UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE FOSS DAM RIVER OUTLET WORKS STILLING BASIN FOSS DIVISION--WASHITA BASIN PROJECT--OKLAHOMA

Hydraulic Laboratory Report No. Hyd-466

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

August 23, 1960

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Subject: Hydraulic model studies of the Foss Dam River Outlet Works Stilling Basin--Foss Division--Washita Basin Project, Oklahoma

PURPOSE OF THE STUDY

This study was made to determine a design for the Foss Dam River Outlet Works stilling basin which would maintain the hydraulic jump within the basin between two extremes of tail-water elevations: a relatively high tailwater expected during initial operation, and a 15-foot lower tailwater anticipated after seventy-three years degradation of the riverbed downstream from the basin.

CONCLUSIONS

1. A floor 1 foot higher at the center than at the walls of the tunnel (Figure 14) improved the flow distribution in the tunnel during 1-gate operation. For normal 2-gate operation, this ridge decreased the tendency for the flow to concentrate in the center of the chute and basin.

2. The pressures on the parabolic chute floor are satisfactory throughout the full range of discharges and tail-water elevations. A minimum pressure of about 1-1/2 feet below atmospheric (Figure 5 B) was recorded for the maximum discharge and low tail water.

3. Conjugate depth control piers are required to maintain the hydraulic jump in the stilling basin at low tail water. The control piers shown in Figure 14 will maintain a good jump in the basin for any discharge throughout the full range of anticipated tail-water elevations.

4. Baffle piers 7-feet high placed 23-feet downstream from the chute blocks (Figure 14) will stabilize the hydraulic jump.

5. A level apron downstream from the conjugate depth control piers (Figure 14) is an improvement over the sloping apron of the preliminary design. The level apron presents a larger flow area, and consequently lower velocities and less tendency to scour where the stream enters the unlined canal.

6. Three flow spreaders on the apron (Figure 14) distribute the flow uniformly across the basin exit during outlet works releases with low-tail water.

7. An end sill as shown in Figure 14 will aid in preventing scour at the downstream end of the apron.

8. The outlet works stilling basin arrangement as shown in Figure 14 will adequately handle the maximum outlet works discharge at maximum tail water or at any lowered tail water.

INTRODUCTION

Foss Dam on the Washita River, about 12 miles west of Clinton, Oklahoma, (Figure 1), is an earthfill structure about 18,000 feet long, 152 feet high above the foundation trenches, and has a crest at elevation 1697.0. The river outlet works and the spillway are located at the right abutment of the dam; the canal outlet works and the municipal outlet works are located 525 feet to the left in the river outlet works. This model study was initiated primarily to investigate the river outlet works stilling basin.

The flow passage for the river outlet works consists of an intake structure, 312-feet of 11-foot-diameter conduit to the gate chamber, two 6- by 7-foot 6-inch high pressure control gates with two guard gates the same size in the control structure, and a single 13-1/2-foot high by 15-foot wide modified horseshoe conduit extending 295.3 feet from the gate chamber to the stilling basin. The outlet works discharge channel joins the spillway channel about 150 feet downstream from the outlet works stilling basin. (Figure 2)

The river outlet works is capable of discharging about 3,500 cfs at normal reservoir elevation 1652.0, and about 3860 cfs at reservoir elevation 1668.6, the elevation of the spillway crest. The river outlet works will operate simultaneously with the spillway during flood releases to handle the maximum design flood of 7,460 cfs at reservoir elevation 1691.0 with 3,050 cfs released through the spillway and the remainder, 4,410 cfs, through the river outlet works.

The riverbed downstream from Foss Dam consists of fine sand and clay. Clear water releases from the reservoir is expected to move large quantities of this fine material. The resulting degradation of the river channel is expected to lower the tail-water elevation for the spillway and the river outlet works as much as 15 feet. This model study was made to develop a stilling basin which would:

1. Provide adequate stilling action for the maximum river outlet works release of 4,410 cfs at high tail-water elevation 1581.3, without overtopping the training wall.

2. Retain an adequate hydraulic jump in the stilling basin after river degradation lowers the tail water as much as 15 feet, and,

3. Keep the scour at the downstream end of the stilling basin to a minimum to prevent undercutting and endangering the structure.

The design of the outlet works control structure was not a part of this study.

The spillway stilling basin will be identical to the outlet works stilling basin, and at the same elevation (Figure 2). Although there is a slightly different approach to the two basins, it was felt that since the spillway will discharge only about 41 percent of the maximum design flood, the stilling basin design proven satisfactory for the outlet works will be satisfactory for the spillway.

THE INVESTIGATION

The Model

The 1:15 scale model (Figure 3) included a simplified control chamber to simulate prototype discharges, the horseshoe tunnel without the tunnel roof, the stilling basin, and a tail box 10 feet wide and 16 feet long which contained an erodible sand bed, a tail-water control gate, and a sand trap. The 6- by 7-foot 6-inch control gates were not included in the model because no hydraulic problems are anticipated in this portion of the structure. Instead, streamlined-control gates were used in the model to provide the proper depth and distribution of flow for 1 or 2-gate operation at the entrance to the modified horseshoe tunnel. It was felt that the development of a basin which would operate satisfactorily over the large range of predicted tail-water elevations would be accomplished by progressive model changes, therefore, no attempt was made to incorporate conjugate depth control features in the preliminary design.

Principal prototype dimensions of the preliminary stilling basin included the following:

The floor of the modified horseshoe tunnel was flat in cross section and on a longitudinal slope of $S = 0.02$. The chute floor followed the parabola, $X^2 = -181.779y$, from elevation 1568.25 at the end of the horseshoe tunnel to elevation 1557.54 at the basin floor. The basin floor was level for 76 feet, then sloped upward to elevation 1565 in 29.9 feet. The walls of the basin diverged from 15 feet apart at the end of the horseshoe tunnel to the 25-foot width of the basin at the end of the chute, were parallel through the 95-foot basin, and then diverged to a spacing of 43 feet at the end of the upward sloping apron. The design basin included 4 chute blocks and 3 baffle piers. The prototype dimensions were reduced by the factor of 1:15 in constructing the model.

Instrumentation included a point gage for tail-water elevation measurements, the laboratory venturi meters for discharge determinations, and a manometer board for determining the pressures at eight piezometer taps along the center line of the parabolic chute floor.

Preliminary Basin Operation

The preliminary basin was operated over a large range of discharges and tail-water elevations. For two-gate operation the jet was not uniformly distributed across the chute, having more water at the chute center line than near the sides. This caused the jump roller to build up in the center of the basin and oscillate from side-to-side. Figure 4 shows the preliminary basin arrangement dry, and with a discharge of 3,860 cfs. Note the jet concentration at the chute center line and the roll buildup at the left training wall in Figure 4B. For one-gate operation with maximum reservoir, the stream crossed to the opposite side of the tunnel, then back across the tunnel to concentrate on the side wall of the chute and create a rough jump in the basin.

Horseshoe Tunnel Floor

Previous experience has shown that raising the tunnel floor along the center line and sloping it downward to the walls will aid in distributing the flow for one gate operation in a two-gate system. It appeared that such a design would also be beneficial in producing a more uniform flow at the chute for two-gate operation. Therefore, the tunnel floor was sloped downward to the walls from a 1-foot rise at the tunnel center line. This change produced the desired effect and was incorporated in the recommended design (Figure 14).

Chute Floor Pressures

The pressures on the preliminary design chute floor (with the revised tunnel floor) were satisfactory for all heads and discharges (Figures 5A and 5B). The lowest pressure recorded was about 1-1/2 feet of water below atmospheric when the system was discharging 4,410 cfs under a head of 120 feet. The chute with the floor following the parabola, $X^2 = -181.779y$, was retained for the recommended design.

Basin Sweepout and Predicted Degradation

Studies were made to determine the sweepout characteristics of the preliminary stilling basin for a range of discharges. Results of these studies are shown in Figure 6, where the sweepout curve is plotted for comparison with the computed tail water elevations versus river discharge for both the present river conditions and after degradation has taken place. These results show that the hydraulic jump will remain in the basin for all discharges with the relatively high tail water predicted for the present river condition. However, at a discharge of 4,000 cfs, with the tail water lowered one foot, the hydraulic jump swept from the outlet works stilling basin. The need for some type of conjugate depth control to force the hydraulic jump to remain in the basin after a few years degradation was evident.

Baffle Piers

During the tests concerning the conjugate depth control piers (discussed in the following section of this report) it was noted that the hydraulic jump was rough, with distinct side-to-side oscillation, in the vicinity of the baffle piers. To minimize this tendency and stabilize the jump, the 4.5-foot high baffle piers were increased in height to 7 feet. The pier width and spacing of the preliminary design was retained. This modification stabilized and improved the appearance of the jump when used in conjunction with conjugate depth control piers. The 7-foot high baffle piers are recommended, Figure 14. Subsequent tests with the conjugate depth control piers disclosed that the upstream face of the baffle piers should be placed 23 feet downstream from the chute blocks for optimum operation.

Conjugate Depth Control Piers

With the velocities and depth expected for the river outlet works at Foss Dam, the computed length of a Type III stilling basin is 84 feet. The length for the preliminary design basin was 125 feet in anticipation that some type of conjugate depth control appurtenance would be installed about 85 feet from the beginning of the basin. The extra basin length would provide a concrete-lined flow passage downstream from the control for protection of the structure. Design required that the maximum expected flood would not overtop the training walls when the tail water was high, and the basin would not sweep out when the tail water was low. For the initial test, two rectangular control piers were installed at Station 13+05, 85 feet from the end of the chute. These control piers, 18 feet high and 5 feet wide, were placed 5 feet apart and equidistant from the training walls. The upstream faces of the control piers were in a plane perpendicular to the basin floor and sidewalls (Figure 7A). With these piers installed and with a maximum flow of 4,410 cfs and the initial high tail water, the water surface above the control piers reached about elevation 1583 or 5 feet below the tops of the training walls. The jump swept out when the tail water was lowered about 9 feet to elevation 1572. This sweepout condition indicated that the control piers did not offer sufficient resistance to the flow.

For structural stability, the piers should be triangular in front elevation with substántial buttresses downstream since the section would have to be quite large to retain the jump in the basin. Conjugate depth control piers shown in Figure 7B were installed at Station 13+05. This made two piers joined at the bottom corners, each 15 feet high, 5 feet wide on top, and 10-1/2 feet wide at the bottom. With a discharge of 4,410 cfs and high tail water, the flow did not overtop the training walls (Figure 8A), but again the basin swept out with lowered tail water (Figure 8B). The test was repeated using the larger baffle piers discussed in the previous section of this report. For maximum discharge and high tail water the jump appeared more stable, and swept out at about tailwater elevation 1570, or 1/2 foot lower than with the smaller preliminary design baffle piers. For all subsequent tests the larger baffle piers were used.

Triangular-shaped conjugate depth control piers of various heights, widths, spacing, and locations in the basin were tested. Piers 17 feet high and with a frontal area of 260 square feet seemed optimum. The most desirable location, hydraulically, of the baffle piers and the control piers was to place the baffle piers 23 feet downstream from the chute blocks and the conjugate depth control piers 60 feet downstream from the baffle piers. With this placement of the appurtenances the basin operated satisfactorily for all discharges and tail-water elevations. The buttresses holding the control piers were made 12 feet long to terminate at a construction joint in the basin floor. The recommended shape and location of the control piers, and the placement of the baffle piers, are shown in Figure 14.

Apron Flow Spreaders and End Sills

The stilling basin with the baffle piers and conjugate depth control piers will satisfactorily handle any discharge independent of any predictable downstream tail water. The remaining problem concerned scour at the downstream end of the apron. With the preliminary design apron this scour was severe with maximum discharge and high tail water; with maximum discharge and low-tail water, much of the cutoff wall at the downstream end of the apron was exposed.

It appeared that some type of piers or baffles installed on the apron and in line with the three openings through the control piers would spread the flow and break up the jets sufficiently to aid in preventing scour. Three such appurtenances, referred to here as "flow spreaders," were installed on the sloping apron in the model. Each flow spreader was 20 feet long, 4 feet wide, and 8.5 feet high at the vertical upstream face, and with the top sloped downward from the upstream face to the downstream end of the apron (Figure 9A). This design was first tested with one gate fully opened and discharging about 2,200 cfs. The tailwater was lowered to elevation 1567, about 7 feet below the initial high tail water. The hydraulic action in the horseshoe tunnel and in the stilling basin was quite satisfactory (Figure 9B), and the scour downstream was nominal.

The basin was next tested with maximum discharge, 4,410 cfs, and tailwater elevation 1581.3 (Figure 10A). Scour for this flow condition was not too severe (Figure 10B). The test was repeated with the tail water lowered to elevation 1568 (Figure 11A). Appreciable scour occurred during this test; the cutoff wall at the downstream end of the apron was exposed to a depth of about 5 feet (Figure 11B). An end sill was added between the flow spreaders (Figure 12) to deflect the high velocity flow upward and away from the cutoff wall. However, the water depth at the end sill was only about 13 feet for high tail water and 5 feet for low tail water, making the average stream velocity here relatively high. Scour downstream from the end sill was extensive with the maximum discharge for either high or low tail water (Figures 12A and 12B).

The sloping apron was removed and replaced with one extending level from the stilling basin floor. This change made a larger flow area, thereby reducing the velocity at the downstream end of the basin. Since the water surface over the flow spreaders in the previous design appeared satisfactory, the tops of the three new spreaders were held at about the same elevation as that of the previous ones. Figure 13A shows the basin with level apron and three flow spreaders discharging 4,410 cfs with tail-water elevation 1568. Figure 13B shows that the scour was not too severe near the cutoff wall, but was about 8 feet deep 25 feet downstream. It appeared, from the pattern of the scour, that the addition of an end sill would minimize the scour for the condition of low tail water. Tests made with an end sill added to the model showed that the scour was nominal for all conditions of discharge and tail-water elevations.

RECOMMENDED DESIGN

Changes and Relocations for Construction

The features of an acceptable stilling basin for the river outlet works had been developed by this model study; however, a few minor changes in the basic stilling basin design were made to aid in construction and to reduce excavation. It appeared that these changes would not affect the hydraulic operation.

The following changes from the preliminary design were made:

1. The entire basin was moved upstream about 12 feet.

2. The length of the diverging portion of the chute was increased from 54 feet to 67 feet.

3. The upstream end of the diverging portion of the chute was moved 25.06 feet upstream into the tunnel.

4. The width at the downstream end of the apron was decreased from 43 feet to 40 feet.

5. The apron length was increased from 29.9 feet to 30.5 feet.

The following dimensions or locations of the preliminary design remained unchanged:

1. The tunnel portal Station of 11+66.

2. The equation of the chute floor $X^2 = -181.779y$.

3. The size and relative location of the chute blocks.

4. The basin length of 95 feet from the end of the diverging chute to the apron.

5. The basin width of 25 feet.

6. The top of the training walls, elevation 1588.

The above-mentioned unchanged portions of the stilling basin, and those portions subjected to minor changes, together with the necessary features determined by model study, constitute the recommended design and is shown in Figure 14.

Operation-Recommended Design

At maximum discharge, 4,410 cfs, and the highest expected tail-water, elevation 1581.3, the operation of the recommended stilling basin was satisfactory (Figure 15A). The highest portion of the jump roller in the basin was about 1 foot below the top of the training wall (Figure 14). Scour downstream from the apron for high-tail water was negligible (Figure 15B).

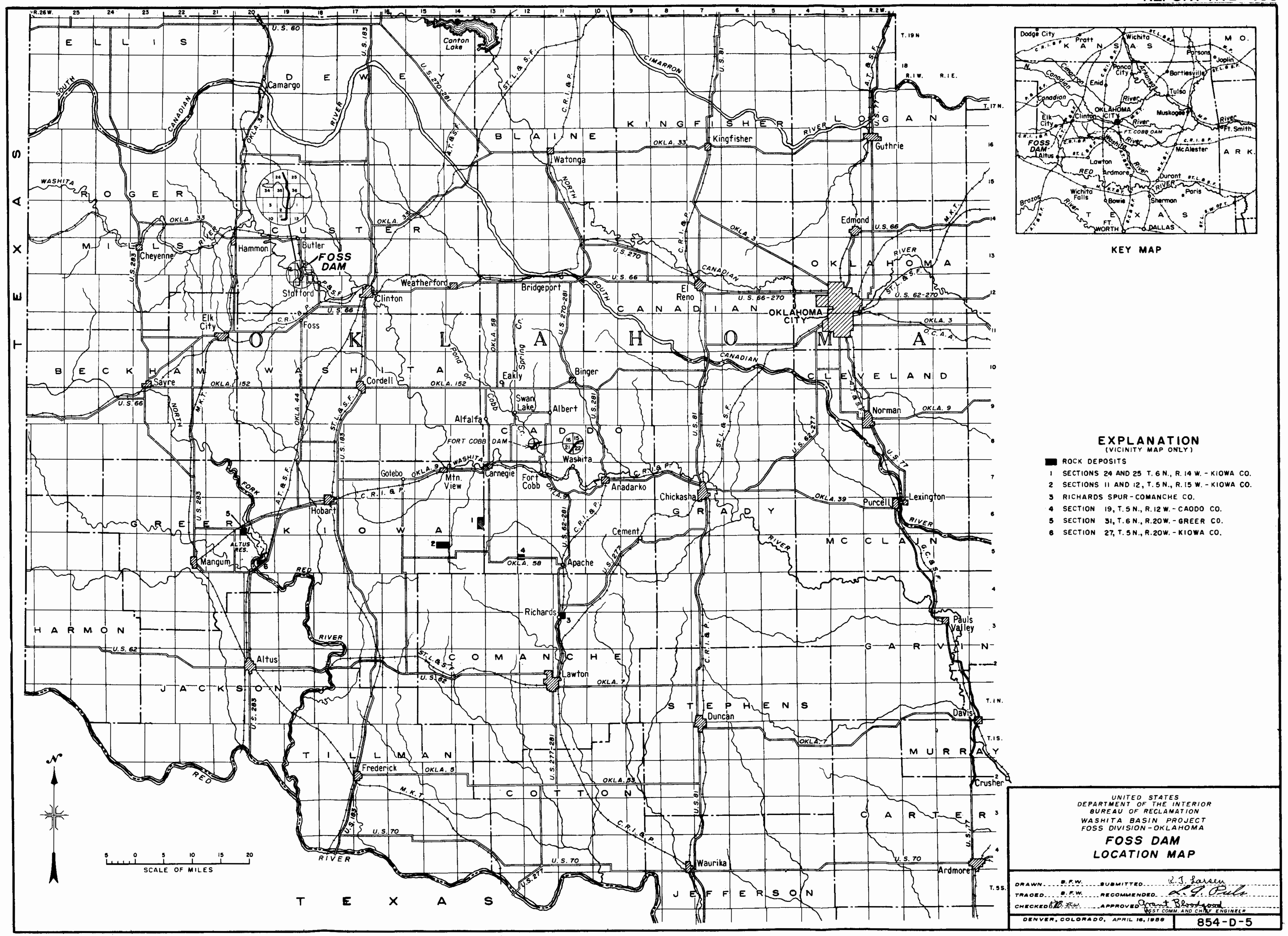
To determine the stilling basin operation for various tail-water elevations, the outlet works discharge was set at 4,410 cfs with high-tail water. The tail water was then lowered slowly to the minimum expected tail water. As the tail water was lowered, the water surface in the basin lowered until, at tail-water elevation 1573 a stable water surface was established in the basin forming a profile as shown for low tail water in Figure 14. Further lowering of the tail water in the river channel had no effect on the conjugate depth in the basin. The water surface in the river channel was dropped to elevation 1568, approximately the minimum tail water expected after degradation of the river channel (Figure 16A). Scour with this operating condition was slight (Figure 16B), and the design was considered adequate to prevent excessive scour in the outlet channel.

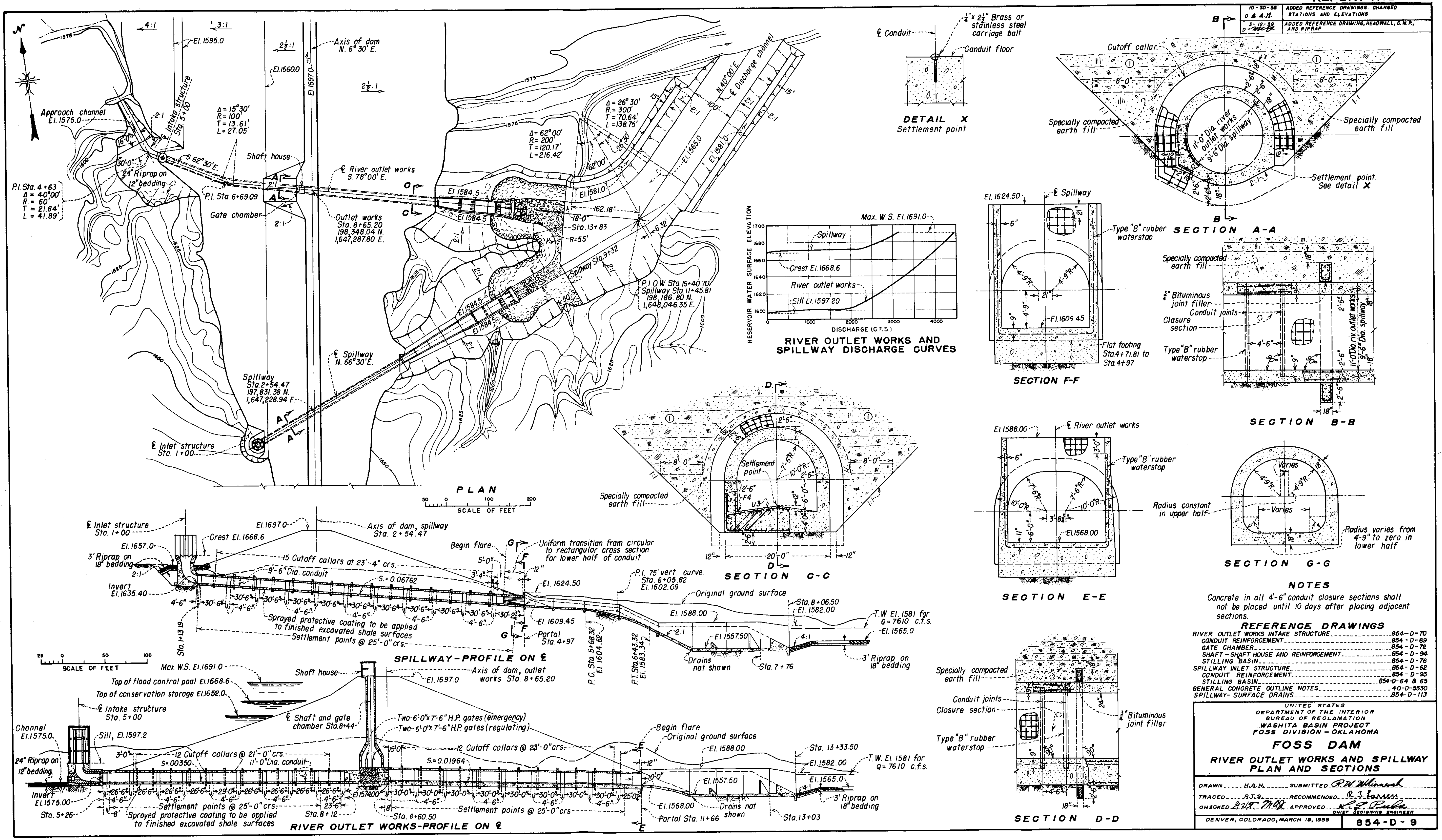
Various combinations of discharge and tail-water elevations were tested, including single-gate operation, and in all cases the appearance of the flow was satisfactory and the scour slight.

Spillway Stilling Basin

Except for the chute, the Foss Dam spillway stilling basin was identical to the outlet works basin in size, shape, and elevations, thus its adequacy was checked on the outlet model. The expected maximum spillway discharge was 3,050 cfs, or about 70 percent of the maximum for the outlet works. The spillway flow entered the stilling basin from a chute on a 2:1 slope. The maximum spillway flow was discharged through the outlet works stilling basin (Figures 17A and 17B), and appeared satisfactory over the full range of tail-water elevations. The sweepout curve for the preliminary design is shown on Figure 5. The jump could not be swept from the recommended basin, regardless of tail-water elevation.

FIGURE 1
REPORT HYD. 466




PLAN
SCALE OF FEET
SPILLWAY-PROFILE ON ℄
RIVER OUTLET WORKS-PROFILE ON ℄
DETAIL X
Settlement point
RIVER OUTLET WORKS AND SPILLWAY DISCHARGE CURVES
RESERVOIR WATER SURFACE ELEVATION
DISCHARGE (C.F.S.)
Max. W.S. El. 1691.0
Spillway
Crest El. 1668.6
River outlet works
Sill El. 1597.20
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
NOTES
Concrete in all 4'-6" conduit closure sections shall not be placed until 10 days after placing adjacent sections.
REFERENCE DRAWINGS
RIVER OUTLET WORKS INTAKE STRUCTURE 854-D-70
CONDUIT REINFORCEMENT 854-D-69
GATE CHAMBER 854-D-72
SHAFT-SHAFT HOUSE AND REINFORCEMENT 854-D-94
STILLING BASIN 854-D-76
SPILLWAY INLET STRUCTURE 854-D-62
CONDUIT REINFORCEMENT 854-D-93
STILLING BASIN 854-D-64 & 65
GENERAL CONCRETE OUTLINE NOTES 40-D-5530
SPILLWAY-SURFACE DRAINS 854-D-113
10-30-58 ADDED REFERENCE DRAWINGS. CHANGED STATIONS AND ELEVATIONS
3-18-59 ADDED REFERENCE DRAWING, HEADWALL, C.M.P., AND RIPRAP
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
WASHITA BASIN PROJECT
FOSS DIVISION-OKLAHOMA
FOSS DAM
RIVER OUTLET WORKS AND SPILLWAY
PLAN AND SECTIONS
DRAWN H.A.H. SUBMITTED
TRACED R.T.S. RECOMMENDED
CHECKED APPROVED
CHIEF DESIGNING ENGINEER
DENVER, COLORADO, MARCH 19, 1958
854-D-9

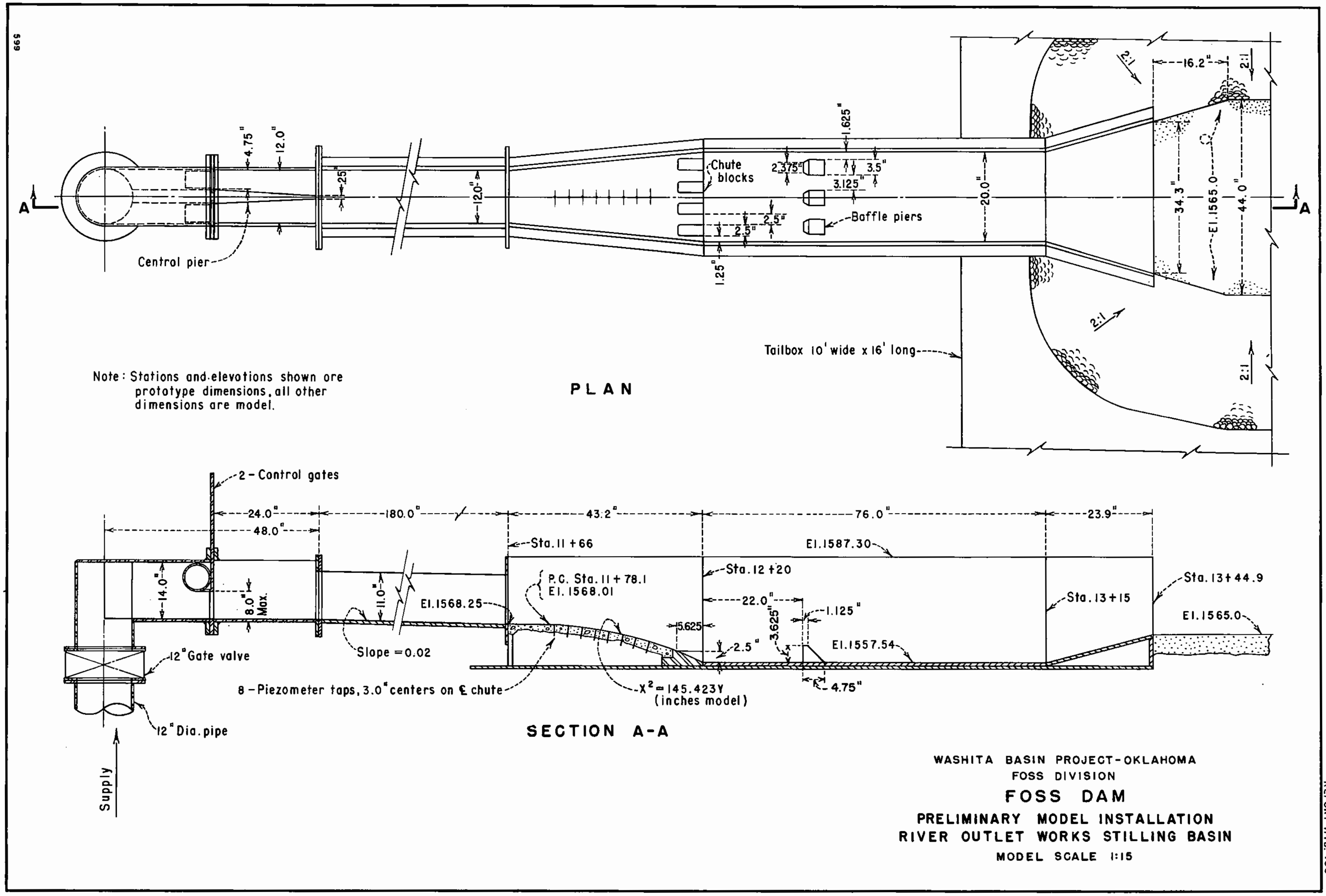
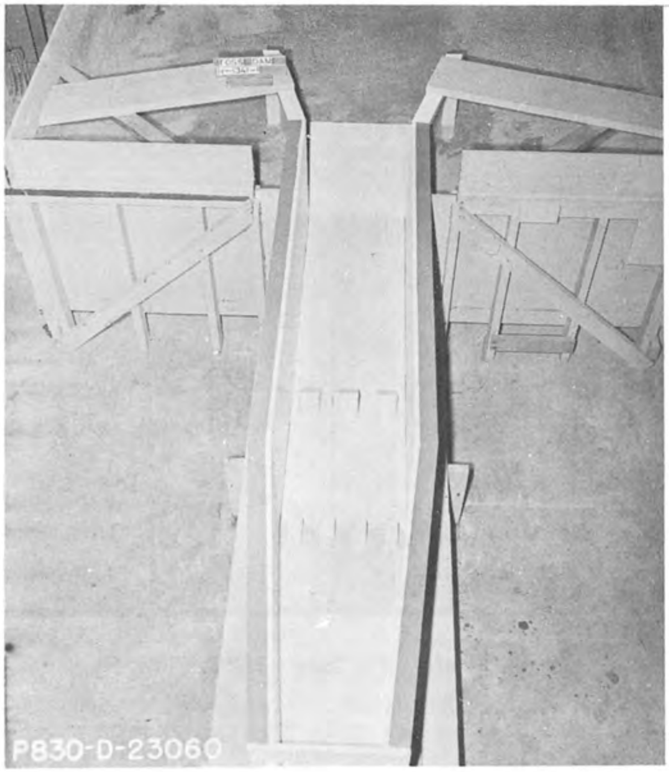
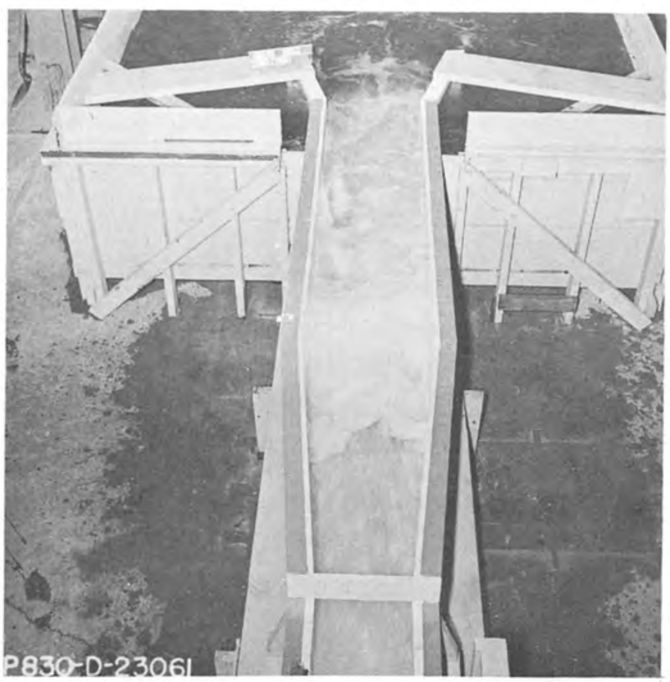


FIGURE 3
REPORT HYD. 466



A. No flow

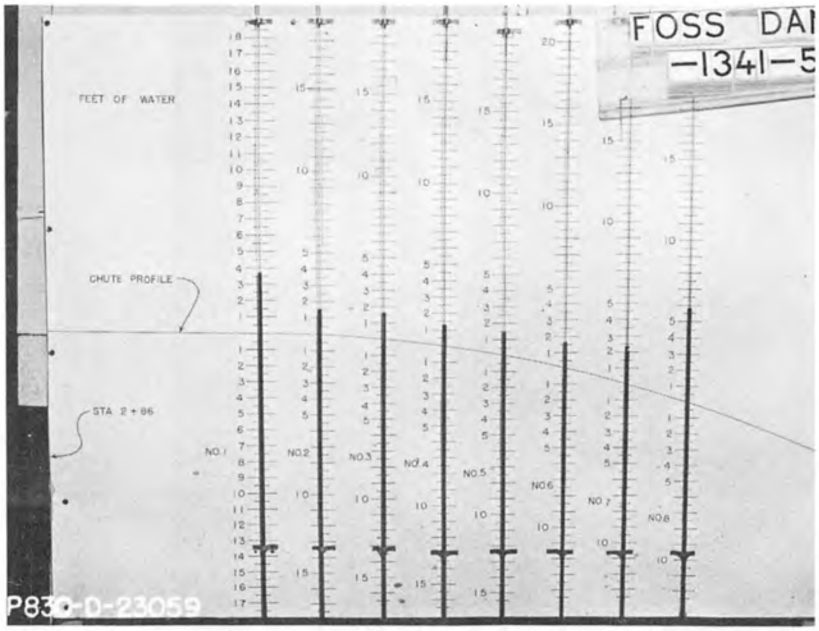


B. Q = 3860, TW = el 1578.6

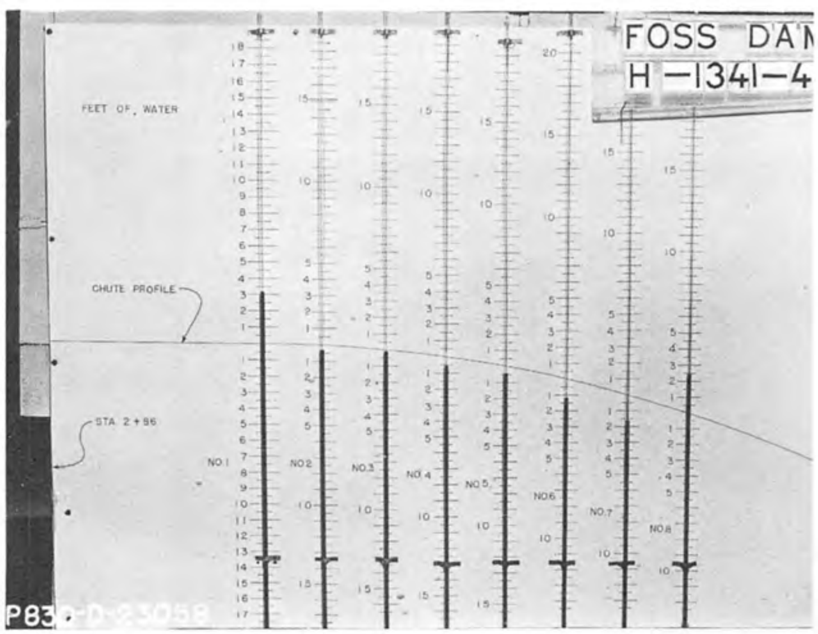
WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM RIVER OUTLET WORKS STILLING BASIN

Preliminary Design

FIGURE 5
REPORT HYD 466



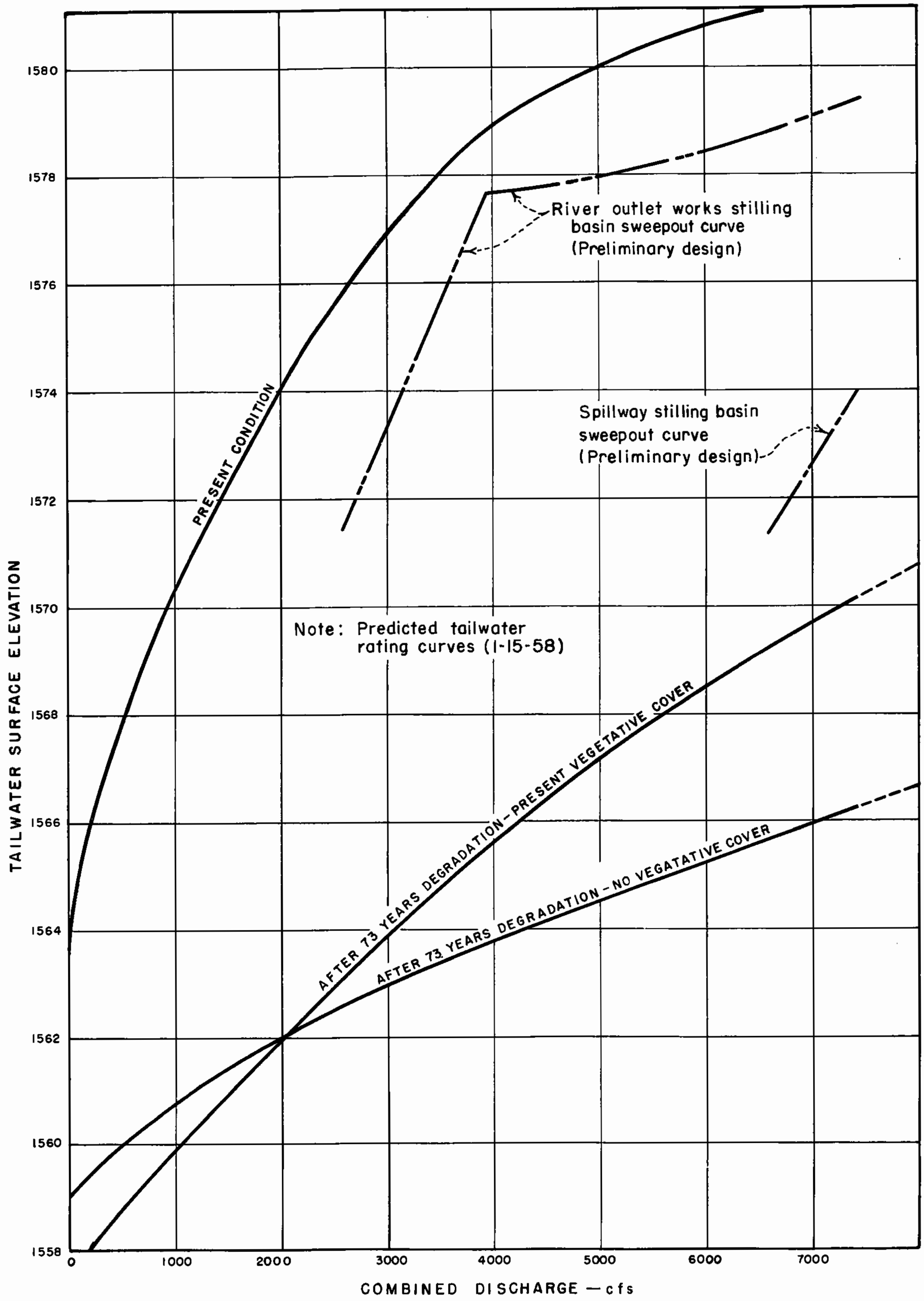
A. For Q = 3300 cfs, TW Elev 1577.6



B. For Q = 4410 cfs, TW Elev 1581.3

WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM RIVER OUTLET WORKS STILLING BASIN

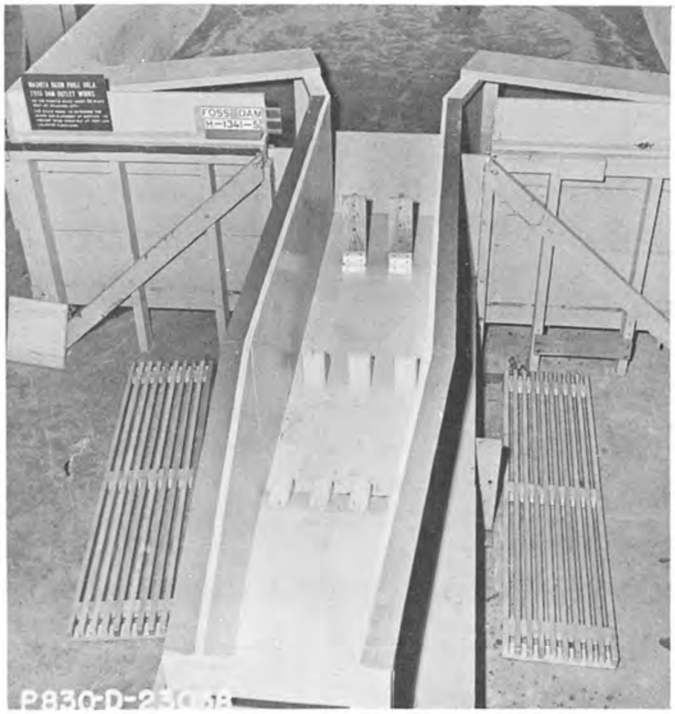
Pressures on Chute Floor Centerline



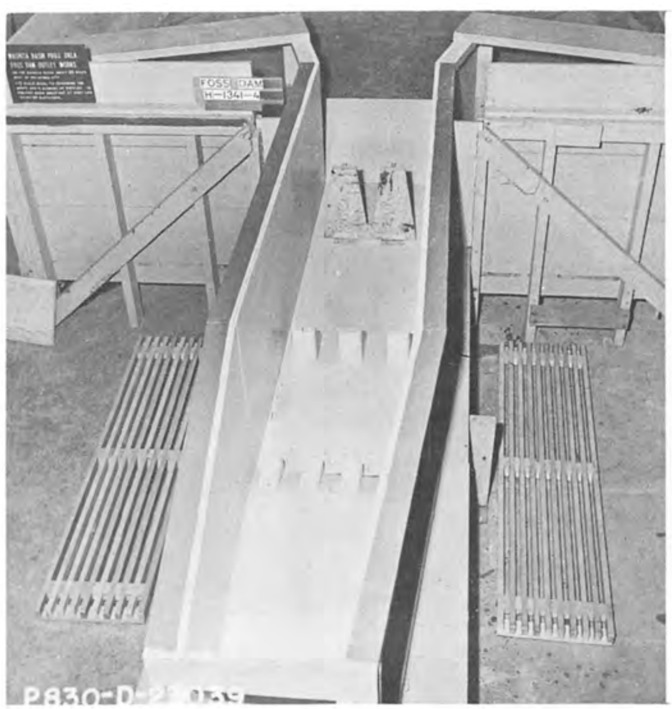
WASHITA BASIN PROJECT-OKLAHOMA
FOSS DIVISION

FOSS DAM

PRESENT AND PROJECTED TAILWATER CURVES
SWEEPOUT CURVES FOR PRELIMINARY OUTLET WORKS
AND SPILLWAY STILLING BASINS, COMBINED FLOW



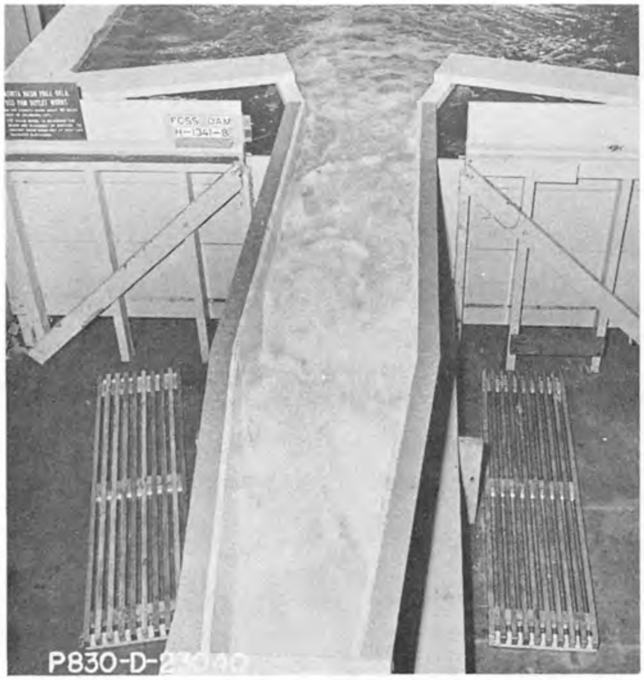
A. Rectangular piers



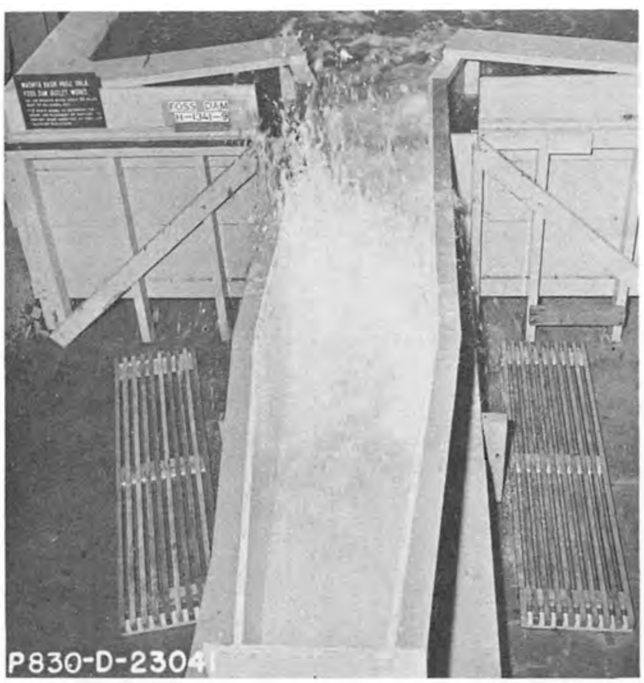
B. Triangular piers

WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM RIVER OUTLET WORKS STILLING BASIN

Initial Conjugate Depth Control Piers



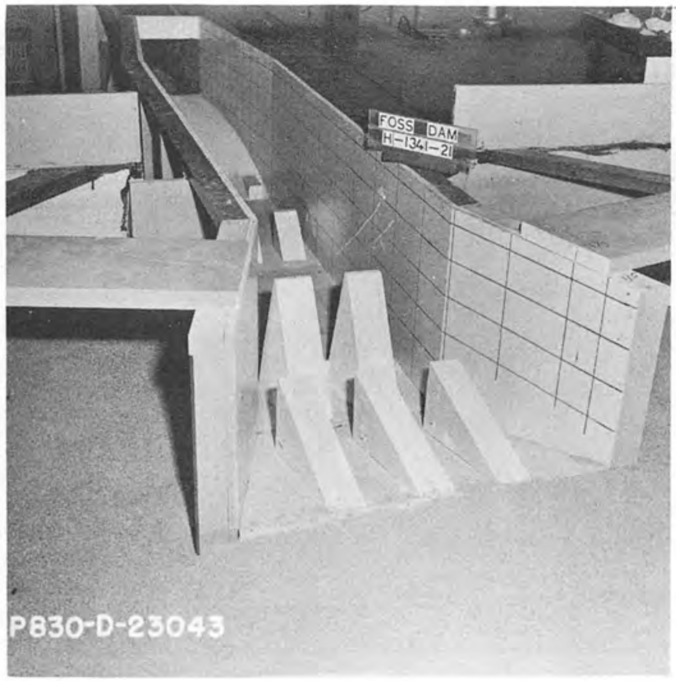
A. Q = 4410 cfs, TW = el 1581.3



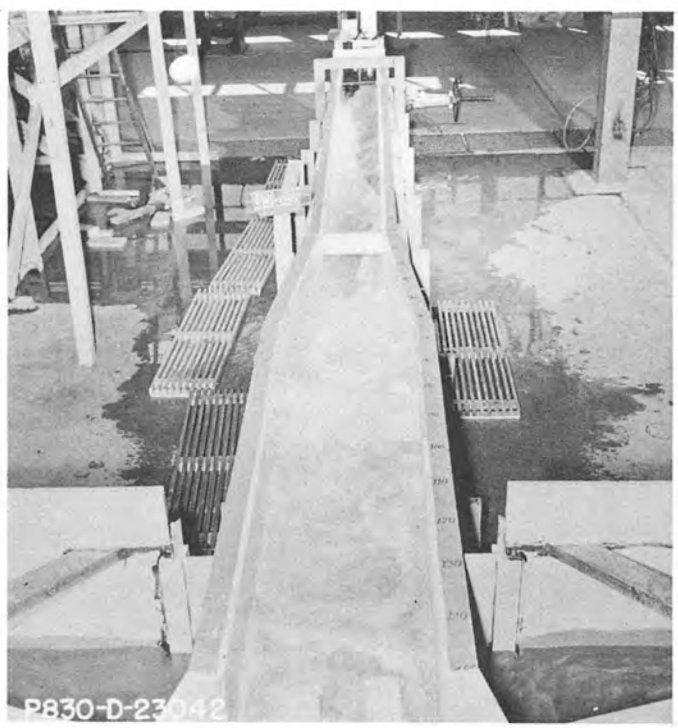
B. Q = 4410 cfs, TW = el 1568.0: Basin swept out

WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM RIVER OUTLET WORKS STILLING BASIN

Operation with Initial Conjugate Depth Control Piers



A. The model arrangement

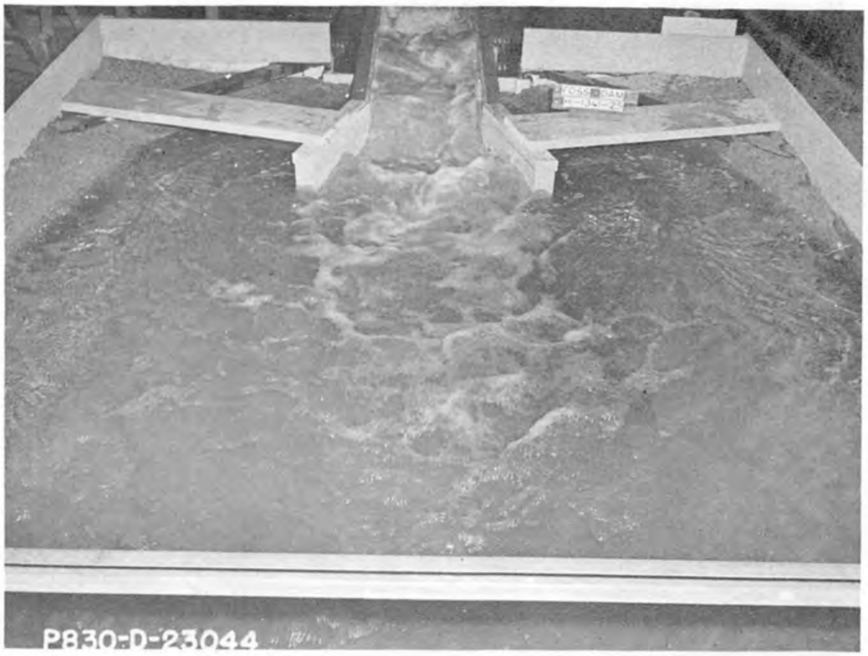


B. One-gate operation, Q = 2200 cfs, TW = el 1567

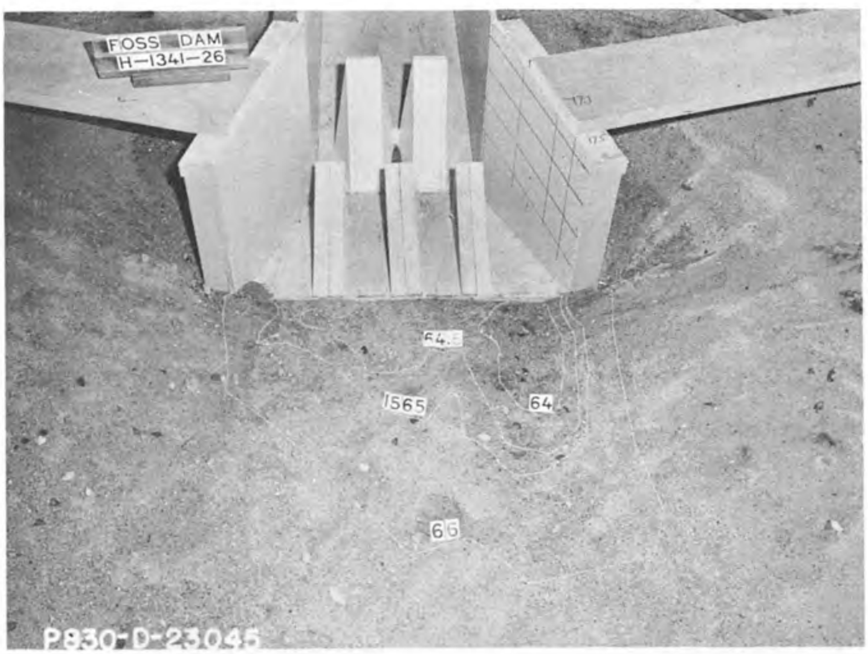
WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM RIVER OUTLET WORKS STILLING BASIN

Seven-foot High Baffle Piers, Triangular Conjugate Depth Control Piers, Flow Spreaders on Sloping Apron.

Flow Conditions for One-gate Operation



A. Q = 4410 cfs, TW = el 1581.3

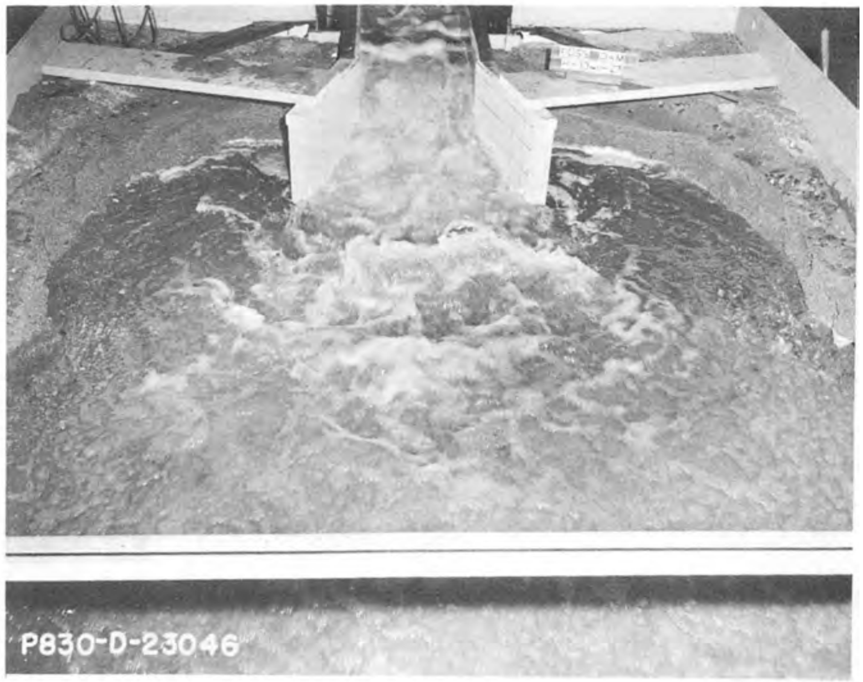


B. Scour after 1/2-hour model operation shown above.

WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM RIVER OUTLET WORKS STILLING BASIN

Flow Condition and Scour for High Tail Water

(Same Basin as Fig. 9)



A. Q = 4410 cfs, TW = el 1568

B. Scour after 1/2-hour model operation shown above.

WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM RIVER OUTLET WORKS STILLING BASIN

Low Tail Water

(Same Basin as Fig. 9)

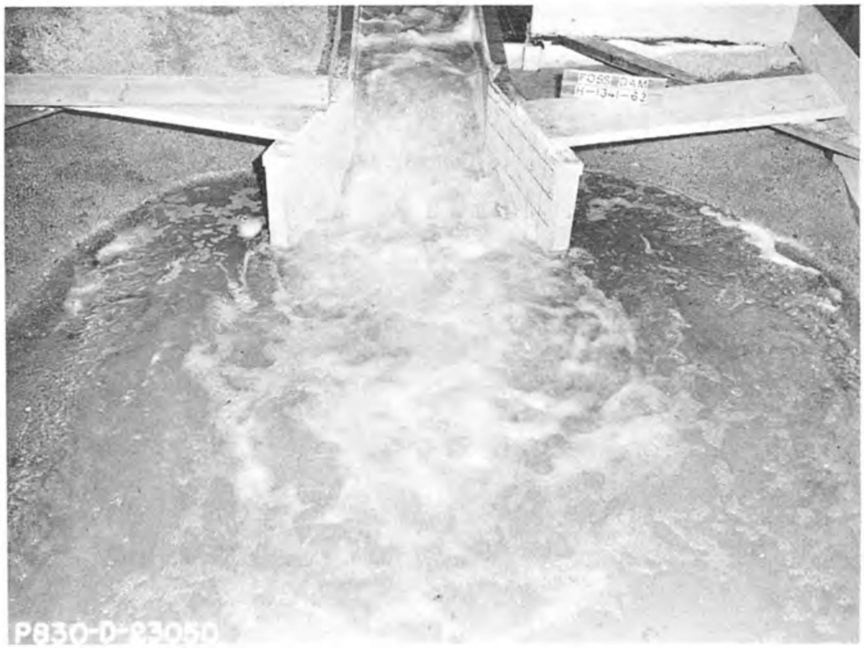
A. Scour after 1/2-hour model operation of
Q = 4410 cfs, TW = el 1581.3

B. Scour after 1/2-hour model operation of
Q = 4410 cfs, TW = el 1567

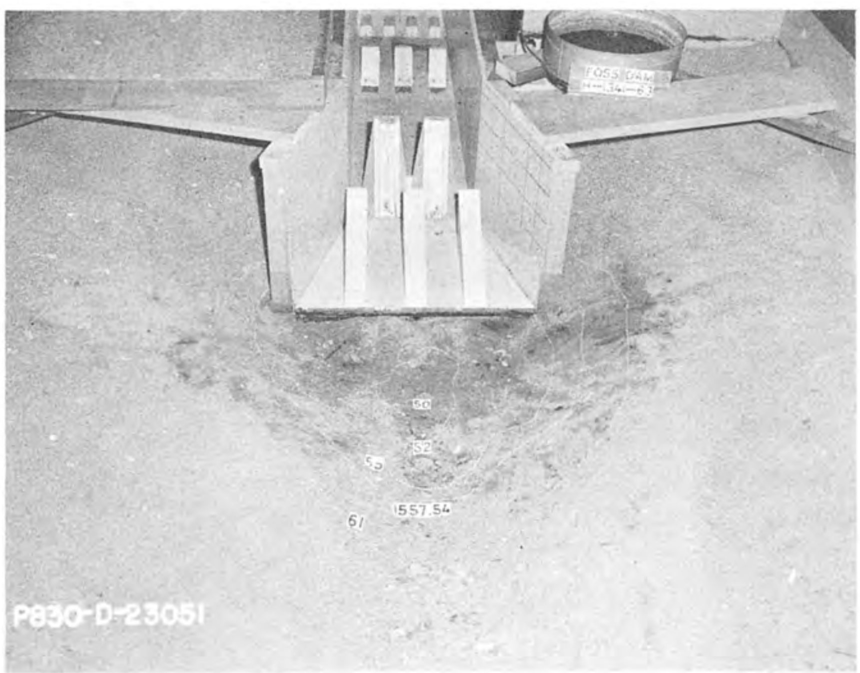
WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM RIVER OUTLET WORKS STILLING BASIN

Scour Conditions

(Same as Fig. 9, Plus End Sill)



A. Q = 4410 cfs, TW = 1568

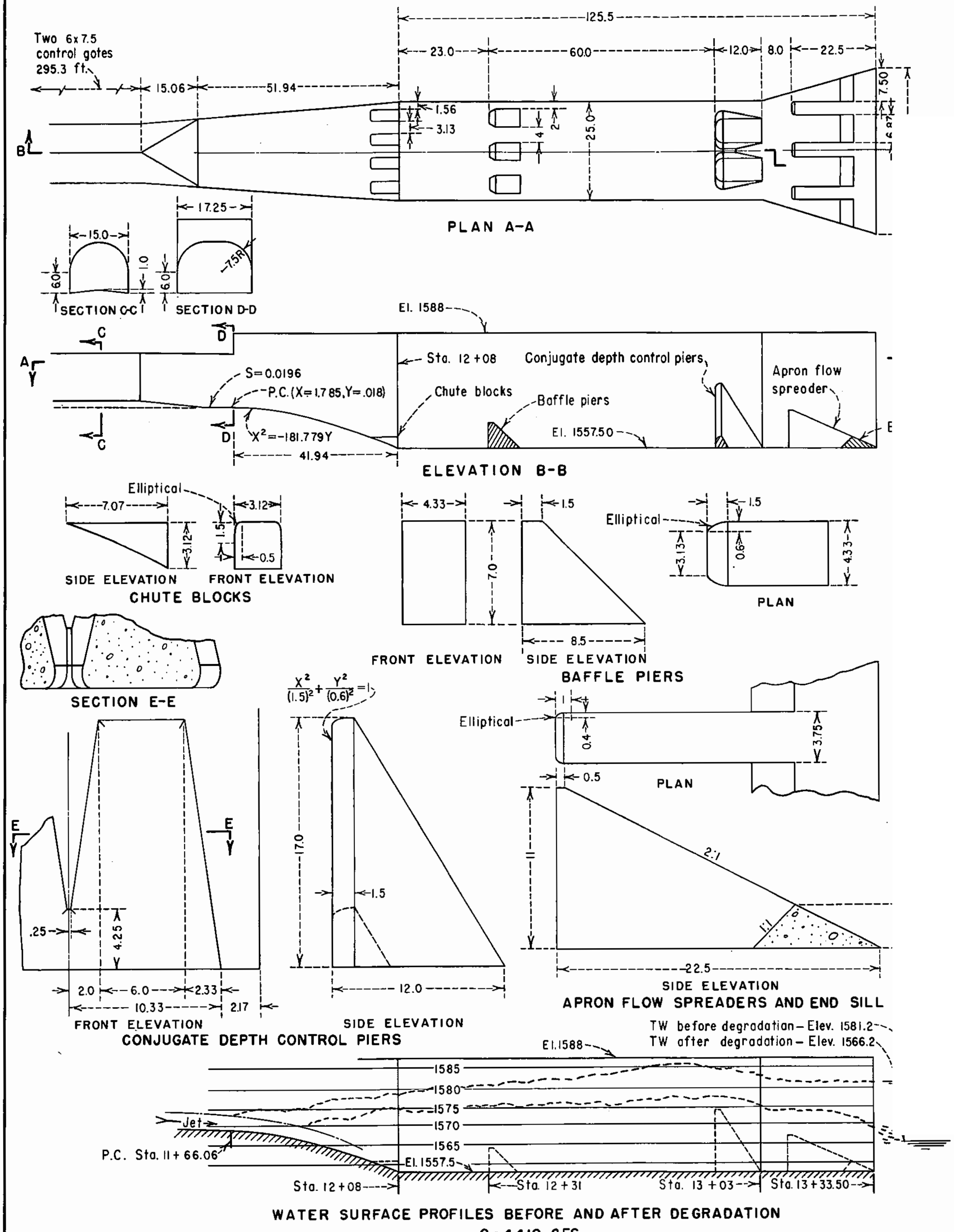


B. Scour after 1/2-hour model operation shown above.

WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM RIVER OUTLET WORKS STILLING BASIN

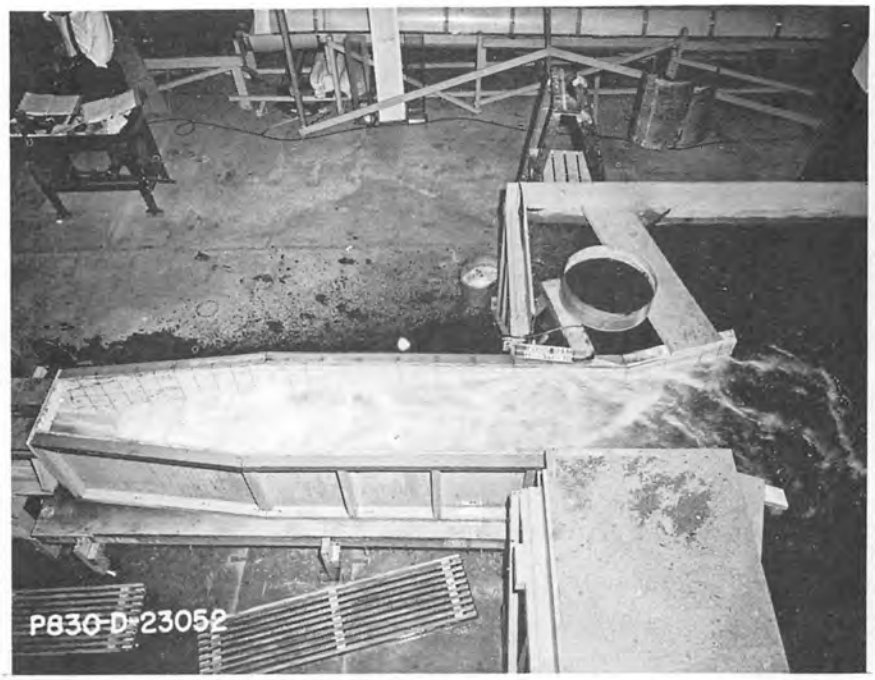
Flow Conditions and Scour

Seven-foot High Baffle Piers, Streamlined Triangular
Conjugate Depth Control Piers, 11-foot High Flow
Spreaders on a Level Apron

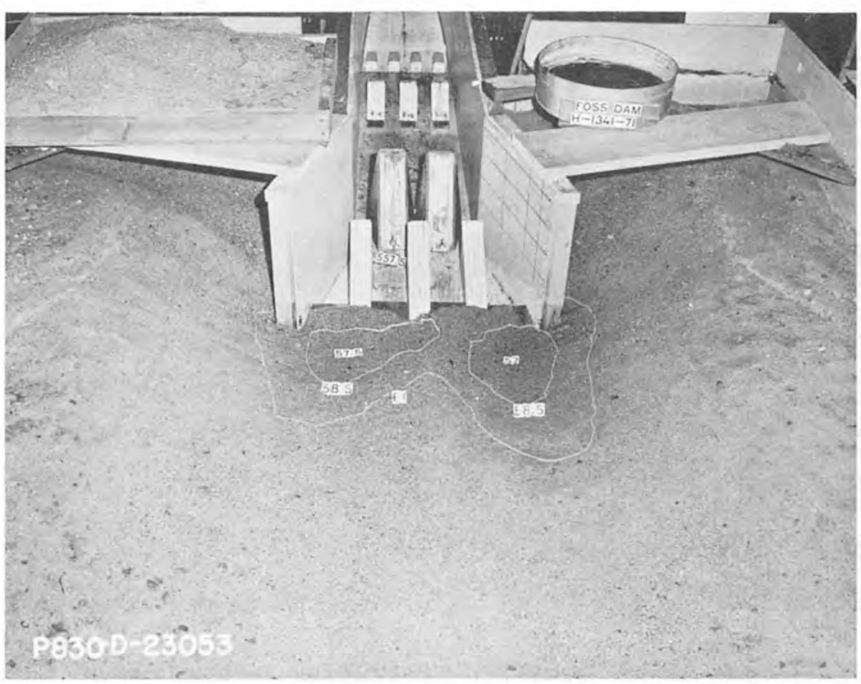


NOTE
All dimensions are in feet.

WASHITA BASIN PROJECT-OKLAHOMA
FOSS DIVISION
FOSS DAM
RIVER OUTLET WORKS STILLING BASIN
RECOMMENDED DESIGN



A. Q = 4410, TW = el 1581.3



B. Scour after 1/2-hour model operation shown above.

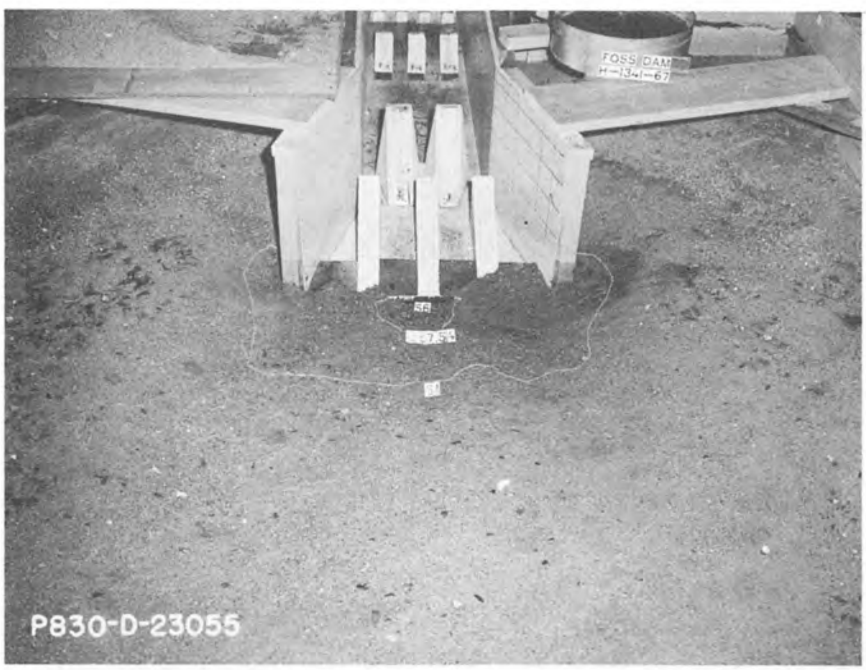
WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM RIVER OUTLET WORKS STILLING BASIN

Flow Conditions and Scour for High Tail Water

Recommended Design

FIGURE 16
REPORT HYD 466

A. Q = 4410 cfs, TW = el 1568

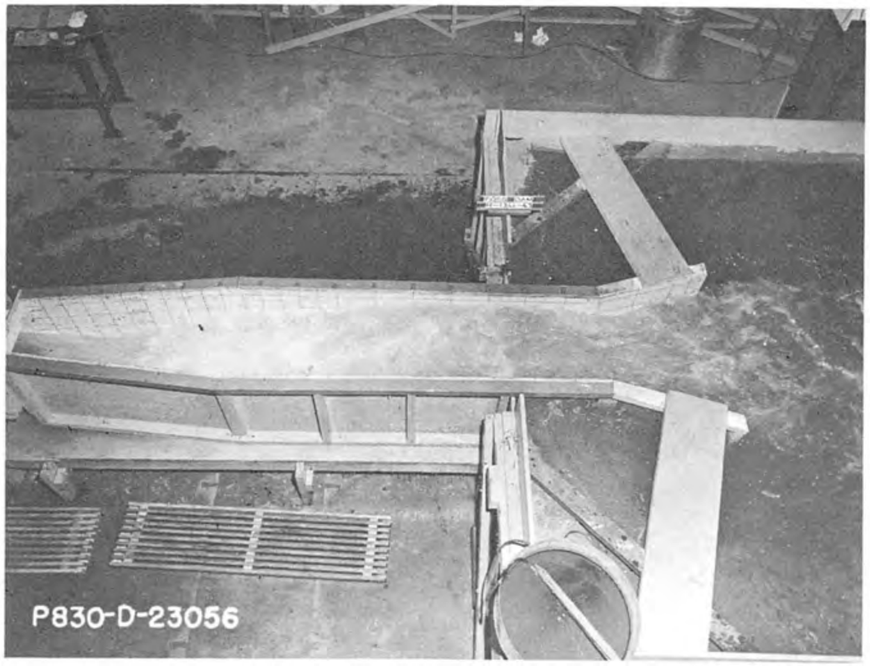


B. Scour after 1/2-hour model operation shown above.

WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM RIVER OUTLET WORKS STILLING BASIN

Flow Conditions and Scour for Low Tail Water

Recommended Design



A. Q = 3050 cfs, TW = el 1581.3

B. Q = 3050 cfs, TW = el 1567

WASHITA BASIN PROJECT-OKLAHOMA, FOSS DIVISION
FOSS DAM SPILLWAY STILLING BASIN

Flow Conditions for Spillway Stilling Basin

GPO 841483