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HYDRAULIC MODEL STUDIES OF THE SPILLWAY AND OUTLET WORKS--HEART BUTTE DAM MISSOURI RIVER BASIN PROJECT

Hydraulic Laboratory Report No. Hyd-326

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

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Laboratory Report No. Hyd-236
Hydraulic Laboratory
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Subject: Hydraulic model studies of the spillway and outlet works--Heart Butte Dam--Missouri River Basin Project

SUMMARY

The hydraulic model studies of the spillway and outlet works of Heart Butte Dam were made with a model built to a scale of 1:21.5. The parts of structure investigated were the spillway entrance structure, the tunnel, the outlet tunnel transition, and the stilling basin.

Tests were started using the preliminary spillway entrance shown in Figure 6A. With the crest submerged, vortex action occurred over the entrance and the tunnel ran full while subatmospheric pressures occurred in the spillway shaft. Tests showed six piers placed on the crest reduced the vortex action to minor proportions. Studies were made on modifications to the shape of the crest, the shaft, and the vertical bend. The tunnel was prevented from flowing full by using a flow deflector at the base of the shaft. This also prevented dangerously low pressures from occurring in the shaft. The elevation of inlet crest for the outlet works was lowered 12 feet to increase the amount of water available for irrigation. The basic entrance shape selected from these studies is shown in Figure 6C.

Special investigations were made to develop air deflectors for the purpose of introducing a flow of air into the spillway water. These air deflectors consisted of projections placed at the top of the shaft above air ports in the shaft wall. They were successful in causing a flow of air into the water which it was believed would cushion the surfaces of the bend from the impact of water and reduce damage if this should occur. The selected air deflectors as installed on the recommended entrance are shown in Figure 25.

Tests showed the tunnel structure to be satisfactory except for the transition at the junction of the outlet works, Figure 34. Operation of the outlet works caused the tunnel at the downstream end of the transition to fill so that with the spillway also discharging, the entire tunnel ran full. A longer transition, Figures 34 and 35, did not correct this condition. Because of the resulting economy, the short transition was recommended for construction with the provision that the outlet be closed during operation of the spillway.

Eight stilling basins at the downstream portal of the tunnel were tested, Figures 36 and 41. High flow concentration occurred with the first basin because of its narrow width. Studies were made with modifications to the basin length, width, and chute design. A wide basin gave satisfactory operation when provided with spreader walls on the chute to expand the flow to the sides of the basin. Pressure tests were made on the nose of the spreader walls and on the baffle piers to develop shapes that would prevent low pressures. The recommended basin, No. 8, Figure 41, was the minimum size that would give good performance. The tail water could be lowered 4 feet below the design tail-water elevation of 2012 for 5,600 second feet before the jump would sweep out of the basin.

INTRODUCTION

Heart Butte Dam is located on the Heart River, 60 miles west of Bismarck, North Dakota, Figure 1, and is a structure of the Heart River Unit of the Missouri River Basin Project. The dam is a compacted earth fill protected with a covering of rock riprap and the crest height above stream bed is 135 feet, Figure 2.

The flood control spillway, located on the right abutment, consists of a 32-foot 6-inch outside diameter morning glory entrance which discharges into a vertical shaft and bend connected to a 14-foot-diameter horizontal tunnel. This in turn discharges into a hydraulic jump stilling basin, Figure 3. The crest is 59.5 feet above the invert of the tunnel and is uncontrolled. Flood regulation is provided for by more than 50 feet of storage above the crest which operates submerged when the reservoir elevation is about 6 feet above the crest.

An unusual feature of the structure is the combining of the outlet works with the spillway. The entrance to the irrigation outlet encircles the spillway shaft and connects to a 5-foot 3-inch-diameter conduit controlled by a 4- by 5-foot high pressure slide gate. This then discharges into the spillway tunnel as shown in Figure 3. The capacity of the outlet is 800 second feet with the reservoir at the crest elevation 2064.50 and the capacity of the spillway is 5,600 second feet at reservoir elevation 2118.2, or a head of 53.7 feet over the crest. The complete spillway and outlet structure was investigated with a hydraulic model built to a scale of 1:21.5.

THE 1:21.5 SCALE MODEL

The 1:21.5 scale model of the spillway and outlet structure is shown in Figure 4. The model was contained in two boxes built of wood and lined with sheet metal. The spillway entrance and surrounding reservoir area were in the head box, while the stilling basin and downstream channel were in the tail box. The tunnel portion of the spillway, between the two boxes, connected the entrance structure and the stilling basin.

Various materials and methods were used to reproduce the different parts of the spillway structure. The entrance structure, bend, tunnel, and transition were made of transparent plastic so that the flow could be observed, Figure 5. Reservoir topography in the head box was built of concrete plastered on metal lath held in place with wooden supports. This method was also used in the tail box for the banks of the river channel with allowance made for a 3-inch cover of sand. A 12-inch depth of sand was used for the riverbed. This movable material permitted erosion studies to be made downstream from the stilling basin. All floor surfaces of the stilling basin were made of concrete screeded to sheet metal templates, and the training walls were built of wood covered with sheet metal. Wood treated with oil was used for small parts such as piers, sills, and chute blocks.

Water was supplied to the model by a portable pump, and an orifice meter in the line was used to measure the discharge. A rock baffle in the head box smoothed out the flow from the inlet pipe. The reservoir elevation was read from a scale on an open-tube manometer connected to the head box. A hinged gate on the tail box was used to regulate the tailwater elevation which was observed from a staff gage.

Two rows of piezometers were placed along the morning-glory entrance and shaft, Figure 12, and piezometers were also used for pressure studies on the stilling basin chute, spreader walls, and baffle piers, Figures 45 and 48.

THE INVESTIGATION

Preliminary Spillway Entrance

Operation. The preliminary morning-glory spillway entrance, Figure 6, had a maximum diameter of 32 feet 6 inches. The shaft, with a diameter of 11 feet, was connected by a transition bend to the 14-foot-diameter tunnel. There were nine air inlets equally spaced around the shaft at elevation 2053.0. The spillway was operated throughout all ranges of discharge up to the maximum of 5,600 second feet, and the appearance of the flow through the entrance, bend and tunnel was satisfactory. Figure 7 shows the flow in the bend and tunnel with the maximum discharge of 5,600 second feet. The tunnel is only partially full, but by closing the air inlets the tunnel would run full and open channel flow could not be re-established without reducing the spillway discharge. Full tunnel operation in the prototype must be avoided since the spillway would act as a siphon which would increase the head and result in excessive discharge. Low pressures would occur which, together with the large flow, might endanger the spillway structure. Methods used to insure against the tunnel running full are discussed in the pressure tests on the spillway entrance.

Pier studies. When the spillway entrance became submerged at reservoir elevation 2070, vortices occurred and remained to reservoir elevation 2084; above this elevation the water surface was smooth.

The photograph, Figure 8A, shows the upper portion of the vortex which extended down the shaft and bend to the horizontal tunnel. A vortex, especially a large one, is undesirable because it reduces the spillway discharge, and being subject to change in size it produces unsteady flow which can result in vibration to the structure.

According to the theory of hydraulic models, the vortex could be expected to occur in the prototype, so studies were made with five pier structures to determine the most practical means of eliminating or reducing the vortex. The first arrangement tested, Pier 1, consisted of two intersecting walls placed on the crest as shown in Figure 9. The vortex action occurred over the same range of reservoir elevation as occurred without piers, but the size of the vortex was reduced, Figure 8B. The use of a single wall was of little value in vortex reduction.

Pier 2 had four piers supporting a conical-shaped cover plate, Figure 9. Vortex action was minor at all reservoir elevations as shown in Figure 10A with a discharge of 3,750 second feet. The cover plate, while giving good suppression to vortex action, was not a practical structure, so the studies were continued using only piers on the crest.

Pier 3, Figure 9, consisted of four piers 14 feet high. Vortex action occurred at the same reservoir elevations as it had in the previous tests. The size of the vortex was less than that occurring with Pier 1 and it was located over the center of the entrance as shown in Figure 10B with a discharge of 3,750 second feet.

For Pier 4, six piers were installed on the crest, Figure 9, and a cover plate was used in the central area of the piers. Vortex action occurred as in all previous tests, but the size of the vortex was smaller than that with Pier 3, and it was located at the edge of the cover plate as shown in Figure 11A with a discharge of 3,750 second feet. The test of Pier 4 demonstrated for the second time that a cover plate, though giving good results, would not eliminate vortex action, since a vortex formed at the edge of the plate and extended down the shaft.

For Pier 5, Figure 9, six piers were used similar to Pier 4, but without a central cover plate. With the entrance submerged, vortex action occurred over the center of the spillway similar to that with Pier 3, but the vortex was smaller. Flow conditions at a discharge of 3,750 second feet, Figure 11B, were considered satisfactory so Pier 5 was recommended for construction on the prototype.

Pressure Tests 1 through 7. With Spillway 1, pressures were measured on the crest and shaft at the piezometer locations shown in Figure 12 to determine if there was danger of cavitation due to low pressures. The curves in Figure 12 show the pressures obtained at discharges of 3,200 and 5,600 second feet with the air-supply ports at elevation 2053.0 both open and closed. With air ports open, the lowest pressure obtained was 4 feet of water below atmospheric near the top of the vertical shaft. With the air vents closed, the tunnel ran full and the lowest pressure was about 30 feet of water below atmospheric at a discharge of 5,600 second feet. This low pressure occurred near the top of the shaft and would result in cavitation in the prototype.

A series of tests were made to determine the alteration to the shaft necessary to prevent low pressures and insure against the tunnel flowing full. One means known to be effective for this purpose was a flow deflector consisting of a projection at the base of the shaft on the inside of the bend.

Pressure Test 2 was made with Deflector 1, 8 feet long, installed as shown in Figure 13. Pressures were measured with the model operating at discharges of 3,500 and 4,840 second feet and the results are plotted in Figure 13. Air was supplied and the lowest pressure was 4 feet of water below atmospheric at Piezometers 3 and 11 located just above the air inlets. The use of the deflector prevented the tunnel from running full even with the air ports closed.

For Pressure Test 3, the length of the deflector was increased to 9 feet and the pressures obtained for three discharges are plotted in Figure 14. The values of the pressures were similar to those obtained in the test with Deflector 2. A test was made with the air vents closed and the lowest pressure was 8 feet of water below atmospheric at a discharge of 3,480 second feet. This was considered an unsatisfactory condition, so tests were continued to find a design that would prevent low pressure.

To determine the effect of length, Deflector 3, Figure 15, with a length of 5 feet, was installed for Pressure Test 4. Pressures were again recorded both with the air vents open and closed and the results are shown in Figure 15. The lowest pressure occurred near the air inlets and was 11 feet of water below atmospheric at a discharge of 3,890 second feet with the air vents closed. With the air vents open at this discharge, the lowest pressure was 5 feet of water below atmospheric. The shorter length deflector was less effective than the two longer deflectors.

A change in deflector shape was made for Pressure Test 5. Deflector 4 had a thickness of 2 feet projecting into the shaft, Figure 16. The straight edge presented to the flow resulted in a smooth water surface in the tunnel which was an improvement over the results with the previous curved deflectors. Pressures throughout the inlet structure were higher than any obtained in the preceding tests. The lowest pressure was 1 foot of water below atmospheric with a discharge of 3,740 second feet and the air vents closed, Figure 16.

The length of the deflector was increased, Figure 17, for Test 6. Flow conditions were similar to that of Test 5, but the shaft pressures were lower. The lowest pressure was 8 feet of water below atmospheric at a discharge of 3,200 second feet with the air vents closed, Figure 17.

In Test 7, two deflectors proposed by the design section were studied. These deflectors, 6 and 7, Figure 18, were installed on the upstream side of the shaft, covering the piezometers so pressures were not measured on Piezometers 1 through 8. The minimum pressures were 5 feet of water below atmospheric, but the water surface in the tunnel was not as smooth as that obtained when the deflectors were located on the downstream side of the shaft.

Calibration. During the pressure tests on the spillway entrance, the reservoir water-surface elevations and discharges were observed. The capacity of the spillway without deflectors exceeded the required discharge of 5,600 second feet at reservoir elevation 2118.2, as this quantity of flow was reached at reservoir elevation 2107.0. The deflectors installed on the lower end of the shaft decreased the spillway capacity according to the effective reduction in cross-sectional area of the shaft.

A discharge capacity curve is shown in Figure 19, Curve 1, with Deflector 3 installed. The general performance of the spillway was fair, and the discharge at reservoir elevation 2118.2 was 5,800 second feet, or 200 second feet greater than the required discharge. Free flow over the crest occurs up to reservoir elevation 2070, the change in the slope of the discharge curve at this point is due to submergence of the crest which continues for all higher reservoir elevations.

Spillway Entrance 2

Operation. Entrance 2 was changed from the preliminary by installing a bend of constant diameter, Figure 6, instead of the transition bend Flow through the entrance and shaft appeared similar to that which occurred with the preliminary entrance; however, the water surface in the tunnel was rough due to the disturbance created by the abrupt increase in diameter at the junction of the bend and tunnel. The smaller diameter of the bend, at the downstream end, prevented the horizontal tunnel from running full since the water surface could not strike the roof of the 14-foot tunnel. The constant diameter bend was not accepted because of the rough flow in the tunnel, but pressure studies on the bend were made both with and without flow deflectors on the downstream side of the shaft.

Pressure Tests 8 through 10 With Entrance 2, pressure curves for four conditions of flow, without a deflector installed, are shown in Figure 20, Pressure Test 8. The lowest pressure was 15 feet of water below atmospheric at a discharge of 3,200 second feet with the air vents closed, or 15 feet of water greater than the lowest pressure obtained in Pressure Test 1 with the diverging bend. Thus, higher pressures resulted with the constant diameter bend since the tunnel could not run full.

Deflector 4 was installed at the bottom of the shaft as shown in Figure 21 for Pressure Test 9. The minimum pressure was 7 feet of water below atmospheric at a discharge of 3,200 second feet with the air vents closed, Figure 21. Flow in the tunnel was rough, showing little improvement over that occurring when the deflector was not used.

For Test 10, Deflector 5 was used with the constant diameter elbow, Figure 22. Pressures were increased over those obtained with Deflector 4 with the lowest pressure being 4 feet of water below atmospheric at a discharge of 3,200 second feet with the air vents closed, Figure 22. Flow in the tunnel was visually unchanged from Test 9 and was considered unsatisfactory.

Calibration. A discharge capacity curve was obtained with Deflector 5 installed in the shaft of Inlet Structure 2. The result, Curve 2 of Figure 19, shows that up to the point of the crest submergence the discharge was the same as obtained with Inlet Structure 1. At higher reservoir elevations, the discharge was less than obtained with the first calibration curve by about 200 second feet, but the discharge at reservoir elevation 2118.2 was slightly above the required value of 5,600 second feet.

Spillway Entrance 3

Operation. The transition bend was reinstalled for Entrance 3 since this gave better flow conditions in the tunnel. The spillway throat was increased to a diameter of 11 feet 8 inches at elevation 2053.85. This made it necessary to modify the crest shape and a tapered shaft was used, Figure 6. The increase in throat size was made to compensate for the loss in area at this point resulting from air deflectors placed above the air vents to increase the air flowing into the water. Development of the air deflectors is discussed under the section of air supply test. Operation of the model showed flow conditions throughout the inlet structure and tunnel to be satisfactory and practically unchanged from those observed when operating spillway Entrance 1. Further tests consisted of pressure studies with two different deflectors at the bottom of the shaft in combination with two sizes of air deflectors over the air inlets.

Pressure Tests 11 through 13. For Pressure Test 11, using Entrance 3, Deflector 8 was installed at the start of the bend and Air Deflector 23 was placed at the top of the tapered shaft, Figure 23. Pressures were similar to those measured in the tests with deflectors on Entrances 1 and 2. The lowest pressure was 14 feet of water below atmospheric at a discharge of 3,200 second feet and the air vents closed, Figure 23. This low pressure was only in the vicinity of the air deflector and would be expected in order to cause a flow of air into the shaft.

For Test 12, the width of the 120° section of Air Deflector 24 was 2 feet, Figure 24. Other features of the structure were unchanged. The lowest pressure of 18 feet of water below atmospheric occurred at a discharge of 3,210 second feet with the air vents closed, Figure 24. This was 4 feet of water lower than occurred when using Air Deflector 23 and resulted from the increase in width of the air deflector.

In Test 13, Figure 25, Air Deflector 23 was used and Deflector 9, with a width of 9 inches, replaced Deflector 8. The lowest pressure obtained with air supplied was 9 feet of water below atmospheric, Figure 25. Pressures in the vertical shaft showed only small variation with a change in flow as indicated by the convergence of the pressure lines for the four discharges.

Calibration. A discharge capacity curve was obtained for Entrance 3 with Deflector 9 and Air Deflector 23, Curve 3 of Figure 19. This was the selected entrance. The discharge at reservoir elevation 2118.2 was 5,450 second feet or 150 less than the required value of 5,600 second feet. However, the design section decided to construct this inlet structure because pressures were satisfactory, considerable air was supplied to the shaft, and flow was smooth in the bend and tunnel. With the six piers 14 feet, high vortex action was not serious at any reservoir elevation.

Air Supply Tests 1 through 7. During development of the inlet structure the design section requested studies on an air supply system to obtain a maximum flow of air into the vertical shaft. Air deflectors investigated were projections on the upstream side of the shaft. Air was admitted to the underside of the deflectors through a pipe which originated above the reservoir water surface. The air flow was determined by observing the pressure drop across an orifice at the entrance to the pipe.

The first four air tests were made to determine the effect of the deflector design on the quantity of air supplied. The features studied were the area of the air slot, the width of the deflector, the vertical position of the deflector, and the angle of the face of the deflector with the wall of the shaft. Air Test 1 used Air Deflector 10, extending 120° around the shaft with a width of 9 inches, Figure 26. Four sizes of air openings were used at the bottom of the deflector. There was no appreciable difference in the quantity of air due to changing the area of the air slot as shown by the air-supply curves in the figure. The air supply was greater at the lower reservoir elevation 2080.

Air Test 2 used Deflectors 11 and 12, Figure 27, having widths of 1.6 and 2.5 feet, respectively. The results of this study, Figure 27, showed that the quantity of air increased with greater deflector widths. More air was supplied at the lower reservoir elevation 2080, as had occurred in Test 1.

The elevation of Air Deflector 13 was varied in Air Test 3, Figure 28. As shown in the figure, the greatest quantity of air was admitted with the deflector near the top of the shaft. As before, more air flow occurred at reservoir elevation 2080, but with the deflector near the top of the shaft the air supplied varied less with an increase in reservoir elevation.

In Air Test 4, nine deflectors were studied, Figure 29. There were three deflector widths, and with each width three angles of the deflector face to the shaft were tried. The results plotted in the figure show only a slight variation in air discharge with different widths. With a deflector angle of 7.5°, the quantity of air showed only a small variation with changes in reservoir elevation. Using a 0° angle, the air discharge decreased with an increase in reservoir elevation, but with a 15° angle the air discharge increased with higher reservoir elevations. The four air tests just described showed that for the greatest flow of air the deflector should be at the top of the shaft, and that the face of the deflector should make an angle of at least 10° with the shaft.

An inlet structure with a side entrance was proposed by the design section to obtain a spillway that would discharge air in addition to water. This side entrance inlet was studied in Air Tests 5 and 6. An air opening was provided above an orifice at elevation 2038.5 which admitted water, Figure 30. Air and water discharge curves are shown in the figure both with the side water inlet open and closed. With water flowing through the side inlet, a maximum air discharge of 134 cfs occurred at a reservoir elevation of 2070, but the air discharge decreased for higher reservoir elevations and remained at 20 cfs when the reservoir elevation was above 2085. Closing the side inlet to the flow of water increased the air discharge to 207 cfs at reservoir elevation 2070, but with the main crest submerged, the air discharge became zero. The intake was changed for Test 6 as shown in Figure 31, Alterations A and B. In both tests there was no air flow into the spillway for any operating condition. Pressures were measured at various points in the structure as shown in the figure. The lowest pressure obtained was 22 feet of water below atmospheric at Piezometer 1 when testing Alteration A. The discharge capacity curves, Figure 31, showed the discharge to be about 30 percent too low with Alteration B. Since no air was supplied and flow conditions were not satisfactory, the side inlet structure was discarded as a means of supplying air to the spillway.

Test 7, Figure 32, used Air Deflector 23 which was installed on the recommended intake structure. Air capacity curves were obtained using Deflectors 8 and 9 at the bottom of the shaft. The curves, Figure 32, showed an increase in air discharge with an increase in reservoir elevation. More air was supplied with Deflector 9, and this deflector was recommended because the water discharge was also greater. From the model results, the air discharge using Deflector 9 was 1 percent of the value of the water discharge. The air contained in the water flowing through the bend is shown in Figure 33.

Due to the extremely small size of the air ducts and ports, the model results are not expected to indicate the true air flow in the prototype. The model results were used strictly on a comparative basis. A further discussion of this subject may be found in Hydraulic Laboratory Report Hyd-332 "Performance tests on the prototype and model of the Heart Butte spillway and outlet works."

Outlet Works Studies

Outlet Tunnel Transition 1. The outlet works, Figure 3, is regulated by a 4- by 5-foot high pressure slide gate. Transition 1, connecting the outlet tunnel with the spillway tunnel, is shown in Figure 34. The transition was 54 feet long to provide room for the jet from the outlet conduit. Flow in the transition section and tunnel is shown in Figure 35A with the outlet discharging 850 second feet. The 4- by 5-foot outlet gate was fully open with the reservoir water surface at the spillway crest elevation 2064.5, and no flow from the spillway. As shown in the photograph, the wave occurring from the jet striking the floor filled the tunnel section at the end of the transition. This flow condition was not objectionable except that it sealed the tunnel to the free passage of air, and when the model was operated with both the spillway and outlets discharging, the tunnel ran full with resulting low pressures in the spillway shaft. However, this condition would not occur in the prototype since it was not intended that the spillway and outlet works would operate simultaneously.

Outlet Tunnel Transition 2. Transition 2 had a 34-foot length of 14- by 22-foot 9-1/2-inch tunnel installed at the upstream end of the transition, Figure 34. This increased the length of the transition, and it was expected that the wave from the outlet jet would occur upstream from the circular tunnel section, so that the tunnel would not be sealed. Flow in the transition and tunnel with a discharge of 850 second feet through the outlet with no flow from the spillway is shown in Figure 35B. The first wave occurred upstream in the transition section, but subsequent waves extended downstream into the tunnel. With the spillway and outlets discharging, the tunnel was sealed and ran full, causing subatmospheric pressures as with Transition 1. Since no improvement resulted with Transition 2, it was decided to use the more economical Transition 1 with the restriction that the outlet be closed during operation of the spillway.

Stilling Basin Studies

Stilling Basin 1. Stilling Basin 1 is shown in Figure 36. A transition section at the end of the tunnel gave a horseshoe-shaped portal 14 feet wide at the bottom. The stilling-basin width was 26.5 feet, and a chute with a hump rising 5 feet above the tunnel portal connected the tunnel and stilling basin. Operation of the basin at the maximum discharge of 5,600 second feet, Figure 37A, showed high velocities and a rough water surface in the stilling basin and river channel. Lowering the tail water 1-1/2 feet caused the jump to sweep out of the basin. Scour was severe after 1/2-hour operation at 5,600 second feet with the tail water at elevation 2012, Figure 37B. The 3-inch layer of sand covering the right bank was washed off by the wave action, and in the stream bed the greatest depth of scour was 12 feet lower than the end of the basin. In this basin, the 3:1 sloping floor at the downstream end reduced the area so that the average velocity at the sill was 17.6 feet per second, which contributed to the rough water surface in the river channel.

Stilling Basin 2. For Stilling Basin 2, the sloping floor at the downstream end of the basin was removed, resulting in a decrease in length of 38.5 feet, Figure 36. The remainder of the basin was unchanged. Operation at 5,600 second feet, Figure 38A, showed a reduction in velocity and wave height in the river channel over that occurring with Basin 1. Scour after 1/2-hour operation at 5,600 second feet and tail-water elevation 2012, showed the lowest stream bed elevation to be 1988, Figure 38B. This was the same as the elevation of the lowest scour obtained with Basin 1. Though Basin 2 showed an improvement in flow conditions, the scour test showed the basin was unsatisfactory.

Stilling Basin 3. The hump in the stilling basin chute was unnecessary for spreading the flow from a width of 14 feet to 26.5 feet, so a shorter chute was installed, giving an increase of 35 feet in length of the horizontal floor, Figure 36. Flow in the basin and river channel was improved with a discharge of 5,600 second feet, Figure 39A. The water spread to the sides of the basin as effectively as it did with the hump. Scour, Figure 39B, after a discharge of 5,600 second feet for 1/2 hour at tail-water elevation 2012, was very similar to that of Basin 2, showing that the energy dissipation of the two basins was about equal.

Stilling Basin 4. The width of the stilling basin was increased to 31.50 feet at the downstream end by increasing the length of the diverging walls as shown in Figure 36. The total length was unchanged, but baffle blocks were installed, and the end sill was modified. Operation, Figure 40A, showed the increased width gave lower velocities and a smoother water surface in the river channel than occurred in previous tests. Lowest elevation of the riverbed was 1988 after 1/2-hour operation at 5,600 second feet, Figure 40B. This was 1/2 foot above the apron, but the eroded area was confined to the first 60 feet of the river channel. The remainder of the channel was only slightly disturbed.

Stilling Basin 5. A width of 42.50 feet was used for Basin 5. The horizontal apron was at elevation 1987.50 and had a length of 102.30 feet. Two spreader walls, Figure 41, were installed on the chute to spread the flow to the greater basin width of 42.50 feet. Very good operation occurred for all discharges with uniform distribution of flow across the width of the basin. The performance at a discharge of 5,600 second feet, is shown in Figure 42A. Scour, Figure 42B, was light, with practically no stream-bed erosion after operating at a discharge of 5,600 second feet for 1/2 hour. The operation and scour tests showed the basin performance was better than necessary. The remaining studies consisted of a progressive reduction in the basin length until a minimum size was obtained consistent with good performance.

Stilling Basin 6. The length of the horizontal floor of the basin was reduced 22.3 feet and the floor raised 2-1/2 feet to elevation 1990.00, Figure 41. Performance at the maximum discharge of 5,600 second feet, Figure 43A, was similar to that of Basin 5, but there was a slight increase in the roughness of the water surface. The 1/2-hour scour test at maximum discharge, Figure 43B, showed some increase in erosion over that obtained with Basin 5, but it was still considered very good.

Stilling Basin 7. For Basin 7, an additional 15 feet was removed from the downstream end, leaving 65 feet of horizontal apron, Figure 41. Operation at the maximum discharge, Figure 44A, showed the water surface in the river channel to be rougher than occurred with Basins 5 or 6, and lowering the tail water 1-1/2 feet caused the jump to sweep out of the basin. Erosion after 1/2-hour operation at 5, 600 second feet, Figure 44B, was greater than obtained with Basin 6, and more sand was washed off the right bank.

Piezometers were installed on the upstream end of one spreader wall and on one of the 4- by 4- by 4-foot baffle blocks. Pressures obtained for three discharges are tabulated on Figure 45 which also shows the location of the piezometers. At maximum discharge, a pressure of 18 feet of water below atmospheric occurred on the spreader wall nose and 10.5 feet of water below atmospheric on the side of the baffle block.

The spreader walls on the chute were removed to determine their effectiveness. Operations of the stilling basin showed the flow was more concentrated in the center of the basin, Figure 46A. Scour in the river channel was more severe, Figure 46B, than occurred with the spreader walls installed.

Stilling Basin 8. The basin length was increased 10 feet, resulting in a 75-foot length of horizontal apron. The floor elevation was lowered to 1987.50, Figure 41, and spreader walls were used. Operation at 5, 600 second feet, Figure 47A, was satisfactory and was similar to Basin 7 with spreader walls. Scour was confined to the channel at the end of the basin, Figure 47B, and a small bar was built up in the channel. From the operation and erosion test results, the basin was considered satisfactory.

Pressure tests were run on a new spreader wall nose and baffle block as well as on the floor of the chute. Results obtained for a discharge of 5, 600 and 3, 200 second feet are shown in Figure 48. The water-surface profile through the stilling basin is also shown in the figure for a discharge of 5, 600 second feet. Lowest pressure on the curved floor of the chute was 3.5 feet of water below atmospheric, and on the spreader wall nose the lowest pressure was 2.8 feet of water below atmospheric. All pressures were above atmospheric on the baffle pier.

At the maximum discharge of 5, 600 second feet the tail water could be lowered 4 feet before the jump would sweep out of the stilling basin. These tests on Stilling Basin 8 indicated the basin was satisfactory, and it was recommended for construction.

Interior - Reclamation - Denver, Colo.

FIGURE I

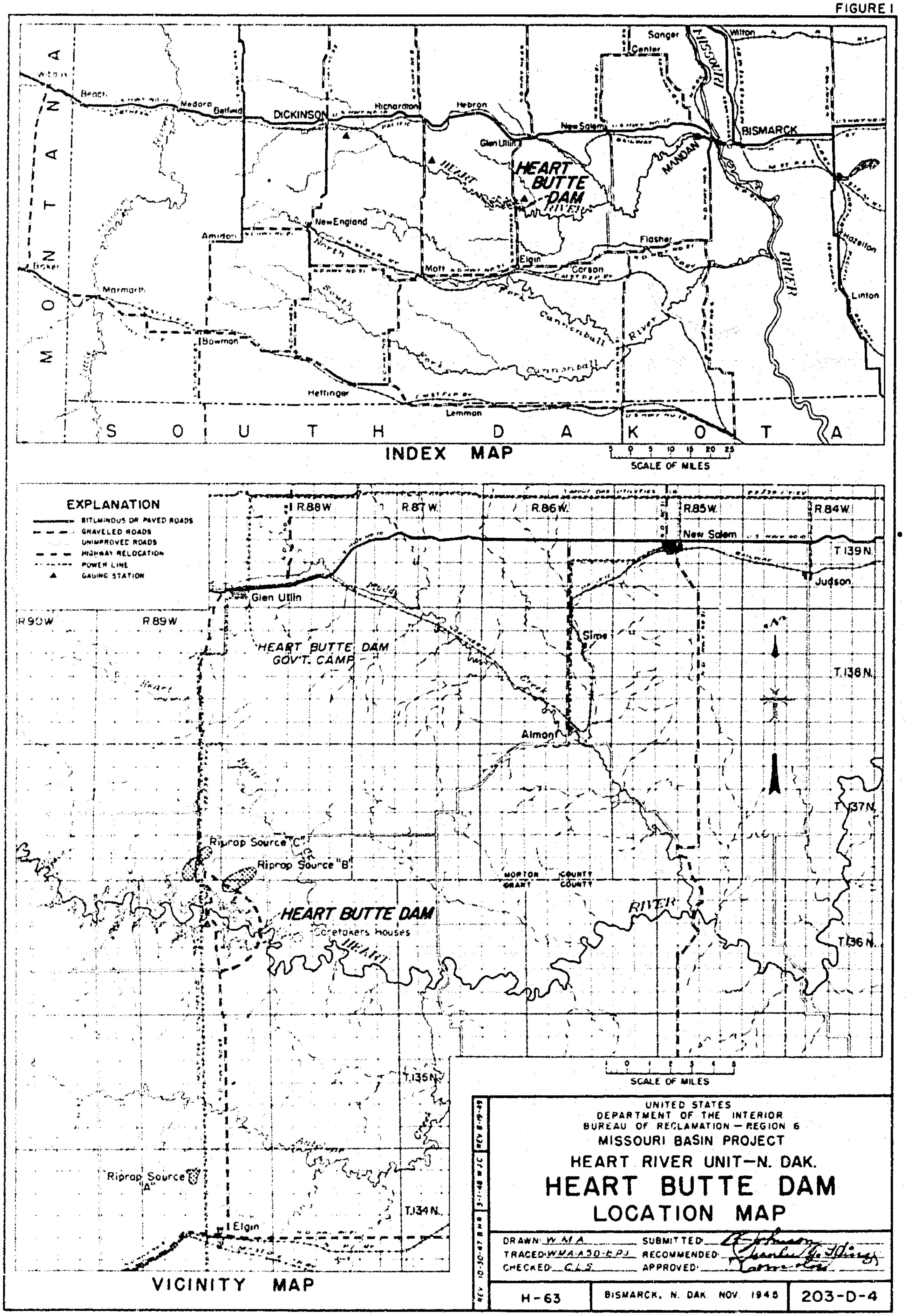
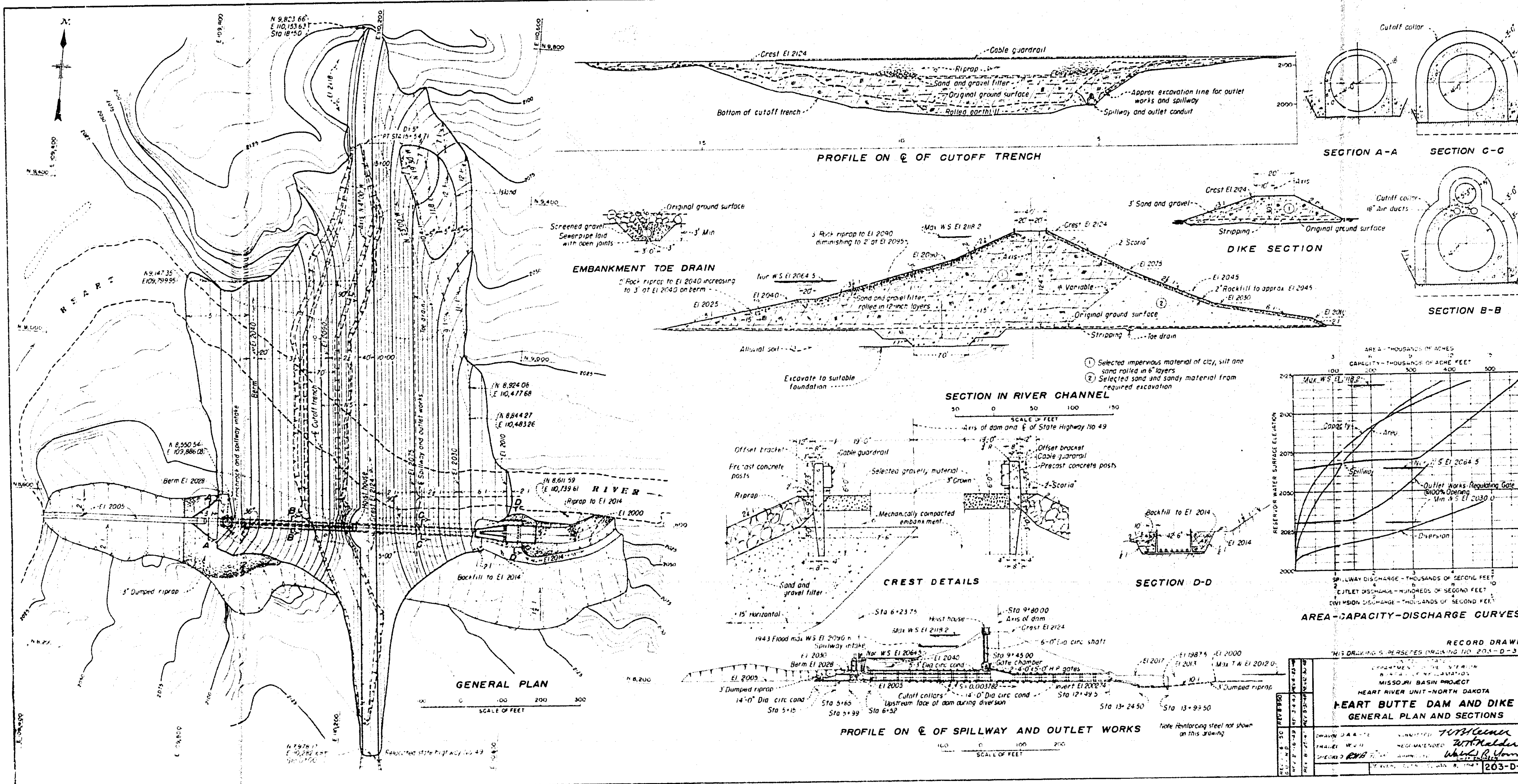
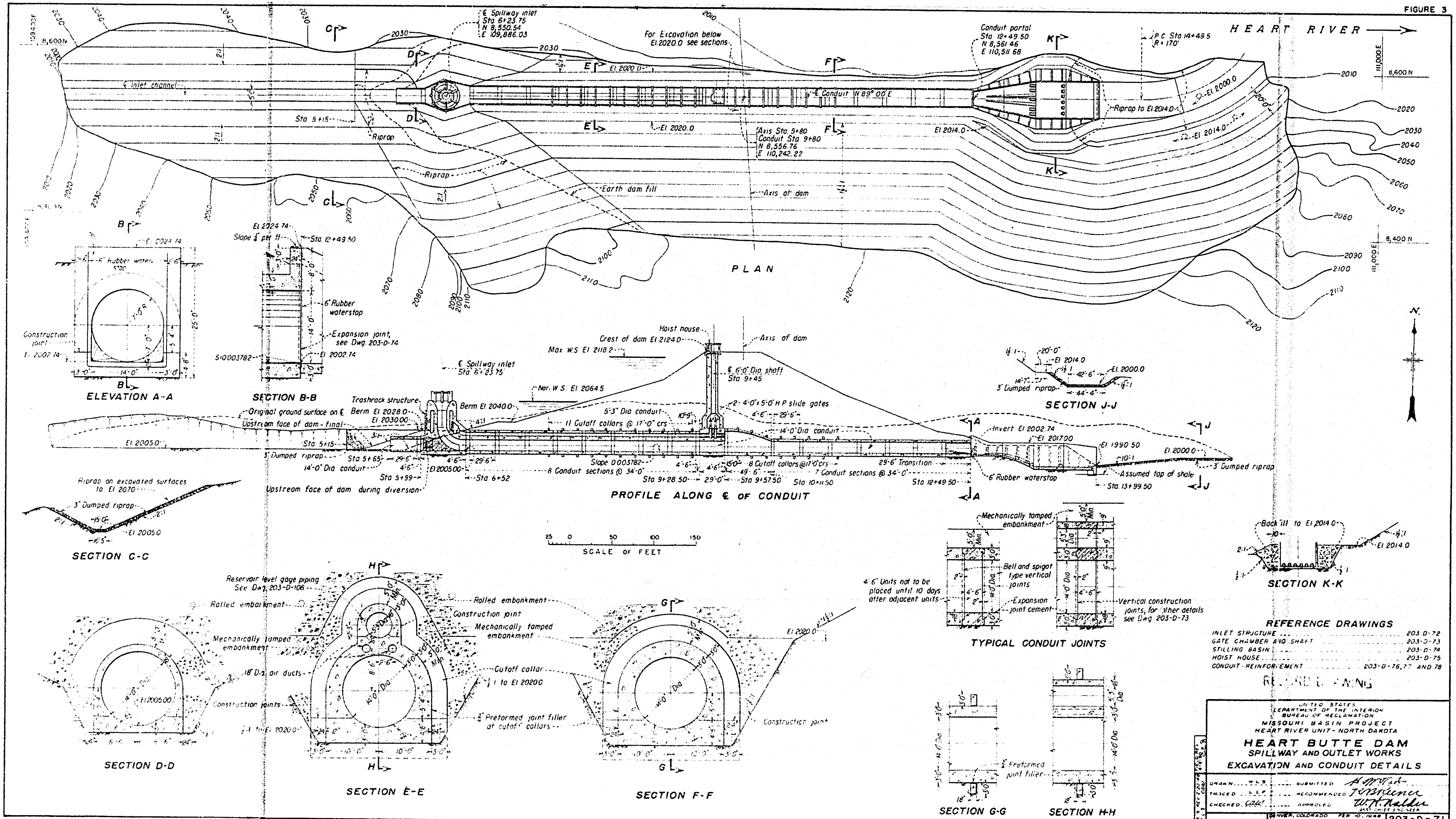

INDEX MAP
MONTANA
SOUTH DAKOTA
Sanger
Center
Wilton
MISSOURI
Beach
Medora
Belfield
DICKINSON
Richardton
Hebron
New Salem
BISMARCK
Glen Ullin
HEART BUTTE DAM
HEART
RIVER
MANDAN
New England
Amidon
North
Flasher
Elgin
Mott
Carson
Baker
Marmarth
Bowman
Cannonball
River
Hettinger
Lemmon
Hazelton
Linton
RIVER
SCALE OF MILES
VICINITY MAP
EXPLANATION
BITUMINOUS OR PAVED ROADS
GRAVELED ROADS
UNIMPROVED ROADS
HIGHWAY RELOCATION
POWER LINE
GAGING STATION
R.88W.
R.87W.
R.86W.
R.85W.
R.84W.
R.90W
R.89W
New Salem
T.139N.
Judson
Glen Ullin
Muddy
Creek
Sims
HEART BUTTE DAM GOV'T. CAMP
T.138N.
Heart
Almont
T.137N.
Riprap Source "C"
Riprap Source "B"
MORTON COUNTY
GRANT COUNTY
RIVER
HEART BUTTE DAM
Caretakers Houses
HEART
T.136N.
T.135N.
Riprap Source "A"
T.134N.
Elgin
SCALE OF MILES
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION — REGION 6
MISSOURI BASIN PROJECT
HEART RIVER UNIT—N. DAK.
HEART BUTTE DAM
LOCATION MAP
DRAWN: W.M.A.
TRACED: WMA-ASD-EPJ
CHECKED: C.L.S.
SUBMITTED:
RECOMMENDED:
APPROVED:
H-63
BISMARCK, N. DAK. NOV. 1948
203-D-4

FIGURE 2



GENERAL PLAN
SCALE OF FEET
PROFILE ON ℄ OF CUTOFF TRENCH
SECTION A-A
SECTION C-C
SECTION B-B
EMBANKMENT TOE DRAIN
DIKE SECTION
SECTION IN RIVER CHANNEL
CREST DETAILS
SECTION D-D
AREA-CAPACITY-DISCHARGE CURVES
PROFILE ON ℄ OF SPILLWAY AND OUTLET WORKS
Crest El 2124
Cable guardrail
Riprap
Sand and gravel filter
Original ground surface
Rolled earthfill
Bottom of cutoff trench
Approx excavation line for outlet works and spillway
Spillway and outlet conduit
Cutoff collar
18" Air ducts
Max W S El 2118.2
Nor W S El 2064.5
Selected impervious material of clay, silt and sand rolled in 6" layers
Selected sand and sandy material from required excavation
Excavate to suitable foundation
Alluvial soil
Stripping
Toe drain
Hoist house
Axis of dam
6'-0" Dia circ shaft
14'-0" Dia circ cond
Gate chamber
Cutoff collars
3' Dumped riprap
Backfill to El 2014
Riprap to El 2014
Relocated state highway No 49
HEART RIVER
Capacity
Area
Spillway
Outlet Works Regulating Gate @100% Opening
Diversion
RESERVOIR WATER SURFACE ELEVATION
SPILLWAY DISCHARGE - THOUSANDS OF SECOND FEET
OUTLET DISCHARGE - HUNDREDS OF SECOND FEET
DIVERSION DISCHARGE - THOUSANDS OF SECOND FEET
Note: Reinforcing steel not shown on this drawing
RECORD DRAWING
MISSOURI BASIN PROJECT
HEART RIVER UNIT - NORTH DAKOTA
HEART BUTTE DAM AND DIKE
GENERAL PLAN AND SECTIONS
203-D-37



REFERENCE DRAWINGS

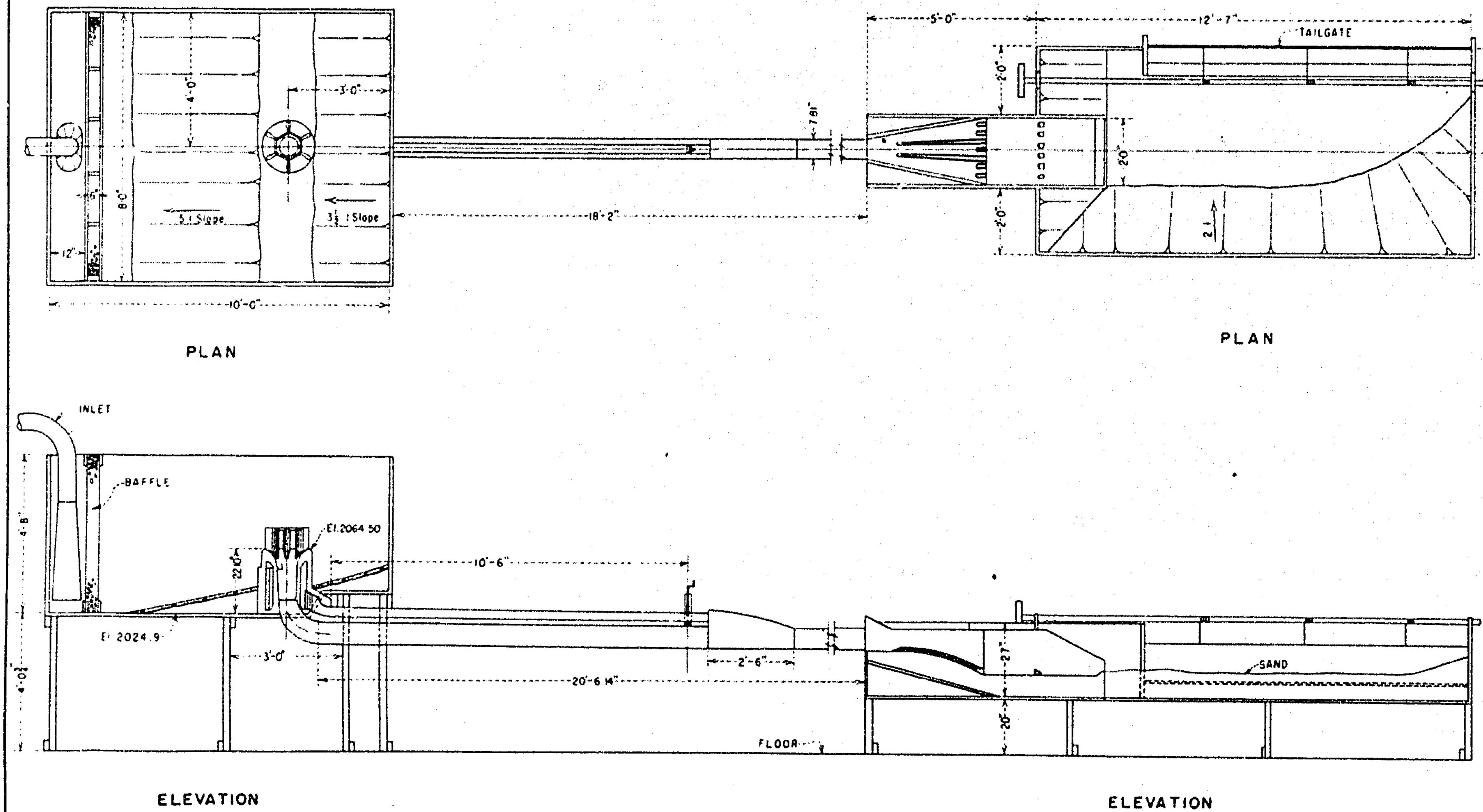
INLET STRUCTURE	203-D-72
GATE CHAMBER AND SHAFT	203-D-73
STILLING BASIN	203-D-74
HOIST HOUSE	203-D-75
CONDUIT - REINFORCEMENT	203-D-76, 77 AND 78

RECORD DRAWING

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
HEART RIVER UNIT - NORTH DAKOTA

HEART BUTTE DAM
SPILLWAY AND OUTLET WORKS
EXCAVATION AND CONDUIT DETAILS

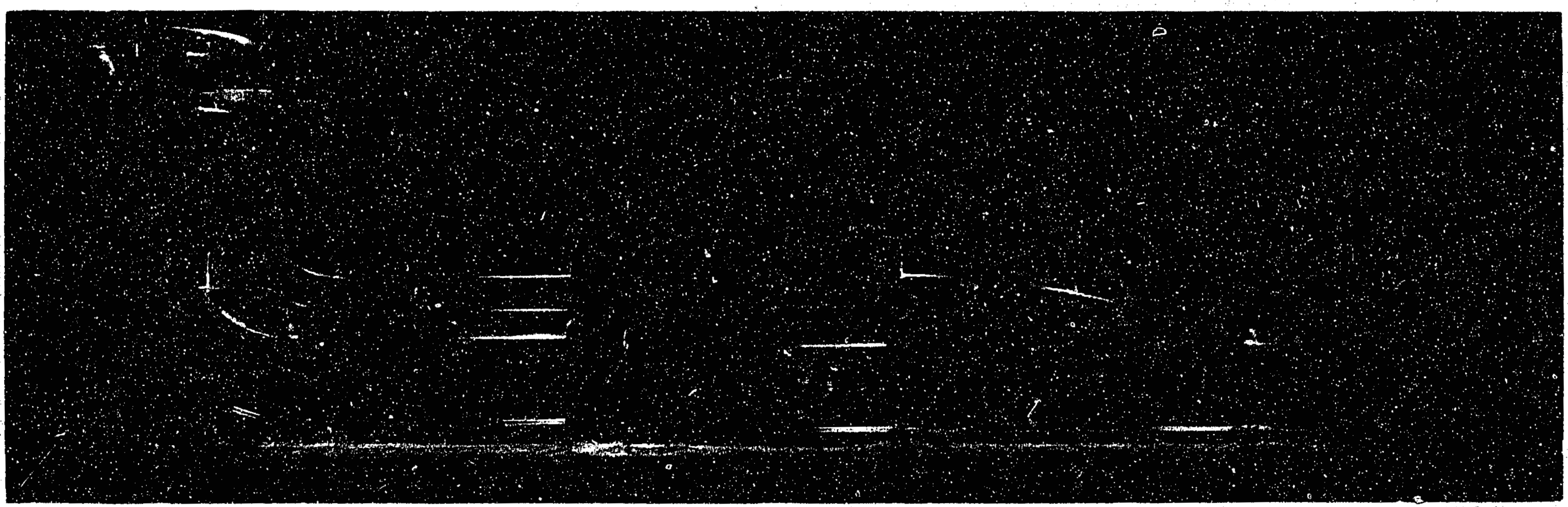
DRAWN W.L.S. SUBMITTED
TRACED L.L.F. RECOMMENDED
CHECKED C.A.W. APPROVED
ASST. CHIEF ENGINEER
DENVER, COLORADO FEB 10, 1948 203-D-71



HEART BUTTE DAM
1:21.5 SCALE MODEL

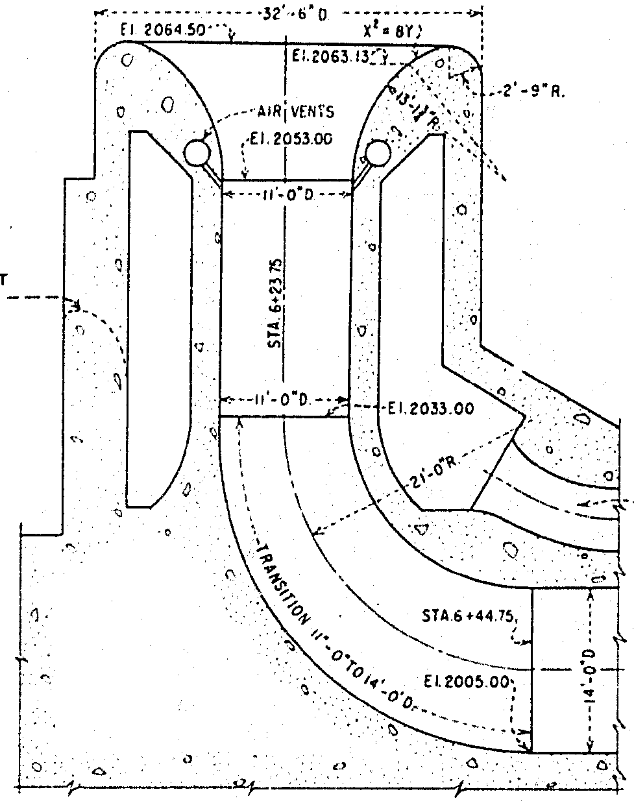
FIGURE 4

330



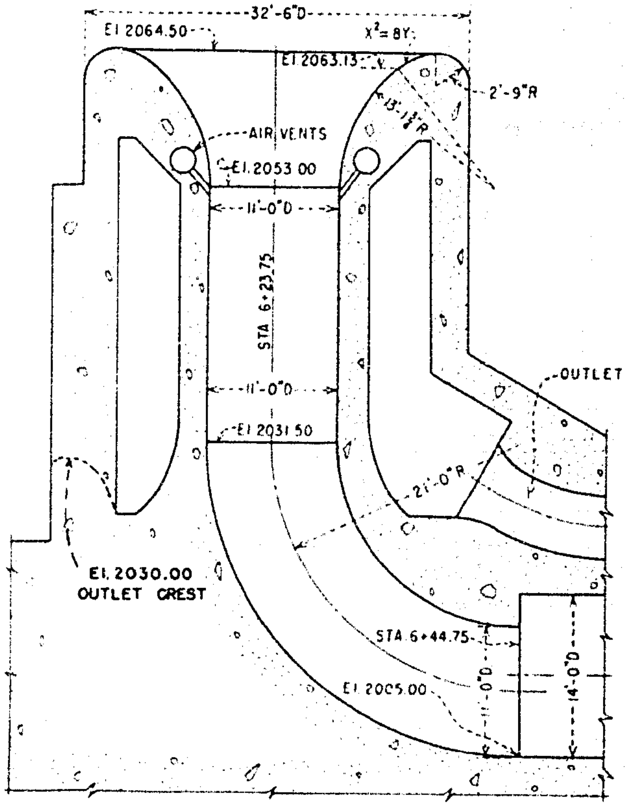
SPILLWAY AND OUTLET STRUCTURE
OF TRANSPARENT PLASTIC
HEART BUTTE DAM
1:21.5 SCALE MODEL

FIGURE 5



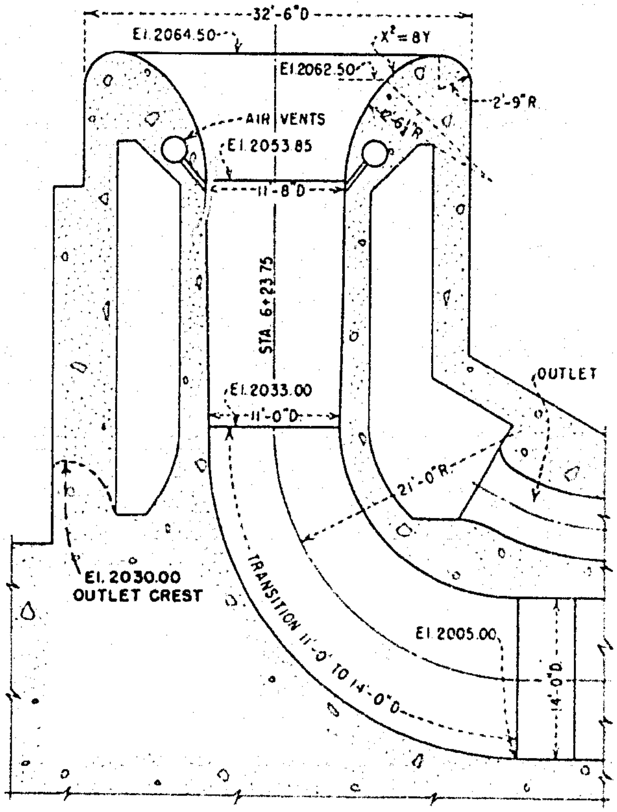
SECTION

A. No. 1-PRELIMINARY



SECTION

B. No. 2

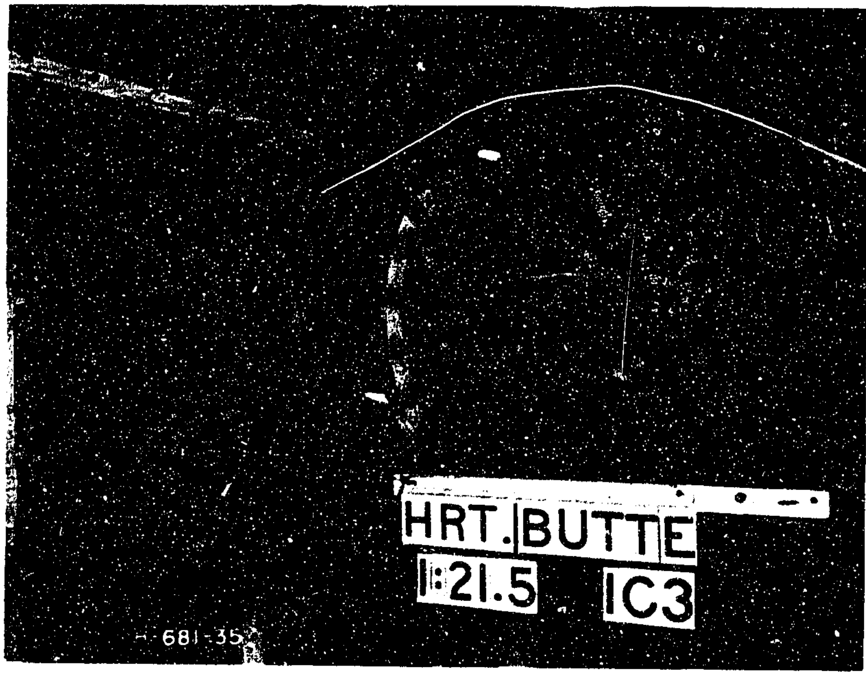


SECTION

C. No. 3-RECOMMENDED

HEART BUTTE DAM

SPILLWAY INLET STRUCTURES



Discharge 5, 600 second-feet
Flow through bend

PRELIMINARY TRANSITION BEND
1:21-1/2 MODEL HEART BUTTE DAM

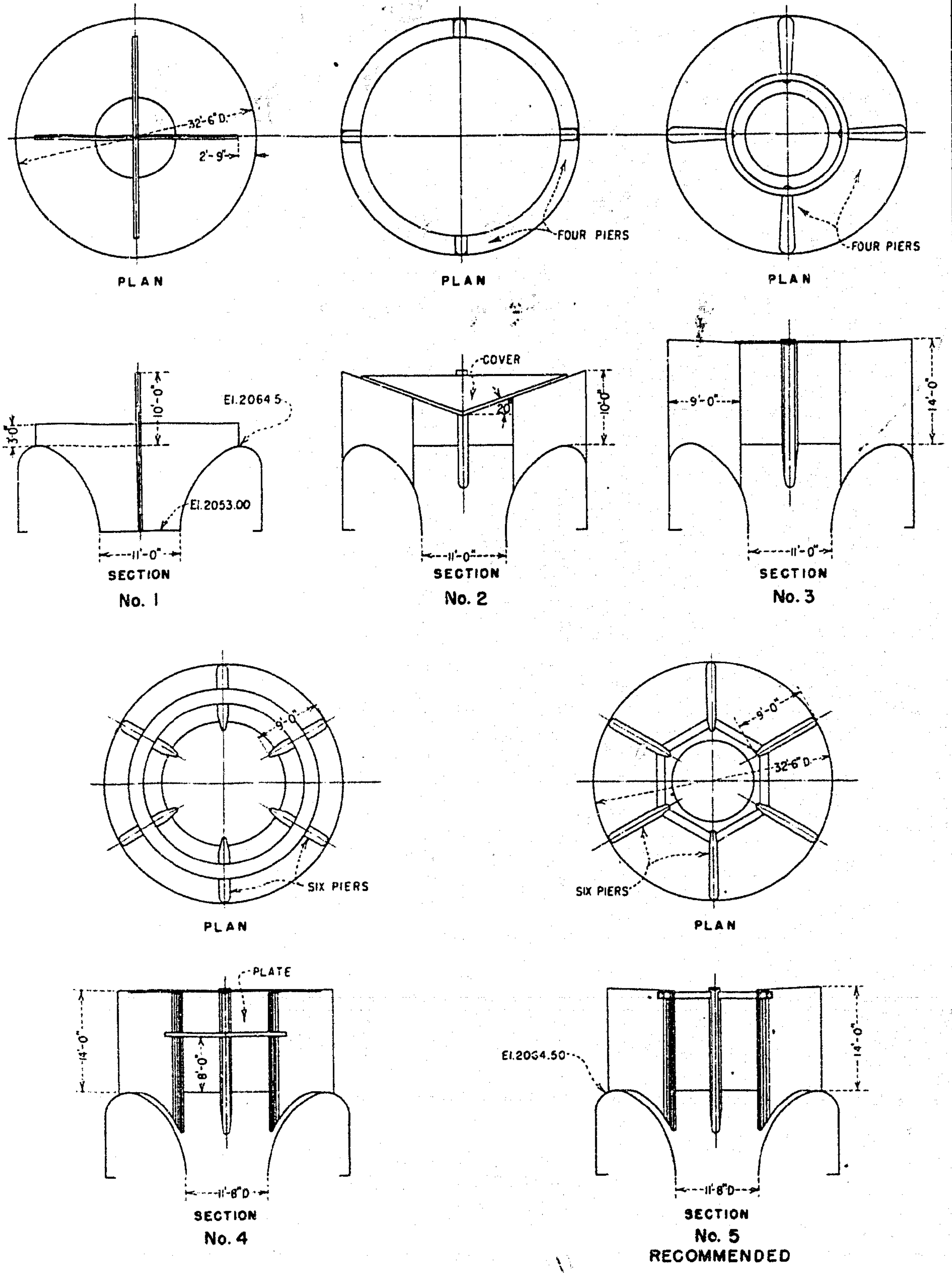
FIGURE 8

A. Crest without piers
Discharge 3, 750 second-feet
Reservoir at Elevation 2077

B. Crest with Pier No. 1
Discharge 3, 750 second-feet
Reservoir Elevation 2077

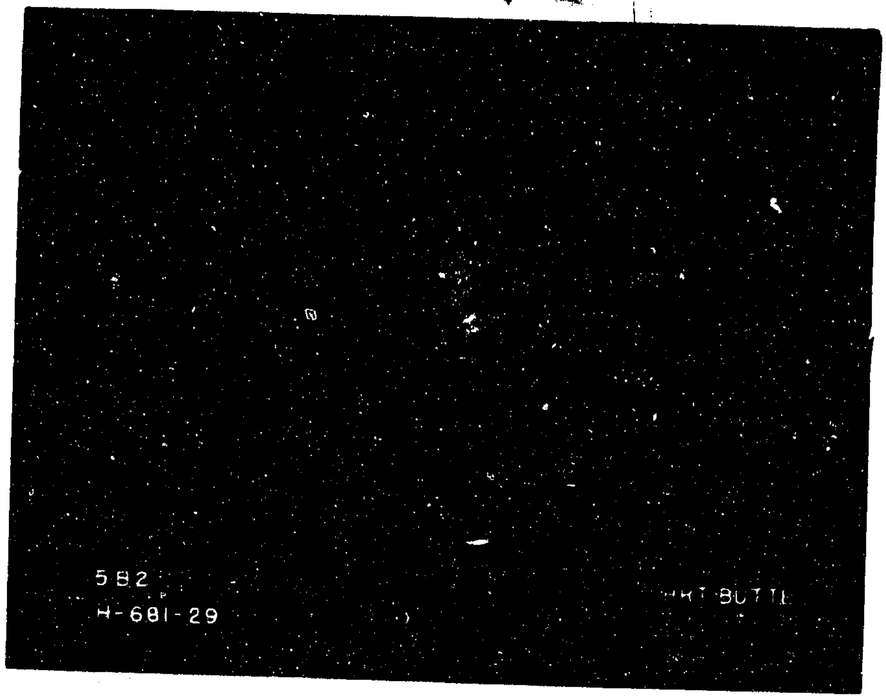
SPILLWAY ENTRANCE
1:21-1/2 MODEL HEART BUTTE DAM

FIGURE 9



HEART BUTTE DAM
PIER STRUCTURES

FIGURE 10



A. Crest with Pier No. 2
Discharge 3,750 second-feet

B. Crest with Pier No. 3
Discharge 3,750 second-feet

SPILLWAY ENTRANCE
1:21-1/2 MODEL HEART BUTTE DAM

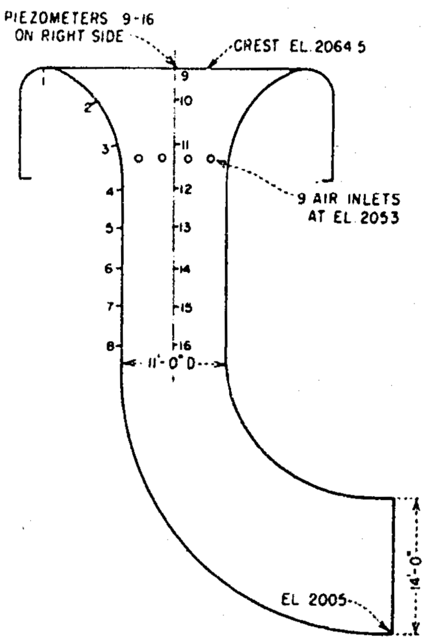
FIGURE 11

A. Crest with Pier No. 4
Discharge 3, 750 second-feet

B. Crest with Pier No. 5--Recommended
Discharge 3, 750 second-feet

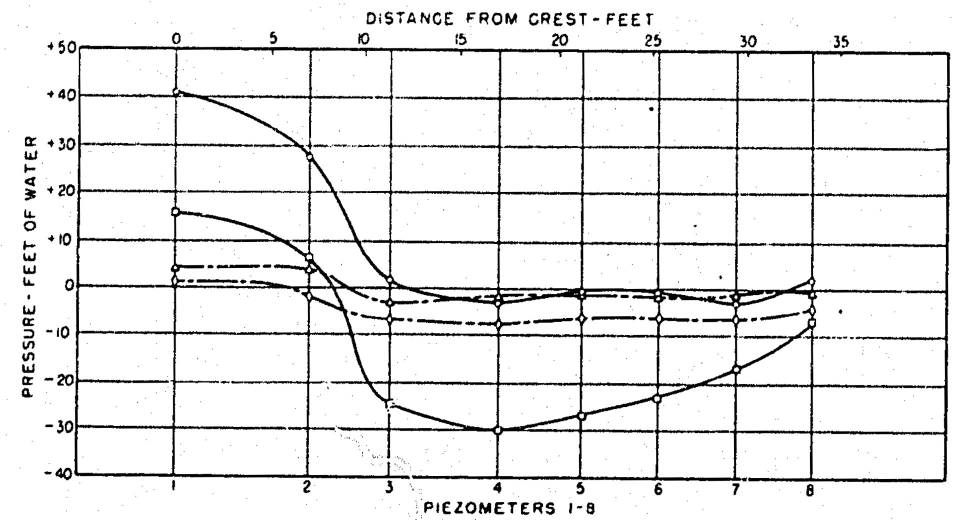
SPILLWAY ENTRANCE
1:21-1/2 MODEL HEART BUTTE DAM

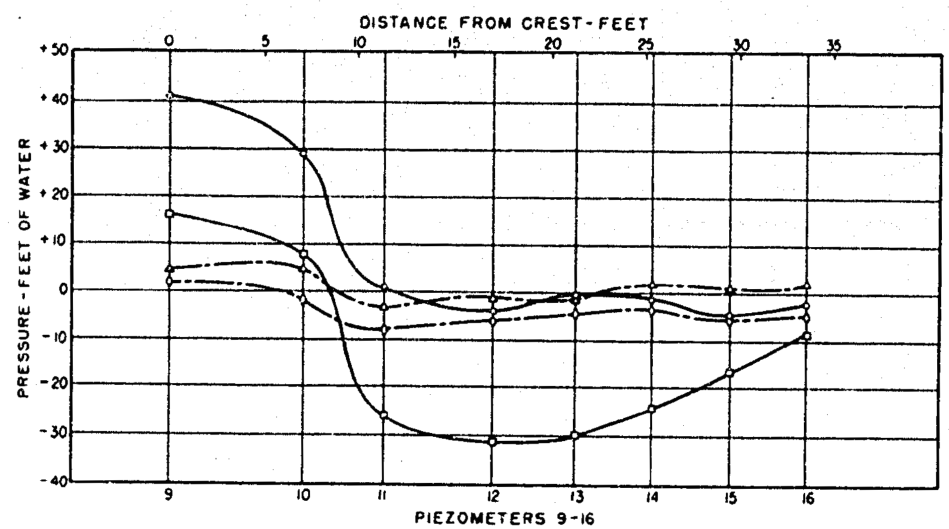
LINE	SYMBOL	RES. EL.	DISCHARGE SEC. FT.	REMARKS
1	——o——	2107	5600	AIR
2	——□——	2082.2	5600	NO AIR
3	—·—△—·—	2070.6	3200	AIR
4	---◇---	2069.2	3200	NO AIR



ELEVATION

PIEZOMETER LOCATIONS





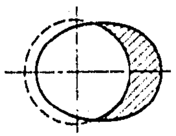
SPILLWAY PRESSURES

HEART BUTTE DAM
SPILLWAY PRESSURES
TEST No. 1 PRELIMINARY

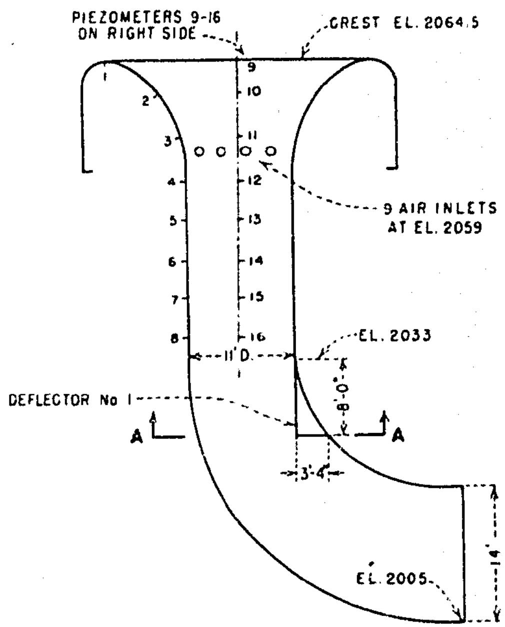
330

FIGURE 12

LINE	SYMBOL	RES. EL.	DISCHARGE SEC. FT.	REMARKS
1	—△—	2111.3	4840	AIR
2	—○—	2074.7	3500	AIR

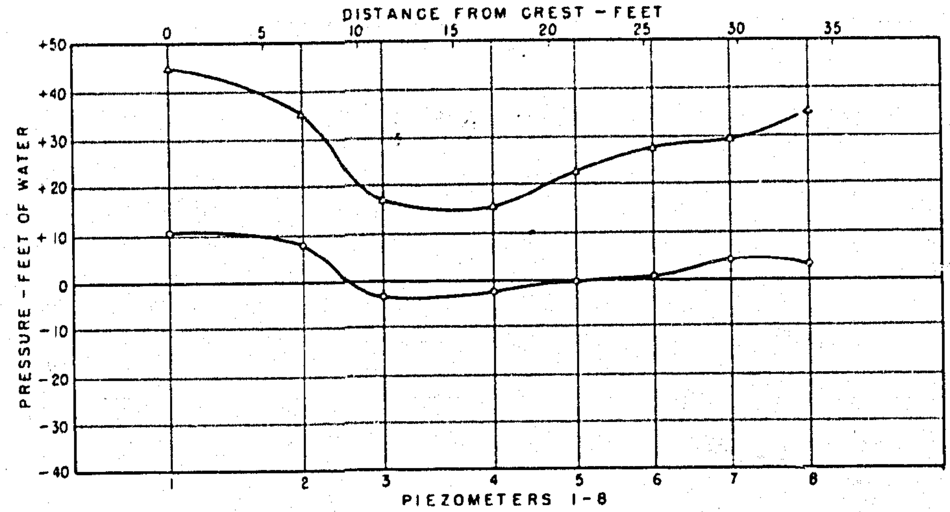


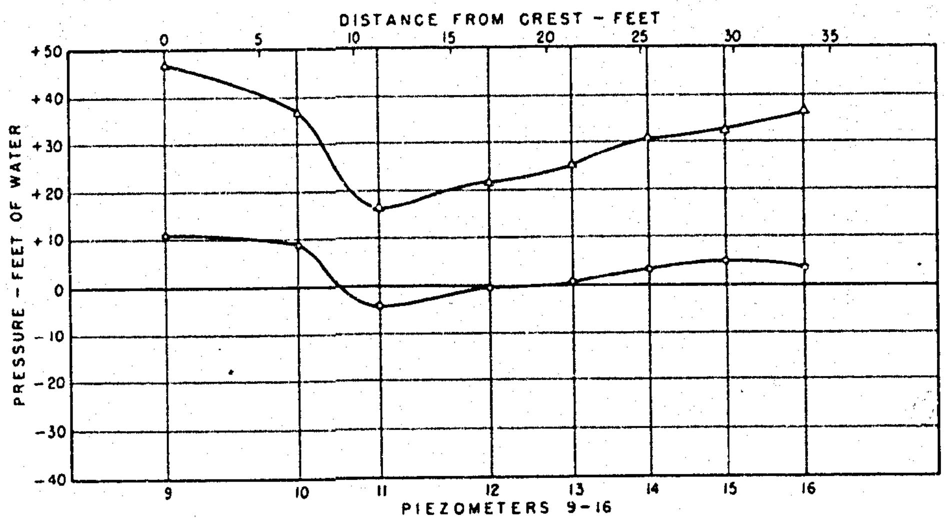
SECTION A-A



ELEVATION

PIEZOMETER LOCATIONS



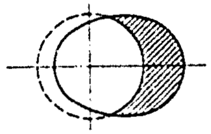


SPILLWAY PRESSURES

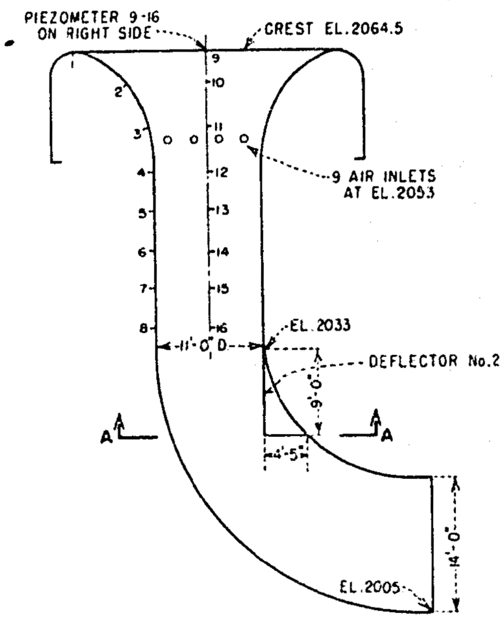
HEART BUTTE DAM
SPILLWAY PRESSURES
TEST No. 2 - PRELIMINARY - DEFLECTOR No. 1

FIGURE 13

LINE	SYMBOL	RES. EL.	DISCHARGE SEC. FT.	REMARKS
1	—o—	2114.8	5090	AIR
2	-–△–-	2089.2	4330	AIR
3	—□—	2074.4	3480	AIR
4	-–◇–-	2070.2	3480	NO AIR

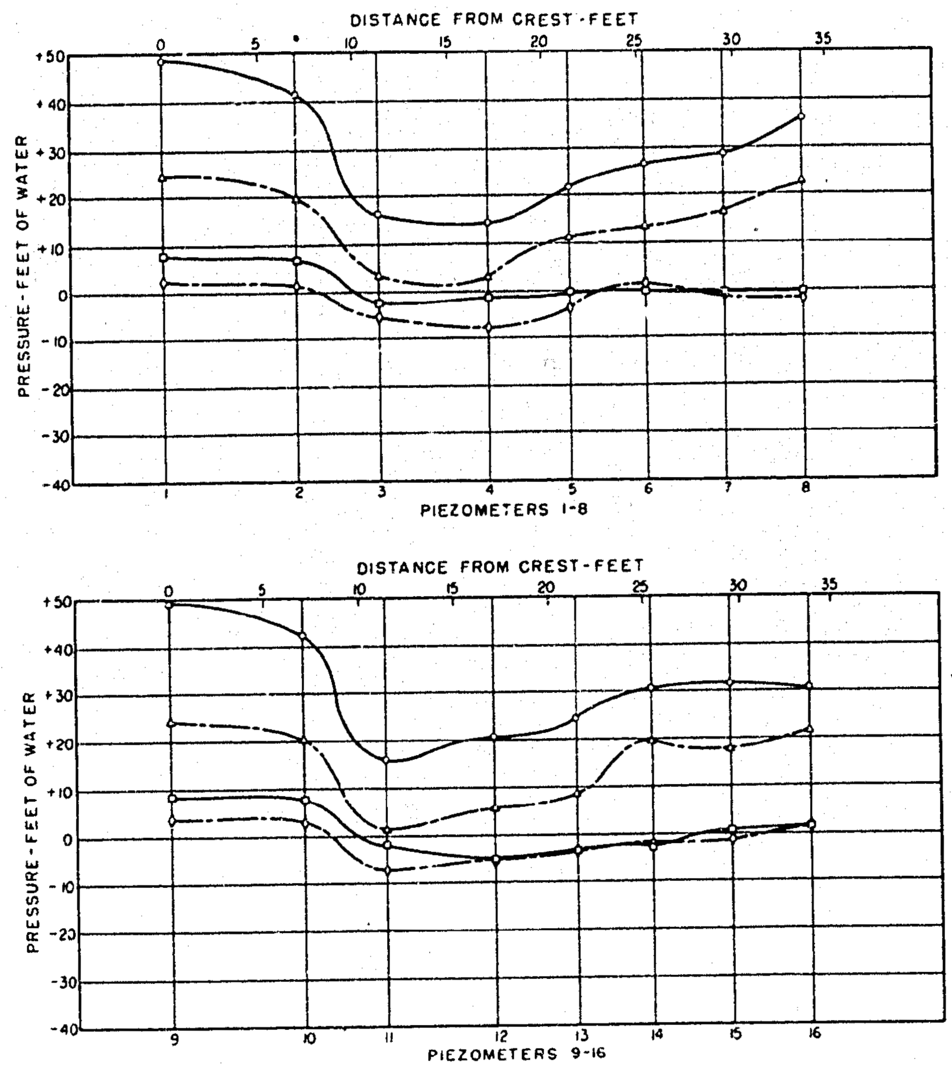


SECTION A-A



ELEVATION

PIEZOMETER LOCATIONS

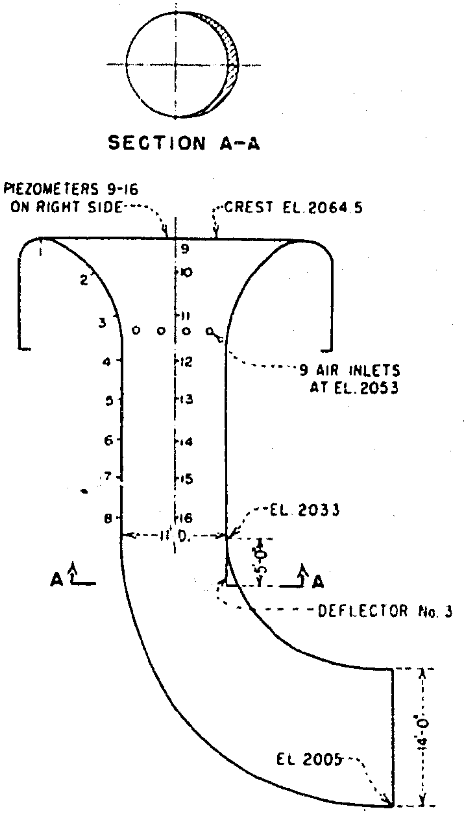


SPILLWAY PRESSURES

HEART BUTTE DAM
SPILLWAY PRESSURES
TEST No 3 - PRELIMINARY - DEFLECTOR No. 2

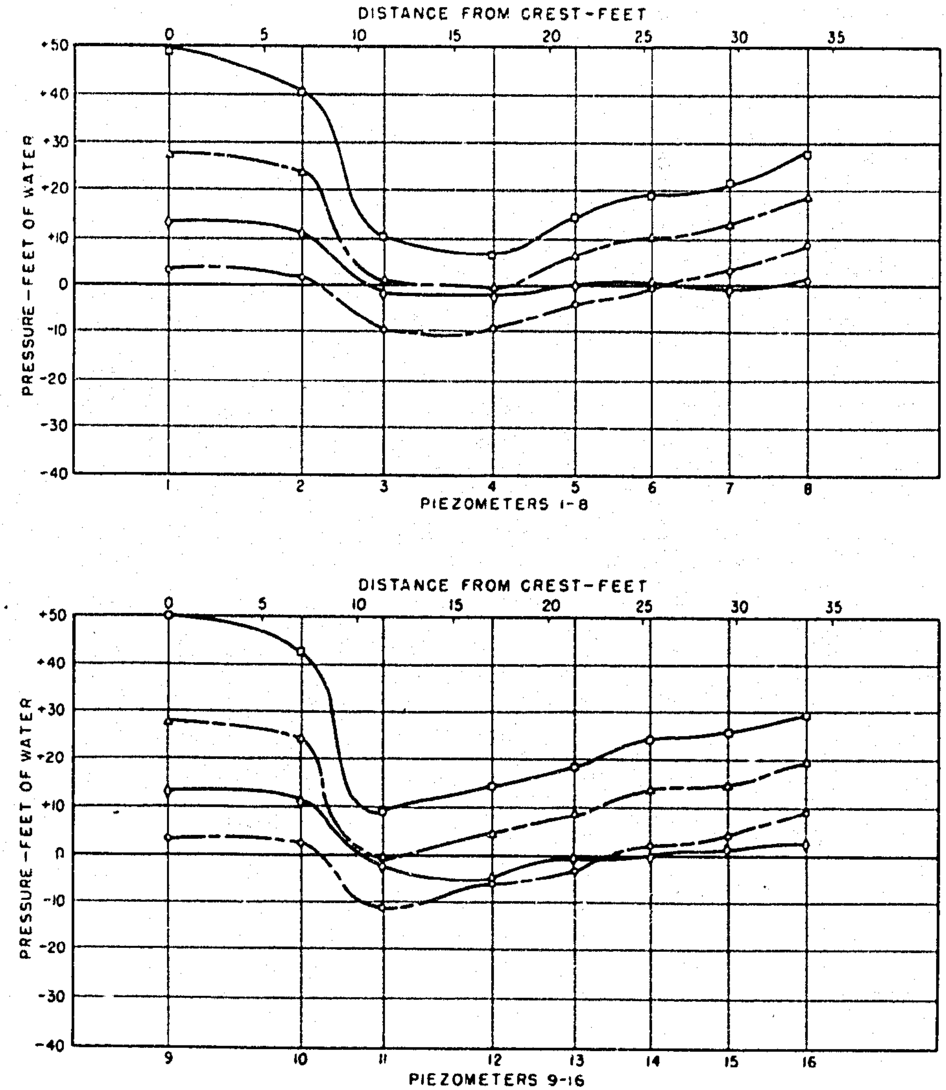
FIGURE 14

LINE	SYMBOL	RES. EL.	DISCHARGE SEC. FT.	REMARKS
1		2115.8	5600	NO AIR
2		2093.6	4800	NO AIR
3		2079.0	3890	AIR
4		2070.4	3890	NO AIR



ELEVATION

PIEZOMETER LOCATIONS



SPILLWAY PRESSURES

HEART BUTTE DAM

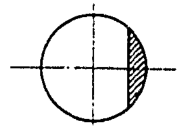
SPILLWAY PRESSURES

TEST No. 4 - PRELIMINARY - DEFLECTOR No. 3

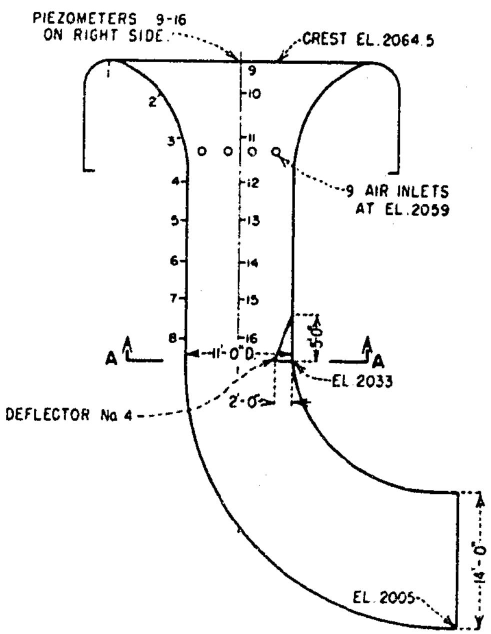
FIGURE 15

330

LINE	SYMBOL	RES. EL.	DISCHARGE SEC. FT.	REMARKS
1	—o—	2115.8	5310	AIR
2	—△—	2080.0	3740	NO AIR

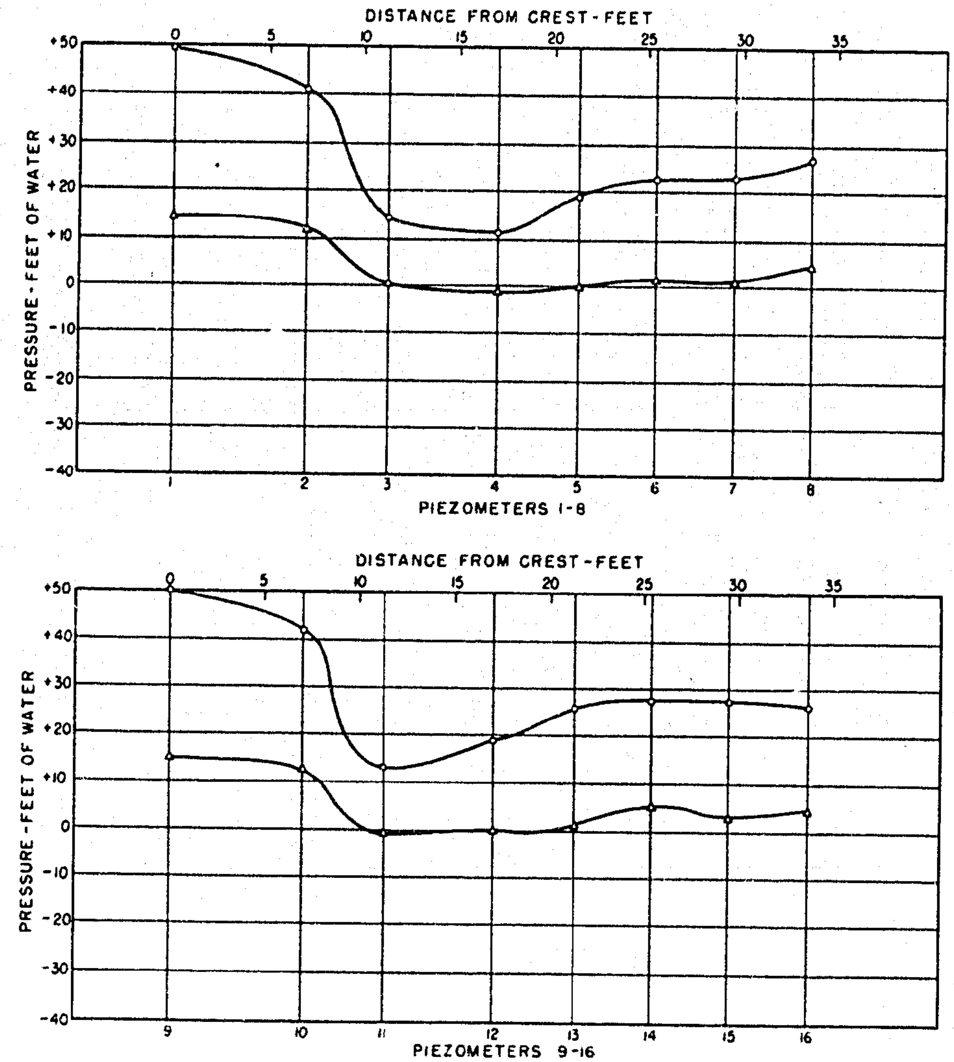


SECTION A-A



ELEVATION

PIEZOMETER LOCATIONS



SPILLWAY PRESSURES

HEART BUTTE DAM

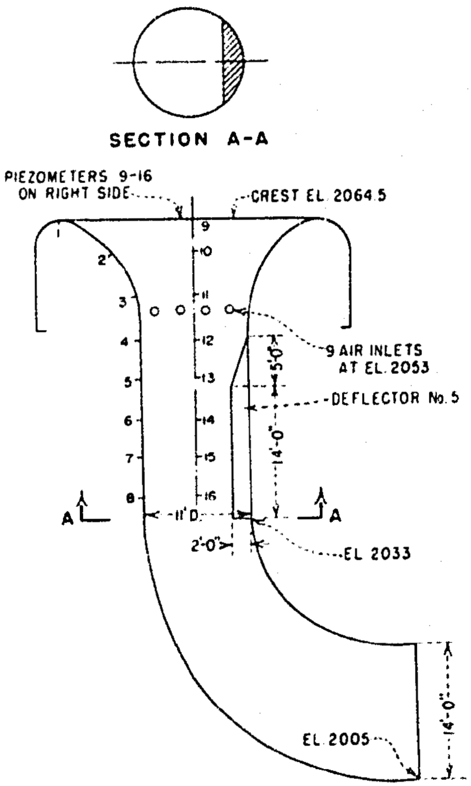
SPILLWAY PRESSURES

TEST No 5 - PRELIMINARY - DEFLECTOR No 4

FIGURE 16

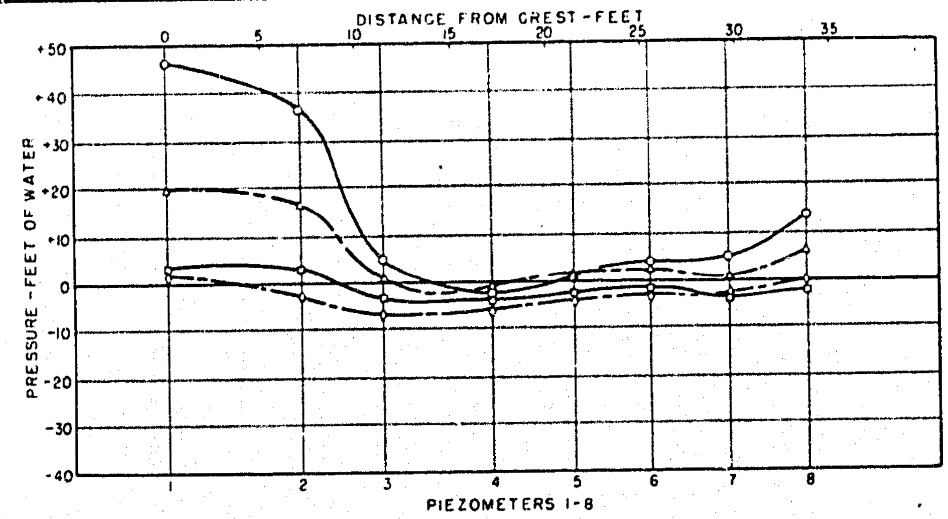
330

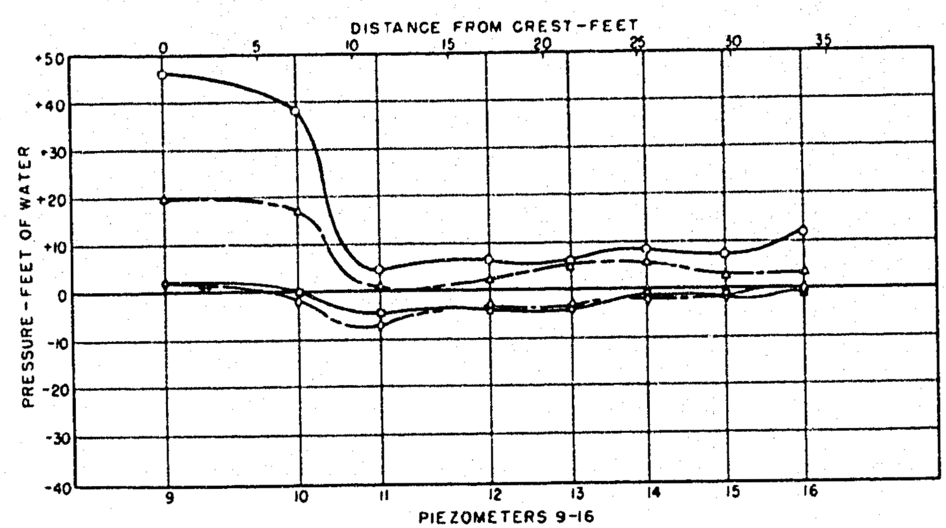
LINE	SYMBOL	RES EL	DISCHARGE SEC FT.	REMARKS
1	——o——	2112.6	5600	AIR
2	—— -△- ——	2084.7	4050	AIR
3	——□——	2069.7	3200	AIR
4	— -◇- —	2069.7	3200	NO AIR



ELEVATION

PIEZOMETER LOCATIONS



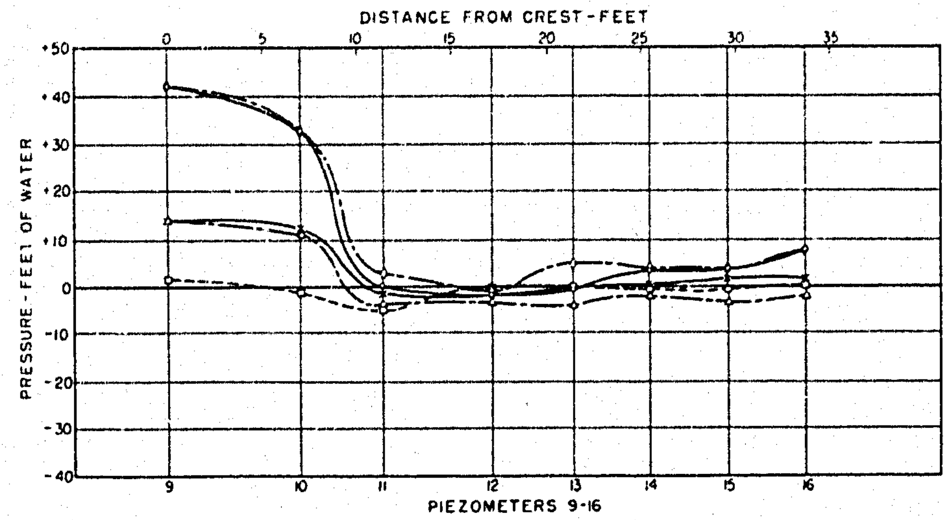


SPILLWAY PRESSURES

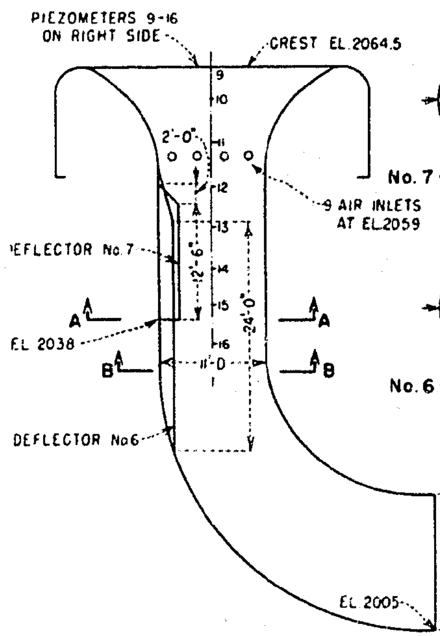
HEART BUTTE DAM
SPILLWAY PRESSURES
TEST No.6 - PRELIMINARY - DEFLECTOR No.5

FIGURE 17

	LINE	SYMBOL	RES. EL.	DISCHARGE SEC. FT.	REMARKS
No. 6	1	—◇—	2107.6	5600	AIR
	2	—×—	2079.1	4050	AIR
	3	—○—	2107.7	5600	NO AIR
	4	—△—	2078.9	4050	NO AIR
	5	--□--	2068.4	3200	NO AIR
No 7	1	—△—	2118.8	5600	NO AIR

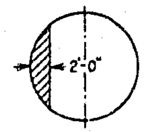


DEFLECTOR No. 6

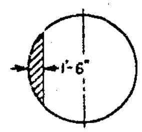


ELEVATION

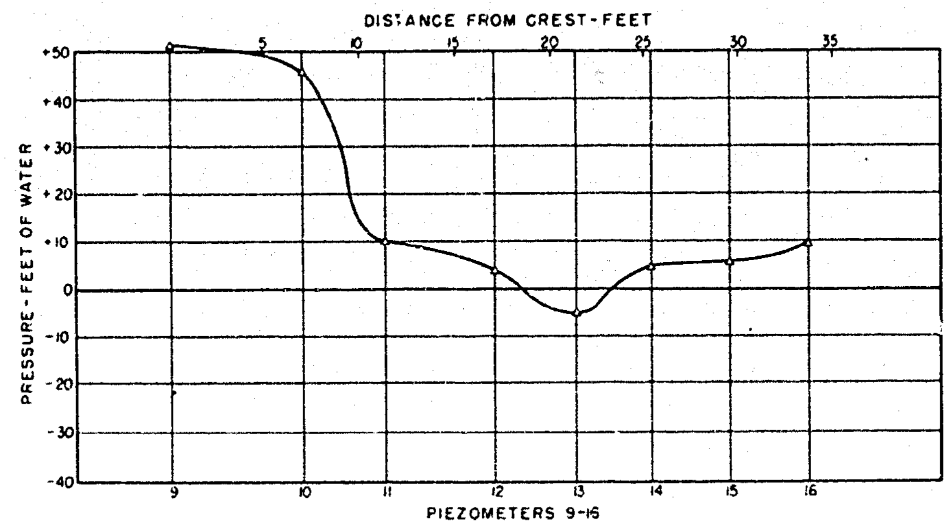
PIEZOMETER LOCATIONS



No. 7 - SECTION A-A



No. 6 - SECTION B-B



DEFLECTOR No 7

SPILLWAY PRESSURES

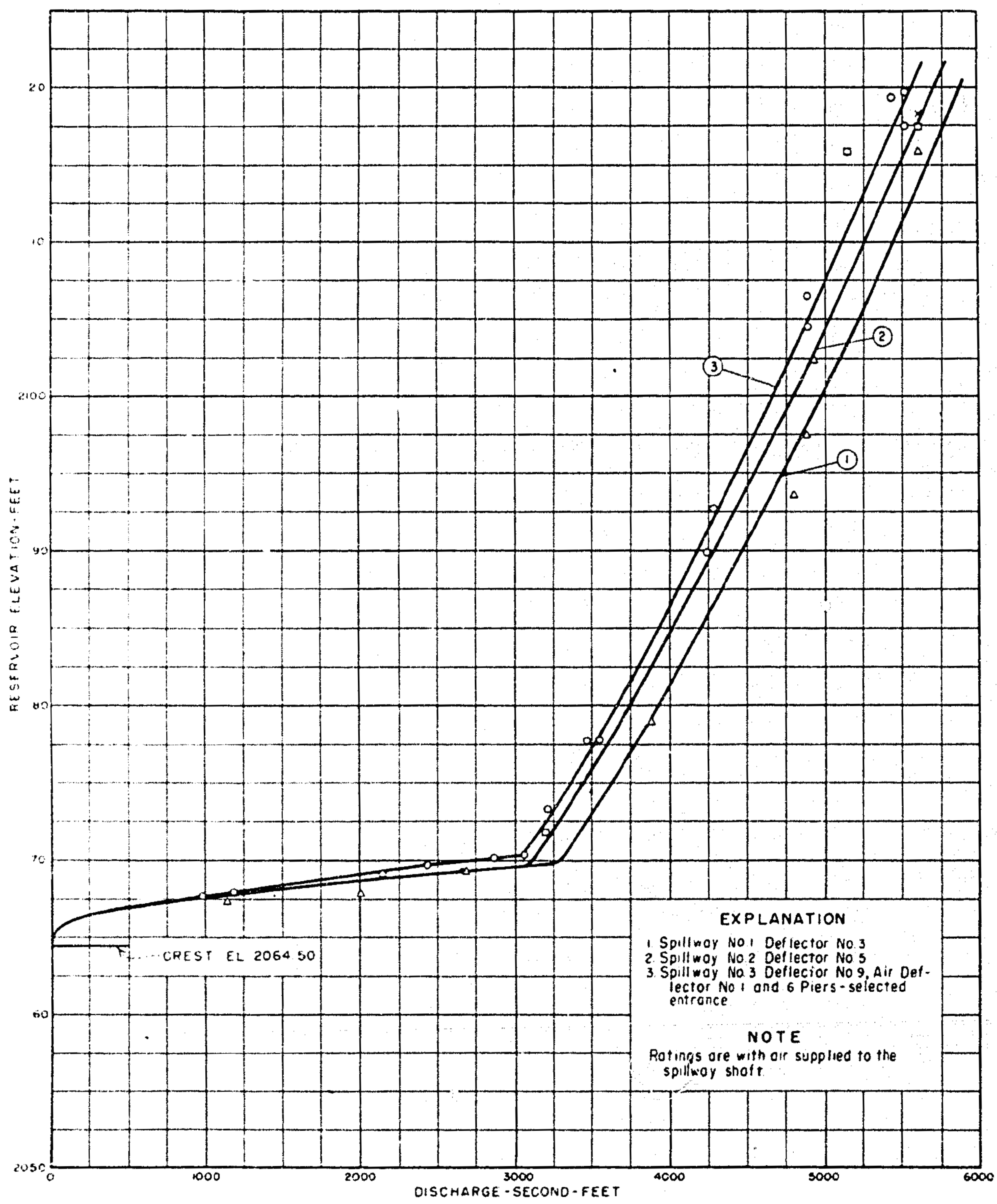
HEART BUTTE DAM

SPILLWAY PRESSURES

TEST No 7 - PRELIMINARY - DEFLECTOR No.6 AND No 7

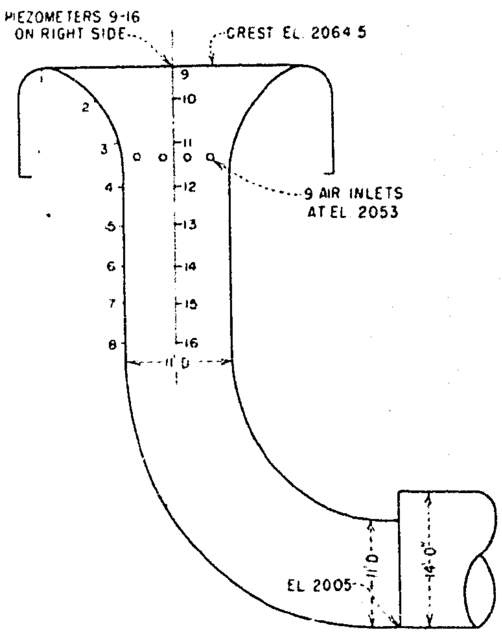
FIGURE 18

330



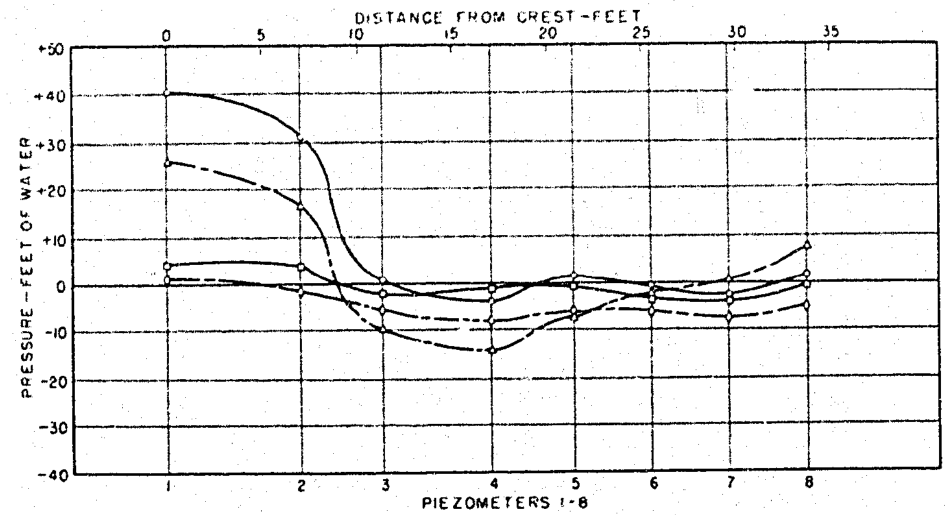
HEART BUTTE DAM
SPILLWAY DISCHARGE CAPACITY CURVES

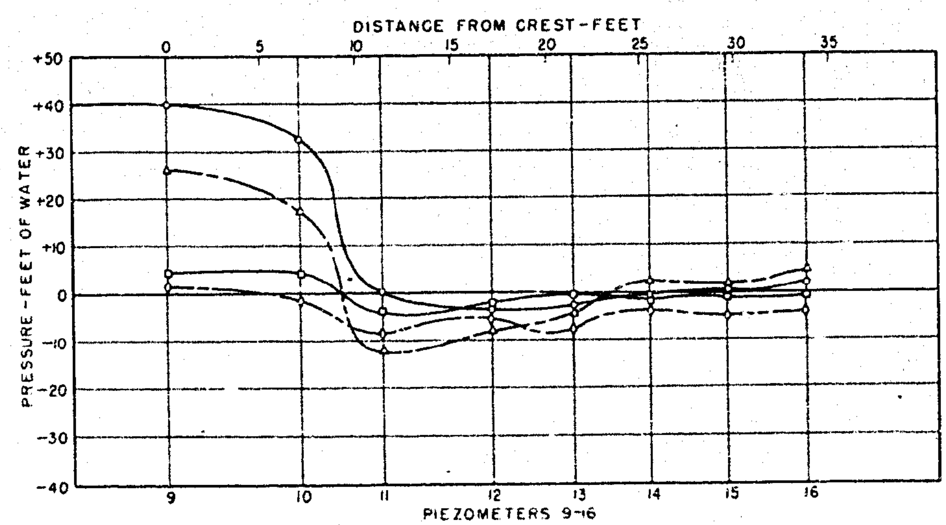
LINE	SYMBOL	RES. EL	DISCHARGE SEC. FT	REMARKS
1	——o——	2107.1	5500	AIR
2	——□——	2070.6	3200	AIR
3	— — △ — —	2092.5	5600	NO AIR
4	——◇— —	2069.2	3200	NO AIR



ELEVATION

PIEZOMETER LOCATIONS





SPILLWAY PRESSURES

HEART BUTTE DAM

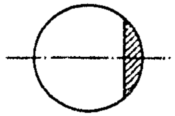
SPILLWAY PRESSURES

TEST No 8 - SPILLWAY ENTRANCE No. 2

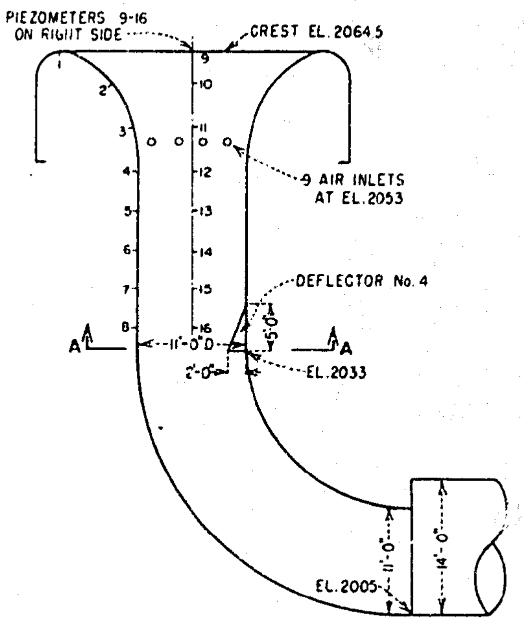
FIGURE 20

330

LINE	SYMBOL	RES. EL.	DISCHARGE SEC. FT.	REMARKS
1	—o—	2115.9	5140	AIR
2	-—△—-	2070.5	3200	AIR
3	—□—	2069.5	3200	NO AIR

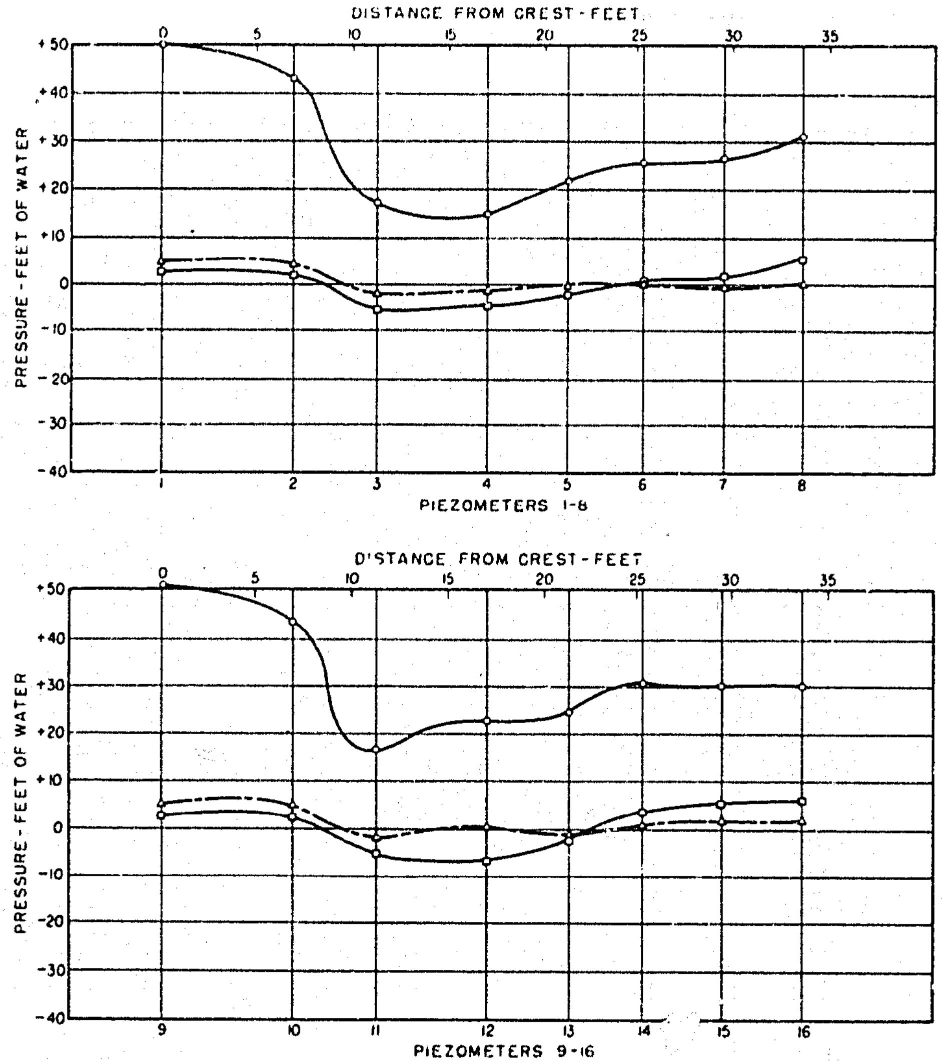


SECTION A-A



ELEVATION

PIEZOMETER LOCATIONS



SPILLWAY PRESSURES

HEART BUTTE DAM

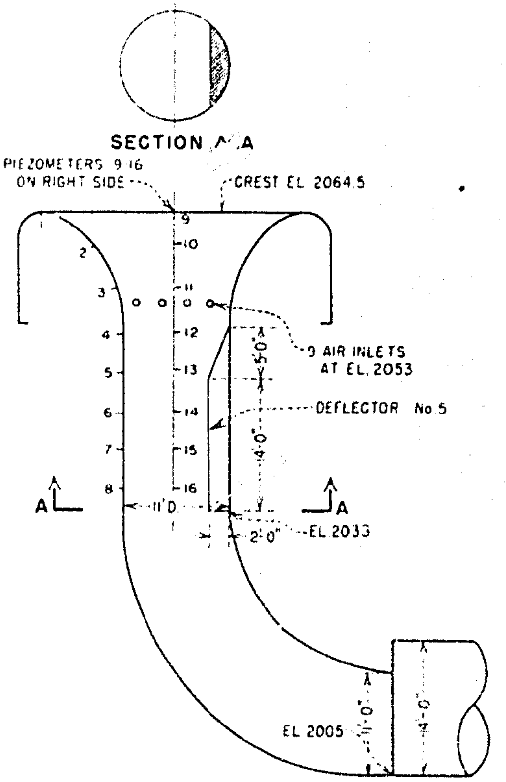
SPILLWAY PRESSURES

TEST No. 9 SPILLWAY ENTRANCE No. 2 - DEFLECTOR No. 4

FIGURE 21

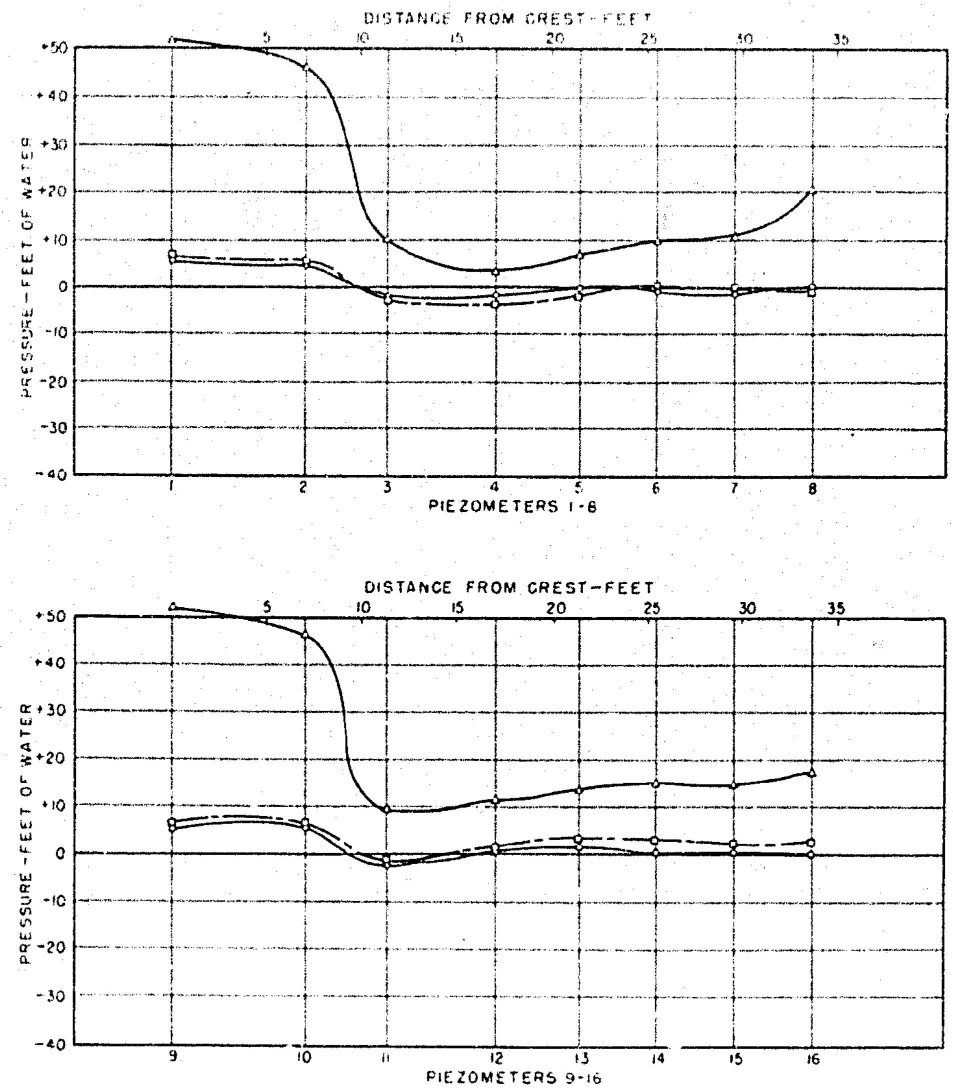
330

LINE	SYMBOL	RES. EL	DISCHARGE SEC. FT.	REMARKS
1	——△——	2117.5	5600	AIR
2	——o——	2071.8	3200	AIR
3	—·—□—·—	2071.5	3200	NO AIR



ELEVATION

PIEZOMETER LOCATIONS



SPILLWAY PRESSURES

HEART BUTTE DAM

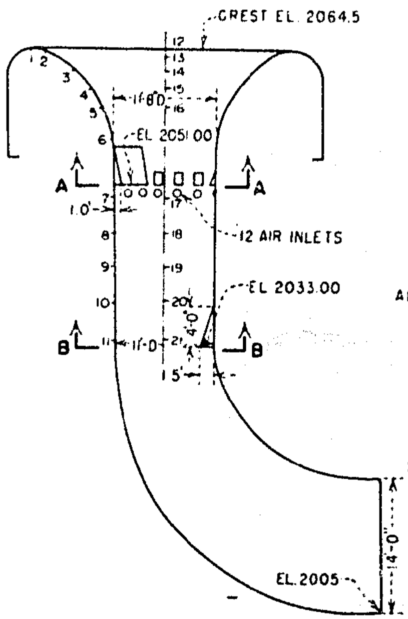
SPILLWAY PRESSURES

TEST No. 10 SPILLWAY ENTRANCE No 2 - DEFLECTOR No. 5

330

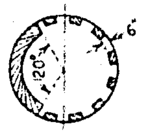
FIGURE 22

LINE	SYMBOL	RES. EL.	DISCHARGE SEC. FT.	REMARKS
1	——o——	2116.75	5200	AIR
2	——◇——	2116.4	5210	NO AIR
3	——□——	2099.1	4585	AIR
4	——△——	2099.1	4640	NO AIR
5	——o——	2070.2	3040	AIR
6	---◇---	2070.2	3200	NO AIR

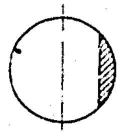


ELEVATION

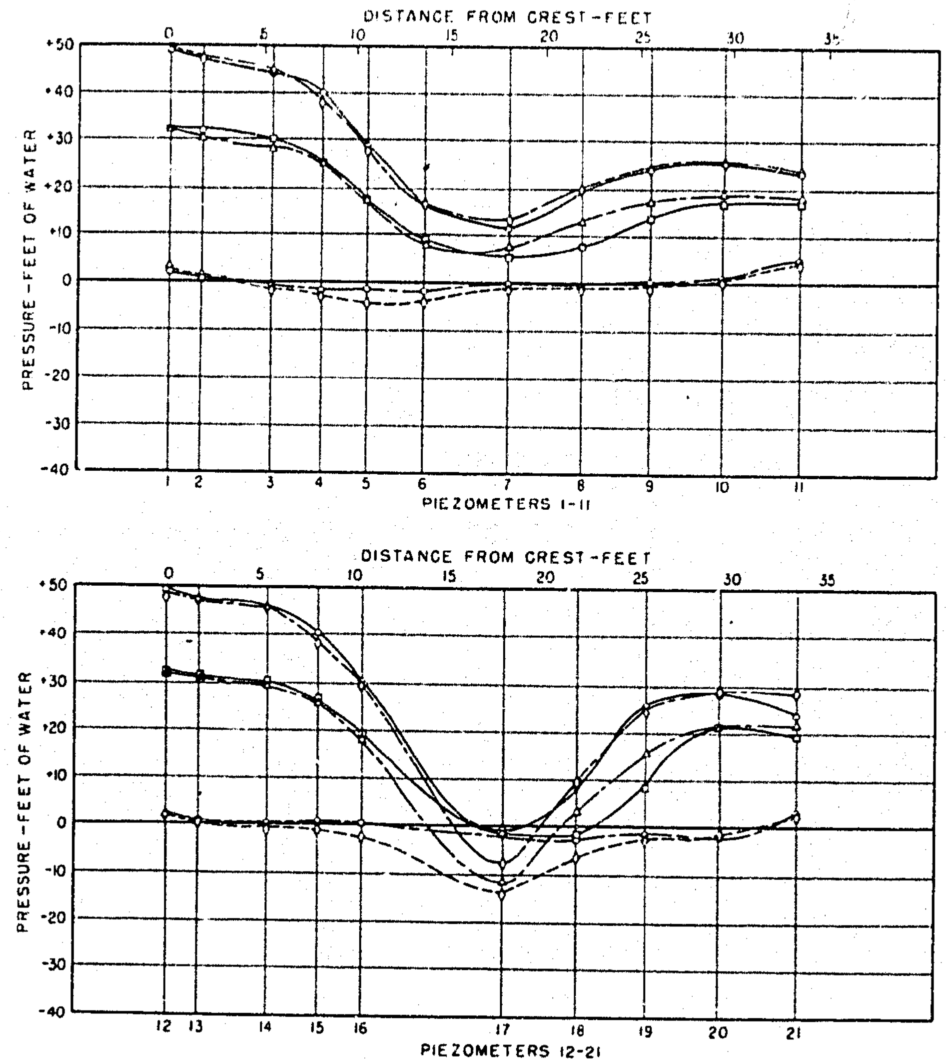
PIEZOMETER LOCATIONS



SECTION A-A
AIR DEFLECTORS No. 23



SECTION B-B
DEFLECTOR No 8



SPILLWAY PRESSURES

HEART BUTTE DAM

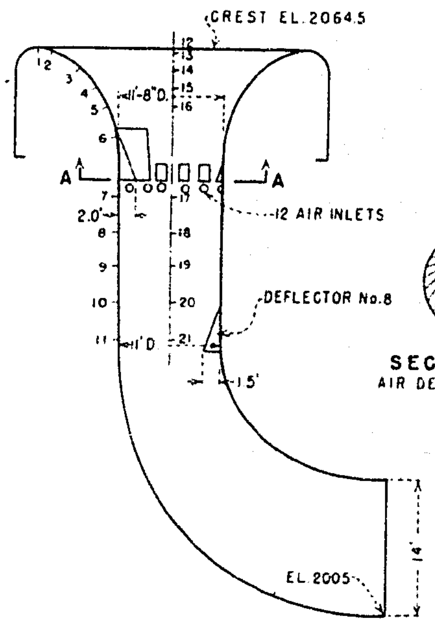
SPILLWAY PRESSURES

TEST No. 11-SPILLWAY ENTRANCE No. 3 DEFLECTOR No. 8
AND AIR DEFLECTOR No. 23

33c

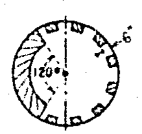
FIGURE 23

LINE	SYMBOL	RES. EL.	DISCHARGE SEC. FT.	REMARKS
1	o———o	2118.7	4780	AIR
2	△—·—△	2116.3	4780	NO AIR
3	□- - -□	2108.5	4300	AIR
4	◇—·—◇	2099.8	4280	NO AIR
5	×-··-×	2085.0	3210	AIR
6	●—·—●	2075.4	3210	NO AIR



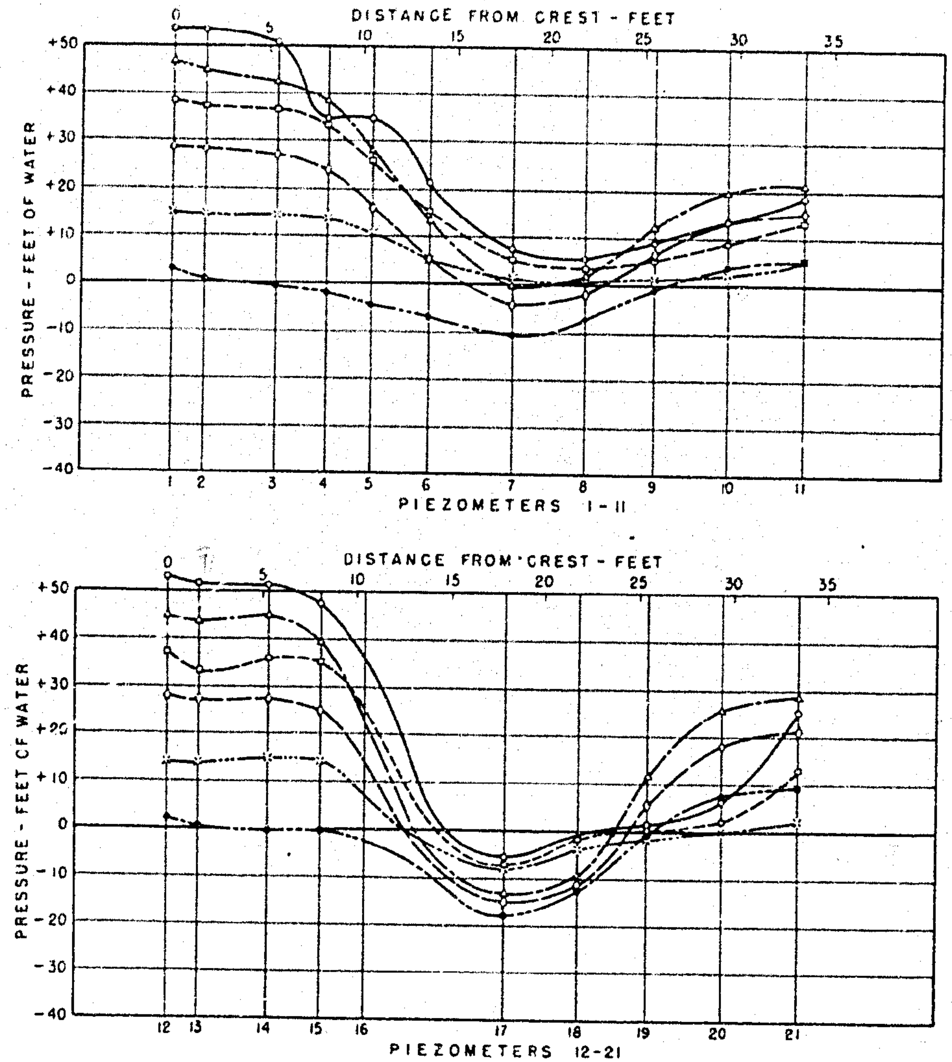
ELEVATION

PIEZOMETER LOCATIONS



SECTION A-A

AIR DEFLECTORS No. 24



SPILLWAY PRESSURES

HEART BUTTE DAM

SPILLWAY PRESSURES

TEST No. 12 - SPILLWAY ENTRANCE No. 3,
DEFLECTOR No. 8, AIR DEFLECTORS No. 24

FIGURE 24

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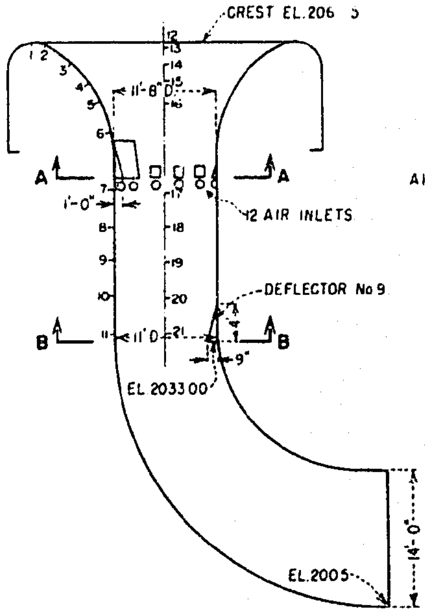
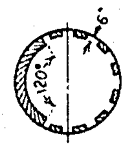
LINE	SYMBOL	RES. EL.	DISCHARGE SEC. FT.	REMARKS
1	—○—	2119.4	5430	AIR
2	--△--	2106.5	4890	AIR
3	—□—	2092.8	4290	AIR
4	--◇--	2077.7	3770	AIR



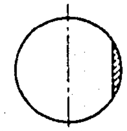
ELEVATION

PIEZOMETER LOCATIONS



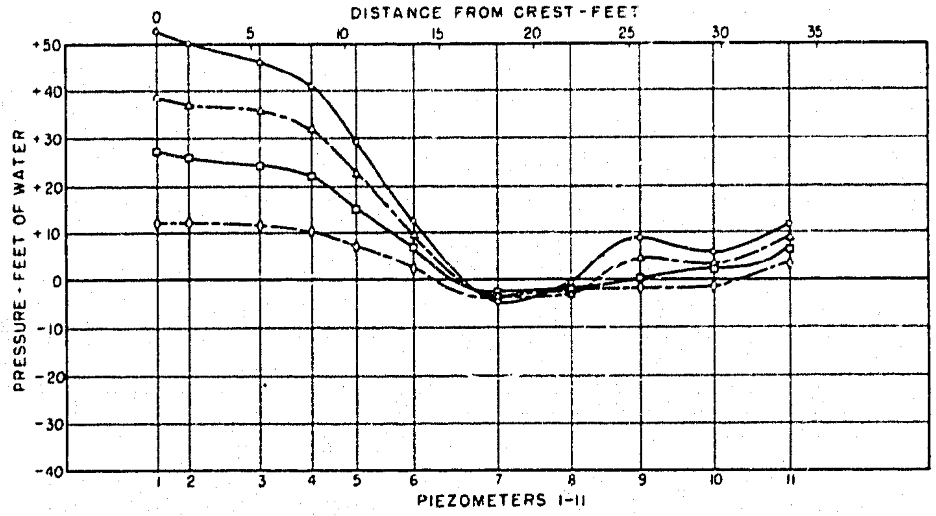
SECTION A-A

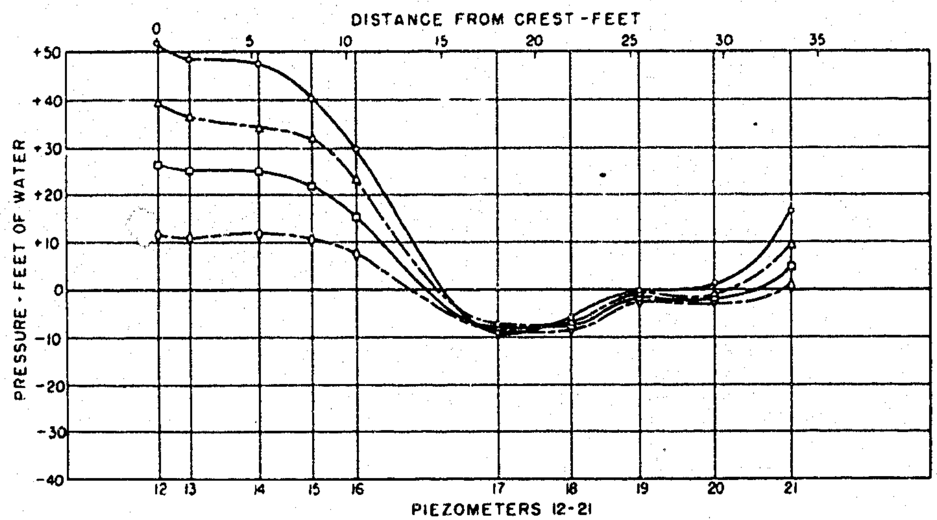
AIR DEFLECTORS No.23



SECTION B-B

DEFLECTOR No 9





SPILLWAY PRESSURES

HEART BUTTE DAM

SPILLWAY PRESSURES

TEST No.13-SPILLWAY ENTRANCE No. 3,
DEFLECTOR No.9, AIR DEFLECTOR No.23
SELECTED ENTRANCE

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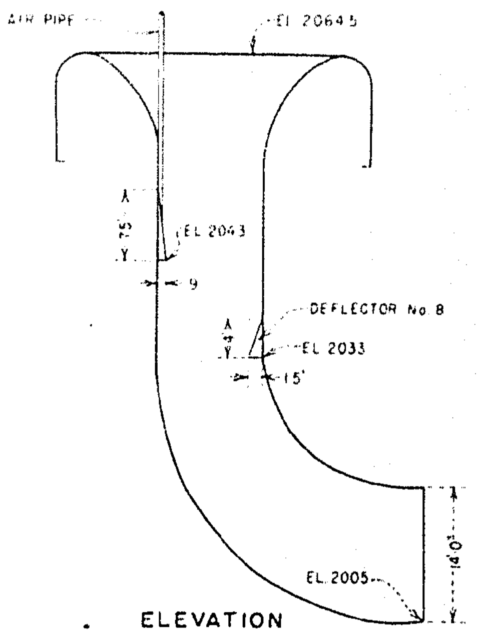
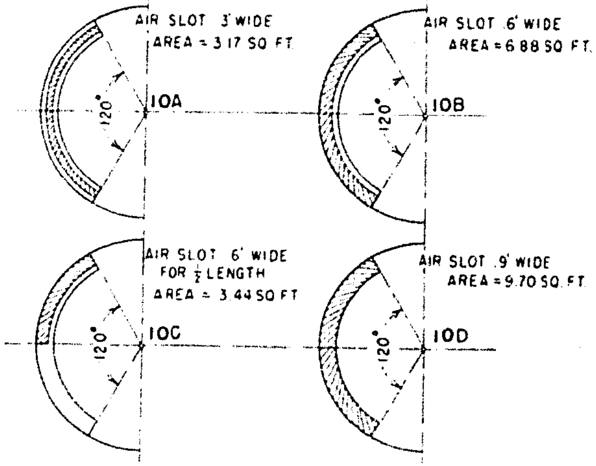
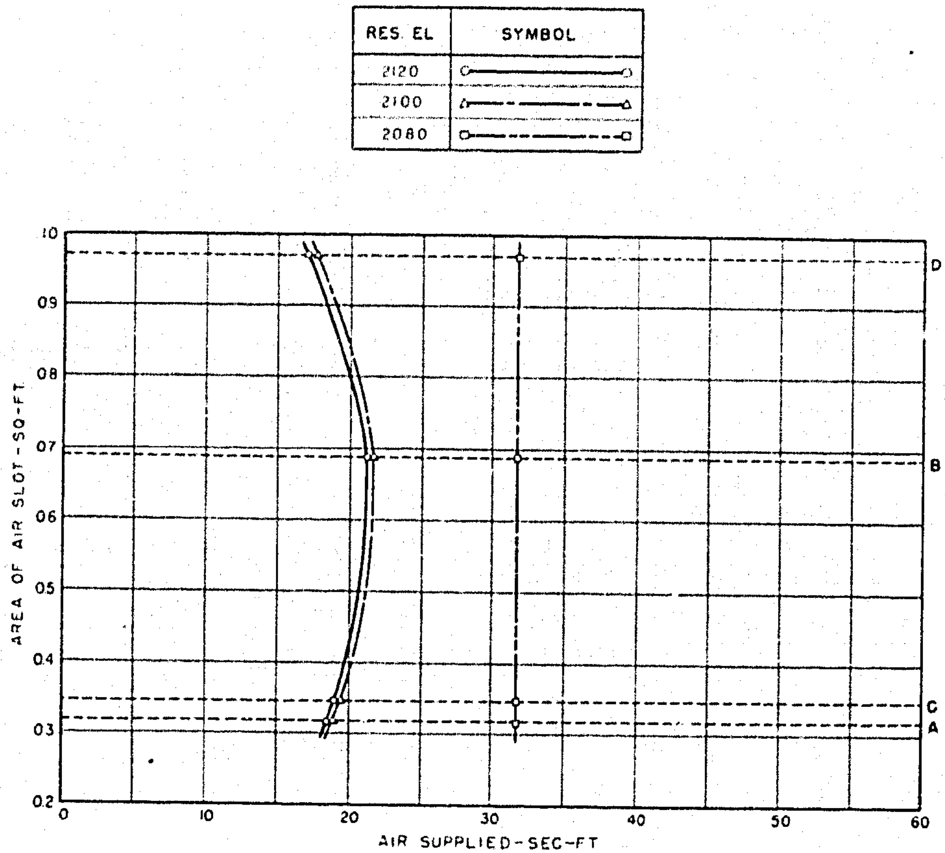
FIGURE 25



ELEVATION
DEFLECTOR No.10A, B, C, AND D



PLAN OF DEFLECTORS

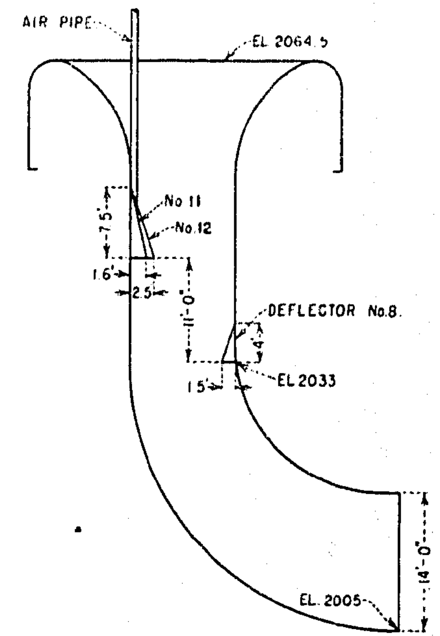


AIR DISCHARGE CAPACITY CURVES

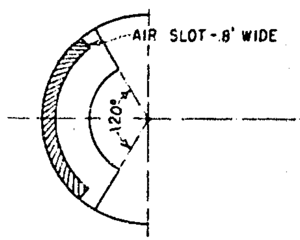
HEART BUTTE DAM
AIR TEST No. 1 - AREA OF AIR SLOT VERSUS AIR DISCHARGE
SPILLWAY No. 1, DEFLECTOR No. 10

330

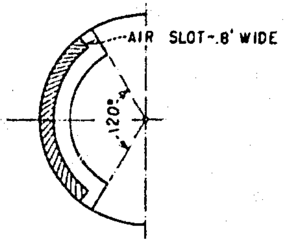
FIGURE 23



ELEVATION

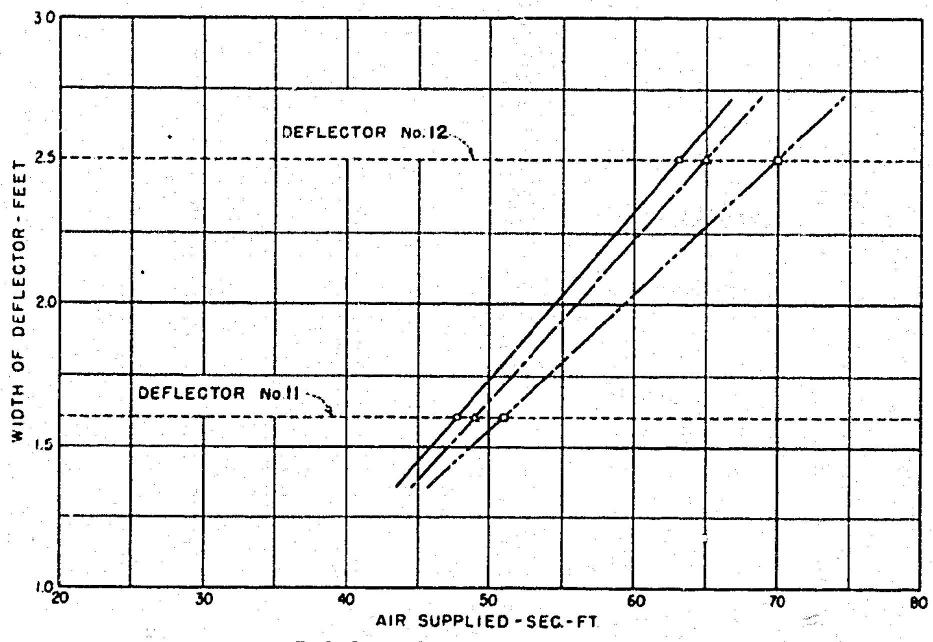


PLAN
DEFLECTOR No.12



PLAN
DEFLECTOR No.11

RES. EL.	SYMBOL
2120	o———o
2100	Δ—·—·—Δ
2080	□—··—··—□



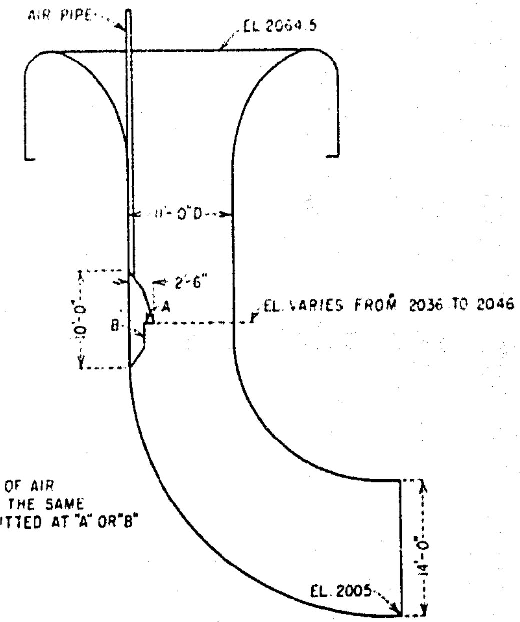
AIR DISCHARGE CAPACITY CURVES

HEART BUTTE DAM

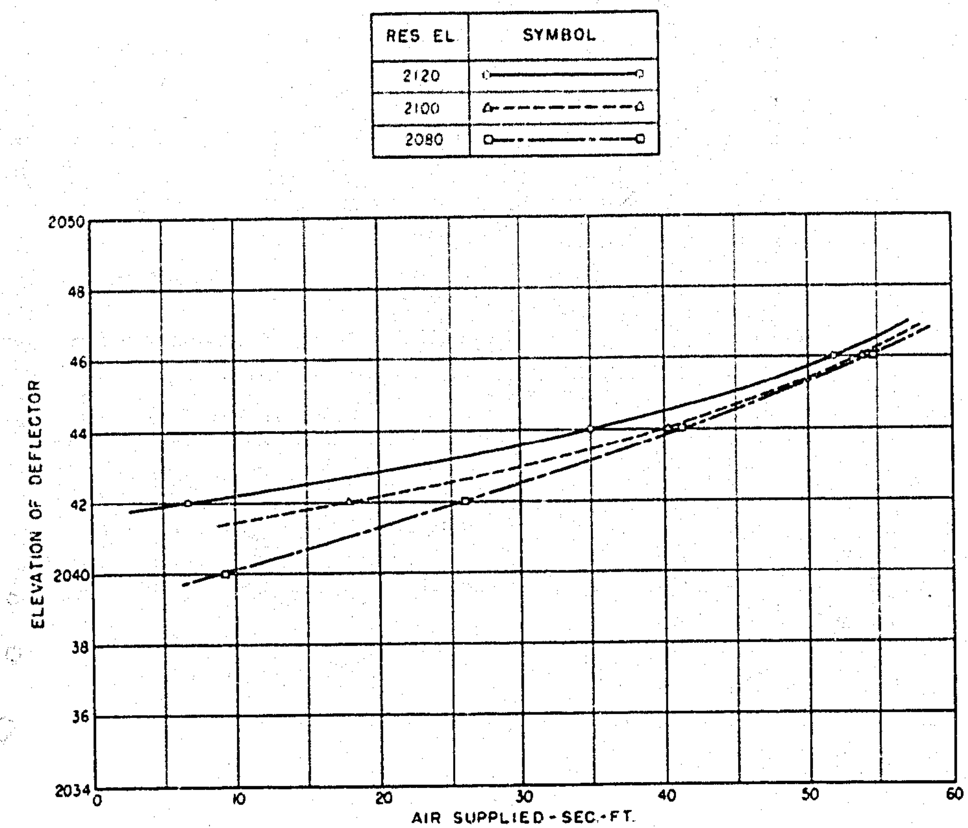
AIR TEST No.2 - WIDTH OF AIR DEFLECTOR VERSUS AIR DISCHARGE

SPILLWAY No.1 - DEFLECTOR Nos. 11 & 12

FIGURE 27



ELEVATION
DEFLECTOR No.13



AIR DISCHARGE CAPACITY CURVES

HEART BUTTE DAM

AIR TEST No.3 - ELEVATION OF AIR DEFLECTOR VERSUS AIR DISCHARGE

SPILLWAY No.1 - DEFLECTOR No.13

FIGURE 28

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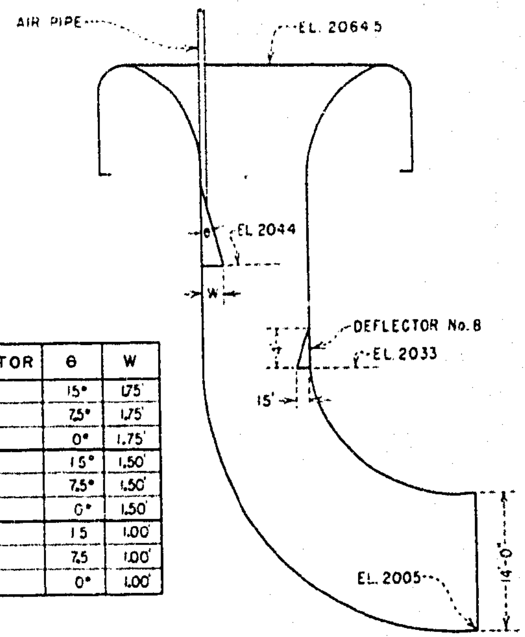
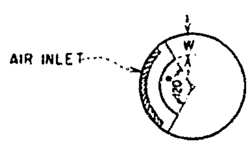
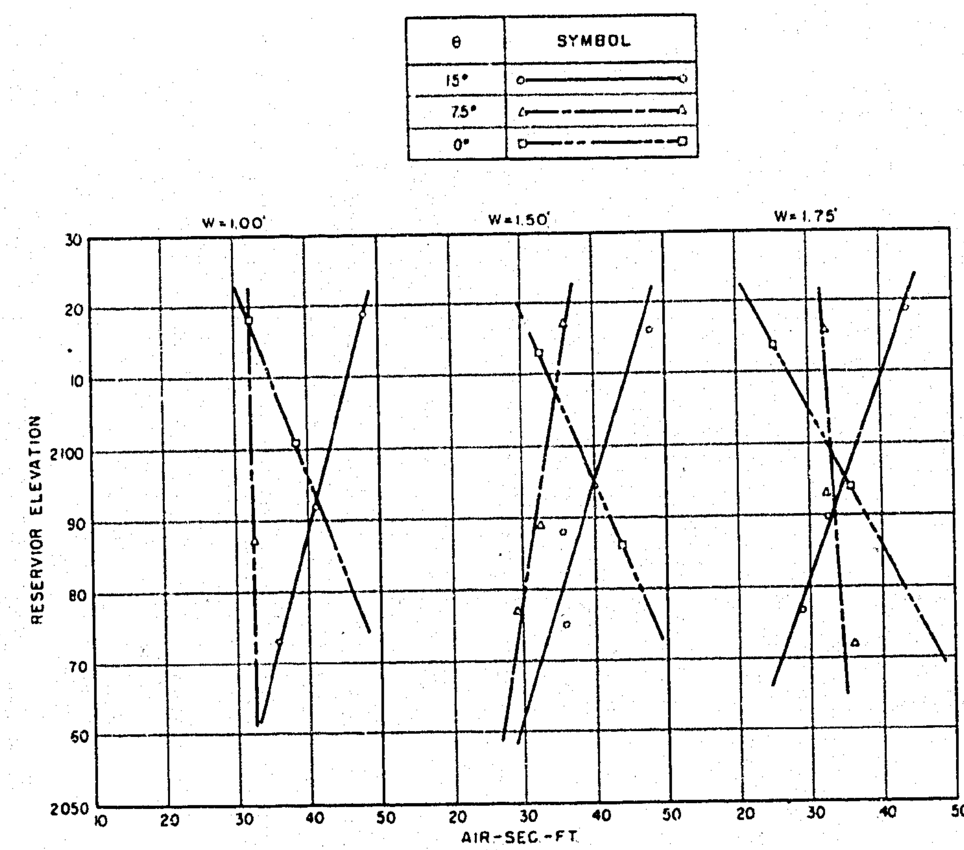


DEFLECTOR	θ	W
#14	15°	1.75'
#15	7.5°	1.75'
#16	0°	1.75'
#17	15°	1.50'
#18	7.5°	1.50'
#19	0°	1.50'
#20	15	1.00'
#21	7.5	1.00'
#22	0°	1.00'

ELEVATION



PLAN OF DEFLECTORS



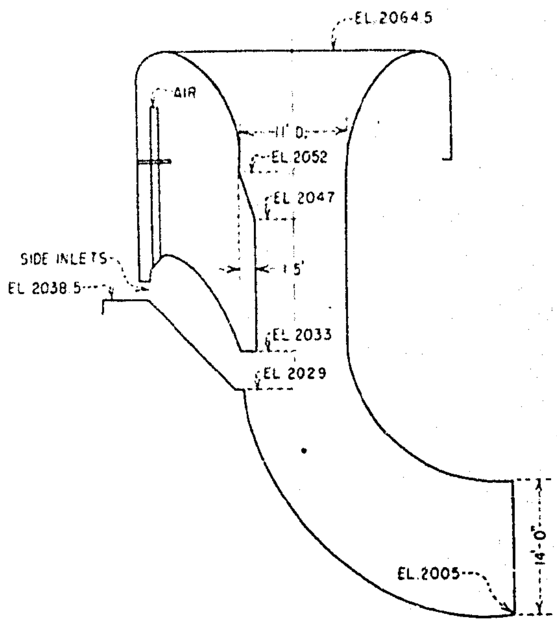
AIR DISCHARGE CAPACITY CURVES

HEART BUTTE DAM

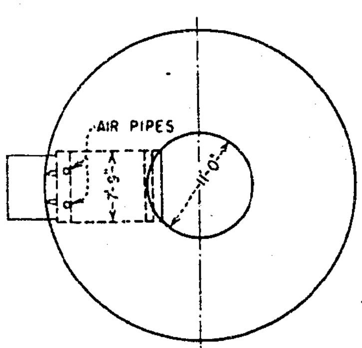
AIR TEST No. 4 – AIR DEFLECTOR WIDTH AND ANGLE VERSUS AIR DISCHARGE

SPILLWAY No. 1 – DEFLECTOR Nos. 14-22

FIGURE 29

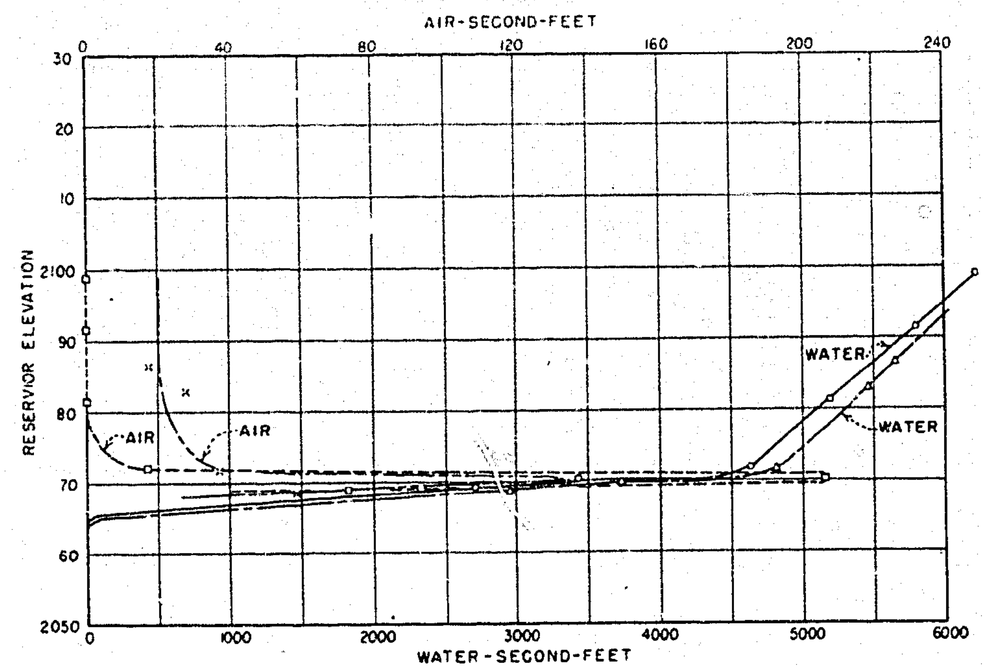


ELEVATION



PLAN

CURVE	SIDE INLETS	LINE
AIR SUPPLY	CLOSED	
AIR SUPPLY	OPEN	
DISCHARGE	CLOSED	
DISCHARGE	OPEN	



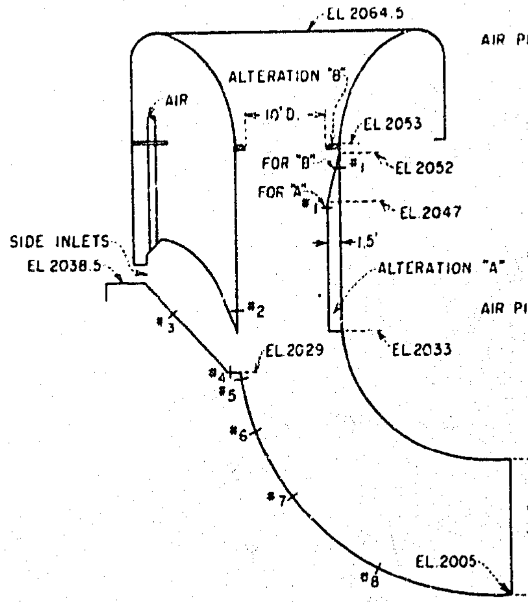
SPILLWAY CAPACITY CURVES

HEART BUTTE DAM

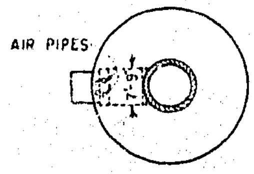
AIR TEST No.5 AIR AND WATER DISCHARGE CALIBRATION

SPILLWAY No.1 WITH SIDE ENTRANCE

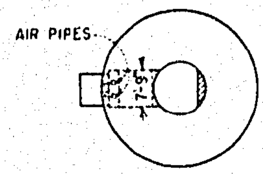
FIGURE 30



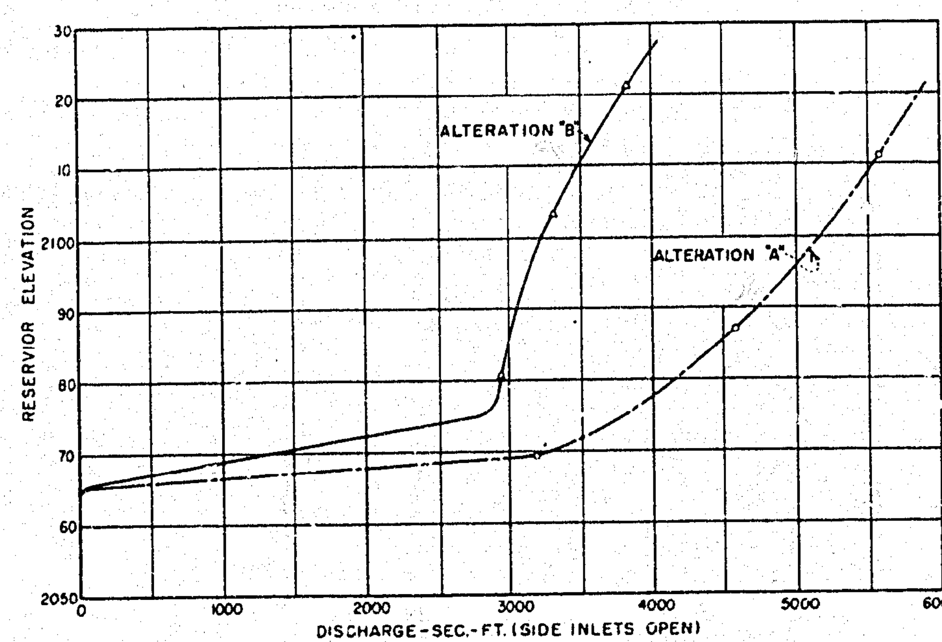
ELEVATION
ALTERATION "A" AND "B"



PLAN
ALTERATION "B"



PLAN
ALTERATION "A"



WATER DISCHARGE CAPACITY CURVES

NOTE
THERE WAS NO AIR SUPPLIED BY THIS DESIGN

ALTERATION "A"

PRESSURES IN FEET OF H_2O			
PIEZ. No.	Q=5600	Q=4600	Q=3200
1	-22	-21	-14
2	+17.5	+10.5	+1.0
3	+26	+17	+3
4	+41.5	+30	+13
5	+9.5	+9	+4
6	+40	+34	+20
7	+49	+38	+26
8	+49	+39	+26

ALTERATION "B"

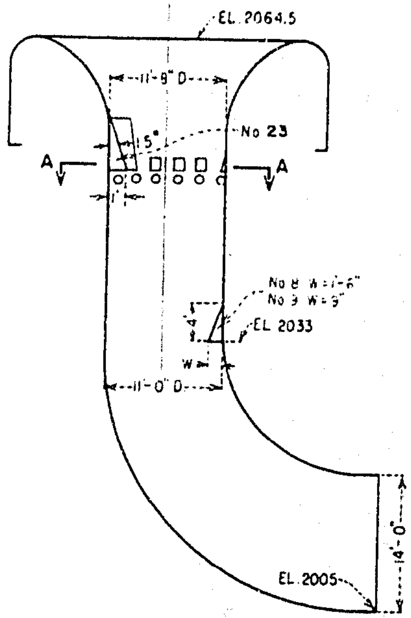
PRESSURES IN FEET OF H_2O			
PIEZ. No.	Q=3850	Q=3320	Q=2950
1	-1.8	-1.3	-0.2
2	-2.5	-1.8	-0.8
3	—	—	—
4	+13	+9	+5.5
5	+9.5	+5.5	+2.0
6	+30	+23.5	+16
7	+41	+34	+23.5
8	+45	+36.5	+28.5

HEART BUTTE DAM

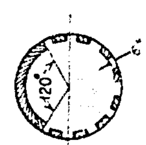
AIR TEST No.6-AIR AND WATER DISCHARGE CALIBATION AND PRESSURES

SPILLWAY No.1-WITH SIDE ENTRANCE
ALTERATION A AND B

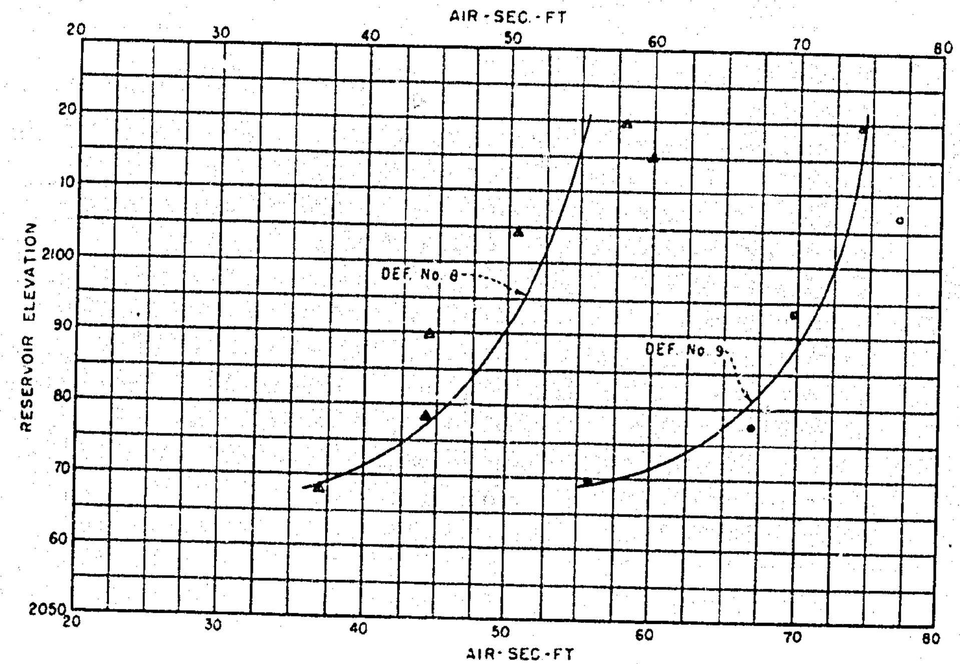
FIGURE 31



ELEVATION



SECTION A-A



AIR CAPACITY CURVES

HEART BUTTE DAM

AIR TEST No.7 - AIR SUPPLIED DISCHARGE CALIBRATION

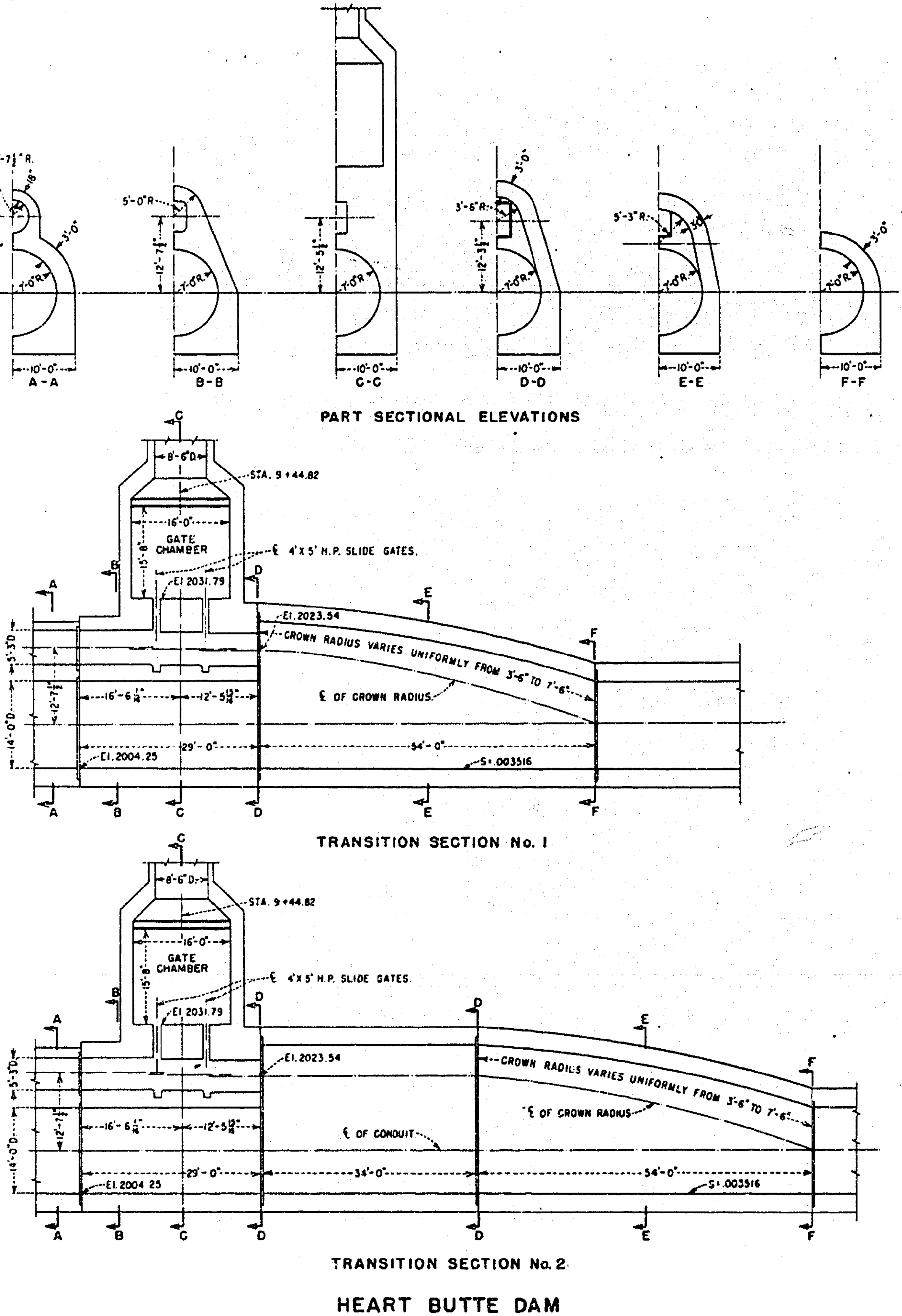
SPILLWAY No.3 - DEFLECTOR 8&9 - AIR DEFECTOR No.23

33C

FIGURE 32

Discharge 5,450 second-feet
Flow of water and air through bend.

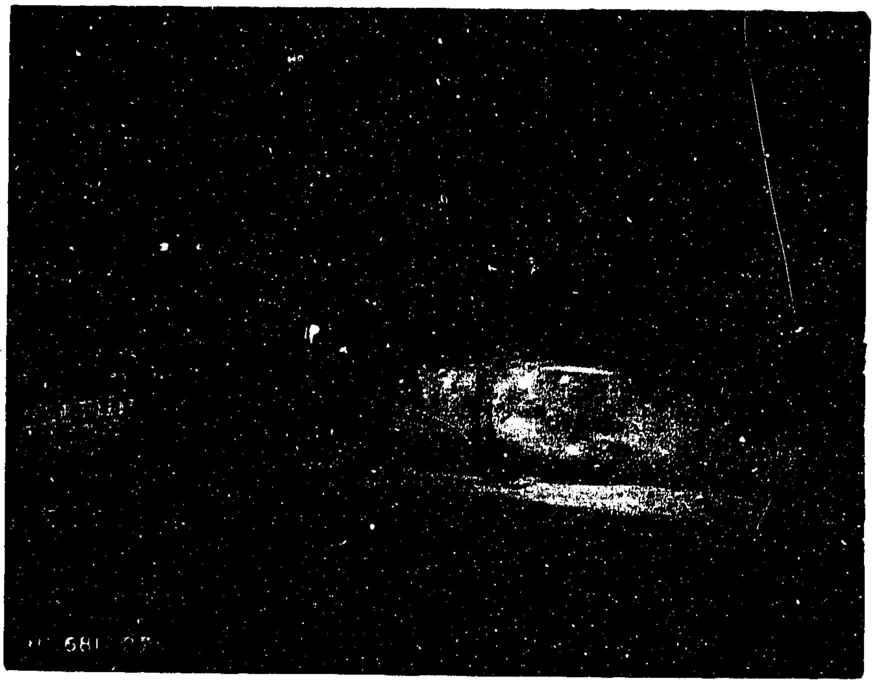
RECOMMENDED TRANSITION BEND
1:21-1/2 MODEL HEART BUTTE DAM



HEART BUTTE DAM

TUNNEL TRANSITIONS

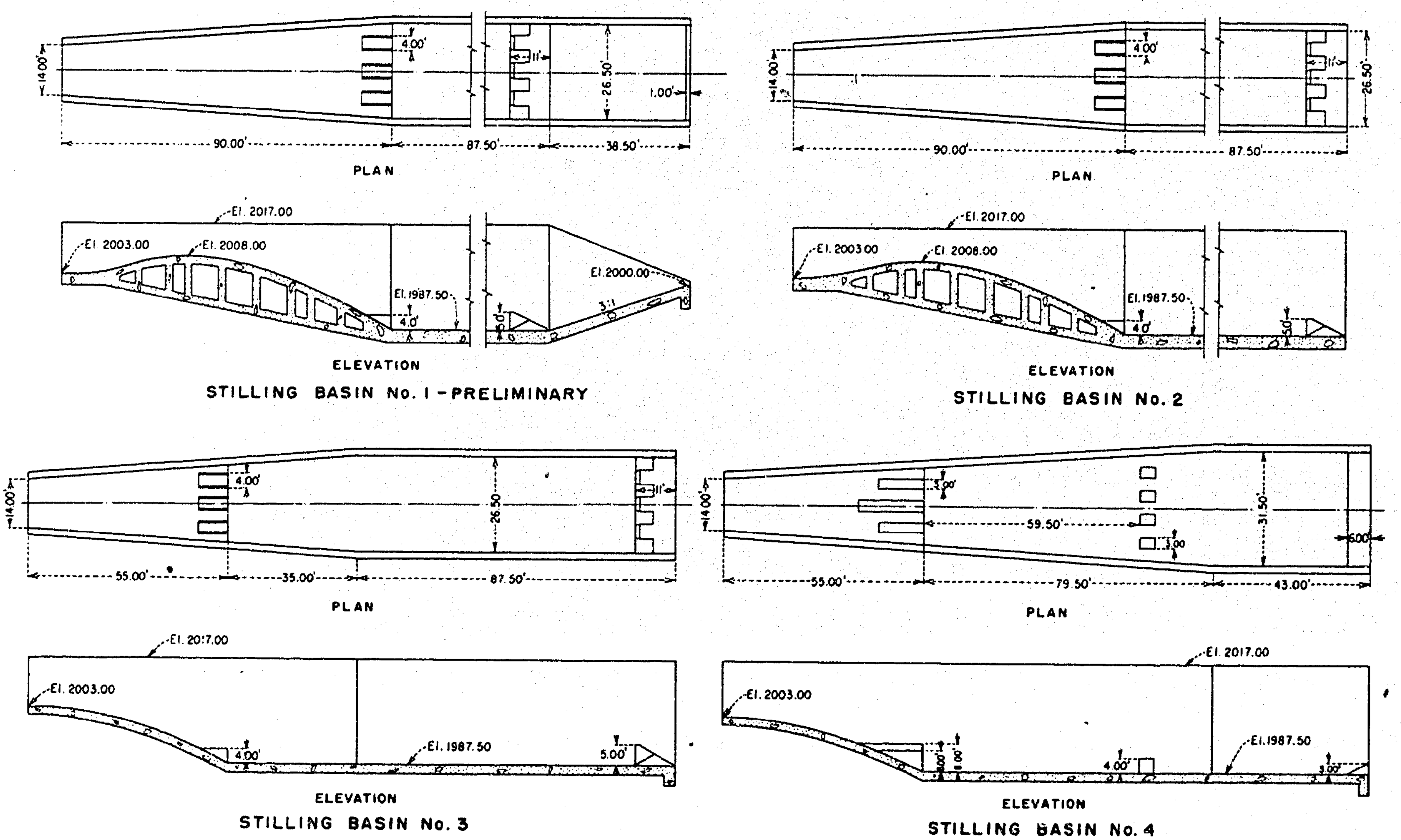
FIGURE 35



A. Transition No. 1, Outlet discharge 850 second-feet

B. Transition No. 2, Outlet discharge 850 second-feet

OUTLET TRANSITIONS
1:21-1/2 MODEL HEART BUTTE DAM

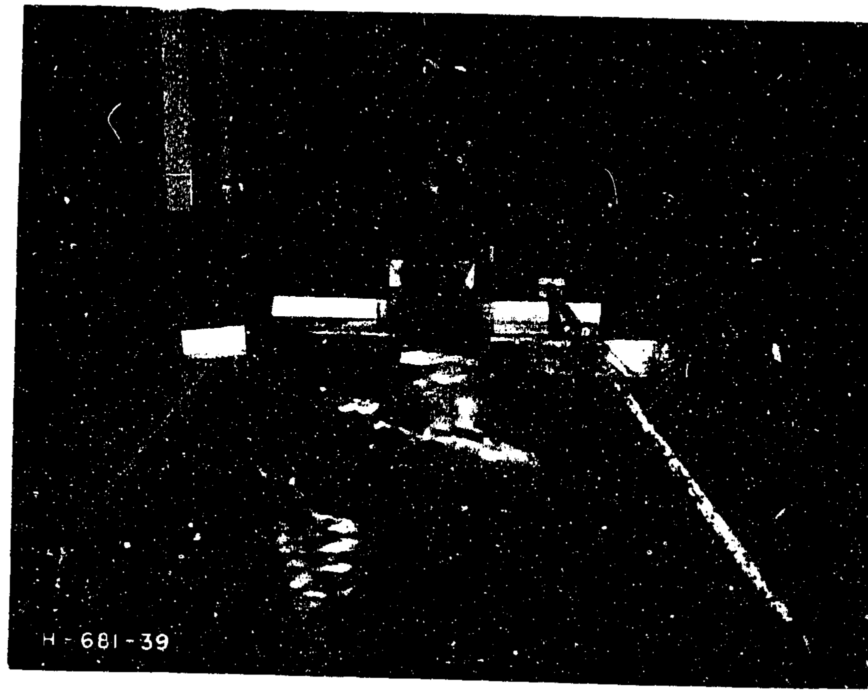


HEART BUTTE DAM

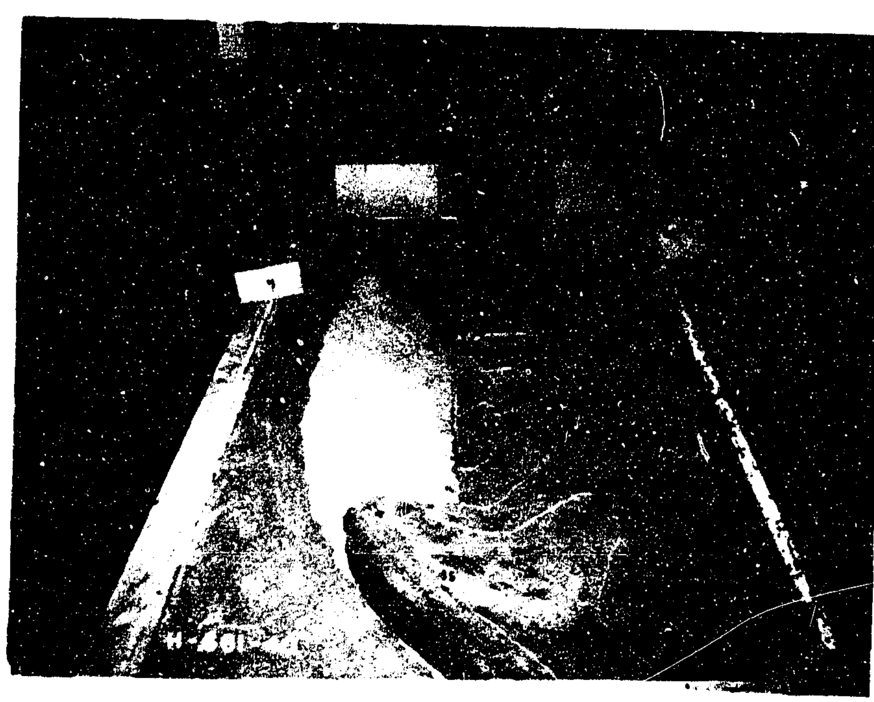
STILLING BASIN 1, 2, 3 AND 4

FIGURE 36

FIGURE 37

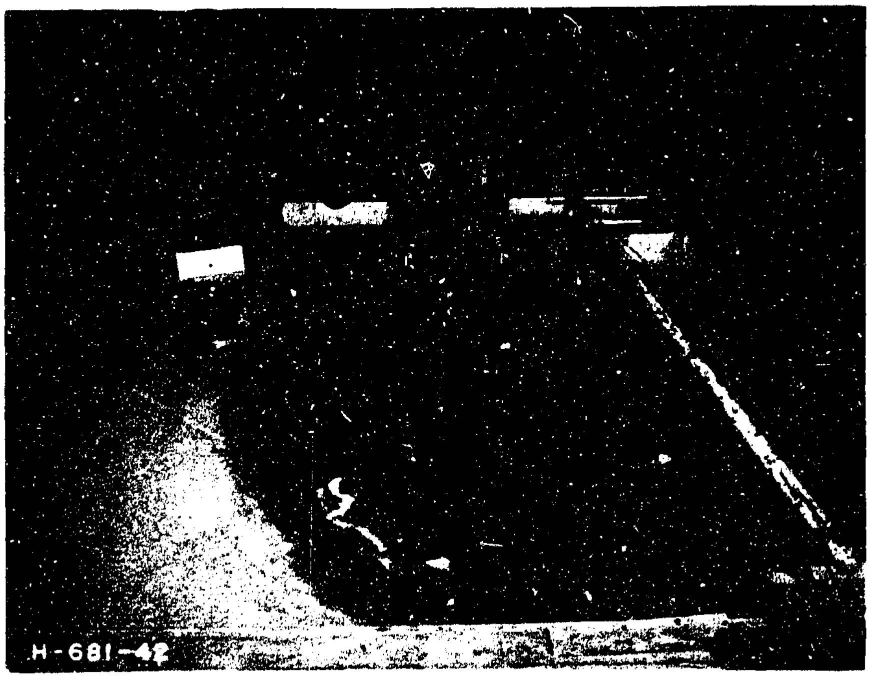


A. Discharge 5,600 second-feet

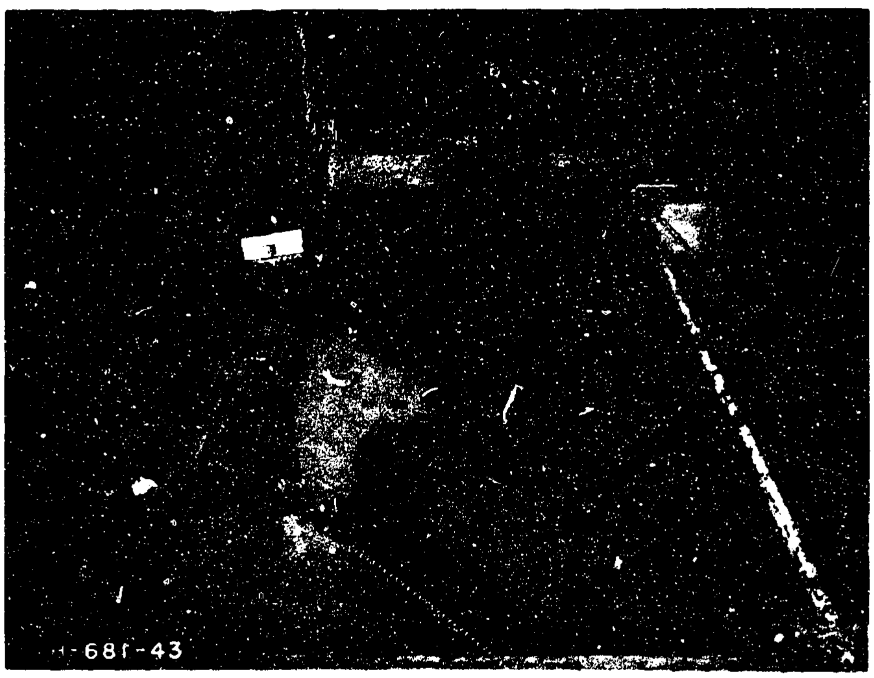


B. Scour after 1/2 hour at 5,600 second-feet
T.W. 2012

STILLING BASIN NO. 1
1:21-1/2 MODEL HEART BUTTE DAM



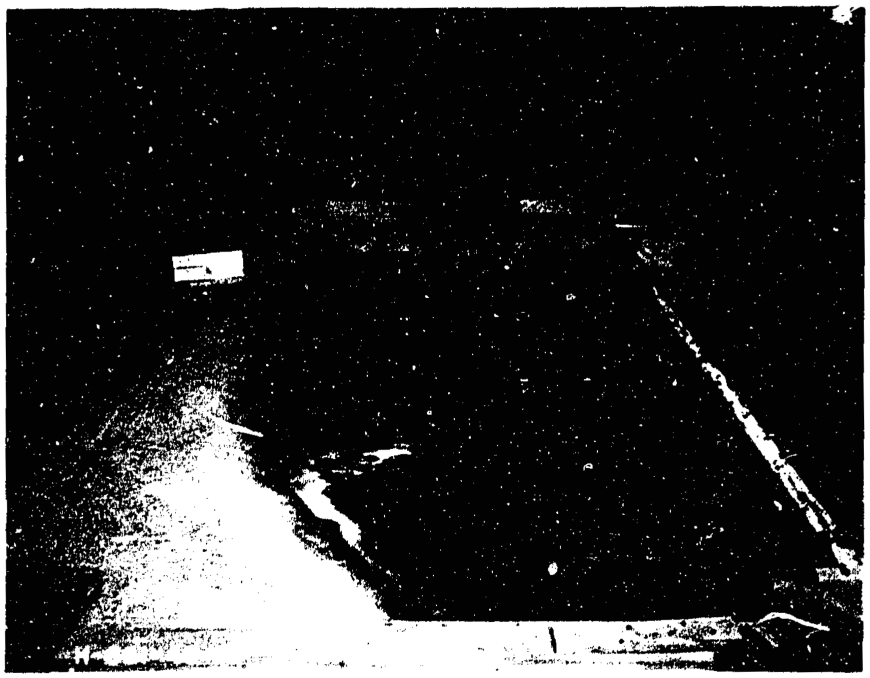
A. Discharge 5,600 second-feet



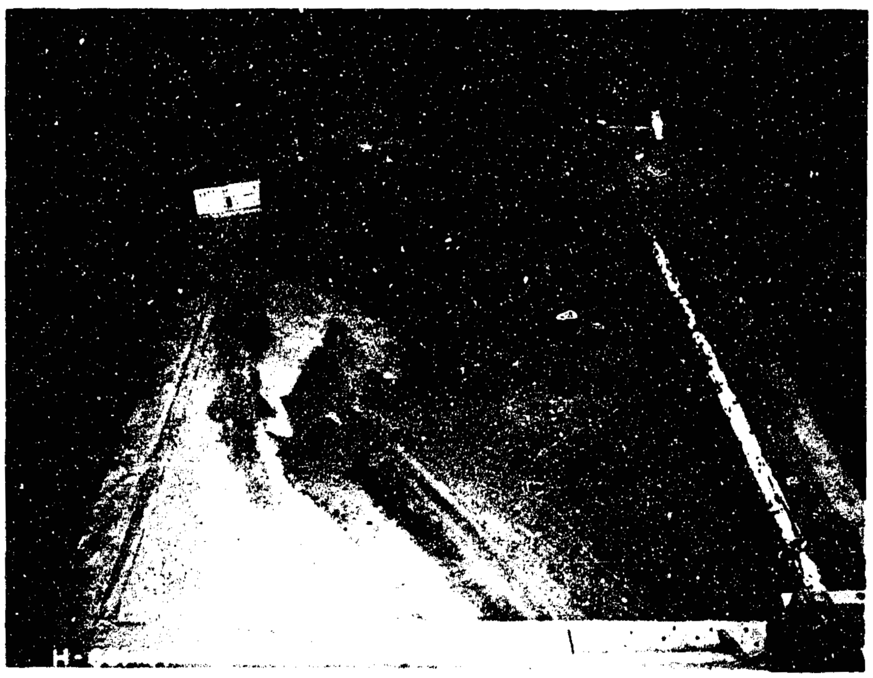
B. Scour after 1/2 hour at 5,600 second-feet
T.W. 2012

STILLING BASIN NO. 2
1:21-1/2 MODEL HEART BUTTE DAM

FIGURE 39



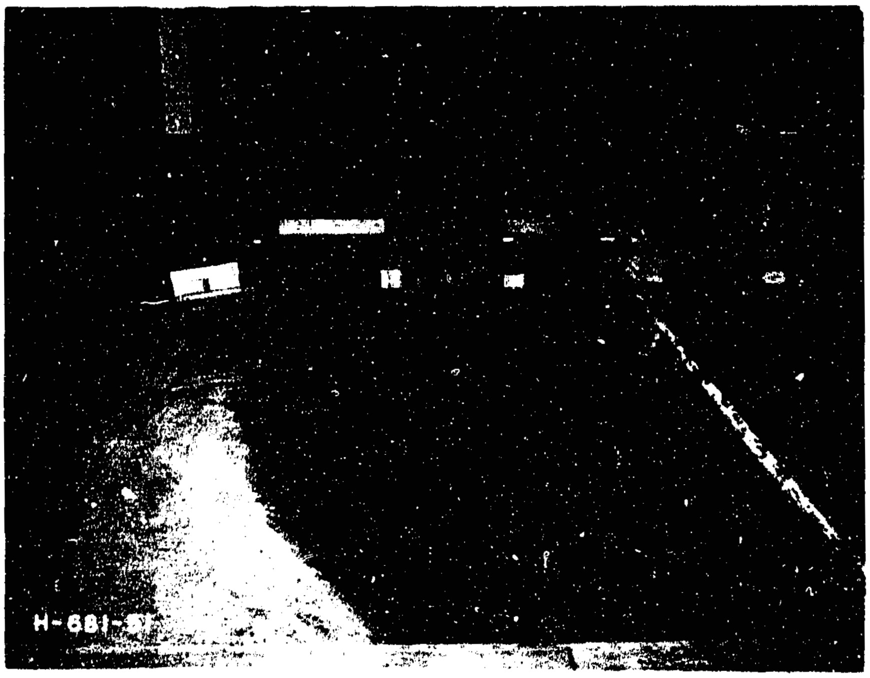
A. Discharge 5,600 second-feet



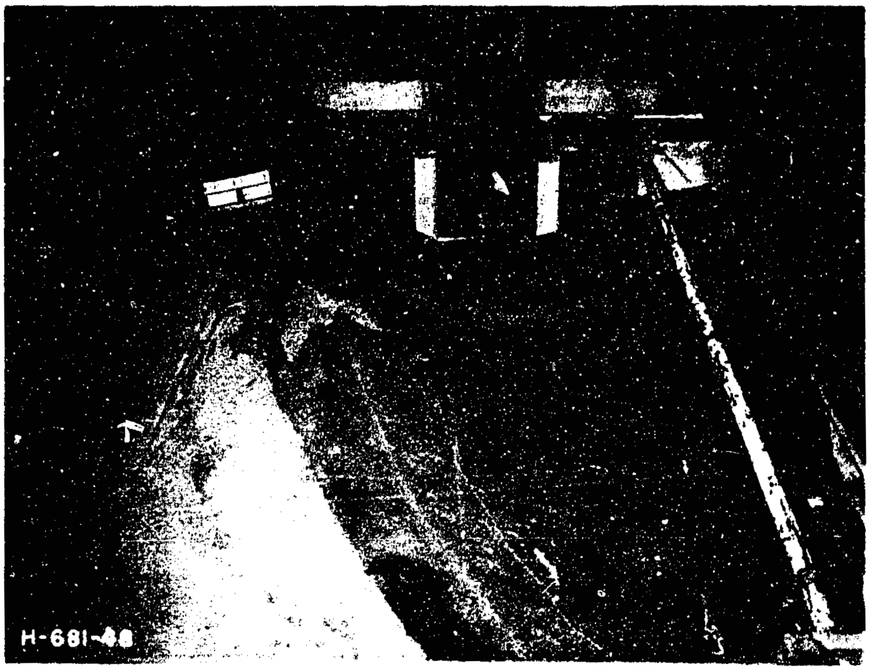
B. Scour after 1/2 hour at 5,600 second-feet
T.W. 2012

STILLING BASIN NO. 3
1:21-1/2 MODEL HEART BUTTE DAM

FIGURE 40

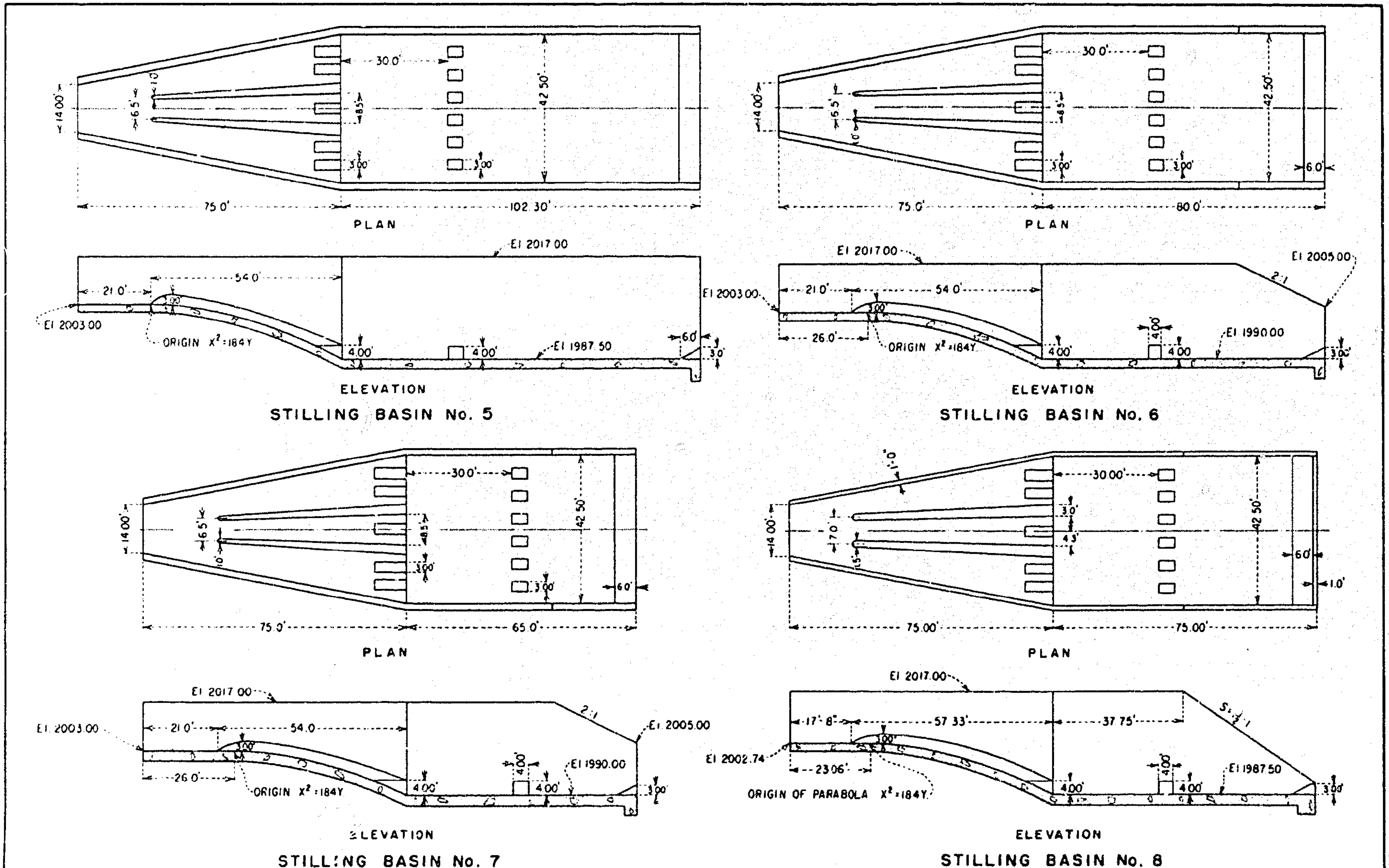


A. Discharge 5,600 second-feet



B. Scour after 1/2 hour at 5,600 second-feet
T.W. 2012

STILLING BASIN NO. 4
1:21-1/2 MODEL HEART BUTTE DAM

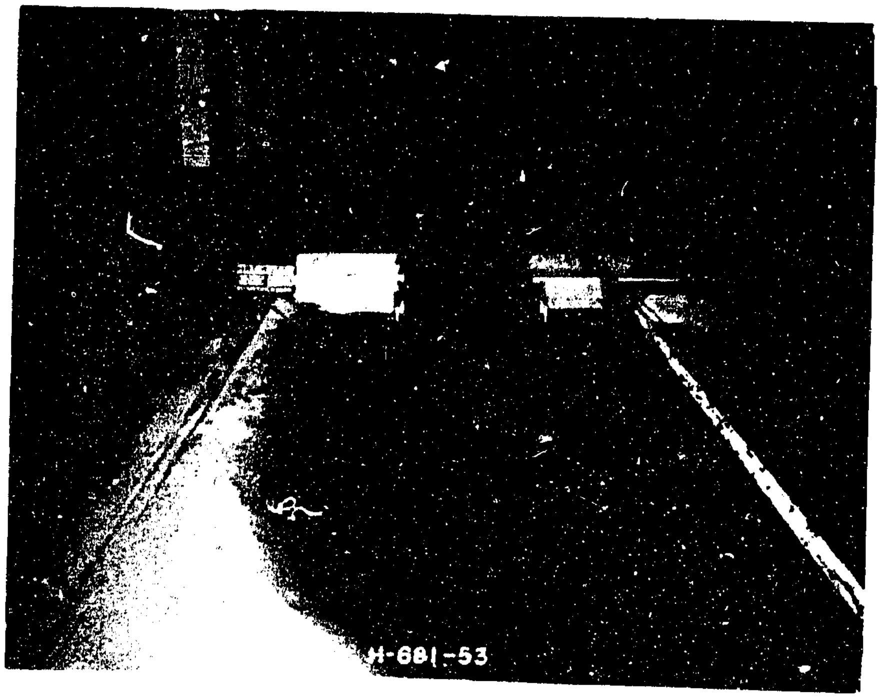


HEART BUTTE DAM

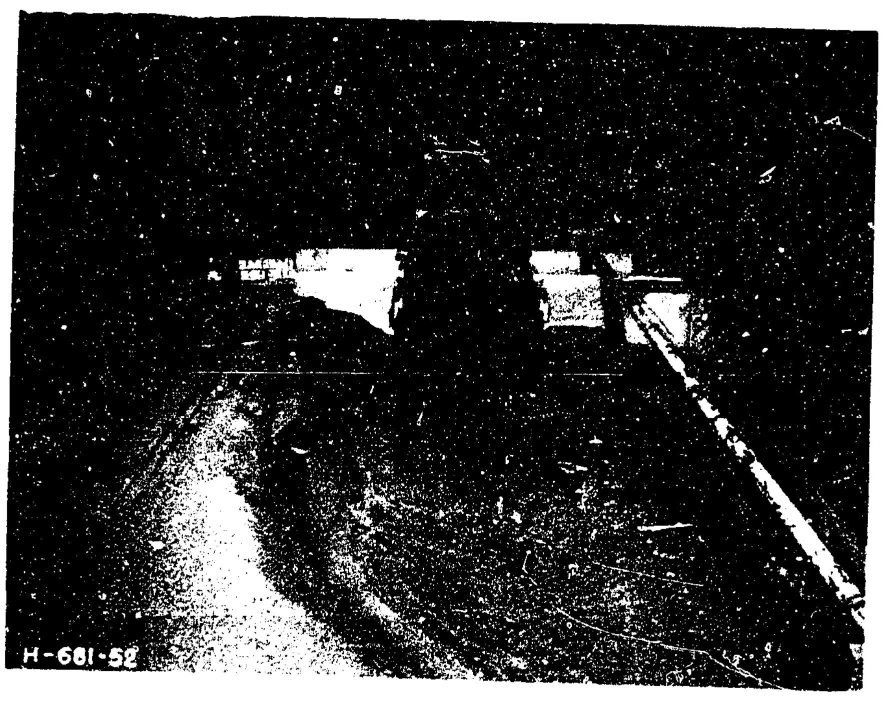
STILLING BASINS 5, 6, 7 AND 8

FIGURE 41

FIGURE 42

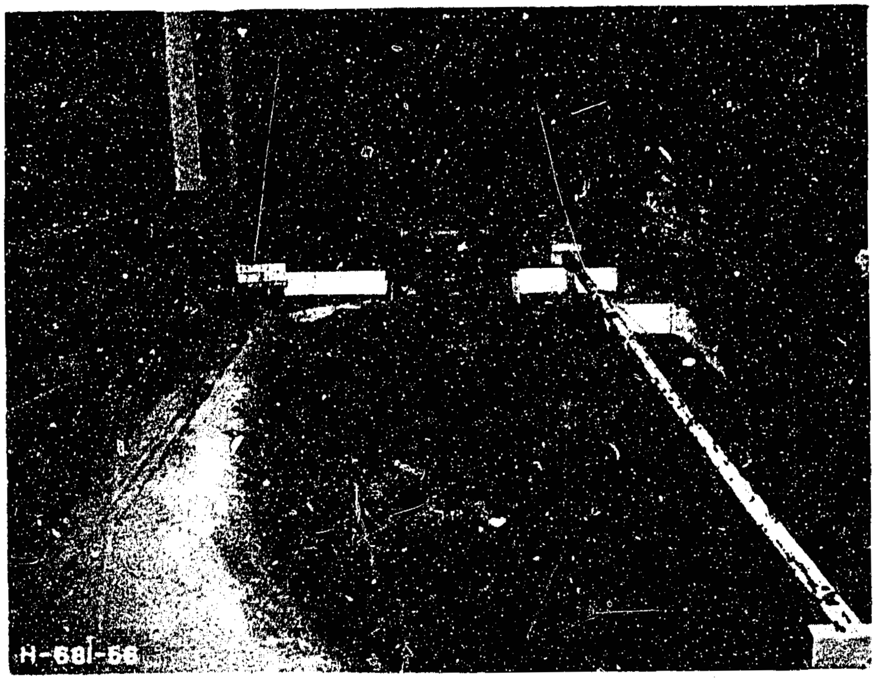


A. Discharge 5, 600 second-feet

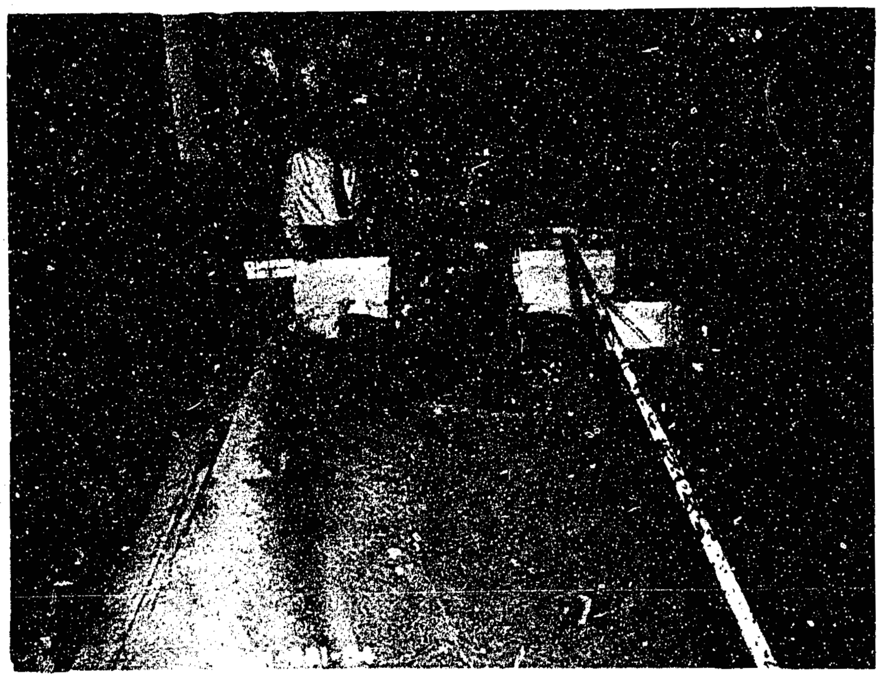


B. Scour after 1/2 hour at 5, 600 second-feet
T.W. 2012

STILLING BASIN NO. 5
1:21-1/2 MODEL HEART BUTTE DAM



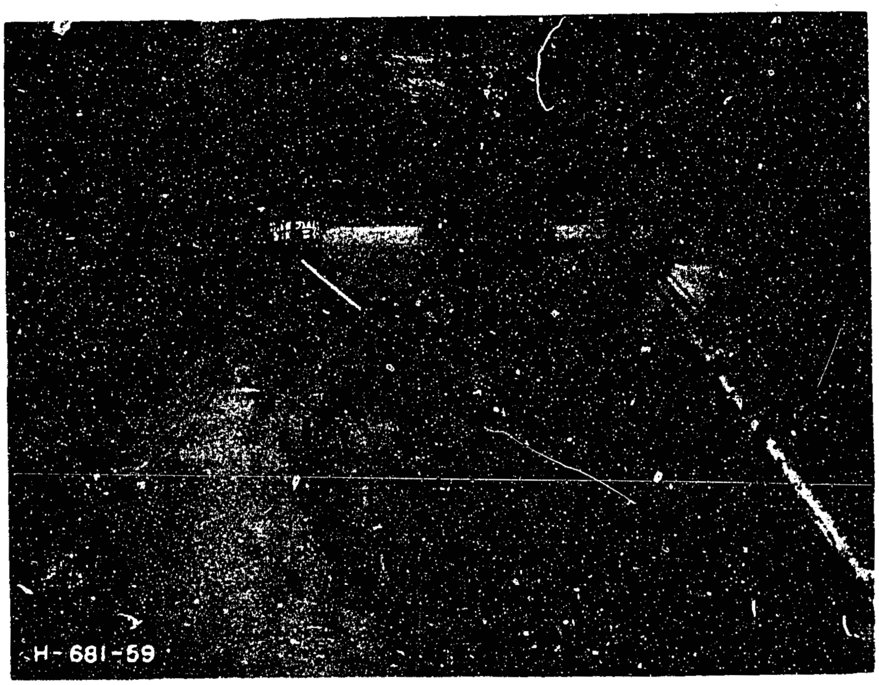
A. Discharge 5,600 second-feet



B. Scour after 1/2 hour at 5,600 second-feet
T.W. 2012

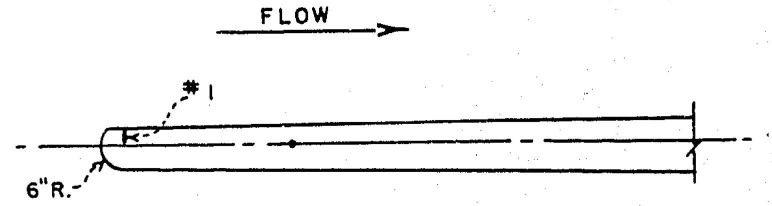
STILLING BASIN NO. 6
1:21-1/2 MODEL HEART BUTTE DAM

A. Discharge 5,600 second-feet

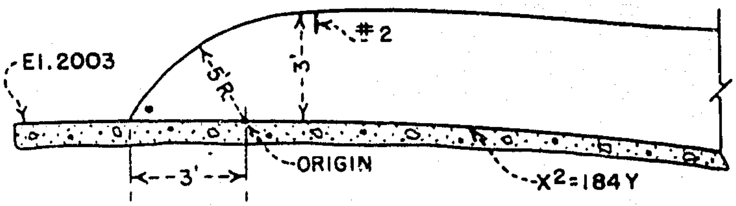


B. Scour after 1/2 hour at 5,600 second-feet
T.W. 2012

STILLING BASIN NO. 7
1:21-1/2 MODEL HEART BUTTE DAM

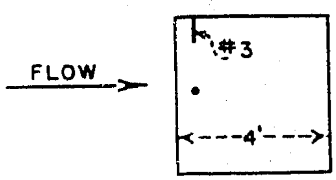


PLAN

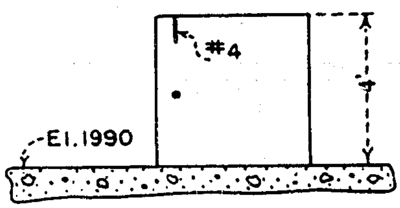


ELEVATION

SPREADER WALL



PLAN



ELEVATION

BAFFLE BLOCK

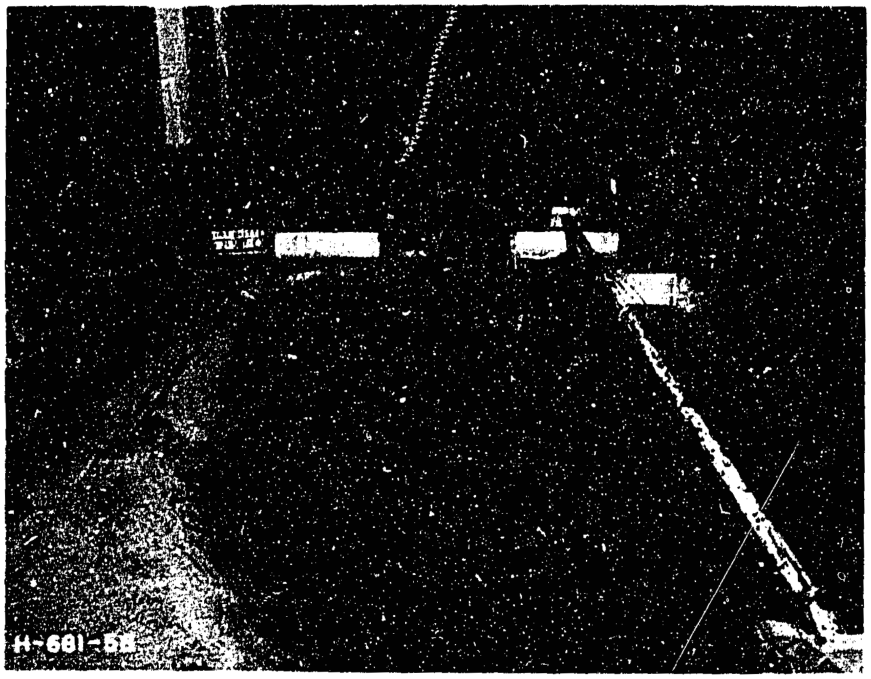
PRESSURES
FEET OF WATER FROM
ATMOSPHERIC

PIEZ	Q=5600	Q=4000	Q=3200
1	−18.0	−0.4	−0.6
2	− 5.5	+2.5	−8.4
3	−10.5	+2.2	−0.5
4	− 2.0	+6.4	+8.5

HEART BUTTE DAM
PRESSURES
STILLING BASIN No. 7

330

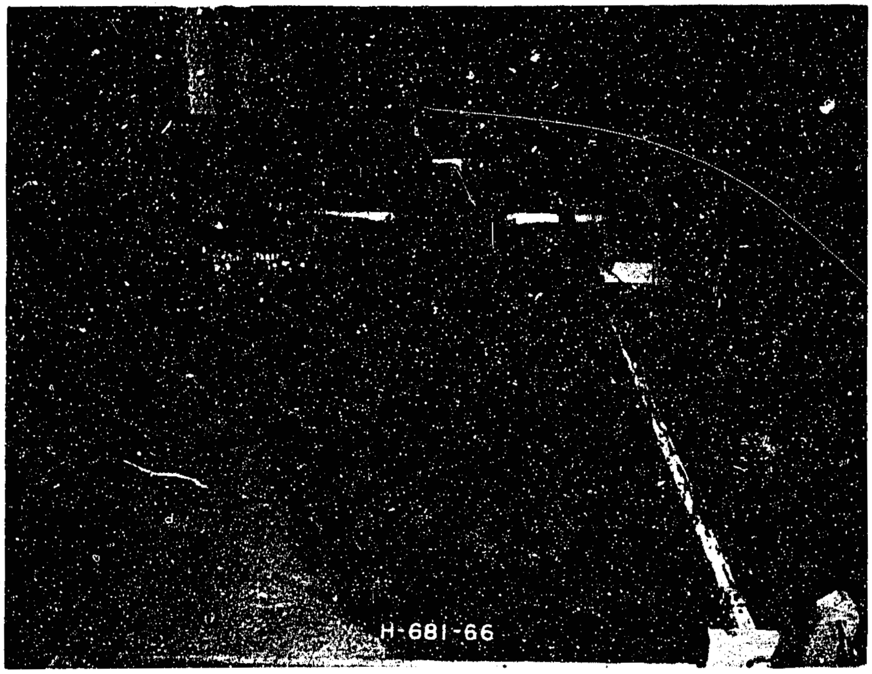
FIGURE 46



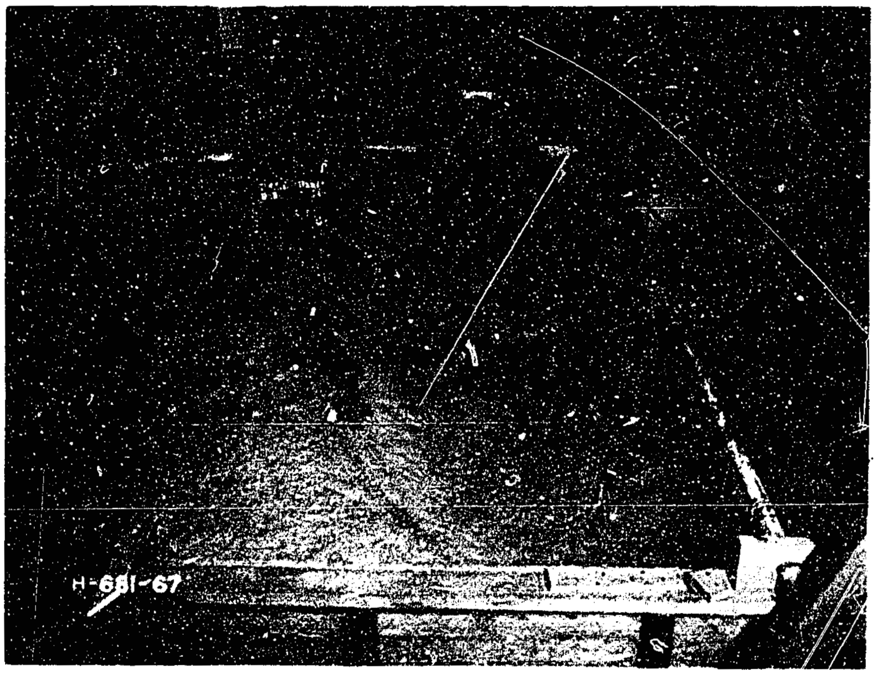
A. Discharge 5,600 second-feet

B. Scour after 1/2 hour at 5,600 second-feet
T.W. 2012

STILLING BASIN NO. 7
Without Spreader Walls
1:21-1/2 MODEL HEART BUTTE DAM

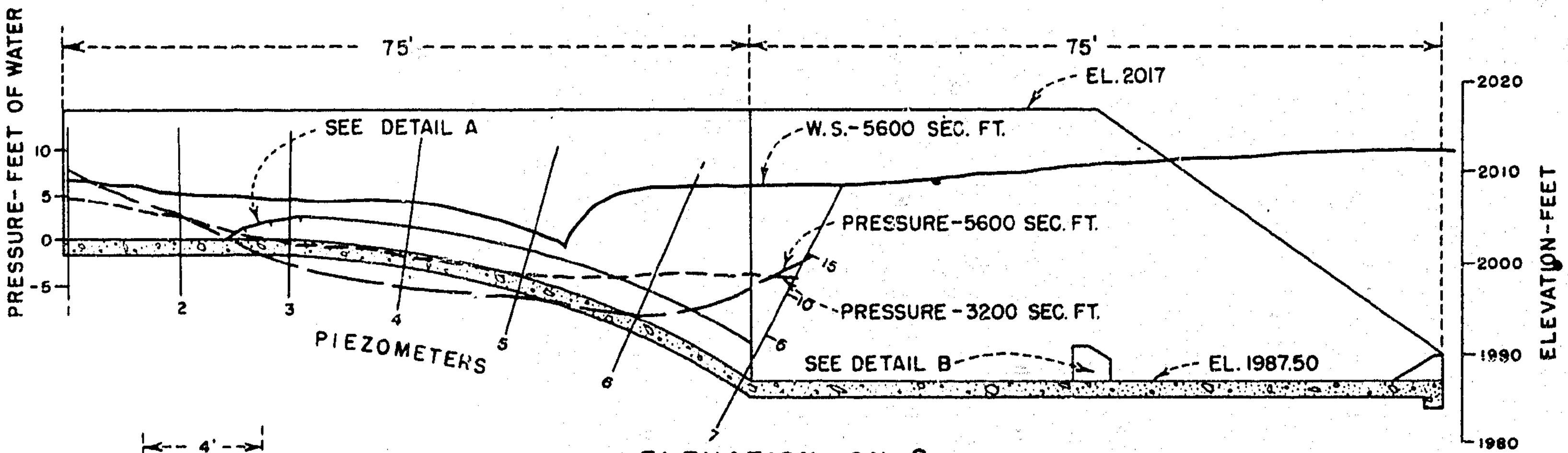


A. Discharge 5,600 second-feet

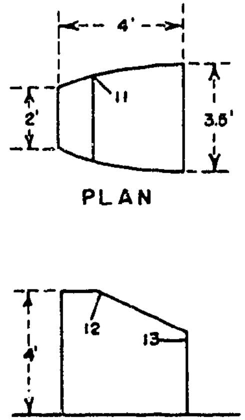


B. Scour after 1/2 hour at 5,600 second-feet
T.W. 2012

STILLING BASIN NO. 8--RECOMMENDED
1:21-1/2 MODEL HEART BUTTE DAM



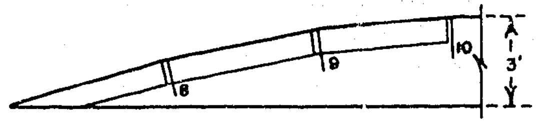
ELEVATION ON ℄



PLAN

ELEVATION

DETAIL B
BAFFLE PIER



ELEVATION

DETAIL A
SPREADER WALL NOSE

PRESSURES
FEET OF WATER FROM ATMOSPHERIC

PIEZ	Q=5600	Q=3200
8	-2.8	-0.4
9	-1.0	-0.8
10	+6.0	+7.0
11	+4.0	+10.0
12	+4.0	+10.0
13	+9.0	+10.0

HEART BUTTE DAM

W. S. PROFILES AND PRESSURES
STILLING BASIN No. 8

FIGURE 48

Interior - Reclamation - Denver, Colo.