GR-82-9

HYDRAULIC MODEL STUDY OF CHOKE CANYON DAM SPILLWAY AND STILLING BASIN

August 1982
Engineering and Research Center

U.S. Department of the Interior
Bureau of Reclamation
Division of Research
Hydraulics Branch

7-2090 (4-81)
Water and Power

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. **GR-82-9**	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE **Hydraulic Model Study of Choke Canyon Dam Spillway and Stilling Basin**		5. REPORT DATE August 1982
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Robert L. George		8. PERFORMING ORGANIZATION REPORT NO. GR-82-9
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bureau of Reclamation Engineering and Research Center Denver, Colorado 80225		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Microfiche and or hard copy available at the E&R Center, Denver, CO

Ed:RNW

16. ABSTRACT

A 1:80 scale hydraulic model of the Choke Canyon Dam spillway and stilling basin was studied. The dam will be 35 meters high and have a crest length of 5640 meters. The spillway chute is 112.2 meters wide and has a Froude number of about 4.4 at the stilling basin entrance. The stilling basin was designed to criteria developed for low Froude number flows. A modified entrance channel was developed as the model was tested. Stilling basin walls were shortened as a result of model studies. A 14-meter apron having 32 meters of riprap extended downstream from the end sill was recommended. The design worked well for all discharges and scour was limited to an area downstream from the riprap.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- / *scour/ approach channels/spillway approach/ *guide walls/ slopes/ *stilling basin

b. IDENTIFIERS-- Choke Canyon Dam, TX

c. COSATI Field/Group 13B COWRR: 1313.1 SRIM:

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED	21. NO. OF PAGES 30
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. PRICE

GPO 831-316

GR-82-9

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SI METRIC

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

The hydraulic model study described in this report was conducted in the Hydraulic Structures Section and was reviewed by E. J. Carlson, Head of the Hydraulic Research Section, in the Hydraulics Branch. Engineers involved in design of Choke Canyon Dam made valuable suggestions during the study.

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PURPOSE

A hydraulic model study of Choke Canyon Dam spillway and stilling basin, requested by the Embankment Dams Section, Dams Branch designers, was performed to provide information needed for design. The model study was initiated to verify stilling basin design, flow conditions, and scour in the spillway *approach* channel. A spillway rating curve for the seven 15 000- by 7230-mm radial gates was developed. Scour in the downstream channel was studied.

INTRODUCTION

The damsite is located on the Frio River in south central Texas about midway between Corpus Christi and San Antonio. It is 5.6 km above the confluence of the Frio and Nueces Rivers (fig. 1).

The main purpose of the dam is to provide municipal and industrial water to Corpus Christi and adjoining areas. The reservoir also will provide some flood control and recreational benefits. Choke Canyon reservoir will have a total capacity of 880.6×10^6 m^3 at the normal water surfce of 67.21 m. The active capacity will be 860×10^6 m^3.

An embankment 35 m high and 5640 m long will form the reservoir. The embankment will be a homogeneous earthfill. A 112.8-m-wide concrete spillway will pass major flood flows. Immediately downstream from the stilling basin, the outlet channel turns to the right and conveys flow to the original river channel.

A St. Anthony Falls [1]* type stilling basin, a design developed at St. Anthony Falls Hydraulic Laboratory using chute blocks, basin floor blocks and an end sill, was considered during preliminary model calculations. It was not used because a scour hole would develop downstream and deep scour in the outlet channel was unacceptable.

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*Numbers in brackets refer to the bibliography.

Drawing model dimensions are in millimeters unless noted and prototype dimensions are shown in meters unless noted.

CONCLUSIONS

1. A low Froude number stilling basin was designed and tested in a hydraulic model for the choke Canyon Dam (fig. 2). As designed, the spillway and stilling basin operated excellently. During model tests, a modified stilling basin was developed that eliminated 5.48 m of the prototype sidewalls and retained a 14-m apron, resulting in a lower cost.

2. The design recommended for Choke Canyon Dam has a concrete apron 14 m long, downstream from the end of the stilling basin, followed by a 32-m-long section of riprap.

3. The approach channel recommended for the prototype spillway is 125 m wide at elevation 54.40 meters mean sea level. The inlet walls and approach channel are shown on figure 14.

4. The spillway discharge rating curve with all 7 radial gates opened equally is shown on figure 23.

THE MODEL

The model was constructed to a length scale of 1:80 and is shown on figure 3. The original model inlet walls and entrance channel were modified to obtain lower velocities and to eliminate excessive scour along the inlet walls at each side of the spillway entrance. Figure 4 shows the model as designed *originally*. The head box contained the reservoir portion of the model. Topography of the reservoir was formed by smoothing the sand to the same shape as the prototype.

The prototype *approach* channel is a trapezoidal channel having a bottom width of 125.0 m and 2:1 side slopes. The *entrance* channel was set at a prototype elevation of 54.40 m.

The spillway is an overflow crest having seven 15 000- by 7230-mm radial gates. Spillway width is 112.2 m. A chute built on a 3-percent slope is located immediately downstream of the gate section and is followed by a vertical curve which connects to the stilling basin. The stilling basin was designed to Bureau of Reclamation criteria [2] developed for low Froude number flows.

Below the stilling basin, the *outlet* channel curves to the right. The bottom width is 112.2 m and the side slopes are 2:1. There is no slope to the outlet channel which is at elevation 41.0 m. About 450 m of the prototype channel downstream from the stilling basin were included in the model. This reach modeled the effect of the curved channel on the stilling basin.

Model Similtude Parameters

The model was constructed to an undistorted scale of 1:80 and was evaluated using the Froude law of similtude. Model discharges were scaled from the prototype by the following relationship:

$$Q_m = \left(\frac{1}{80} \right)^{5/2} Q_p \qquad (1)$$

where

Q_m = model discharge

Q_p = prototype discharge

The maximum Q_p of 7080 m^3/s was represented by a 0.124-m^3/s Q_m discharge. Spillway velocities and discharges were represented accurately at the 1:80 model scale. All model elevations were measured with respect to mean sea level (metric scale).

Sand used in the model was scaled—based on settling velocity [3]—to nearly the same size as the largest soil and rock at the damsite. Smaller size sediment at the damsite was less than 75 μm (passing a No. 200 seive). The laboratory had a limited amount of 75 μm sediment and it was placed at the downstream end of the stilling basin. Consequently, scour around the inlet walls indicated where scour would occur in the prototype for the largest material and these areas should be protected. Scour below the stilling basin represented the expected prototype conditions, and scour holes in the model bed indicated places that would need to be modified or protected.

MODEL TESTS

Preliminary Tests

Initial tests indicated that the spillway and stilling basin functioned well for all discharges. However, a sharp drawdown occurred around the inlet walls of the entrance channel and scour occurred at the base of the walls and deposited sediment in the stilling basin. All tests for comparing scour are for a maximum $Q_m = 0.124$ m^3/s for 1 hour ($Q_p = 7080$ m^3/s for 8.94 hours) unless otherwise noted. One hour model time was selected because the rate of the material removed had stabilized and little scour (model observation) appeared to occur after an hour. Figures 5a and 5b show the extent of scour along the inlet walls for the model as designed originally. As a result of this scour, alternate designs for the approach channel and walls were developed and tested.

Entrance Modifications

The first entrance modification proposed by the designers was a dike formed by extending the 2:1 side slopes above the normal water surface. Figure 6 shows scour around the inlet walls and erosion of the dikes. The approach velocity was too high in the channel and the dike was destroyed.

A second alternative was straight wingwalls at 30° to the approach channel connected by circular arcs as shown on figure 7. Neither the straight wingwalls nor wingwalls having various lengths of dikes was acceptable as shown on figures 8 through 10. The approach channel was subsequently widened to 125 m and made 1.683 m deeper to decrease the entrance velocities.

The deepened and widened approach channel decreased the velocity enough to minimize the transport of sediment into the stilling basin. A segmented wall resembling an ellipse was installed in the model and the maximum model discharge of 0.124 m^3/s (Q_p = 7080 m^3/s) was run for 1 hour. Scour was significantly less than any previous run. Figures 11a and 11b show the smaller amount of scour. Next a 300-mm (24-m prototype) radius arc for 120° was installed having a 3:1 side slope at the wall and a transition to the 2:1 side slopes in 200 mm (16-m prototype). After this configuration was operated for several hours, the 3:1 slope had scoured to nearly a 3-1/2:1 slope. Therefore, the side slopes were cut to 3-1/2:1 at the inlet walls and then transitioned to 2:1 side slopes upstream in a length of 400 mm (32-m prototype). Figure 12 shows a discharge of 0.083 m^3/s (Q_p = 750 m^3/s), the equivalent of a 1000-year flood with the 3-1/2:1 side slopes. Note that the drawdown is minimal. Scour from the maximum probable flood Q_m = 0.124 m^3/s (Q_p = 7080 m^3/s) was slight (figs. 13a and 13b).

The design recommended for the inlet channel is the deepened and widened channel having 24.0-m radius inlet walls and short wingwalls extending beyond the curves. Figure 14 shows the recommended design of the inlet walls, and approach and entrance channels.

Stilling Basin

The original design of the stilling basin is shown on figure 2. This design worked well throughout the range of discharges tested with less than 2 meters of vertical scour downstream from the apron. Several different floods were tested, from less than the 10-year return frequency up to the maximum probable flood of 7080 m^3/s. The largest scour occured at Q_m = 0.124 m^3/s (Q_p = 7080 m^3/s) discharge and had stabilized in about an hour of model time (8.94 h prototype). There was a slight asymmetry to the scour pattern with more scour occurring on the left side of the channel.

The designers suggested a test be performed using a discharge simulating a 1000-year flood (4750 m^3/s) and that the length of the stilling basin site walls be shortened so that this flood would still be contained in the basin. Tests were made with stilling basin sidewalls shortened 5.48 m. These tests developed scour holes downstream from the end sill, with the scour hole on the left side about 2 m deeper than the right side. Figure 15 compares the scour with the sidewall cut back 5.48 m from the original design with and without the downstream apron. Note the scour hole on the left is about 2 m deeper than the right. Each contour line represents a 1-m difference in elevation.

As water flowed around the channel bend downstream from the stilling basin, it became superelevated and caused an upstream current along the left bank between the curve and the stilling basin. The upstream current mixed with water leaving the stilling basin, and a scour hole was caused by the resulting vortex.

Several tests were made to obtain a solution to the scour along the left side of the channel.

A 2-1/2:1 side slope around the inlet sidewall replaced the 2:1 side slope. A transition to the 2:1 slope downstream from the stilling basin was made in 400 mm (32-m prototype). Figure 16 shows the scour from a 1- hour test at the maximum probable flood $Q_m = 0.124$ m³/s ($Q_p = 7080$ m³/s). Figure 17 shows the scour from a model discharge that was allowed to run until equilibrium was obtained. This run represented 53.7 hours in the prototype (6-h model).

A wall 14 m long along the left side provided an acceptable solution but was longer than the original design. A more economical solution was desired. A low wall, 5 m high and 14 m long, also was tried unsuccessfully.

Because scour was occurring along the floor of the stilling basin, the apron was extended 14 m downstream. Scour for this design with discharge of 7080 m³/s for 8.94 hours was acceptable (fig. 18). A 32-m-long blanket of riprap was placed downstream of the apron for additional protection. This configuration was tested and scour measurements were observed at 1, 3.75, and 5.50 hours model times (8.9, 33.5, 49.2 h prototype). Figures 19 to 21 show the scour that resulted from these tests. Performance of the basin shortened by 5.48 m from the original design, and with riprap installed downstream was acceptable for the maximum design flood and smaller floods.

The recommended design for the stilling basin was a concrete apron extending 14 m beyond the end sill with a 32-m-long riprap section downstream. The final design (fig. 22) has an 8.8-m apron and 30 m of riprap. A savings was realized from the shortened walls.

Radial Gate Calibration

The radial gate seat is 0.214 m below the spillway crest. All gate openings are referenced to vertical distances *above the crest* for the model tests. Gate opening curves at 1-m intervals and for free discharge, were developed and scaled to prototype values (fig. 23). Figure 23 represents the discharge capacity curve for the gated structure with all seven gates opened equally. Gates were set at a particular gate opening and the model was operated at a constant discharge until the water surface remained stable. Data were recorded for the water surface and discharge. Several discharges were tested for each gate opening to develop each curve. Each discharge was run for about 1 hour model time—generally long enough to maintain a stable water surface upstream of the dam in the model.

Safety Boom

A safety boom upstream from the spillway crest was designed and tested in the model. The final layout for the safety boom and anchors is shown on figure 24. Figure 25 shows the safety boom at the maximum probable flood, $Q_m = 0.124\ m^3/s$ ($Q_p = 7080\text{-}m^3/s$). After the model boom was installed, several tests were run to check if the safety boom affected the discharge curves. The discharge curves did not change.

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[2] George, R. L., "Low Froude Number Stilling Basin Design," REC-ERC-78-8, 16 pp., Bur. Reclam., 1978.

[3] Enger, P. F., "Hydraulic Model Studies of Bartley Diversion Dam—Progress Report No. 3 on General Studies of Headworks and Sluiceway Structures," Missouri River Basin Project, Nebraska, Laboratory Rep. Hyd-384, February 1954.

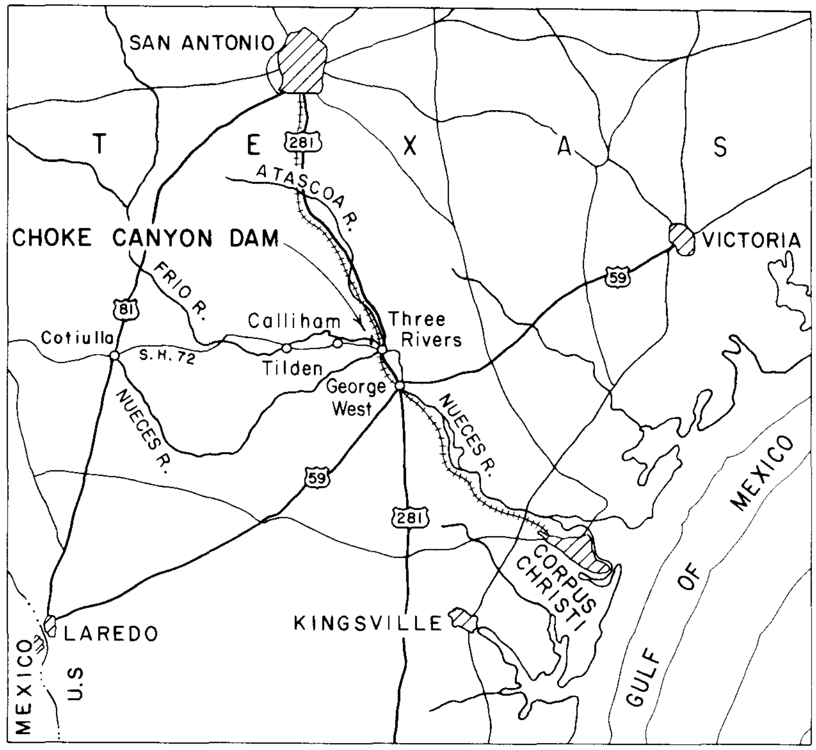


Figure 1.—Location map for Choke Canyon Dam.

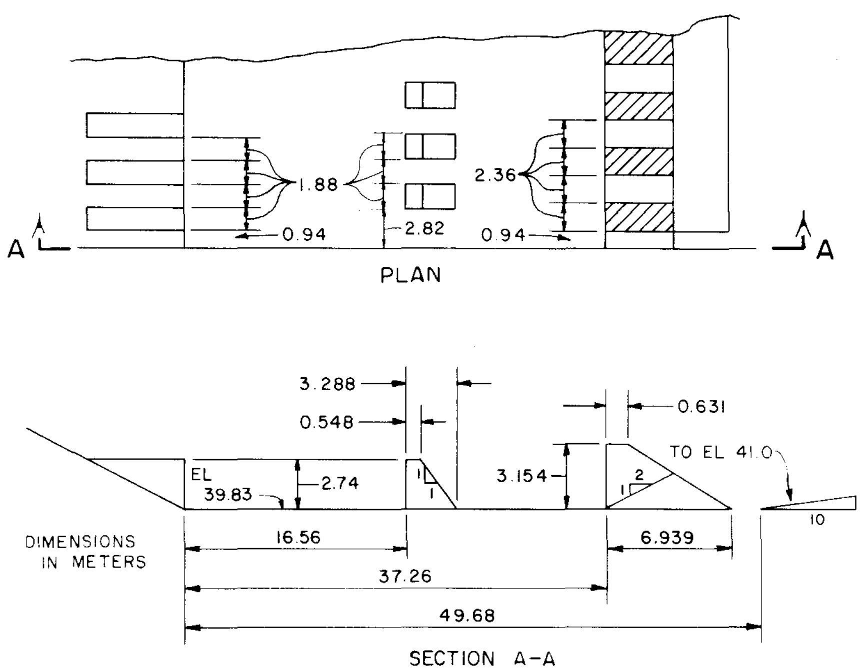


Figure 2.—Sketch of low Froude number stilling basin—Choke Canyon Dam—original design.

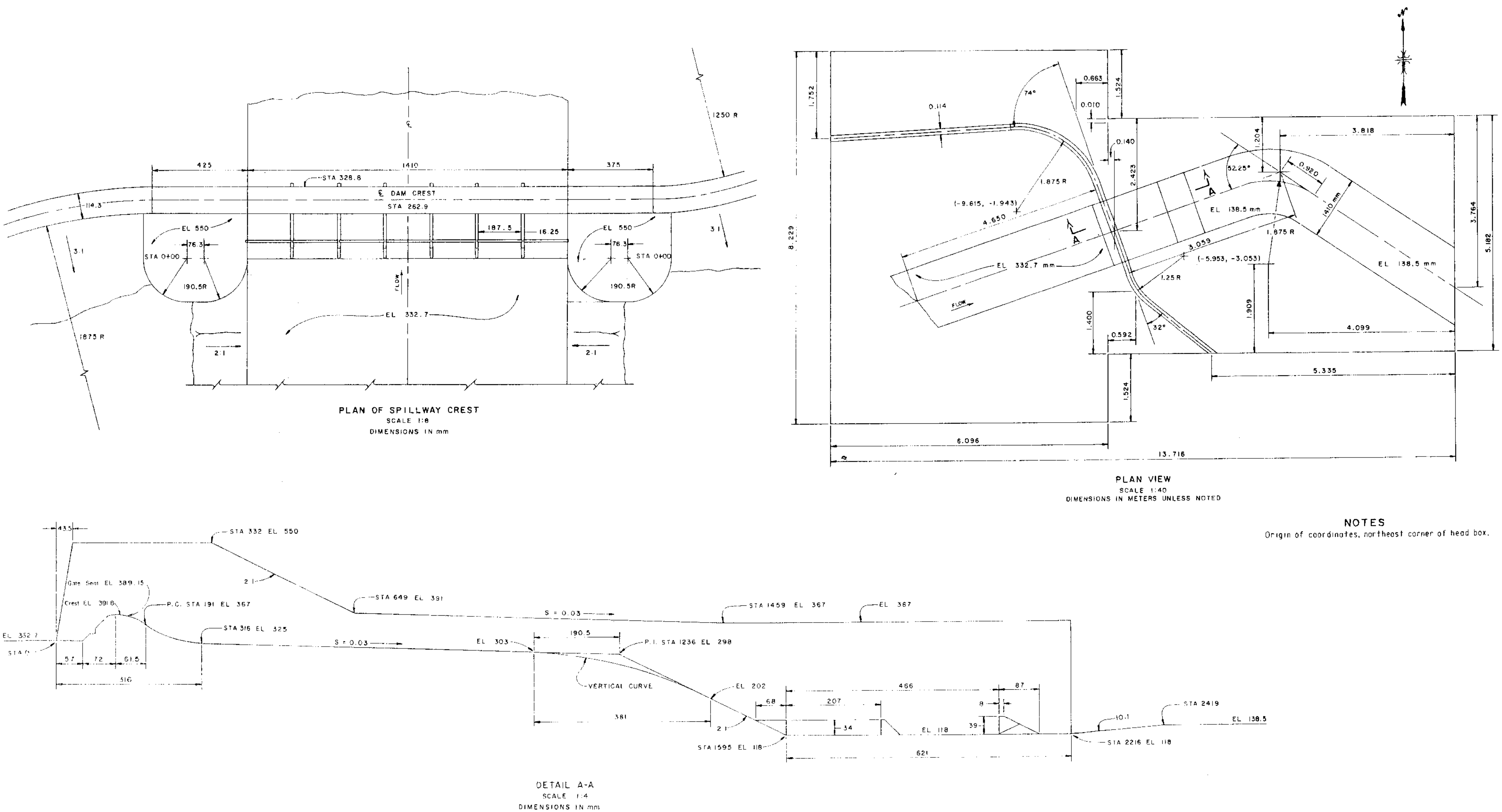


Figure 3.—Drawing of the model—showing the original model design.

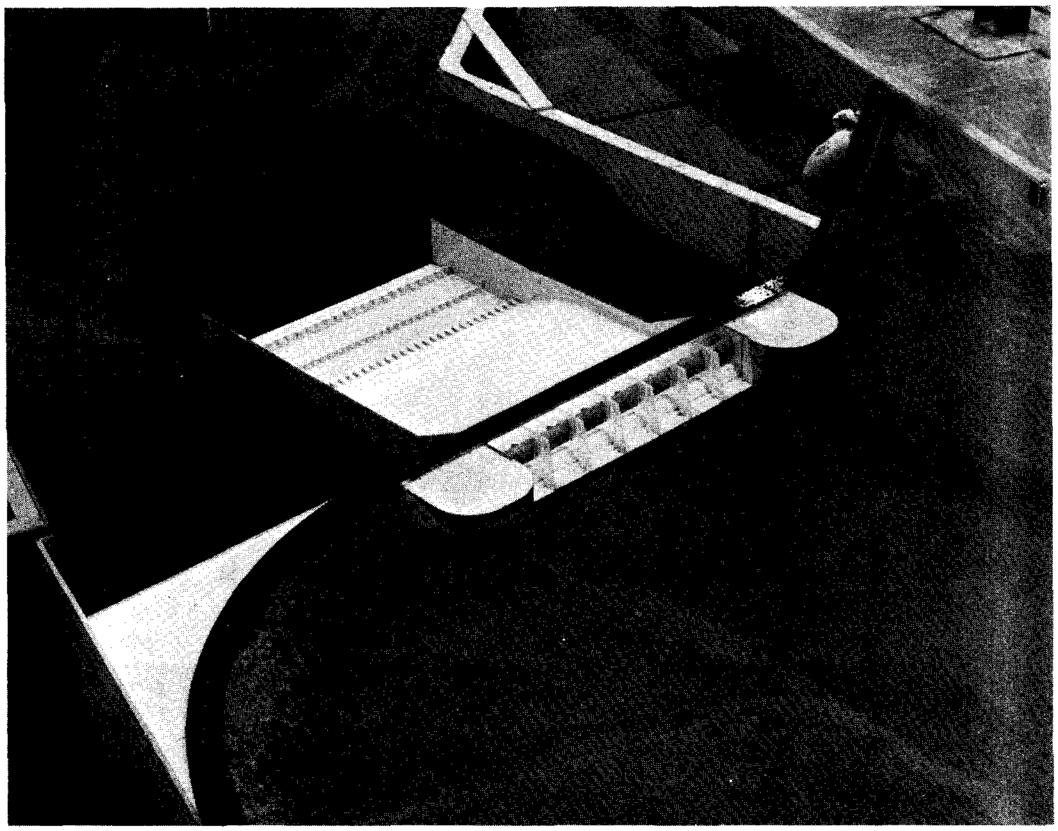


Figure 4.—Model as designed originally. The inlet walls were modified as was the approach channel. P801-D-79816

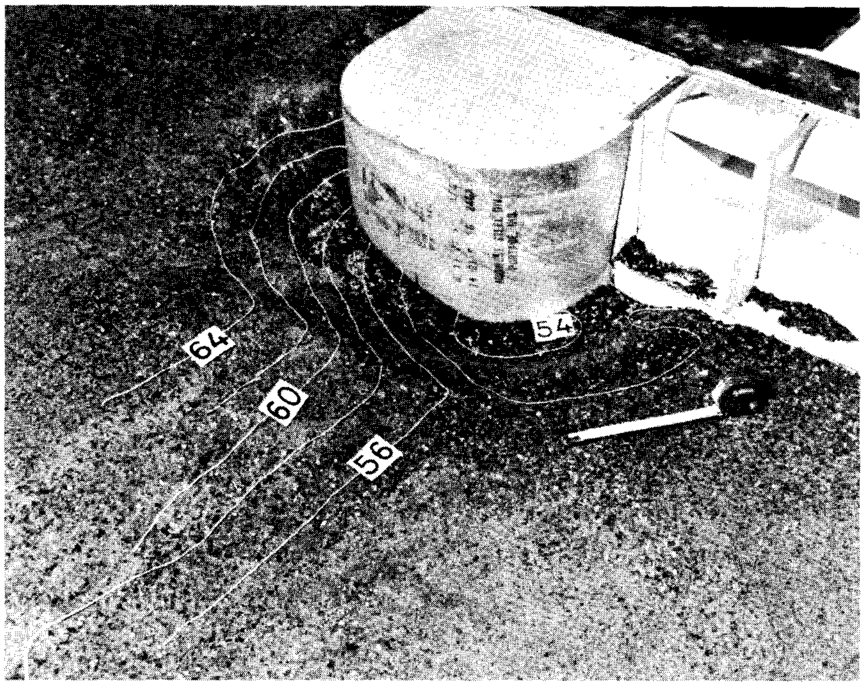


Figure 5a.—Scour around left inlet wall, Q_p = 7080 m^3/s tested for 8.94 hours—model as designed originally. Contour lines in meters. P801-D-79817

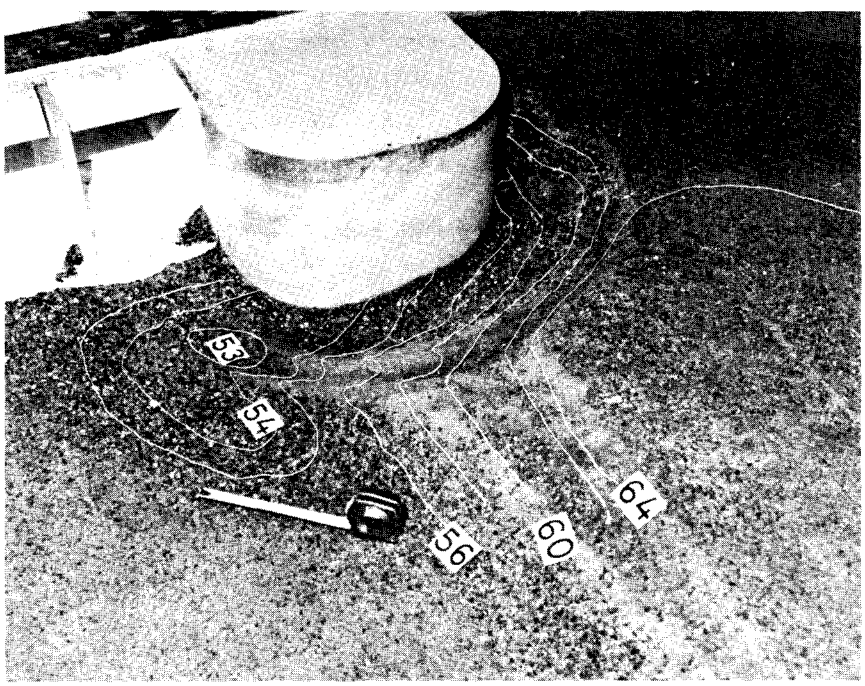


Figure 5b.—Scour around right inlet wall, Q_p = 7080 m^3/s tested for 8.94 hours—model as designed orginally. Contour lines in meters. P801-D-79818

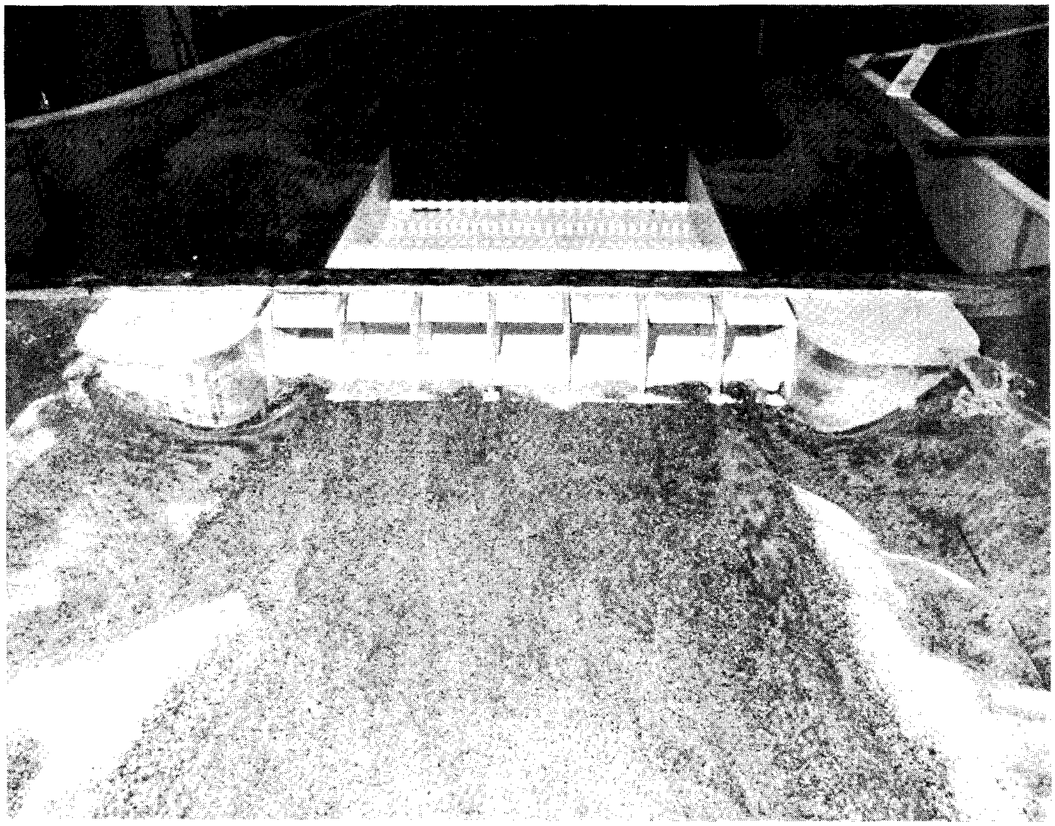
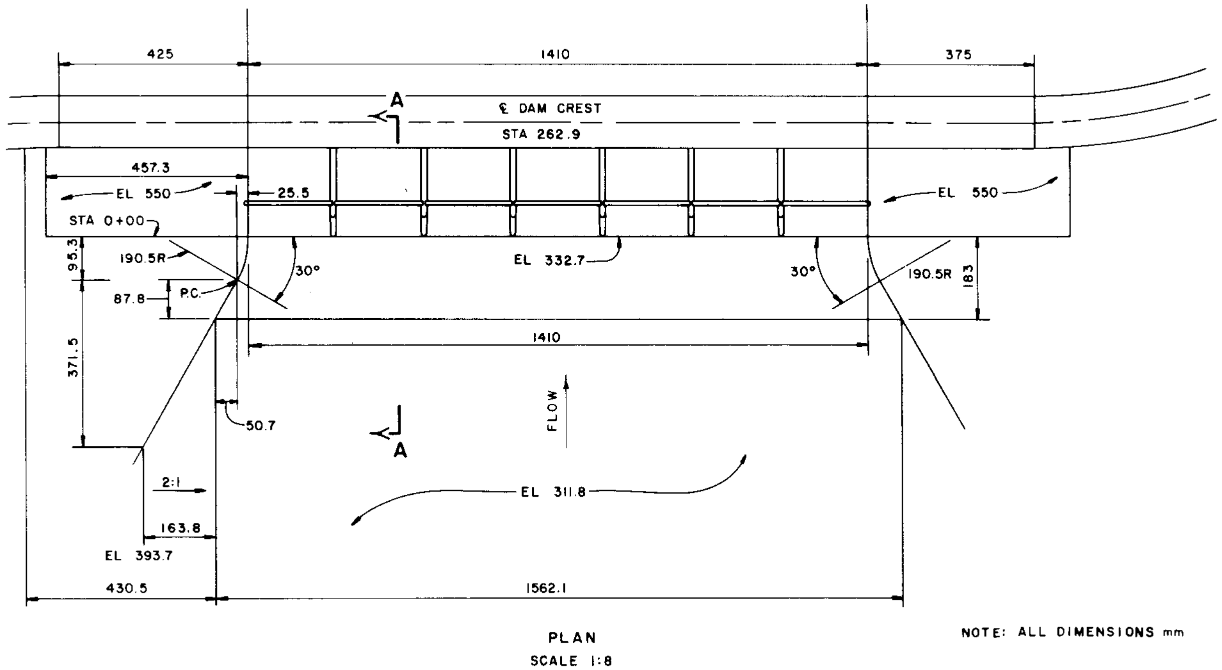


Figure 6.—Scour pattern with straight dikes, Q_p = 7080 m^3/s tested for 8.94 hours. P801-D-79819



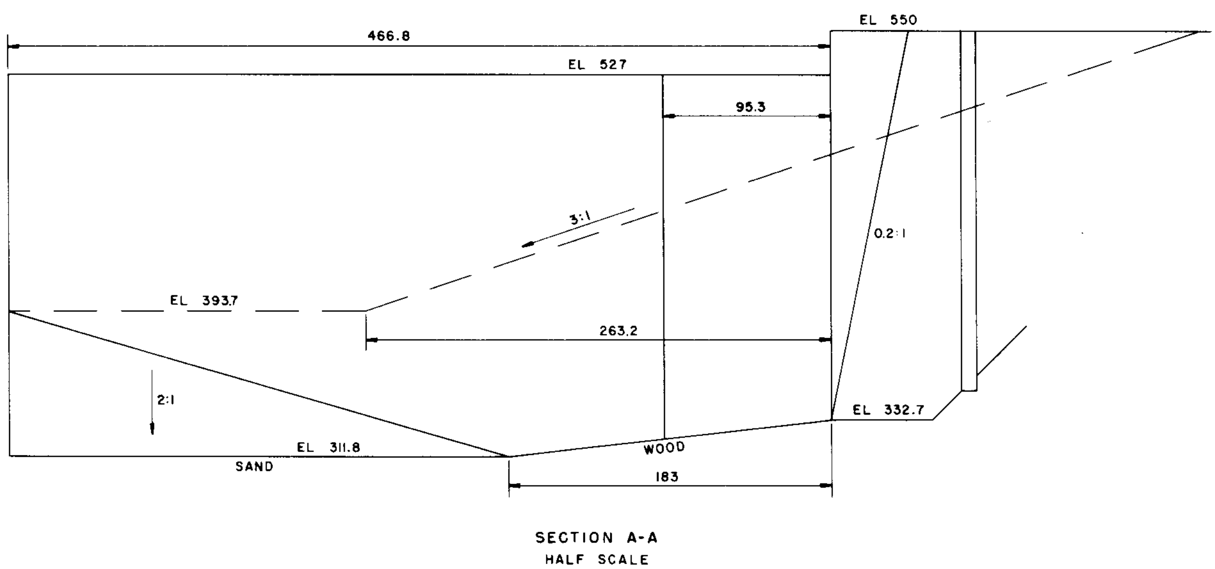


Figure 7.—Sketch of model with 30° wingwalls.

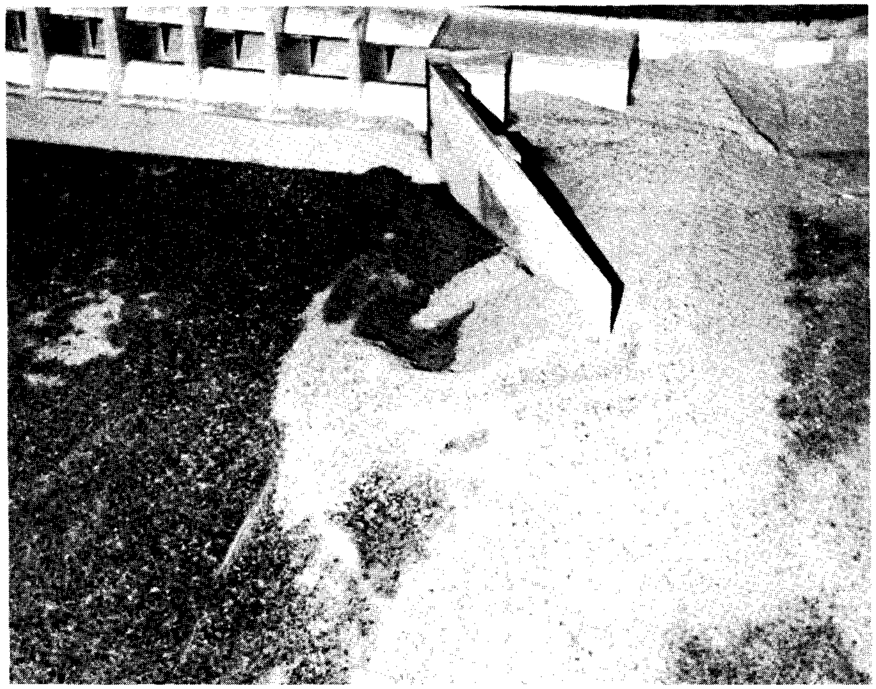


Figure 8.—Scour around right 30° wingwall with 100-m dike, Q_p = 7080 m³/s for 8.94 hours. P801-D-79820

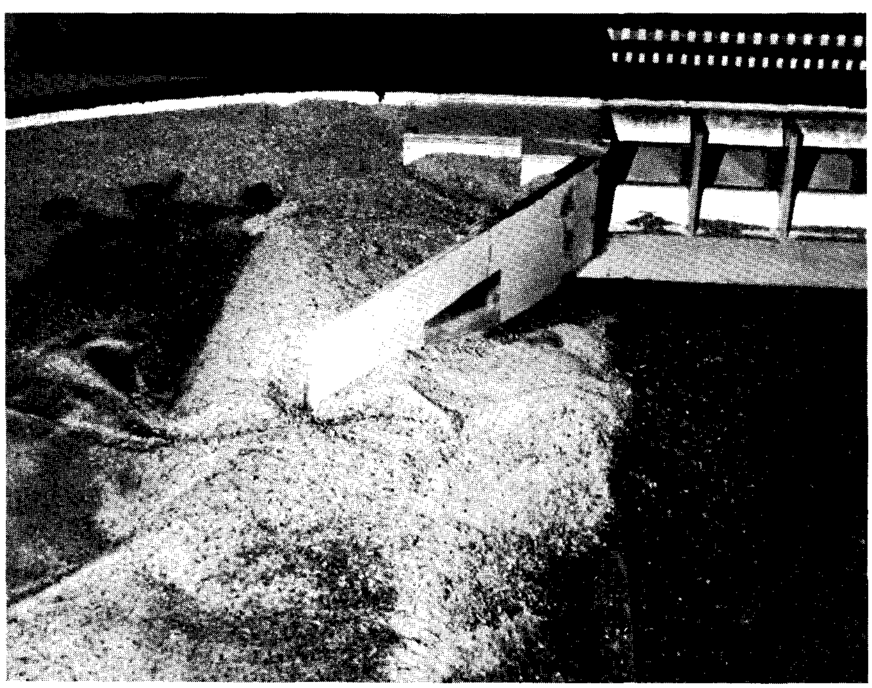


Figure 9.—Scour around left 30° wingwall with 100-m dike, Q_p = 7080 m³/s for 8.94 hours. P801-D-79821

Figure 10.—Scour in vicinity of 30° wingwall with 200-m dike, Q_p = 7080 m^3/s for 8.94 hours. P801-D-79822

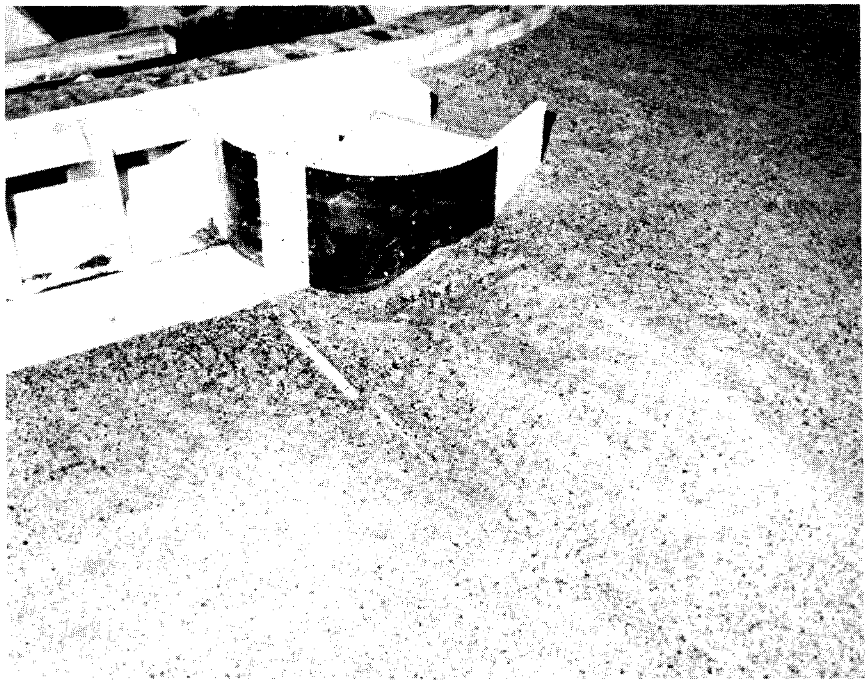


Figure 11a.—Scour with segmented right inlet wall, Q_p = 7080 m³/s for 8.94 hours. P801-D-79823

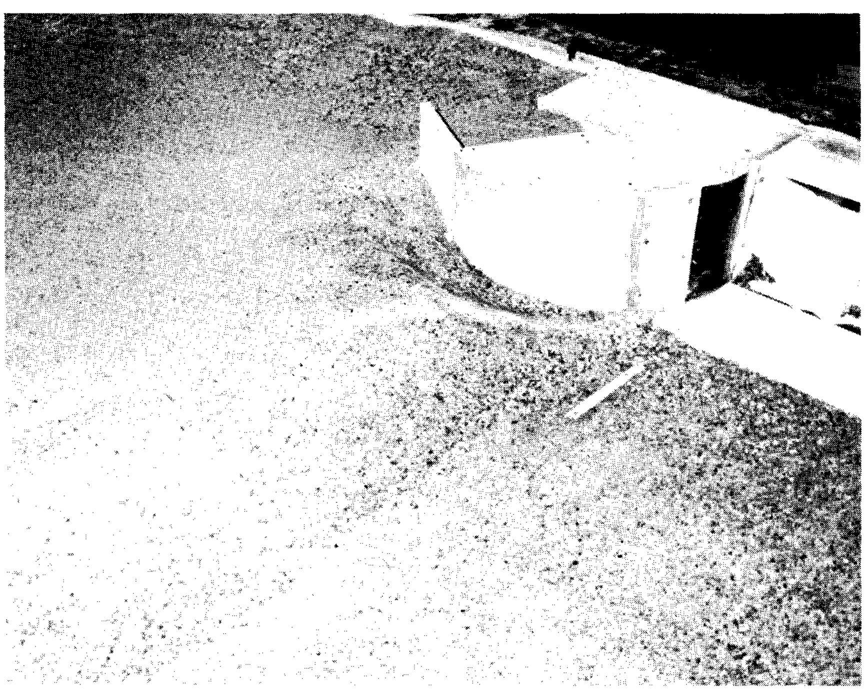


Figure 11b.—Scour with segmented left inlet wall, Q_p = 7080 m³/s for 8.94 hours. P801-D-79824

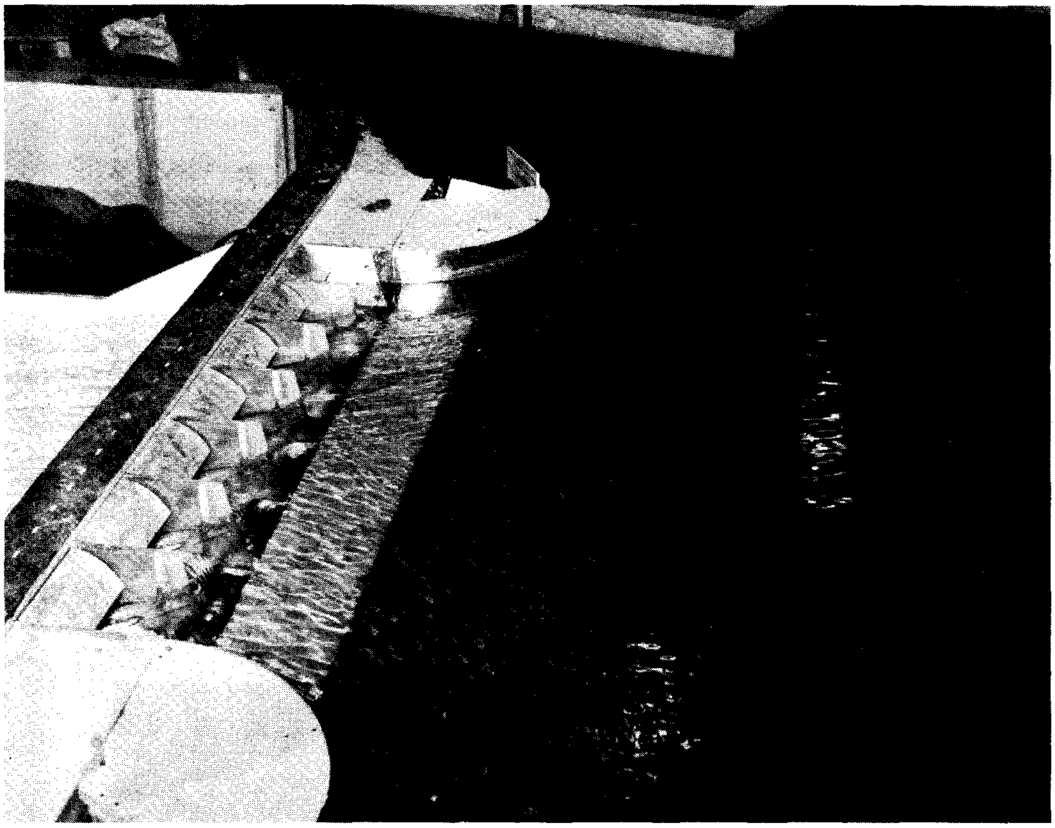


Figure 12.—Model discharging 0.083 m^3/s (Q_p = 4750 m^3/s), equivalent to 1000-year flood. P801-D-79825

Figure 13a.—Scour from 300-mm (24 m prototype) radius inlet wall with 400-mm (32 m prototype) extension at 90° to left inlet wall. P801-D-79826

Figure 13b.—Scour from 300-mm (24 m prototype) radius inlet wall with 210-mm (16.8 m prototype) extension at 120° to right inlet wall. P801-D-79827

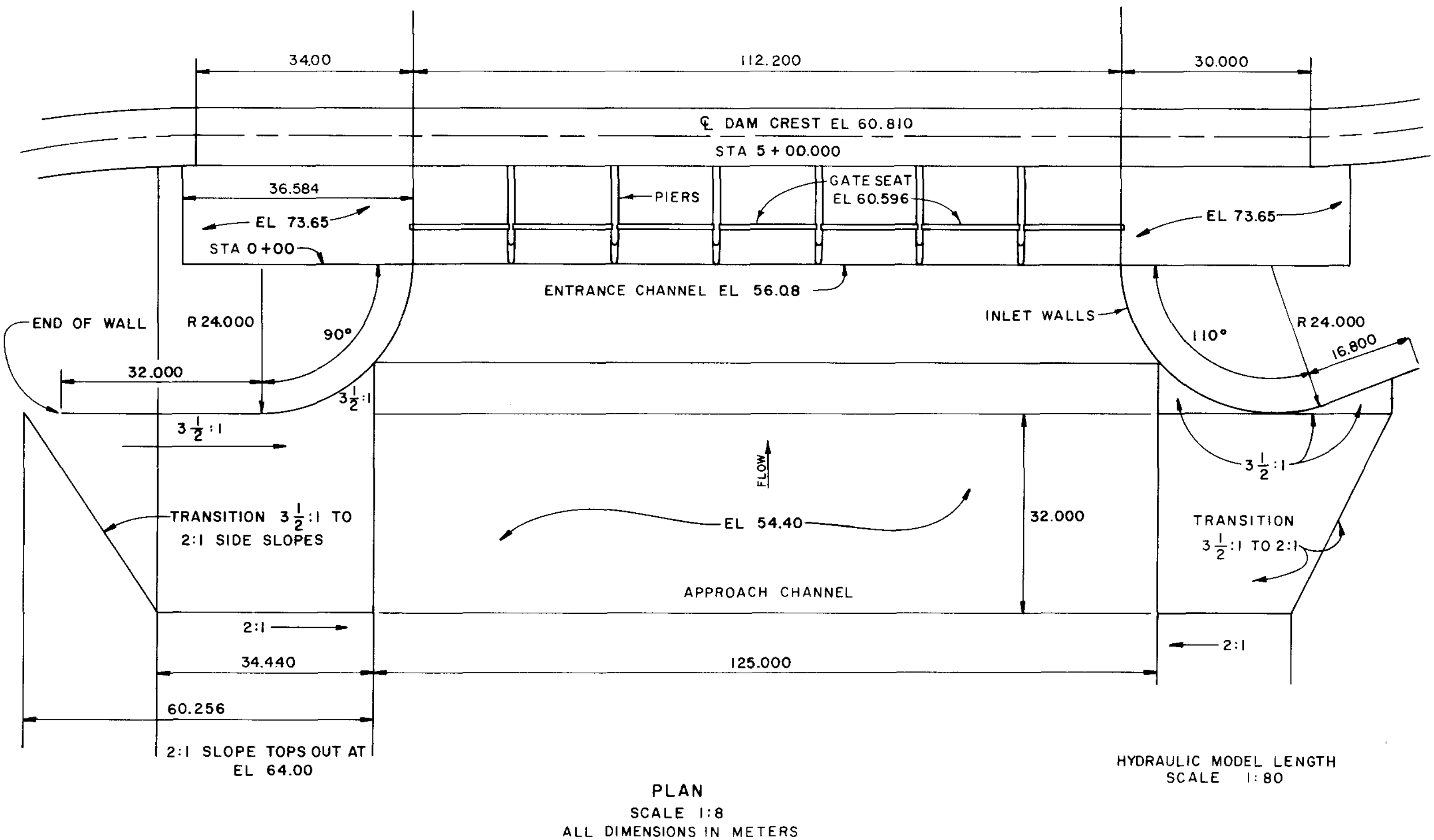


Figure 14.—Recommended design of inlet walls and approach channel—Choke Canyon Dam.

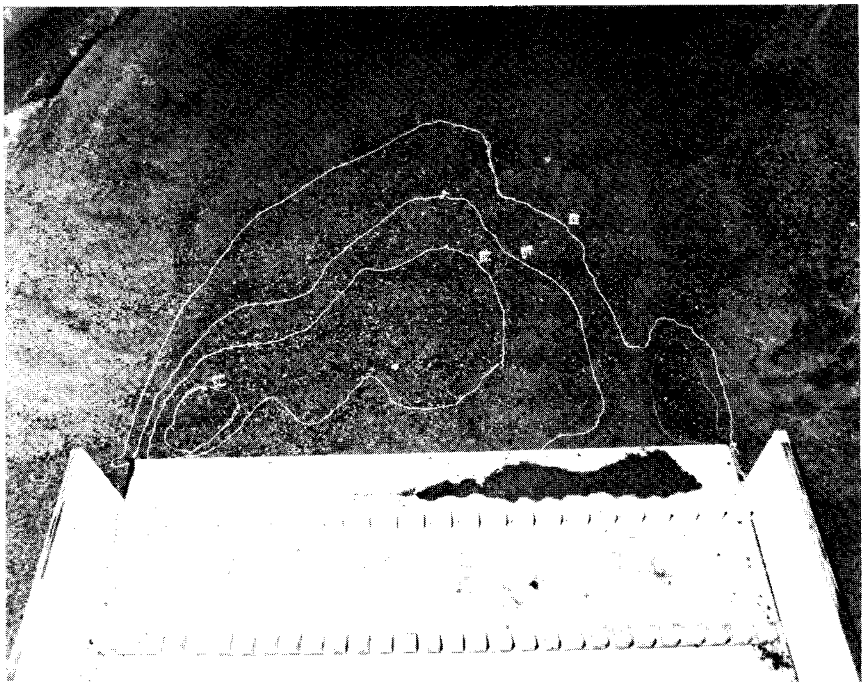


Figure 15a.—Scour pattern with sidewalls shortened 5.48 m and original apron, Q_p = 7080 m³/s for 8.94 hours. P801-D-79828

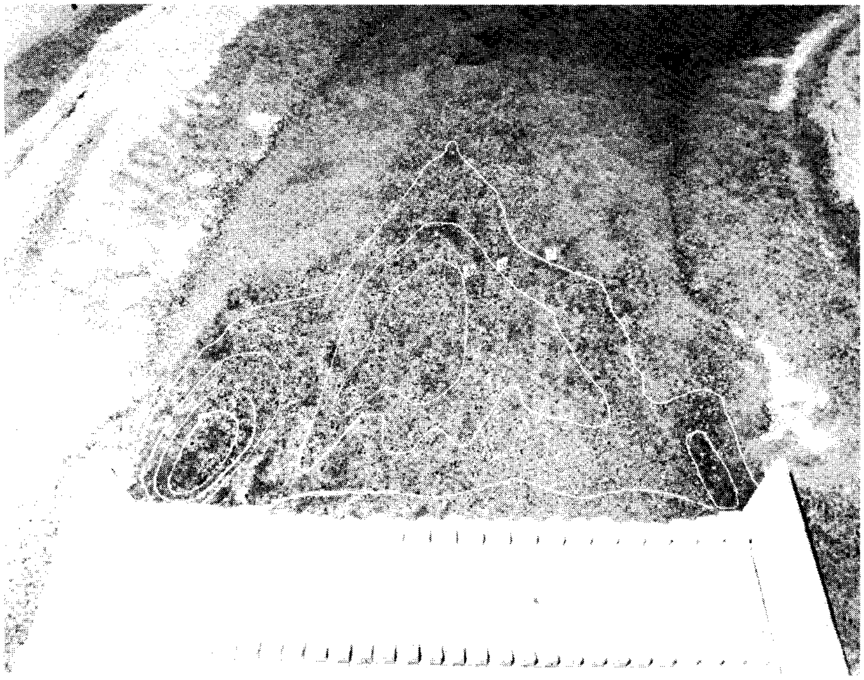


Figure 15b.—Scour pattern with sidewalls and apron shortened 5.48 m, Q_p = 7080 m³/s for 8.94 hours. Contour lines represent 1 m. P801-D-79829

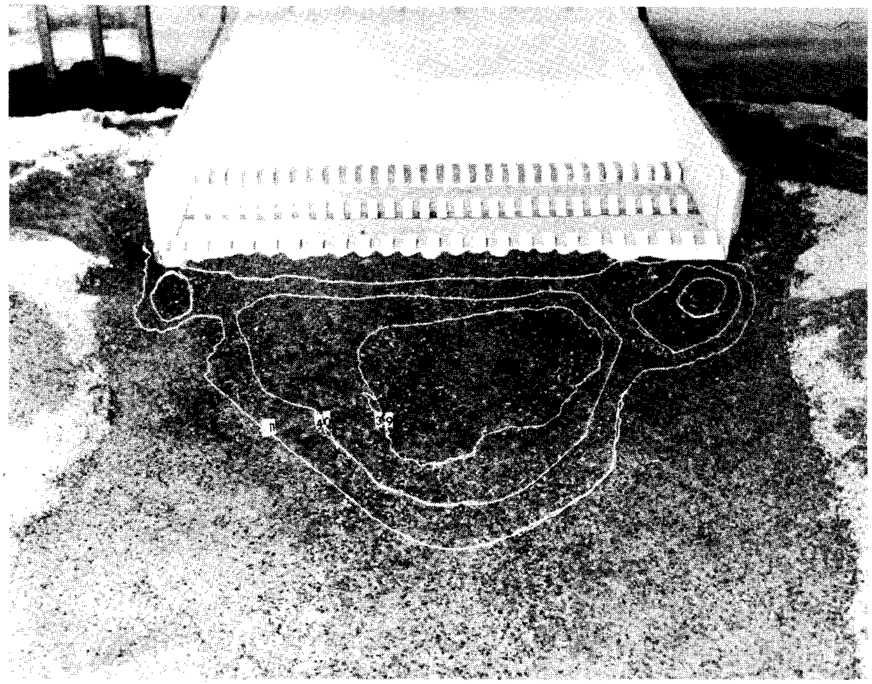


Figure 16.—Scour pattern with 2-1/2:1 side slopes around side-walls, basin shortened 5.48 m, Q_p = 7080 m³/s for 8.94 hours. P801-D-79830

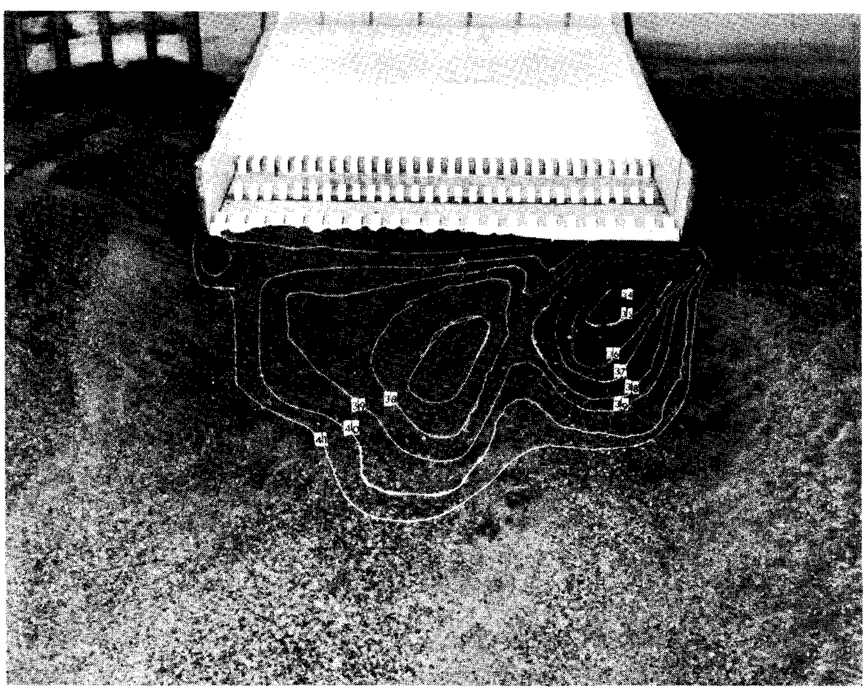


Figure 17.—Long-term scour test, Q_p = 7080 m³/s for 53.7 hours (6-h model time). P801-D-79831

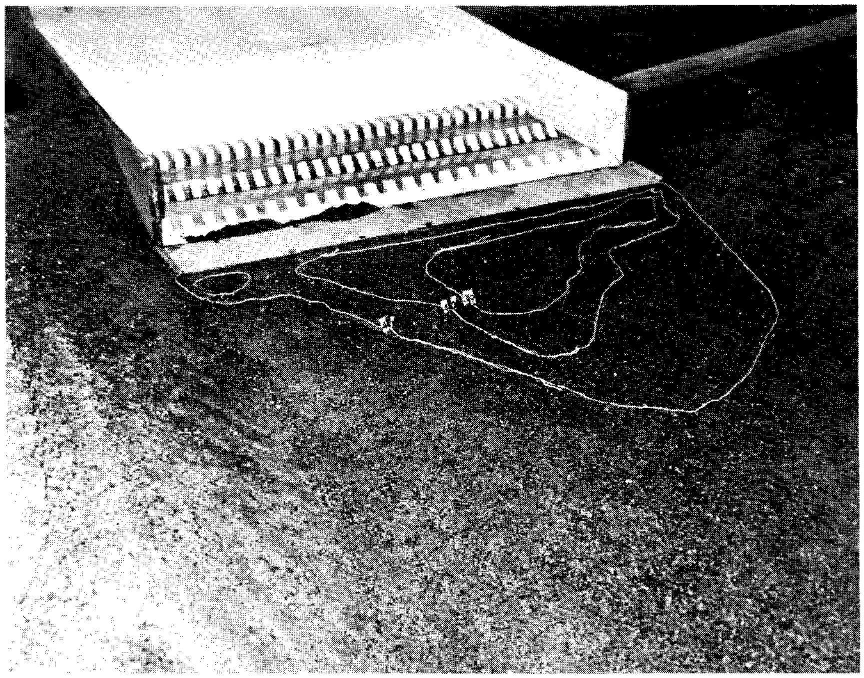


Figure 18.—Scour after 8.94 hours at Q_p = 7080 m³/s with 14-m apron. P801-D-79832

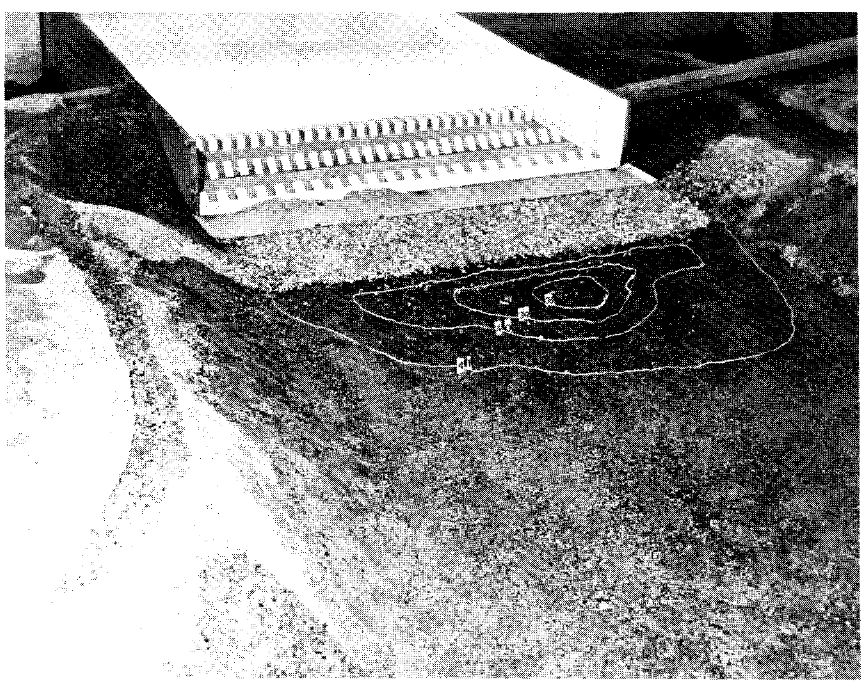


Figure 19.—Scour after 8.94 hours with 14-m apron and 32 m of riprap downstream, Q_p = 7080 m³/s. Contour lines represent 1 meter. P801-D-79833

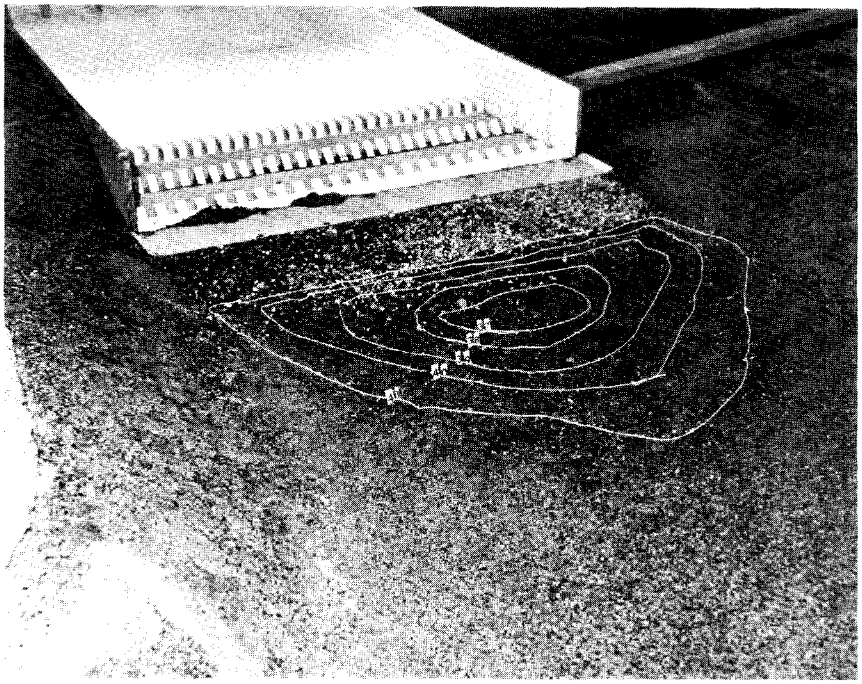


Figure 20.—Scour after 33.5 hours, 14-m apron and 32-m of riprap downstream Q_p = 7080 m³/s, (3.75 h model). P801-D-79834

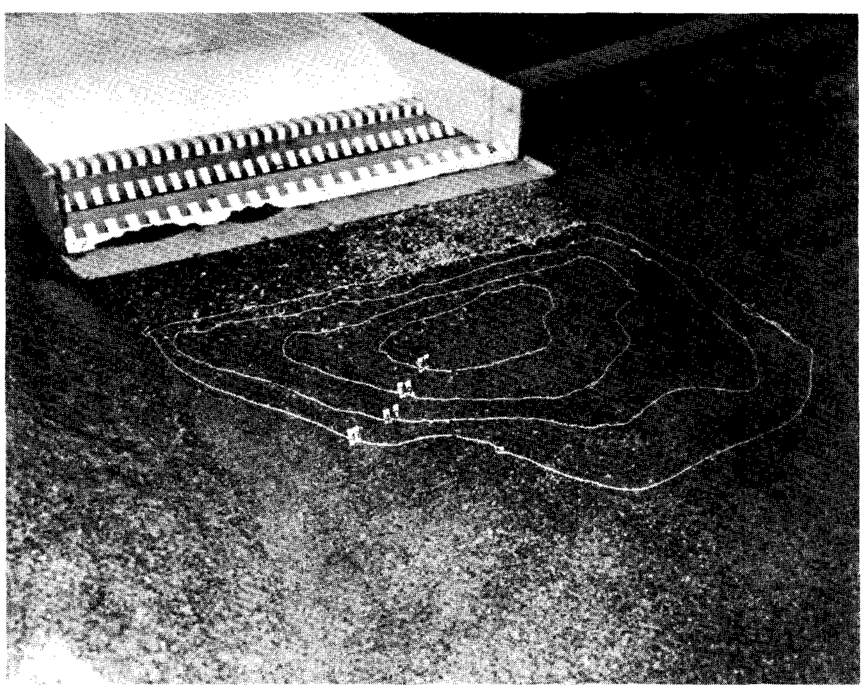


Figure 21.—Scour after 49.2 hours, 14-m apron and 32 m of riprap downstream, Q_p = 7080 m³/s, (5.50 h model). P801-D-79835

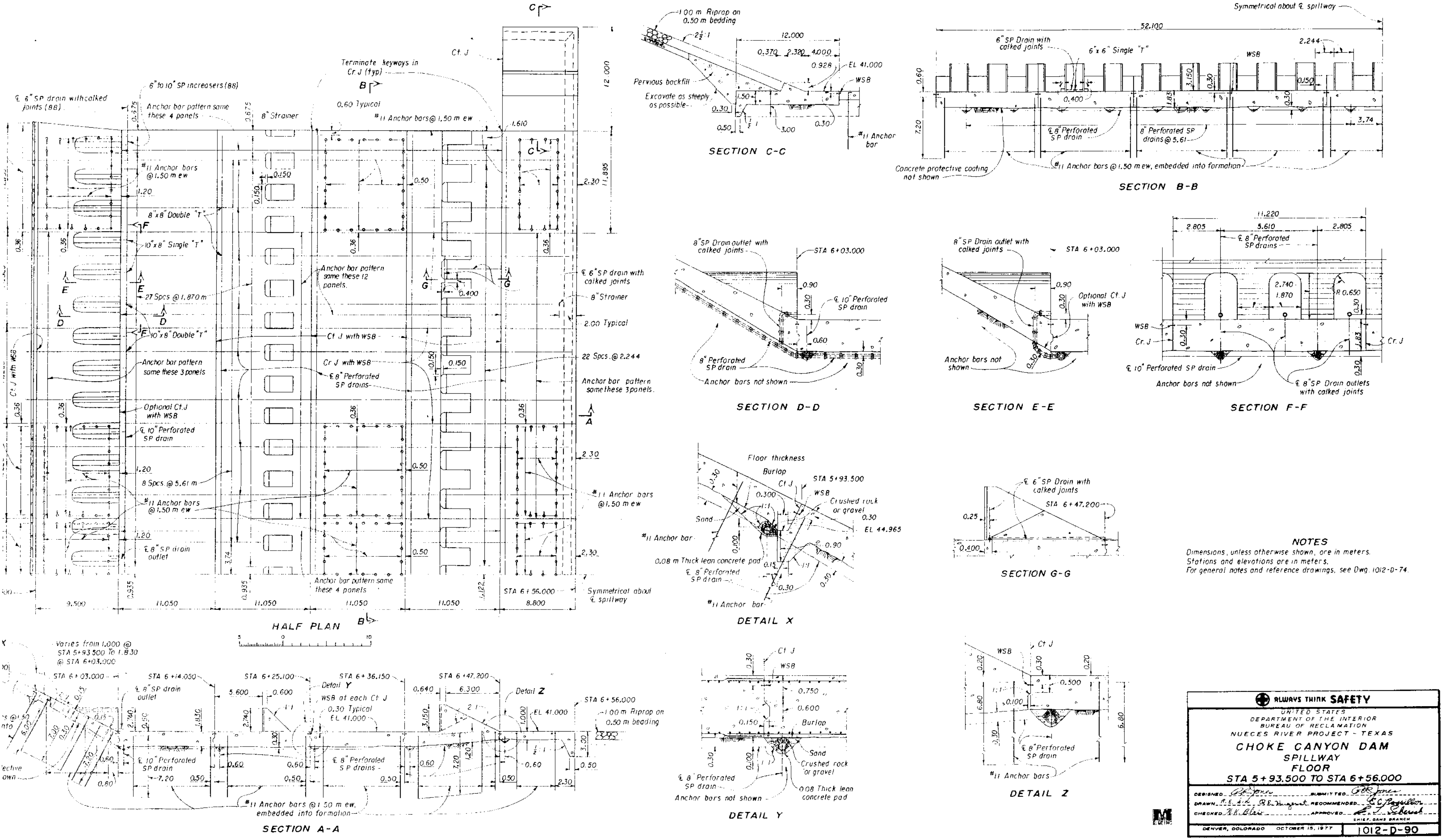


Figure 22.—Final design of Choke Canyon Dam stilling basin.

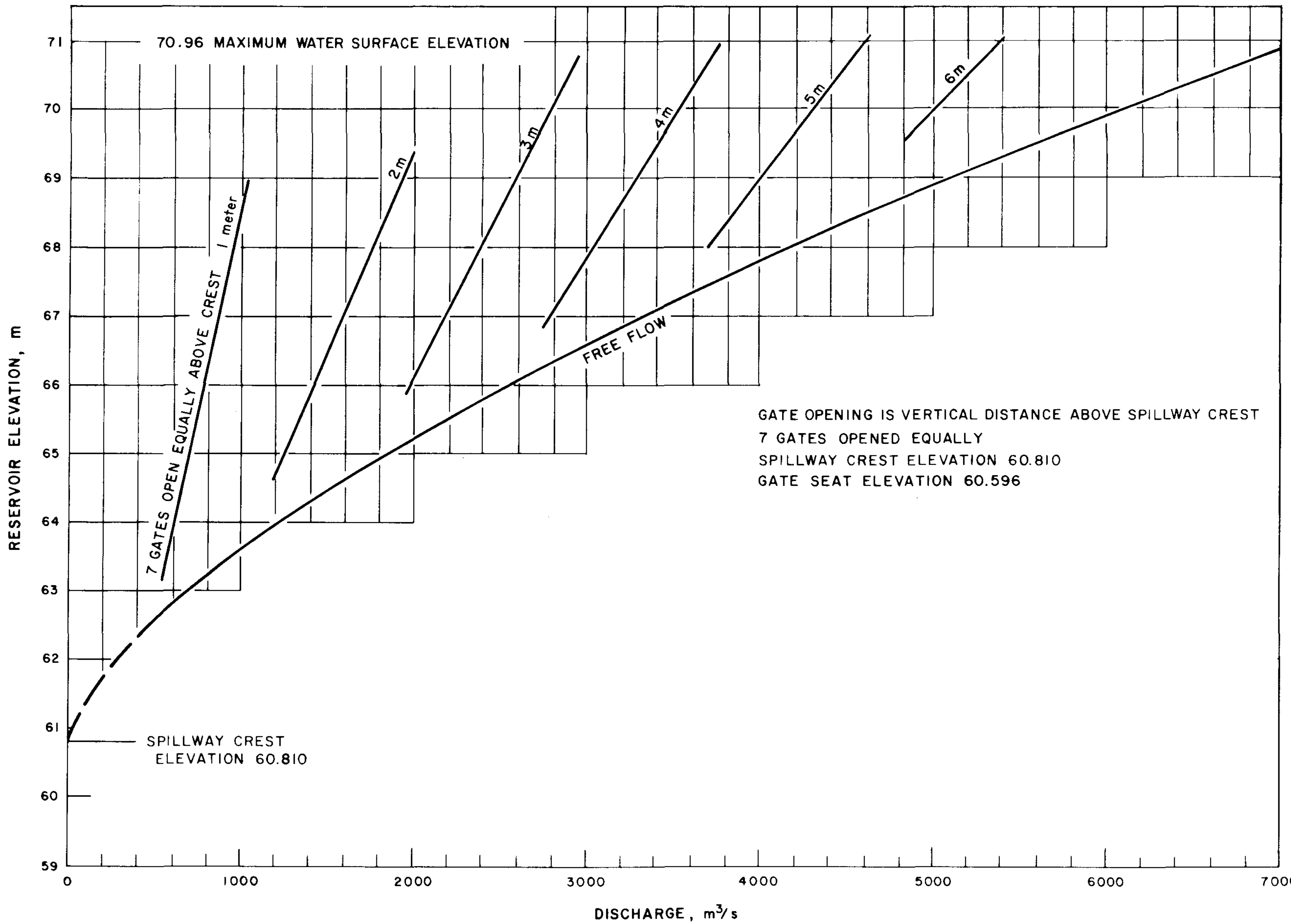


Figure 23.—Spillway discharge curves—Choke Canyon Dam.

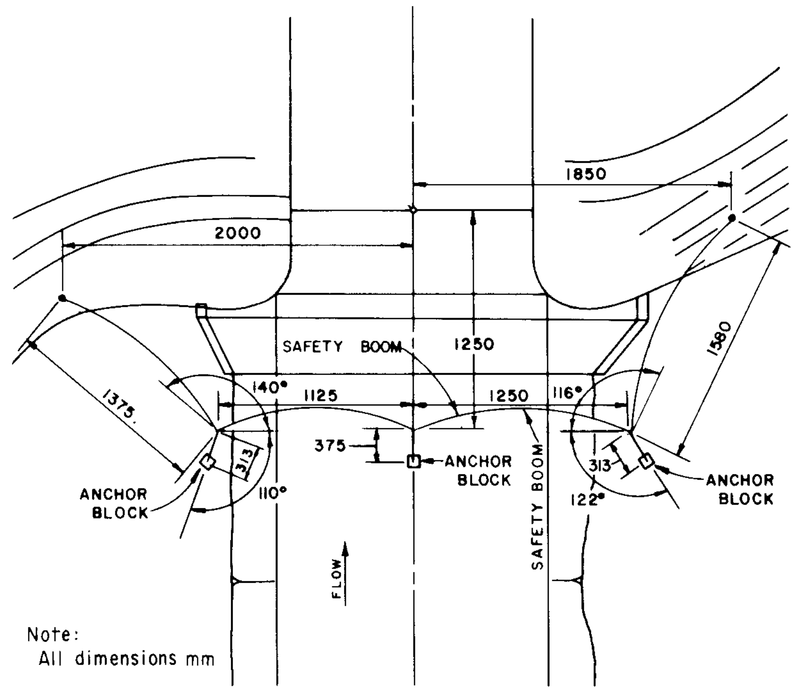


Figure 24.—Sketch of Choke Canyon Dam model safety boom.

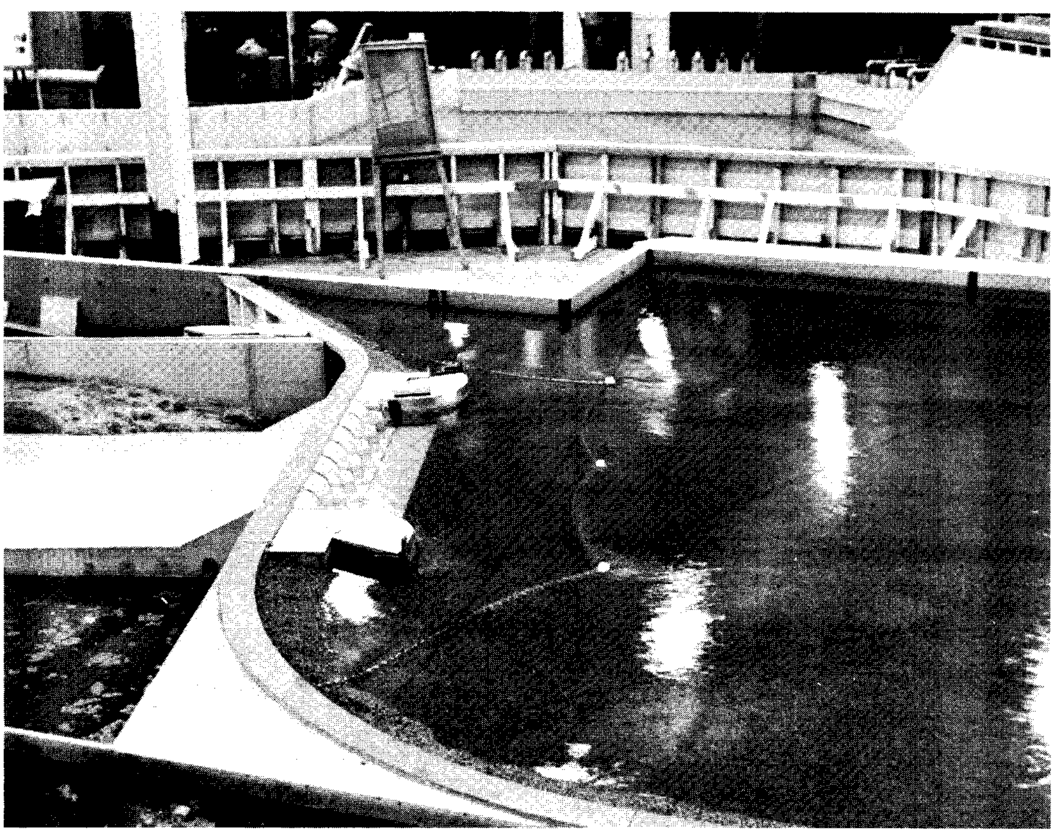


Figure 25.—Choke Canyon Dam model safety boom in place, Q_p = 7080 m³/s. P801-D-79836

GPO 836-917

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.