FINAL REPORT OF THE HYDRAULIC MODEL STUDY MCCLURE DAM EXISTING AND RCC EMERGENCY SPILLWAYS

BY

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U.S. GPO 1986-773-540

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OCT 14

Mr. V. Phillip Soice
Division Manager
Sangre De Cristo Water Company
PO Box 1268
Santa Fe NM 87504

Dear Mr. Soice:

The final report of the laboratory studies for McClure Dam spillway is enclosed. We have sent copies of the report to Scanlon and Associates and the New Mexico State Engineers Office.

It has been a pleasure working with your organization.

Sincerely yours,

DeWayne O Campbell

FOR Francis G. McLean
Chief, Division of Research
and Laboratory Services

Enclosure

Blind to: D-1530
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D-1531 (Houston)

KLHouston:flh

FINAL REPORT OF THE HYDRAULIC MODEL STUDY FOR THE MCCLURE DAM EXISTING AND RCC EMERGENCY SPILLWAYS

By

Kathleen L. Houston

BACKGROUND

A joint agreement between the Bureau of Reclamation, the city and county of Santa Fe, and the Public Service Company of New Mexico allows delivery of San Juan-Chama Project water to the city of Santa Fe. The Sangre de Cristo Water Company, a division of the Public Service Company of New Mexico, owns and operates three dams upstream of Santa Fe. A safety of dams study revealed inadequate spillway capacity at two of these dams, McClure and Nichols. As a result, Scanlon and Associates, a consulting firm, was contracted by the Sangre de Cristo Water Company to perform the feasibility studies of several alternatives for rehabilitating the dams. The RCC (roller compacted concrete) spillway alternative, due to mutual interest by the Bureau and the Water Company, was model studied in the hydraulic laboratory.

TEST PLAN

The existing spillway was investigated to determine if modifications could be made that would allow its use for passage of the more frequent low discharges. During the feasibility study, Scanlon and Associates determined that the 47.67-foot-long ogee crest would pass more discharge than the chute capacity. Therefore, a concrete bulkhead will be constructed over the ogee crest to form a 3.5-foot-high orifice which will restrict the discharge as the head is increased. The following items for the existing spillway were investigated:

- Discharge rating curves for a 3.5-foot-high orifice above the entire 47.67-foot-long ogee crest and for a narrower 30-foot-long section of the crest.

- An orifice opening that restricts the existing spillway discharge to an amount that would not require modification of the chute.

- The capacity and flow conditions in the chute for each of the above, including wall heights necessary to contain the flow.

- Superelevation of the horizontal bend to prevent overtopping the chute wall downstream.

The RCC spillway will be used as an emergency spillway to pass a unit discharge of 100 ft^2/s (total discharge of 16,534 ft^3/s). The following items were investigated for the RCC emergency spillway:

- The discharge capacity of the RCC spillway with a broad crest 32.53 feet wide in the direction of flow and 167 feet long.

- Flow conditions and energy dissipation characteristics down the spillway with parallel and converging walls for discharges of 5,000, 10,000, 16,534, and 24,800 ft^3/s.

- The effect of 1- and 4-foot step heights on flow depths and energy dissipation.

- Stilling basin performance with and without an end sill.

THE HYDRAULIC MODEL

The 1:30 scale model included the reservoir approach area, a 450-foot-wide section of the embankment dam, the existing and proposed RCC emergency spillways, and about 360 feet of the downstream river channel (figure 1). The model was designed to allow passage of up to 150 percent of the design discharge through the RCC spillway and to investigate the capacity of the existing spillway under increased head requirements. The model structures were built according to drawings provided by Scanlon and Associates (figure 2). The existing 47.67-foot-long ogee spillway crest (El. 7876.5), located 3 feet lower than the RCC spillway crest (El. 7879.5), and the orifice opening were modeled from the drawings (no center pier). The chute channel geometry was estimated from a drawing based on aerial photographs. The downstream channel transitions quickly to a 20-foot width which is approximately maintained throughout the remainder of the chute. The right side of the channel consists primarily of the excavated mountainside, the left side is a 5-foot-high wall (figure 3). The broad crest of the RCC spillway is 32.53 feet wide in the flow direction and 167 feet long. The stepped RCC spillway chute is located on the downstream face of the 2.18:1 sloping embankment dam. The chute and stilling basin walls, built on a 0.8:1 slope, will also be constructed of RCC. The RCC model spillway was constructed to allow modification of the step height, the convergence angle of the spillway chute walls, and the stilling basin width.

EXISTING SPILLWAY TEST RESULTS

Rectangular Orifice Openings

Testing of the existing spillway began with a rectangular orifice formed by the entire 47.67-foot crest width and a 3.5-foot-high opening. This orifice was designed to allow free flow for low discharges, then restrict the flow to the capacity of the chute channel as the head increased. (The model approximated the concrete beam forming the orifice over the crest with a sharp-edged sheet metal orifice.) The discharge curve (figure 4) indicates a free flow discharge of 1,330 ft^3/s at 3.5 feet of head above the ogee crest and a discharge of 3,440 ft^3/s with orifice control under a head of 13.5 feet (reservoir El. 7890).

Free flow discharges up to 709 ft^3/s at a head of 2.19 feet above the crest were adequately contained in the chute. However, as the head increased, flow overtopped the chute walls on the embankment or left side of the spillway channel. Only the left wall of the spillway was overtopped as the right side consisted of the mountainside. Flow from the right side of the crest impinged on the right transition wall downstream and reflected a wave across the channel that overtopped the left wall downstream from the transition. Flow from the left side of the crest overtopped the left wall near the end of the transition where the chute width was 20 feet (figure 5). Overtopping also occurred about 150 feet downstream from the center of the horizontal bend (figure 6).

The width of the existing service spillway orifice was narrowed to 30 feet and centered on the crest with the height remaining at 3.5 feet. Restricting the flow from the right side of the crest and centering the opening would hopefully prevent the majority of the left wall overtopping. A free flow discharge of 620 ft^3/s was passed with no overtopping of the chute walls. At about 1,100 ft^3/s, during orifice control, flow overtopped the left wall and continued to do so through the maximum discharge of 1,650 ft^3/s 1/ at 13.5 feet of head (figure 4). The unusual shape of the discharge curve cannot be readily explained by approach channel flow conditions or observations of the model. The curve indicates a choking of the flow between reservoir heads of 8 and 10.5 feet as would be expected under orifice control; however, the the slope of the curve flattens under higher heads.

1/ Change from summary report.

The jet from the rectangular orifice opening, regardless of the flow rate, sprang free from the ogee crest, impacted on the invert of the chute and spread laterally to the side walls in the transition section. This flow overtopped the left side wall immediately downstream of the crest. The jet hit the transition side wall on the right side and sent a wave across the chute that overtopped the left wall in the transition further downstream (figure 7). The left wall downstream from the horizontal bend was also overtopped in the same area as with the full crest opening, however, by a lesser amount.

Investigations showed that the jet from any width rectangular opening sprang free from the crest and impinged on the invert, creating waves that overtopped the chute walls. Alternatives for correcting the chute wall overtopping created by flow from a rectangular opening are:

- Channelling the flow with structural walls extending from the orifice sides to the minimum chute width section.

- Installing flow vanes on the floor of the chute to break up or redirect the waves.

- Raising the side walls on the left side of the chute to contain the flow.

Of these alternatives, raising the side walls seemed most appropriate because slight incorrect placement of the flow vanes would not successfully redirect the flow, and channelling the flow could be very expensive.

Chute water surface profiles along the left wall were measured for the 30- by 3.5-foot orifice opening. Sections of the left wall must be raised to contain the flow and/or to provide the required 2.5 feet of wall freeboard. For 50 feet downstream of the crest (measured along the chute centerline) the wall must be raised an additional 6.25 feet (total height, including freeboard, 11.25 feet). Between 50 and 75 feet downstream of the crest the 5-foot wall height contained the flow adequately. The wall should be raised an additional 4.4 feet (total height 9.4 feet) between 76 and 113 feet downstream of the crest and then taper down to the existing 5-foot wall height 190 feet downstream from the crest.

Triangular Orifice Opening

Extensive modifications in the chute will be needed to use a rectangular orifice of any meaningful size. The only orifice type opening that maintained 2.5 feet of chute wall freeboard with the existing 5-foot wall height was a 43.68-ft^2 triangular orifice (figure 8). This opening was formed by the ogee crest as a base and a 2.25-foot-high apex located 21.5 feet from the left wall with the right corner returning to the crest 8.84 feet from the right wall. The location of the triangular orifice on the crest was critical to prevent the fin in the center of the chute from travelling to the left and overtopping the wall. The discharge capacity of this opening was only 286 ft^3/s at 13.5 feet of head over the crest. The opening was also so small that debris could easily collect and greatly reduce the discharge.

Superelevation of the Horizontal Bend

Discharges greater than 1,100 ft^3/s through the existing spillway, regardless of the crest geometry, will overtop the sloping left wall downstream of the horizontal bend. Superelevation was added at the bend by forming 75-foot transition spirals into and out of a 5-foot banked section in the center of the bend. The addition of the superelevation prevented overtopping of the left wall downstream of the bend for the entire discharge range of the 30- by 3.5-foot rectangular orifice (figure 9) and for the 47.67- by 3.5-foot orifice.

Containing the flow within the chute downstream of the horizontal bend is not as critical as preventing overtopping onto the embankment near the crest. Rehabilitation of the existing spillway should be directed toward protecting the embankment near the top of the dam from erosion due to overtopping of the chute walls in this area.

RCC EMERGENCY SPILLWAY TEST RESULTS

As a basis for comparison, the RCC spillway was tested first with parallel chute walls or no wall convergence (figure 10). Methods used to evaluate the performance of the stepped spillway were, measuring the velocity on the face of the chute before the jet entered the stilling basin, and observing the jump in the stilling basin.

Discharge Capacity

A total discharge of 16,534 ft^3/s is passed over the 167-foot-long RCC crest at 10.26 feet of head, 0.24 feet below maximum water surface at El. 7890 (figure 11). The discharge coefficient at design discharge was 3.01, typical of a broad crested weir. Various head/discharge relationships may be determined from the equation:

$$H = (0.0155)Q^{0.6687}$$

$$Q = 508.45H^{1.495}$$

To pass 150 percent of the RCC spillway design discharge required a head of 13.46 feet. This head would overtop the embankment by almost 3 feet.

Velocity Measurement Techniques

The velocity of the jet on the face of the stepped spillway face was determined. Data were gathered 90 feet vertically down from the crest at the chute centerline and 15 and 30 feet to either side. Data for computing velocities were measured using several methods: a pitot-static tube; WPP (wave probability probe); video camera; pressure cells mounted on a plate; and by a miniature current meter. The results of these measuring techniques varied significantly. Data from the pitot-static tube and the WPP gave the most consistent and repeatable results and were used to compute the average velocities across the chute width.

The pitot-static tube measured the static and dynamic pressure head with the velocity computed from:

$$V = (2g\Delta P)^{\frac{1}{2}}$$

where ΔP = pressure differential

The WPP was used to measure the flow depth at each measurement location. These depths were averaged across the width of the chute and the average velocity computed from:

$$V = Q/A = Q/dw$$

where d = average flow depth across the chute

w = width of the chute at the measurement station

These velocities were then compared to theoretical velocities, based on the velocity head, for a non-stepped, smooth spillway to determine the energy dissipation produced by the steps.

Results for 1-foot Step Heights

Initial tests were performed with 1-foot steps for the entire 167-foot chute width or no convergence of the chute walls. Results from these tests indicated that investigation of converging chute walls was applicable. The same tests were then completed for wall convergences that produced 116- and 50-foot chute widths at the toe of the dam slope (figure 10).

Flow conditions in the chute and stilling basin with no side wall convergence were excellent. For small unit discharges the flow became turbulent very near the crest and the turbulence increased down the length of the chute with the jet entering the basin and breaking up before impinging on the floor (figure 12). As the discharge increased, the jet travelled further down the spillway face before becoming turbulent; however, energy dissipation was excellent at the toe of the slope (figure 13).

The chute walls were modified to converge at 5.6° producing a 116-foot width at the toe of the slope. Flow conditions near the crest were identical to those with no wall convergence. Flow depths increased as the width decreased, particularly along the side walls; however, no cross waves developed in the chute. Flow conditions were again excellent throughout the chute and stilling basin indicating that the steps were still performing adequately (figure 14).

The 12.68° wall convergence, producing a 50-foot width at the toe of the slope was then investigated. Flow conditions remained excellent; however, flow depths increased significantly. Fins rose up both side walls, but no cross waves formed, probably because of the turbulence created by the steps. Figure 15 shows the spillway operating at 5,000 and 16,534 ft^3/s with the chute converging to 50 feet at the toe of the slope.

Velocities

Velocities were computed from measurements taken during each of the tests conducted to investigate the feasibility of converging the chute walls. The velocities generally increased as the walls converged. The greater flow depths created by the wall convergence reduced the ability of the steps to dissipate energy. The velocities are listed in the following table.

Chute velocities with 1-foot-high steps

	Velocity - ft/s		
Discharge ft^3/s	No convergence	116' basin width	50' basin width
5000	34.2	32.5	---
10000	39.6	44.6	50.3
16534	44.1	52.4	55.8
24800	57.8	60.8	---

The velocities do not significantly increase as the angle of convergence increased. Flow conditions in the chute were acceptable with the maximum wall convergence. The chute walls must be high enough to contain a flow depth of 7 feet, measured from the downstream edge of the step normal to the slope. Stilling basin performance was satisfactory with convergence of the walls to the 50-foot width. The spillway chute with the side walls converging to a 50-foot-wide stilling basin will provide adequate energy dissipation.

Results for 4-foot Step Heights

The 4-foot steps were added to the model on top of the 1-foot steps, beginning 1 foot below the broad crest (figure 16). Tests were conducted only for the convergence to a 50-foot width at the toe of the slope. The 4-foot steps were tested to determine if the greater step height would increase the energy dissipation.

Observation of the flow on the stepped face indicated that turbulent flow occurred closer to the crest (figure 17). The turbulence was indicated by "white water" or a rough water surface. The more turbulent water surface created a greater flow depth throughout the chute than with the 1-foot steps. Figure 16 shows the water surface profiles along the right and left chute walls for 4-foot steps. At the design discharge, a maximum flow depth was 8.5 feet, measured from the edge of the steps normal to the slope.

The velocities, computed by techniques discussed previously, varied considerably. An estimate of the velocity at the design discharge was 55 ft/s, based upon the results from three measurement techniques. This velocity was essentially the same as had been measured with the 1-foot steps. Comparison of the stilling basin action to that with the 1-foot steps indicated that the jump had moved upstream only slightly (figures 15 and 17). Basic flow conditions in the stilling basin were not significantly different for the two step heights.

It had been expected that the 4-foot steps would dissipate more energy than the 1-foot steps. Closer examination of the flow down the spillway chute indicated a possible explanation for the similarity in energy dissipation characteristics of the two step heights. As the flow left the crest and began tumbling down the steps it appeared that the jet impinged on the edge of a step and left the surface of the spillway, returning again after jumping over the next row of steps. This phenomena occurred at low discharges and continued as the discharge increased. Reducing the contact of the jet with the stepped face reduced the capability of the steps to dissipate energy.

These results indicate that under these flow conditions (head, unit discharge, flow depth, chute slope, and wall convergence) any step height, from 1 to 4 feet could be used, depending upon which is the most economical construction alternative.

Stilling Basin Investigation

Energy dissipation characteristics of the trapezoidal stilling basin both with and without an end sill were observed. Tailwater elevations were referenced to the streambed elevation 7767.86 with a tailwater depth of 11 feet at design discharge. Tests conducted with no end sill indicated very poor flow conditions. The tailwater was not adequate to produce an acceptable jump with any of the discharges tested. At

5,000 ft^3/s the jet from the chute impinged on the floor of the basin and formed a weak hydraulic jump that dissipated very little energy. Higher discharges swept out the end of the basin. The 17.7-foot end sill at the end of the 131-foot-long basin and the appropriate tailwater produces excellent energy dissipation in the basin for all discharges.

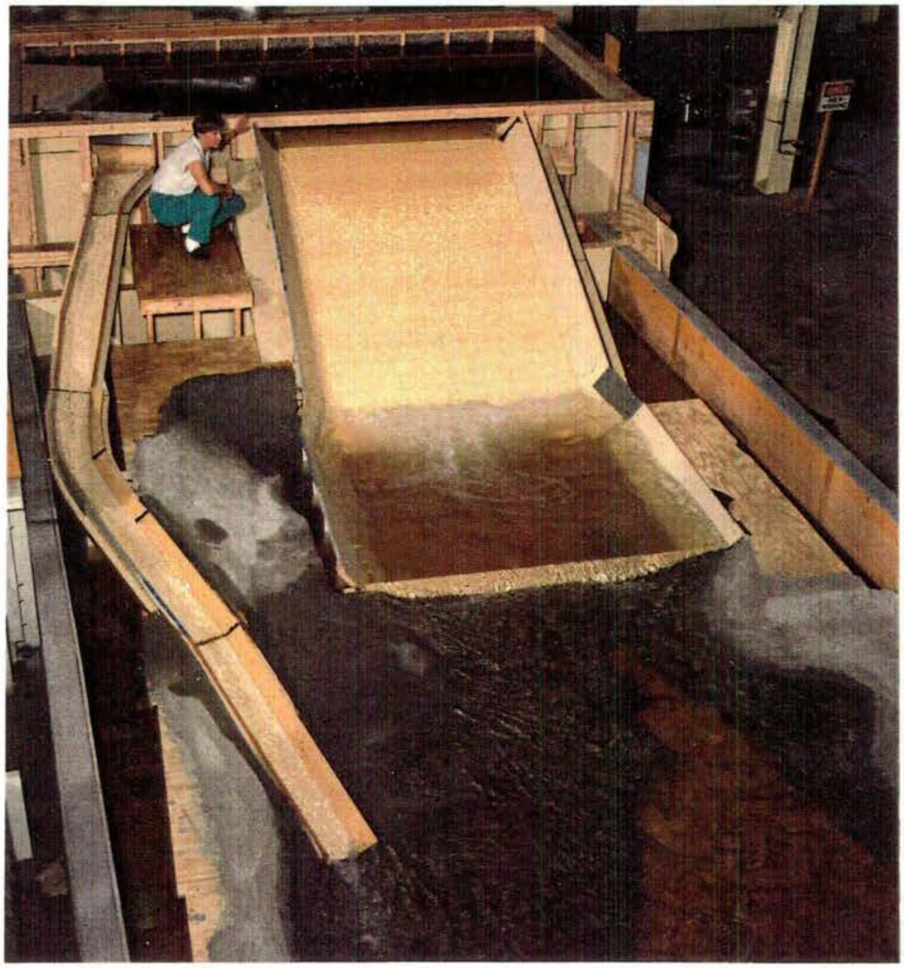


Figure 1. - 1:30 scale model of the initial design for the existing and RCC spillways.

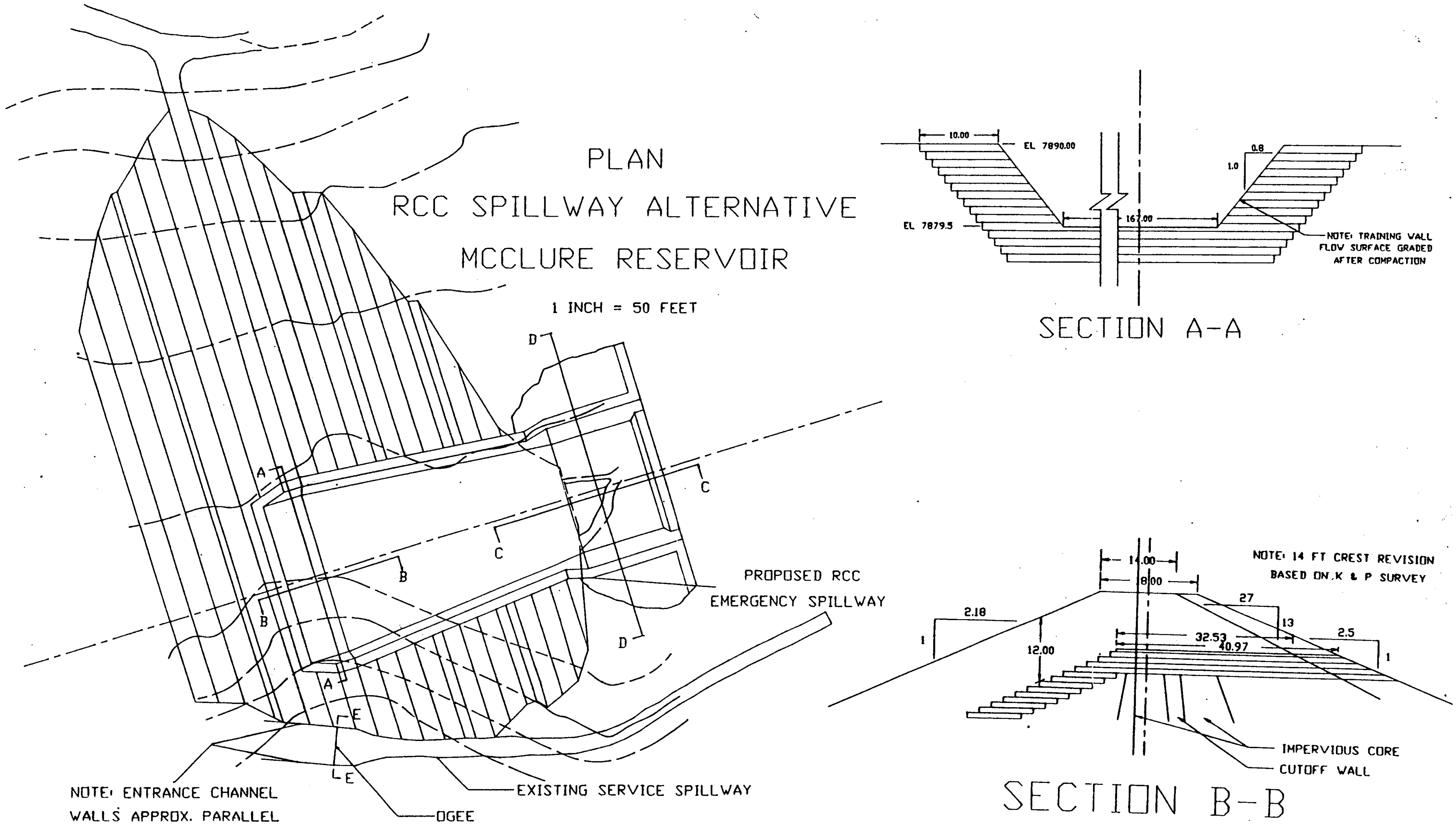
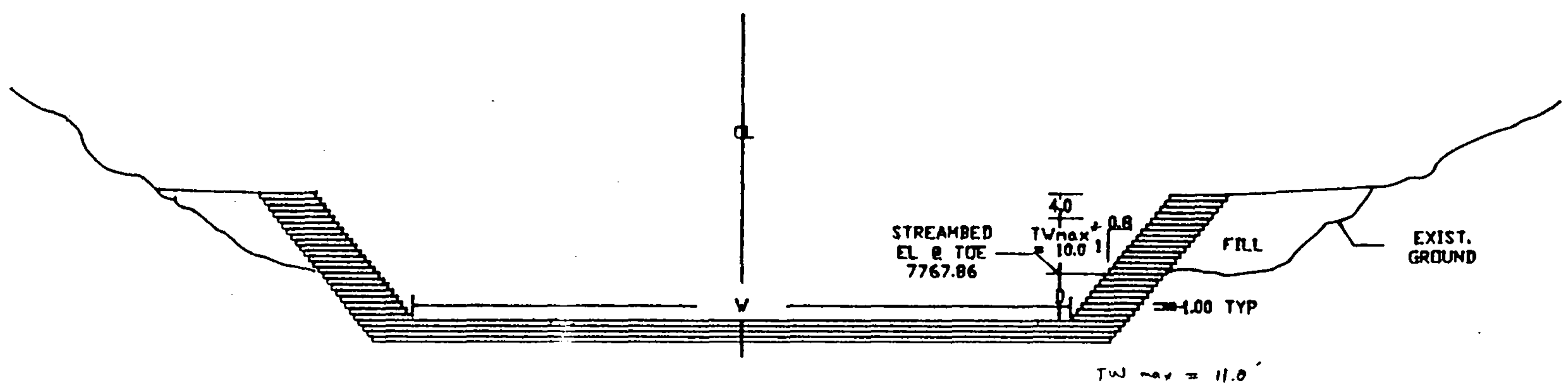
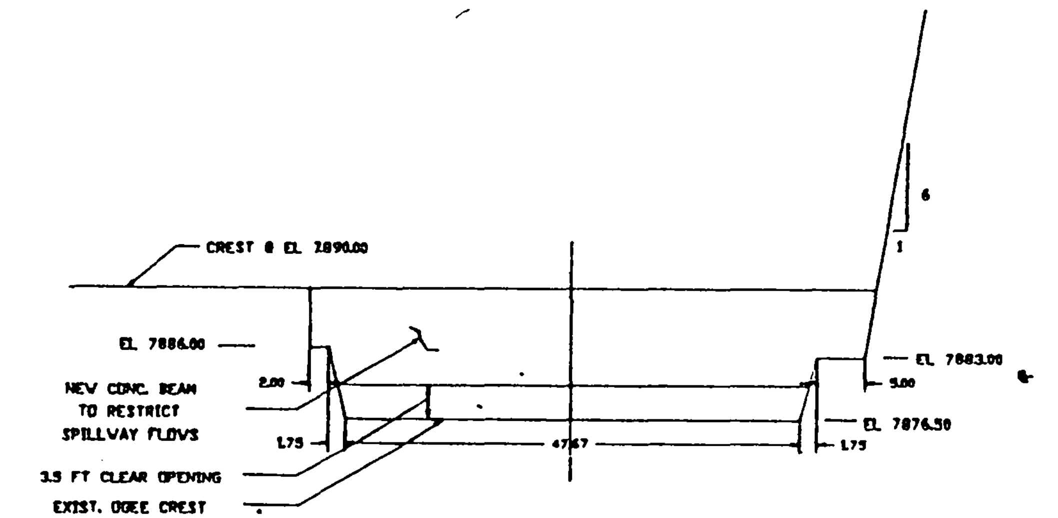


Figure 2.- Feasibility drawings of the RCC emergency spillway for McClure Dam.

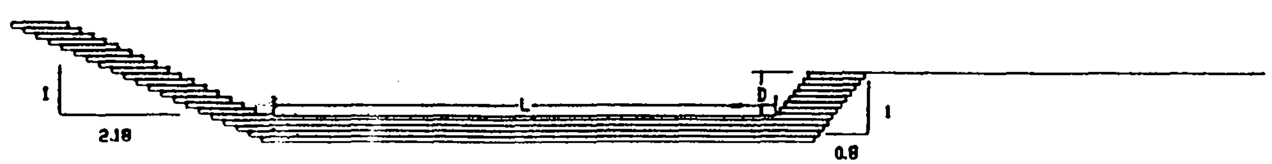


SECTION D-D

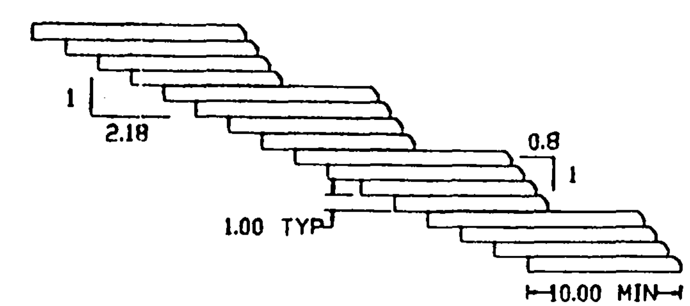


SECTION E-E

STILLING BASIN WIDTH	DEPTH 'D'	LENGTH 'L'
116	7.4	86
50	17.7	131



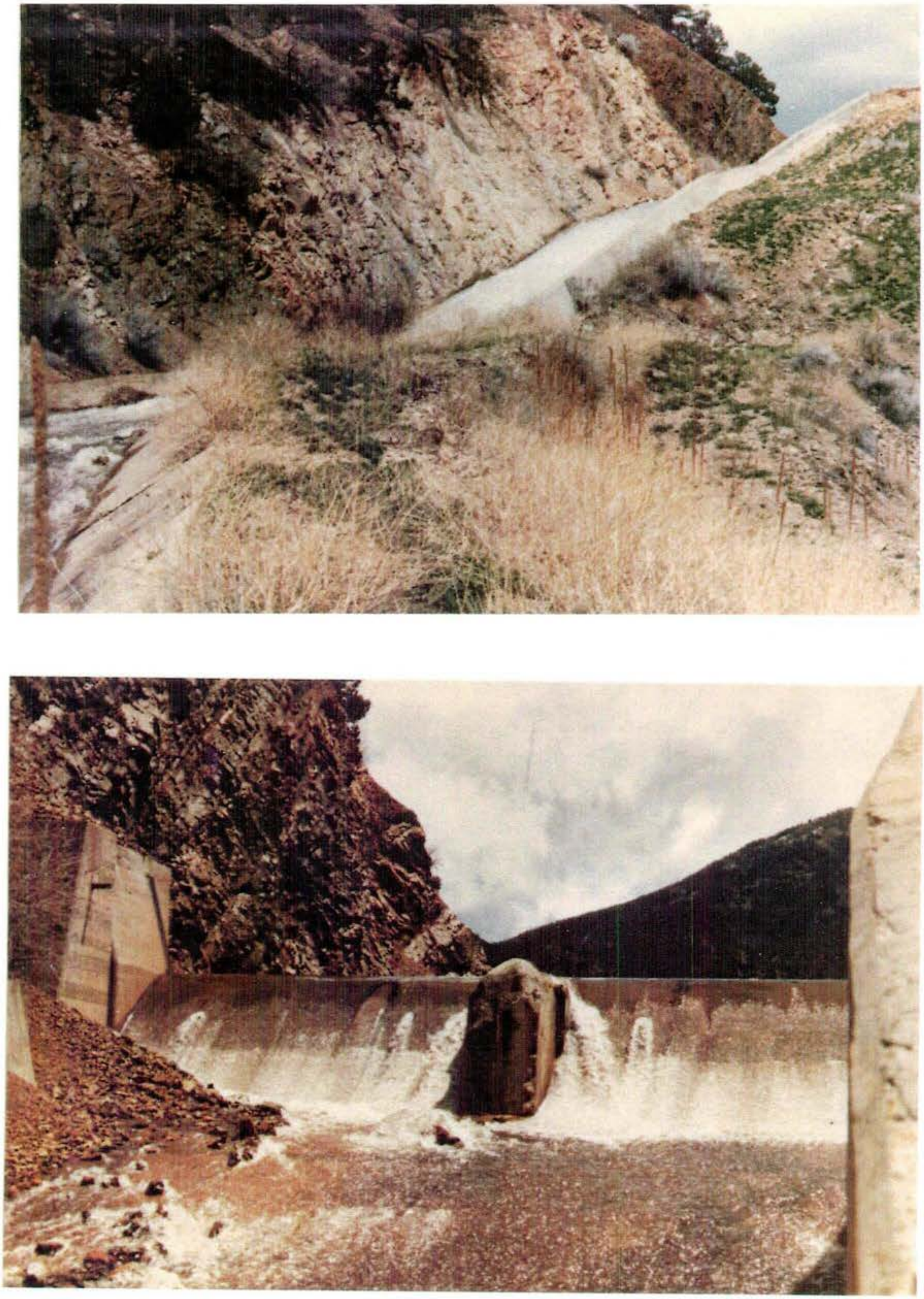
SECTION C-C



SPILLWAY FLOW SURFACE

ALTERNATE STEP CONFIGURATION

Figure 2.- continued.



(Note: Center pier not included in model.)

Figure 3. - Existing service spillway at McClure Dam.

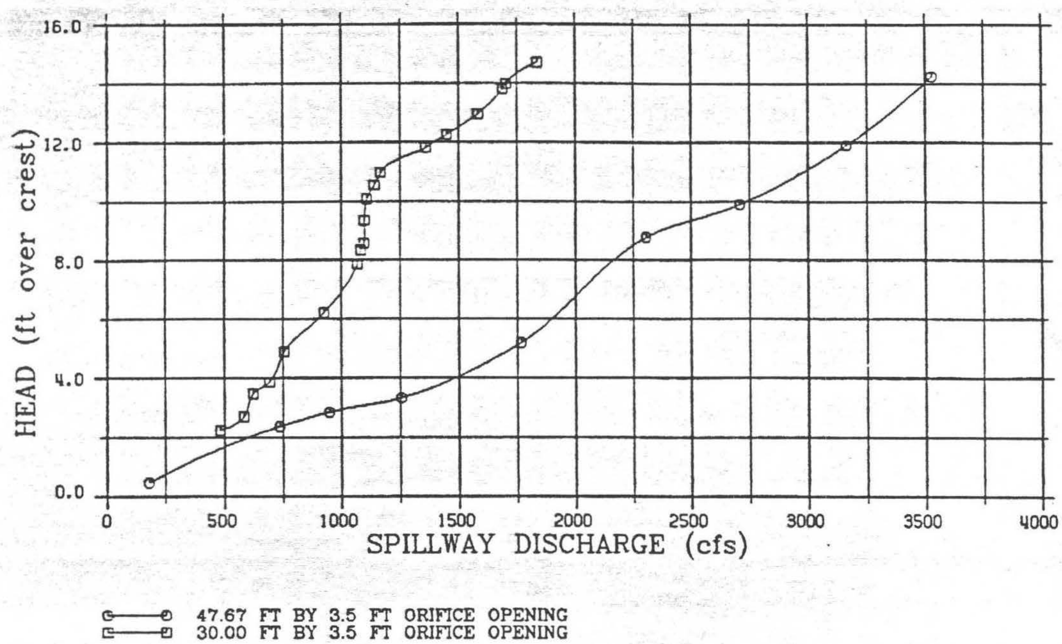


Figure 4. - Discharge rating curve for the existing spillway with an orifice opening constructed above the crest.

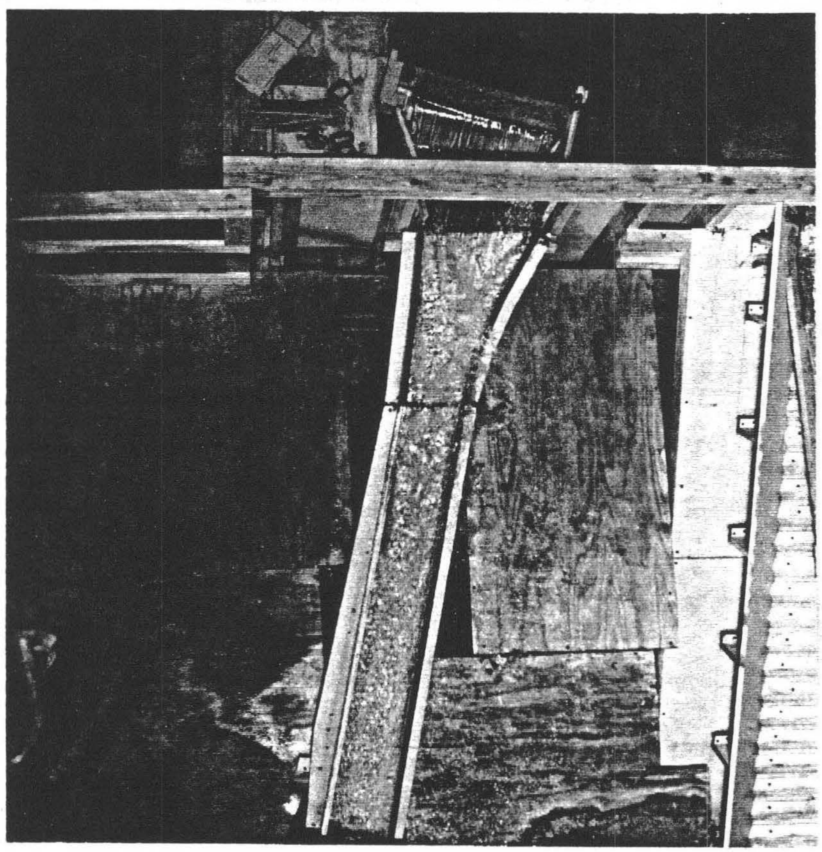


Figure 5. - Overtopping of the left chute wall downstream of the crest for a discharge of 3,400 ft^3/s through the 47.67- by 3.5-foot opening.

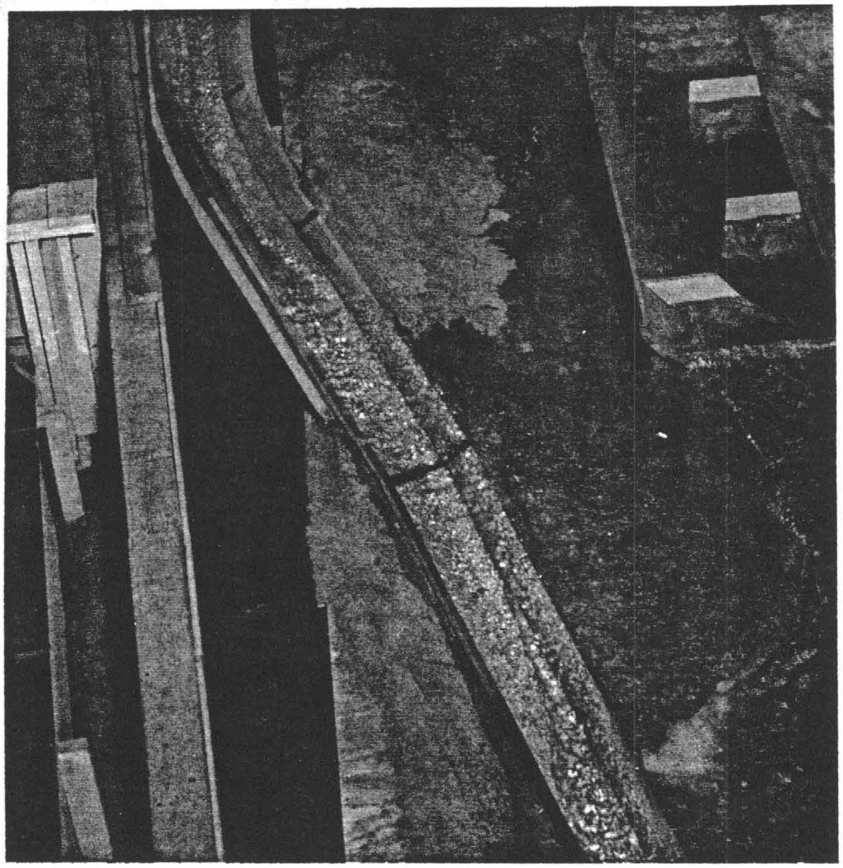


Figure 6. - Overtopping of the left wall downstream of the horizontal bend for a discharge of 3,440 ft^3/s through the 46.67- by 3.5-foot opening.

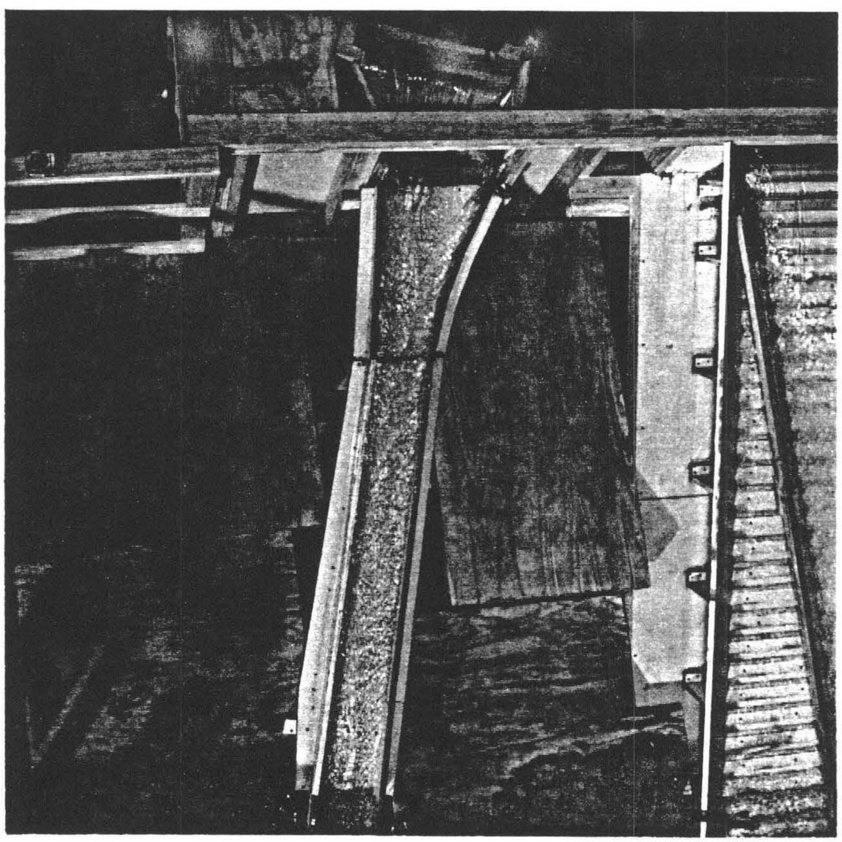


Figure 7. - Overtopping of the left wall downstream of the crest (30- by 3.5-foot opening).

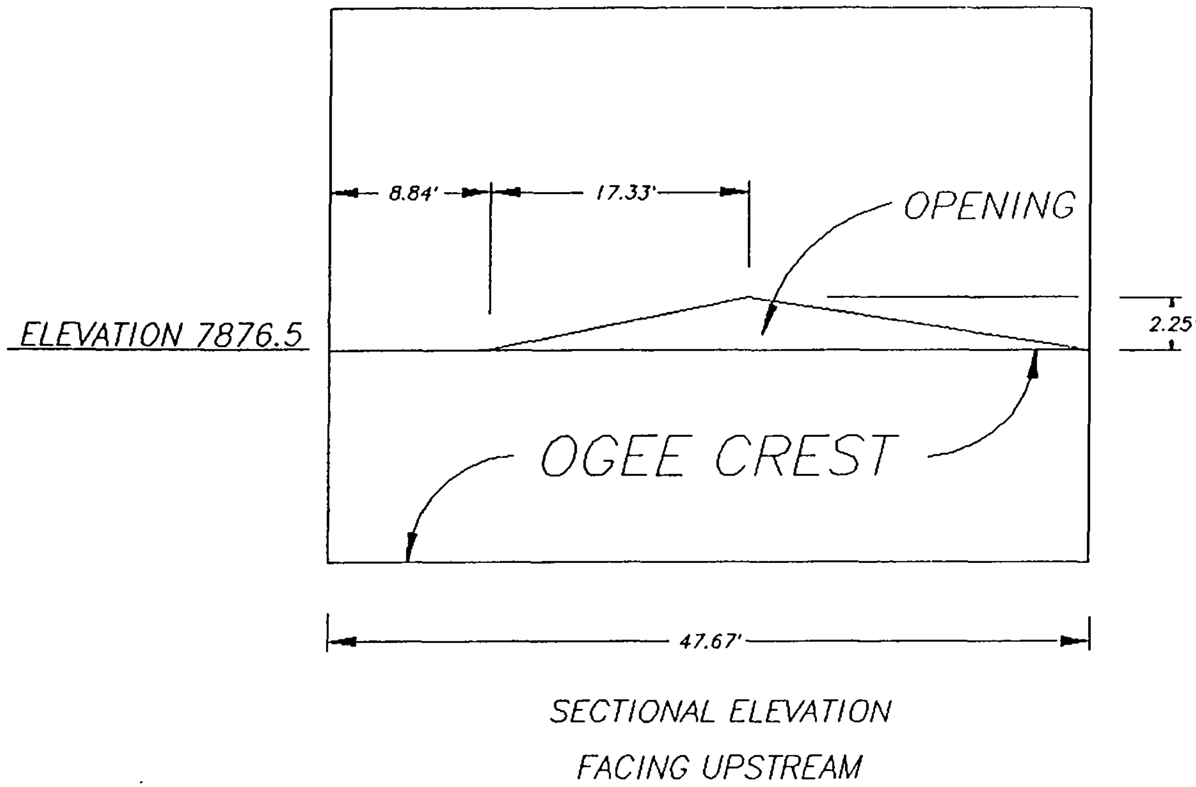


Figure 8. - Triangular orifice that successfully restricts chute discharge at maximum water surface.

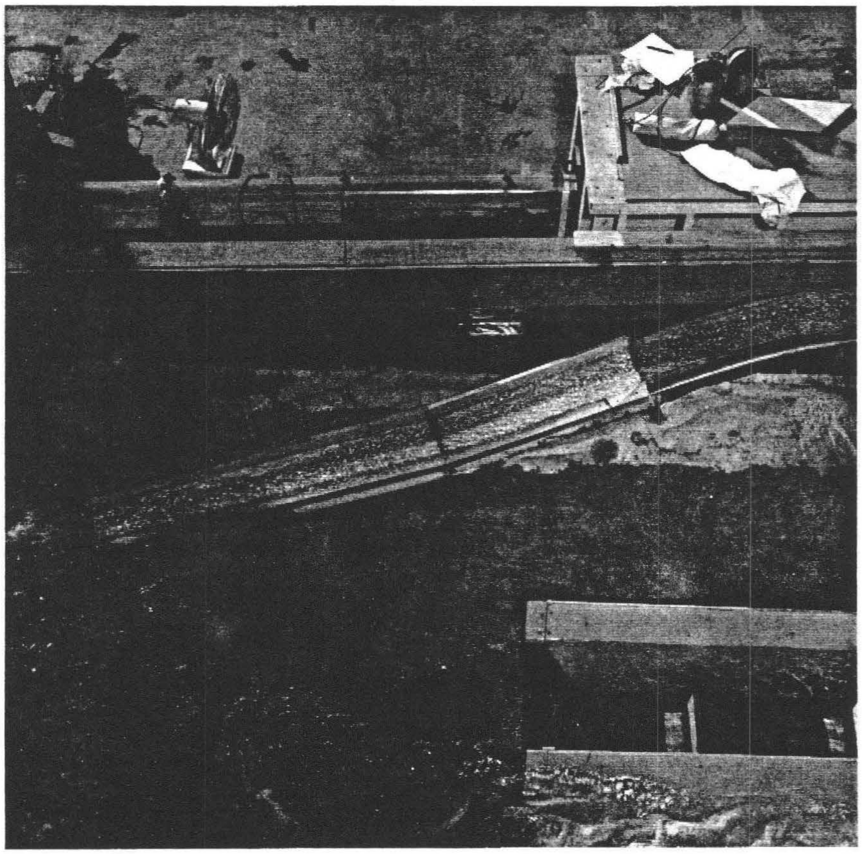


Figure 9. - Superelevation of the bend prevented overtopping of the left chute wall downstream.

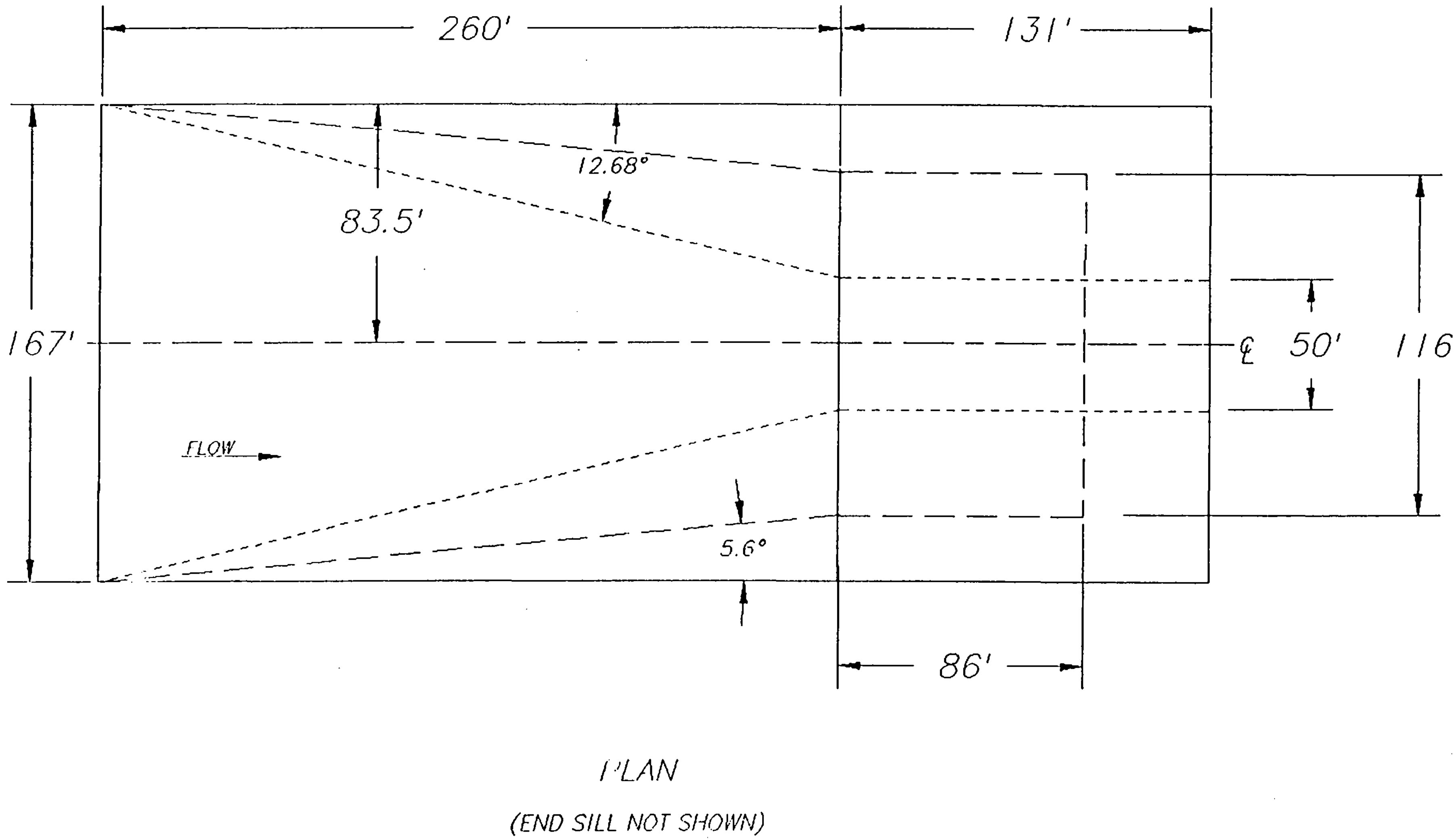


Figure 10. - Plan of the RCC spillway and stilling basin showing the wall convergences tested.

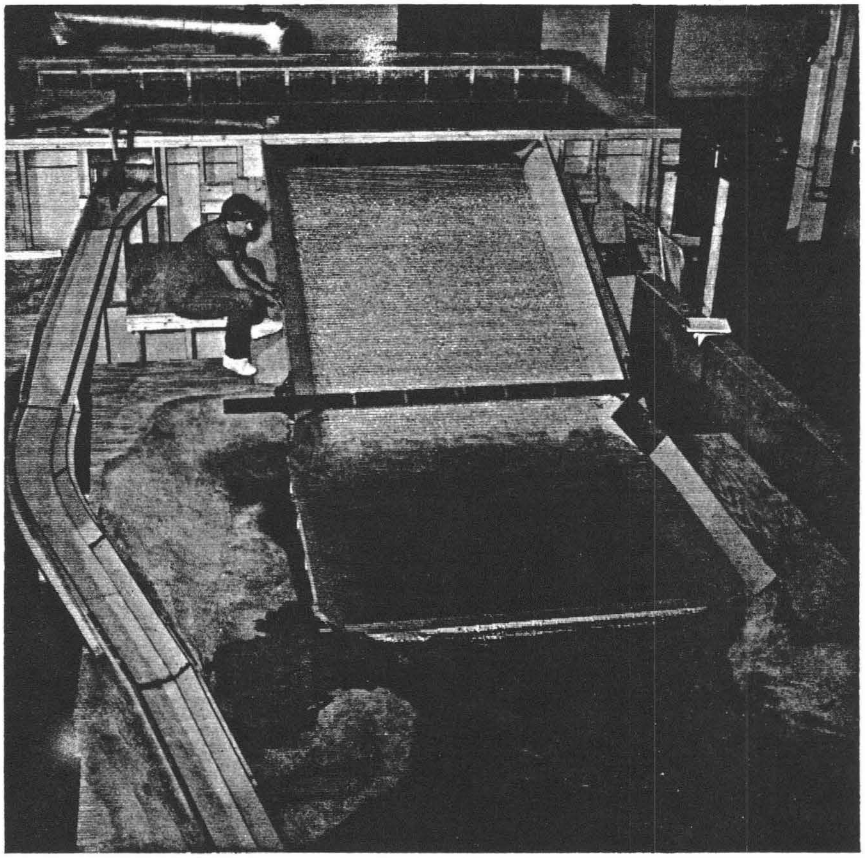


Figure 12. - A discharge of 5,000 ft^3/s over the 1-foot-high stepped RCC spillway with no chute wall convergence.

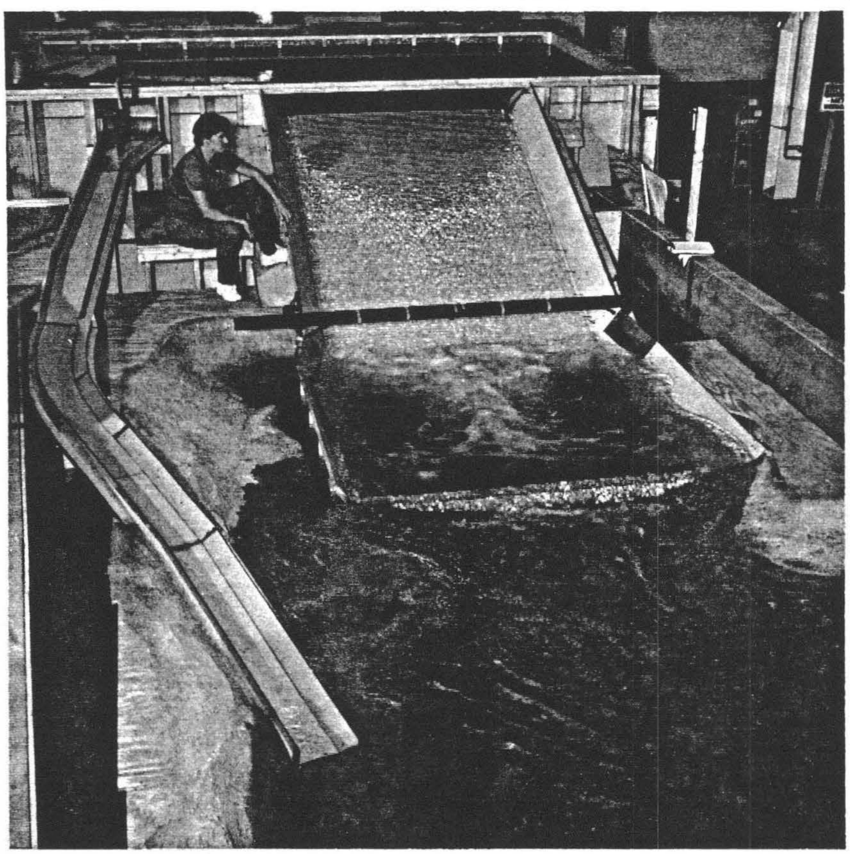
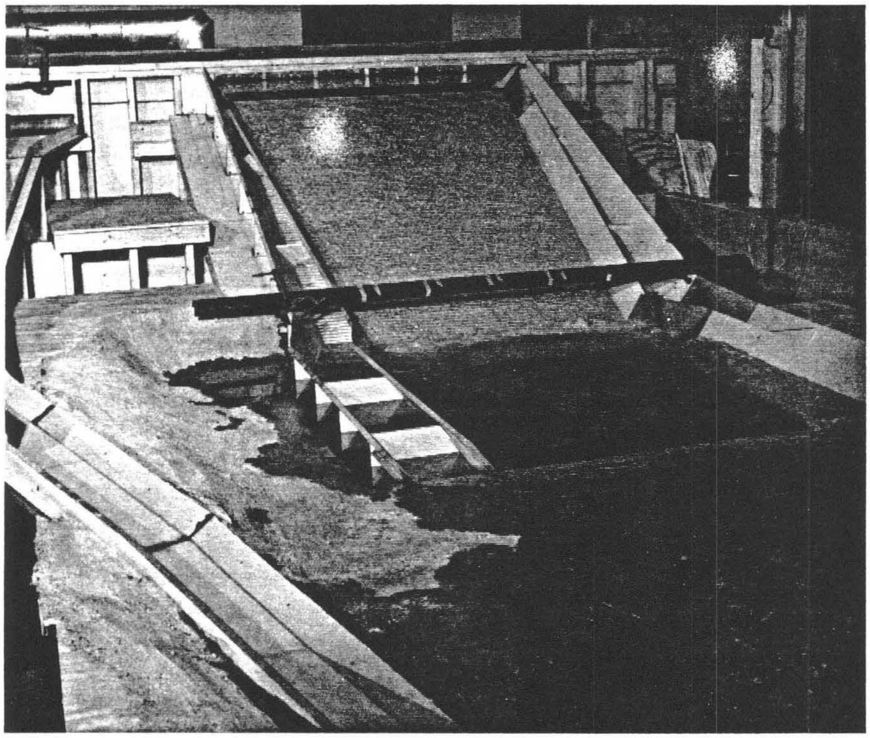
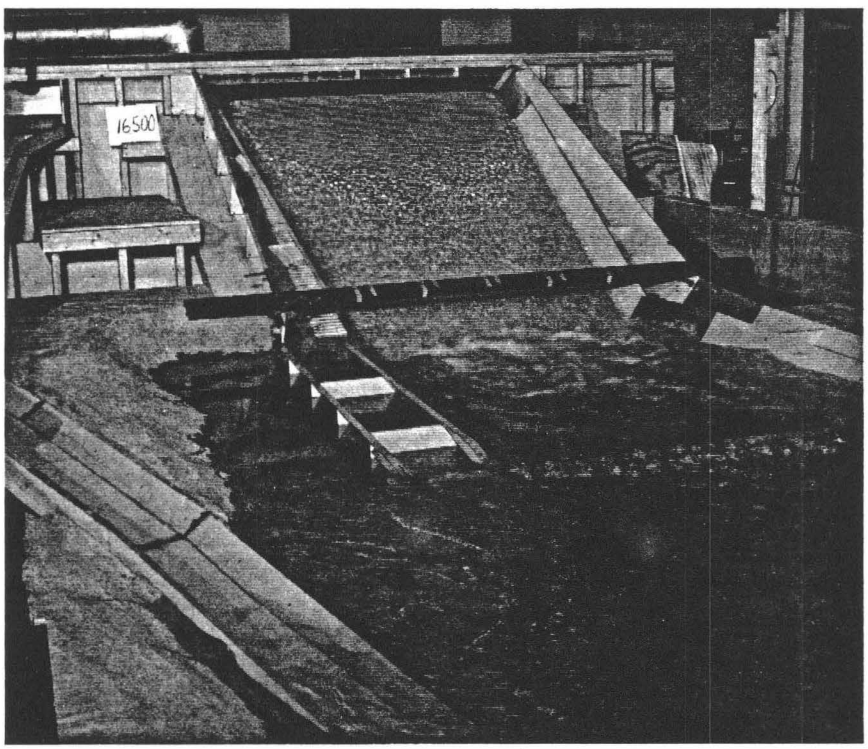


Figure 13. - Passage of design discharge over the 1-foot-high stepped RCC spillway.

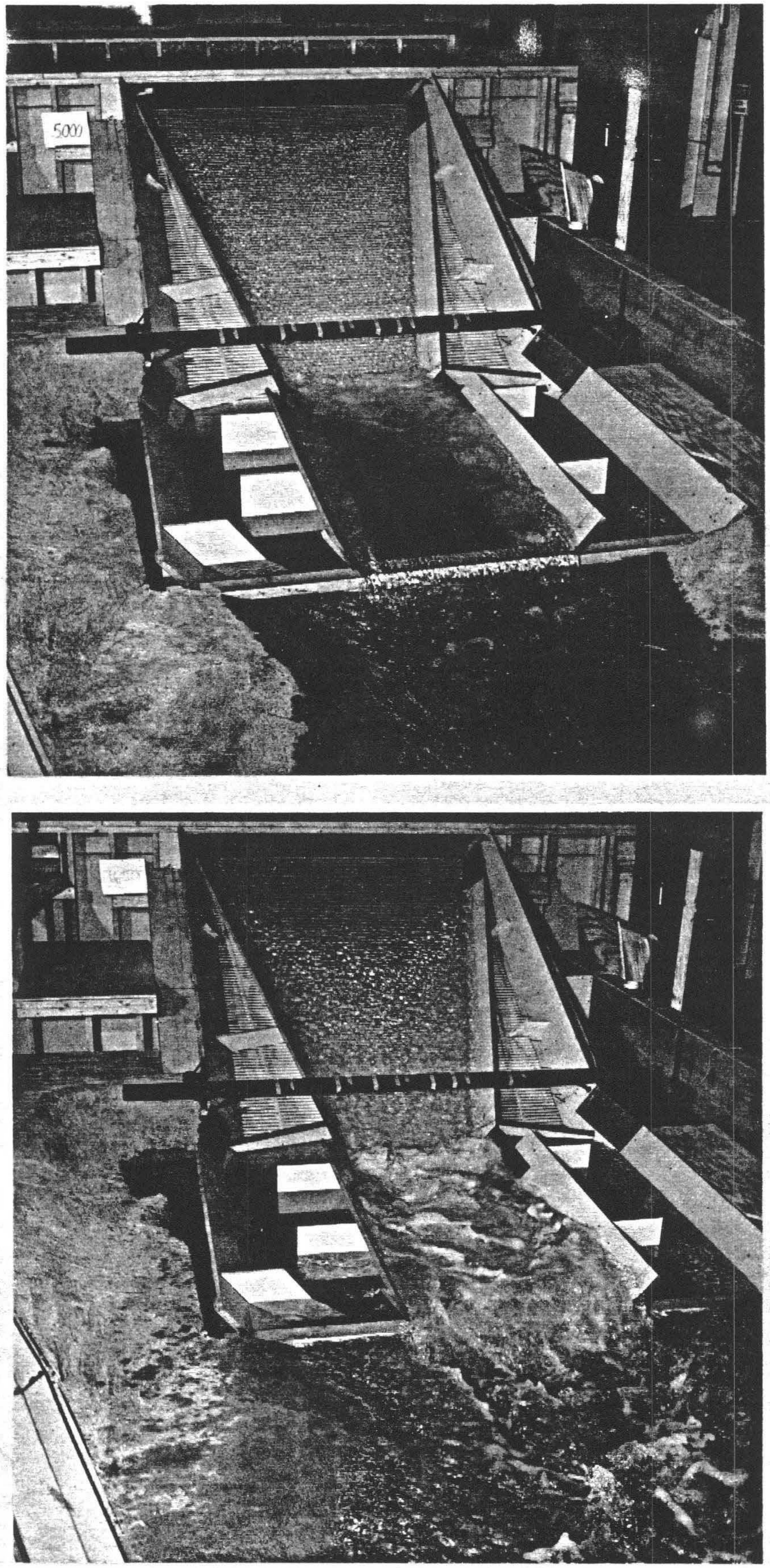


a. Q = 5,000 ft^3/s.



b. Q = 16,534 ft^3/s

Figure 14. - The RCC spillway with 1-foot steps and a 116-foot chute width at the dam toe.



a. Q = 5,000 ft^3/s.

b. Q = 16,534 ft^3/s.

Figure 15. - The RCC spillway with 1-foot steps and a 50-foot chute width at the dam toe.

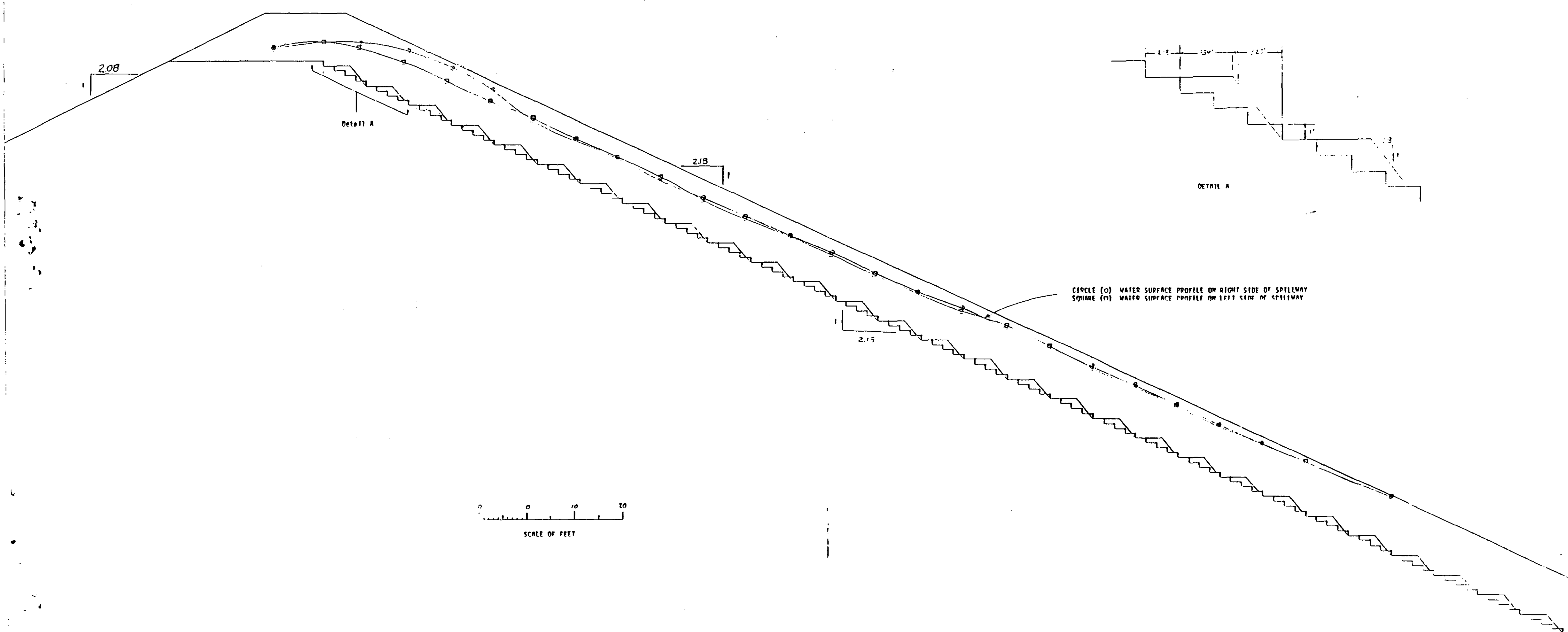
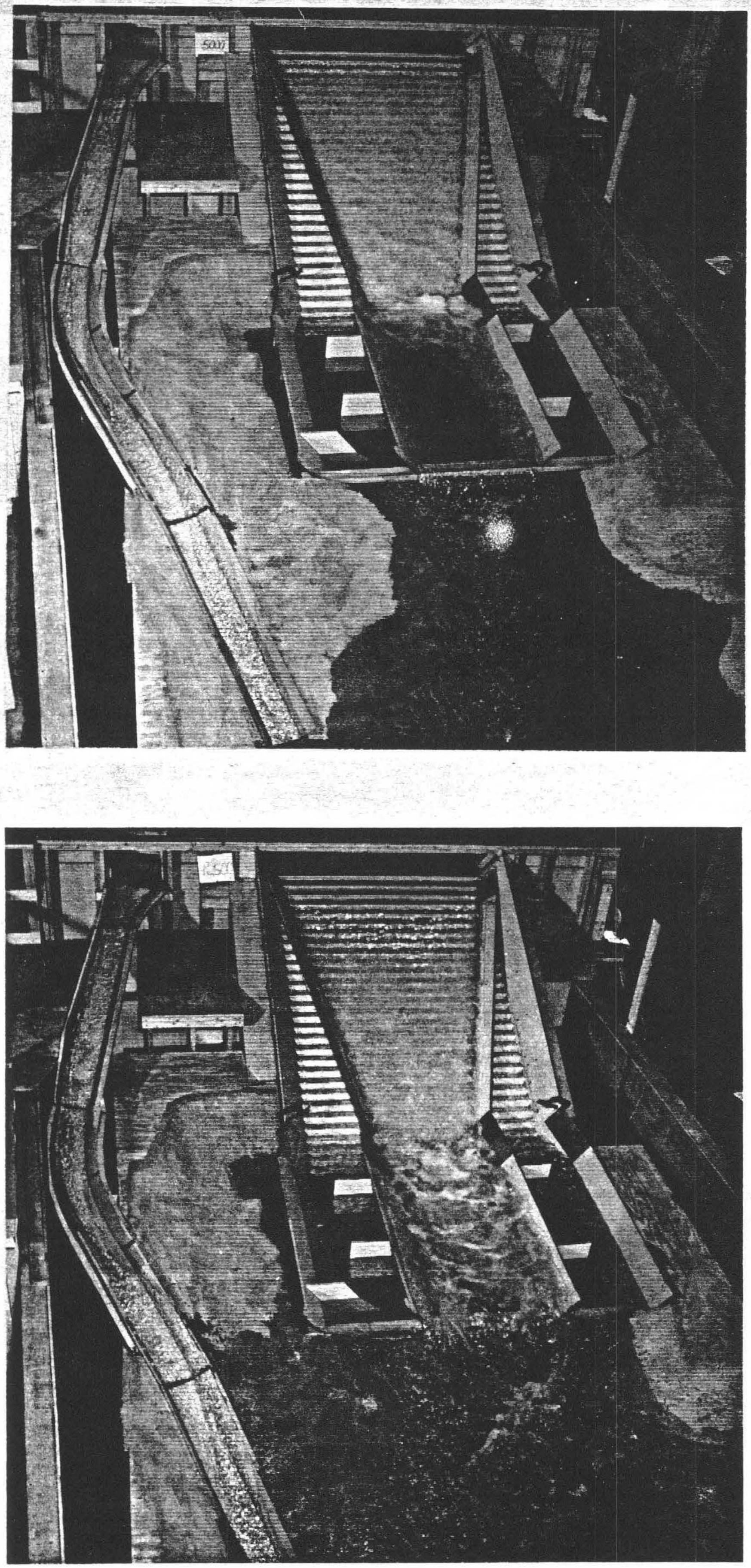


Figure 16.- Step geometry and chute water surface profiles for 4 foot steps.



a. Q = 5,000 ft^3/s.

b. Q = 16,534 ft^3/s.

Figure 17. - The RCC spillway with 4-foot steps and a 50-foot chute width at the dam toe.