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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Design and Construction Division
Engineering Laboratories Branch
Denver, Colorado
January 16, 1952

Laboratory Report No. Hyd-329
Hydraulic Laboratory
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Subject: Hydraulic model studies of the service spillway--Shadehill Dam--Missouri River Basin Project

SUMMARY

Model tests were made to investigate the hydraulic performance of the service spillway of Shadehill Dam. This was a tunnel spillway with a morning-glory type entrance, Figure 2, and was designed for a maximum discharge of 5,000 second feet at reservoir elevation 2297.0. The model of the spillway, Figure 4, was built to a scale of 1:20.732. The model studies indicated desirable changes to improve the hydraulic performance of the morning-glory entrance and the stilling basin.

Tests of the preliminary spillway entrance, Figure 5, showed that the design in general was satisfactory. Flow through the entrance and the bend was smooth and pressures on the face of the crest and bend indicated satisfactory flow conditions. Small vortices appeared over the entrance in the vicinity of the piers and they became larger when the piers were submerged, indicating that the pier heights should be increased. Calibration of the preliminary spillway, Figure 7, showed a discharge of 4,530 second feet at reservoir elevation 2297.0, indicating that the throat diameter should be increased to give the required 5,000 second feet discharge. The spillway was operated after removing the deflector on the downstream side of the throat. At discharges above 3,300 second feet, with the crest submerged, the tunnel ran full and pressures were below atmospheric in the spillway entrance. This unsatisfactory performance demonstrated the need for a deflector in the throat.

The recommended entrance structure, Figure 9, has piers 14 feet high and a throat diameter of 13 feet 6 inches. Flow was satisfactory at all discharges. Vortex action occurred as before, but the higher piers reduced the size of the vortices. Pressures throughout the crest and bend were satisfactory. The discharge capacity curve for the recommended entrance, Figure 7, showed a discharge of 5,000 second feet at reservoir water-surface elevation 2297. The spillway capacity was influenced by the deflector width which was adjusted to give the required discharge.

The preliminary stilling basin, Figure 11, gave unsatisfactory performance because the jet did not spread in passing down the chute, thus causing a flow concentration in the center of the stilling basin. Stilling Basin No. 2, Figure 13, had a longer and flatter parabolic chute section than Basin No. 1. The performance was improved, but the flow was still concentrated in the center of the basin, and the scour was practically unchanged. A longer chute with a more gradual parabolic slope was then used for Basin No. 3, Figure 15. The horizontal floor was lowered 4 feet and baffle piers and a solid end sill were used instead of the dentated end sill. Operation was satisfactory with the spreader walls installed, but their removal resulted in better spreading of the flow. Pressures on the chute and baffle piers were above atmospheric and scour in the river channel was moderate. Accordingly, this basin was recommended for construction.

INTRODUCTION

Shadehill Dam in the Missouri River Basin is located on the Grand River near Lemmon, South Dakota, at the northern border of the state, Figure 1. It is for the purpose of flood control and storage of irrigation water. The dam is a compacted earth-fill structure covered with a protective layer of rock riprap and the crest, at elevation 2318, is 125 feet above the streambed. An emergency spillway on the left abutment consists of a flat section 1,500 feet in length excavated to elevation 2297, or 21 feet lower than the crest of the dam. An outlet works installed at the left riverbank discharges into the stilling basin at the head of an irrigation canal, Figure 2.

A service or tunnel spillway is located at the left riverbank as shown in Figure 3. The entrance to the spillway is of the morning-glory type with an outside diameter of 33 feet 8 inches, the crest at elevation 2272.00. A 90° bend connects the crest structure to the 13.5-foot-diameter horizontal tunnel which was used to divert the river flow during construction of the dam. The tunnel discharges into a concrete, hydraulic-jump-type stilling basin. Maximum spillway discharge is 5,000 second feet at reservoir elevation 2297.00. The model studies of the service spillway, described in this report, were made to observe and, where necessary, to improve the hydraulic performance.

THE MODEL

The model of the morning-glory spillway was built to a scale of 1:20.732. This scale ratio resulted from using 7.81-inch-inside-diameter plastic conduit, which was in stock in the laboratory, to represent the 13.5-foot-diameter tunnel. The model, Figure 4, was built in two sheet metal-lined wooden boxes. A 6-inch supply pipe from a portable pump emptied into the head box behind a rock baffle which stilled the flow before it entered the spillway entrance area. An orifice meter in the supply line was used to measure the flow to the model which required a maximum discharge of 2.5 second feet.

The 8- by 10-foot head box supported above the laboratory floor contained the morning-glory entrance and bend which were made of transparent plastic. The tunnel was also made of transparent plastic and the piers on the crest were built of wood. Topography surrounding the spillway entrance, which represented the upstream face of the dam embankment, was formed of concrete plastered on metal lath and held in place by wooden supports.

The tail box contained the stilling basin and a portion of the downstream river channel. The horizontal apron and chute of the basin were made of concrete screeded to metal templates and the training walls were made of wood faced with sheet metal. Chute blocks, baffle piers, spreader walls, and end sill were made of wood. An erodible riverbed was formed by using sand of which all passed a No. 8 sieve and 90 percent was retained on a No. 50 sieve. A hinged gate at the end of the tail box was used to regulate the tail-water elevation which was measured with a staff gage.

The model was geometrically similar to the prototype except the model slope of the tunnel was increased to 0.05378 from the prototype slope of 0.04344. This distortion is a necessary correction for models of this type and the following discussion explains briefly the reason for the increase in slope 1/. A model requires extremely smooth surfaces to represent the prototype surface to the proper scale. Since such a surface cannot be produced, the friction losses in the model are too high and velocities at the terminus of a model structure are lower than the scale velocity. Increasing the slope of the tunnel compensates for the greater model friction so that the proper velocity is obtained for the flow entering the stilling basin.

In testing the model, flows representing up to the maximum of 5,000 second feet were passed through the structure. The morning-glory entrance and bend were first studied and modified until satisfactory results were obtained. Then the stilling basin was tested and altered until the operation was satisfactory. Pressures were measured on the entrance and bend by two rows of piezometers located, as shown in Figure 6, and pressures were obtained on the chute and baffle piers of the stilling pool as shown in Figure 17. All pressures are reported in terms of prototype dimensions. Erosion of the river channel was used as a criterion in determining the effectiveness of the stilling basin.

1/A more detailed account can be found in the Hydraulic Laboratory Report No. Hyd-158.

INVESTIGATION OF MORNING-GLORY ENTRANCE AND BEND

Preliminary Entrance and Bend

Operation and pressures. The preliminary spillway entrance and bend is shown in Figure 5. The crest was at elevation 2272.00 and the maximum entrance diameter was 32 feet 8 inches, with a throat diameter of 12 feet 6 inches at elevation 2260. A transition bend started at the throat and connected the morning glory to the 13.5-foot-diameter horizontal tunnel. Six piers 10 feet high were spaced equidistant around the crest and a deflector was located on the downstream side of the bend consisting of a projection 5 feet 9 inches wide, as shown in Figure 5.

The spillway was operated at various capacities up to 5,000 second feet, and the appearance of the flows through the morning-glory entrance and bend was observed. The deflector prevented the horizontal tunnel from running full. Hydraulic performance of the preliminary design was considered satisfactory as judged visually. Other considerations, as discussed later, required some modifications to the entrance structure.

Pressures were measured along the upstream and downstream side of the crest and bend at the locations shown in Figure 6. The Curves A, B, and C in the figure show the pressures for three different discharges. With a discharge of 2,950 second feet the pressure near the throat was 2 feet of water below atmospheric but at all other piezometers and with various discharges, pressures were above atmospheric. Since the lowest pressures were only slightly below atmospheric, the entrance and bend were considered satisfactory in regard to cavitation.

The deflector in the spillway throat was then removed and the tunnel ran full for flows above 3,000 second feet. Curves D and E, Figure 6, show the pressures for two discharges with the tunnel filled. The pressures were lower than those obtained at corresponding discharges with the deflector in place, the lowest pressure measured being 29 feet of water below atmospheric at Piezometer 19 with a discharge of 4,980 second feet. With the tunnel running full, a suction head was produced causing the general lowering of all pressures and an instability of flow. The low pressures demonstrated the need for a deflector to keep the water surface free of the inner radius of the bend and the tunnel roof.

Calibration. A discharge capacity curve was obtained for the preliminary entrance, with deflector, by determining the reservoir water surface elevation for various discharges measured by an orifice meter in the supply line. The curve, plotted on Figure 7, has two predominant slopes, with the change occurring at reservoir elevation 2277. At reservoir elevations below this point, free flow exists over the crest and an increase in head results both in an increase in area and velocity so the discharge depends on $H^{3/2}$. When the crest becomes submerged above reservoir elevation 2277 an increase in head increases the velocity through the entrance, but the area remains constant; consequently the discharge depends on $H^{1/2}$. These two relations of discharge to H explains the change in slope of the discharge curve that results when the crest becomes submerged.

The discharge at reservoir elevation 2297 was 4,530 second feet, or 470 less than the required 5,000 second feet. This lack of capacity indicated that an increase in the diameter of the morning-glory entrance would be necessary and this was one of the changes made.

Pier and vortex studies. With the spillway operating submerged, small vortices occurred on the water surface over the entrance for reservoir elevations between 2277 and 2290. The vortices were largest when the piers were submerged between reservoir elevations 2282 and 2286, indicating higher piers were necessary. As the reservoir water surface was raised above elevation 2286, the size of the vortices decreased until no vortex action was present at reservoir elevation 2290 and above. This test established that at a head of 18 feet or more over the crest no vortices occurred.

The model was next operated with the piers removed to determine if they were necessary for proper operation of the spillway. Vortex action occurred over the same range of reservoir elevations as before when the piers were in place. However, the vortex was much larger than occurred with the piers installed. The size of the vortex was a maximum at reservoir elevation 2279 and measurements were made of the diameter of the vortex at various distances below the water surface. This data is plotted in Figure 8. The curves through these points, representing the water surface of the vortex, are defined by the equation $hr^2 = 11.3$. The vortex extended below the spillway crest with the tail of the vortex ending at the downstream end of the vertical bend. The large vortex that formed without piers on the crest showed the importance of piers in decreasing the vortex size.

Recommended Entrance and Bend

Operation and pressures. The second entrance and bend tested is shown in Figure 9. The diameter of the spillway throat was equal to that of the tunnel or 13.5 feet, so that the vertical bend was of constant diameter. The maximum spillway entrance diameter was increased 1 foot to 33 feet 8 inches. The crest remained at elevation 2272.00 and the shape of the morning-glory crest section was the same as that of the preliminary entrance. The piers were 14 feet high, an increase of

4 feet over those initially tested. The deflector on the downstream side of the throat was reduced from a 9-inch width at the bottom to a 4-inch width. This dimension was actually determined in the model from calibration tests.

The spillway was operated throughout its range of reservoir elevations and discharges up to the maximum of 5,000 second feet. The flow had a satisfactory appearance throughout the entrance, the bend and the tunnel. Small vortices occurred on the water surface near the piers for reservoir elevations 2277 through 2290. With the 14-foot-high piers the vortices were smaller for reservoir water surface elevations 2282 through 2286 than had occurred in the test using 10-foot-high piers. This reduction in vortex action justified the increase in pier height and the 14-foot piers were recommended for construction in the prototype.

Pressures were measured on two opposite faces of the entrance by the 14 piezometers located as shown in Figure 10. The curves in Figure 10 show the pressures on these piezometers for the four discharges indicated. The minimum pressure occurred just above the throat as on the preliminary entrance, and was 3 feet of water below atmospheric at Piezometer No. 6 with a discharge of 2915 second feet. A water-surface profile through the bend, as shown in Figure 10 for a discharge of 5,000 second feet, shows the effectiveness of the deflector in forcing the water to remain free of the roof of bend and tunnel. This arrangement was considered satisfactory from the results of the pressure studies and from visual observations.

<u>Calibration</u>. The discharge capacity was then checked, using the 4-inch-wide deflector in the throat. The curve, labeled recommended on Figure 7, shows the desired discharge of 5,000 second feet at reservoir elevation 2297. This curve has the same characteristics and shape as the former, but it is shifted to the right because of the increased diameter of the entrance structure. The calibration completed, the spillway entrance tests and studies were next made on the stilling basin at the tunnel portal.

INVESTIGATION OF SPILLWAY STILLING BASIN

<u>Preliminary Stilling Basin</u>

<u>Operation and erosion</u>. The preliminary stilling basin, Figure 11, was 151 feet long and the maximum width was 44 feet. A transition section 28 feet long changed the circular tunnel to a horseshoe tunnel at the portal. The horizontal basin floor, except for side fillets, was at elevation 2186.0; giving a tailwater depth of 18.5 feet at the maximum discharge of 5,000 second feet. Diverging walls placed

on the chute were expected to help spread the flow from the 13.5-foot width at the portal to the 44-foot width at the toe of the chute.

Operation of the stilling basin with the maximum discharge of 5,000 second feet is shown in Figure 12A. The jump formed too far downstream as the toe of the chute was exposed. The water surface in the channel was rough with 3-foot high waves. The profile of the chute did not conform to the trajectory of the water flowing over it. This caused low pressures on the chute, and very little spreading of the flow. The flow was concentrated in the center of the basin, thus the spreader walls were ineffective.

An erosion test was run by operating the model for 1 hour at a discharge of 5,000 second feet with the tail water at elevation 2204.5. The scour that resulted is shown in Figure 12B. The lowest streambed elevation was 3 feet below the apron floor and occurred at the cut-off wall on each side of the basin. While the condition of the bed showed fair stilling action, the removal of all sand from the concrete side slopes indicated turbulent flow and high velocities near the water surface.

Stilling Basin No. 2

Operation and erosion. The concentration of flow in the center of the basin was the greatest objection to the performance of the preliminary stilling basin. This was caused by the shape of the chute section so this portion of the basin was modified for Stilling Basin No. 2. The training wall divergence was changed by eliminating the 90-foot radius at the tunnel portal to give straight walls, Figure 13. The vertical curve and steep slope of the chute floor were replaced by a parabolic-shaped floor as shown in the same figure. Remaining features of the basin were unchanged from the preliminary.

Operation of the model with the maximum discharge of 5,000 second feet is shown in Figure 14A. Comparison of the photograph with Figure 12A shows a smoother water surface in Stilling Basin No. 2 than in the preliminary basin. The change in the shape of the chute resulted in this improvement since greater spreading of the flow occurred, giving a more uniform energy distribution across the stilling basin. The flow spread more in the chute because the parabolic floor conformed to the trajectory of the water, giving higher floor pressures, which is essential to spreading of the flow. However, the velocity of the water at the training walls of the stilling basin was lower than in the center which showed that further spreading of the flow was desirable. The jump was contained in the basin and the chute blocks were not exposed as in the preliminary design. However, the depth of water over the horizontal floor was not considered great enough for safe operation since a 2-foot decrease in tail water caused the jump to sweep out.

The erosion resulting from operating the model 1 hour at a discharge of 5,000 second feet is shown in Figure 14B. The scour was similar to that obtained with the preliminary stilling basin, but a depression in the streambed extending 150 feet downstream from the right side of the basin indicated a concentration of flow in this region. Less scour would occur by having more uniform flow across the stilling basin together with more tail-water depth.

Stilling Basin No. 3

Basin with spreader walls. Stilling Basin No. 3 is shown in Figure 15. The length of the chute trajectory and horizontal section were both increased so that the total length was 190 feet instead of the previous length of 151 feet. Length of the tunnel transition at the portal was increased to 40 feet to allow more length for spreading of the flow. The horizontal floor was lowered 4 feet to elevation 2182.00 and a solid end sill, 3 feet high, and baffle blocks were used instead of a dentated end sill. The parabolic chute floor was less steep than the parabola of Stilling Basin No. 2. Spreader walls were also used and are shown by the dotted lines in Figure 15. Five piezometers were installed along the centerline of the chute and four piezometers were placed in one of the baffle piers.

Operation of the model at 5,000 second feet discharge and tail water at elevation 2204.5 is shown in Figure 16A. The performance was greatly improved over that of Basin No. 2. The jump was contained in the basin and the water surface in the river channel was smooth. It required lowering of the tail water 6 feet before the jump would sweep out.

The erosion resulting from operating 1 hour at a discharge of 5,000 second feet is shown in Figure 16B. The streambed at the end of the basin was 1 foot above the apron floor instead of 3 feet lower than the apron as occurred in the two former studies. Erosion was less throughout the length of the tail box than had occurred in any previous tests.

With the spreader walls in place, pressures on the chute and water-surface profiles were measured. The results are shown in Figure 17 with a discharge of 5,000 second feet and tail-water elevation 2204.5. All pressures were above atmospheric and varied from 7 feet to 1 foot of water. The water surface profiles showed a greater depth of water at the centerline of the chute than at the sides. Transverse Section AA of Figure 17 shows this greater depth at the center. The spreader walls shown in the section appear to confine the flow to the center instead of acting to spread the water to the training walls.

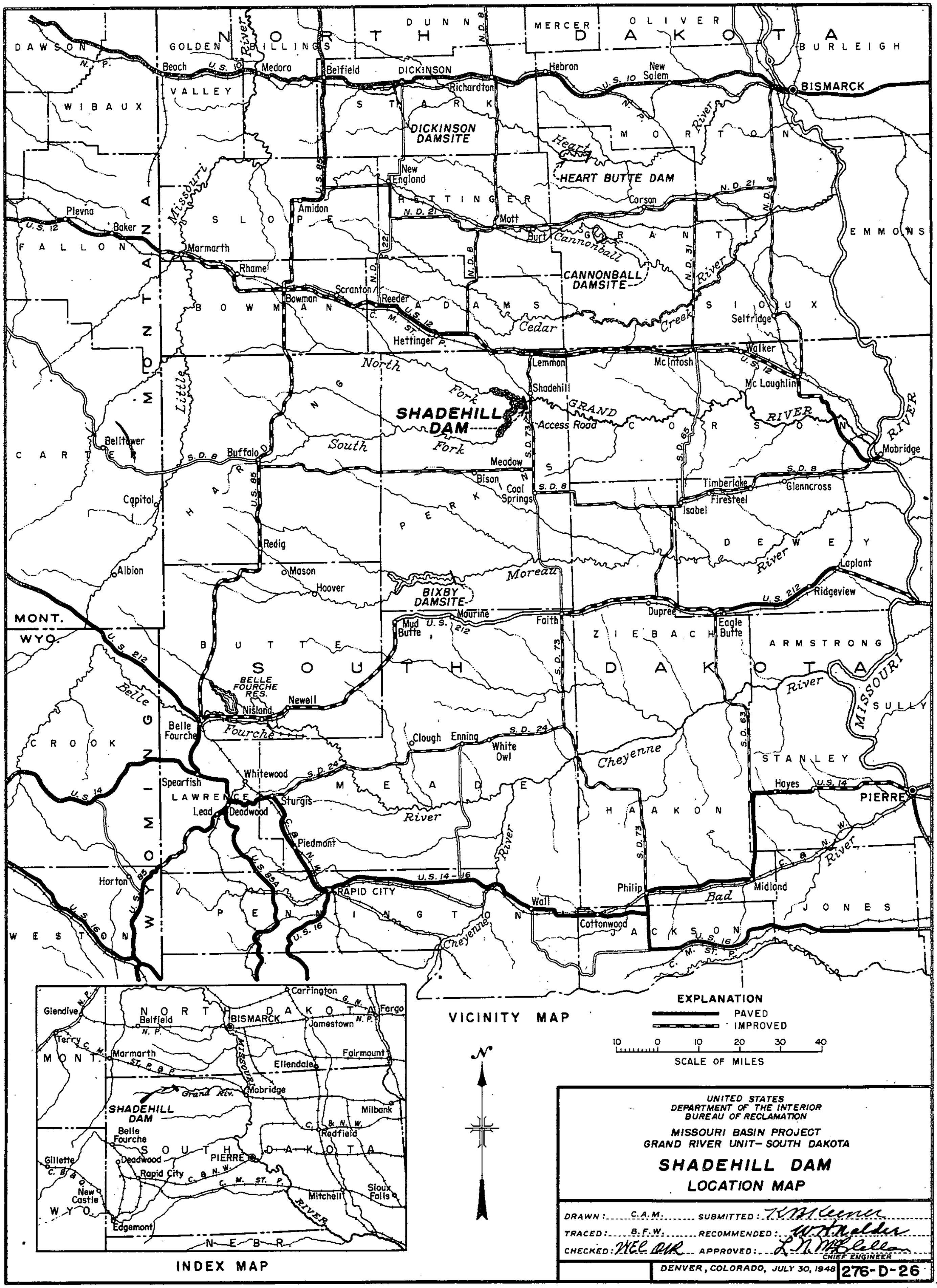
Basin without spreader walls—Recommended. The spreader walls on the chute were removed and the concrete side slopes in the tail box were cut off for a length of 50 feet at the end of the basin and replaced with sand. Performance of the basin with a discharge of 5,000 second feet, Figure 18A, showed improvement over that with the spreader walls in place. A more uniform flow distribution occurred across the basin with a resulting smoother water surface in the river channel.

Pressures were measured on the centerline of the chute and on the four piezometers on the baffle pier; the results for discharges of 3,400 and 5,000 second feet are shown in Figure 17. Pressures on the chute were all above atmospheric and showed less variation along the length of the chute than occurred with the spreader walls installed. The pressures on the baffle pier were above atmospheric for all operating conditions, pressures being higher for the lower discharge as shown in the table of Figure 17. Water surface profiles are shown in the figure for a discharge of 5,000 second feet with tail-water elevation 2204.5 and 2215.0. The depth of water in the chute was more uniform than had occurred with the spreader walls in place. A second transverse Section AA in Figure 17 shows the depth of water at the training walls to be only slightly less than the depth at the centerline which was an improvement over any results obtained with the spreader walls installed.

Two erosion tests were run without the spreader walls. The first test was for 1 hour at 5,000 second feet, Figure 18B. Greatest depth of scour was 1 foot below the apron floor at the cut-off wall on the right side of the basin but was considered satisfactory. Sand on the concrete side slopes indicated a less turbulent water surface than occurred with any of the previous basins.

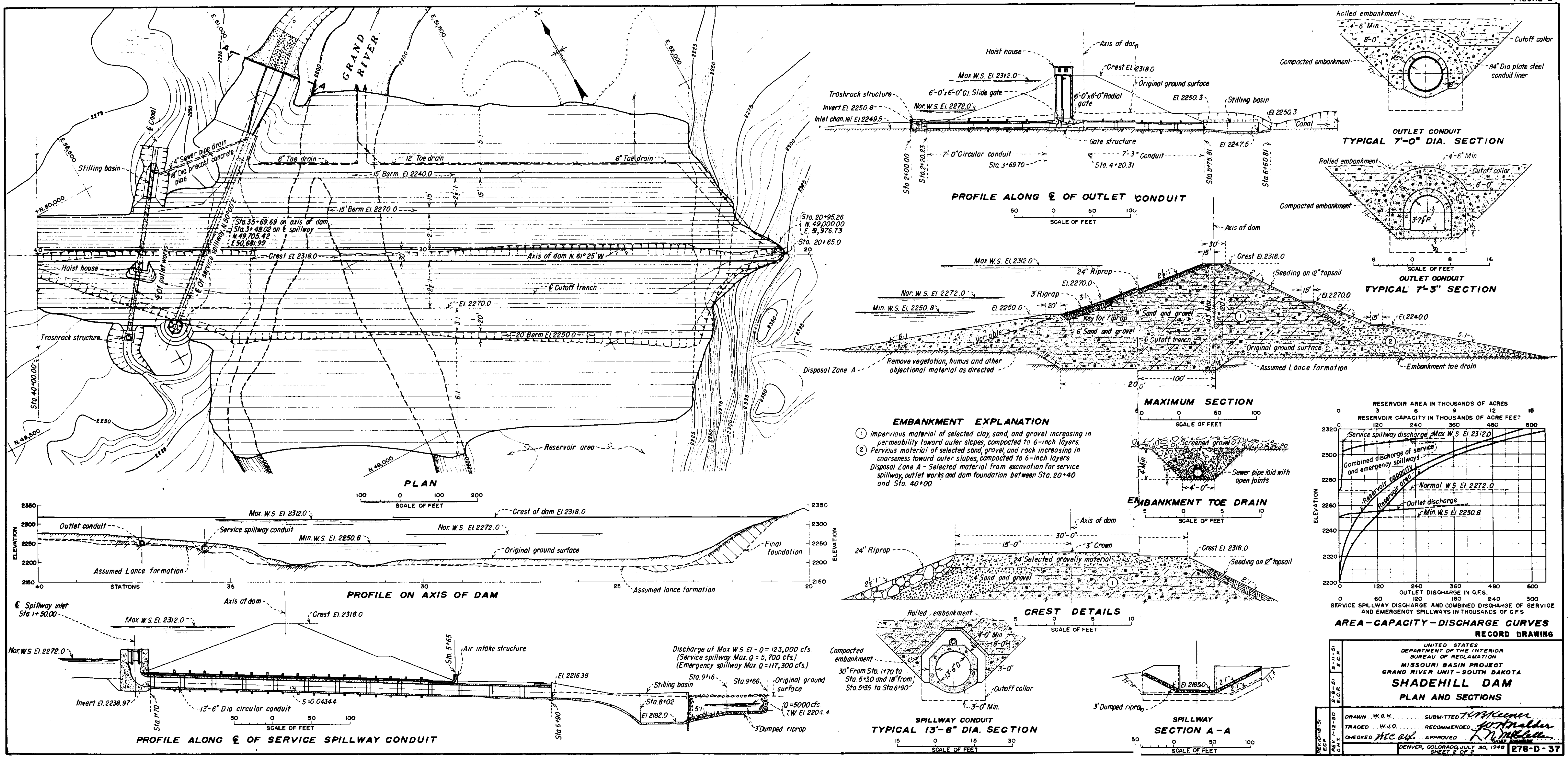
The second erosion test made use of a different bed material. The sand in the tail box was stabilized by mixing with cement in the ratio of 1 part of cement to 90 parts of sand by weight. The materials were formed to the shape of the river channel and after setting for 48 hours, the bed was firm and ready for the erosion test. The model was operated for 7 hours at the maximum discharge of 5,000 second feet and tail-water elevation 2204.5. The resulting erosion is shown in Figure 19A and B. Scour was not severe and was confined to the bed of the channel. The banks were smooth indicating minor erosion from wave action. With stabilized sand, holes eroded in the channel were not filled by loose sand so that areas subjected to the most scour could be located. This test indicated erosion to be greatest, not at the end of the stilling basin, but 100 feet downstream from this point. From these tests, together with the operating and pressure test, the stilling basin was considered satisfactory and was recommended for construction.

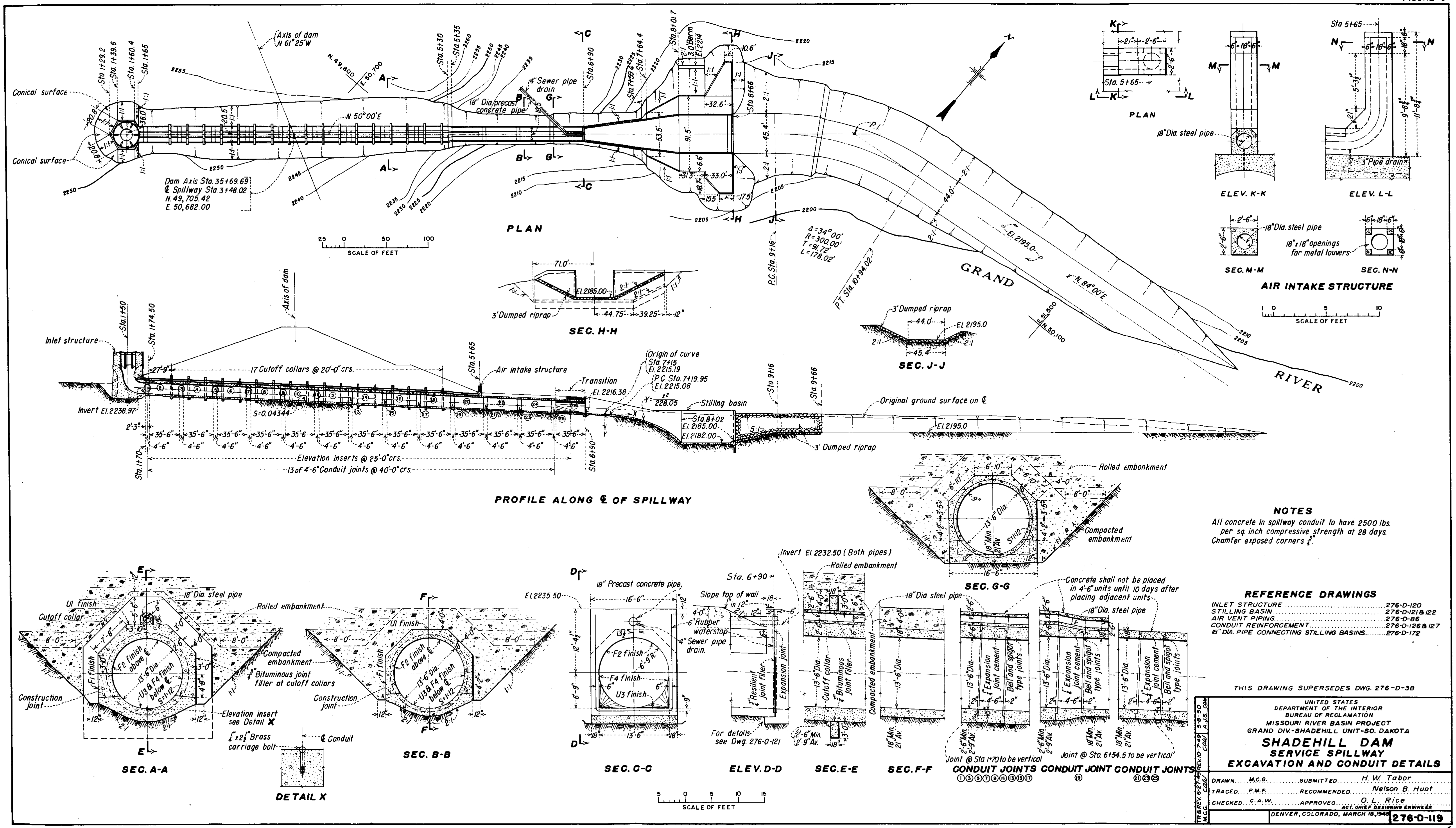
FIGURE I

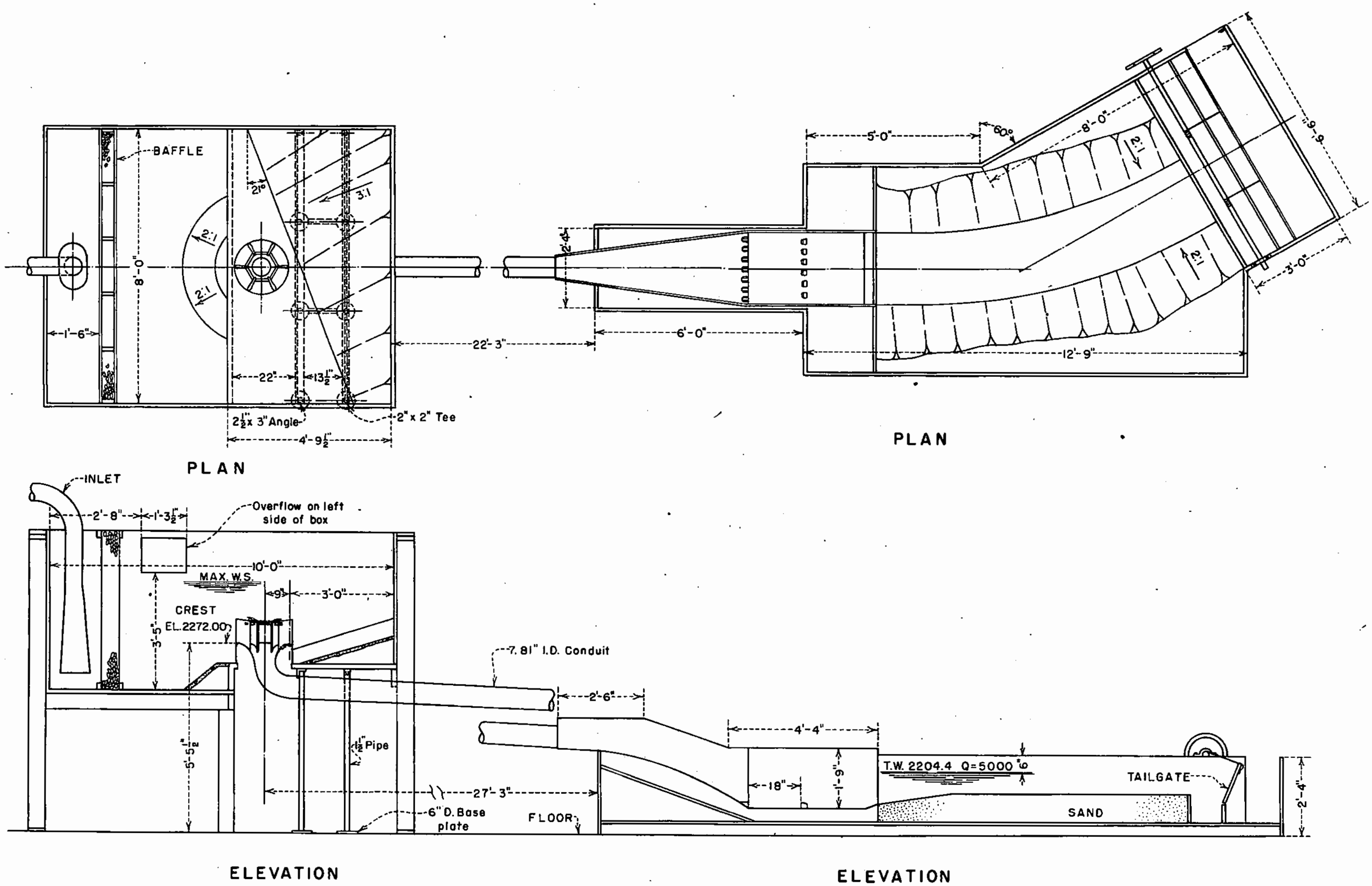


NORTH DAKOTA
DAWSON
GOLDEN VALLEY
BILLINGS
DUNN
MERCER
OLIVER
BURLEIGH
WIBAUX
STARK
MORTON
SLOPE
HETTINGER
GRANT
EMMONS
FALLON
BOWMAN
ADAMS
SIOUX
MONTANA
CARTER
HARDING
PERKINS
CORSON
DEWEY
BUTTE
ZIEBACH
ARMSTRONG
SOUTH DAKOTA
SULLY
CROOK
LAWRENCE
MEADE
HAAKON
STANLEY
PENNINGTON
JACKSON
JONES
WESTON
WYOMING
MONT.
WYO.
Beach
Medora
Belfield
DICKINSON
Richardton
Hebron
New Salem
BISMARCK
DICKINSON DAMSITE
HEART BUTTE DAM
New England
Amidon
Carson
Mott
Burt
Plevna
Baker
Marmarth
Rhame
Bowman
Scranton
Reeder
Hettinger
CANNONBALL DAMSITE
Selfridge
Lemmon
McIntosh
Walker
Mc Laughlin
Shadehill
SHADEHILL DAM
Access Road
Mobridge
Belltower
Buffalo
Meadow
Bison
Coal Springs
Timberlake
Glenncross
Firesteel
Isabel
Capitol
Redig
Albion
Mason
Hoover
BIXBY DAMSITE
Laplant
Ridgeview
Mud Butte
Maurine
Faith
Dupree
Eagle Butte
BELLE FOURCHE RES.
Newell
Nisland
Belle Fourche
Clough
Enning
White Owl
Spearfish
Whitewood
Sturgis
Lead
Deadwood
Hayes
PIERRE
Piedmont
Horton
RAPID CITY
Wall
Philip
Midland
Cottonwood
Missouri River
Little Missouri
Heart River
Cannonball River
Cedar Creek
North Fork
South Fork
GRAND RIVER
Moreau River
Belle Fourche
Cheyenne River
Bad River
MISSOURI RIVER
U.S. 10
U.S. 12
U.S. 85
U.S. 212
U.S. 14
U.S. 14-16
U.S. 16
U.S. 85A
N.D. 8
N.D. 21
N.D. 22
N.D. 31
N.D. 6
S.D. 8
S.D. 24
S.D. 65
S.D. 63
S.D. 73
N.P.
C.M. St. P.
C. & N.W.
VICINITY MAP
EXPLANATION
PAVED
IMPROVED
10 0 10 20 30 40
SCALE OF MILES
N
Glendive
Belfield
Terry
Marmarth
Carrington
Fargo
Jamestown
Fairmount
Ellendale
Mobridge
Grand Riv.
SHADEHILL DAM
Milbank
Redfield
Belle Fourche
Gillette
Deadwood
Rapid City
New Castle
Edgemont
Mitchell
Sioux Falls
NEBR.
INDEX MAP
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
GRAND RIVER UNIT- SOUTH DAKOTA
SHADEHILL DAM
LOCATION MAP
DRAWN: C.A.M.
SUBMITTED:
TRACED: B.F.W.
RECOMMENDED:
CHECKED:
APPROVED:
CHIEF ENGINEER
DENVER, COLORADO, JULY 30, 1948
276-D-26

FIGURE 2


PLAN
SCALE OF FEET
GRAND RIVER
Stilling basin
℄ Canal
4" Sewer pipe drain
18" Dia precast concrete pipe
8" Toe drain
12" Toe drain
15' Berm El 2240.0
15' Berm El 2270.0
Sta. 35+69.69 on axis of dam
Sta. 3+48.02 on ℄ spillway
N. 49,705.42
E. 50,681.99
Sta. 20+95.26
N. 49,000.00
E. 51,976.73
Sta. 20+65.0
Crest El 2318.0
Axis of dam N. 61° 25' W.
Hoist house
℄ Of outlet works
℄ Of service spillway
℄ Cutoff trench
El. 2270.0
20' Berm El 2250.0
Trashrock structure
Sta. 40+00.00
Reservoir area
PROFILE ON AXIS OF DAM
Max. W.S. El. 2312.0
Crest of dam El. 2318.0
Nor. W.S. El. 2272.0
Min. W.S. El. 2250.8
Outlet conduit
Service spillway conduit
Original ground surface
Final foundation
Assumed Lance formation
STATIONS
ELEVATION
PROFILE ALONG ℄ OF SERVICE SPILLWAY CONDUIT
℄ Spillway inlet Sta 1+50.00
Axis of dam
Crest El. 2318.0
Max W.S. El. 2312.0
Nor. W.S. El. 2272.0
Sta. 5+65
Air intake structure
Discharge at Max W.S. El – Q = 123,000 cfs.
(Service spillway Max. Q = 5,700 cfs.)
(Emergency spillway Max Q = 117,300 cfs.)
Invert El. 2238.97
13'-6" Dia circular conduit
S = 0.04344
El. 2216.38
Stilling basin
Sta. 9+16
Sta. 9+66
Original ground surface
Sta. 8+02
El. 2182.0
Q = 5000 cfs.
T.W. El. 2204.4
3' Dumped riprap
Sta. 6+90
PROFILE ALONG ℄ OF OUTLET CONDUIT
Hoist house
Axis of dam
Crest El. 2318.0
Original ground surface
Max W.S. El. 2312.0
Trashrock structure
6'-0" x 6'-0" Cl. Slide gate
6'-0" x 6'-0" Radial gate
Nor. W.S. El. 2272.0
Invert El. 2250.8
Inlet channel El. 2249.5
El. 2250.3
Stilling basin
Canal
7'-0" Circular conduit
7'-3" Conduit
Gate structure
Sta. 3+69.70
Sta. 4+20.31
El. 2247.5
MAXIMUM SECTION
Max. W.S. El. 2312.0
Nor. W.S. El. 2272.0
Min. W.S. El. 2250.8
24" Riprap
3' Riprap
Key for riprap
Sand and gravel
6' Sand and gravel
℄ Cutoff trench
Seeding on 12" topsoil
El. 2270.0
El. 2240.0
Original ground surface
Assumed Lance formation
Embankment toe drain
Remove vegetation, humus and other objectional material as directed
Disposal Zone A
EMBANKMENT EXPLANATION
(1) Impervious material of selected clay, sand, and gravel increasing in permeability toward outer slopes, compacted to 6-inch layers.
(2) Pervious material of selected sand, gravel, and rock increasing in coarseness toward outer slopes, compacted to 6-inch layers.
Disposal Zone A - Selected material from excavation for service spillway, outlet works and dam foundation between Sta. 20+40 and Sta. 40+00.
EMBANKMENT TOE DRAIN
Screened gravel
Sewer pipe laid with open joints
CREST DETAILS
24" Riprap
3" Crown
24" Selected gravelly material
4' Sand and gravel
Seeding on 12" topsoil
SPILLWAY CONDUIT
TYPICAL 13'-6" DIA. SECTION
Rolled embankment
Compacted embankment
30" From Sta. 1+70 to Sta. 5+30 and 18" from Sta. 5+35 to Sta. 6+90
Cutoff collar
SPILLWAY
SECTION A-A
El. 2185.0
3' Dumped riprap
OUTLET CONDUIT
TYPICAL 7'-0" DIA. SECTION
84" Dia plate steel conduit liner
OUTLET CONDUIT
TYPICAL 7'-3" SECTION
AREA-CAPACITY-DISCHARGE CURVES
RESERVOIR AREA IN THOUSANDS OF ACRES
RESERVOIR CAPACITY IN THOUSANDS OF ACRE FEET
OUTLET DISCHARGE IN C.F.S.
SERVICE SPILLWAY DISCHARGE AND COMBINED DISCHARGE OF SERVICE AND EMERGENCY SPILLWAYS IN THOUSANDS OF C.F.S.
Service spillway discharge
Combined discharge of service and emergency spillways
Reservoir area
Reservoir capacity
Outlet discharge
RECORD DRAWING
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI BASIN PROJECT
GRAND RIVER UNIT - SOUTH DAKOTA
SHADEHILL DAM
PLAN AND SECTIONS
DENVER, COLORADO, JULY 30, 1948
SHEET 2 OF 2
276-D-37

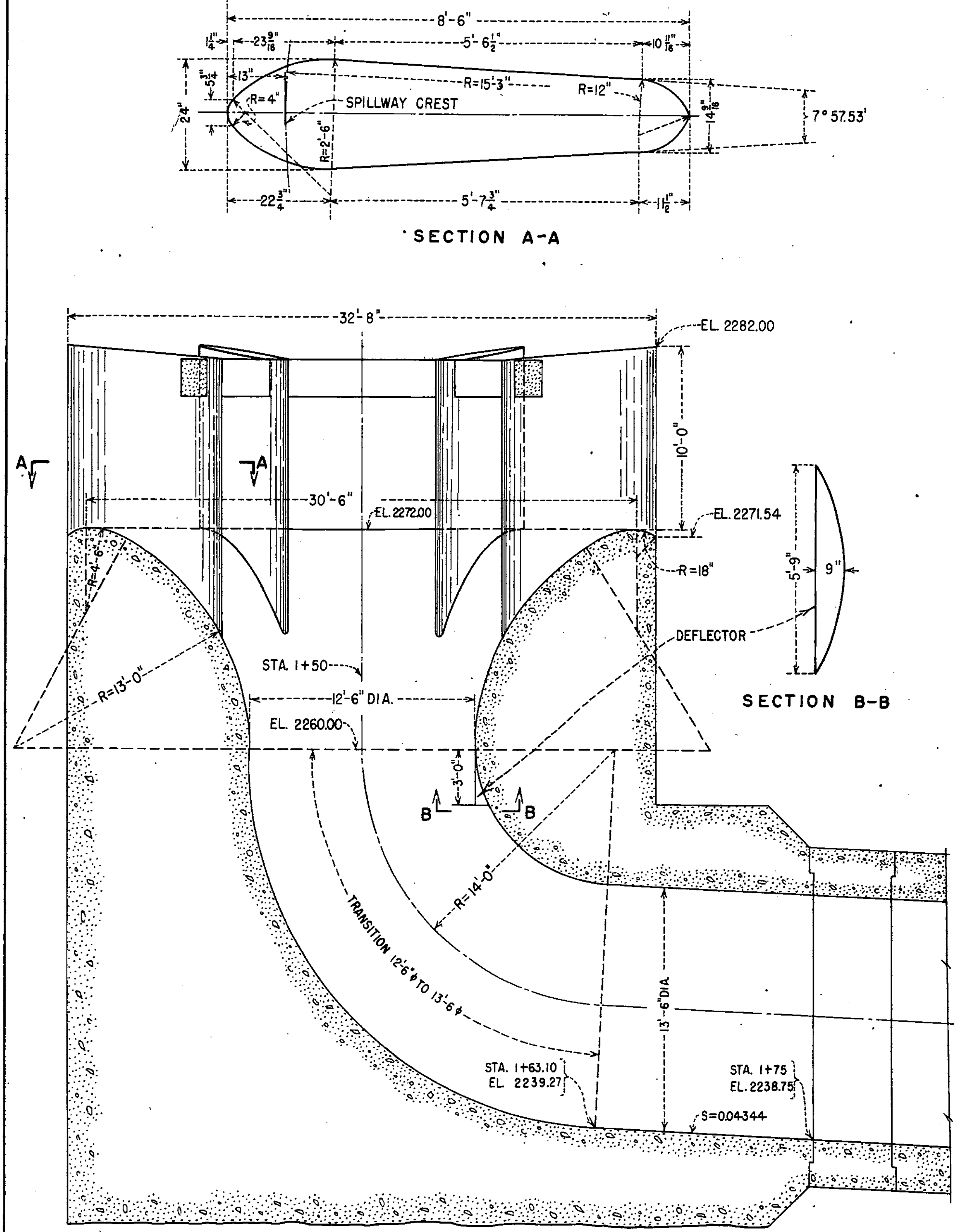

PLAN
SCALE OF FEET
Axis of dam N 61°25'W
Conical surface
Dam Axis Sta. 35+69.69
℄ Spillway Sta. 3+48.02
N. 49,705.42
E. 50,682.00
4" Sewer pipe drain
18" Dia. precast concrete pipe
Δ = 34°00'
R = 300.00'
T = 91.72'
L = 178.02'
P.C. Sta. 9+16
P.T. Sta. 10+94.02
GRAND
RIVER
AIR INTAKE STRUCTURE
ELEV. K-K
ELEV. L-L
SEC. M-M
SEC. N-N
18" Dia. steel pipe
18" x 18" openings for metal louvers
3" Pipe drain
SEC. H-H
SEC. J-J
3' Dumped riprap
PROFILE ALONG ℄ OF SPILLWAY
Inlet structure
Air intake structure
17 Cutoff collars @ 20'-0" crs.
Transition
Stilling basin
Original ground surface on ℄
Elevation inserts @ 25'-0" crs.
13 of 4'-6" Conduit joints @ 40'-0" crs.
Invert El. 2238.97
S = 0.04344
SEC. G-G
Rolled embankment
Compacted embankment
NOTES
All concrete in spillway conduit to have 2500 lbs. per sq. inch compressive strength at 28 days. Chamfer exposed corners ¾".
REFERENCE DRAWINGS
INLET STRUCTURE 276-D-120
STILLING BASIN .... 276-D-121 & 122
AIR VENT PIPING 276-D-86
CONDUIT REINFORCEMENT .... 276-D-126 & 127
18" DIA. PIPE CONNECTING STILLING BASINS 276-D-172
SEC. A-A
DETAIL X
SEC. B-B
SEC. C-C
ELEV. D-D
SEC. E-E
SEC. F-F
CONDUIT JOINTS
CONDUIT JOINT
CONDUIT JOINTS
Joint @ Sta. 1+70 to be vertical
Joint @ Sta. 6+54.5 to be vertical
Concrete shall not be placed in 4'-6" units until 10 days after placing adjacent units
Invert El. 2232.50 (Both pipes)
For details see Dwg. 276-D-121
THIS DRAWING SUPERSEDES DWG. 276-D-38
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
GRAND DIV.-SHADEHILL UNIT-SO. DAKOTA
SHADEHILL DAM
SERVICE SPILLWAY
EXCAVATION AND CONDUIT DETAILS
DRAWN M.C.G. SUBMITTED H. W. Tabor
TRACED P.M.F. RECOMMENDED Nelson B. Hunt
CHECKED C.A.W. APPROVED O. L. Rice
ACT. CHIEF DESIGNING ENGINEER
DENVER, COLORADO, MARCH 18, 1949
276-D-119



SHADEHILL DAM
SERVICE SPILLWAY MODEL
1:20.732 SCALE MODEL

FIGURE 4

FIGURE 5

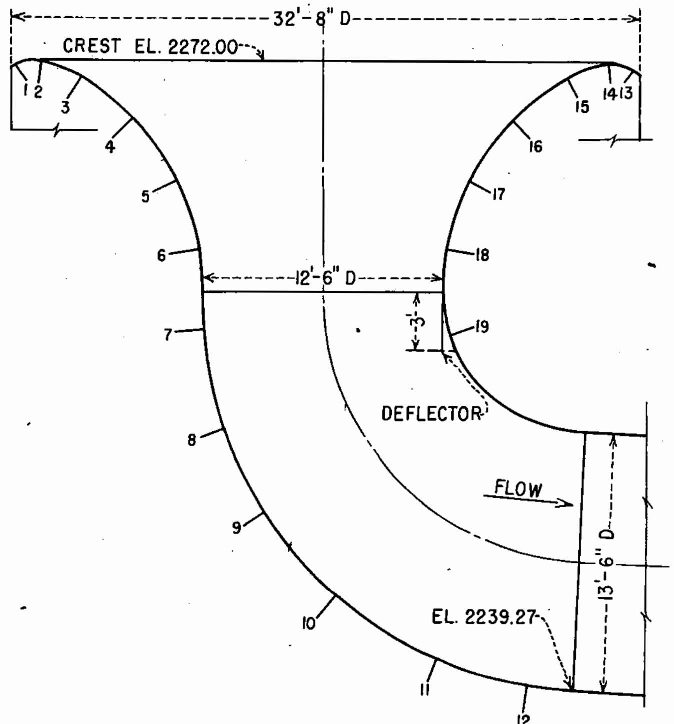


SHADEHILL DAM

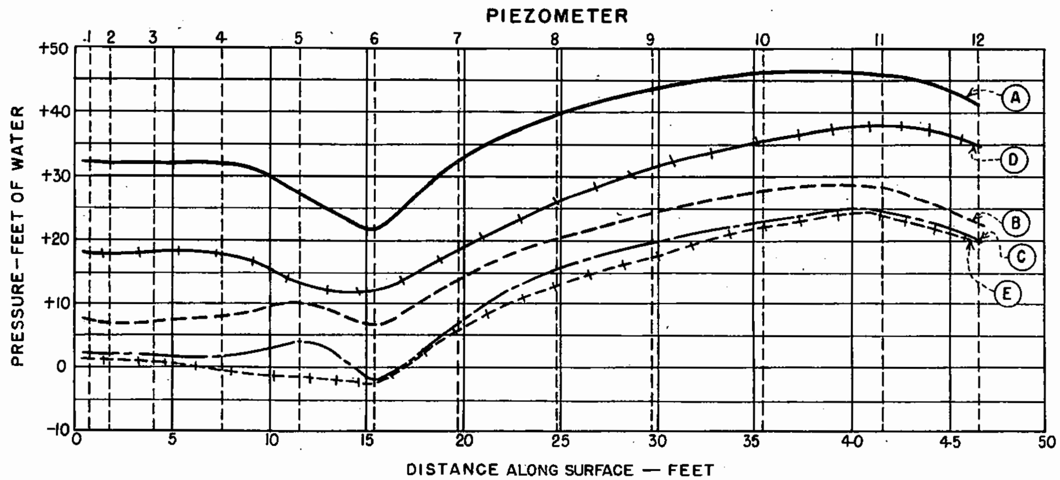
SERVICE SPILLWAY ENTRANCE

PRELIMINARY

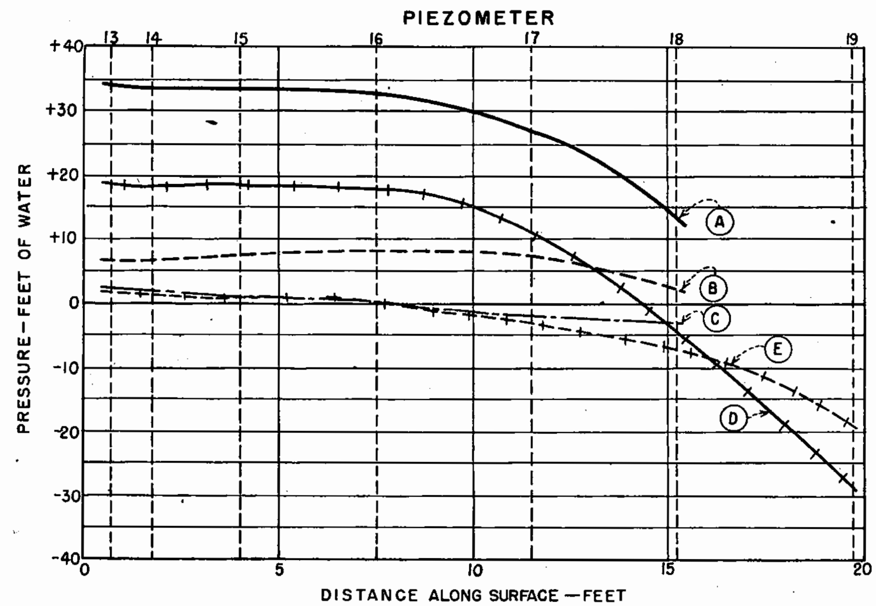
LINE	SYMBOL	RESERVOIR ELEVATION	DISCHARGE SEC.-FT.	REMARKS
(A)	———	2306.0	4980	
(B)	– – –	2280.0	3550	DEFLECTOR IN PLACE
(C)	—·—·—	2276.6	2950	
(D)	+++	2291.0	4980	DEFLECTOR REMOVED & TUNNEL RUNNING FULL
(E)	-+-+	2276.6	3550	



SECTION
SHOWING PIEZOMETER LOCATION



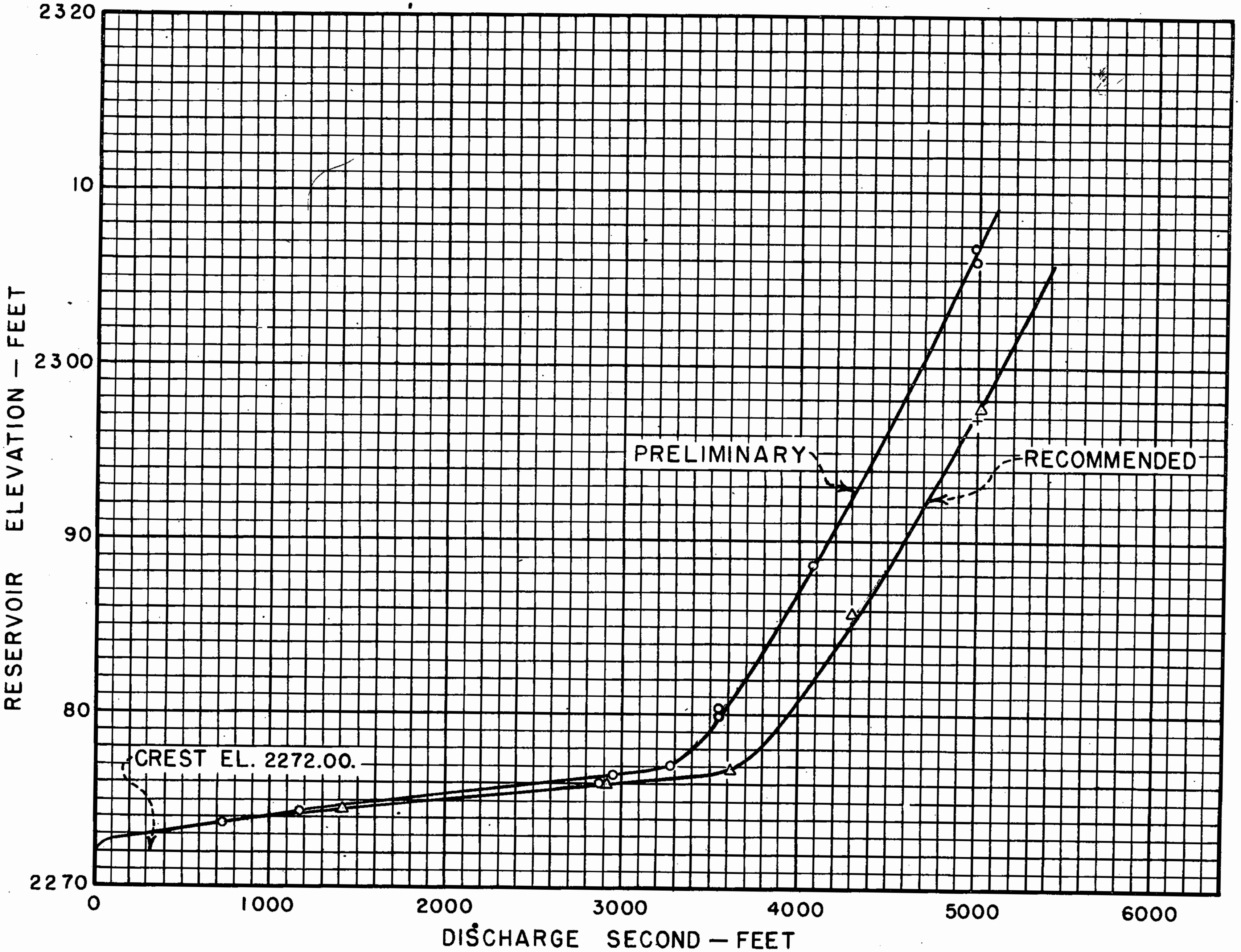
PRESSURES ALONG UPSTREAM CURVE



PRESSURES ALONG DOWNSTREAM CURVE

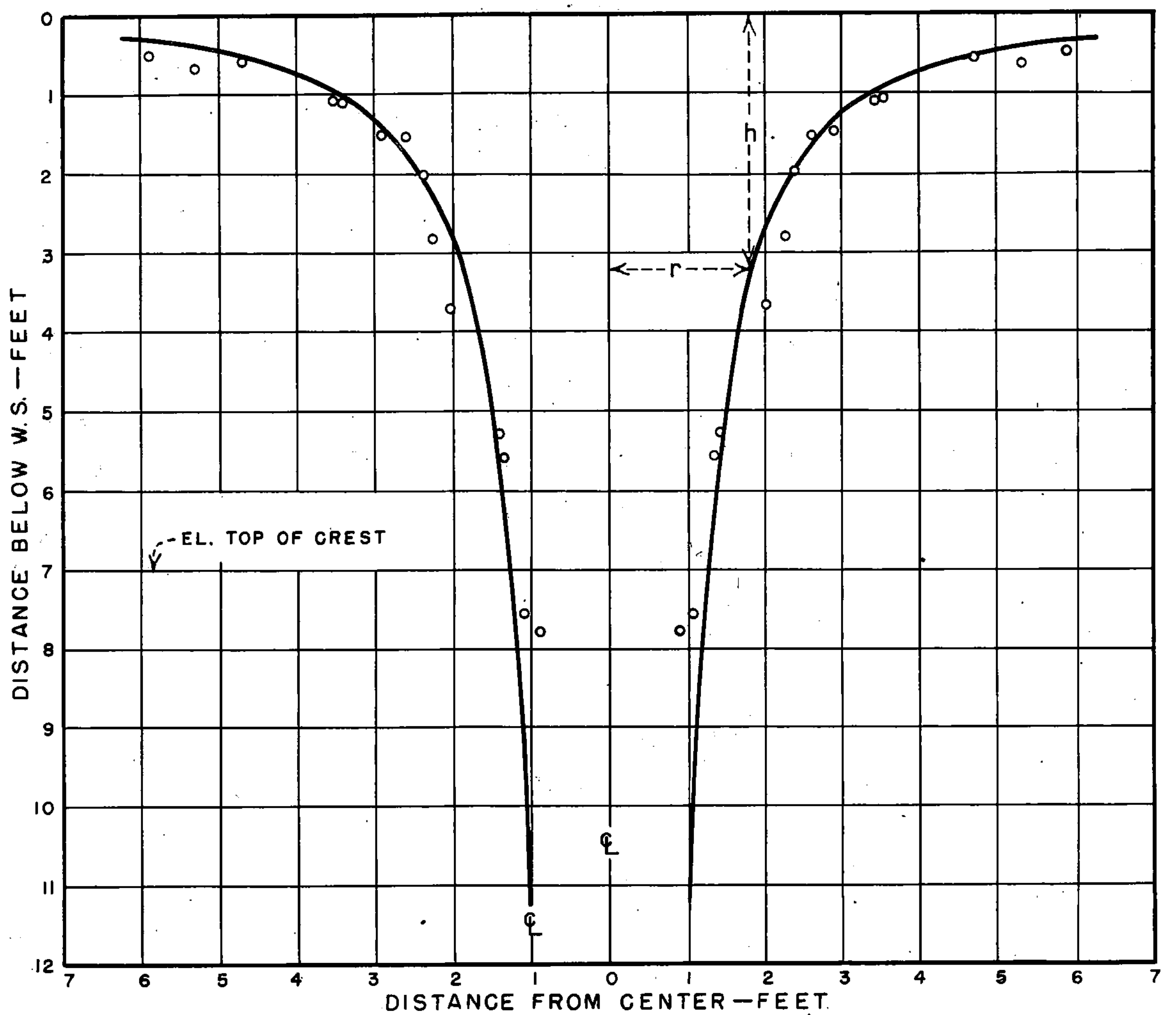
SHADEHILL DAM
SERVICE SPILLWAY
PRESSURES IN ENTRANCE AND ELBOW
PRELIMINARY

FIGURE 6



SHADEHILL DAM SPILLWAY
DISCHARGE CAPACITY CURVES

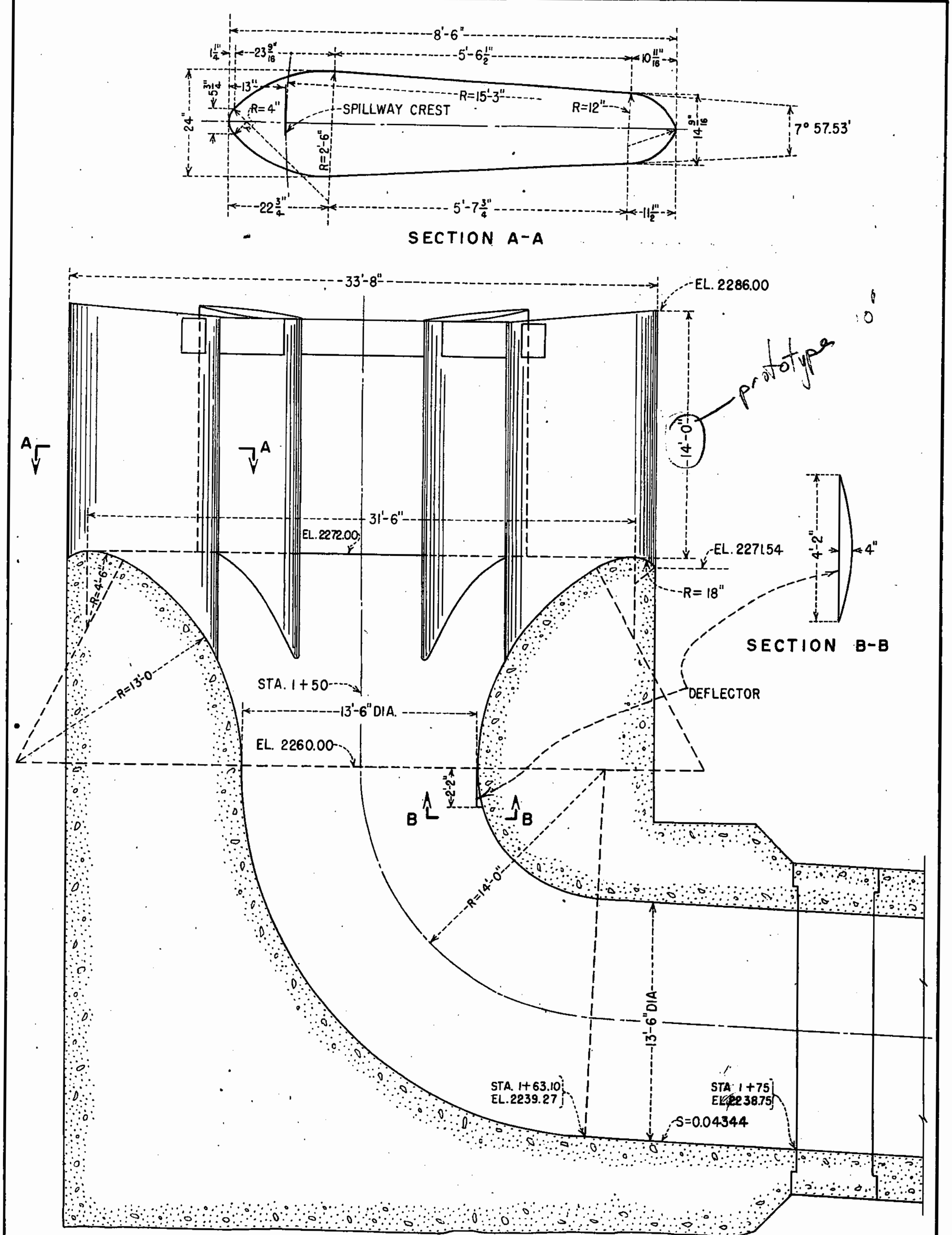
FIGURE 7



VORTEX CROSS SECTION

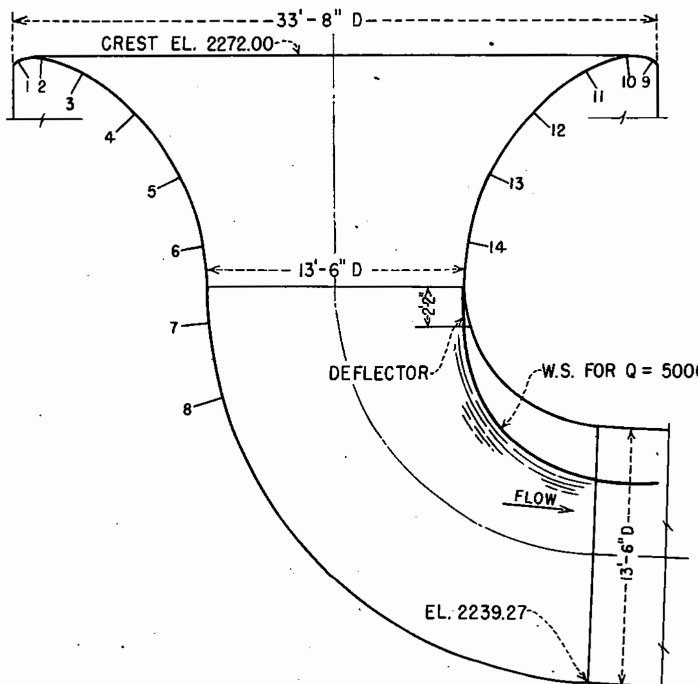
—o— MEASUREMENT IN MODEL WITH RESERVOIR ELEVATION 2279 AND PIERS REMOVED, $hr^2 = 11.3$

SHADEHILL DAM
VORTEX OVER SPILLWAY
ENTRANCE

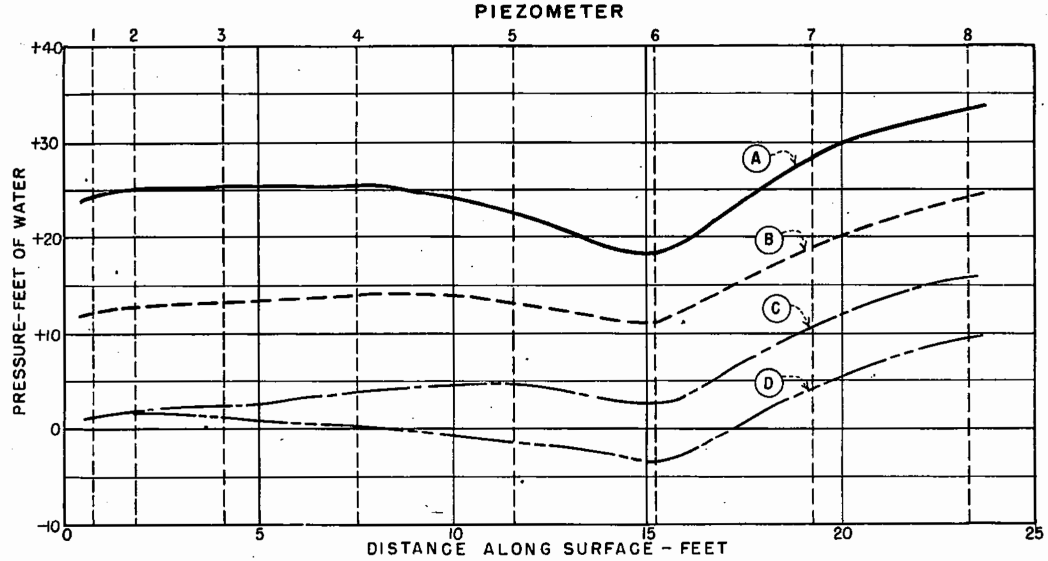


SHADEHILL DAM
SERVICE SPILLWAY ENTRANCE
RECOMMENDED

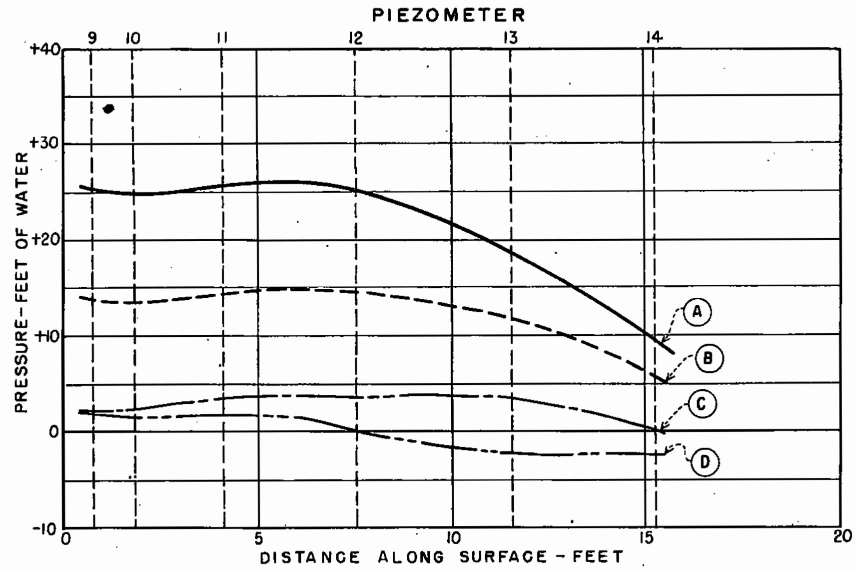
LINE	SYMBOL	RESERVOIR ELEVATION	DISCHARGE SEC.-FT.
A	———	2297.6	5010
B	— — —	2285.8	4305
C	—·—·—	2276.8	3610
D	—··—··	2276.0	2915



SECTION
SHOWING PIEZOMETER LOCATION



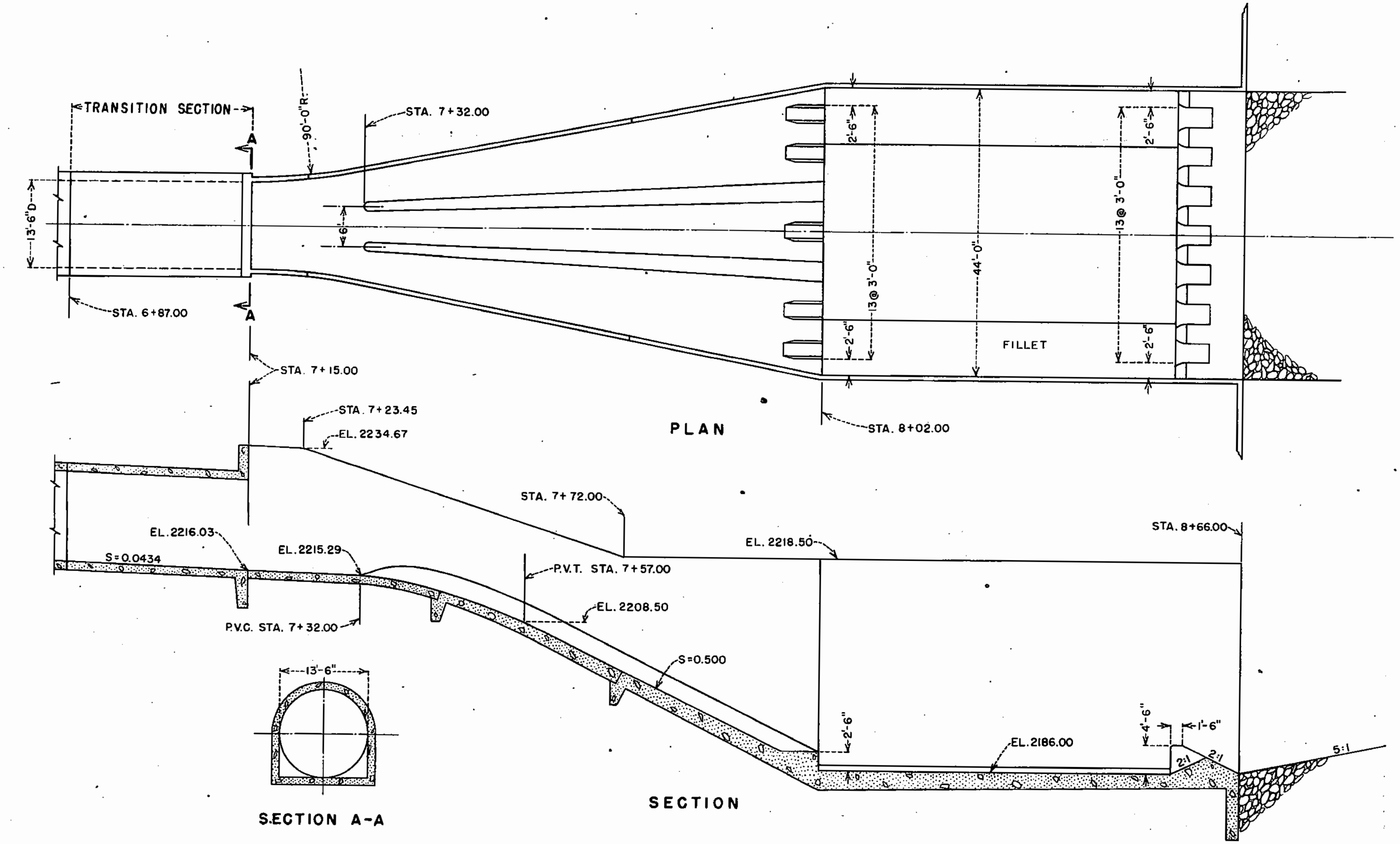
PRESSURES ALONG UPSTREAM CURVE



PRESSURES ALONG DOWNSTREAM CURVE

SHADEHILL DAM
SERVICE SPILLWAY
PRESSURES IN ENTRANCE AND ELBOW
RECOMMENDED

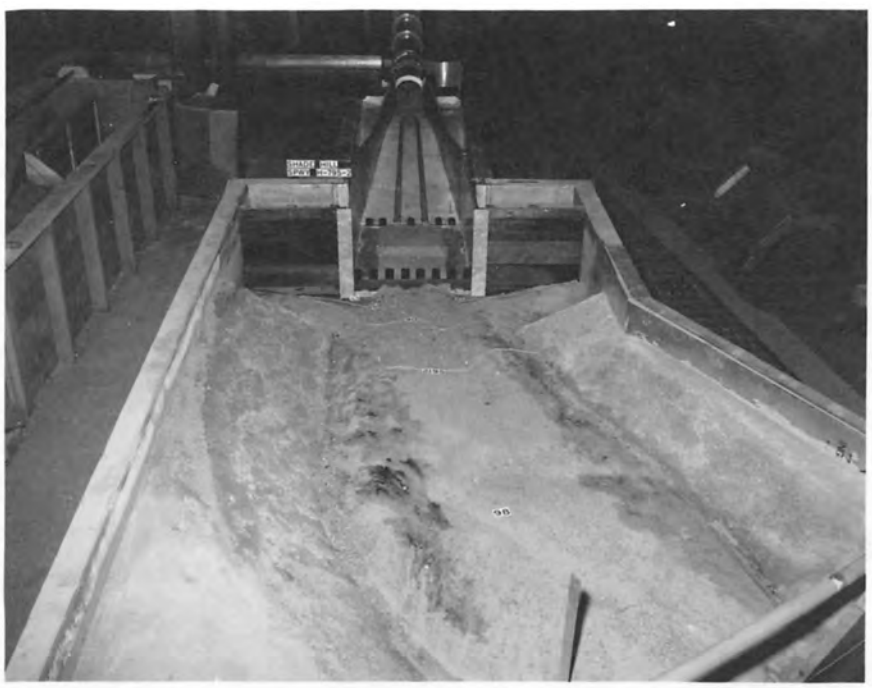
FIGURE 10



SHADEHILL DAM
SERVICE SPILLWAY SPILLING BASIN
PRELIMINARY

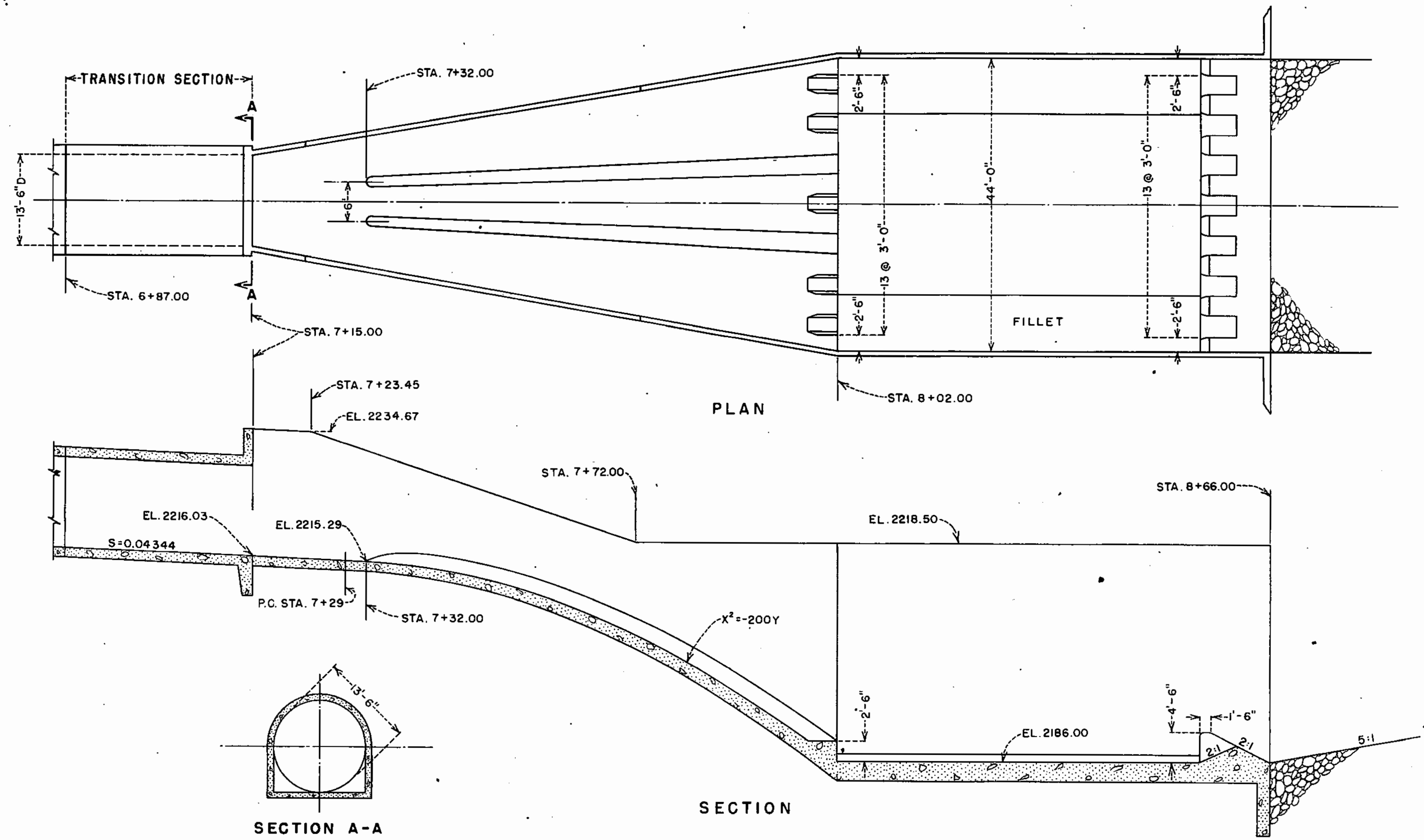
FIGURE 11

A. Operation at 5,000 second-feet
Tailwater elevation 2204.5



B. Scour after 1 hour at 5,000 second-feet
Tailwater elevation 2204.5

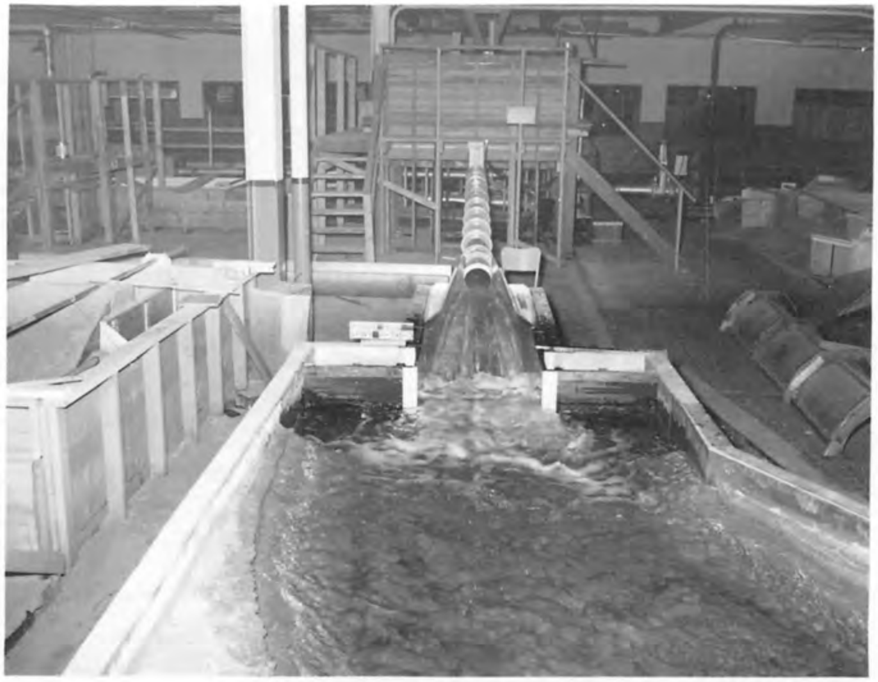
SHADEHILL DAM
Service Spillway
Preliminary Stilling Basin



SHADEHILL DAM

SERVICE SPILLWAY SPILLING BASIN No. 2

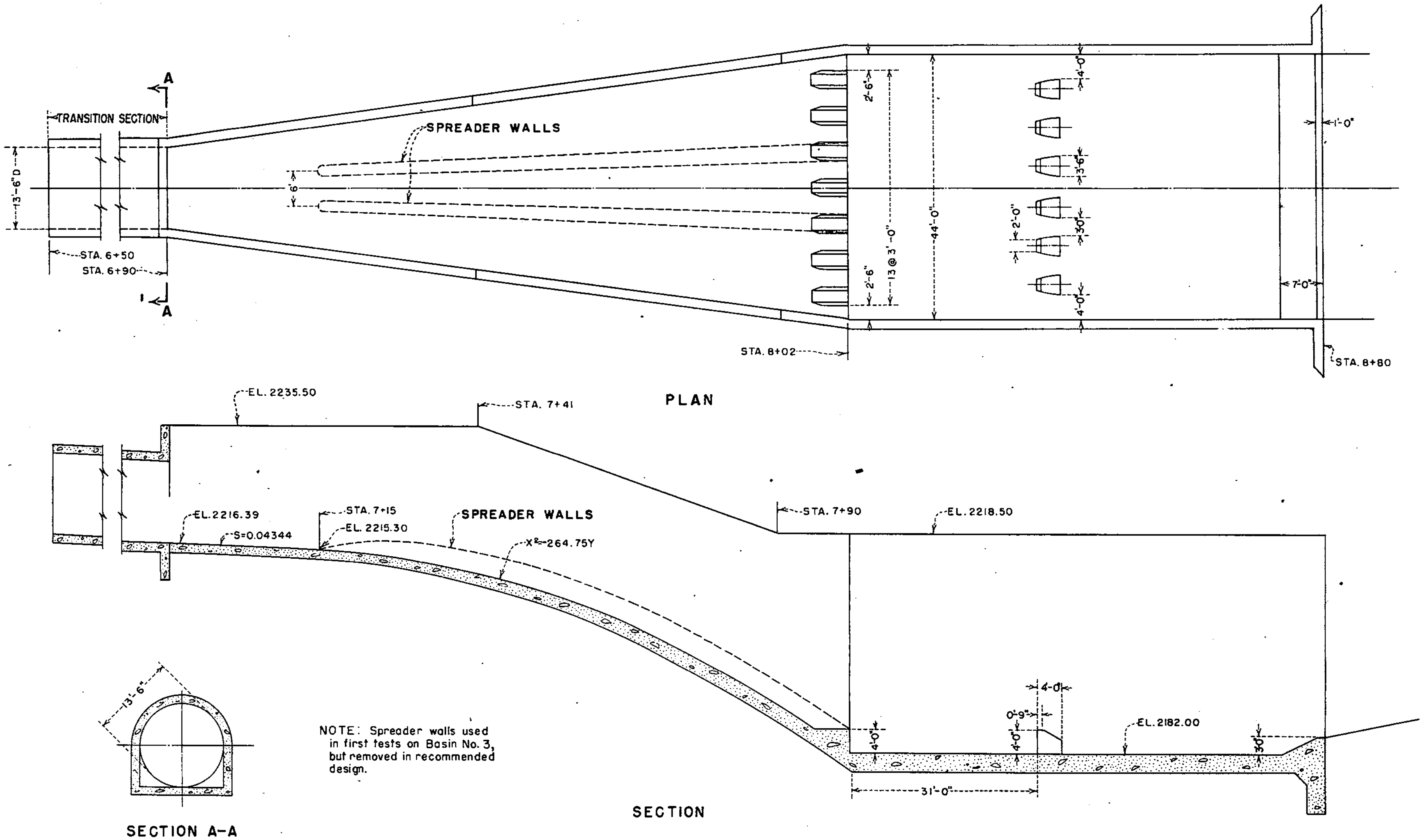
FIGURE 13



A. Operation at 5,000 second-feet
Tailwater elevation 2204.5

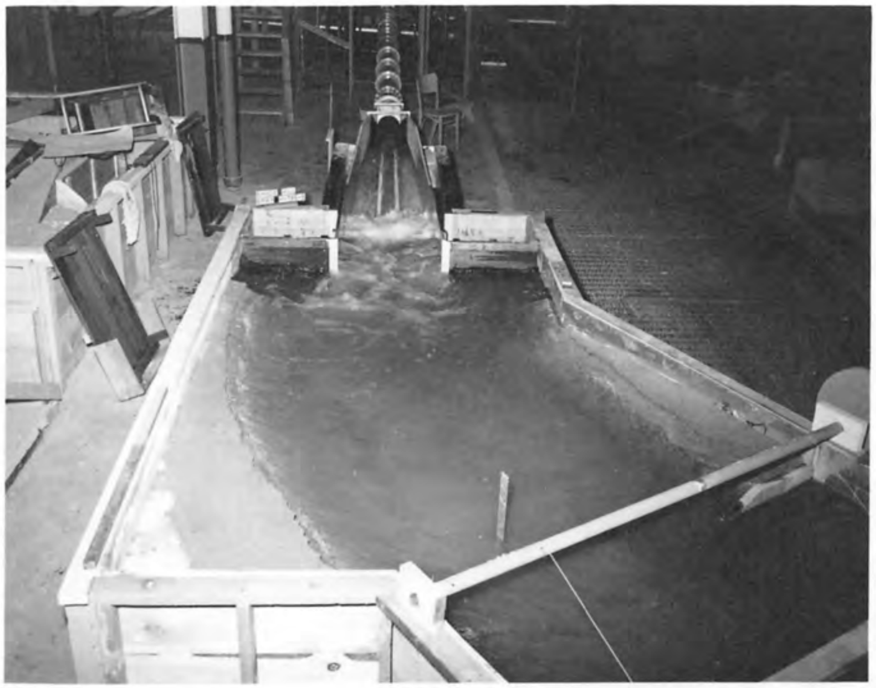
B. Scour after 1 hour at 5,000 second-feet
Tailwater elevation 2204.5

SHADEHILL DAM
Service Spillway Stilling Basin No. 2



SHADEHILL DAM
SERVICE SPILLWAY STILLING BASIN
No. 3-RECOMMENDED

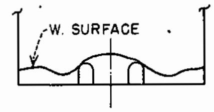
FIGURE 15



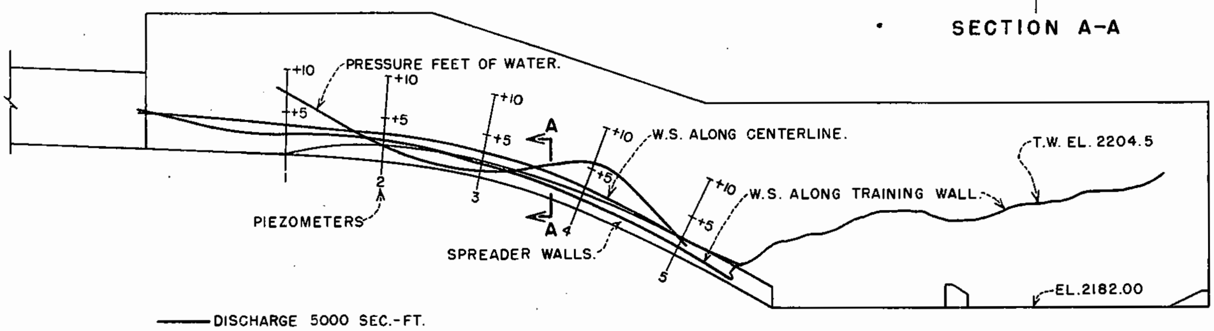
A. Operation at 5,000 second-feet
Tailwater elevation 2204.5

B. Scour after 1 hour at 5,000 second-feet
Tailwater elevation 2204.5

SHADEHILL DAM
Service Spillway Stilling Basin No. 3
With Spreader Walls

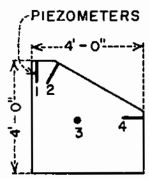


SECTION A-A

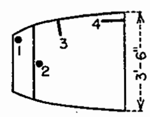


ELEVATION

WATER SURFACE PROFILES AND PRESSURES
SPREADER WALLS INSTALLED



ELEVATION

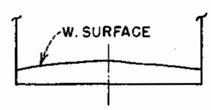


PLAN

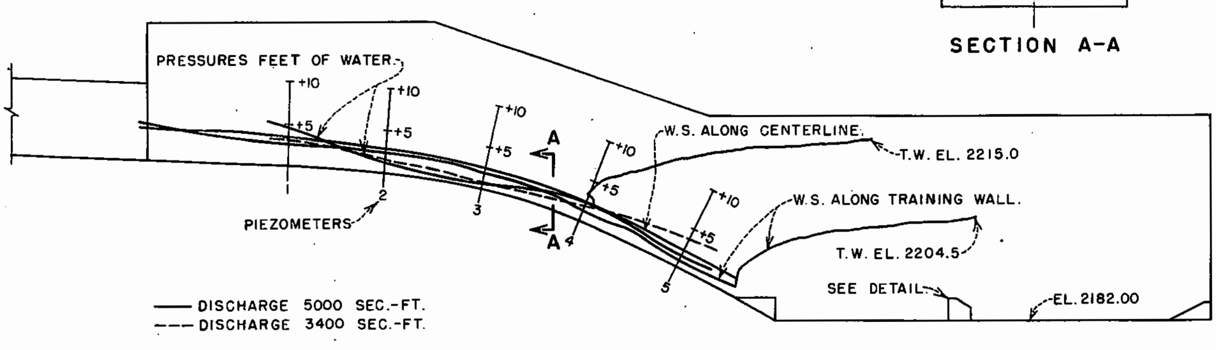
BAFFLE PIER DETAIL

PIEZOMETER	PRESSURE FEET OF WATER	DISCHARGE SEC.-FT.	TAILWATER ELEVATION
1	+7.2'	5000	2204.5
2	+6.5'	5000	2204.5
3	+7.8'	5000	2204.5
4	+7.0'	5000	2204.5
1	+11.5	3400	2202.0
2	+10.5	3400	2202.0
3	+10.5	3400	2202.0
4	+7.8	3400	2202.0

PRESSURES
ON BAFFLE PIER



SECTION A-A



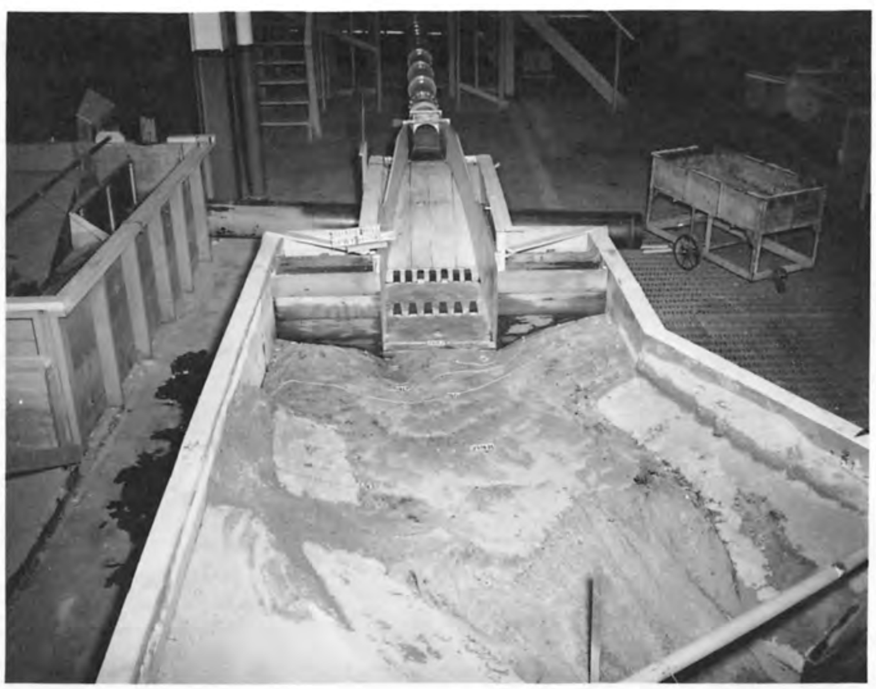
ELEVATION

WATER SURFACE PROFILES AND PRESSURES
NO SPREAD WALLS — RECOMENDED

SHADEHILL DAM
SERVICE SPILLWAY STILLING BASIN No. 3

Interior - Reclamation - Denver, Colo.

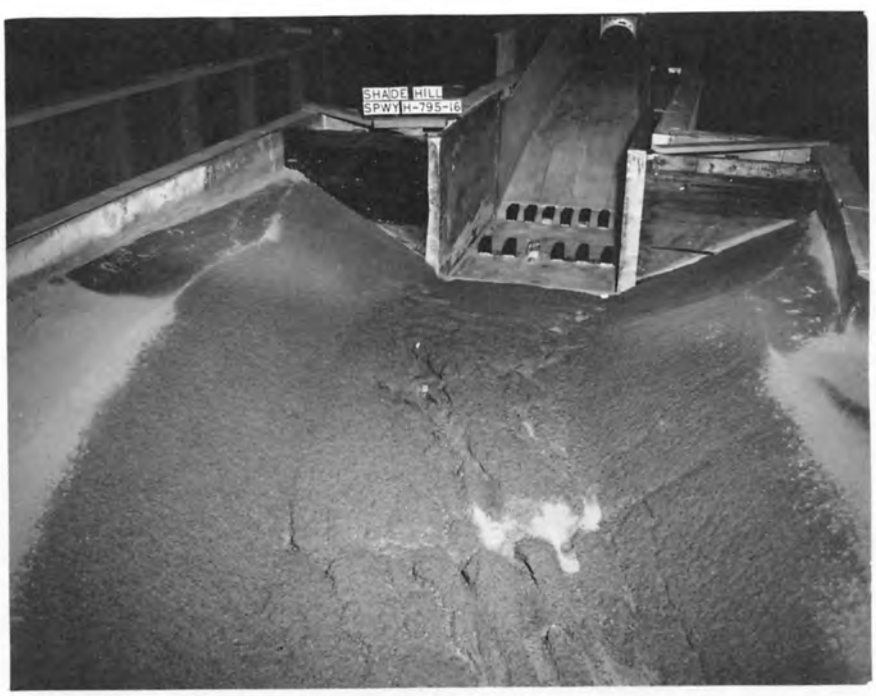
A. Operation at 5,000 second-feet
Tailwater elevation 2204.5



B. Scour after 1 hour at 5,000 second-feet
Tailwater elevation 2204.5

SHADEHILL DAM
Service Spillway Stilling Basin No. 3
Without Spreader Walls--Recommended

A. Scour after 7 hours at 5,000 second-feet
with stabilized sand-overall view
Tailwater elevation 2204.5



B. Scour after 7 hours at 5,000 second-feet
with stabilized sand--closeup view

SHADEHILL DAM
Service Spillway Stilling Basin No. 3
Without Spreader Walls--Recommended