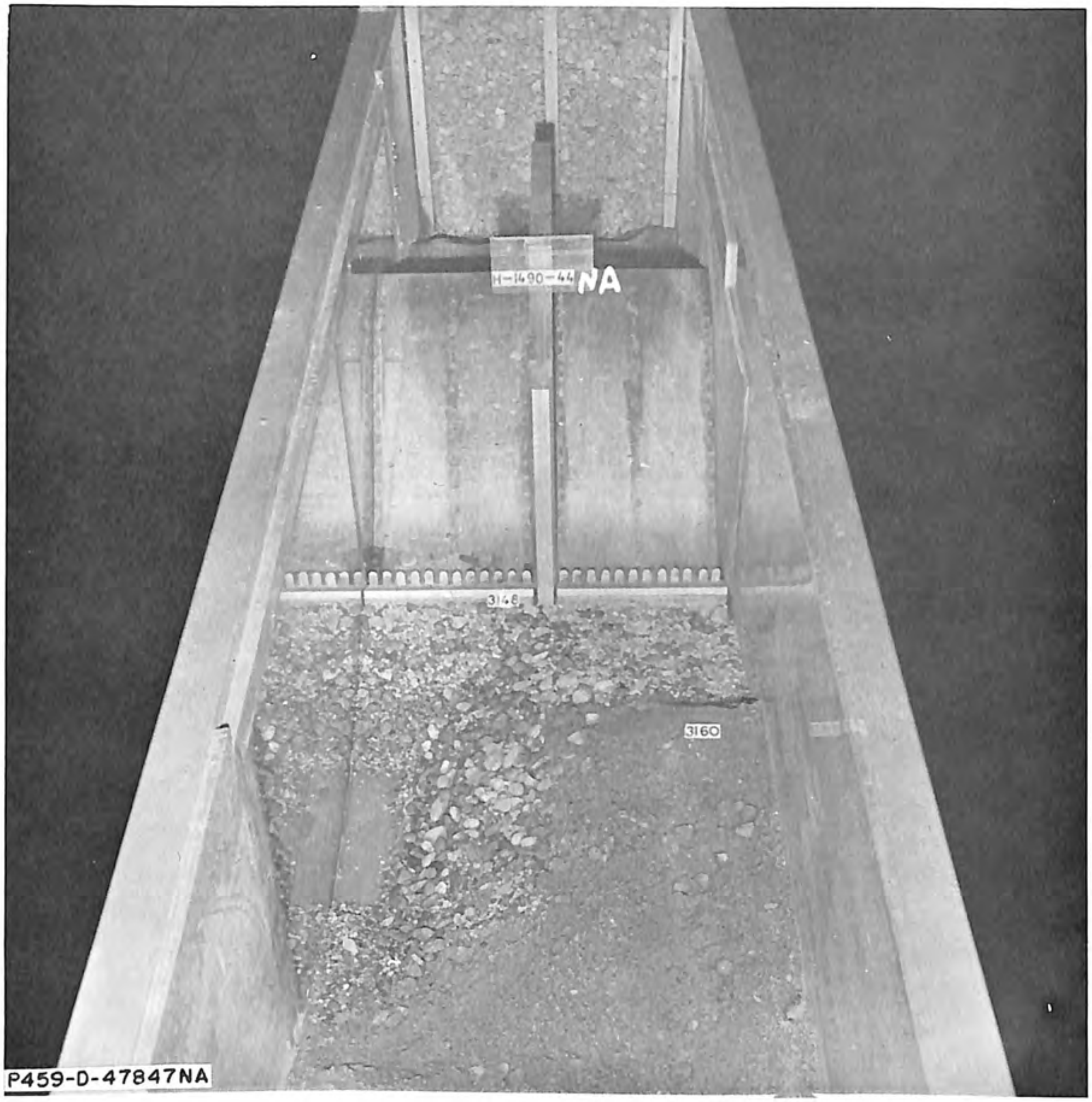




YELLOWTAIL AFTERBAY DAM
OVERFLOW WEIR
1:24 SCALE MODEL
WITH PRELIMINARY SLOTTED BUCKET

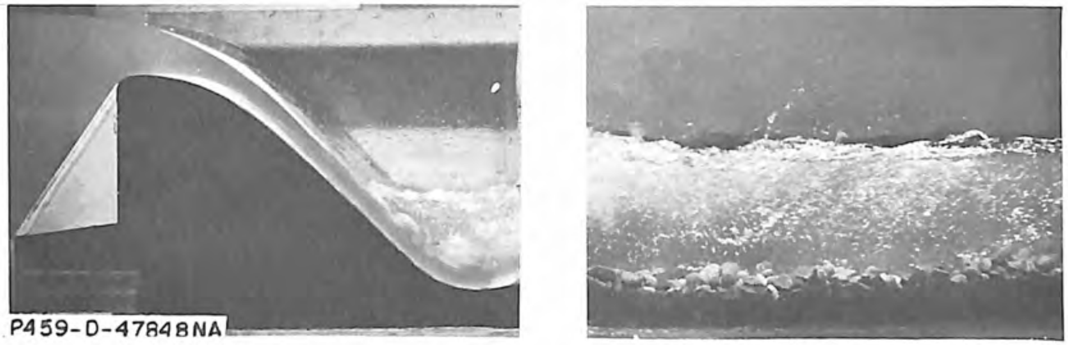
689

Figure 14
Report Hyd-523

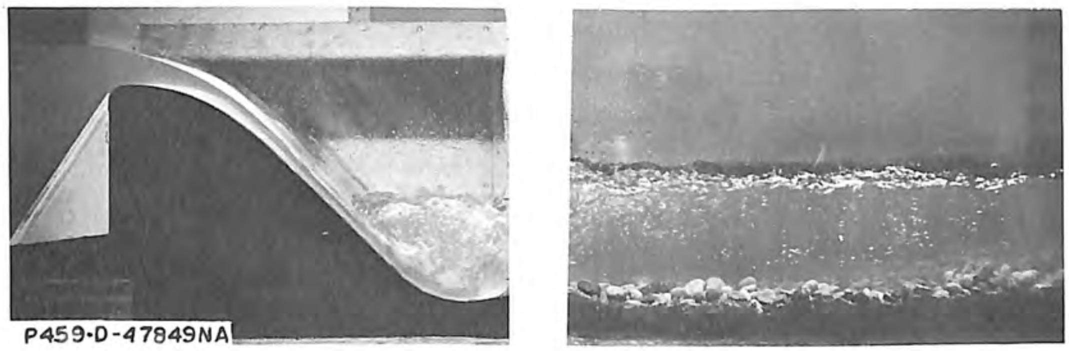


YELLOWTAIL AFTERBAY DAM
1:24 Scale Model

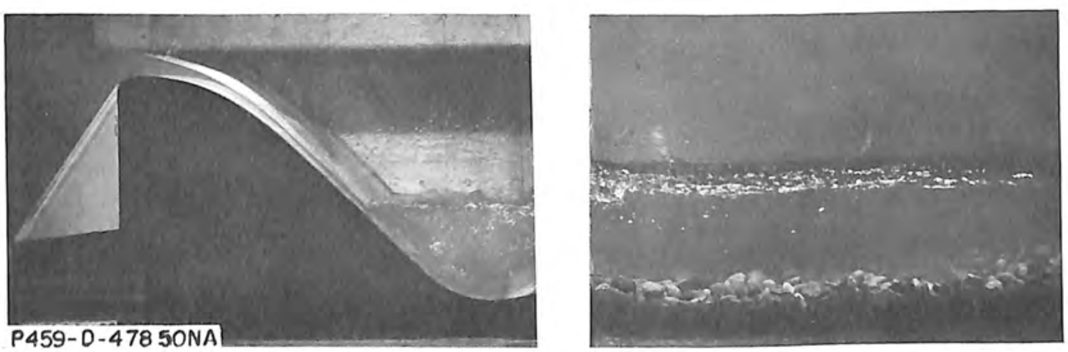
Overflow Weir With
Slotted Bucket



A. Maximum discharge 3, 100 cfs per bay (15, 500 cfs total). Reservoir elevation 3189. 5, tailwater elevation 3165. 5.



B. One-half maximum discharge 1, 550 cfs per bay (7, 750 cfs total). Reservoir elevation 3185. 5, tailwater elevation 3163. 5.

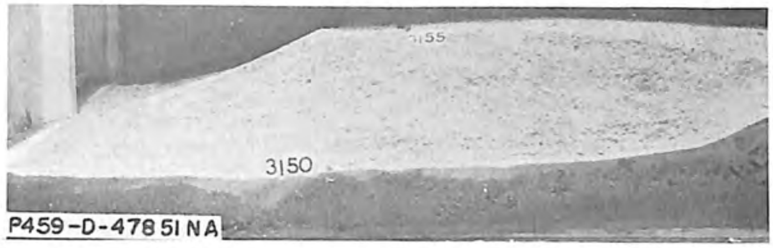


C. One-quarter of maximum discharge 775 cfs per bay (3, 875 cfs total). Reservoir elevation 3183. 5, tailwater elevation 3162. 0.

YELLOWTAIL AFTERBAY DAM
OVERFLOW WEIR
1:24 Scale Model

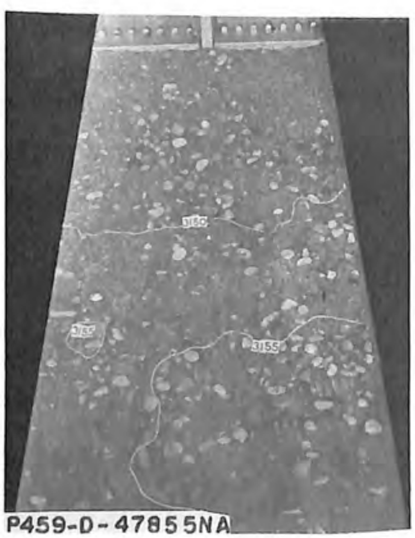
Flow Conditions in the Slotted Bucket

Figure 16
Report Hyd-523



A. The riverbed downstream from the basin before erosion tests. Preliminary design.

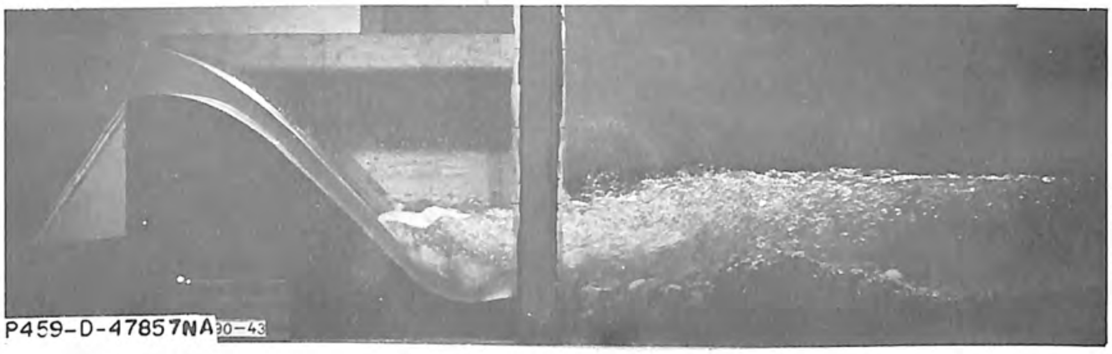
B. The riverbed after a 2-hour (prototype) erosion test at maximum discharge. Preliminary design.



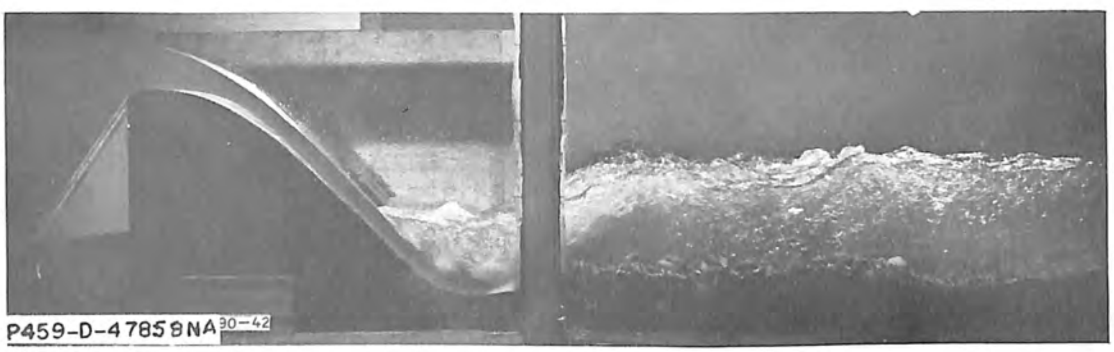
C. The riverbed after a 2-hour (prototype) erosion test at maximum discharge. Seven dentates per bay, preliminary end sill.

YELLOWTAIL AFTERBAY DAM
OVERFLOW WEIR
1:24 Scale Model

Erosion Tests With the Slotted Bucket
(for the Two Bays Adjacent to the Sluiceway)



A. Basin with 12 dentates per bay with 12-inch spaces between dentates and the initial (18° rise) end sill.



B. Same as A but with the end sill rise increased to 26°.

YELLOWTAIL AFTERBAY DAM
OVERFLOW WEIR
1:24 Scale Model

Comparison of Flow Conditions in the
Slotted Bucket at Maximum Discharge

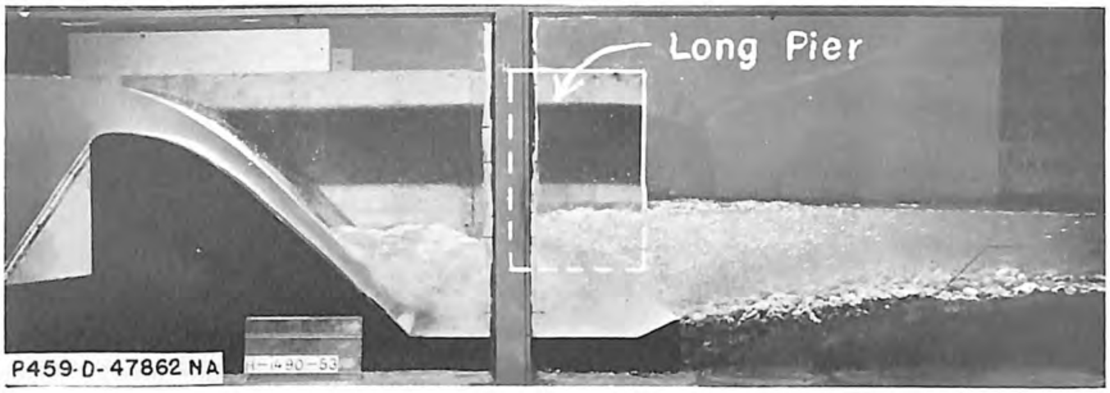
Figure 18
Report Hyd-523

A. Riverbed downstream from the basin before erosion test.

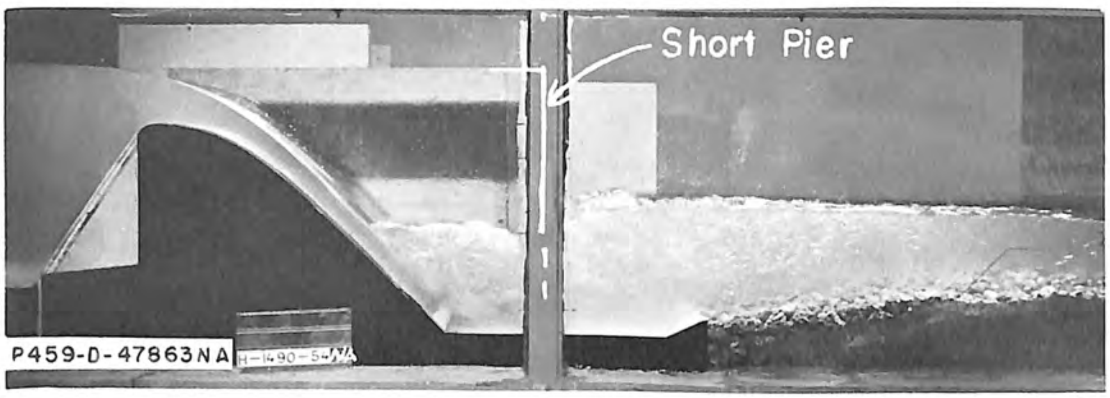
B. The riverbed and riprap after a 2-hour (prototype) erosion test at maximum discharge.

YELLOWTAIL AFTERBAY DAM
OVERFLOW WEIR
1:24 Scale Model

Erosion Tests With Slotted Bucket
Twelve dentates per Bay and
the 26° End Sill Rise



A. Operation with the pier extended to the end of the basin.

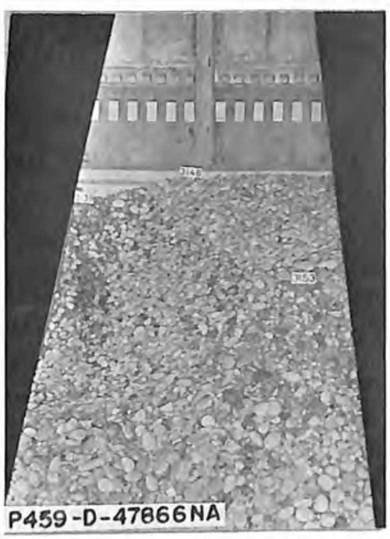


B. Operation of basin with the short pier (recommended).

YELLOWTAIL AFTERBAY DAM
OVERFLOW WEIR
1:24 Scale Model

Operation of the Type III Stilling Basin

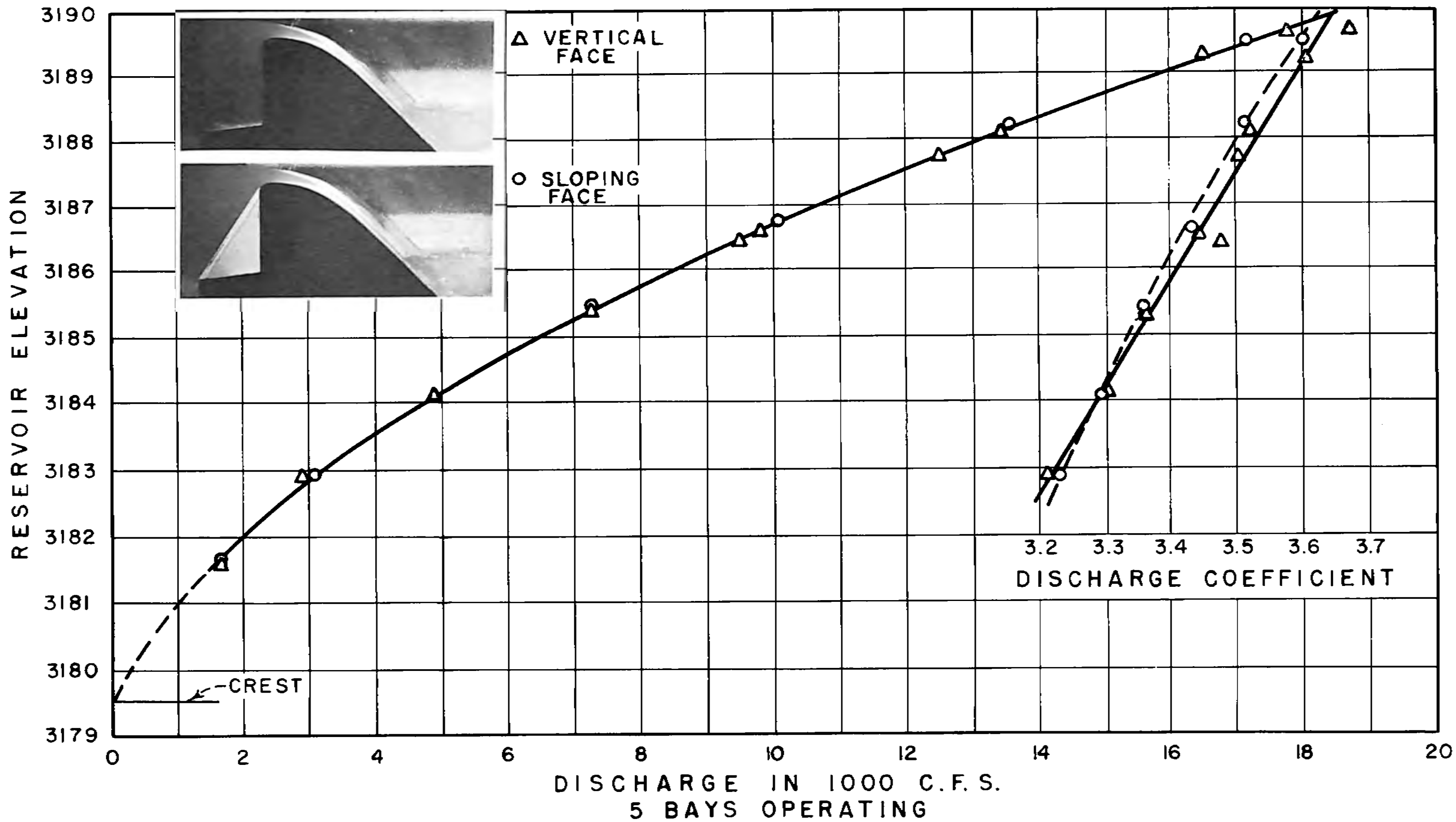
A. Arrangement of riverbed and riprap prior to testing.



B. Result of the 2-hour erosion test with maximum Q tailwater elevation 3165. 5.

YELLOWTAIL AFTERBAY DAM
OVERFLOW WEIR
1:24 Scale Model

Erosion Test of the Type III Stilling Basin (Recommended Design)



YELLOWTAIL AFTERBAY DAM
OVERFLOW WEIR
1:24 SCALE MODEL
DISCHARGE CAPACITY

FIGURE 21
REPORT HYD-523

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 and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

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

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

Table 1

QUANTITIES AND UNITS OF SPACE

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

Table II

QUANTITIES AND UNITS OF MECHANICS

MASS

Multiply	By	To obtain
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

Multiply	By	To obtain
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)

Multiply	By	To obtain
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

Multiply	By	To obtain
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

Multiply	By	To obtain
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

Multiply	By	To obtain
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*

Multiply	By	To obtain
Feet per second^2	0.3048*	Meters per second^2

FLOW

Multiply	By	To obtain
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*

Multiply	By	To obtain
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes

WORK AND ENERGY*

Multiply	By	To obtain
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

Multiply	By	To obtain
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts

HEAT TRANSFER

Multiply	By	To obtain
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

Multiply	By	To obtain
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

ABSTRACT

Model studies to develop hydraulic design of the sluiceway and overflow weir for Yellowtail Afterbay Dam indicated the most efficient energy dissipators for each. The sluiceway has three 10-ft-wide bays separated by 2-ft tapered piers with the flow controlled by 10- by 8-ft slide gates and energy dissipated by a hydraulic jump stilling basin. It is designed for a 4,500-cfs maximum discharge. The overflow weir includes five 30-ft-wide bays separated alternately by 4- and 2-ft piers with a maximum design discharge of 15,500 cfs. Discharge is controlled by five 30- by 13.5-ft radial gates and energy dissipated by a stilling basin. Two types of energy dissipators were investigated for each structure. For the sluiceway either a hydraulic jump basin with chute blocks and a dentated end sill (Type II basin) or a basin with chute blocks, baffle piers, and a solid end sill (Type III) would be satisfactory. Since an abutment wall forms one side of the stilling basin, it was decided to extend the apron and use the Type II basin. For the overflow weir the studies showed that a slotted bucket type energy dissipator was not satisfactory but that a Type III basin should be used. The recommended basins for both structures provided excellent energy dissipation with minor wave action and channel bed erosion. Discharge capacity and coefficient curves were prepared for both structures.

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Hyd-523
Arris, W. F.
HYDRAULIC MODEL STUDIES OF THE SLUICEWAY AND OVERFLOW WEIR--YELLOWTAIL AFTERBAY DAM--MISSOURI RIVER BASIN PROJECT, MONTANA
Laboratory Report, Bureau of Reclamation, Denver, 14 pp., 1 tab, 21 fig, 1965

DESCRIPTORS--dentated sills/ spillways/ *stilling basins/ piers/ hydraulic jumps/ wave action/ discharge coefficients/ discharge measurement/ spillway crests/ Froude number/ hydraulic models/ hydraulic similitude/ riprap/ flow control/ turbulent flow/ training walls/ research and development/ baffles/ laboratory tests/ *energy dissipation/ *weirs/ hydraulics/ aprons/ slide gates/ model tests/ stream erosion

IDENTIFIERS--chute blocks/ sweepout/ hydraulic design/ Yellowtail Afterbay Dam/ Missouri River Basin Proj/ *sluiceways/ *slotted buckets/

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