UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE ENDERS DAM SPILLWAY AND OUTLET WORKS--MISSOURI BASIN PROJECT

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SUMMARY

Spillway Studies

The spillway studies described in this report were made to develop a structure that would provide satisfactory performance over the expected ranges of operation. All tests were made on a model built to a scale of 1:72, Figures 5 and 7A.

The spillway tests were divided into two distinct parts consisting of the stilling-basin studies and the spillway-structure studies. In the investigation of the stilling-basin, tests were run on eight different designs, Figure 6. After completion of tests on the original design the original tailwater curve was revised, resulting in lower tailwater elevations for a given discharge, Figure 8. As a result, it was found necessary to lower the apron elevation 5 feet, Test 3 Figure 6.

In subsequent tests with the lowered apron, a solid end sill was found unsatisfactory, Test 4 Figure 6 and Figure 11. Best performance was obtained with a dentated end sill 12 feet high, Test 6 Figure 6. Performance of the basin without chute blocks was found acceptable, Test 3 Figure 6 and Figure 10. Reducing the apron width resulted in less satisfactory operation than with the original width of 400 feet, Test 8 Figure 6 and Figure 15. A 45° wing-wall at the downstream end of the right training-wall resulted in less scour in the river channel, Figure 7B and 9B, but results were considered satisfactory with a less costly 90° wing-wall. The recommended stilling-basin, Figure 16, differed from the original in having a 5-foot lower apron elevation and a 3-foot higher end sill.

In the studies on the spillway structure, a contraction occurred at the left training-wall nose, Figure 17B, which resulted in a rise in water surface under the counterweight of the radial gate, Figure 18. A riprap fill extending upstream from the training-wall nose, Figures 19 and 20, reduced this contraction until the water surface did not interfere with the counterweight, Figure 18. However, it was found more economical to re-design the counterweight to clear the water surface resulting from the contraction than to construct the riprap fill.

The projecting covers over the ice-prevention-system nozzles on the upstream face of the controlled crest, Figures 3 and 21 did not cause any measurable interference with flow over the spillway.

Pressures were measured on the controlled and uncontrolled crests, Figure 22, and were above atmospheric pressure for all ranges of operation.

Spillway-capacity curves were obtained for the uncontrolled crest operating alone, Figure 23, and for the uncontrolled and controlled crests operating together for free flow and also for various gate openings, Figure 24.

Outlet Works Studies

Tests on the outlet works, employing an entirely separate 1:20 scale model, Figure 25, were concerned primarily with the development of a satisfactory and economical stilling-basin.

Although the performance of the original design, which made use of a hydraulic jump type of energy dissipator was not entirely satisfactory, any degree of perfection could have been obtained by making the basin longer. This would have added to the cost of the structure. It was felt by the laboratory however, that if the hydraulic jump type of dissipator was abandoned that equal perfection in performance could also be obtained with a much smaller and more economical structure. Tests indicated that this contention was sound and the basin recommended for construction was less than half as long as the original basin, had no expensive center dividing wall, and required less depth as well as quantity of excavation.

Initial tests were conducted on the original basin design, Figure 26, and on Basin Studies No. 2 and 3, Figure 29. The center dividing wall was used only in Basin Study No. 1. Performance of these designs proved unsatisfactory, but did suggest the basic principles used in the recommended design.

The next series of eight basin studies were made to develop the recommended design. In these tests a deflector plate or hood was placed over the jets from the valves. Basin Study No. 4, the first of this series, Figure 29, used a flat deflector plate with the hollow-jet valves tilted downward 15°. This design showed great improvement over the preliminary tests. Basin Studies No. 5, Figure 29, and No. 6, Figure 34, employing a convex deflector plate showed little improvement over the flat plate deflector. Basin Study No. 7, and the following tests employed a concave deflector plate which resulted in better performance of the stilling-basin. The concave deflector plate of Basin Study No. 9, Figure 34, was found to be the most satisfactory. The remaining studies, No. 10 and 11, were made to obtain a satisfactory shape for the stilling-basin downstream from the deflector.

Basin Study No. 10, Figure 40, was found to give the best operation with the least scour for any of the schemes tested, but in the interest of economy the recommended basin, Figure 45, was developed. The recommended basin with valves set horizontally had an offset floor with the downstream section 9 feet higher than the upstream section. Operation with either one or two valves open resulted in good distribution of velocity at the downstream end of the basin, Figure 48. The water surface in the river channel was fairly smooth and scour was slight, Figures 46, 51, and 52.

PART I--SPILLWAY

Introduction

Enders Dam is located on Frenchman Creek, 1 mile south of Enders, Nebraska, Figure 1. The resulting reservoir is linked with Medicine Creek Reservoir for flood control and irrigation storage. The dam is a compacted earth structure with a protective cover of rock riprap. The major dimensions are: crest length 2,750 feet; thickness at base 600 feet; and height 100 feet.

Flood discharges are released through an open-channel spillway at the right or south abutment of the dam. It has a capacity of 200,000 second-feet and discharges into a concrete stilling-basin, Figure 2. The spillway has a controlled crest of six bays and an uncontrolled crest of one bay. The controlled crest at elevation 3097 feet has each bay regulated by a 30- by 50-foot radial gate. The uncontrolled crest at elevation 3112 feet has a width of 13 feet. Overall width of the spillway at the crest is 361 feet. The stilling-basin apron is horizontal and has a constant width of 400 feet.

The outlet works, Figure 4, for release of irrigation water is located 200 feet to the left of the spillway. The structure consists of a tunnel through the base of the dam terminating in two 60-inch hollow-jet valves. The valves discharge into a stilling-basin, which was developed from model studies discussed in Part II of this report.

The 1:72 Scale Model

The hydraulic model of the spillway, Figure 5, was built to a scale of 1:72. It consisted of the spillway and stilling-basin structure together with an approach section of the reservoir and a portion of the river channel downstream from the basin. The spillway crest and radial gates were made of sheet metal and the piers were made of wood. The spillway chute and the stilling-basin apron were of concrete formed to sheet metal templates. Training-walls were of wood covered with sheet metal. The downstream river channel was molded in find sand. A portable 6-inch pump supplied water to the model through an 8-inch line containing an orifice meter for measuring the flow. A rock baffle smoothed out the flow before it entered the spillway-approach section. A point gage located upstream from the crest a distance of 550 feet, prototype, was used to measure the reservoir elevation and a point gage near the downstream end of the tailbox was employed to set the tailwater elevation. Piezometers, installed in the uncontrolled crest and in one bay of the controlled crest, were used to measure the crest pressures, Figure 22.

The Investigation

The spillway studies were divided into two parts: (1) the stilling-basin; and (2) the spillway structure. The stilling-basin tests were planned so that performance data on the basin could be used to evaluate individual parts of the structure. From these results the most effective design was determined, consistent with construction cost. In determining the effectiveness of the stilling-basin, the factors used to judge its performance were: (1) location and appearance of the jump; (2) depth and extent of the scour downstream from the apron; and (3) height of waves in the river channel.

In the studies on the spillway structure, various lengths of dike were constructed upstream from the nose of the left training-wall. The dikes were for the purpose of reducing the height of the water-surface profile in the vicinity of the radial gates.

Tests were made with the ice-prevention nozzle hoods installed on the crest to determine whether they had any effect on flow conditions or capacity of the spillway. Pressures on both the controlled and uncontrolled crests were measured for various discharges and the discharge capacity of the spillway was obtained for the full range of headwater elevation.

Spillway Stilling-Basin Studies

Test 1. In the study on the original design, Test 1, Figure 6, the apron was at elevation 3021 feet. The model before operation is shown in Figure 7A. Coarse gravel was used to mold the first 100 feet of river channel below the apron and the remainder was formed in sand. The spillway was operated at discharges up to the maximum of 200,000 second-feet, using tailwater elevations from Curve A, Figure 8. This curve was obtained from the United States Engineers.

For all discharges the location and appearance of the jump was satisfactory. After 95 minutes of operation at 200,000 second-feet, the scour was observed and measured. Erosion was slight with the greatest depth of scour occurring just downstream from the right training-wall, Figure 7B, where there was a tendency to undermine the spillway apron. Erosion would have been deeper if a finer bed material had been used at the end of the apron.

Test 2. To reduce the scour tendencies at the downstream end of the right training-wall, a 45° wing-wall was installed, Test 2, Figure 6. The second tailwater Curve B, Figure 8, submitted by the design section was used for setting the tailwater elevation in this and all subsequent tests. Also, the coarse gravel at the end of the stilling-basin was removed and sand was used throughout the river channel. Other features remained as in the test on the original design, Test 1.

At a discharge of 200,000 second-feet, Figure 9A, the water surface was slightly rougher in the river channel than in Test 1, and the jump moved downstream exposing the chute blocks. Both effects were caused by the lower tailwater elevation indicated on Curve B and used in this test. Lowering the tailwater 3 feet caused the jump to sweep off the apron. Scour after 30 minutes operation, Figure 9B, was excessive downstream from the left training-wall where there was a tendency to undermine the apron. Absence of scour at the right training-wall was attributed to the presence of the 45° wing-wall. Also, the erosion in general was more extensive because of the removal of the coarse gravel and the use of a lower tailwater elevation.

Test 3. The downstream position of the jump in Test 2 indicated that the apron elevation was too high. Consequently, it was lowered 5 feet to elevation 3016, Test 3, Figure 6, and the chute blocks were also removed.

The appearance and location of the jump at maximum discharge, Figure 10A, were satisfactory. The jump remained on the apron even after lowering the tailwater 6 feet. Erosion, Figure 10B, after 45 minutes of operation at 200,000 second-feet was slight and the tendency to undermine the end of the apron was eliminated. The deepest erosion hole, elevation 3005, was 5 feet higher than the lowest point of Test 2. Results of this test showed that the apron elevation was satisfactory, but additional studies were made on chute blocks, and sills, training-walls, and wing-walls to be certain of obtaining the most economical and satisfactory design.

Test 4. For Test 4, the dentated end sill was replaced with a solid sill of the same height, Figure 6. The action of the basin at a discharge of 200,000 second-feet was unsatisfactory because of a high boil over the end sill. Scour was more severe than in any of the previous tests, Figure 11. The deepest erosion hole, elevation 2996, was 9 feet below the lowest elevation of Test 3.

Test 5. In Test 5, the chute blocks and dentated sill of the original design were re-installed, Figure 6. The appearance of the jump, Figure 12A, was very similar to that of Test 3. The jump remained on the apron after lowering the tailwater 7 feet, indicating the chute blocks were of value in holding the jump on the apron. The chute blocks had a negligible effect on the erosion pattern, however, as the results of a 45-minute scour test at a discharge of 200,000 second-feet, Figure 12B, were practically the same as Test 3, with the chute blocks removed, Figure 10B.

Test 6. In Test 6 the chute blocks were removed and the height of the dentated sill was increased to 12 feet, Figure 6. The appearance of the jump and the flow conditions in the river channel at 200,000 second-feet, Figure 13A, were similar to Test 5. Results of the jump sweep-out tests were the same as Test 5; the tailwater was lowered 7 feet and the jump remained on the apron. Scour after a discharge of 200,000 second-feet for 45 minutes, Figure 13B, was satisfactory. The lowest riverbed elevation was one foot higher than that of Test 5.

Test 7. The 45° wing-wall was replaced by a 90° wing-wall, Figure 6, for Test 7, since the designers decided that a 45° wing-wall was too expensive for the improvement it produced. The appearance of the flow, Figure 14A, was unchanged from that of Test 6, except for a slight eddy at the end of the right training-wall. Scour, Figure 14B, was similar for the two tests, except for some increase in erosion at the end of the right training-wall. This was not objectionable, however, since the scour was no deeper than at the end of the left training-wall where a 45° wing-wall could not be used because of the presence of the outlet works.

Test 8. In previous tests it appeared that the stilling-basin was too wide, and the purpose of Test 8 was to determine whether a reduction in width was possible. Auxiliary walls were installed in the stilling-basin, and extended upstream until they intersected the diverging training-walls of the spillway chute. Because the training-walls were sufficiently far apart that the alinement of one would not affect flow along the other, each wall was moved toward the centerline of the basin a different amount. The right wall was moved in 9.9 feet and the left wall 19.5 feet as shown in Figure 6.

At 200,000 second-feet, the flow along each training-wall appeared to be satisfactory, Figures 15A and 15B. Scour, however, was heavy after 45 minutes of operation, Figure 15C, and there was more tendency toward undermining the apron at the left training-wall. From these results it was decided that no reduction in the width of the stilling-basin should be made.

Recommended design. The recommended stilling-basin, Figure 16, was the same as that used in Test 8, with the addition of chute blocks. The chute blocks were included to help hold the jump on the apron in event of damage to the end sill or of decreased tailwater due to retrogression of the streambed. Tests were not made with the 12-foot sill and the chute blocks in place at the same time, since it was necessary to disassemble the model before the decision was made to retain the chute blocks. Also, it had been demonstrated that conditions of flow and erosion would be as good or better than those of Test 8.

Spillway Structure Studies

Left training-wall nose. The original spillway entrance was installed in the model with a 40-foot radius nose at the upstream end of each training-wall as shown in Figures 17A and B. With the gates partially opened, flow entering the spillway was smooth at all discharges, but with the gates raised free of the water surface, a noticeable contraction existed at the left nose for flows above 100,000 second-feet. The depressed water surface caused by this contraction for a discharge of 200,000 second-feet is shown in Figure 17B. A rise in water surface resulted downstream from the crest along the training-wall as shown by water surface Profile B, Figure 18. This surface was higher than the lowest portion of the gate counterweight when the radial gate was fully open. The water surface, Profile A, Figure 18, along the centerline of the second gate bay is a normal water surface profile, unaffected by the contraction.

To lower the water surface in the vicinity of the counterweight required a reduction of the contraction in the flow around the training-wall nose. This was accomplished by constructing a dike or wall upstream from the existing structure. A concrete structure was not practical, because of inadequate foundation, so an earth fill faced with rock riprap was investigated. The model riprap represented rock from one-half cubic foot to one-half cubic yard in the prototype. By trial the earth fill was made the minimum length consistent with good performance. Shorter lengths did not correct the depressed water surface and were eroded by the higher approach velocities close to the spillway crest. The design found satisfactory, Figure 19, had a total length of 150 feet. The dike in place in the model is shown in Figure 20A. Operation at maximum discharge, Figure 20B, was satisfactory since the water surface was lower than the counterweight as shown by Profile C, Figure 18.

Slight disturbance of the water surface was visible at the upstream end of the dike, but had no measurable effect on the flow. Along the riprap face, a maximum velocity of about 17 feet per second prototype occurred in the vicinity of the disturbance. This velocity was not sufficient to move the model riprap.

Because of the difficulty of obtaining riprap of sufficient size for prototype use, and because the dike reduced the elevation of the water surface under the counterweight only about 2 feet, it was decided not to construct the dike, but to solve the problem by the alternative of re-designing the gate counterweight to clear the high water surface resulting from the contraction. Thus, by reducing the depth of the counterweight, until it cleared the water surface, the original entrance design could be used.

<u>Effect of ice-prevention nozzles.</u> Installation of the ice-prevention system in the prototype will result in the placing of six air nozzles in each gate bay on the upstream face of the controlled crest. Each nozzle will be protected by a partially streamlined cover 15 inches in height which projects into the flow area, Figure 3. Since the effect of these projections on spillway discharges was unknown, they were installed in the model, Figure 21A. Operation at flows from near zero to maximum produced no visible disturbance to the water flowing over the crest as shown in Figure 21B. Careful tests showed that there was no measurable change in the spillway discharge coefficient with the nozzles in place. Accordingly, it was concluded that no adverse hydraulic effects would be produced by the ice-prevention nozzles.

Crest pressures. Ten piezometers were installed along the centerline of the uncontrolled crest and ten along the centerline of the controlled crest of the second gate bay from the right side of the spillway. Each piezometer was connected to an open water-manometer. Pressures for all piezometers were recorded simultaneously by photographing the manometer board at discharges of 50,000, 100,000, 150,000, and 200,000 second-feet with the radial gates fully open. Pressure curves for both crests are shown in Figure 22. All pressures were above atmospheric for the discharges tested, with the magnitude generally increasing with the discharge. Lowest pressures were found for the combination of maximum reservoir elevation with small gate openings on the controlled crest. However, since all pressures were greater than atmospheric, the crest designs were considered satisfactory.

Calibration of spillway. The spillway was calibrated for various combinations of flow conditions. An orifice meter was used to measure the discharge for flows above 2,000 second-feet. For low flows, a weighing tank was employed. The reservoir elevation was measured with a point gage, located 550 feet upstream from the crest, Figure 5.

With all control gates closed, a curve was obtained of reservoir elevation versus discharge for the uncontrolled crest, Figure 23. From these results the coefficient of discharge C was computed from the formula $Q = CL\,(H + h_v)^{3/2}$ The curve C versus reservoir elevation is shown in Figure 23. The expression $(H + h_v)$ in this formula is the total head on the spillway crest and includes the measured height H of the water surface above the spillway crest, and the velocity head, h_v. The head measured in the model represented the total head since the point gage was upstream 550 feet in a region of extremely low velocity.

The discharge curve of the spillway for all gates fully open and for gate openings at 4-foot intervals is shown in Figure 24. Above headwater elevation 3112, flow over the uncontrolled crest has been included in the discharges. The coefficient of discharge C versus reservoir elevation for discharge over the controlled crest only with the gates raised free of the water surface, is also shown in Figure 24.

PART II—OUTLET WORKS

Introduction

A 1:20 scale model entirely separate from the spillway model was used in the study of the outlet works. The two 60-inch hollow-jet valves of the prototype were represented by 3-inch hollow-jet valves in the model. Provisions were made in the model to pass the maximum prototype discharge of 930 second-feet with one valve operating and 1,360 second-feet with both valves operating.

The model studies were in two parts. In the first or initial studies the original design, Figure 26, was tested. Also in the initial tests were Basin Studies No. 2, and No. 3, Figure 29. The remaining studies were made to develop a design employing a deflector plate or valve hood, Figures 29, 34, and 40. Although some of the designs appeared satisfactory, others were tested to be certain of obtaining the greatest possible improvement.

The 1:20 Scale Model

Design

The original 1:20 scale model of the outlet works is shown in Figure 25. The stilling-basin training-walls were of wood covered with sheet metal and the apron was of concrete formed to sheet metal templates. The dividing wall was made of wood. The tailbox, lined with sheet metal, contained sand molded to represent the bottom of the river channel. Two 3-inch model hollow-jet valves were located at the upstream end of the basin. Water to the model was supplied by a 6-inch pump connected to an orifice meter for measuring the flow. The pipe from the meter terminated in an 8-inch-diameter header to which was connected two 3-inch pipes which supplied water to the hollow-jet valves.

Operation

In the stilling-basin tests the maximum discharges used were 930 second-feet for one valve operating and 1,360 second-feet for both valves operating. Piezometers were used to measure the pressure head at the valves. This head was set to the corresponding prototype pressure head calculated for the given discharges. A point gage was used to measure the tailwater elevation, which was set at elevation 3038 for the two discharges.

After the test on the original design, the center dividing wall was removed and was not used again on any of the remaining studies. The model was rebuilt and the stilling-basin shortened after completing Basin Study No. 9. At this time a glass window was also installed in the left training-wall to observe flow conditions under the hood and in the section downstream from the hood.

Investigation of Outlet Works Stilling-Basin

Investigation of the outlet works was concerned primarily with studies of the stilling-basin. Three factors were used in judging the effectiveness of the designs tested. They were: (1) roughness and general appearance of the water surface in the river channel; (2) velocity distribution in the downstream section of the basin; and (3) scour in the river channel. As the tests progressed toward the final design, piezometers were installed in the model and pressures determined on those parts of the structure in contact with high-velocity flow.

Initial Studies

Basin Study No. 1. The original stilling-basin design, Figure 26, had a total length of 175 feet with a center dividing wall 22 feet high. Operation with one and two valves at the maximum discharges is shown in Figures 27A and B. The location of the jump and resulting flow in the river channel was unsatisfactory with two valves operating. With one valve discharging the jump moved too far downstream, resulting in incomplete energy dissipation.

Erosion after 1-hour operation with one valve at 930 second-feet, Figure 28A, was not excessive, but showed a tendency to undermine the apron. A hole 5 feet deep occurred at the end of the basin. Scour from the operation of both valves was slight, Figure 28B.

Basin Study No. 2. It was desirable to eliminate the center dividing wall, since it was expensive to construct and was only for the purpose of giving good flow conditions when operating one valve. In Basin Study No. 2, Figure 29, a hood was substituted for the wall. The hood was placed over the full width of the stilling-basin to spread the jets so that even with one valve operating, flow would be uniformly distributed over the width of the basin.

Sufficient spreading of the jet did not occur with one valve operating at 930 second-feet, Figure 30A, because of the high velocity of the jet. Decreasing the opening between the lower end of the hood and the basin floor to obtain greater spreading of the jet only created backwater which submerged the valves. Operation of both valves with a total discharge of 1,360 second-feet showed some improvement over that for the original design.

Basin Study No. 3. In Basin Study No. 3, a raised floor in the upstream end of the basin, Figure 29, was used to intercept and spread the jets from the valves. Unsatisfactory flow resulted with either one or two valves operating, Figures 31A and B. Very little spreading of the jets occurred because of the short length of raised floor, and flow was concentrated on the surface of the basin and river channel. Lowering the downstream end of the raised floor, caused an even rougher water surface in the river channel.

Development of Recommended Design

Basin Study No. 4. In this test a hood or deflector plate was placed above the valves, and the floor was placed at elevation 3020, for the full length of the basin, Figure 29. The hollow-jet valves were tilted downward at an angle of 15°. Operation of one and two valves, Figures 32A and B, showed marked improvement over previous designs. With two valves operating, a fairly uniform distribution of velocity occurred in the downstream end of the basin as well as a smooth water surface. This was true to a lesser extent with one valve open. In fact, flow conditions at the end of the stilling-basin had been improved sufficiently to allow a 50-foot reduction in the basin length.

By experiment, the most effective height of the opening between the hood and basin floor was found to be between 3 and 4 feet. With larger openings, spreading of the jet was insufficient and with smaller openings, the flow backed up under the hood and partially submerged the valves.

The results of Basin Study No. 4 indicated the hood principle could be used to provide an efficient and economical stilling-basin; consequently further tests were made to improve this design.

Basin Study No. 5 and 6. In Basin Study No. 5 a convex deflector plate was used with a 4-foot opening at the lower end and the valves were depressed 30° below horizontal, Figure 29. Performance with one and two valves at maximum discharge, Figure 33A and B, was similar to Basin Study No. 4. However, the design section decided the 30° angle of the valves could not be used in the prototype because it would require raising the tunnel to a higher elevation.

For Basin Study No. 6, the valves were depressed 11° below horizontal since the designers had indicated that this was the maximum permissible angle for the given tunnel elevation. The convex plate deflector was changed to fit the 11° valve angle, Figure 34, and piezometers were installed. Conditions of flow for one and two valves discharging, Figure 35A and B, was good and indicated that a reduction of 60 feet in the basin length was possible. Pressures on the deflector, Figure 34, were above atmospheric for both tests. The pressures varied from a minimum of 1 foot of water at Piezometer No. 3, when one valve was operating, to a maximum of 15 feet of water at piezometer No. 8, when both valves were operating. The elevation of the water surface upstream from the hood was lower than the tailwater elevation, indicating that there was no tendency for the valves to become submerged.

Basin Study No. 7 and 8. A concave hood was installed for Basin Study No. 7, since it was necessary to explore all possible deflector shapes before selecting any design. The 11° valve angle was maintained. Best operation was obtained with the lower end of the deflector, placed 5.50 feet above the basin floor, Figure 34. Performance of the stilling-basin for the two maximum operating conditions, Figure 36A and B, was much better than any of the previous tests. Pressures on the deflector were all above atmospheric, and generally higher than those in Study No. 6, Figure 34. The pressures shown are plotted to the same scale as the stilling-basin drawings. The maximum pressure was 28 feet of water at Piezometer No. 6, and the minimum was 4 feet of water at Piezometer No. 3, both occurring with one valve operating. Since the concave shape of the hood provided considerable improvement in basin performance, the concave shape was maintained in subsequent designs.

In Basin Study No. 8, the 11° depression of the valves was eliminated at the request of the designers because of structural considerations. In addition, part of the space beneath the deflector was filled in, as shown in Figure 34.

Satisfactory transverse flow distribution resulted with this design, Figures 37A and B, but the valves were partially submerged at maximum discharges. In the prototype this might produce dangerous negative pressures within the valve. The submergence was not relieved by increasing the opening between the lower end of the deflector and the floor from 5 to 6 feet because of the steep angle at which the jets were directed toward the floor.

Basin Study No. 9. It was believed that the most suitable hood shape could be determined from the shape of the jets issuing from the valves. Consequently the upper nappe profile was determined, Figure 38, and the hood curve fitted to it. The filled-in area beneath the jets was also modified, and tests were made first with a sloping, and then with a curved floor, Figure 34.

Uniform flow and a smooth water surface in the river channel was obtained for all test conditions, Figures 39A and B. Tests showed the height of the opening at the downstream end of the deflector could be reduced from 6 feet to 4.5 feet without causing sufficient backwater to submerge the valves. This was a favorable characteristic of the design since it demonstrated that close tolerances in dimensions would not be necessary when building the deflector.

The curved floor shown by the dashed line, Figure 34, restricted the amount of turbulent action of the water under the deflector and required more stilling-basin length than the straight floor with a 1.5:1 slope. Again, all pressures on the deflector were above atmospheric, Figure 34, but were less than those of Basin Study No. 7. The maximum pressure, which occurred, was 18 feet of water at Piezometer No. 4, when one valve was operating. The minimum pressure which occurred was 1 foot of water at Piezometer No. 2, when both valves were operating.

Basin Study No. 10 and 11. The model was rebuilt and a glass panel was installed in a section of the left training wall. The length of the stilling-basin was also reduced 60 feet. Basin Study No. 10, Figure 40, used a parabolic hood in which piezometers were installed. Piezometers were also placed in the floor of the stilling-basin.

Performance at maximum flow with one and two valves operating, Figure 41A and B, was unchanged from Basin Study No. 9. Pressures on the deflector and floor, Figure 40, were above atmospheric in all tests. The maximum pressure on the hood was 17 feet of water at Piezometer No. 6, when one valve was operating and the minimum was 3 feet of water at Piezometer No. 4, when both valves were operating. Flow in the stilling-basin as seen through the glass wall is shown in Figure 42. Entrained air in the water and the path of the turbulence along the floor is shown in the photographs. The high speed photograph, Figure 42B, stopped the motion of flow and shows the character of the jet issuing from the valves.

Very slight scour resulted after 1 hour of operation with one valve discharging 930 second-feet, Figure 43A. With two valves discharging 1,360 second-feet, practically no erosion occurred, Figure 43B. Velocity distribution was good with a smooth water surface in the river channel. The designers, after viewing these tests, decided that better stilling action occurred than was considered necessary. Upon consultation with the structural designers, it was decided that considerable savings in cost could be made by raising the stilling-basin floor downstream from the deflector. Further tests were made to develop the basin with a higher floor.

The downstream section of floor was raised 9 feet, Figure 40. Subsequent trials indicated that this was the maximum height the floor could be raised and still maintain good hydraulic performance. The deflector of Basin Study No. 10 was used in Basin Study No. 11, and all remaining tests. Figure 44A and B show the flow at the two maximum flow conditions, as seen through the glass window. For all discharges the water was directed upward, creating a high boil, which smoothed out to some extent upon reaching the river channel, but the surface velocity in the channel was relatively high.

The length of the basin was reduced an additional 40 feet, making the total length 100 feet less than the original design, and 5 additional tests were made, designated as Basin Studies No. 11A through 11E, Figure 40. In Study No. 11A the downstream floor elevation was 3026; and for the following four studies, it was 3029. As shown in Figure 40, the two floor elevations were connected by sloping and vertical walls and various blocks were placed against these walls for three of the studies.

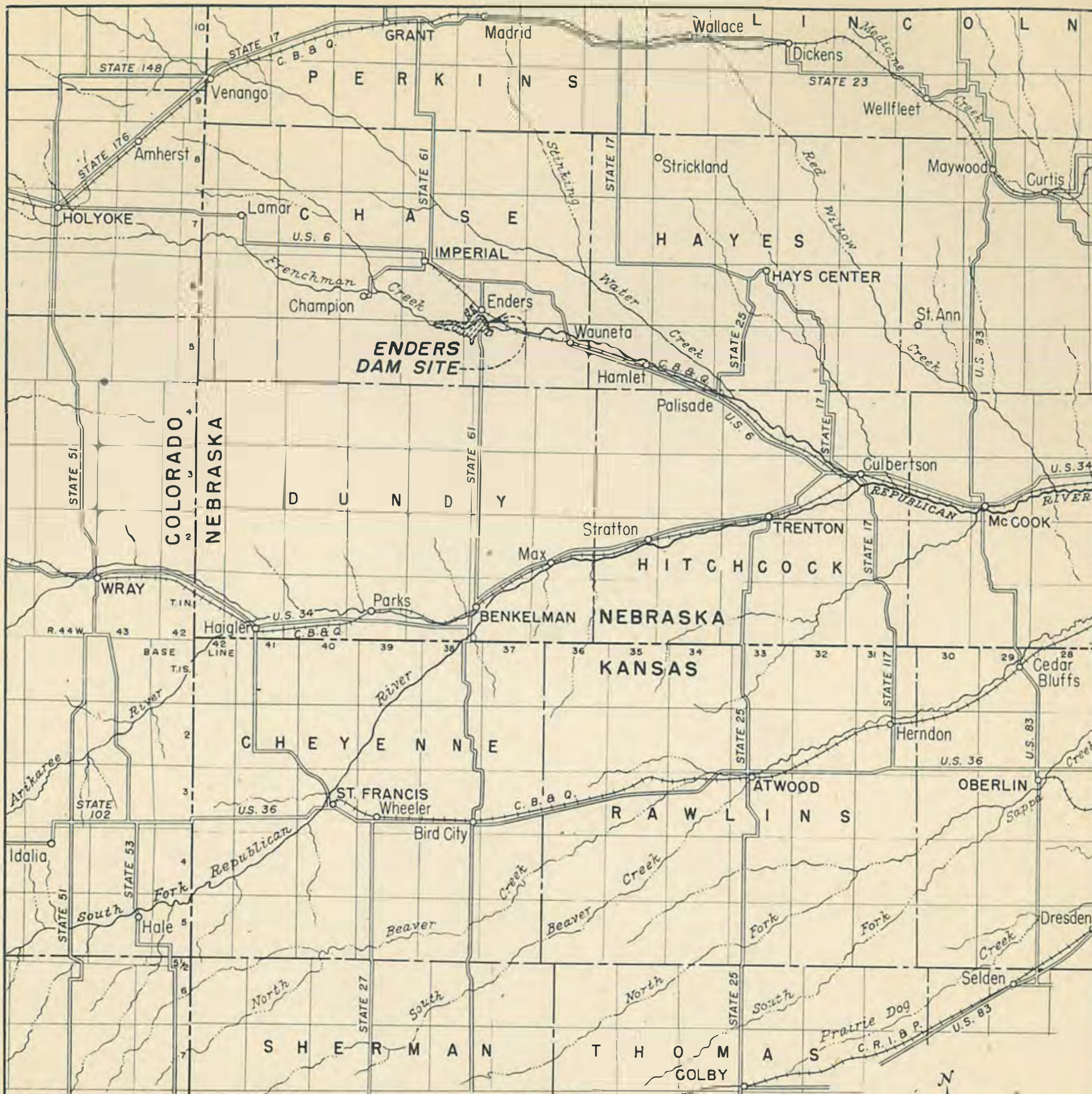
Results of these tests indicated that the boil intensity on the water surface was affected by the shape of the surface between the two horizontal floors. With a vertical wall, the velocity was directed parallel to the wall, resulting in a higher boil. With the sloping wall, the boil was directed farther downstream, and a greater stilling-basin length was required. The use of baffle-type blocks placed against the face of the wall reduced the height of the boil by spreading it over a larger area.

Recommended Design

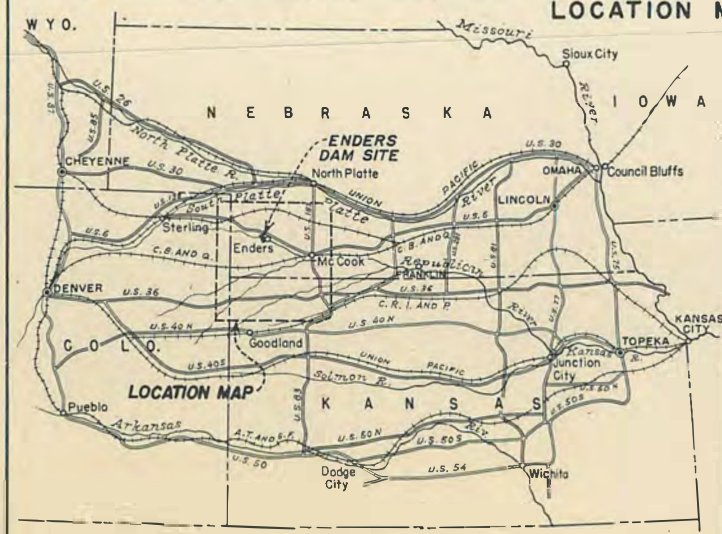
The recommended stilling-basin, Figure 45, employed two blocks located downstream from the end of the deflector. With maximum discharge from one and two valves, Figure 46A and B, the boil was well distributed over the surface of the stilling-basin. Flow conditions as seen through the glass window for these discharges, are shown in Figure 47A and B. Velocity distribution at the downstream end of the stilling-basin was satisfactory as shown by the velocity contours plotted in Figure 48. Surface velocities were higher than those on the bottom, but were not objectionable. With one valve operating, higher velocities occurred on the side with the valve discharging.

The table of Figure 45 shows pressures on the deflector and floor at the locations indicated. All pressures were above atmospheric for every operating condition with the highest pressures occurring on the deflector hood. Photographs of the manometer boards used in determining these pressures, Figures 49 and 50, show the water-column heights for one and two valves discharging. The zero for each piezometer is indicated by the short horizontal lines.

Erosion after 1 hour operation with one and two valves discharging was slight, using bank-run sand, Figures 51A and B. Greater scour occurred when using 50-100- and 100-200-mesh sand at the downstream end of the stilling-basin, Figures 52A and B, with two valves discharging 1,360 second-feet. Even with the 100-200-mesh sand, however, the results were considered satisfactory, and this design was recommended for construction in the field.



LOCATION MAP



INDEX MAP

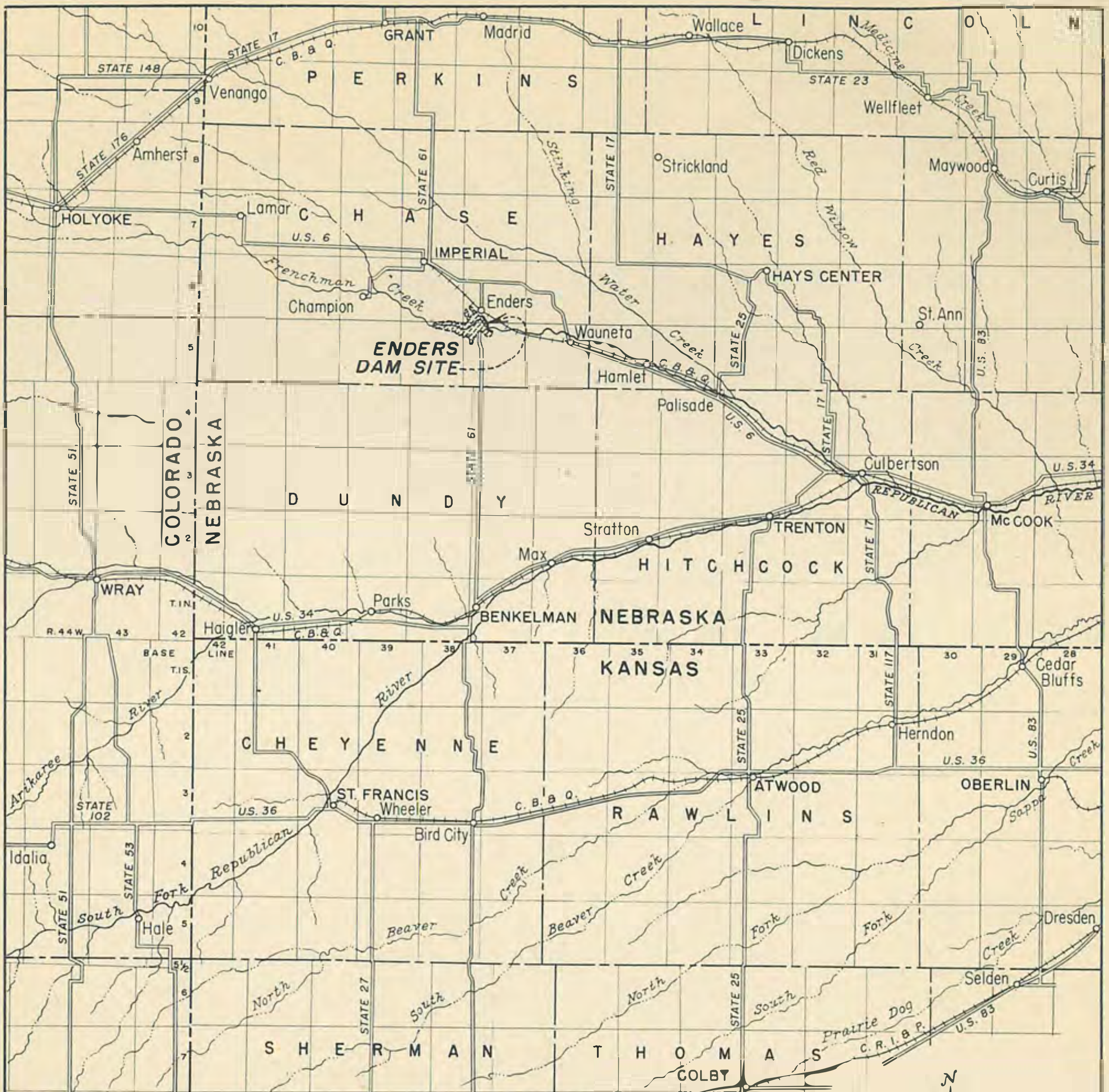
SCALE OF MILES

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
FRENCHMAN-CAMBRIDGE UNIT-NEBR.

ENDERS DAM
LOCATION MAP

DRAWN G.W.M.	SUBMITTED T.V.B. Keener
TRACED C.M.A.	RECOMMENDED W.H. Nalder
CHECKED B.C.W. O.H.	APPROVED Walker R. Young CHIEF ENGR.

DENVER COLORADO, MAY 28, 1946 328-D-74



LOCATION MAP

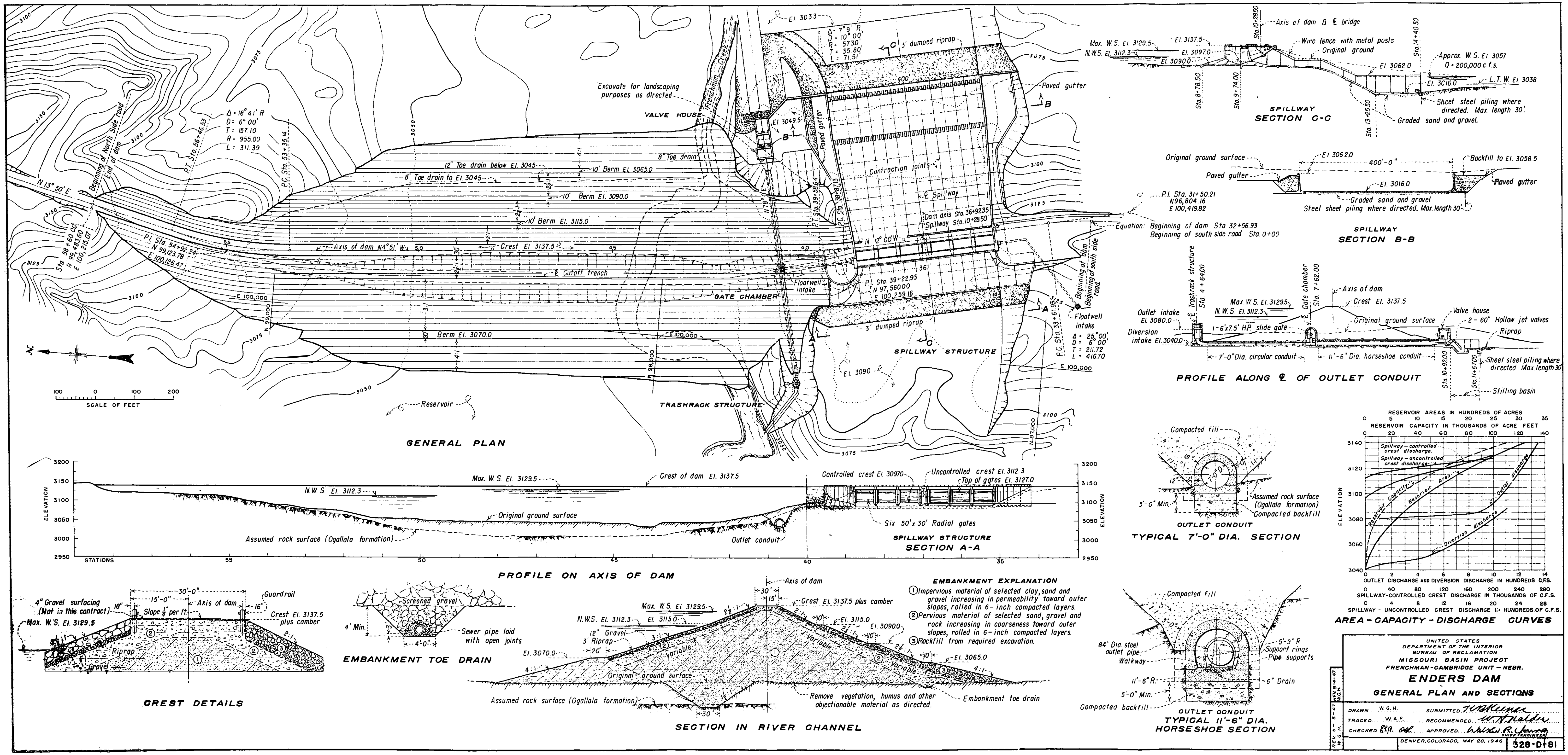
INDEX MAP

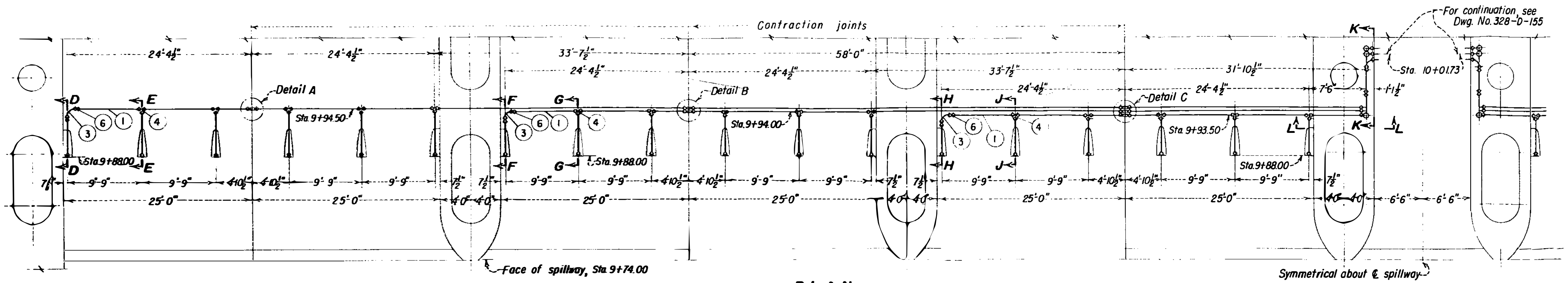
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
FRENCHMAN-CAMBRIDGE UNIT-NEBR.

ENDERS DAM

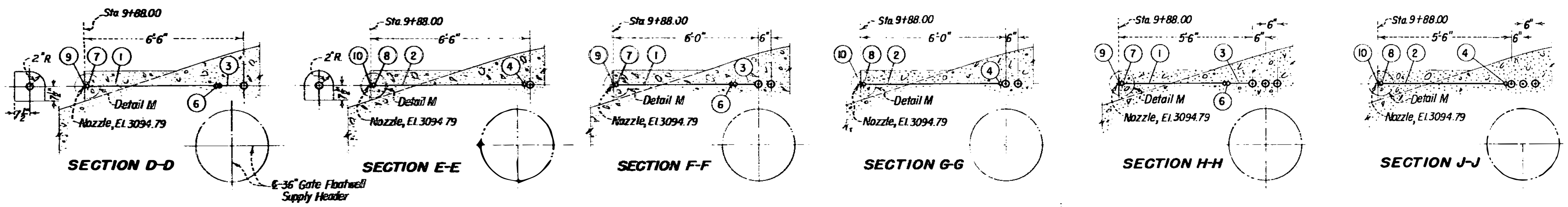
LOCATION MAP

DRAWN G.W.M.	SUBMITTED [signature]
TRACED C.M.A.	RECOMMENDED [signature]
CHECKED [signature]	APPROVED [signature] CHIEF ENG.
DENVER COLORADO, MAY 28, 1946	328-D-74

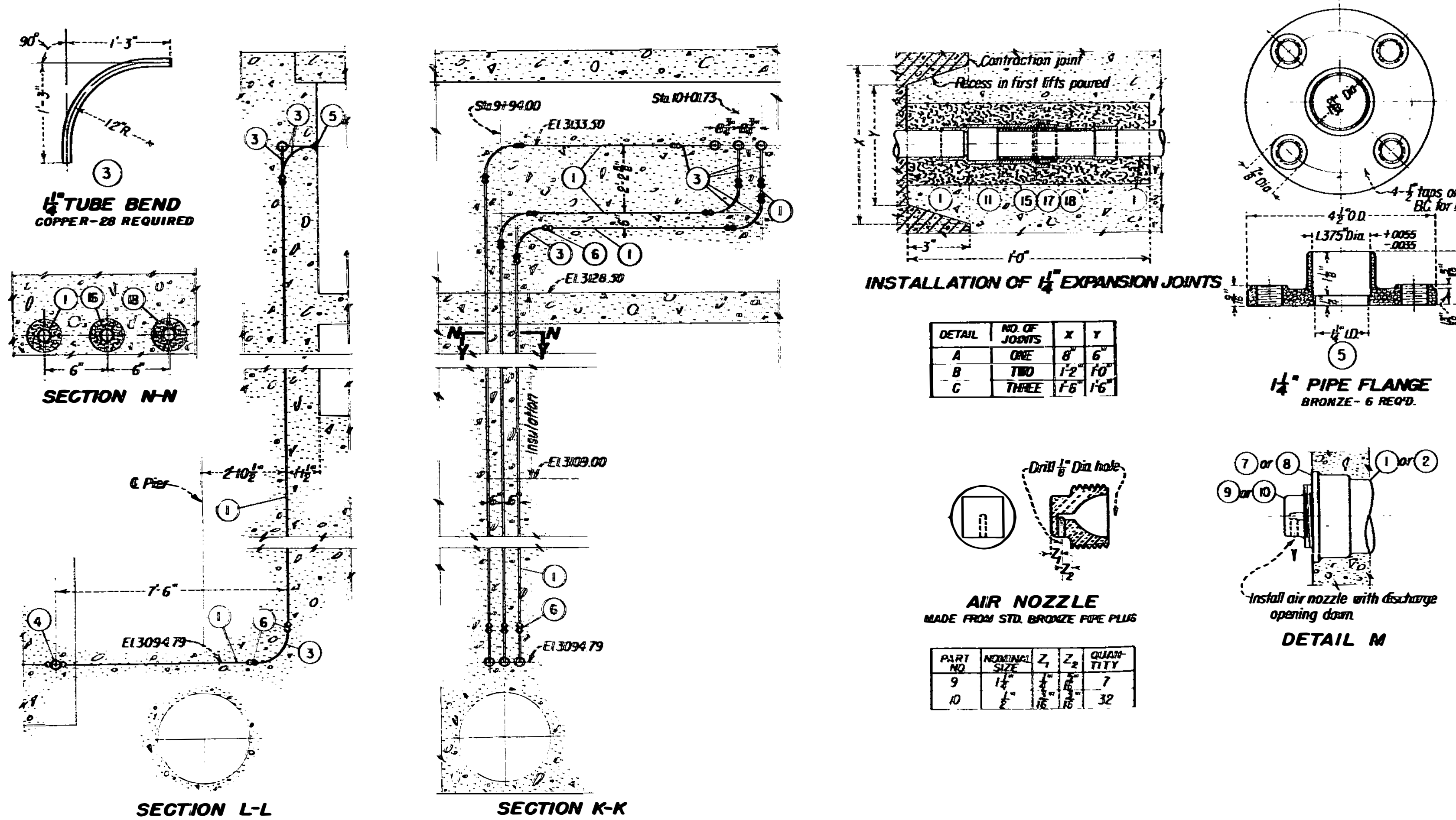

GENERAL PLAN
VALVE HOUSE
GATE CHAMBER
TRASHRACK STRUCTURE
SPILLWAY STRUCTURE
Reservoir
Frenchman Creek
Excavate for landscaping purposes as directed
Axis of dam N4°51' W
Crest El. 3137.5
Cutoff trench
10' Berm El. 3065.0
10' Berm El. 3090.0
10' Berm El. 3115.0
Berm El. 3070.0
12" Toe drain below El. 3045
8" Toe drain to El. 3045
8" Toe drain
Floatwell intake
3' dumped riprap
Paved gutter
Contraction joints
Spillway
Dam axis Sta. 36+92.35
Spillway Sta. 10+28.50
Equation: Beginning of dam Sta. 32+56.93
Beginning of south side road Sta. 0+00
Beginning of North Side road
End of dam
SCALE OF FEET
PROFILE ON AXIS OF DAM
Max. W.S. El. 3129.5
N.W.S. El. 3112.3
Crest of dam El. 3137.5
Original ground surface
Assumed rock surface (Ogallala formation)
Outlet conduit
Controlled crest El. 3097.0
Uncontrolled crest El. 3112.3
Top of gates El. 3127.0
Six 50' x 30' Radial gates
SPILLWAY STRUCTURE
SECTION A-A
SPILLWAY
SECTION C-C
SPILLWAY
SECTION B-B
PROFILE ALONG ℄ OF OUTLET CONDUIT
7'-0" Dia. circular conduit
11'-6" Dia. horseshoe conduit
2 - 60" Hollow jet valves
Stilling basin
OUTLET CONDUIT
TYPICAL 7'-0" DIA. SECTION
OUTLET CONDUIT
TYPICAL 11'-6" DIA. HORSESHOE SECTION
AREA - CAPACITY - DISCHARGE CURVES
RESERVOIR AREAS IN HUNDREDS OF ACRES
RESERVOIR CAPACITY IN THOUSANDS OF ACRE FEET
OUTLET DISCHARGE AND DIVERSION DISCHARGE IN HUNDREDS C.F.S.
SPILLWAY-CONTROLLED CREST DISCHARGE IN THOUSANDS OF C.F.S.
SPILLWAY - UNCONTROLLED CREST DISCHARGE IN HUNDREDS OF C.F.S.
CREST DETAILS
4" Gravel surfacing (Not in this contract)
Guardrail
EMBANKMENT TOE DRAIN
Screened gravel
Sewer pipe laid with open joints
SECTION IN RIVER CHANNEL
Remove vegetation, humus and other objectionable material as directed.
Embankment toe drain
EMBANKMENT EXPLANATION
① Impervious material of selected clay, sand and gravel increasing in permeability toward outer slopes, rolled in 6-inch compacted layers.
② Pervious material of selected sand, gravel and rock increasing in coarseness toward outer slopes, rolled in 6-inch compacted layers.
③ Rockfill from required excavation.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
FRENCHMAN-CAMBRIDGE UNIT - NEBR.
ENDERS DAM
GENERAL PLAN AND SECTIONS
DRAWN W.G.H.
TRACED W.A.F.
SUBMITTED
RECOMMENDED
CHECKED
APPROVED
CHIEF ENGINEER
DENVER, COLORADO, MAY 28, 1946
328-D-81



PLAN



SECTION D-D SECTION E-E SECTION F-F SECTION G-G SECTION H-H SECTION J-J



$1\frac{1}{4}$" TUBE BEND
COPPER–28 REQUIRED

SECTION N-N

SECTION L-L

SECTION K-K

INSTALLATION OF $1\frac{1}{4}$" EXPANSION JOINTS

DETAIL	NO. OF JOINTS	X	Y
A	ONE	8'	6"
B	TWO	1'-2"	1'-0"
C	THREE	1'-6"	1'-6"

AIR NOZZLE
MADE FROM STD. BRONZE PIPE PLUG

PART NO.	NOMINAL SIZE	Z_1	Z_2	QUANTITY
9	$1\frac{1}{4}$"			7
10	$\frac{1}{2}$"			32

$1\frac{1}{4}$" PIPE FLANGE
BRONZE- 6 REQ'D.

DETAIL M

LIST OF PARTS

PART NO.	DESCRIPTION	MATERIAL	QUANTITY	
1	$1\frac{1}{4}$" Tubing 20'-0" length.	Copper	54	*
2	$\frac{1}{2}$" Tubing 20'-0" length.	Copper	14	*
3	$1\frac{1}{4}$" Tube bend (see detail).	Copper	28	
4	Tee-$1\frac{1}{4}$" Copper x $1\frac{1}{4}$" copper x $\frac{1}{2}$" copper.	Bronze	32	
5	$1\frac{1}{4}$" Pipe flange (see detail).	Bronze	6	
6	Coupling-$1\frac{1}{4}$" copper x $1\frac{1}{4}$" copper.	Bronze	65	*
7	Coupling-$1\frac{1}{4}$" copper x $1\frac{1}{4}$" I.P.S. female thread.	Bronze	7	
8	Coupling-$\frac{1}{2}$" copper x $\frac{1}{2}$" I.P.S. female thread.	Bronze	32	
9	$1\frac{1}{4}$" Air nozzle (see detail).	Bronze	7	*
10	$\frac{1}{2}$" Air nozzle (see detail).	Bronze	32	*
11	Expansion joint (see detail).	Bronze	12	
12	$\frac{1}{2}$" x 1" Hex. head cap screw, semi-finished.	Naval Brass	26	*
13	Solder, $\frac{1}{8}$" round wire (95% tin and 5% antimony).	Standard	6#	*
14	Solder flux.	Standard	12 oz.	*
15	Hair felt, 1" thick x 3'-0" wide.	Standard	6'-0"	*
16	Wool felt, (see general note).	Standard	130'	*
17	Twine jute, three ply.	Standard	$\frac{1}{2}$#	*
18	Paint, asphaltic emulsion.	Standard	1 Gal.	*

GENERAL NOTE

Joints indicated as copper connections shall be properly sized and finished for capillary type of solder joints. Solder joint type of fittings shall be made of cast bronze alloy conforming to Federal Specification QQ-B-691b, composition 2, and shall be air-tested under water at 90 lbs./in.^{2} gauge pressure.

Threaded I.P.S. joints shall have full clean cut American National pipe threads.

Copper tubing shall be of type "K" hard copper and conform to Federal Specification WW-T-799 a, and shall be furnished in lengths specified. All bends shall be made up complete by manufacturer. A light anneal for making the bends will be permitted, so that the bending will return the tubing to its approximate initial hardness.

Part 5 shall be made of cast bronze alloy conforming to Federal Specification QQ-B-691b, composition 2.

Part 11 shall be a threaded gland type expansion joint allowing a traverse of 3" ± and shall be furnished with graphited braided asbestos packing.

Part 16 shall be 1" thickness of pre-shrunk wool felt pipe insulation for $1\frac{1}{4}$" copper tubing, furnished complete with canvas finish and metal bands similar to Johns-Manville No. IN-270.

Total quantities marked with an asterisk * include excess.

Each part or package shall be marked to show the drawing number and part number, thus: 154-1, etc.

INSTALLATION NOTE

Male pipe threads and flange faces shall be coated with a thin coat of red or white lead or equivalent when assembled.

During concreting and pressure grouting, maintain a hydrostatic pressure in all embedded pipes, as directed by the contracting officer.

Protect faces of flanges 5 against damage before placing of concrete.

Air nozzles 9 and 10 shall be installed with discharge opening facing downward.

Expansion joints 11 shall be installed with sleeve in middle of traverse and shall be wrapped with 1" minimum thickness of hair felt. The hair felt wrapping 15 shall be tied with jute twine 17 and painted with $\frac{1}{16}$" minimum thickness of cold asphaltic emulsion 18.

The pre-shrunk wool felt 16 shall be painted with $\frac{1}{16}$" minimum thickness of cold asphaltic emulsion 18.

REFERENCE DRAWINGS

SPILLWAY, GATE STRUCTURE 328-D-84

LIST OF DRAWINGS

ICE PREVENTION AIR SYSTEM:
SPILLWAY, PLAN AND SECTIONS 328-D-154
COMPRESSOR PIPING AND FOUNDATIONS 328-D-155

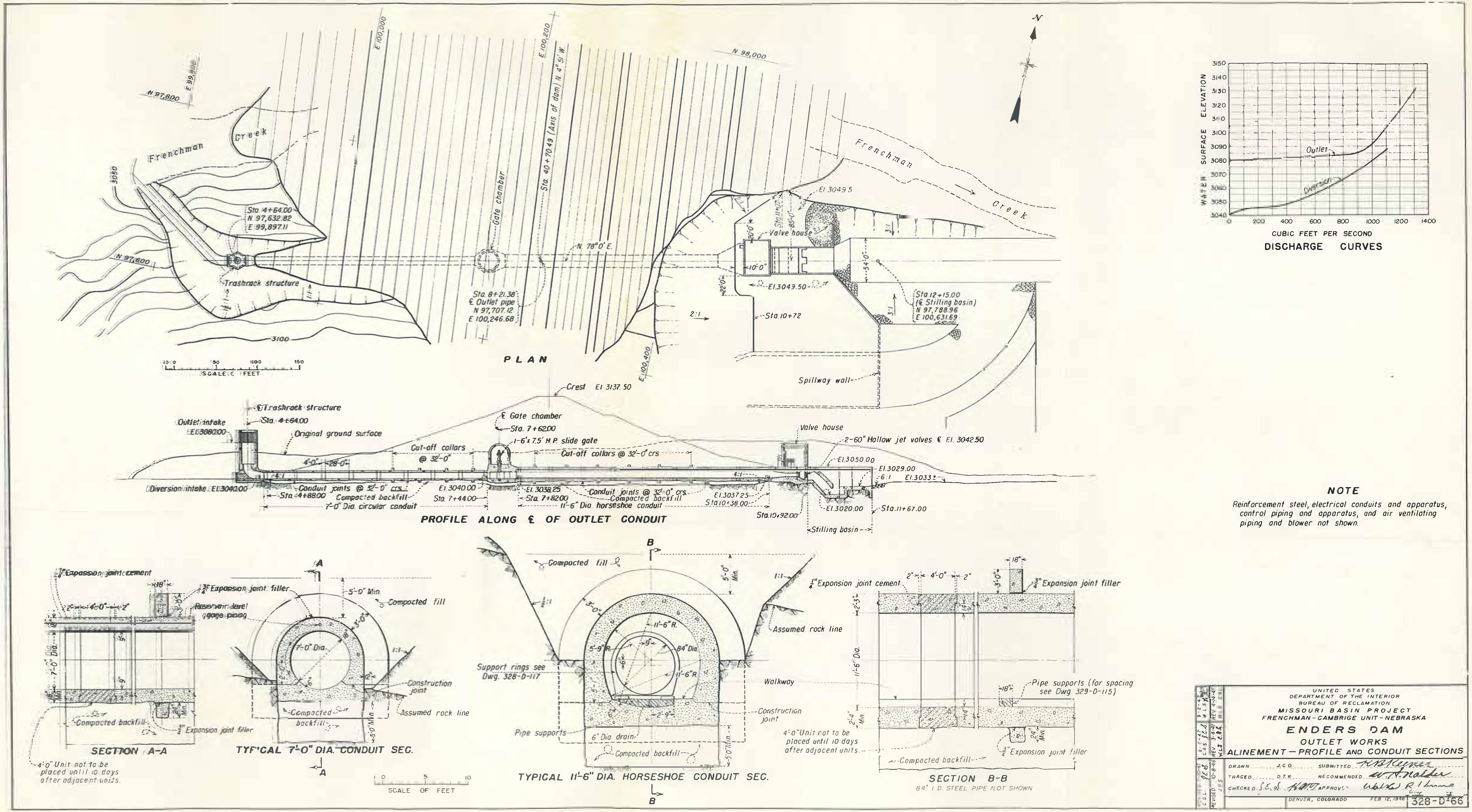
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
FRENCHMAN-CAMBRIDGE UNIT-NEBRASKA

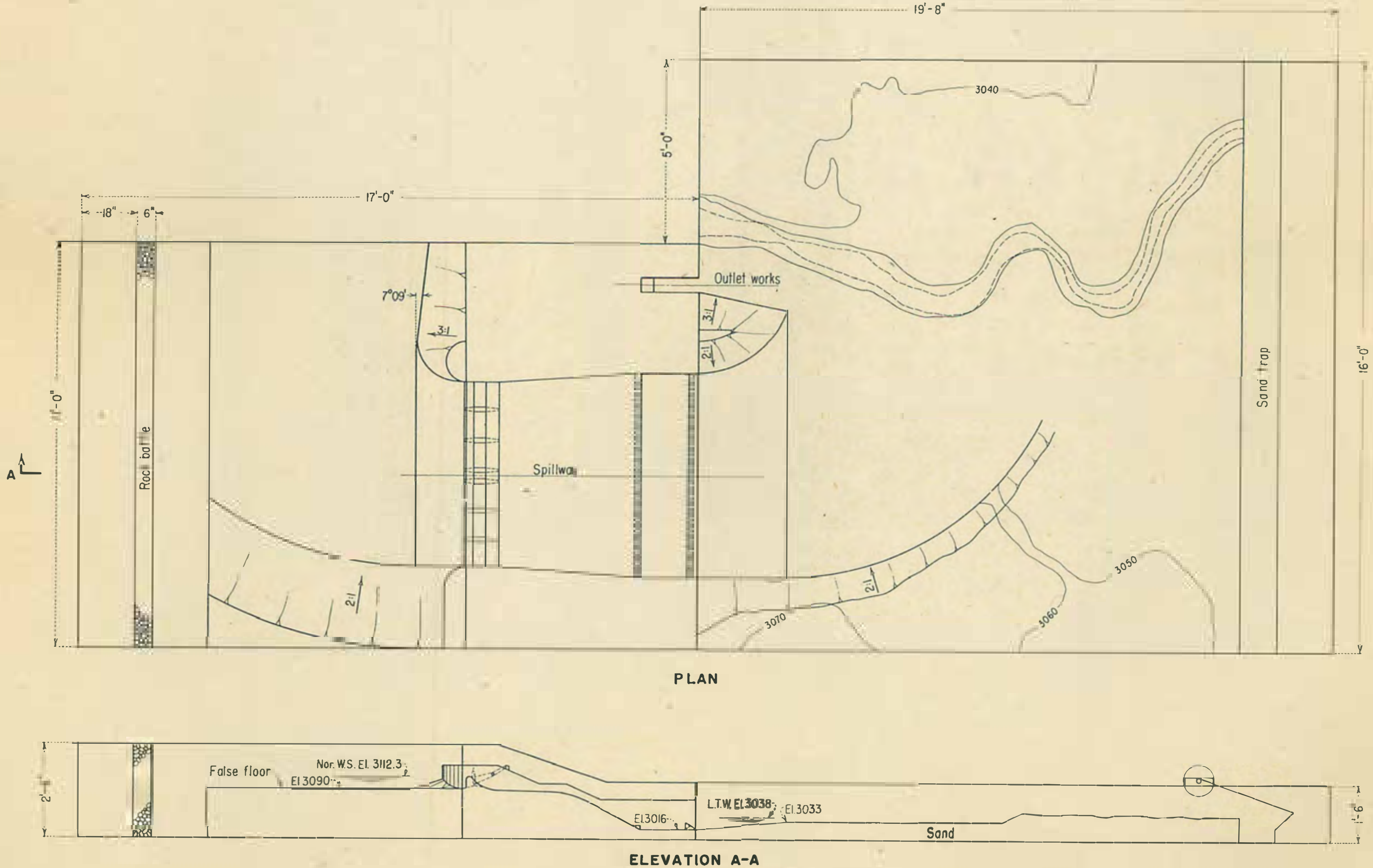
ENDERS DAM
SPILLWAY
ICE PREVENTION—AIR SYSTEM
DISTRIBUTION PIPING

DRAWN REW.-GMM SUBMITTED [signature]
TRACED J.L.V. RECOMMENDED [signature]
CHECKED L.U.L. C.O.S. APPROVED H. H. Plumb
ACT. ASS'T. CHIEF ENGINEER

REV. B TRCD 6-16-47 2-25-48

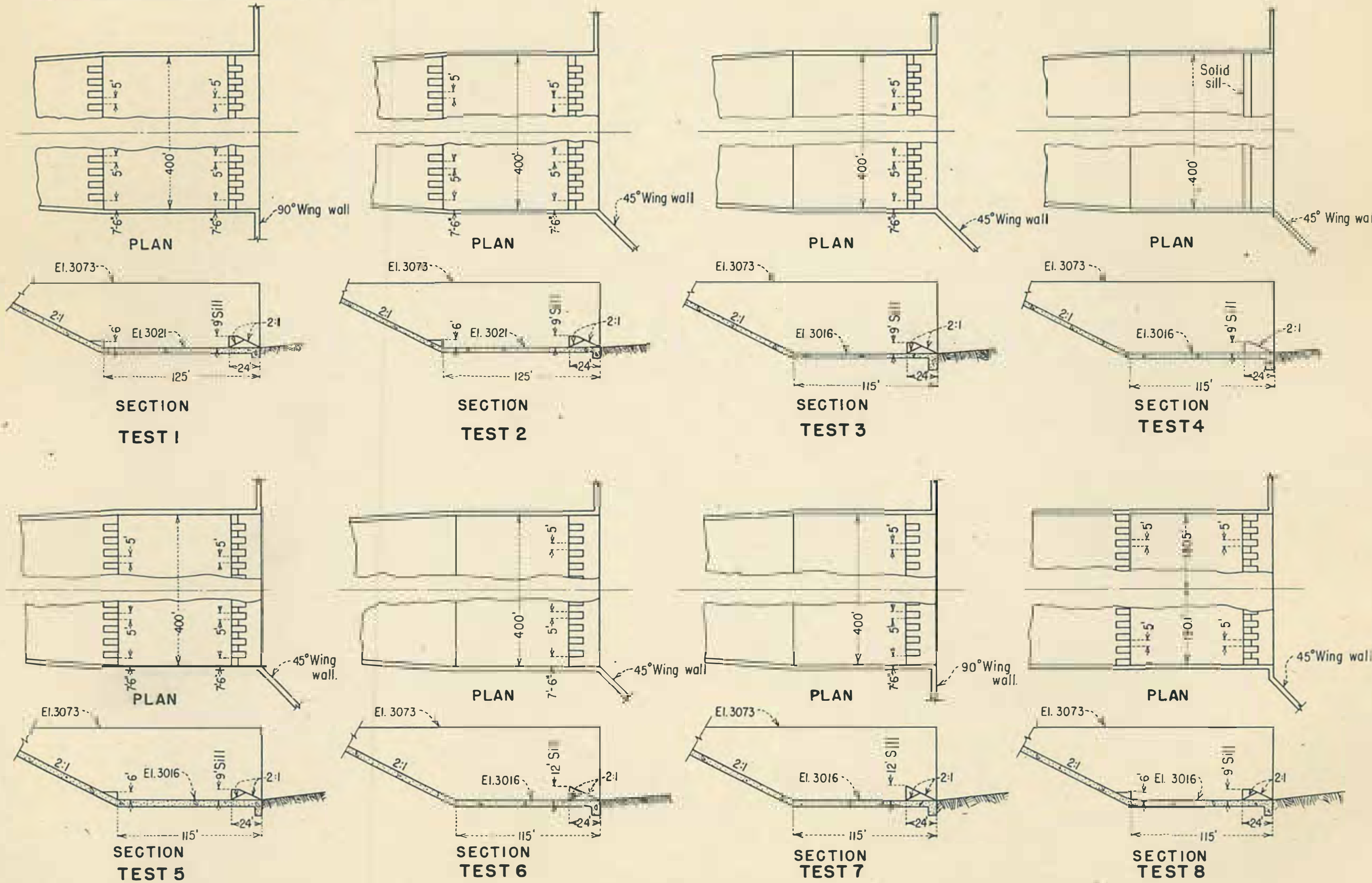
DENVER, COLORADO APRIL 10, 1947 SHEET 1 OF 2 328-D-154


PLAN
Frenchman Creek
Trashrack structure
Gate chamber
Sta. 40+70.49 (Axis of dam) N. 4° 51' W.
Sta. 4+64.00 N 97,632.82 E 99,897.11
Sta. 8+21.38 ℄ Outlet pipe N 97,707.12 E 100,246.68
N. 78° 0' E.
Valve house
Sta. 10+72
Sta. 12+15.00 (℄ Stilling basin) N 97,788.96 E 100,631.69
Spillway wall
SCALE OF FEET
PROFILE ALONG ℄ OF OUTLET CONDUIT
Crest El. 3137.50
℄ Trashrack structure
Sta. 4+64.00
Outlet intake El. 3080.00
Original ground surface
℄ Gate chamber
Sta. 7+62.00
1-6'x7.5' H.P. slide gate
Cut-off collars @ 32'-0"
Cut-off collars @ 32'-0" crs
Valve house
2-60" Hollow jet valves ℄ El. 3042.50
El. 3050.00
El. 3029.00
El. 3033±
Diversion intake El. 3040.00
Conduit joints @ 32'-0" crs.
Sta. 4+88.00
Compacted backfill
7'-0" Dia. circular conduit
El. 3040.00
Sta. 7+44.00
El. 3038.25
Sta. 7+82.00
Conduit joints @ 32'-0" crs.
Compacted backfill
11'-6" Dia. horseshoe conduit
El. 3037.25
Sta. 10+38.00
Sta. 10+92.00
El. 3020.00
Sta. 11+67.00
Stilling basin
SECTION A-A
TYPICAL 7'-0" DIA. CONDUIT SEC.
Compacted fill
Assumed rock line
Construction joint
Compacted backfill
4'-0" Unit not to be placed until 10 days after adjacent units.
TYPICAL 11'-6" DIA. HORSESHOE CONDUIT SEC.
Support rings see Dwg. 328-D-117
Pipe supports
Walkway
6" Dia. drain
SECTION B-B
84" I.D. STEEL PIPE NOT SHOWN
Pipe supports (for spacing see Dwg 329-D-115)
¾" Expansion joint filler
¼" Expansion joint cement
SCALE OF FEET
DISCHARGE CURVES
WATER SURFACE ELEVATION
CUBIC FEET PER SECOND
Outlet
Diversion
NOTE
Reinforcement steel, electrical conduits and apparatus, control piping and apparatus, and air ventilating piping and blower not shown.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
FRENCHMAN-CAMBRIDGE UNIT-NEBRASKA
ENDERS DAM
OUTLET WORKS
ALINEMENT—PROFILE AND CONDUIT SECTIONS
DENVER, COLORADO FEB. 12, 1946
328-D-66



ENDERS DAM
1:72 MODEL OF SPILLWAY

FIGURE 5



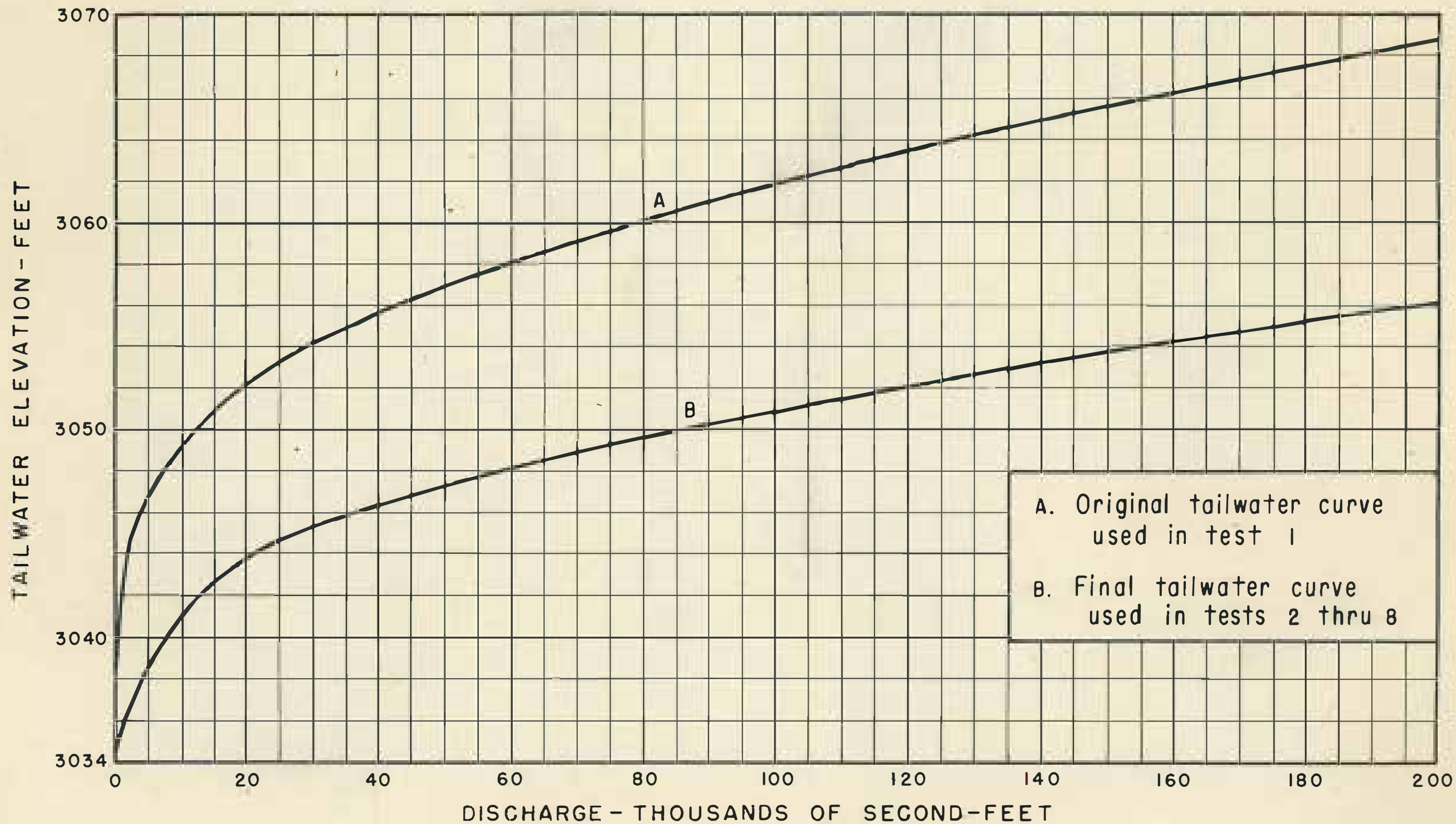
ENDERS DAM
STILLING BASIN DESIGNS
1:72 SCALE MODEL

FIGURE 6

A. No flow, looking upstream

B. Scour at end of right training wall after 95 minutes operation at 200,000 second-feet, tailwater curve A

TEST 1. 1:72 MODEL ENDERS SPILLWAY
ORIGINAL DESIGN

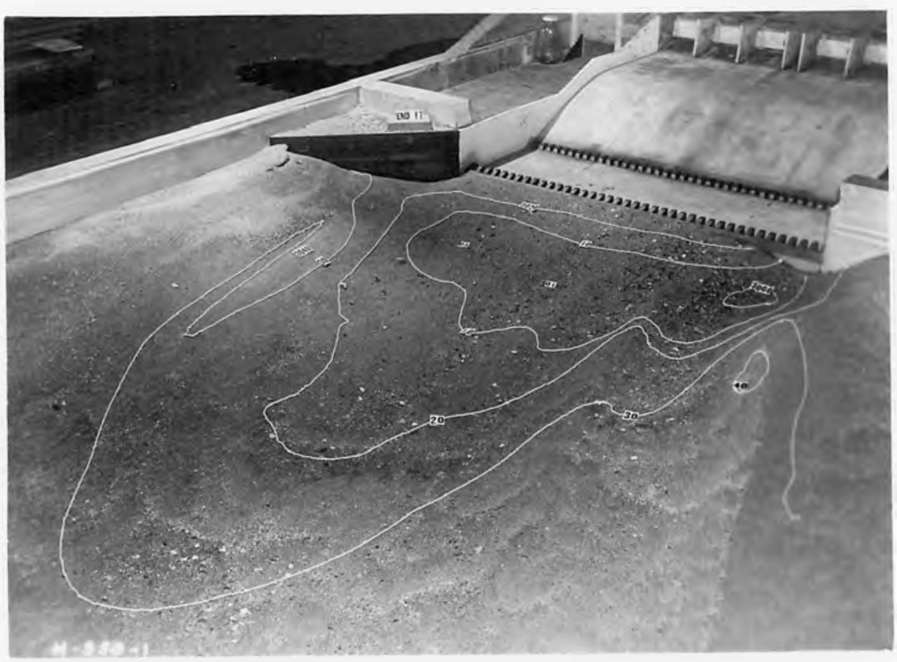


ENDERS DAM

TAILWATER CURVES FOR SPILLWAY

FIGURE 8

A. Operation at 200,000 second-feet discharge



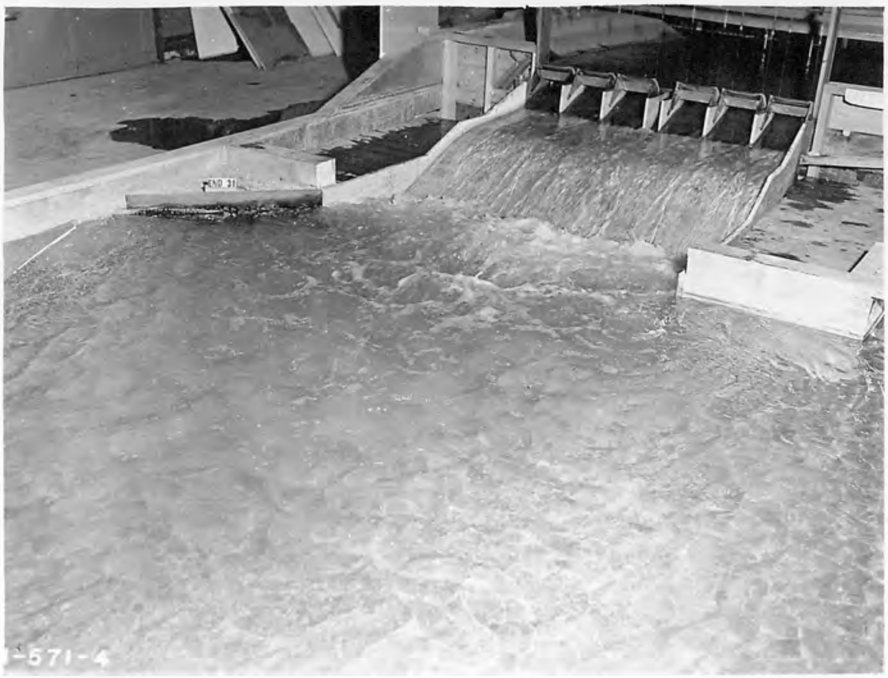
B. Scour after 30 minutes operation
at 200,000 second-feet

TEST 2. 1:72 MODEL ENDERS SPILLWAY ORIGINAL
DESIGN WITH 45 DEGREE WING WALL

A. Operation at 200,000 second-feet discharge

B. Scour after 45 minutes operation
at 200,000 second-feet

TEST 3. 1:72 MODEL ENDERS SPILLWAY APRON
ELEVATION 3016, NO CHUTE BLOCKS



A. Operation at 200,000 second-feet discharge

B. Scour after 45 minutes operation
at 200,000 second-feet

TEST 5. 1:72 MODEL ENDERS SPILLWAY
ORIGINAL SILL AND CHUTE BLOCKS

A. Operation at 200,000 second-feet discharge

B. Scour after 45 minutes operation
at 200,000 second-feet

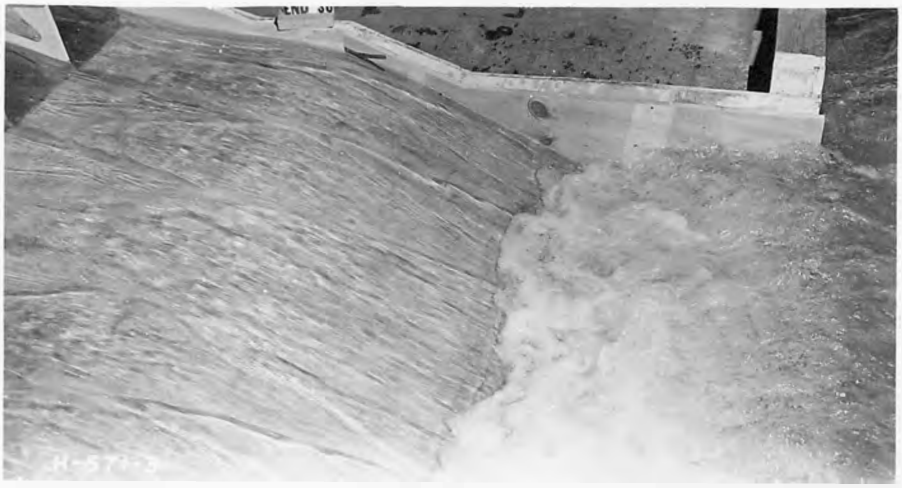
TEST 6. 1:72 MODEL ENDERS SPILLWAY
HIGH SILL NO CHUTE BLOCKS

A. Operation at 200,000 second-feet discharge

B. Scour after 45 minutes operation
at 200,000 second-feet

TEST 7. 1:72 MODEL ENDERS SPILLWAY
RECOMMENDED DESIGN

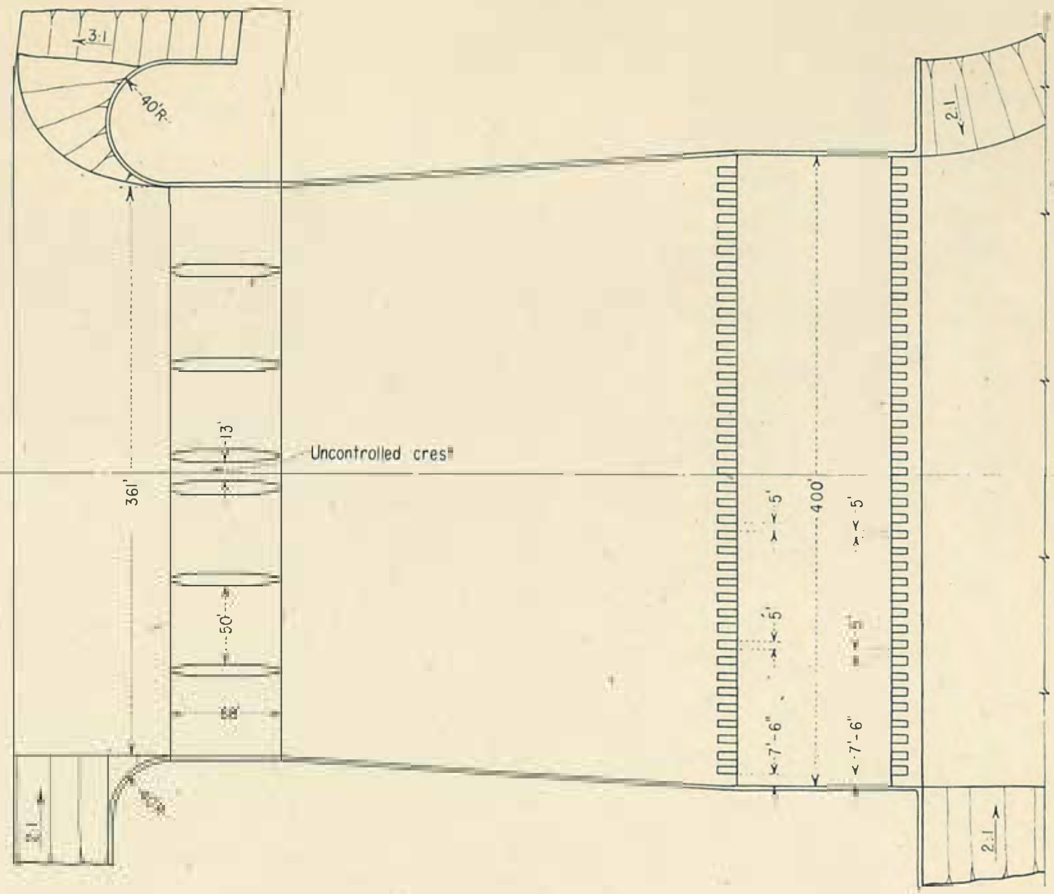
A. Flow at right training wall for 200,000 second-feet discharge



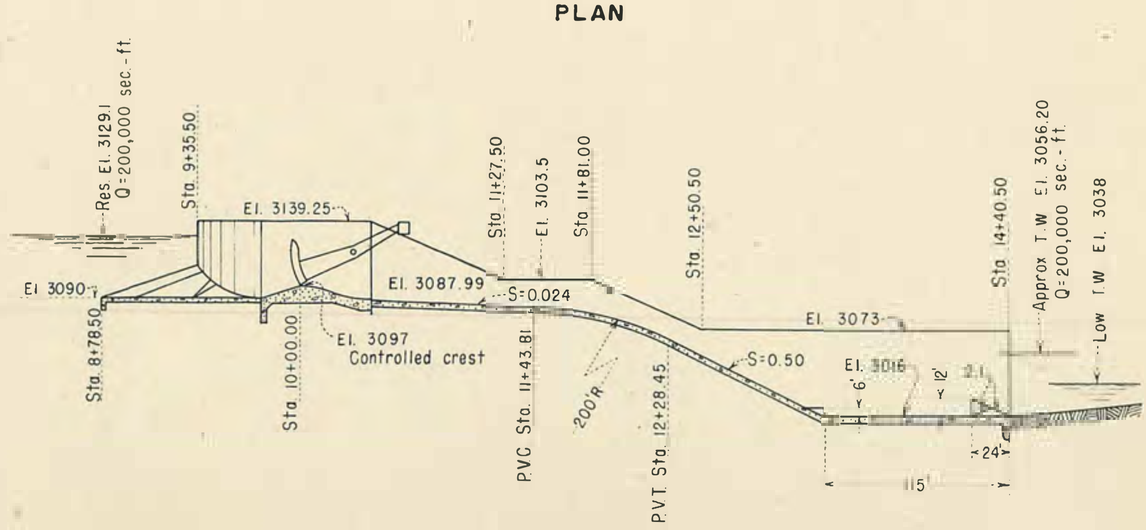
B. Flow at left training wall for 200,000 second-feet discharge

C. Scour after 45 minutes operation at 200,000 second-feet

TEST 8. 1:72 MODEL ENDERS SPILLWAY
REDUCED BASIN WIDTH



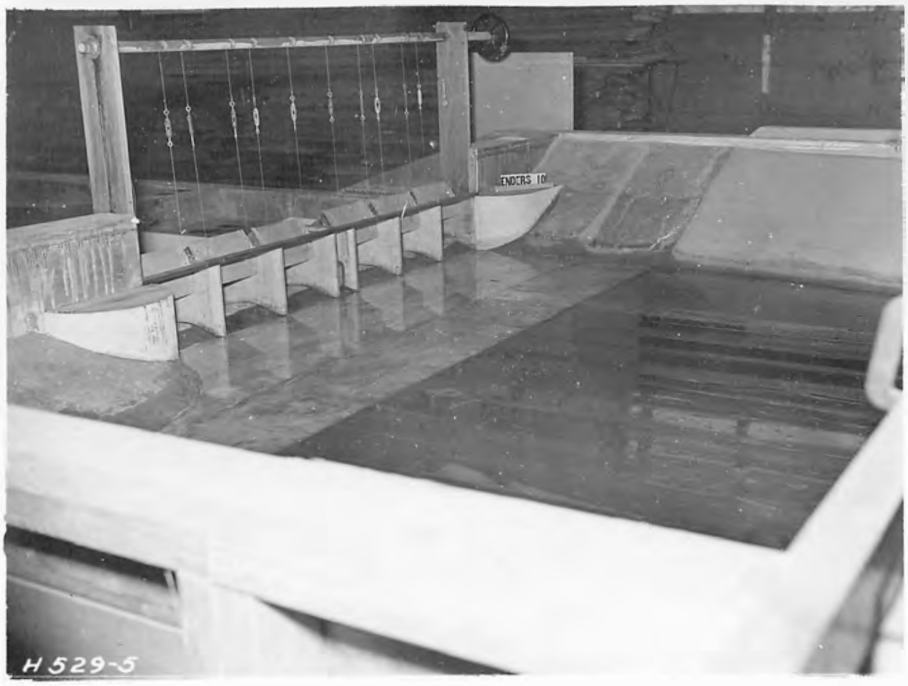
PLAN



SECTION

ENDERS DAM

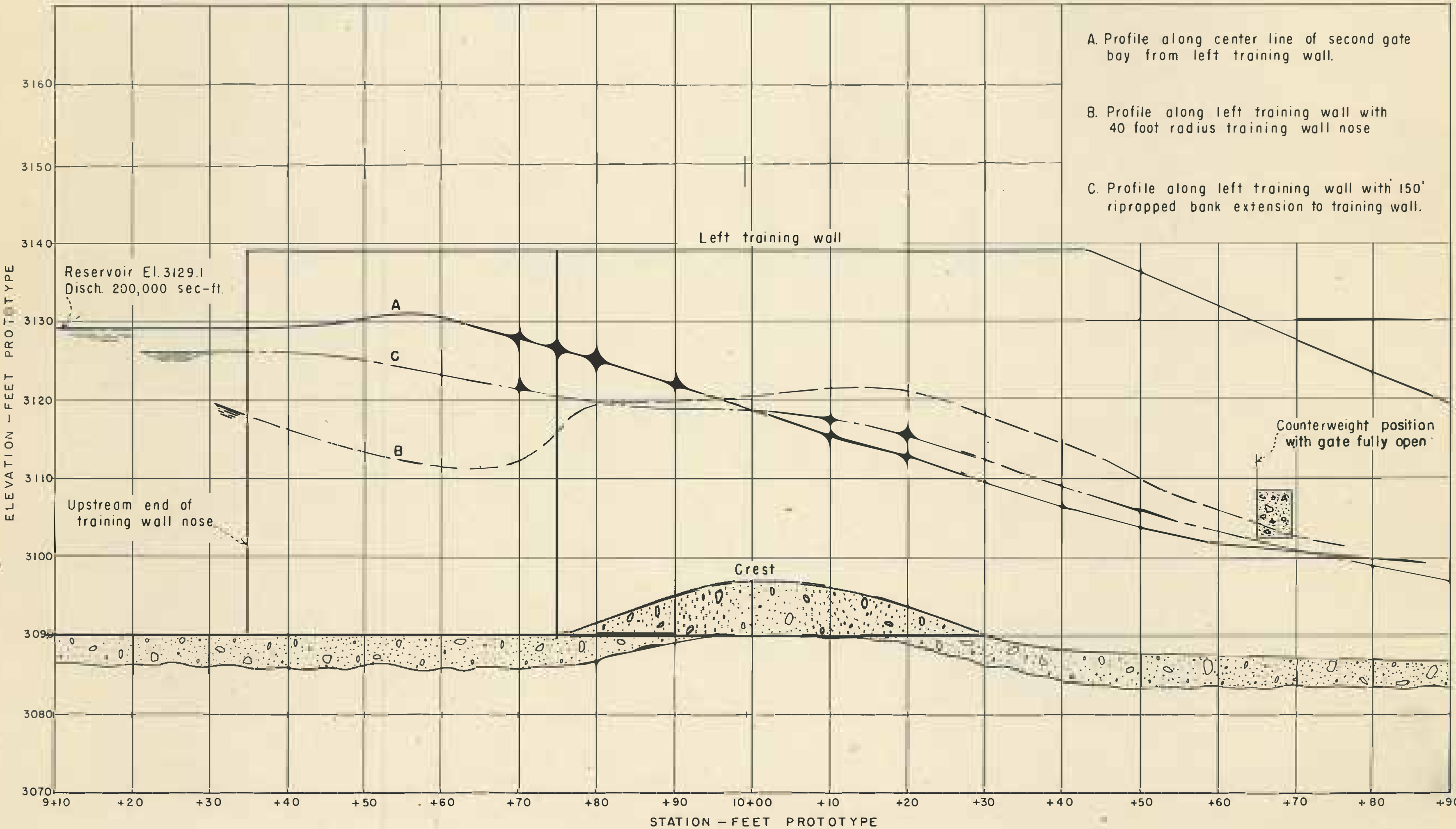
RECOMMENDED SPILLWAY DESIGN



A. Original design, no flow

B. Drawdown at left training wall nose with a discharge of 200,000 second-feet

1:72 MODEL ENDERS SPILLWAY ENTRANCE

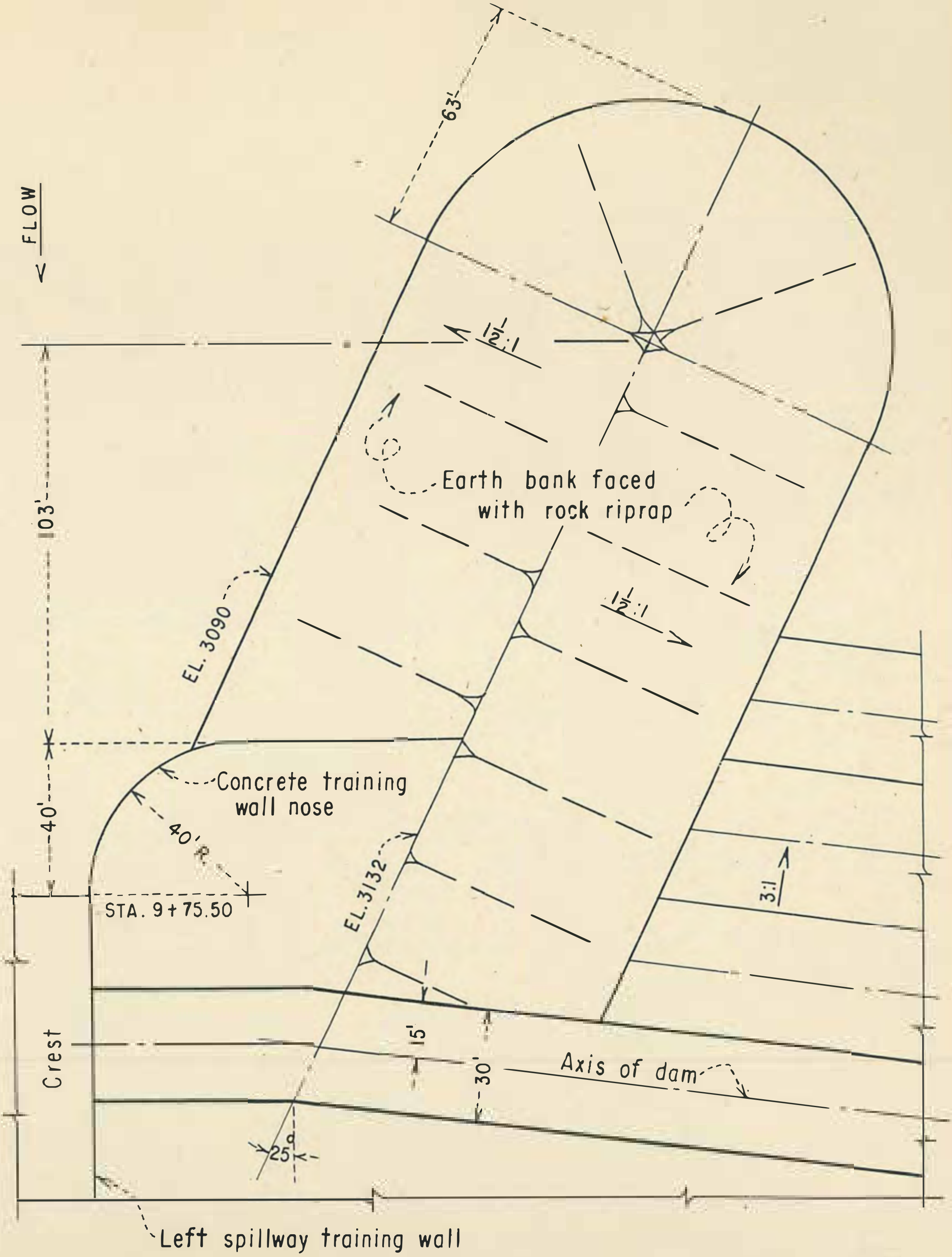


ENDERS DAM SPILLWAY

WATER SURFACE PROFILES OVER CONTROLLED CREST

AT DISCHARGE OF 200,000 SECOND – FEET

FIGURE 18



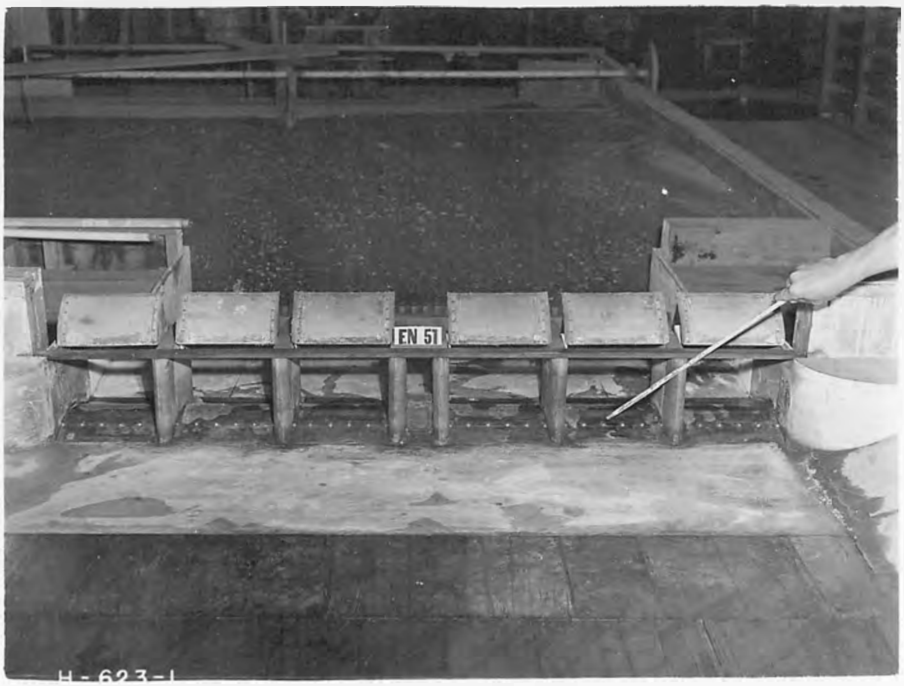
ENDERS DAM

PLAN OF RIPRAPPED DIKE AT LEFT SIDE OF SPILLWAY ENTRANCE

A. Riprapped dike upstream from left training wall nose, no flow

B. Conditions of flow at discharge of 200,000 second-feet

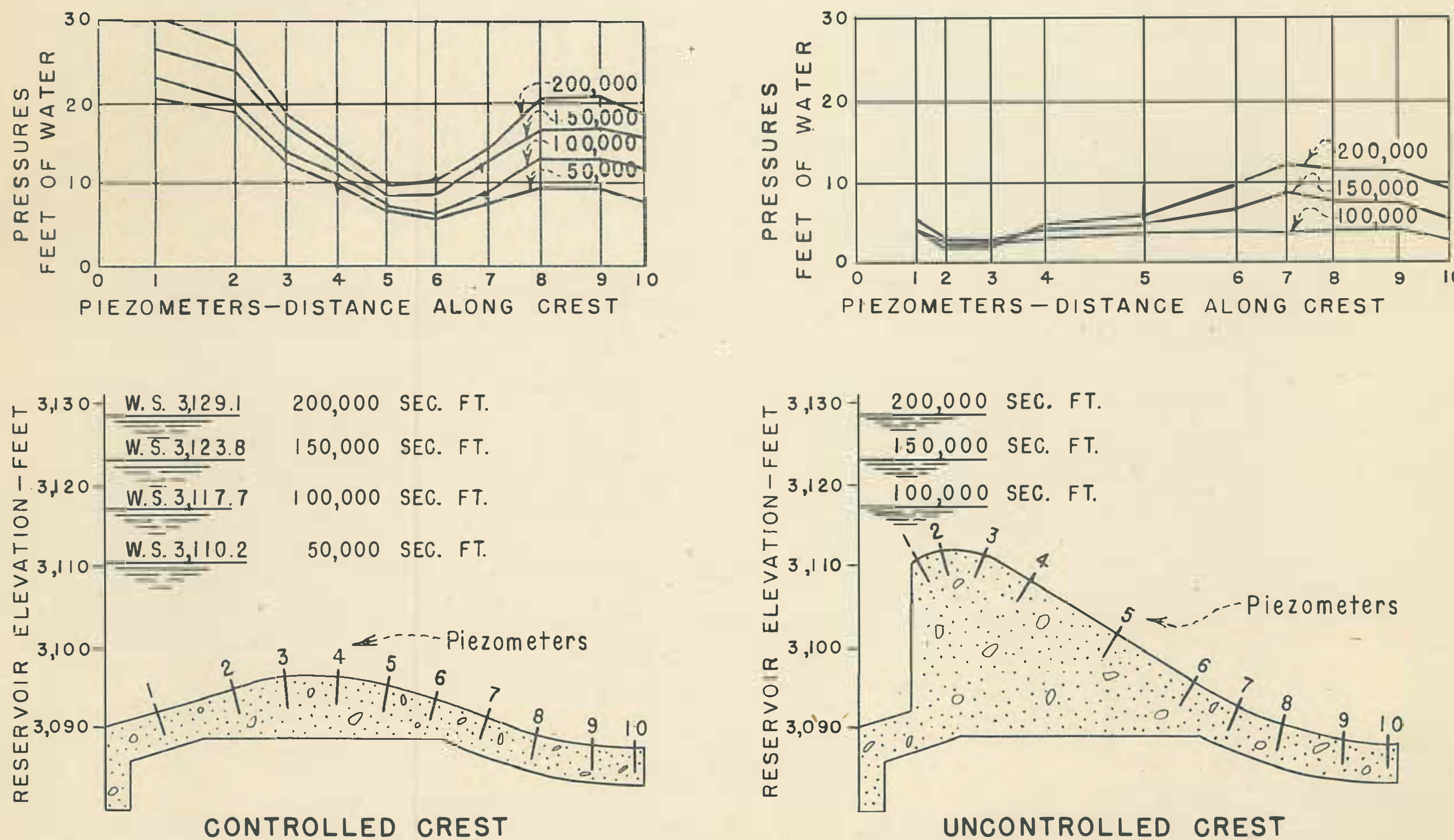
1:72 MODEL ENDERS SPILLWAY ENTRANCE



A. Installation on crest, looking downstream

B. Operation at 50,000 second-feet

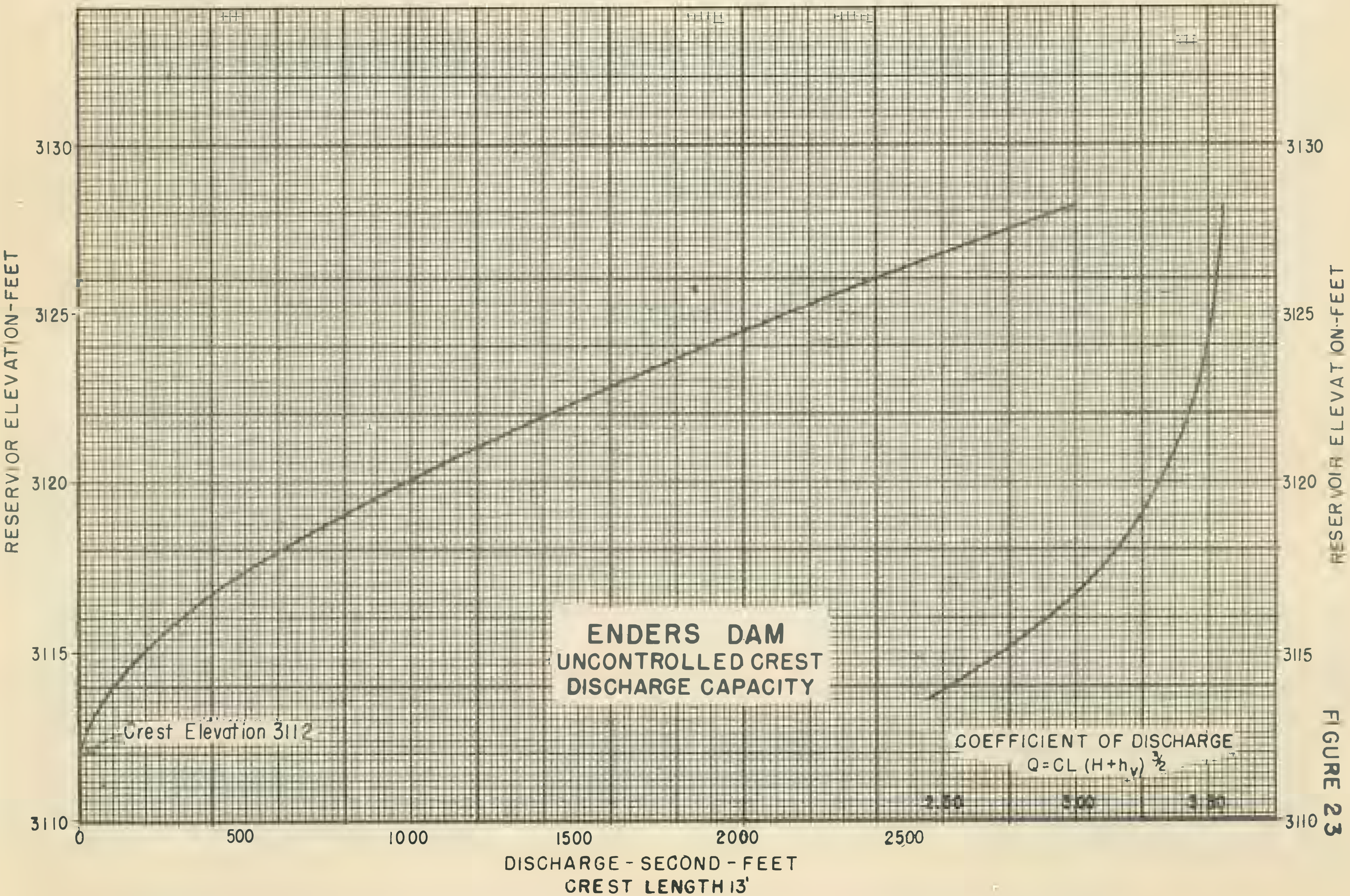
1:72 MODEL ENDERS SPILLWAY
ICE PREVENTION SYSTEM



ENDERS DAM

PRESSURES ON CRESTS 1:72 MODEL

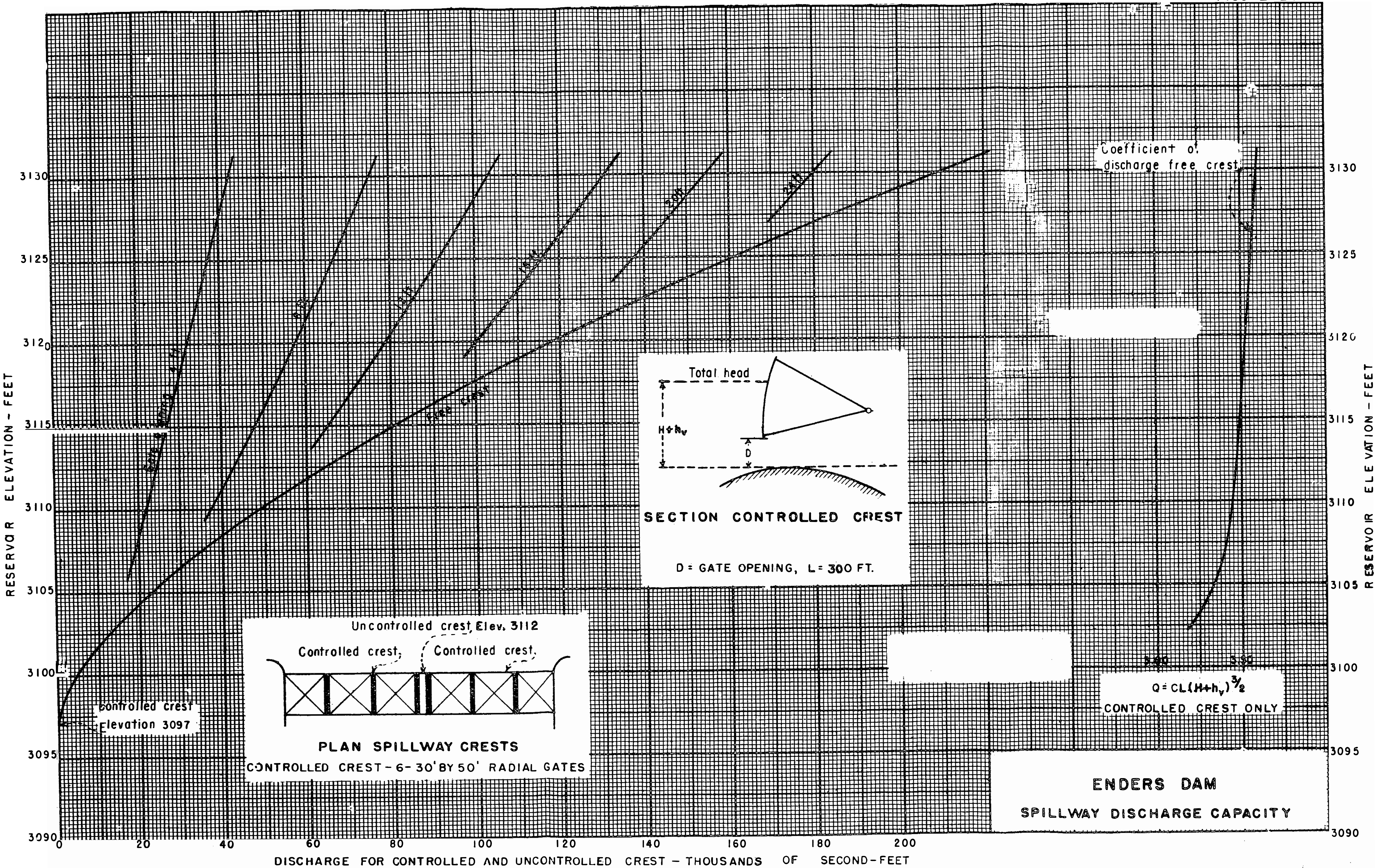
FIGURE 22



ENDERS DAM
UNCONTROLLED CREST
DISCHARGE CAPACITY
Crest Elevation 3112
COEFFICIENT OF DISCHARGE
Q=CL (H+h_v) 3/2
2.50
3.00
3.50
RESERVIOR ELEVATION-FEET
RESERVOIR ELEVATION-FEET
3110
3115
3120
3125
3130
0
500
1000
1500
2000
2500
DISCHARGE - SECOND - FEET
CREST LENGTH 13'

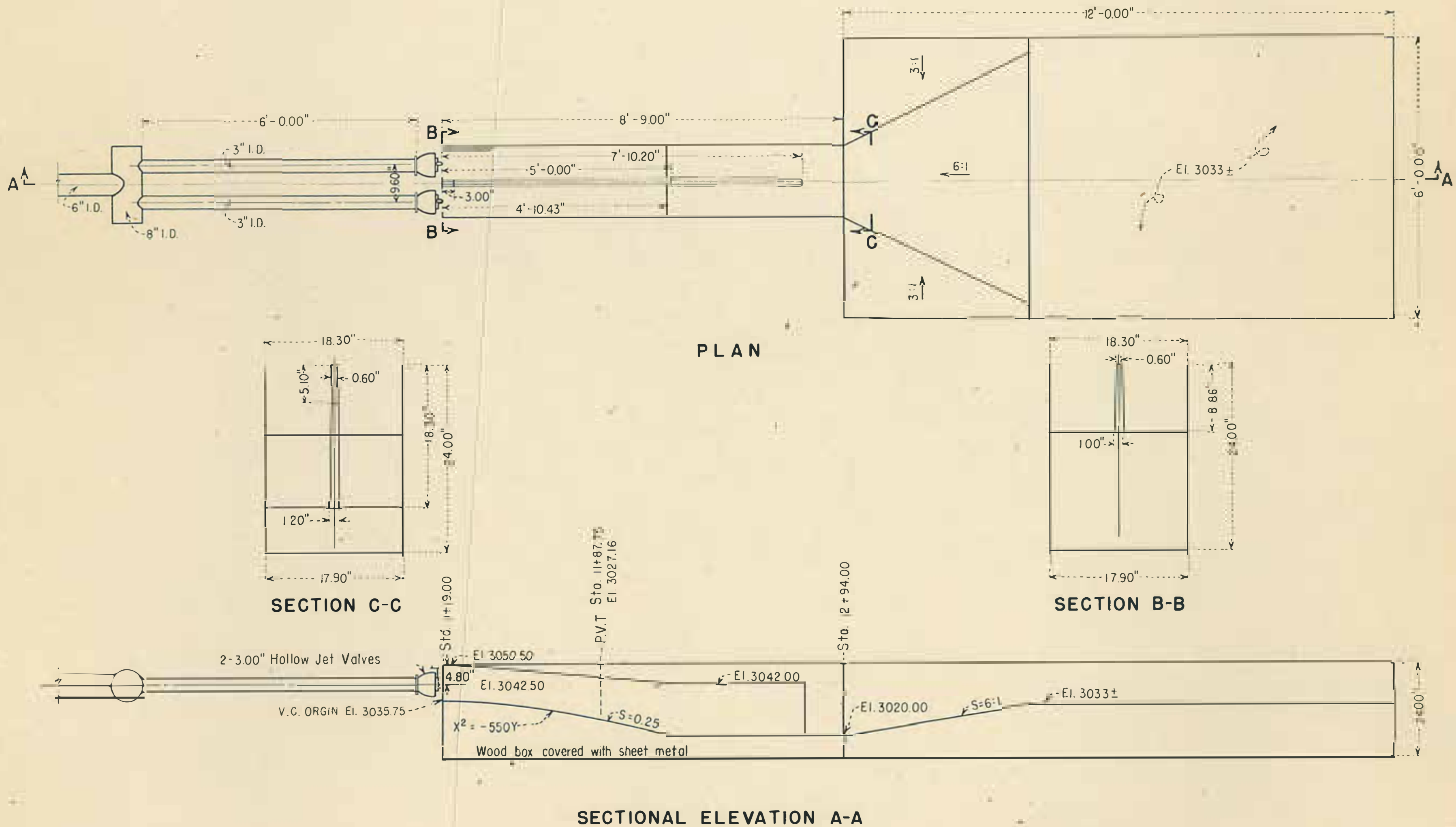
FIGURE 23

FIGURE 24



ENDERS DAM

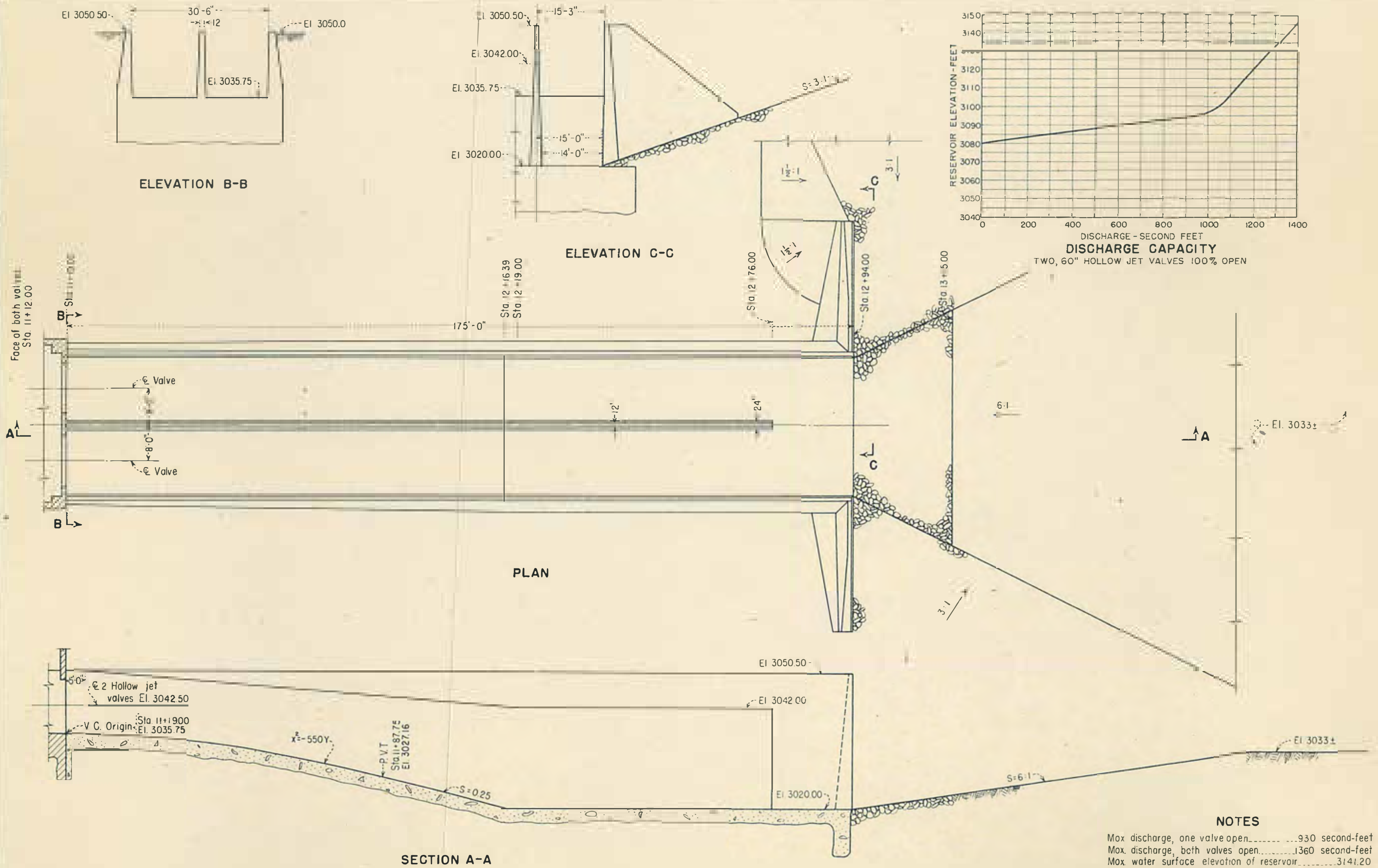
SPILLWAY DISCHARGE CAPACITY



ENDERS DAM

1:20 MODEL OF OUTLET WORKS STRUCTURE

FIGURE 25

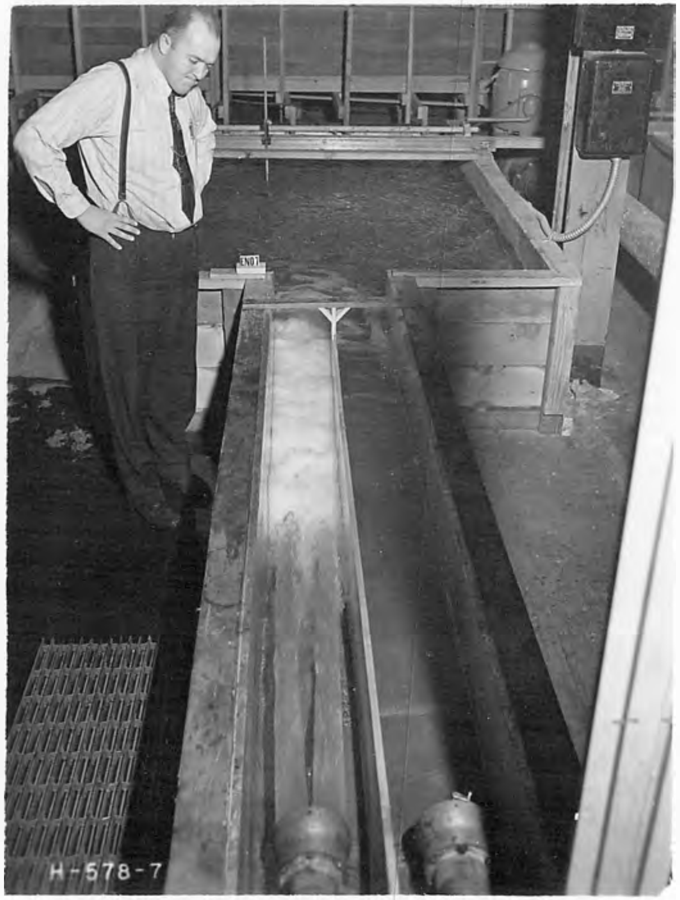


ENDERS DAM OUTLET WORKS
ORIGINAL DESIGN

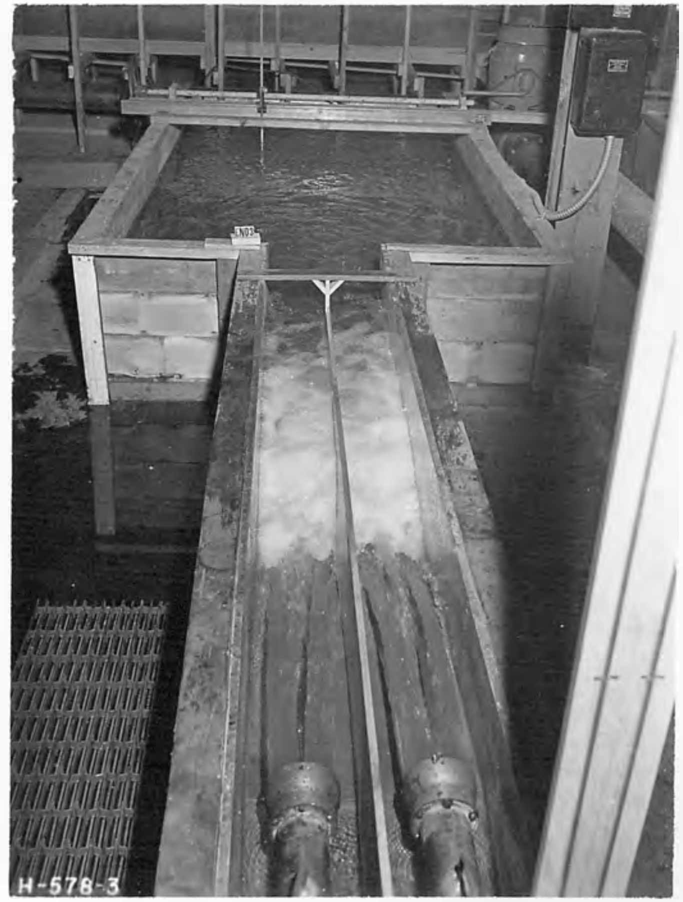
NOTES

Max. discharge, one valve open .... 930 second-feet
Max. discharge, both valves open .... 1360 second-feet
Max. water surface elevation of reservoir 3141.20
Required discharge 1,000 second feet, reservoir El. 3095.00
Tailwater for all discharges assumed as El. 3038.00.

FIGURE 26



A. Left valve - 930 second-feet



B. Both valves - 1360 second-feet

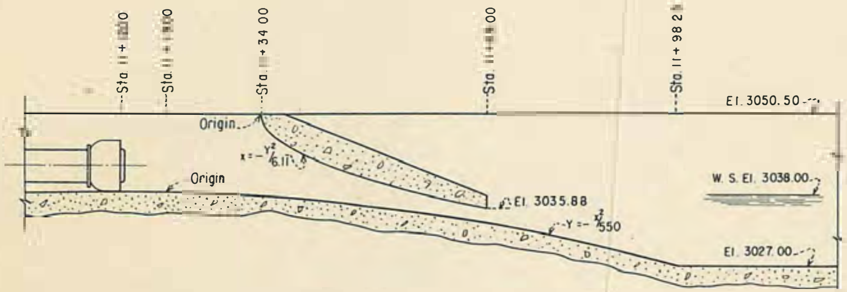
ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 1 ORIGINAL DESIGN, LOOKING DOWNSTREAM

FIGURE 27

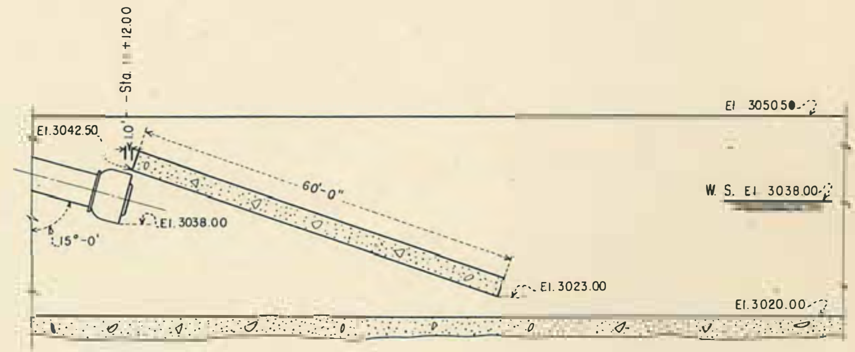
A. Scour after 1 hour operation at left valve at 930 second-feet

B. Scour after 1 hour operation of both valves at 1360 second-feet

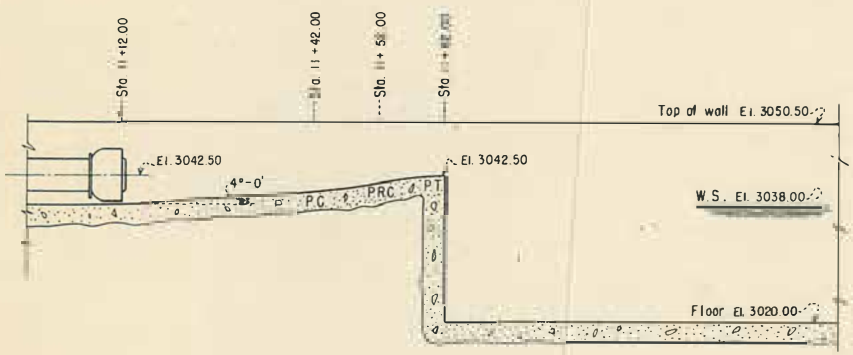
ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 1 ORIGINAL DESIGN, LOOKING UPSTREAM



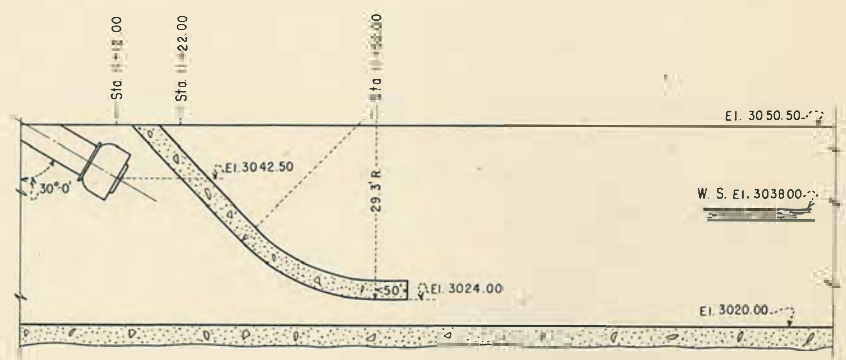
BASIN STUDY NO. 2



BASIN STUDY NO. 4



BASIN STUDY NO. 3

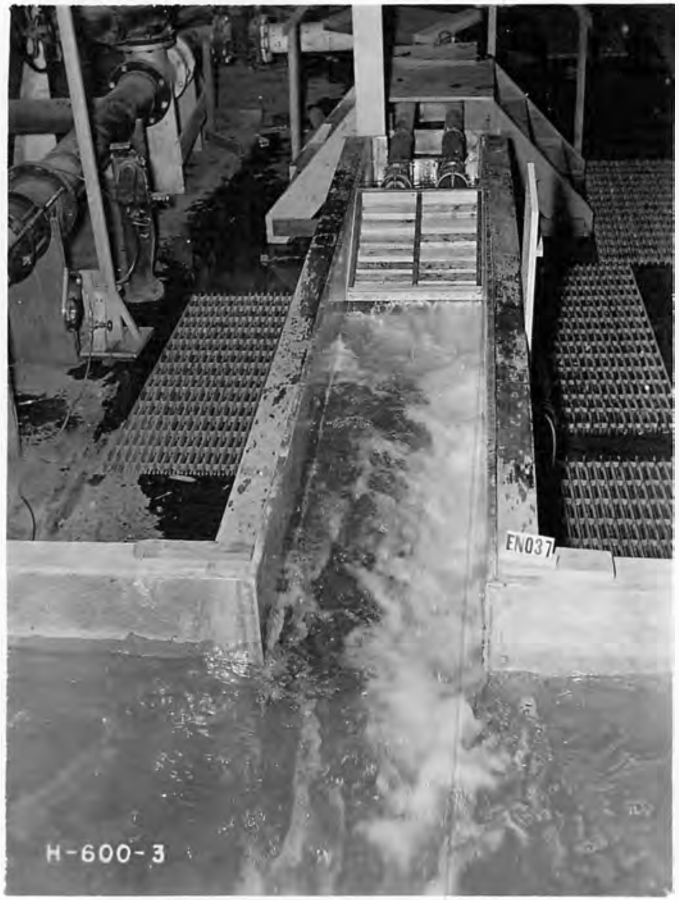


BASIN STUDY NO. 5

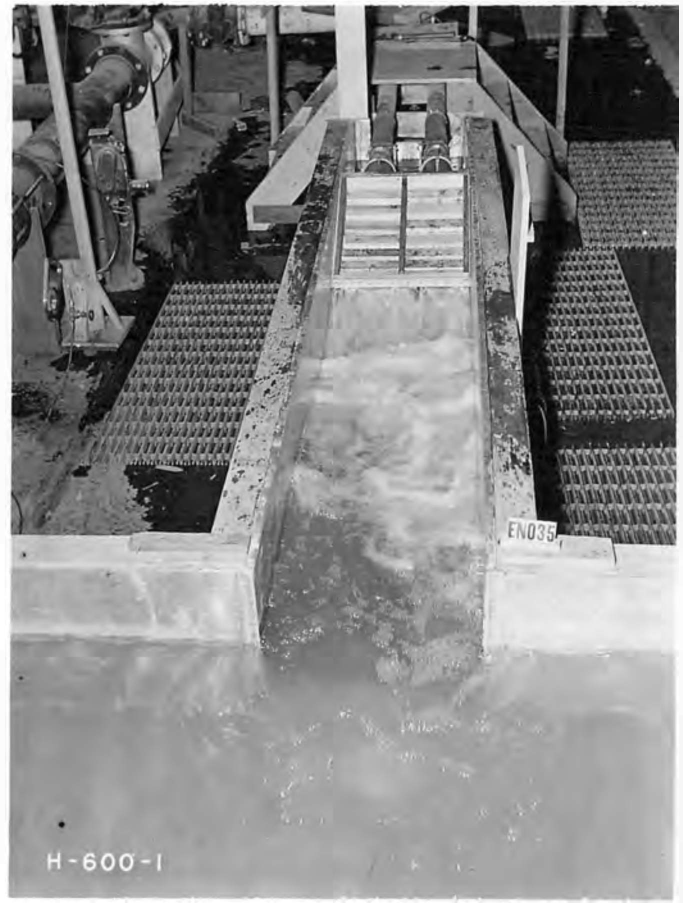
ENDERS DAM OUTLET WORKS

STILLING BASIN STUDIES 2, 3, 4 AND 5

FIGURE 29



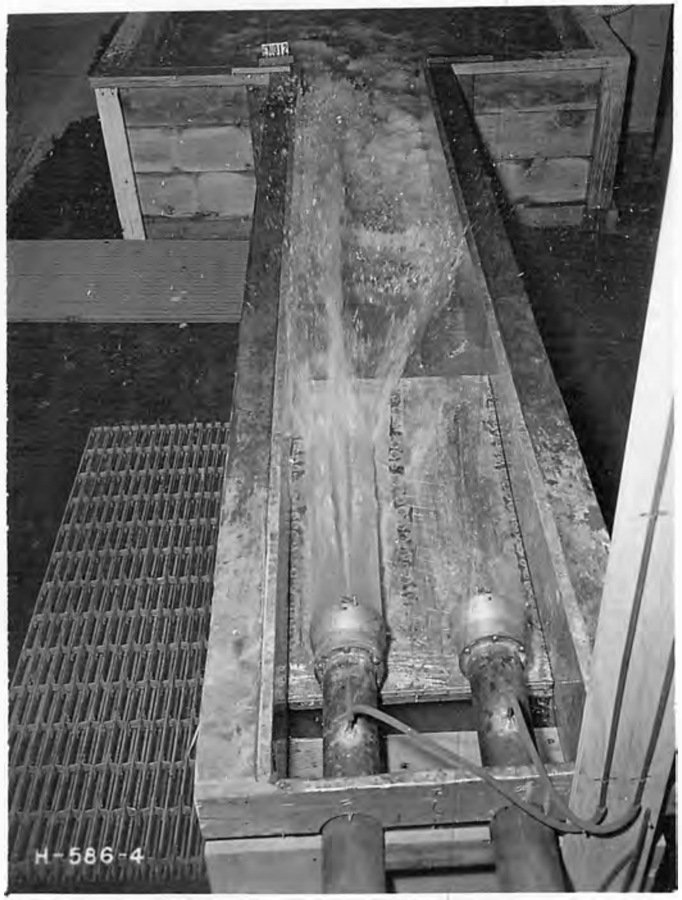
A. Left valve - 930 **second-feet**



B. Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 2, LOOKING UPSTREAM

FIGURE 30

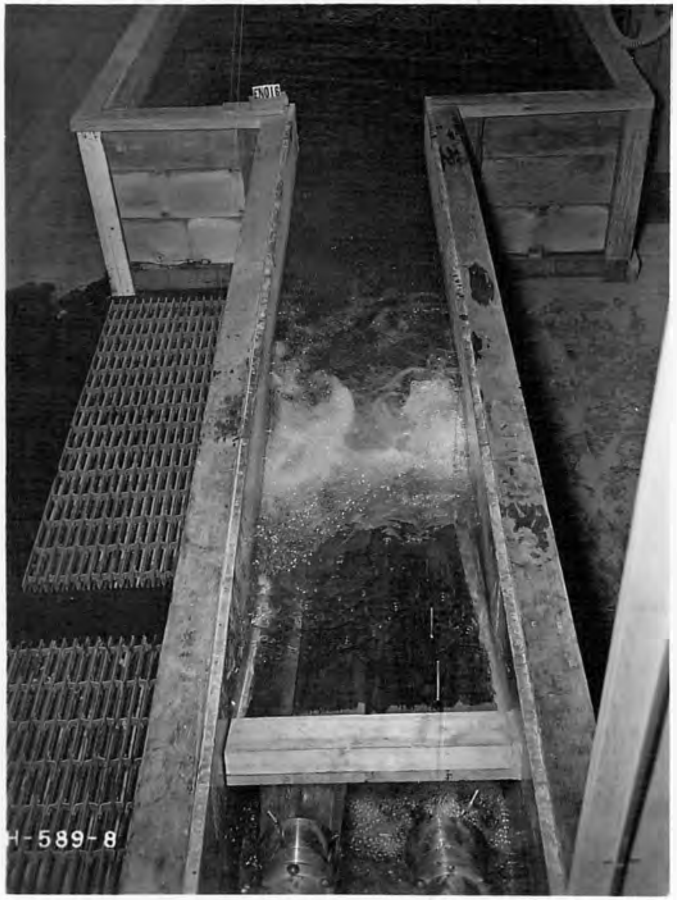


A. Left valve - 930 second-feet

B. Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 3, LOOKING DOWNSTREAM

FIGURE 31



A. Left valve - 930 second-feet

B. Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 4, LOOKING DOWNSTREAM

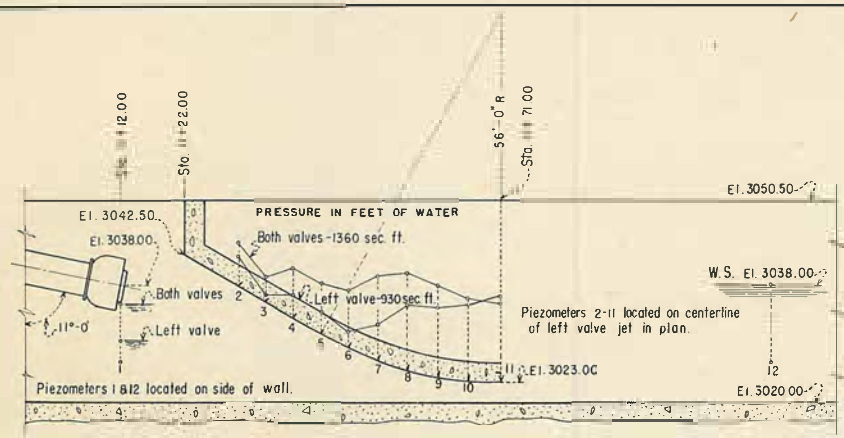
FIGURE 32

A. Left valve - 930 second-feet

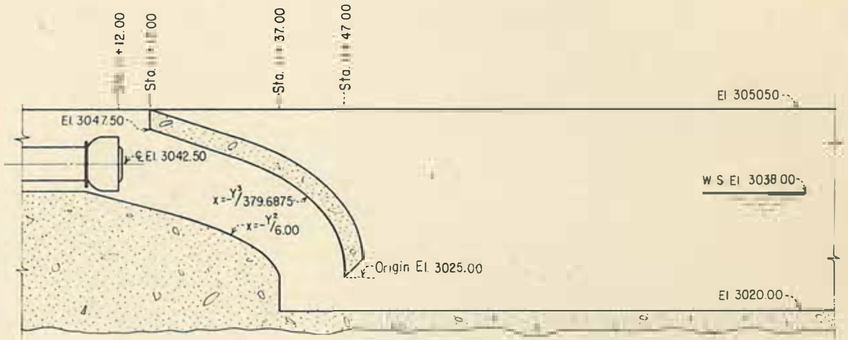
B. Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 5, LOOKING DOWNSTREAM

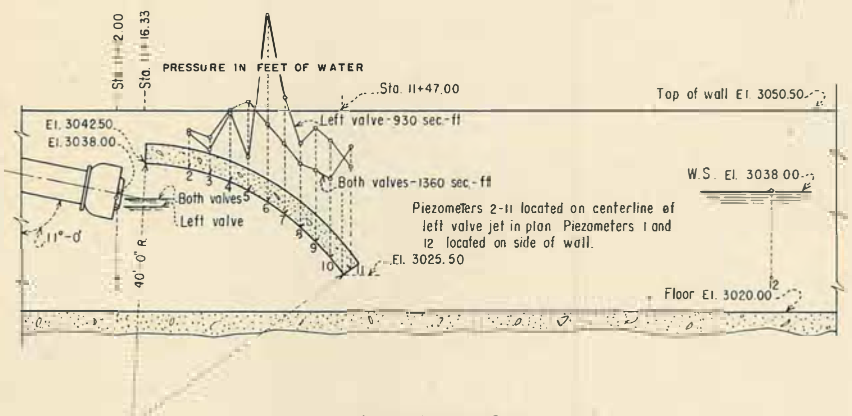
FIGURE 33



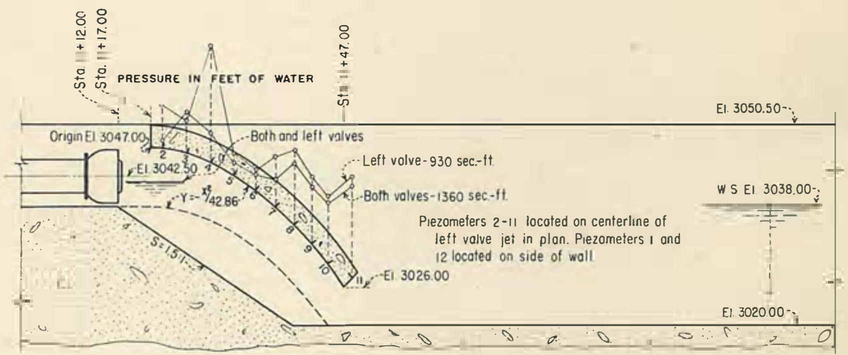
BASIN STUDY NO. 6



BASIN STUDY NO. 8



BASIN STUDY NO. 7



BASIN STUDY NO. 9

ENDERS DAM OUTLET WORKS

STILLING BASIN STUDIES 6, 7, 8 AND 9

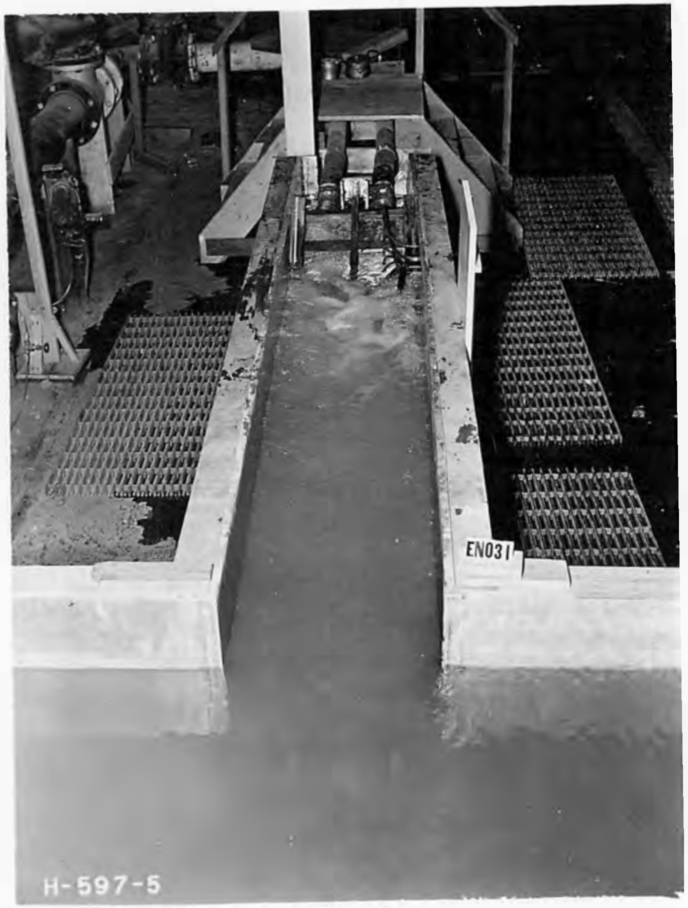
FIGURE 34

A. Left valve - 930 second-feet

B. Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 6, LOOKING UPSTREAM

FIGURE 35



A. Left valve - 930 second-feet

B. Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 7, LOOKING UPSTREAM

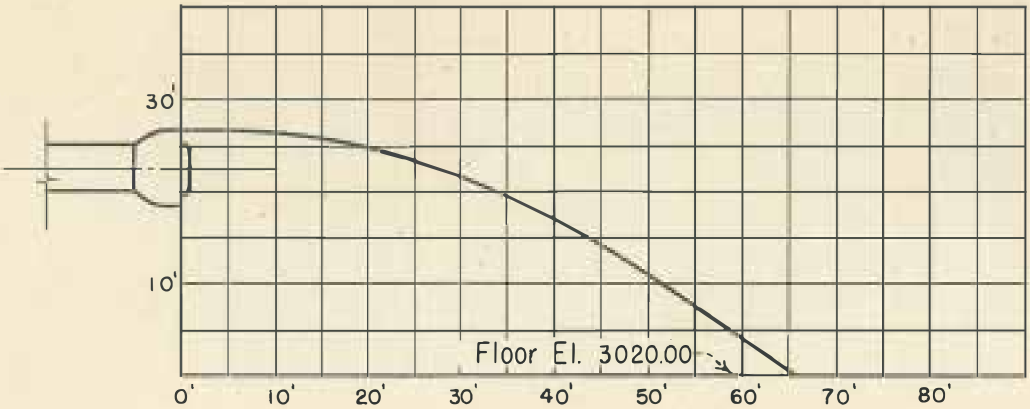
FIGURE 36

A. **Left valve - 930 second-feet**

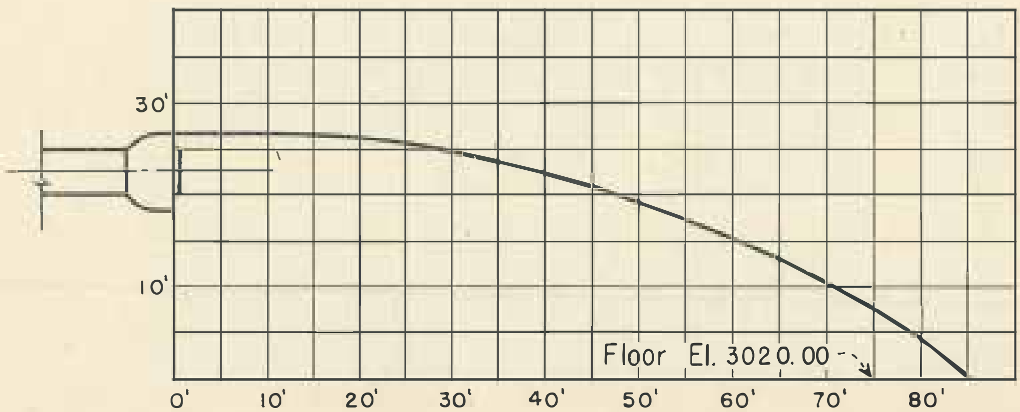
B. Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 8, LOOKING DOWNSTREAM

FIGURE 37



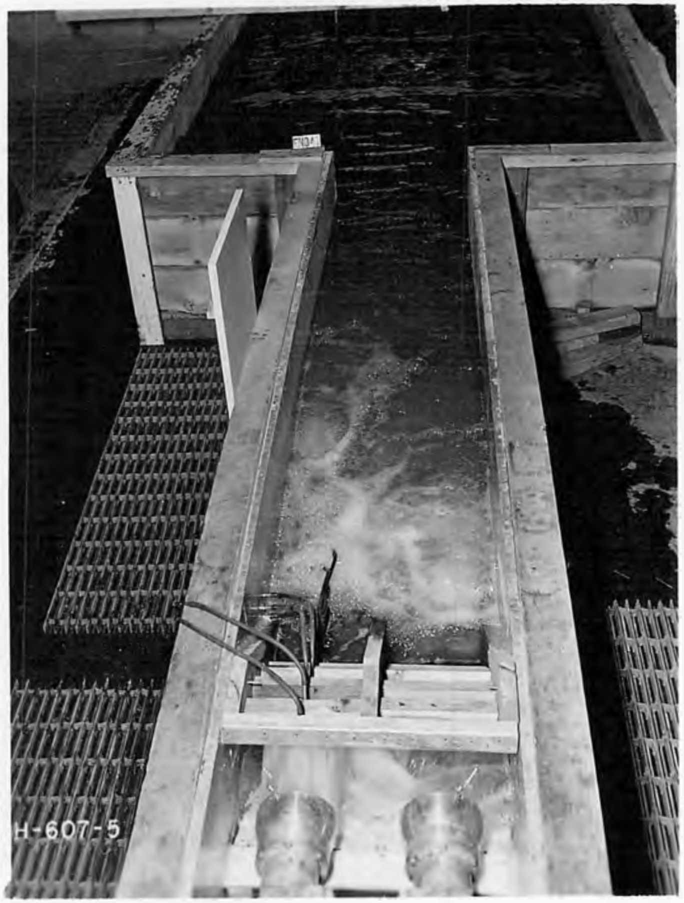
BOTH VALVES — 1360 SEC. FT.
HEAD — 98.70 FT.



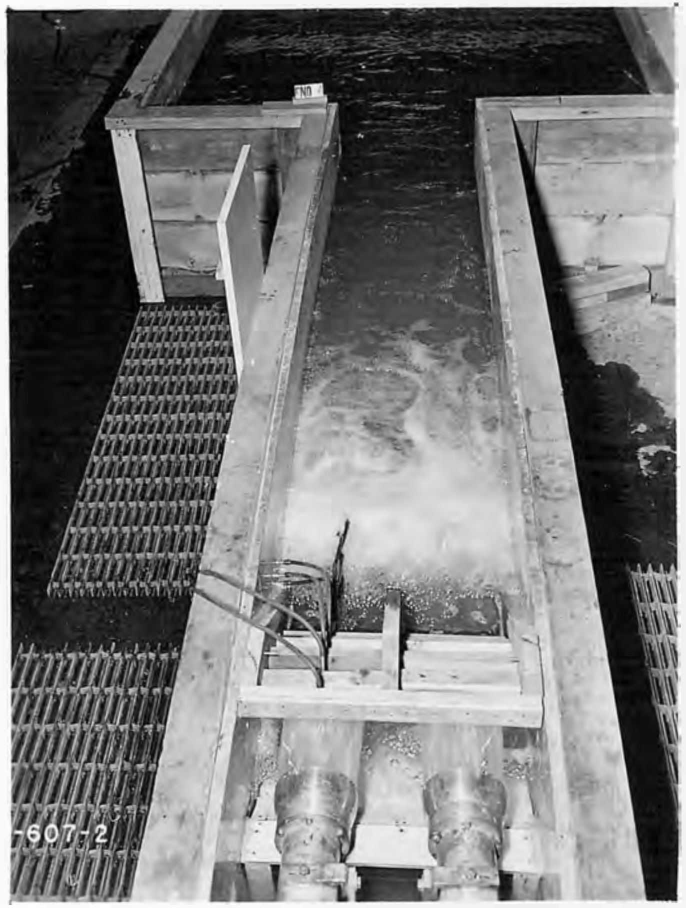
LEFT VALVE — 930 SEC. FT.
HEAD — 98.70 FT.

ENDERS DAM OUTLET WORKS

LONGITUDINAL PROFILES OF UPPER NAPPE OF JET



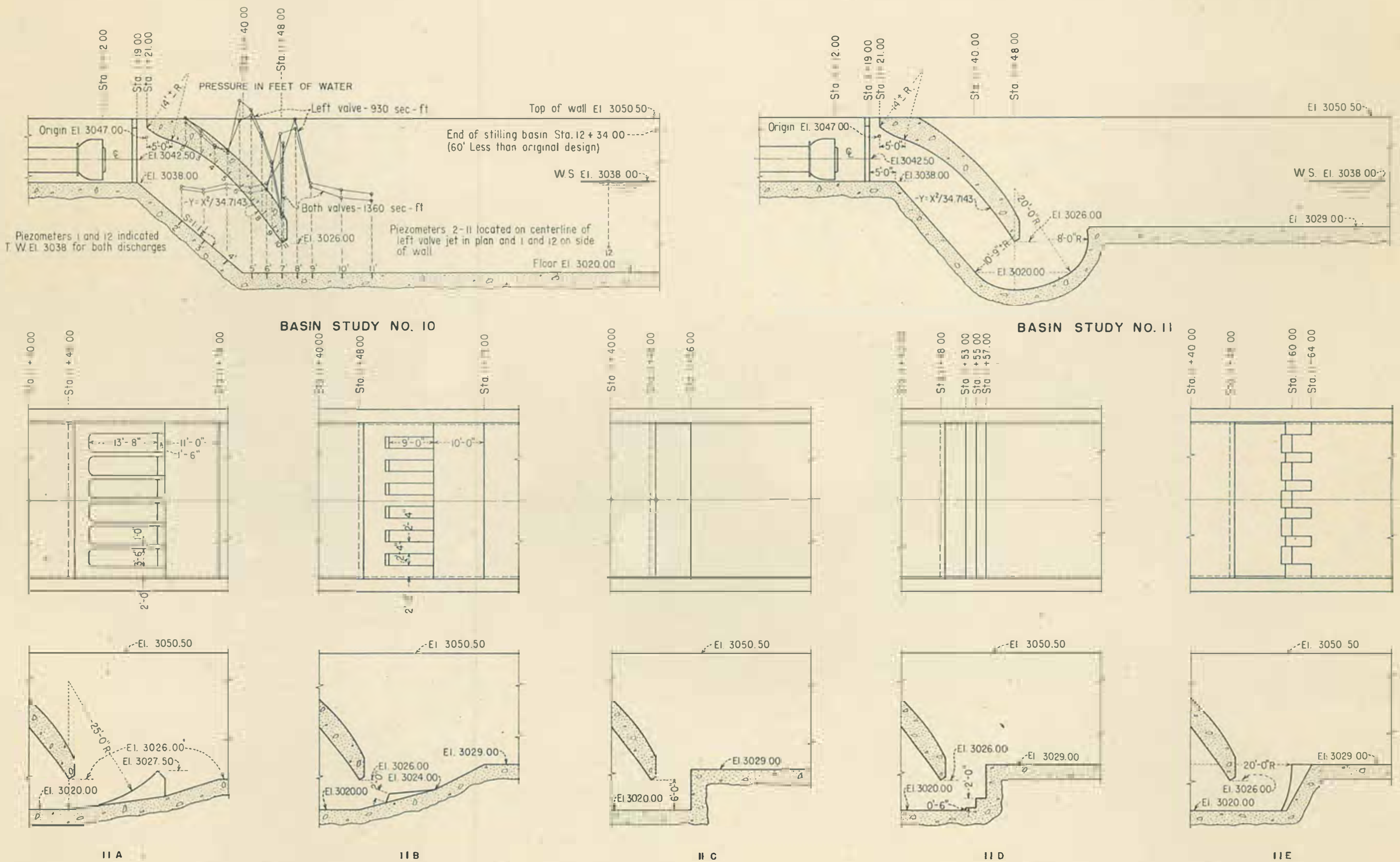
A. Left valve - 930 second-feet



B. Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 9, LOOKING DOWNSTREAM

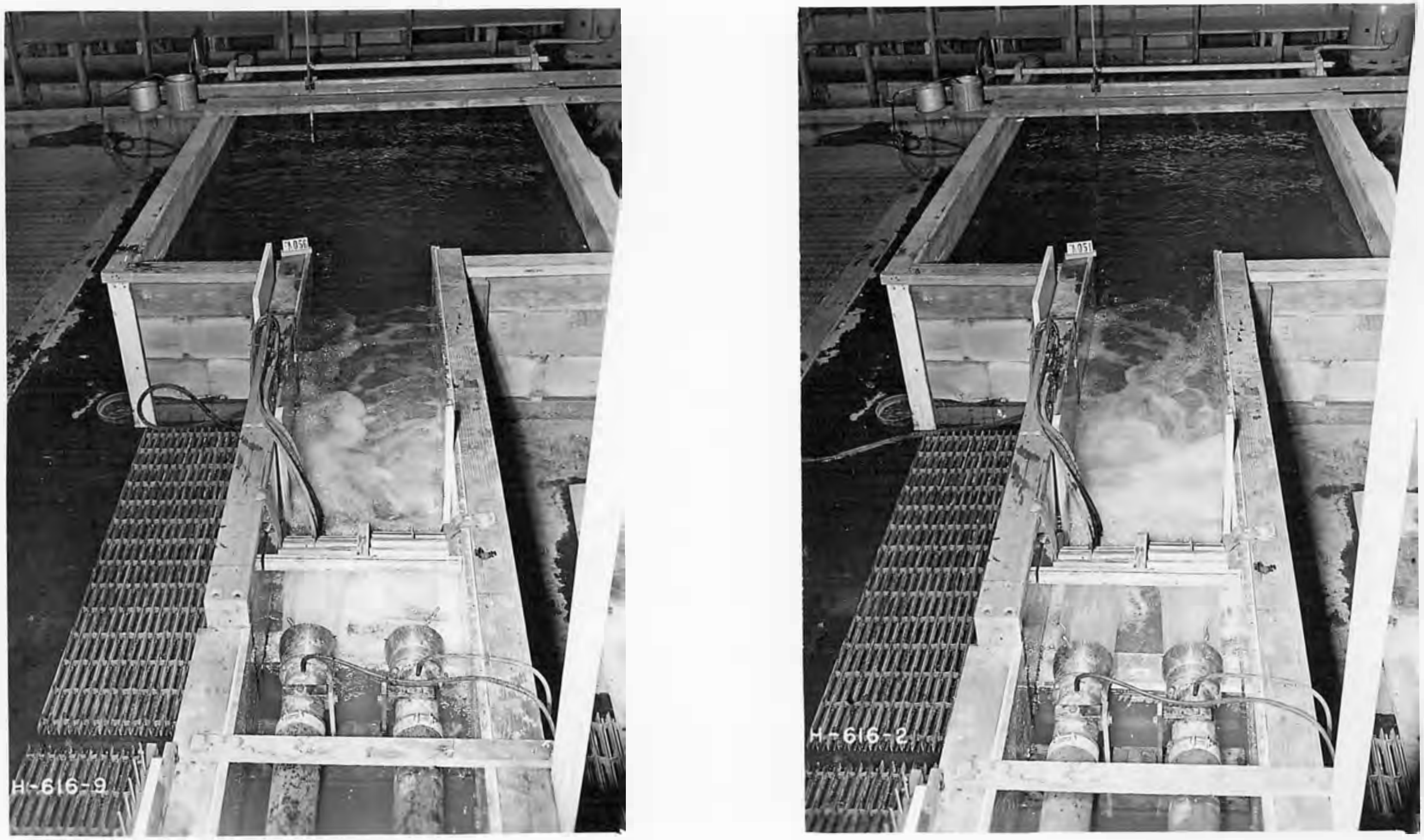
FIGURE 39



ENDERS DAM OUTLET WORKS

STILLING BASIN STUDIES 10 & 11

FIGURE 40

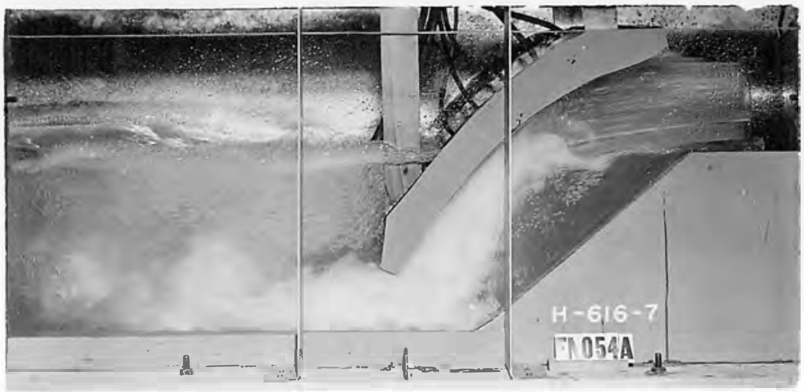


A. Left valve - 930 second-feet

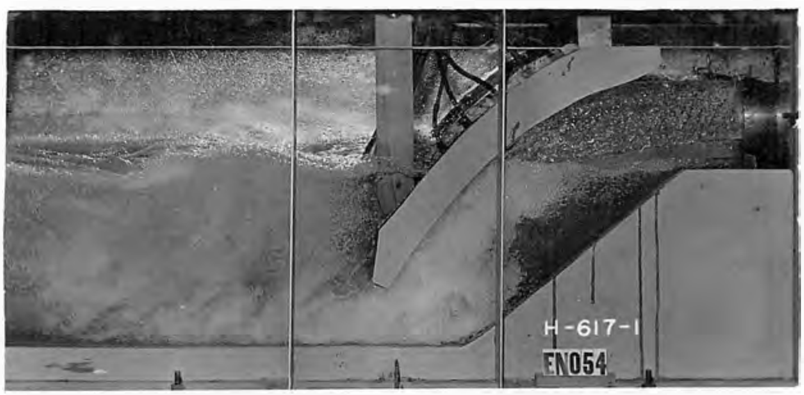
B Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 10, LOOKING DOWNSTREAM

FIGURE 41



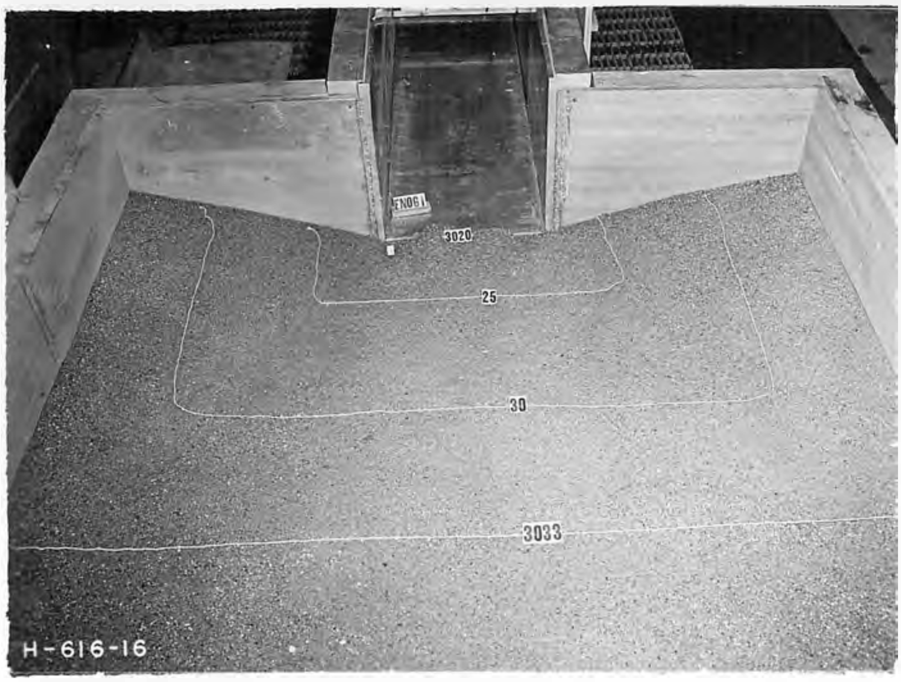
A. 1/200 second exposure



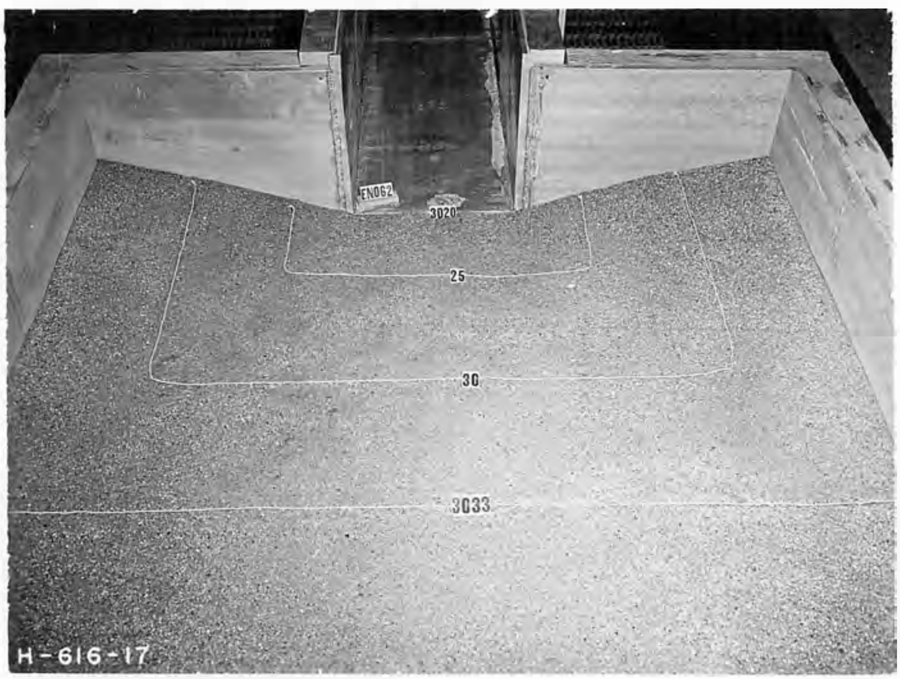
B. 1/20,000 second exposure

Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 10, SIDEVIEW

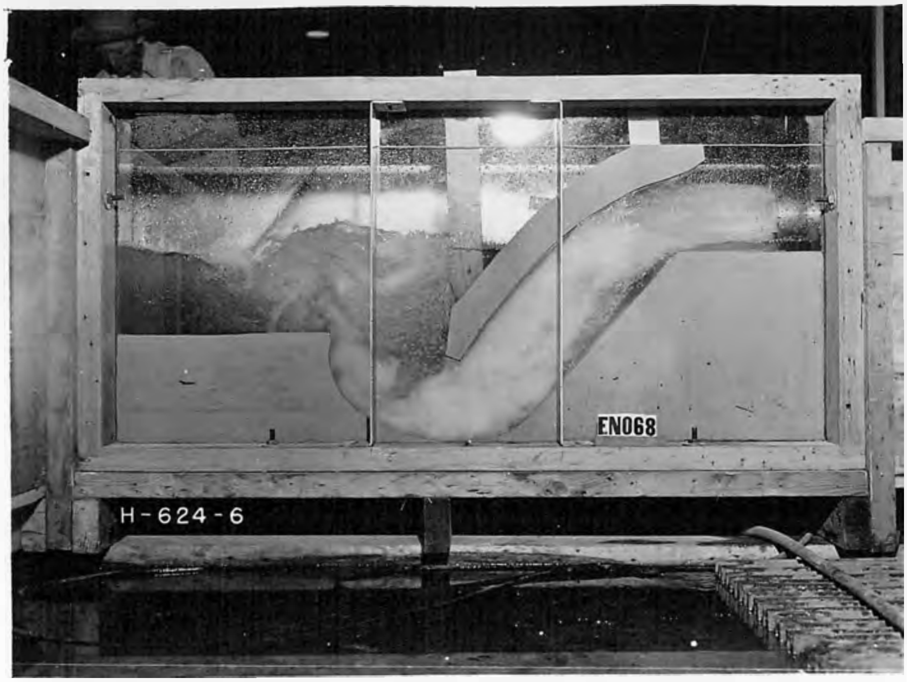


A. Scour after 1 hour operation of left valve at 930 second-feet

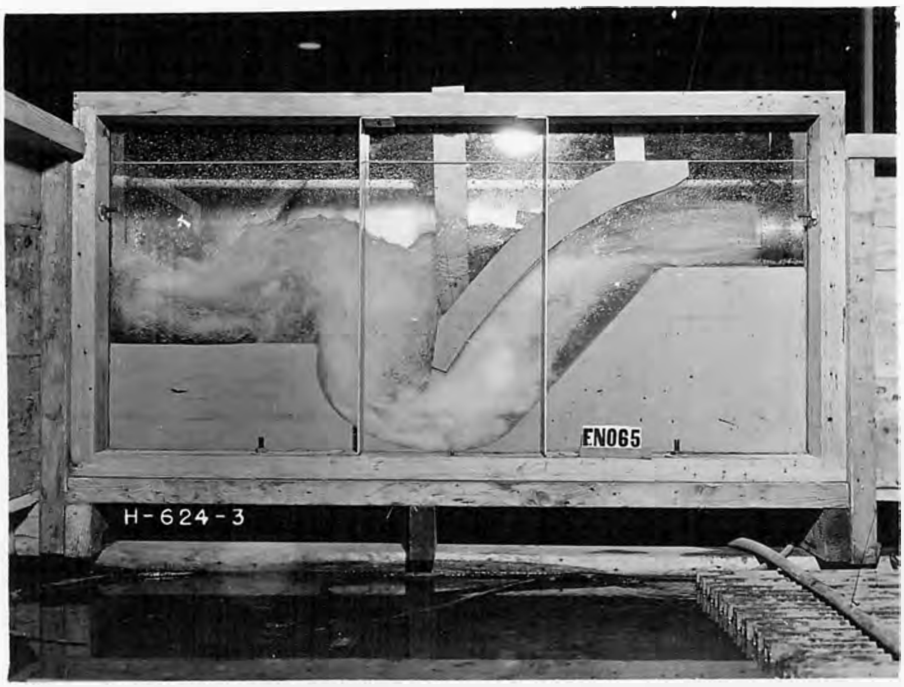


B. Scour after 1 hour operation of both valves at 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO. 10, LOOKING UPSTREAM

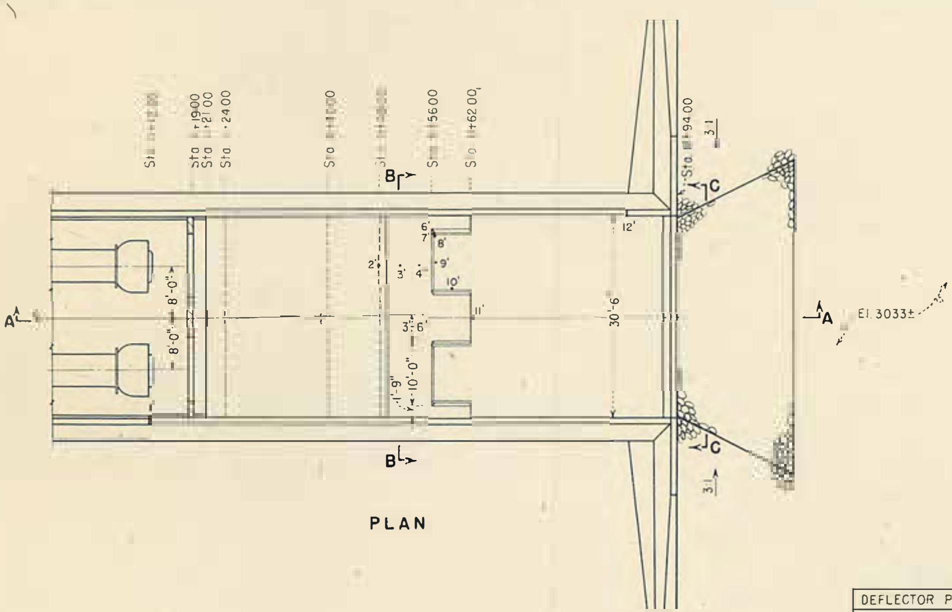


A. Left valve - 930 second-feet

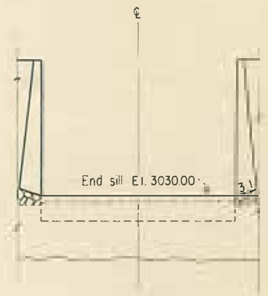


B. Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
BASIN STUDY NO 11, SIDEVIEW



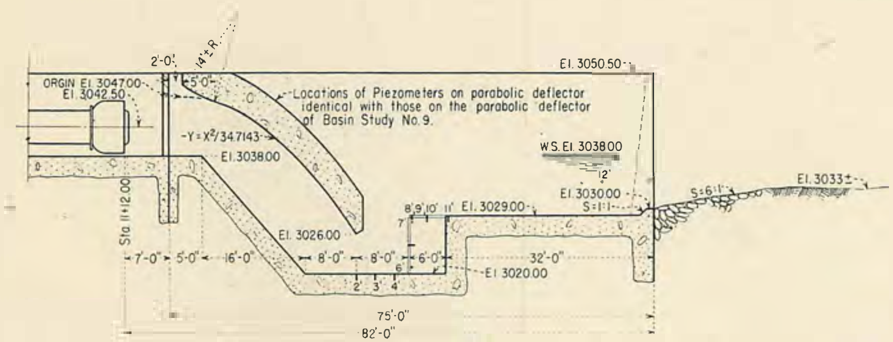
PLAN



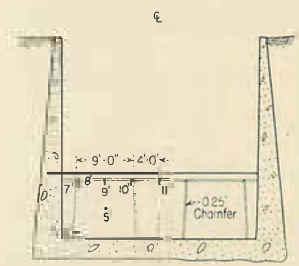
SECTION C-C

PRESSURE IN FEET OF WATER ABOVE El. 3020.00

DEFLECTOR PIEZOMETER	1	2	3	4	5	6	7	8	9	10	11	12
Both valves-1360 C.F.S.	19.1	36.5	27.5	26.0	35.5	25.1	32.1	22.3	19.5	19.0	21.7	18.0
Left valve-930 C.F.S.	18.9	32.8	28.6	25.2	35.3	30.2	31.8	21.3	19.4	19.0	19.8	18.0
FLOOR PIEZOMETER	1'	2'	3'	4'	5'	6'	7'	8'	9'	10'	11	12'
Both valves-1360 C.F.S.	19.2	25.1	33.2	25.3	18.8	15.6	17.0	17.0	17.0	16.8	18.0	18.0
Left valve-930 C.F.S.	18.5	30.5	35.6	28.5	18.5	16.0	16.3	17.1	17.0	16.8	13.8	18.0



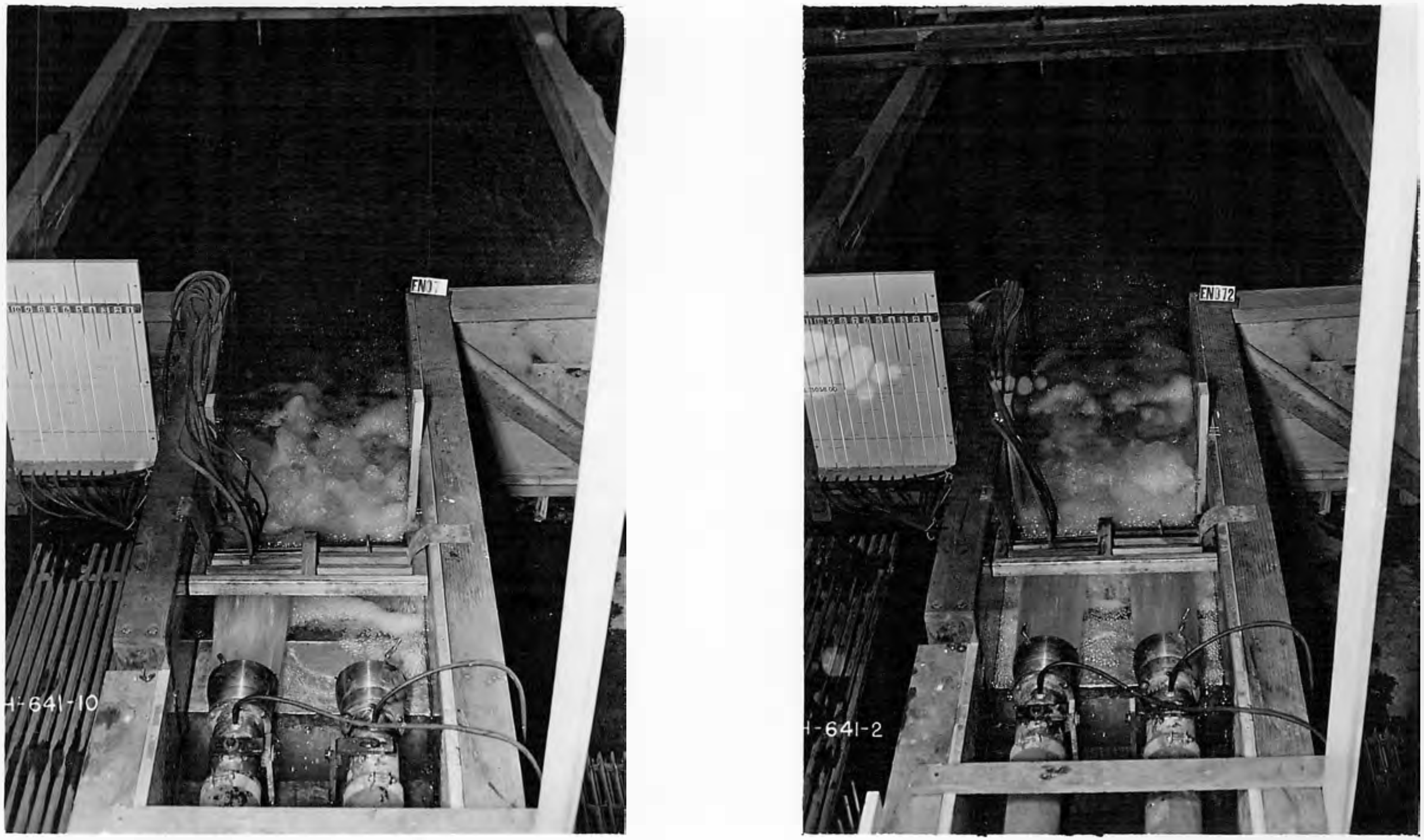
SECTION A-A



SECTION B-B

ENDERS DAM OUTLET WORKS
RECOMMENDED DESIGN

FIGURE 45



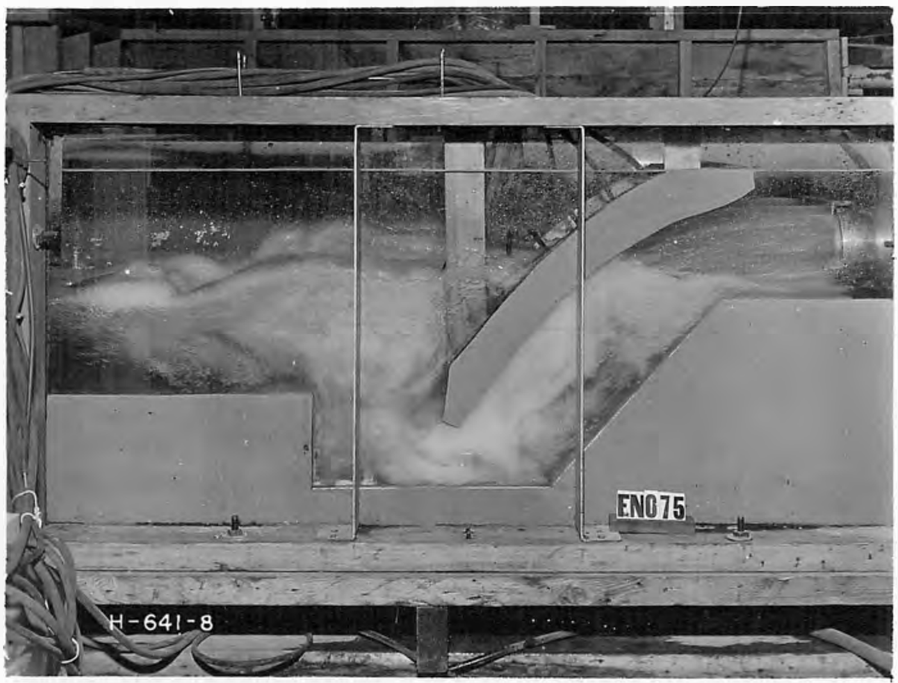
A. Left valve - 930 second-feet

B Both valves - 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
RECOMMENDED DESIGN, LOOKING DOWNSTREAM

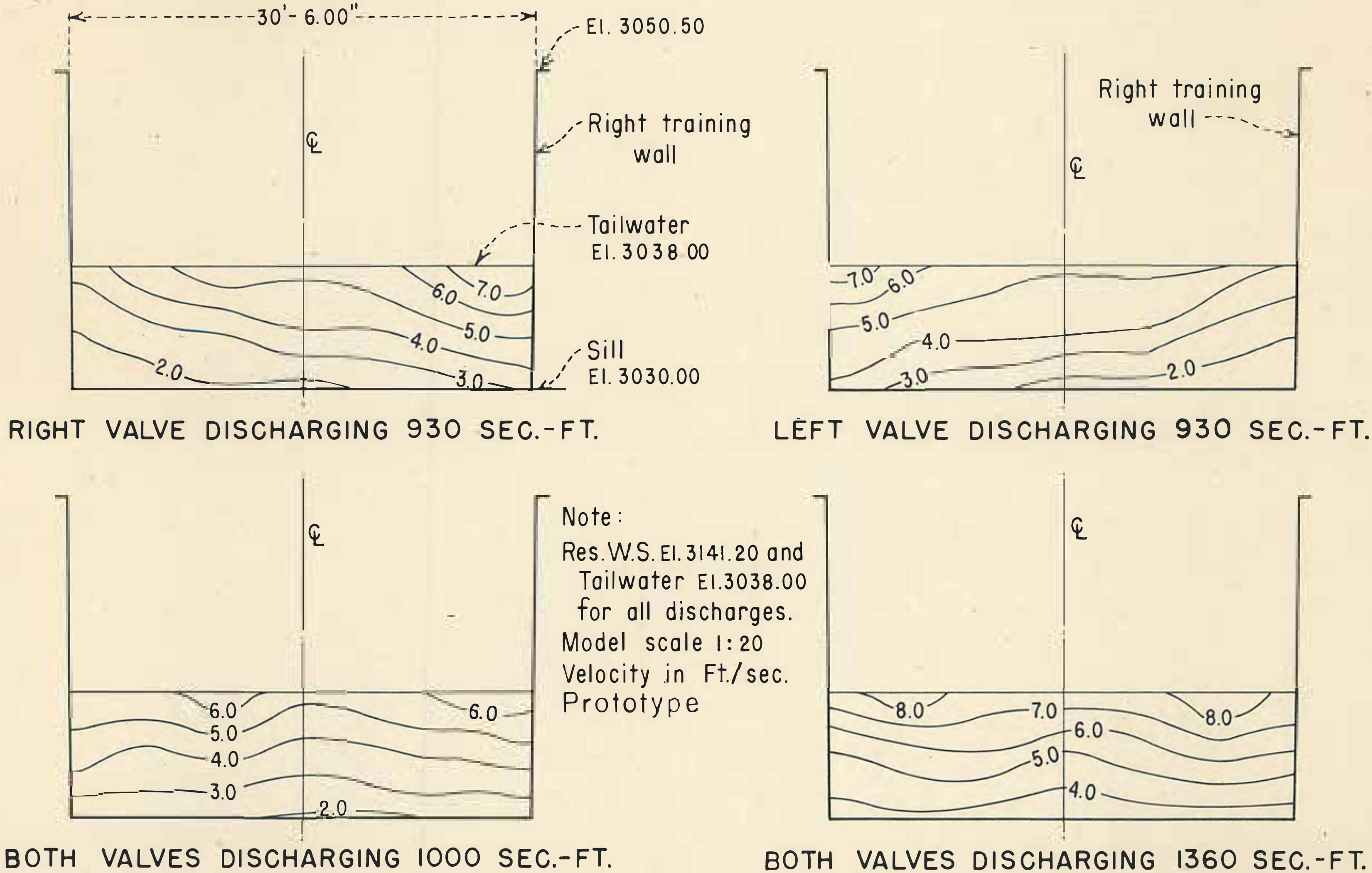
FIGURE 46

A. Left valve - 930 second-feet



B. Both valves - 1360 second-feet

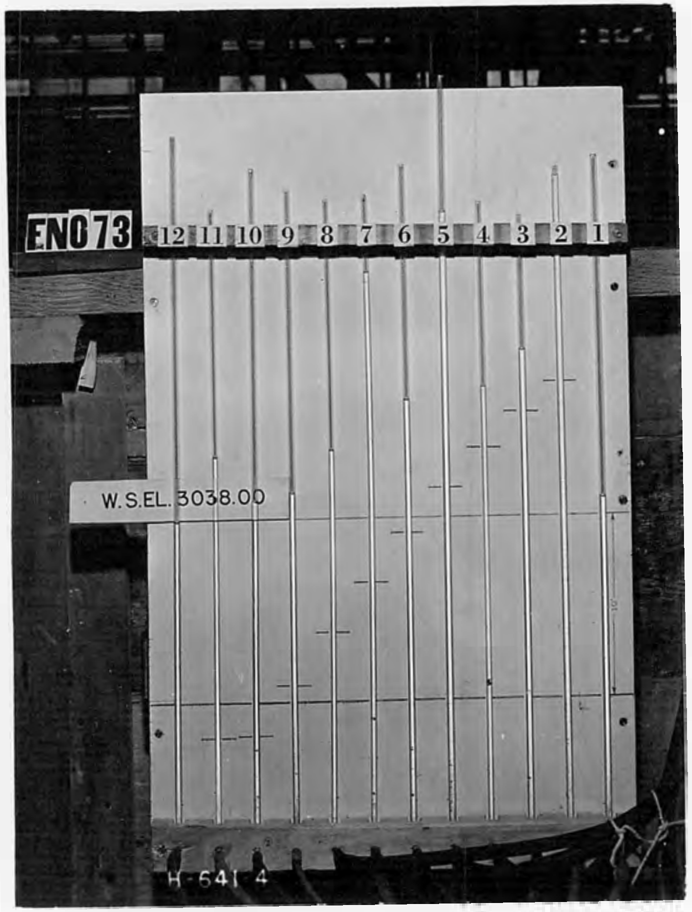
ENDERS DAM
OUTLET WORKS - 1:20 MODEL
RECOMMENDED DESIGN, SIDEVIEW



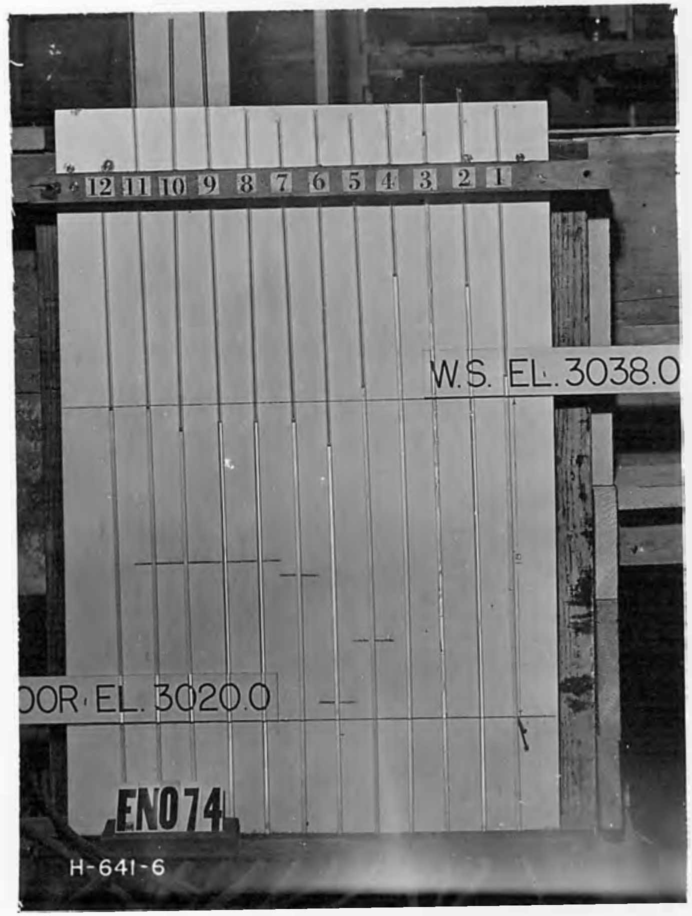
ENDERS DAM OUTLET WORKS

VELOCITY DISTRIBUTION-AT END STA. 11 + 94.00
RECOMMENDED DESIGN

FIGURE 48



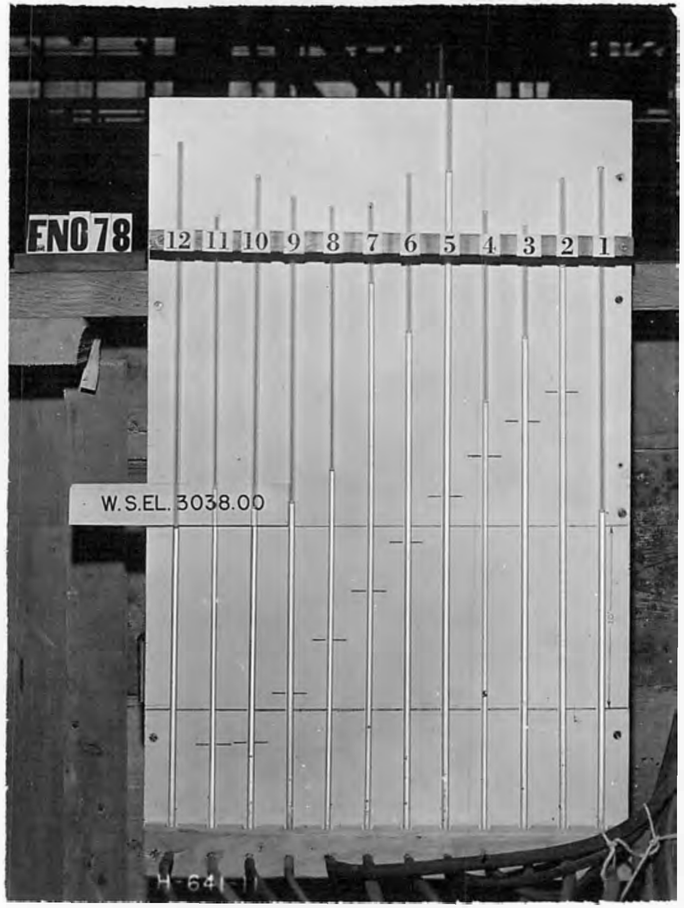
A. Piezometer readings on deflector hood



B. Piezometer readings on floor

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
RECOMMENDED DESIGN, BOTH VALVES - 1360 SECOND-FEET

FIGURE 49

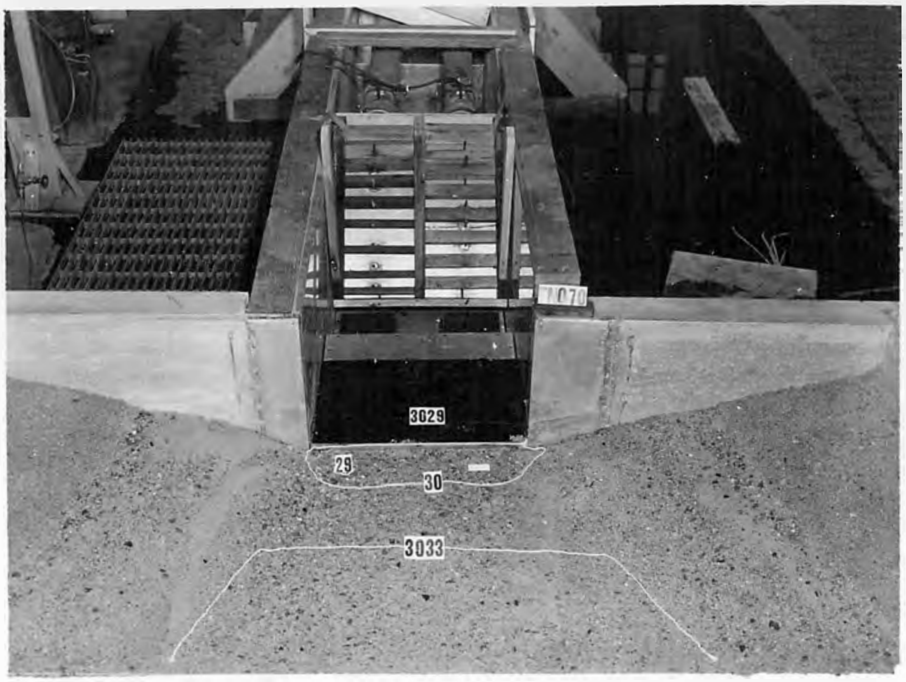


A. Piezometer readings on deflector hood

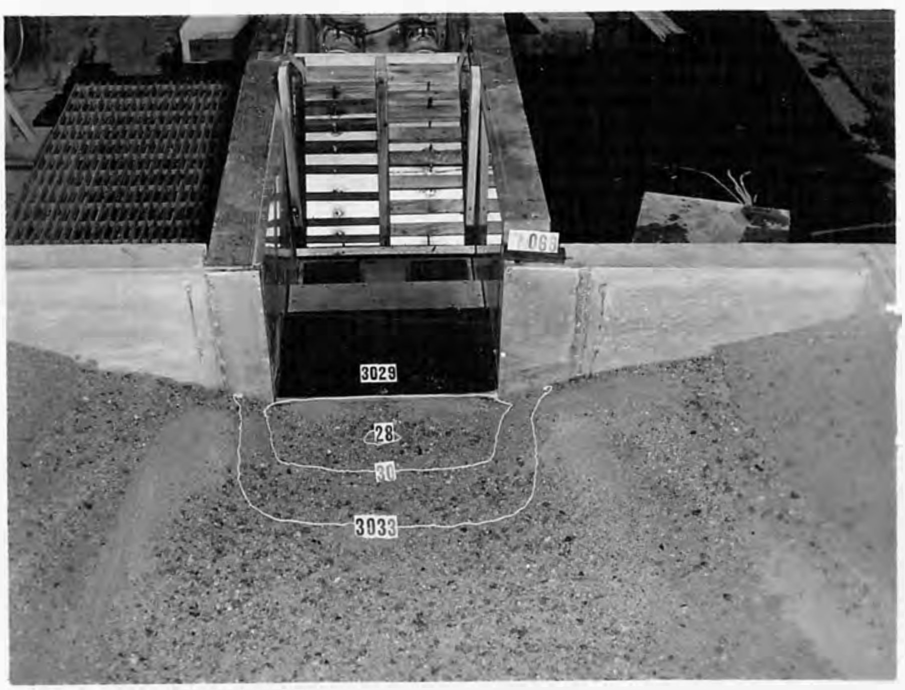
B. Piezometer readings on floor

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
RECOMMENDED DESIGN, LEFT VALVE - 930 SECOND-FEET

FIGURE 50



A. Scour after 1 hour operation of left valve at 930 second-feet



B. Scour after 1 hour operation of both valves at 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
RECOMMENDED DESIGN, LOOKING UPSTREAM

A. 50 - 100 mesh-sand - Both valves, discharge 1360 second-feet

B. 100 - 200 + mesh-sand - Both valves, discharge 1360 second-feet

ENDERS DAM
OUTLET WORKS - 1:20 MODEL
RECOMMENDED DESIGN, SCOUR AFTER 1 HOUR OPERATION