GR-79-2

T OR C BAFFLED APRON SPILLWAY

Hydraulics Branch
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16. ABSTRACT

Studies were made on a 1:30 scale model of the emergency spillway for the T or C - Williamsburg, Site 8-C Dam located in New Mexico. The dam, to be constructed by the U.S. Soil Conservation Service, will be 90 ft (27.4 m) high and have a crest length of 1920 ft (585.2 m). The 200-ft (61.0-m)-wide spillway, with a capacity of 25 100 ft^3/s (710.8 m^3/s), will be a baffled apron spillway with blocks sized for two-thirds of this maximum discharge. The adequacy of this design and the scour at the base of the spillway were determined. Maximum scour observed was about 17.8 ft (5.5 m), at the base of the spillway. A discharge rating curve was developed for operation of the ungated spillway. The entrance was modified to reduce the high velocities observed immediately downstream from the entrance.

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ACKNOWLEDGMENTS

Valuable data and information on the preliminary design, and field data were supplied by Gary Richardson and Lamont Robbins, U.S. Soil Conservation Service, Albuquerque, New Mexico; their assistance is greatly appreciated.

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PURPOSE

The purposes of the model study were to determine the depth of local scour (scour from the original streambed at the base of the spillway) and general scour (scour away from the structure) that resulted from the passage of the freeboard hydrograph flow (fig. 1), to develop a discharge rating curve, and to verify the overall performance of the emergency spillway. In addition, the scour caused by long-term (8.22-hour prototype) constant-discharge flow was determined. The data on the performance of the ungated, baffled apron spillway and entrance are general and can be applied to other sites. However, the data on scour are site-specific and should not be applied to other sites unless they are similar to this one.

INTRODUCTION

The T or C[1] — Williamsburg, Site 8C Dam will be located in Mud Springs Canyon in the southern part of Sierra County in south-central New Mexico. Site 8C will be a single purpose flood retarding structure, built by the U.S. Soil Conservation Service. The dam will be about 1 mi (1.6 km) upstream from Williamsburg and about 1½ mi (2.4 km) from the confluence of Mud Springs Canyon and the Rio Grande River. Mud Springs Canyon enters the Rio Grande River about 4 mi (6.4 km) below Elephant Butte Reservoir.

The dam will be about 90 ft (27.4 m) high, with a 20-ft (6.1-m) top width and a crest length of approximately 1920 ft (585.2 m). The reservoir formed behind the dam will have a total storage capacity of 2403 acre-feet (2 964 000 m^3) below the emergency spillway crest elevation, 4469.7 ft (1362.36 m), with 942 acre-ft (1 162 000 m^3) for sediment storage and 1461 acre-feet (1 802 000 m^3) allocated for flood storage. The capacities and elevations in the foregoing were obtained by rerouting the freeboard

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[1] T or C is an abbreviated form of Truth or Consequences (N. Mex.).

hydrograph flood through the reservoir and raising the spillway crest elevation from the 4468.41 ft (1361.971 m) shown on figure 2. These changes resulted when the sediment storage was increased from 830 to 942 acre-feet (1 024 000 to 1 162 000 m^3), and the model studies indicated the spillway crest could be raised.

The reservoir storage and the capacity of the principal spillway will be adequate for all discharges from storms with 1 percent or greater chance of occurrence. For larger storms, such as shown on the outflow hydrograph of figure 1, the 200-ft (61.0-m)-wide baffled apron emergency spillway will be used.

CONCLUSIONS

1. The performance of the spillway with a 50-percent surcharge was very adequate.

2. The maximum local scour at the base of the spillway was 17.8 ft (5.43 m) for the freeboard hydrograph flood.

3. A discharge rating of the spillway crest was developed.

SPILLWAY DESIGN

Design Criteria

The emergency spillway was designed according to the design criteria of *Hydraulic Design of Stilling Basins and Energy Dissipators* [1][2] and "A Baffled Apron as a Spillway Energy Dissipator" [2]: The height of the blocks, H, should be $0.8D_c$; where D_c is

[2] Numbers in brackets refer to references in the bibliography.

the critical depth, $D_c = \sqrt[3]{q^2/g}$. For this study, the unit discharge, q, was based on two-thirds of the maximum freeboard hydrograph discharge of 25 123 ft^3/s (711.4 m^3/s). The width of the blocks and spacing between the blocks should be $1.5H$. Spacing between rows of blocks was $3H$ for the 3:1 slope of the spillway. The height of the sidewalls, perpendicular to the slope, should be 3 times the height of the blocks plus the critical depth for any surcharge. The height of the sidewall above the entrance should be 1.5 times the critical depth of the total discharge.

Baffled Apron Spillway Dimensions

Table 1 summarizes some pertinent dimensions used to size the emergency spillway and to build the spillway model. The emergency spillway sidewalls were designed for a discharge of 25 123 ft^3/s (711.4 m^3/s); however, block heights and spacings were developed for two-thirds of 25 123 ft^3/s, which is 16 748 ft^3/s (474.3 m^3/s).

Table 1. - *Emergency spillway data*

Description		
Freeboard hydrograph discharge	25 123 ft^3/s	711.4 m^3/s
Design discharge	16 748 ft^3/s	474.3 m^3/s
Width of spillway	200 ft	61.0 m
Slope of spillway	3:1	3:1
Crest elevation	4468.41 ft	1361.971 m
Nominal elevation at base of spillway	4387 ft	1337.2 m

Figure 2 shows the emergency spillway proportioned according to the previous criteria and data furnished in Design Engineer Report, T or C Williamsburg Watershed Site 8C [3].

Spillway Calculations

Discharge		Unit discharge, q		Critical depth, D_c	
(ft^3/s)	(m^3/s)	(ft^3/s)/ft	(m^3/s)/m	(ft)	(m)
25 123	711.4	125.62	11.67	7.88	2.402
16 748	474.3	83.74	7.78	6.02	1.835
8 374	237.1	41.87	3.89	3.79	1.155

(1) Block height - $H = 0.8D_c = 0.8\ (6.02) = 4.81$ ft (1.466 m)
(2) Block width - $1.5H = 1.5 \times 4.81 = 7.22$ ft (2.201 m)
[3]6.06 ft (1.847 m)
(3) Spacing between rows - $3H = 3 \times 4.81 = 14.43$ ft (4.398 m)
(4) Sidewall height - $3 \times 4.81 + 3.79 = 18.22$ ft (5.553 m)
(5) Sidewall above crest - $1.5 \times 7.88 = 11.82$ (3.603 m)
[3]12.06 ft (3.676 m)

THE MODEL

The model was constructed to a scale of 1:30. The head box, tailbox, and spillway were constructed from plywood (fig. 3). The tailbox was filled with graded sand to represent the topography at the damsite. The model included 1100 ft (335.3 m) downstream from the centerline of the dam and 300 ft (91.4 m) either side of the centerline of the spillway, which is located near the center of the dam. Water entered the model through a 4-in (100-mm) rock baffle to produce a wave-free reservoir. The completed model is shown in figure 4. The strings indicate contour lines on the model sand bed.

MODEL SIMILITUDE PARAMETERS

The model was constructed to an undistorted linear scale of 1:30 and was evaluated according to the Froude laws of similarity. Discharge of the model, Q_m, was determined by $Q_m = L_r^{5/2}\ Q_p$, where Q_p is the prototype discharge and L_r is the ratio of

[3] Actual values used in design of the structure.

model length to prototype length. A model discharge of 5.10 ft^3/s (0.144 m^3/s) represented 25 100 ft^3/s (710.8 m^3/s) in the prototype.

All water surfaces, depth of scour, and distances on the model were accurately modeled at a scale of 1:30. The accurate representation of the scour was possible by scaling of the bed material in the model. The gradation of the sand in the model was scaled from the original grain size distribution by determining the settling velocities of each fraction, then the velocities were scaled according to the Froude model relationship $V_m = (L_r^{1/2})\ (V_p)$, where V_m is the model velocity and V_p is the prototype velocity. Next, the grain size distribution that corresponds to the scaled settling velocities was determined and this distribution was used in the model.

The gradation of pit TC-3 was used to represent the field conditions and is shown in table 2. Also shown are the scaled gradation, based on scaling of the settling velocities, and the gradation that resulted from mixing graded sand in the laboratory. The mixed sand was used in the downstream section of the model.

Table 2. - *Field and model soil gradations, percent retained*

Sieve	Field	Model scaled	Model used
3 inches	4		
1-1/2 inches	6		
3/4 inch	15		
3/8 inch	38		
No. 4	56	2	2
No. 8	68	8	7
No. 16	78	20	19
No. 30	85	37	42
No. 50	90	68	66
No. 100	94	88	94
Pan	100	100	100

Time scaling in Froude models is the same as velocity scaling. That is, $t_m = t_p L_r^{1/2}$, where t_m and t_p are model time and prototype time, respectively. This relationship was used to scale the times of the prototype data to model times. Conversely, some timed events in the model have been scaled and reported as a prototype time in this report. Hydraulic models of scour and sediment movement sometimes vary slightly from the above scaling relationship when verified by field data. That is, the scour to a particular depth occurs slower or faster than indicated by $t_m = t_p L^{1/2}$. However, the scour to a stable condition (long-term scour) was modeled accurately for each specific set of conditions tested.

MODEL TESTS

Freeboard Hydrograph Scour Tests

Two different scour tests were conducted on the model. First, the complete stepped model freeboard hydrograph, figure 5, was run and scour was measured at the end of the test. During these tests, the model was started at the first value of discharge for the time interval indicated on figure 5. Then the discharge was changed to the next value for the corresponding time interval. This procedure was repeated until the continuous hydrograph of figure 5 had been simulated by a series of constant discharges.

The second test was an incremental hydrograph where the model was run following the stepped freeboard hydrograph until the end of a selected constant discharge, the scour measurements were taken, and the model was restarted at the next discharge on the stepped freeboard hydrograph and run for another increment of time. This procedure was repeated throughout the complete freeboard hydrograph. Scour measurements were taken at the times indicated on figure 5. These times correspond to prototype times of 1.55, 4.11, and 8.22 hours after the start of the freeboard hydrograph.

The results of the complete freeboard hydrograph tests are shown in the photographs of figure 6 and in table 3. The measured local scour at the base of the spillway 315 ft (96 m) downstream from the centerline of the dam and general scour 665 ft (203 m) from the centerline of the dam were 17.8 ft (5.43 m) and 6 ft (1.83 m), respectively.

Very little bed material moved after 90 minutes (8.22 hours in the prototype) of the complete freeboard hydrograph, so most of the model tests were stopped at this point.

Table 3.—*Scour from complete and incremental freeboard hydrographs*

Type of hydrograph	Prototype time (h)	Local scour		General scour	
		(ft)	(m)	(ft)	(m)
Complete*	—	17.0	5.2	6.0	1.8
	—	18.5	5.6	6.0	1.8
	avg.	17.8	5.4	6.0	1.8
Incremental	0	0.0	0.0	0.0	0.0
	1.55	17.0	5.2	4.0	1.2
	4.11	19.0	5.8	6.0	1.8
	8.22	19.0	5.8	6.25	1.9

* Two complete freeboard hydrograph tests were run.

A photograph taken after the incremental freeboard hydrograph tests is shown on figure 7 and the data are shown in table 3. The local scour reached elevation 4370 ft (1332.0 m), 17 ft (5.2 m) below starting elevation 4387 ft (1337.2 m), during the first 1.55 hours (prototype) of the hydrograph. The rate of scour then slowed down considerably; after 8.22 hours (prototype), the local scour stabilized at 19 ft (5.8 m) below elevation 4387 ft (1337.2 m). Downstream scour progressed uniformly throughout the test. This combination of rapid erosion at the base of the spillway and gradual erosion away from the spillway caused a steep gradient to form in the early stages of the freeboard hydrograph flow. This steep gradient gradually decreased to a gentler slope by the end of the test.

Figure 8 shows a comparison of the final scour of the complete freeboard hydrograph tests, the incremental freeboard hydrograph tests, and the results of a mathematical model study of the scour problem as performed by CSU (Colorado State University). The results from CSU agree very well with the laboratory data.

Long-Term Constant Discharge Tests

In addition to the freeboard hydrograph scour tests, constant discharge scour tests were run. Constant discharges of 5000 ft^3/s (141.6 m^3/s), 16 800 ft^3/s (475.7 m^3/s), and 25 100 ft^3/s (710.8 m^3/s) were used for these tests. The duration of each test was 90 minutes (8.22 hours prototype). The photographs in figure 9 show the scour that resulted from these tests, and the results are summarized in table 4. The maximum local scour ranged from 13 to 19 ft (4 to 5.8 m).

Table 4.—*Scour from constant discharge tests*

Discharge		Local scour		Scour 665 ft (203 m) downstream from centerline of the dam	
(ft^3/s)	(m^3/s)	(ft)	(m)	(ft)	(m)
5 000	141.6	13.0	4.0	1.0	0.3
16 800	475.7	17.0	5.2	4.5	1.4
25 100	710.8	19.0	5.8	6.0	1.8

The differences of scour patterns and depth of scour between the long-term constant discharge and the complete freeboard hydrograph are not great. This is seen by comparing figures 6 and 9c. The local scour for a constant discharge of 25 100 ft^3/s was 19 ft (5.8 m) and the local scour of the complete hydrograph was 17.7 ft (5.4 m).

Flow on the Spillway

The baffled spillway dissipated the energy very well for all discharges. However, at the top of the spillway the velocity became too high before the flow struck the first row of blocks placed 28.86 ft (8.796 m) from the entrance. A rough, wavy surface developed downstream from this row of blocks. This can be seen in figure 10 for discharges of 5000, 16 800, and 25 100 ft^3/s (141.6, 475.7, and 710.8 m^3/s). The roughest surface occurred near the discharge of 16 800 ft^3/s.

An additional row of blocks was placed at 14.43 ft (4.398 m) from the entrance to prevent the high velocities and the resulting rough flow. These blocks performed well, as can be seen in the photographs of figure 11. The flow is much smoother for all discharges with the extra row of blocks.

The water surface profiles on the spillway are shown on figure 12 for flows of 5000, 16 800 and 25 100 ft^3/s. Because of the resulting smoother surface on the upstream portion of the spillway and slightly less splash, the additional row of blocks at 14.43 ft is recommended.

A series of tests was run with 2.4-ft (0.73-m)-high blocks installed 14.43 ft from the entrance. These short blocks, 50 percent of the original height, were ineffective. As happened with no blocks at this location, the high-velocity flow struck the row of blocks 28.86 ft from the entrance and caused a rough water surface.

Stilling Basin Water Surface

The water surface at the base of the spillway was observed for discharges of 5000, 16 800, and 25 100 ft^3/s as part of the long-term scour tests. After the scour patterns were measured, a piece of sheet metal marked with a grid was placed at the base of the spillway. Photographs were then taken of the spillway in operation (see fig. 13). The vertical distance between the grid lines is 5 ft (1.5 m) prototype and the horizontal spacing is 10 ft (3.05 m) prototype. Elevations of the top of the grid plate for the various flows are noted on figure 13. Maximum heights of the standing waves were about 2, 5, and 8 ft (0.6, 1.5, and 2.4 m), prototype, for discharges of 5000, 16 800, and 25 100 ft^3/s.

Entrance Water Surface Profiles

Drawdown of the water surface occurs at the entrance to the spillway. At high discharges the drawdown at both sides of the spillway reduces the discharge capacity. The approach flow could be improved by providing a curved inlet channel for the flow, which would minimize the drawdown and improve the discharge capacity. Experience from previous model tests has shown that the smoothest flow is obtained with an elliptical curve. However, the drawdown is not critical in this application and improving the flow conditions would not be worth the additional cost to modify the inlet channel.

Profiles of the flow were obtained for 5000, 16 800, and 25 100 ft^3/s along three lines in the entrance to the spillway. One profile was taken along the centerline of the spillway and the others were parallel to the centerline 15 ft (4.6 m) (prototype) from the sidewalls. The water surface profiles are shown on figures 14, 15, and 16 for these three discharges. Note that the water surface becomes rougher along the sidewalls as the discharge increases. These profiles were not affected when the additional row of blocks was placed 14.43 ft (4.398 m) downstream from the entrance.

Discharge Rating

The spillway discharge capacity was determined for free flow conditions. No change in the discharge rating occurred when the additional row of 4.81-ft (1.466-m)-high blocks was placed 14.43 ft downstream from the entrance. Figure 17 is the discharge capacity curve for the spillway. The maximum discharge of 25 100 ft^3/s (710.8 m^3/s) was obtained with a reservoir elevation of 4476.8 ft (1364.53 m), which is 3.7 ft (1.13 m) below the present sidewalls. As a result, the height of the dam could be reduced without affecting the discharge capacity, or the elevation of the spillway crest could be increased. The latter case would not change the amount of scour predicted by this model study because this design maintains near-critical flow down the entire length of the spillway chute.

RECOMMENDED DESIGN

The design as initially tested in the model worked very well overall; however, the high velocities at the upstream end of the spillway should be reduced by adding a row of blocks 14.43 ft (4.398 m) downstream from the entrance, as shown on figure 2. The scour at the base of the spillway during the freeboard hydrograph flow uncovers the last row of blocks at elevation 4368.02 ft (1331.37 m). A greater factor of safety against undermining the spillway would be obtained by adding another row of blocks below elevation 4368.02 ft.

Erosion around the downstream end of the spillway was determined with and without wingwalls at the end of the spillway chute. The wingwalls tested were 20 ft (6.1 m) long and were perpendicular to the sidewalls of the spillway. Erosion without the wingwalls was not excessive and was not reduced significantly when the wingwalls were used. As a result, wingwalls are not recommended.

Riprap should be placed along the sides of the spillway from the top to the bottom and should extend laterally a distance equal to the wall height. The riprap should be large enough to be stable at the toe of the spillway when submerged and exposed to critical velocity and wave action. Above the water surface, the riprap will provide protection from the water that will splash over the sidewalls.

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[3] Soil Conservation Service, *Design Engineers Report, T or C Williamsburg Watershed Site 8C,* Albuquerque, New Mexico, June 1977.

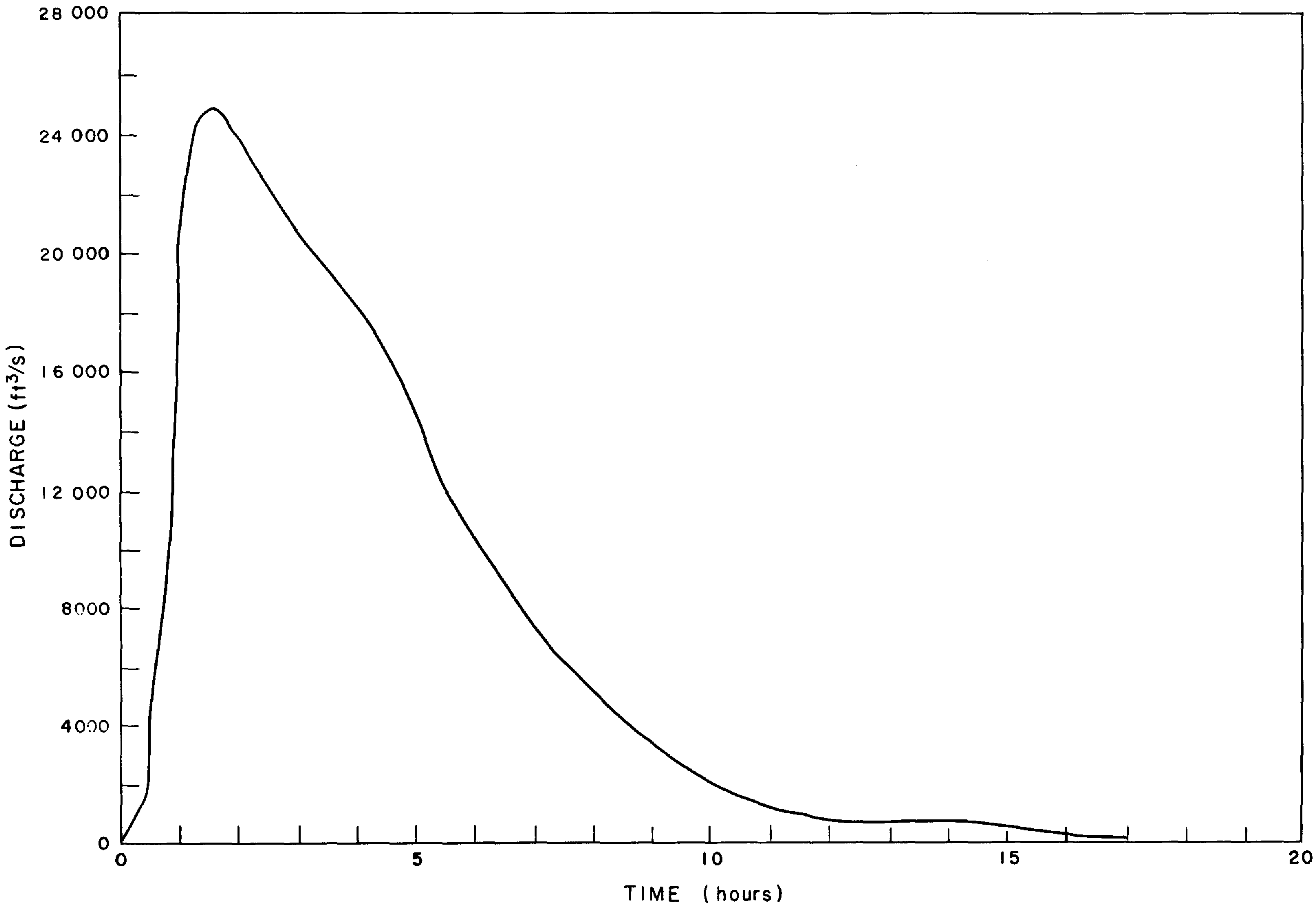


Figure 1.—Outflow hydrograph.

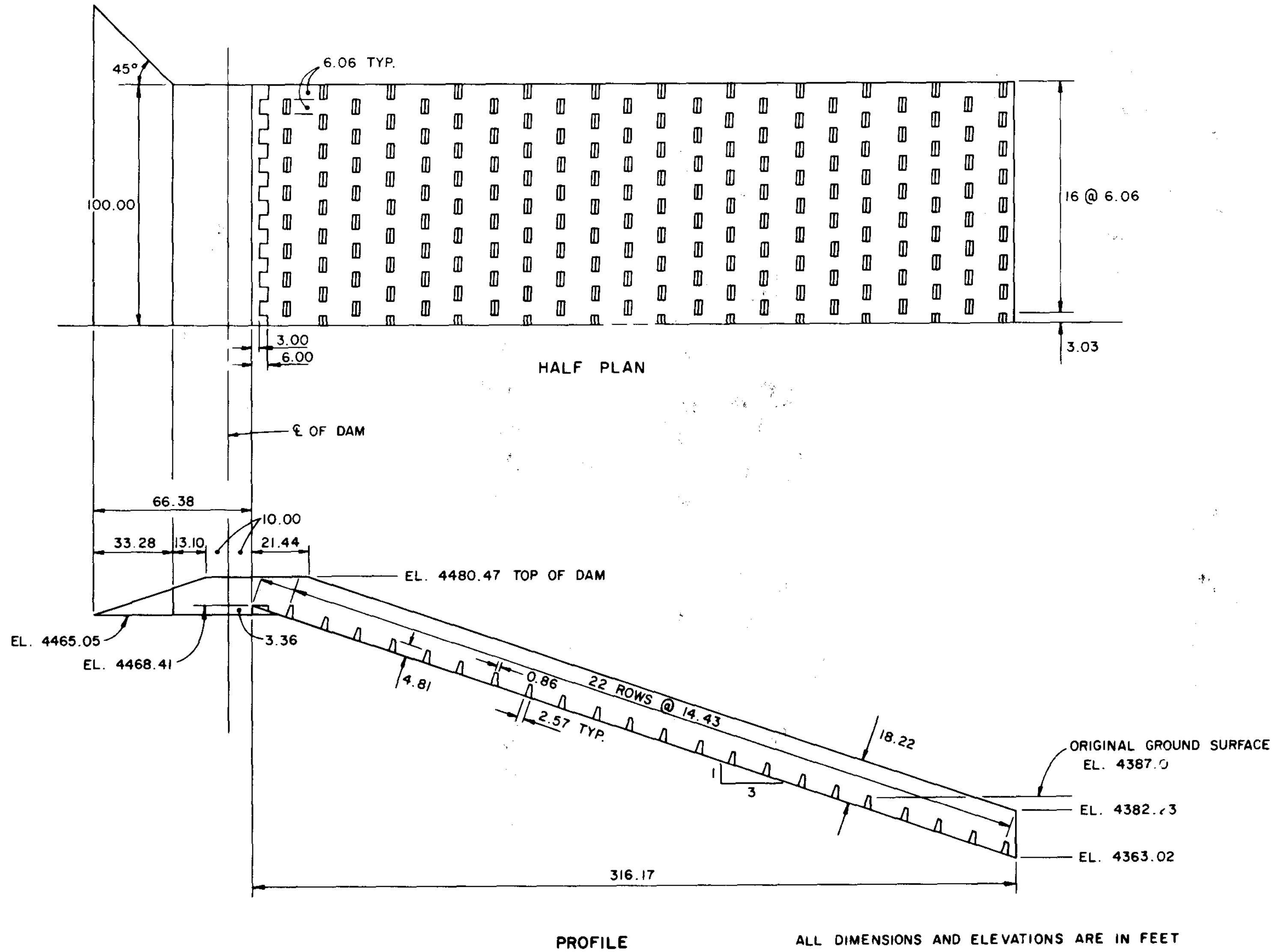


Figure 2.—Baffled apron spillway.

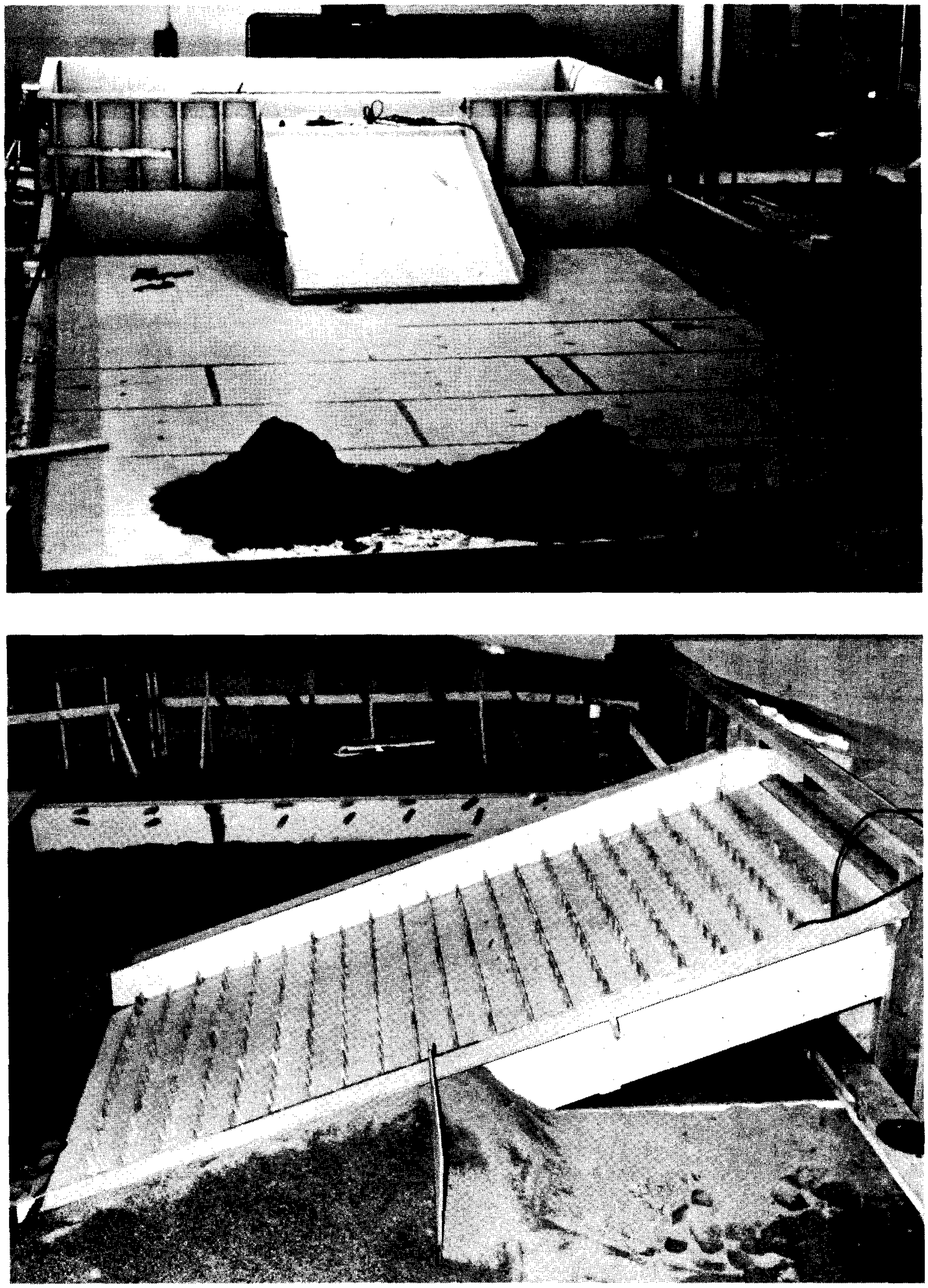


Figure 3.—Model during construction. Photo P801-D-79010

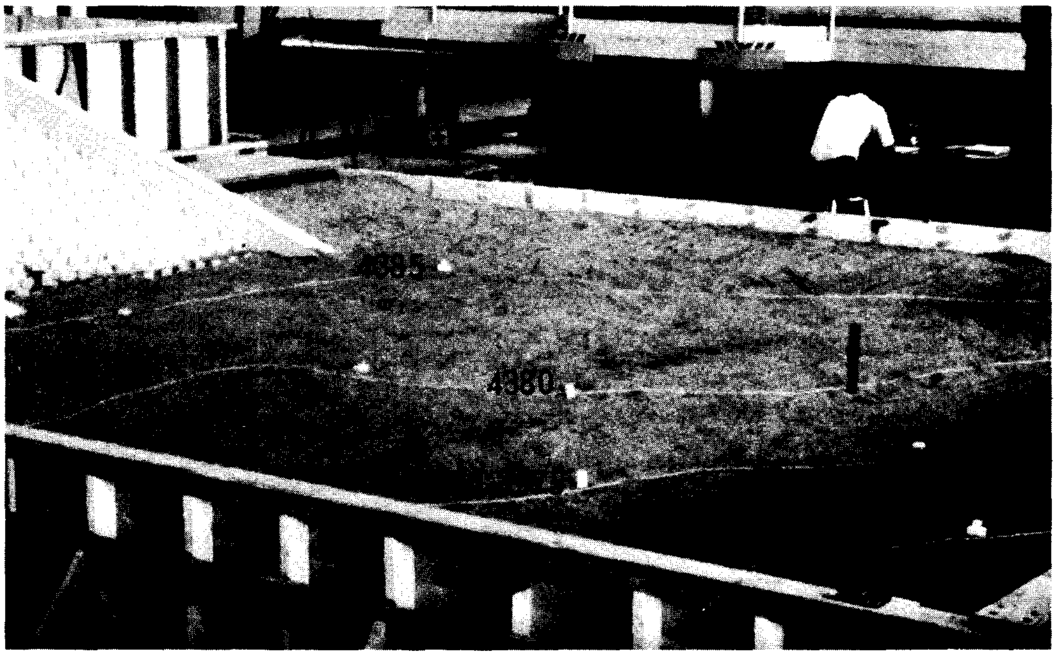


Figure 4.—Contours on original topography. (Elevations in feet.) Photo P801-D-79012

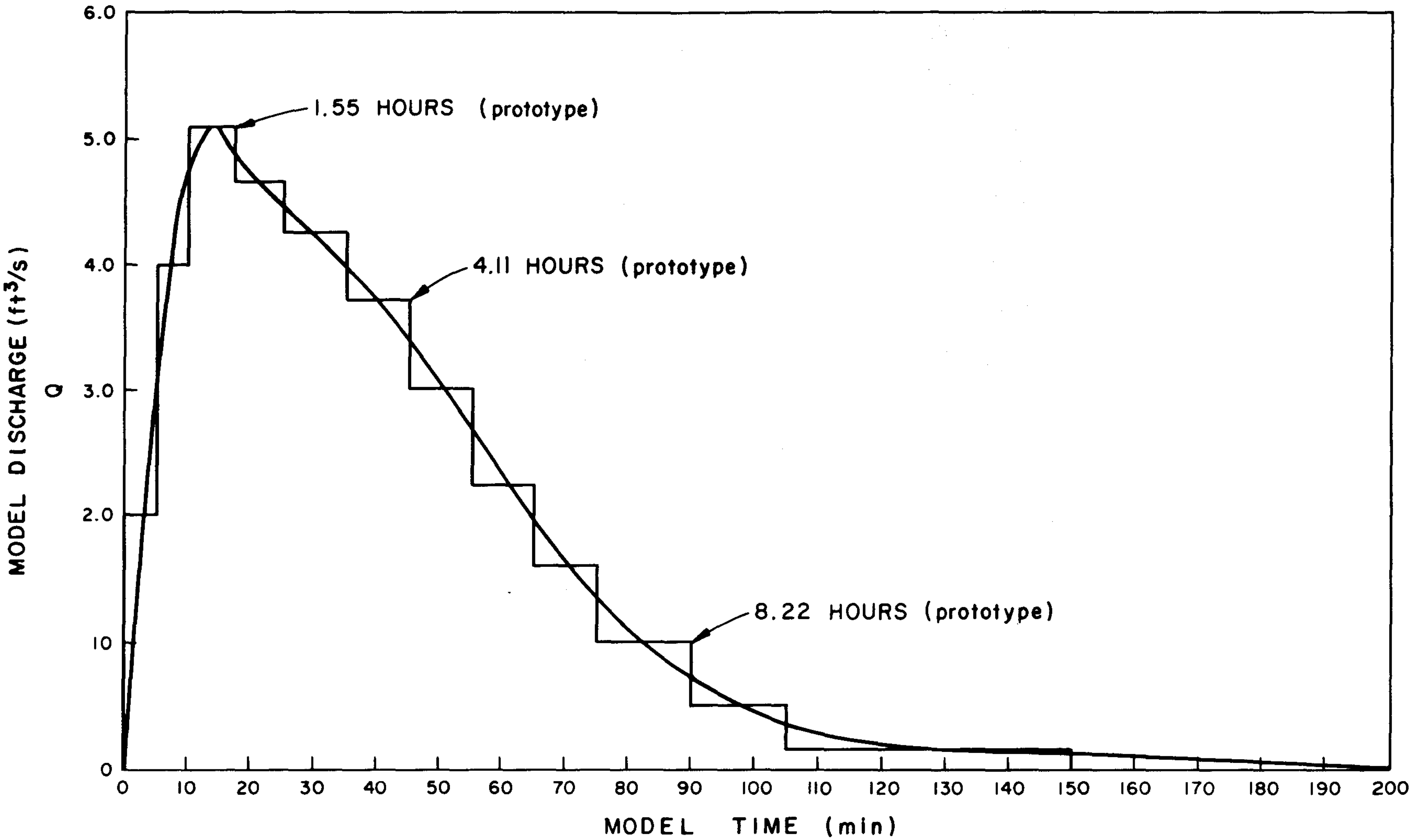


Figure 5.—Stepped model hydrograph.

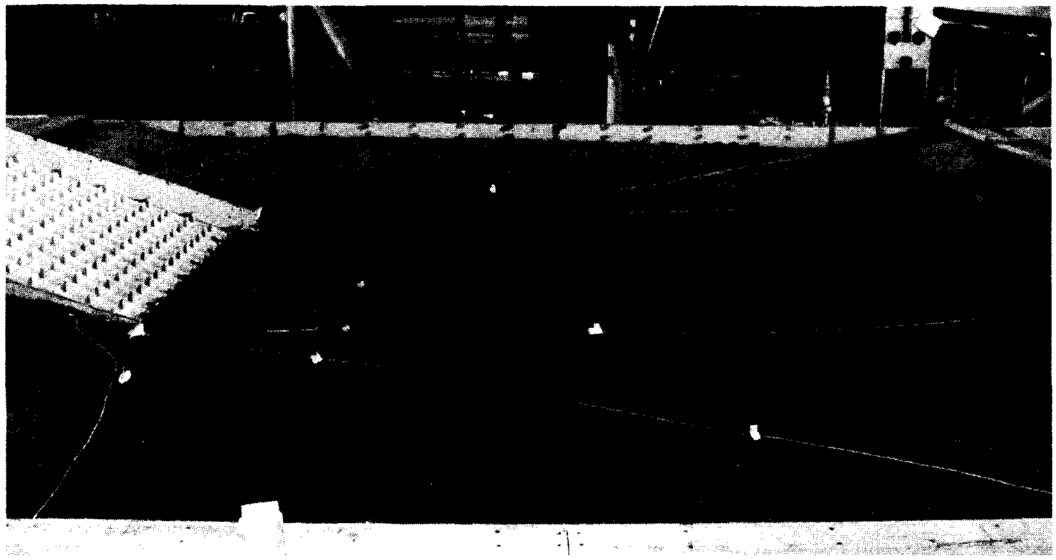


Figure 6.—Scour from complete freeboard hydrograph. (Contour elevations in feet.) Photo P801-D-79013

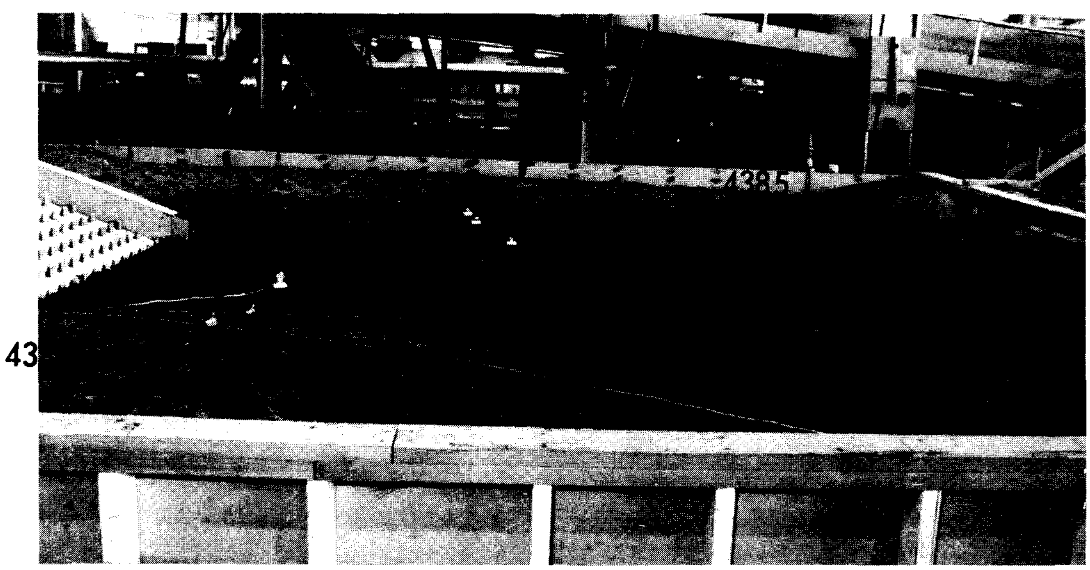


Figure 7.—Scour from incremental freeboard hydrograph after 90 minutes. (Contour elevations in feet.) Photo P801-D-79014

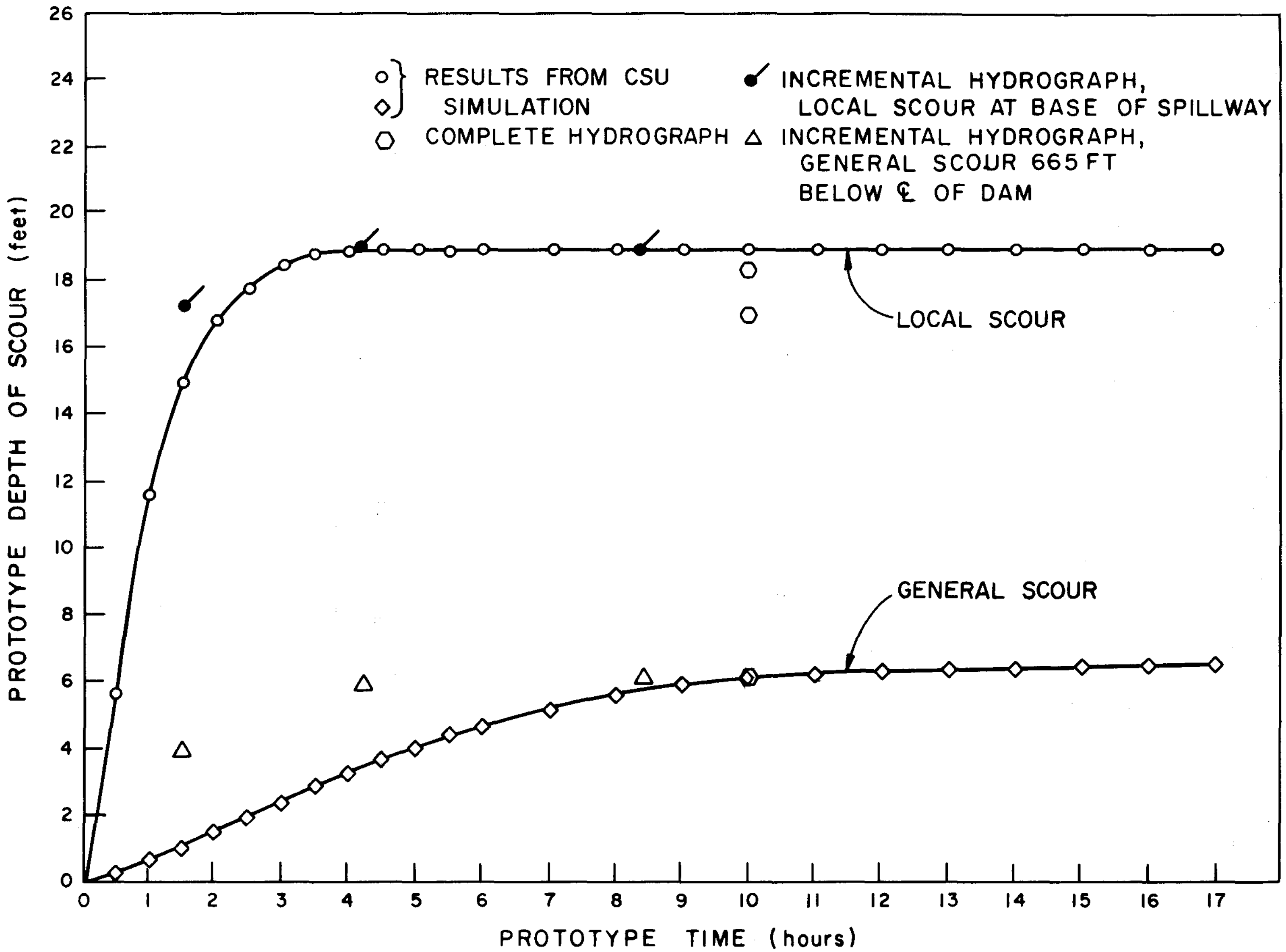
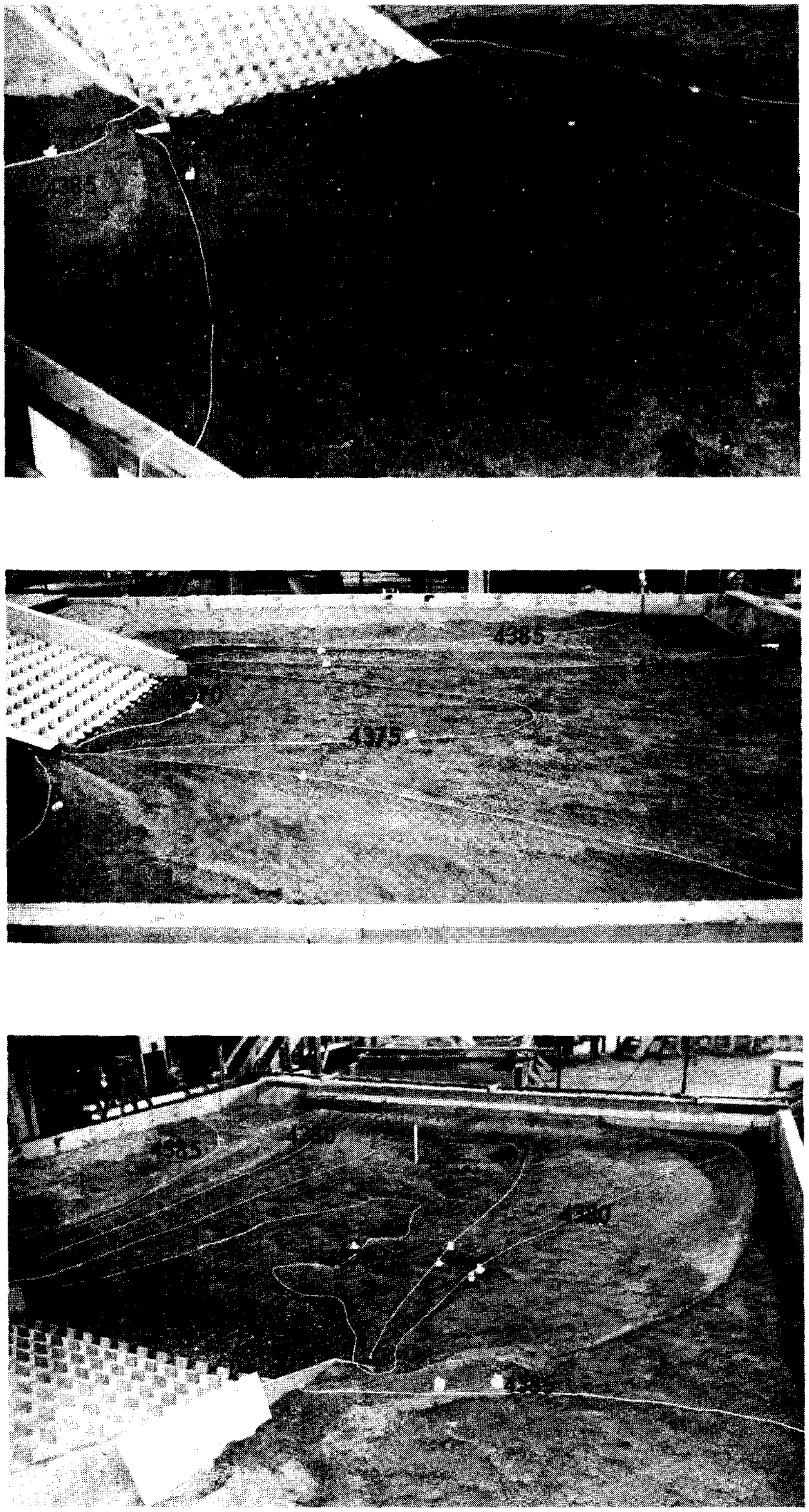


Figure 8.—Comparison of scour from complete and incremental freeboard hydrograph and CSU simulation.

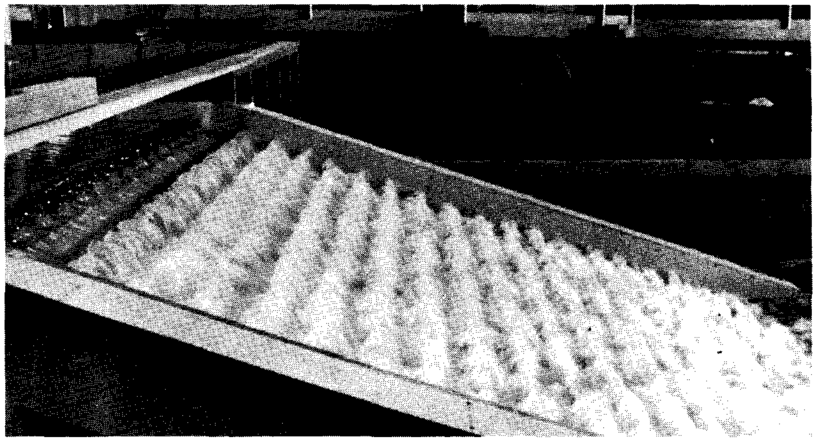


a) Discharge 5000 ft³/s.
Photo P801-D-79015

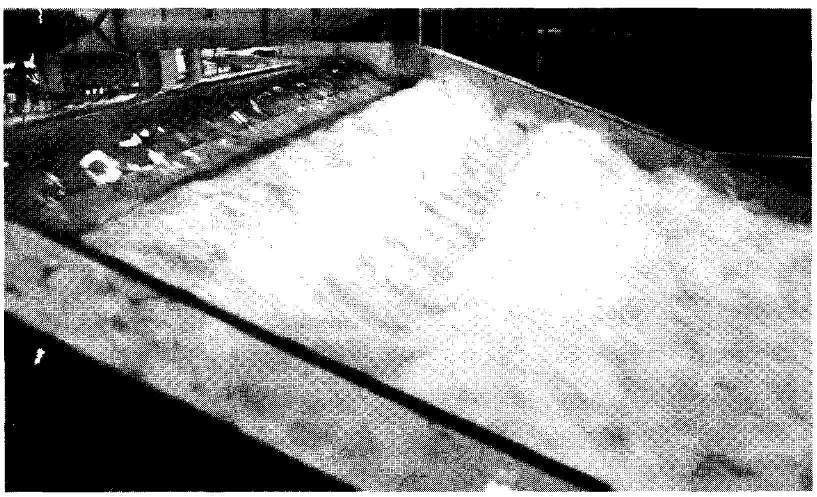
b) Discharge 16 800 ft³/s.
Photo P801-D-79016

c) Discharge 25 100 ft³/s.
Photo P801-D-79017

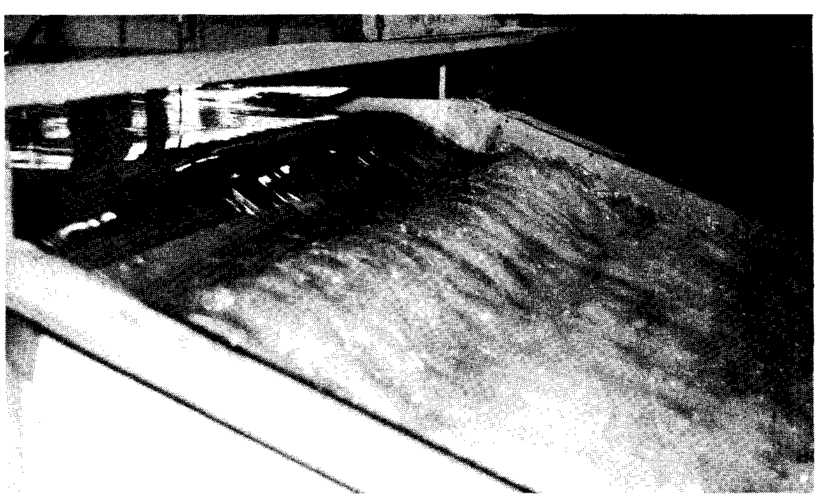
Figure 9.—Scour from constant discharge tests. (Contour elevations in feet.)



a) Discharge 5000 ft³/s.
Photo P801-D-79018

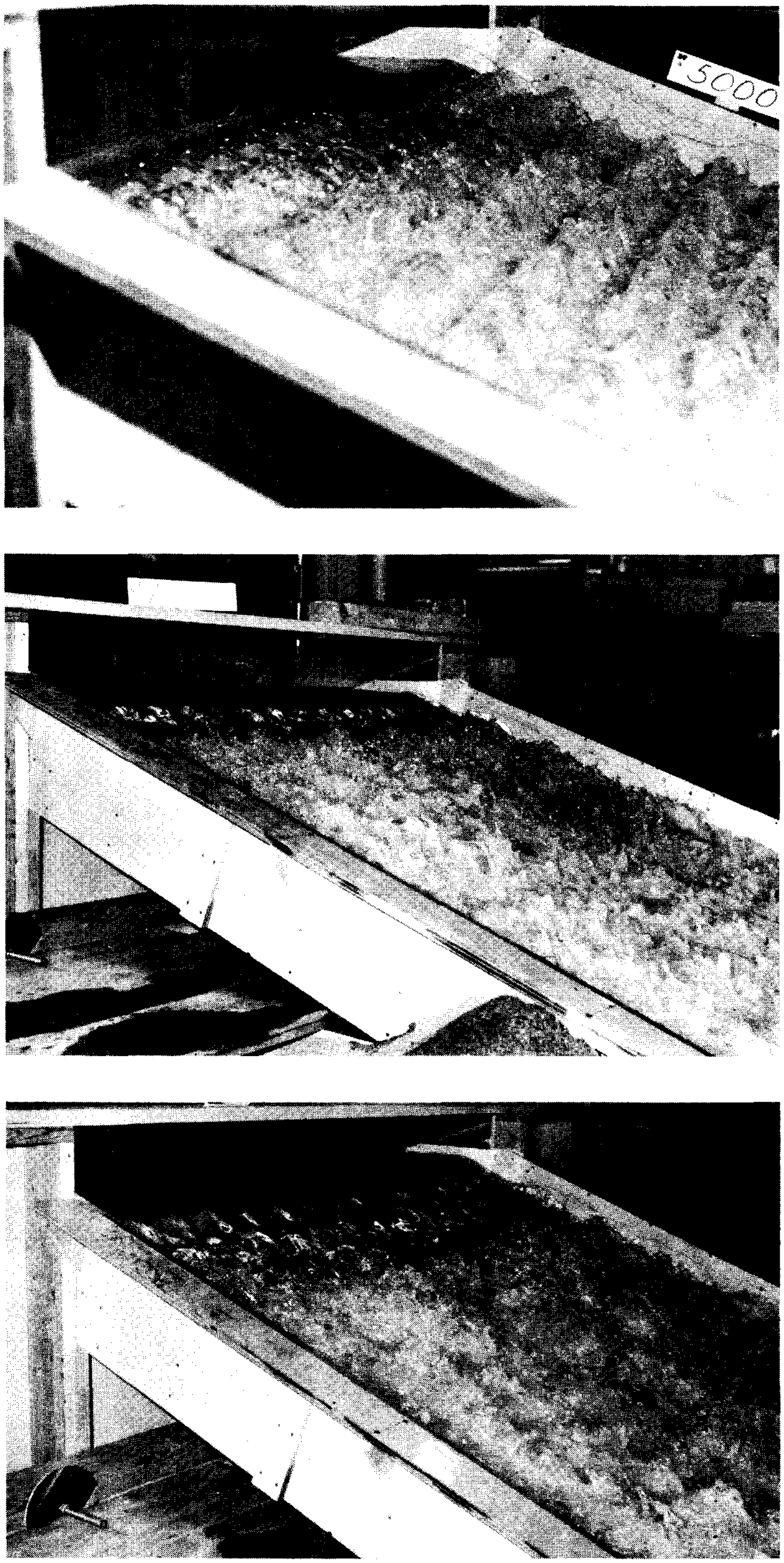


b) Discharge 16 800 ft³/s.
Photo P801-D-79019



c) Discharge 25 100 ft³/s.
Photo P801-D-79020

Figure 10.—Spillway flows for selected discharges without first row of blocks.



a) Discharge 5000 ft³/s.
Photo P801-D-79021

b) Discharge 16 800 ft³/s.
Photo P801-D-79022

c) Discharge 25 100 ft³/s.
Photo P801-D-79023

Figure 11.—Spillway flows for selected discharges with first row of blocks.

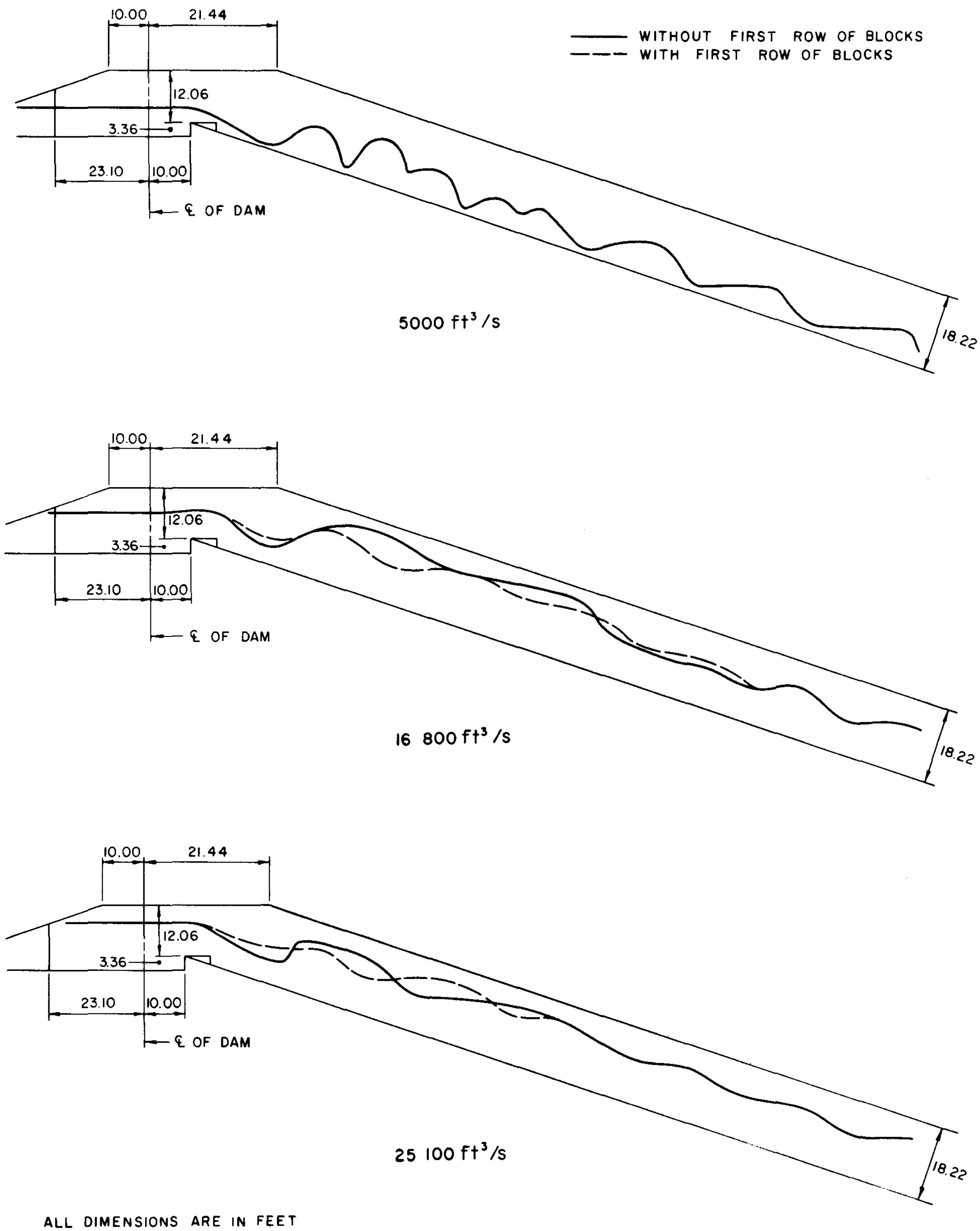
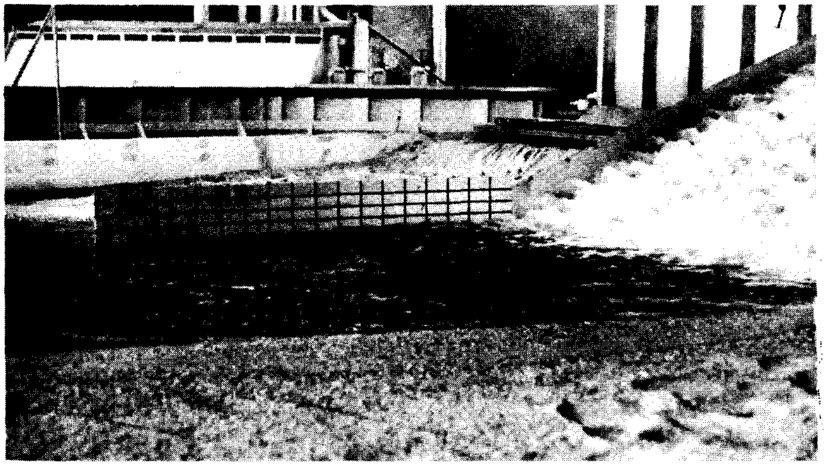
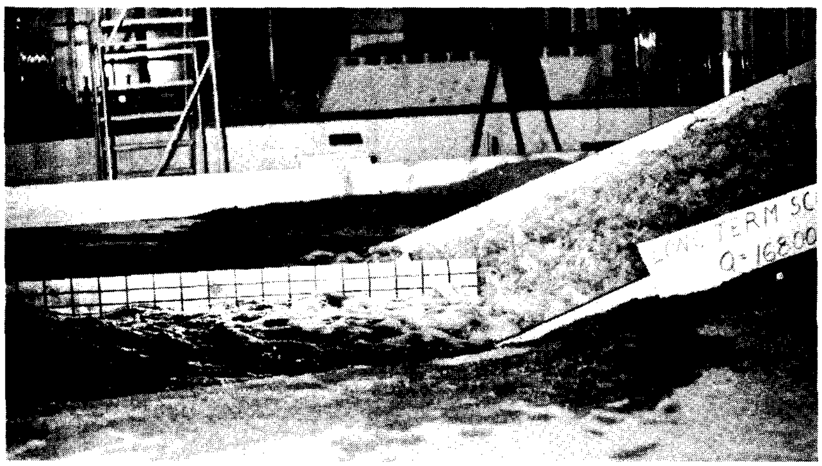


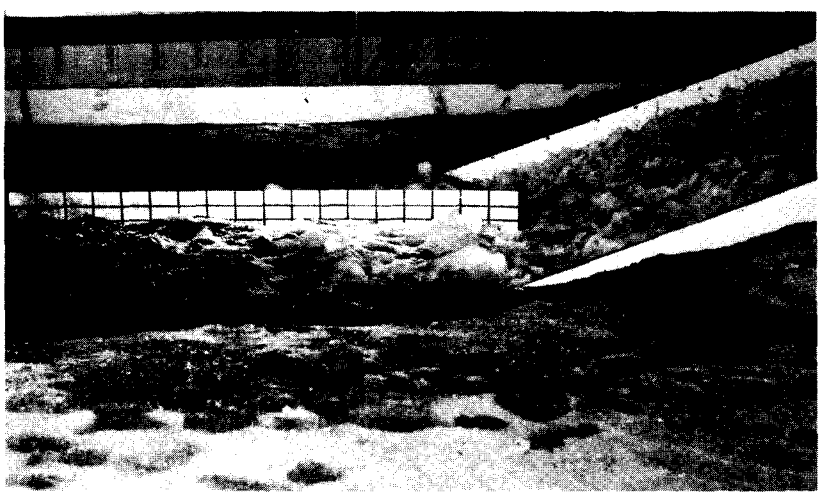
Figure 12.—Water surface profiles.



a) Discharge 5000 ft³/s, top of plate at El. 4405.
Photo P801-D-79024



b) Discharge 16 800 ft³/s, top of plate at El. 4395.
Photo P801-D-79025



c) Discharge 25 100 ft³/s, top of plate at El. 4395 ft.
Photo P801-D-79026

Figure 13.—Stilling basin water surface.

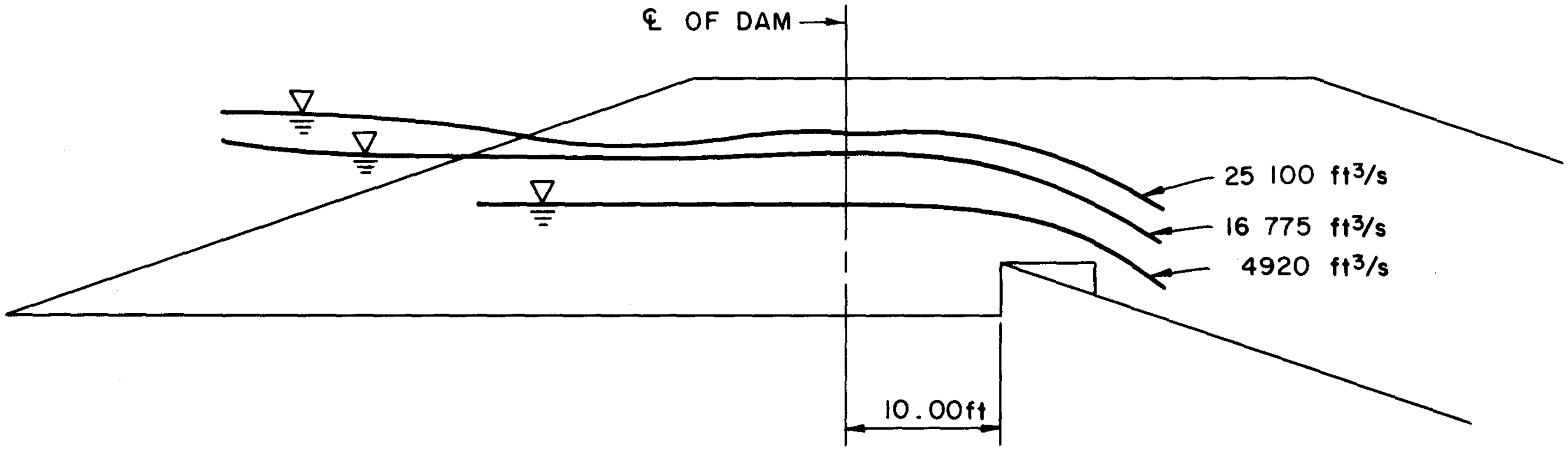


Figure 14.—Water surface profiles 15 ft from the left sidewall.

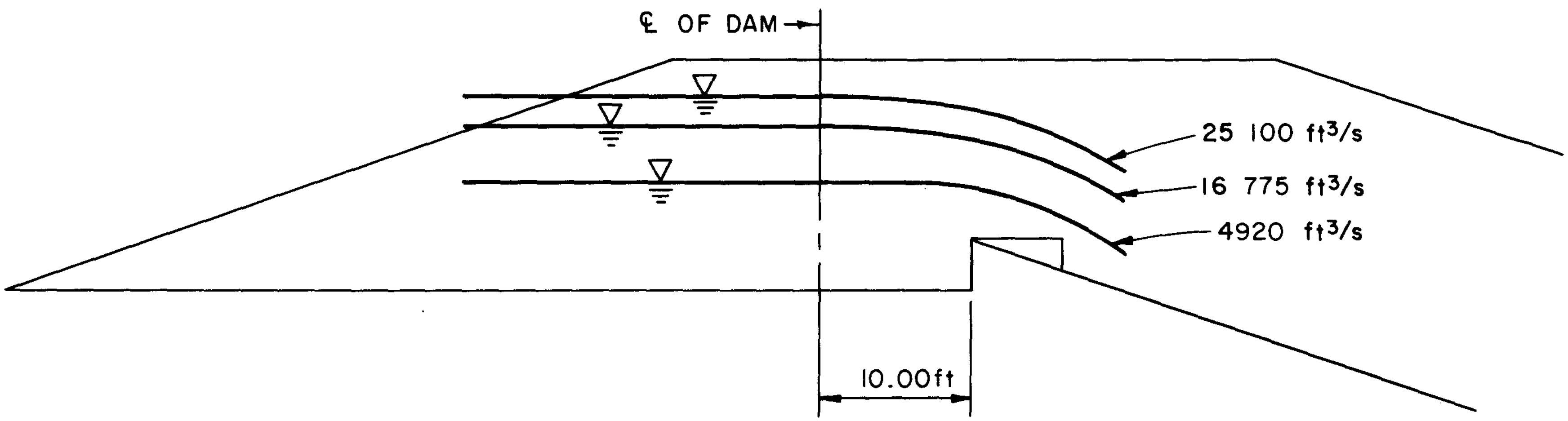


Figure 15.—Water surface profiles along centerline of the spillway.

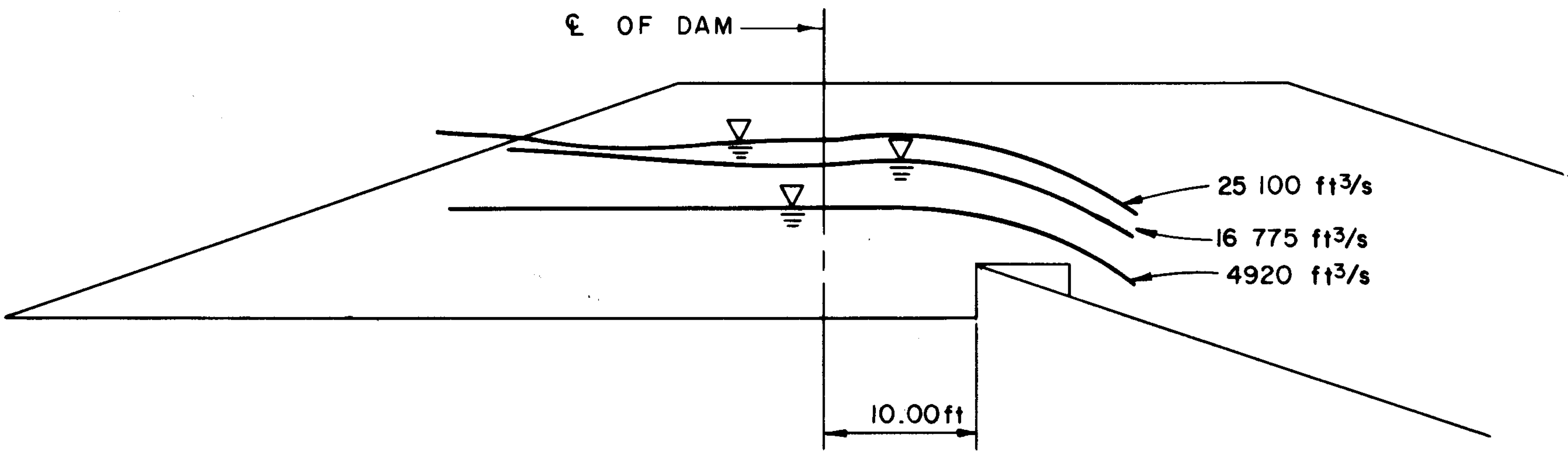


Figure 16.—Water surface profiles 15 ft from the right sidewall.

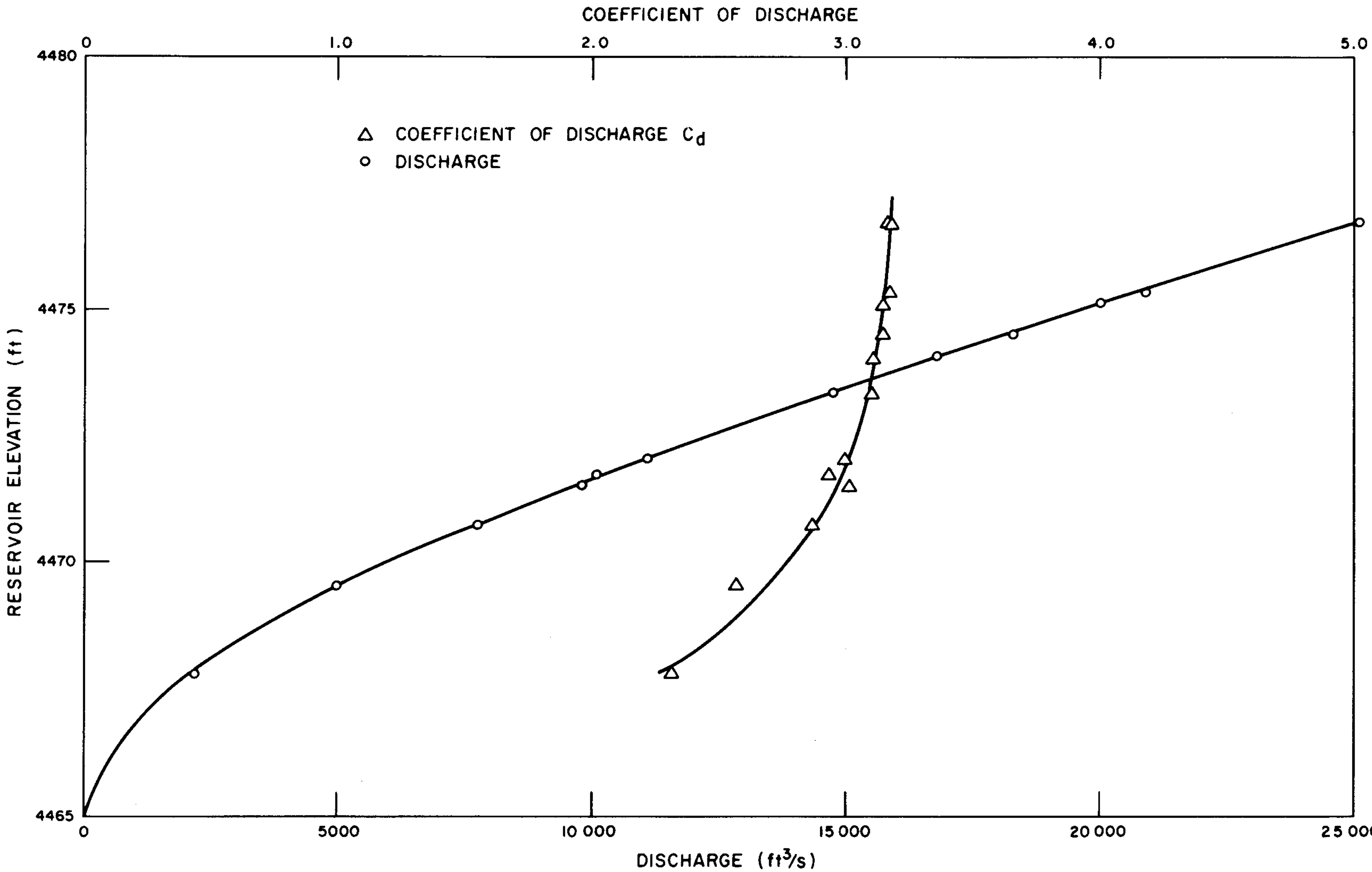


Figure 17.—Discharge capacity curve.

GPO 852-374

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.