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HYDRAULIC MODEL STUDIES OF TOA VACA DAM SPILLWAY - PUERTO RICO WATER RESOURCES AUTHORITY

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16. ABSTRACT

A 1:48 scale model was used to develop the hydraulic design of the spillway at Toa Vaca Dam, Puerto Rico. The spillway consists of an approach channel, a gate structure with three 30- by 33.38-ft (9.14- by 10.17-m) radial gates, a sloping chute, a combination stilling basin and flip bucket, and a discharge channel. The spillway is designed for a maximum discharge of approximately 77,000 cfs (2,180 cms). Energy is dissipated by hydraulic jump for low discharges and by flip-out for high discharges. The model included the entire spillway with approach and discharge channels, reservoir topography extending approximately 600 ft (182.88 m) upstream from the dam, and river channel topography extending approximately 600 ft (182.88 m) downstream from the stilling basin. Model studies included investigation of approach flow conditions, distribution of flow through the gates, water surface profiles, discharge coefficients, pressures on the crest, pressures in the stilling basin, flow characteristics in the combination stilling basin-flip bucket, and erosion in the discharge channel. Details of the testing and recommended modifications prompted by the testing are described.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS--/ *stilling basins/ *flip buckets/ erosion/ spillway gates/ hydraulic structures/ *hydraulic models/ discharges/ performance/ radial gates/ spillway crests/ open channels/ *chutes/ subsurface drains/ water surface profiles/ *model tests/ channels/ pressure/ calibrations/ Puerto Rico/ piers/ test procedures/ *spillways/ hydraulic design/ operations

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by

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October 1970

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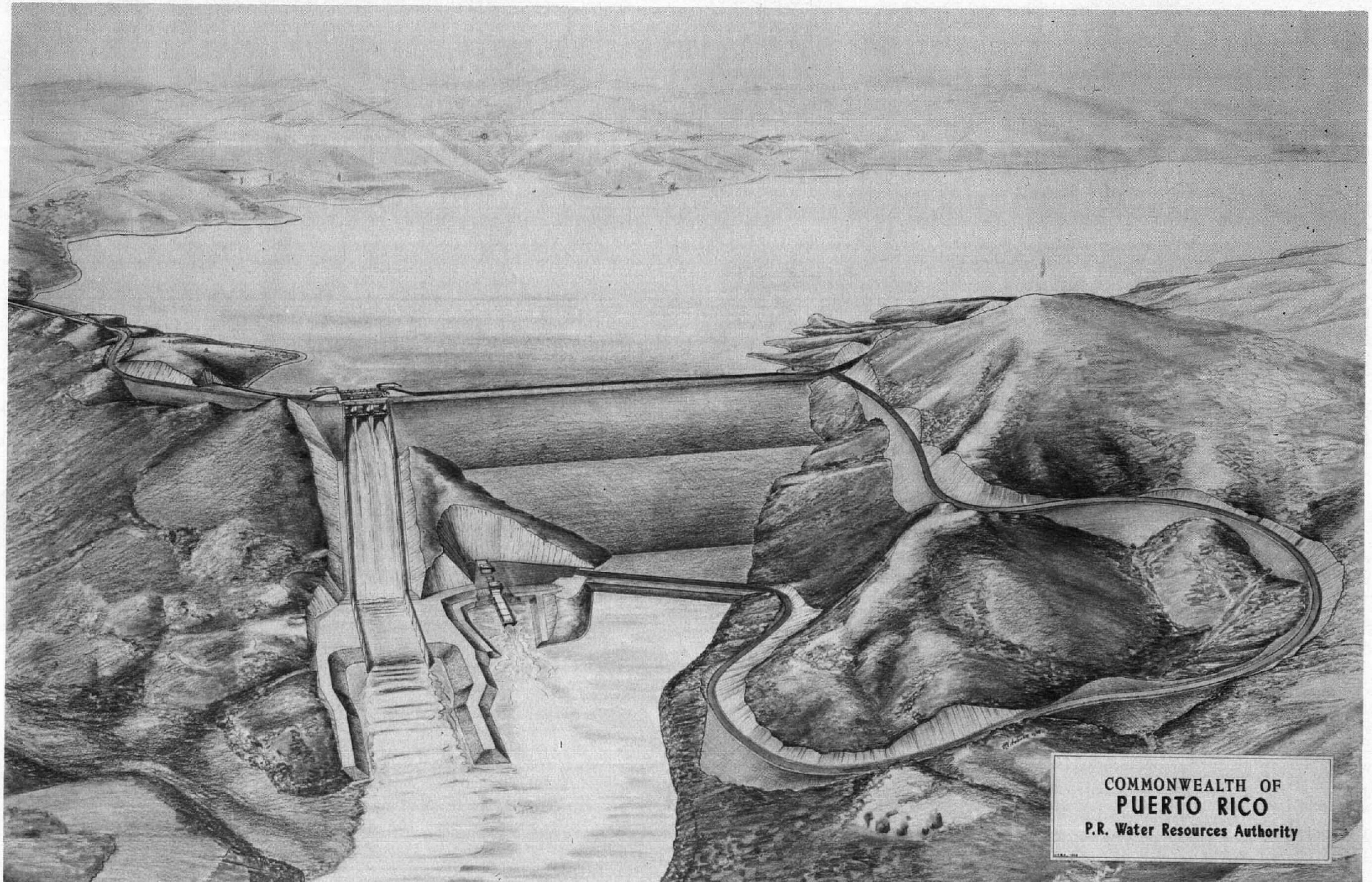


TOA VACA DAM & SPILLWAY

CONTENTS

LIST OF FIGURES

CONTENTS—Continued

PURPOSE

The hydraulic model study was conducted to develop the hydraulic design of the spillway. The study included investigation of the approach flow conditions, distribution of flow through the gates, water-surface profiles, discharge coefficients, pressures on crest, pressures in the stilling basin, flow characteristics in the combination stilling basin-flip bucket and erosion in the discharge channel downstream from the structure.

CONCLUSIONS

1. The flow approached the spillway crest with only minor disturbances in the reservoir area surrounding the spillway entrance.

2. The discharge capacity and crest pressures were satisfactory.

3. Water-surface profiles through the gate section were well below the gate lip and the gate counterweights with the gates fully open.

4. Water-surface profiles through the chute were below the top of the chute training walls. The minimum freeboard of 2 feet [0.61 m (meters)] occurred at a point on the right training wall approximately 258 feet (78.64 m) downstream from the piers.

5. The radius of the flip bucket was shortened to increase the rate of curvature which stabilized the hydraulic jump and increased the basin stilling capacity.

6. The length of the stilling basin was reduced 40 feet (13.19 m) to retain the hydraulic jump in the basin for no more than the design requirement of 26,400 cfs [747.57 cms (cubic meters per second)].

7. The excavated channel from the stilling basin was extended upstream along the outside of the basin walls to receive waves and splashes overtopping the walls.

8. Pressure measurements on the chute, basin, and flip bucket were used to find a proper location for the subdrainage outlets into the spillway and to determine the structural requirements of the flip bucket.

9. A concrete apron extending downstream from the basin in the preliminary design appeared to be a possible debris trap and, therefore, was replaced with riprap.

10. The discharge channel bed was widened from 106 feet (32.31 m) to 141 feet (42.98 m) to provide more protection to the channel banks.

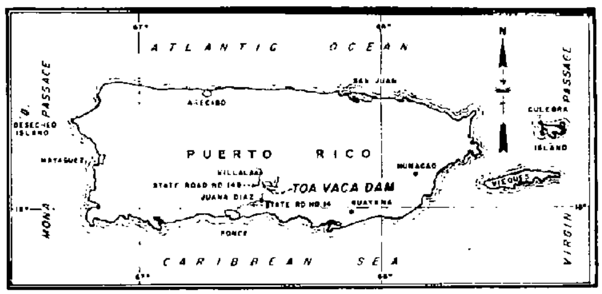
APPLICATION

Generally, the results of this study can be applied to the design of any radial-gate-controlled spillway discharging onto a sloping chute.

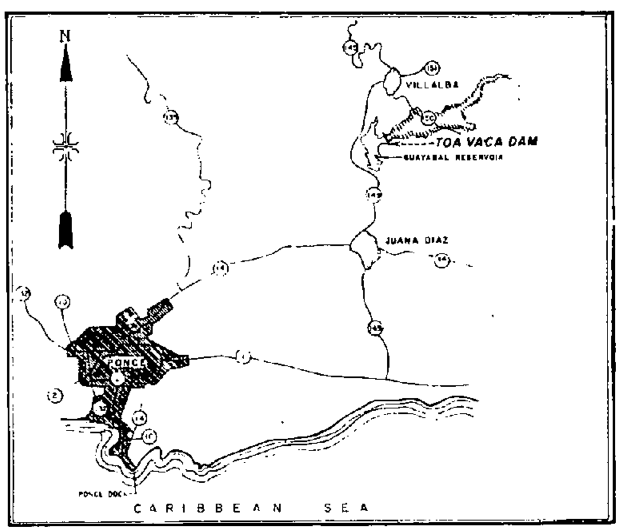
The stilling basin studies can be applied only to specific facilities requiring a combination hydraulic jump-flip bucket type of energy dissipator.

INTRODUCTION

Toa Vaca Dam, as shown in the artist's conception in the frontispiece of this report, is to be constructed under direction of the Puerto Rico Water Resources Authority. The map below shows the location of the damsite in south central Puerto Rico.



LOCATION MAP



KEY MAP

(NOT TO SCALE)

Toa Vaca Dam will be an earthfill-rockfill structure having a spillway and outlet works, Figure 1.

The spillway, Figures 2 through 5, consists of an approach channel, a concrete gate structure with three 30- by 33.38-foot (9.14- by 10.17-m) radial gates, a sloping chute, and a combination stilling basin flip bucket located at the right abutment. As a flip bucket the design discharge is approximately 77,000 cfs (2,180 cms) at reservoir elevation 546.2 feet (166.48 m), Figure 6. Before flip out occurs, the hydraulic jump will remain in the stilling basin for discharges up to about 26,400 cfs (747.57 cms), Figure 7.

THE MODEL

The model, Figure 8, built to a geometrical scale of 1:48 included reservoir topography extending approximately 600 feet (182.88 m) upstream from the dam; the approach channel; the gate section, including radial gates and piers; the chute; the stilling basin with flip bucket end sill; the discharge channel downstream from the structure, and the river channel topography 600 feet (182.88 m) wide for a distance of about 600 feet (182.88 m) downstream from the basin.

Topography in the reservoir area of the model was molded of concrete placed on metal lath which was nailed over wooden templates shaped to the ground surface contour. Model concrete surfaces that simulated natural topography were given a rough finish, while the upstream face of the dam was given a smooth finish. Topography in the spillway approach channel and in the discharge channel was shaped using gravel to provide a movable bed in which to study erosion characteristics of the flow approaching and leaving the structure.

The spillway crest was molded in concrete screeded to sheet metal templates to provide an accurate crest shape. The pressures were measured using 1/16-inch [1.59-mm (millimeter)] inside-diameter copper-tube piezometers that were soldered normal to the profile of the crest centerline template.

The radial gates were fabricated of sheet metal with rubber strips fastened along the two upstream sides to provide a water seal between the gate and the wall. The pier walls and outside walls were constructed of sugar pine painted to minimize swelling.

The spillway chute and stilling basin were constructed from 3/4-inch [19.05-mm (millimeters)] resin-coated plywood shaped to the profile of the spillway surface. The flip-bucket-type end sill was made from sheet metal.

A rock baffle at approximately right angles to the flow lines smoothed the flow coming into the reservoir from a 12-inch (30.48-cm) supply line, Figure 9. A wooden flap-type tailgate controlled the elevation of the water surface in the spillway channel downstream from the structure.

The reservoir elevation was measured with a hook gage in a well connected to the model through a piezometer tap located as shown in Figure 8. The tailwater elevation was measured using a permanently mounted staff gage located near the downstream end of the discharge channel.

Head losses due to friction in the model were greater proportionately than the prototype losses. Therefore, to maintain proper similarity of the flow velocity entering the stilling basin, the gates were closed slightly to appreciably raise the reservoir head, and thus increase the flow velocity in the spillway chute.

INVESTIGATION

The primary purpose of the study was to confirm the hydraulic design of the spillway structure including the criteria for hydraulic jump sweepout from the stilling basin. To accomplish this, it was necessary to study the characteristics of the flow as it approached and passed through the spillway as well as the characteristics of the flow as it left the spillway structure and flowed through the discharge channel. (Note: The data discussed are in prototype terms unless otherwise noted.)

Spillway Approach Area

Hydraulic characteristics of the flow approaching the spillway were satisfactory. Surface currents for the gate-controlled flows and for free flow of 78,000 cfs (2,308 cms), Figure 10, showed only minor disturbances along the approach training walls. The large slow eddy to the right of the approach did not disturb the pea gravel in the vicinity of the model entrance, indicating that the curvature of the dam embankment into the right abutment was satisfactory. The only erosion into the layer of pea gravel occurred at the base of the right training wall and under the pier noses; however, no problem is anticipated in the prototype since these areas are to be paved, Figure 2.

Dye used to observe flow currents below the water surface showed no adverse conditions near the location of the floatwell intake, Figure 1.

Spillway Gate Section

Water-surface profiles.—Uncontrolled and controlled flow through the gate section, Figure 10, appeared to be satisfactory in every respect. Water-surface profiles recorded for 78,000 cfs (2,208.73 cms), Figure 11, showed all parts of the gate, Figure 3, including the counterweights to adequately clear the water surface. The pileup of the water surface at the pier nose and drawdown downstream as shown by the profiles was expected and not considered to be objectionable.

Crest pressures.—Pressures recorded on the centerline of the spillway crest, Figure 12, showed a subatmospheric pressure area downstream of the gate seat for gate-controlled flows. At approximately 8.75-feet (2.67-m) gate opening the maximum subatmospheric pressure was about 5 feet of water at 26,400 cfs (742.57 cms) discharging from maximum reservoir elevation 546.2 feet (166.48 m). This pressure is considered nominal for this gate section. Maximum pressures on the crest profile centerline were equivalent to about 35 feet (11.48 m) of water above atmospheric at a discharge of 78,000 cfs (2,208.73 cms).

Calibration.—With gates full open the free crest was capable of discharging 78,000 cfs (2,208.73 cms) at reservoir elevation 546.6 (166.48 m), Figure 13. However, the maximum allowable reservoir water surface was revised downward to elevation 546.2 feet (166.48 m). Based on a discharge coefficient of 3.62 as determined from the model data, Figure 13, the free-flow discharge will be about 77,000 cfs (2,180 cms) at the revised maximum reservoir elevation.

The crest section was also calibrated for gate-controlled flow. The data points, Figure 13, were recorded with the three gates equally opened from 5 to 30 feet (1.52 to 9.14 m) in 5-foot (1.52-m) increments. Curves for increments of 2.5 feet (0.76 m) were interpolated by cross plotting the gate opening curves established by the data points.

Spillway Chute

Water-surface profiles.—The spillway chute, Figure 2, is 106 feet (32.31 m) wide and drops 175 feet (53.34 m) in elevation in a distance of 583 feet (177.70 m) from the downstream end of the piers to the upstream end of the basin's horizontal apron. Controlled flow of 26,400 cfs (747.57 cms) with the three gates opened equally and uncontrolled flow of 78,000 cfs (2,208.73 cms) produced standing wave patterns throughout the chute as shown in Figures 6, 7, and 10. The flow patterns were almost symmetrical; however, the standing waves that intersected the right training wall of the chute were a little higher than those on the left training wall. This is evident in the water-surface profiles recorded along the training walls for 78,000 cfs (2,208.73 cms), Figure 14, and is due to the nonsymmetrical approach to the spillway. At a distance of 258 feet (78.64 m) downstream from the piers the freeboard reaches a minimun of 2 feet (0.61 m) on the right training wall and a minimum of 4 feet (1.22 m) at a distance of 253 feet (77.11 m) downstream on the left wall.

Unsymmetrical Gate Operation Versus Symmetrical Operation

All flows up to 26,400 cfs (747.57 cms) with the three gates opened equally were uniformly distributed across the basin at the toe of the chute, Figure 15. Flows up to 26,400 cfs (747.57 cms) through only one or two gates did not produce as good flow distribution through the chute and stilling basin as with all three gates opened equally. The two outside gates opened equally with the center gate closed produced satisfactory flow, but with the outside gates closed and the center gate open two large, strong eddies occurred along the walls of the stilling basin. With either one of the two outside gates alone discharging or with the center gate and one outside gate operating together, a very violent eddy occurred in the basin. Unsymmetrical flows, especially at 26,400 cfs (747.57 cms), are not recommended for prototype operation. These unsymmetrical flows, however, did not overtop the chute training walls.

Subdrainage outlets.—Initially, the 6-inch (15.24-cm) perforated drains beneath the spillway chute emerged at the junction of the chute floor with the horizontal apron of the basin, Figure 16. However, a piezometer in the vertical face of the recess at the proposed drainage portal registered a high positive pressure, even with the jump swept out, making drainage impossible.

Two alternate locations for the recessed drainage portal were investigated. The first location was higher on the face of the chute; the second location was in the wall of the basin 2 feet (0.61 m) downstream from the chute and 10 feet (3.05 m) above the floor, Figure 16.

Pressures in the face of the slot in the alternate chute location were satisfactory for the drain. However, subatmospheric pressures measured at the downstream end of the slot indicated a possible source of cavitation erosion. Therefore, the location in the basin wall was recommended, Figure 16.

Spillway Stilling Basin—Flip Bucket

Test procedures.—The stilling basin was tested over a range of entrance velocities for the design stilling basin capacity of 26,400 cfs (747.57 cms) to simulate different Manning's roughness coefficients in the spillway chute. For a roughness coefficient of n = 0.014 the computed average velocity at Station 8+18 was about 97.7 feet (29.78 m) per second; for a roughness coefficient of n = 0.008 it was about 109 feet (33.22 m) per second. Velocities of these magnitudes were represented in the proportionately rougher model by slightly closing the gates and blocking the opening between piers above the radial gates, to increase the reservoir elevation. For a velocity of 97.7 feet (29.78 m) per second at 26,400 cfs (747.57 cms), the reservoir was raised to elevation 557 feet (169.77 m). A curve was derived by recording the tailwater elevation at which the hydraulic jump for a discharge of 26,400 cfs (747.57 cms) swept from the basin for the range of flow velocities that could be represented in the model, Figure 17. A velocity of 109 feet (33.22 m) per second could not be represented in the model; therefore, this curve was extrapolated to predict the sweepout tailwater elevation. Using Figure 17 it was predicted that at this velocity for a roughness coefficient "n" of 0.008, the jump would sweep out at approximately 7 feet (2.13 m) higher tailwater than for the velocity at roughness coefficient of n = 0.014.

Preliminary basin performance.—At the lower velocity limit (n = 0.014), the hydraulic jump remained in the preliminary basin for flows up to 30,000 cfs (849.51 cms), Figure 18. At 30,000 cfs (849.51 cms) waves frequently overtopped the basin walls, as shown by the water-surface profiles in Figure 20. In the upstream part of the basin the waves were more like splashes; whereas, in the downstream portion they were in the form of surges. Three methods for containing the surges within the basin were tested: extending the height of wall, extending a seawall-type lip inward at the top of the wall, and extending the top of wall outward horizontally and then upward.

The seawall-type lip was completely ineffective in containing the surges within the basin. Extending the walls sufficiently high to contain the surges or extending the walls both outward and upward was considered too costly. Therefore, it was concluded that the preliminary wall would provide a reasonable amount of freeboard for the average water surface and that excavation of the discharge channel could be extended upstream along the back side of the walls to catch the spillover. The banks in this area could be protected with riprap to provide a riprapped pool for the splashes and waves generated by the overflow.

It was determined that the length of the basin could be shortened since the design stilling capacity of 26,400 cfs (747.57 cms) was exceeded. However, before shortening the basin, testing proceeded using the flip bucket for flows ranging from 30,000 to 78,000 cfs (849.51 to 2,208.73 cms), Figure 20.

Preliminary flip-bucket performance and channel erosion.—The preliminary flip bucket was tested for flows ranging from 30,000 to 78,000 cfs (849.51 to 2,208.72 cms), Figure 20. In no case did erosion occur near the structure. Erosion began on the 5:1 slope of the channel more than 50 feet (15.23 m) downstream from the paved apron extension, Figure 19, and never moved upstream from this point. In fact, during operation, eroded bed material circulated upstream and was deposited on the paved apron extension, Figure 20.

Many modifications to the paved apron extension were tested to prevent the apron from becoming a debris trap where erosion by abrasion would likely occur. These included the addition of end sills and baffles, changes in the elevation of the apron and channel bed, and elimination of the vertical end wall. None of the modifications was satisfactory, and it was decided to replace the apron with riprap to protect the fractured layers of rock that were believed to underlie this area.

Modifications.—Increasing the rate of curvature of the flip-bucket end sill by using a 75-foot (22.86-m) radius instead of 130 feet (39.62 m) added to the stability of the hydraulic jump and increased the capacity of the stilling basin to 32,000 cfs (906.14 cms) for chute velocities computed for a roughness coefficient "n" of 0.014. Therefore, the basin was shortened 40 feet (12.19 m) to reduce the capacity of the basin to the design discharge of 26,400 cfs (747.57 cms).

Recommended basin and flip bucket.—The recommended basin, which was 40 feet (12.19 m) shorter than the preliminary basin, and included the 75-foot (22.86-m) radius flip bucket, Figures 2, 4, and 5, performed satisfactorily. The hydraulic jump remained in the basin for discharges up to 26,400 cfs (747.57 cms), at the flow velocity anticipated for a roughness coefficient "n" of 0.014, Figure 21. Sweepout occurred at about 27,800 cfs (787.21 cms) above which the flip bucket performance was very satisfactory for flows up to 78,000 cfs (2,208.73 cms), Figures 22, 23, and 24. As the flow receded, the jump fell back into the basin at considerably less than the 26,400 cfs (747.57 cms). The exact discharge at which the jump returns will depend on the extent of channel degradation and resulting tailwater. (In actual practice the spillway gates will probably be closed to reestablish the jump in the basin.)

If the prototype roughness coefficient "n" is as low as 0.008, sweepout is predicted to occur at approximately 23,000 cfs (651.29 cms) using the tailwater curve for no channel degradation.

If flip-bucket operation causes the channel to degradate from elevation 340 feet (103.63 m) to elevation 330 feet (100.58 m), the lower tailwater curve in Figure 21 will prevail. However, the bucket lip at elevation 342 feet (104.24 m) will hold the jump in the basin for flows in excess of the 20,000 cfs (566.15 cms) which meets design requirements if roughness coefficient of the chute is only n = 0.008.

Water-surface profiles for the design flow of 26,400 cfs (747.57 cms), Figure 25, show that waves overtop the downstream portion of the wall. Some overtopping also occurred for lesser flows exceeding approximately 15,000 cfs (424.75 cms); however, the discharge channel pool is designed to extend upstream along the outside of the walls to intercept this spillover.

Pressures along the centerline of the basin were satisfactory for all flows, Figure 26.

Channel Erosion Study

Several arrangements for the excavated discharge channel downstream from the recommended basin were investigated to provide a stable operating channel at minimum cost.

Since the concrete apron in the preliminary design was eliminated, there was some question as to how deep the channel immediately downstream of the basin should be excavated. The depth will depend greatly upon the condition of the rock to be encountered in this area. Available information indicates that much of the bedrock is fractured and, therefore, erodible, particularly along the left side of the channel.

Erosion tests at a discharge of 26,400 cfs (747.57 cms) before sweepout showed that severe erosion might occur downstream of the end sill with the initial bed placed at elevation 340 feet (103.63 m), or 2 feet (0.61 m) below the sill. Therefore, for a distance of 150 feet (45.72 m) downstream from the sill, the bed was placed at elevation 328 feet (99.97 m) where it was believed that the bedrock was in better condition, Figure 27A. An erosion test over a sustained period of time at a discharge of 26,400 cfs (747.57 cms) showed that erosion equivalent to 6 feet (1.83 m) in depth would occur in loose erodible material such as pea gravel, Figure 27B. A further test was conducted using a mixture of stones that would pass a 3/4-inch (19.05-mm) mesh to represent riprap up to 36 inches (91.44 cms) in diameter in the channel bed. The amount of movement of the bed material and maximum depth of erosion was reduced to about 5 feet (1.52 m), Figure 27C. At the corners of the basin the riprap reduced the depth of erosion by 3 feet (0.91 m) and is, therefore recommended for prototype use.

In preliminary tests using a channel bed width equal to the basin width, the toe of the riprap banks eroded and allowed the riprap to slough. Reducing steepness of the banks prevented this action. However, the best and recommended arrangement was to move the banks outward by widening the channel bed to 141 feet (42.98 m) in a length of 43.8 feet (13.35 m), Figure 2. The diverging section from the basin to the wider channel is preferred since an abrupt increase in width at the end of the basin caused an increase in erosion at the basin corners.

Flip-bucket operation caused severe erosion in the erodible bed, but the erosion occurred on the 5:1 upward slope of the bed, a safe distance from the structure. A firmer bed than was represented in the model is expected. The channel bed immediately downstream of the basin remained stable during the transition to the jump sweepout-operating condition.

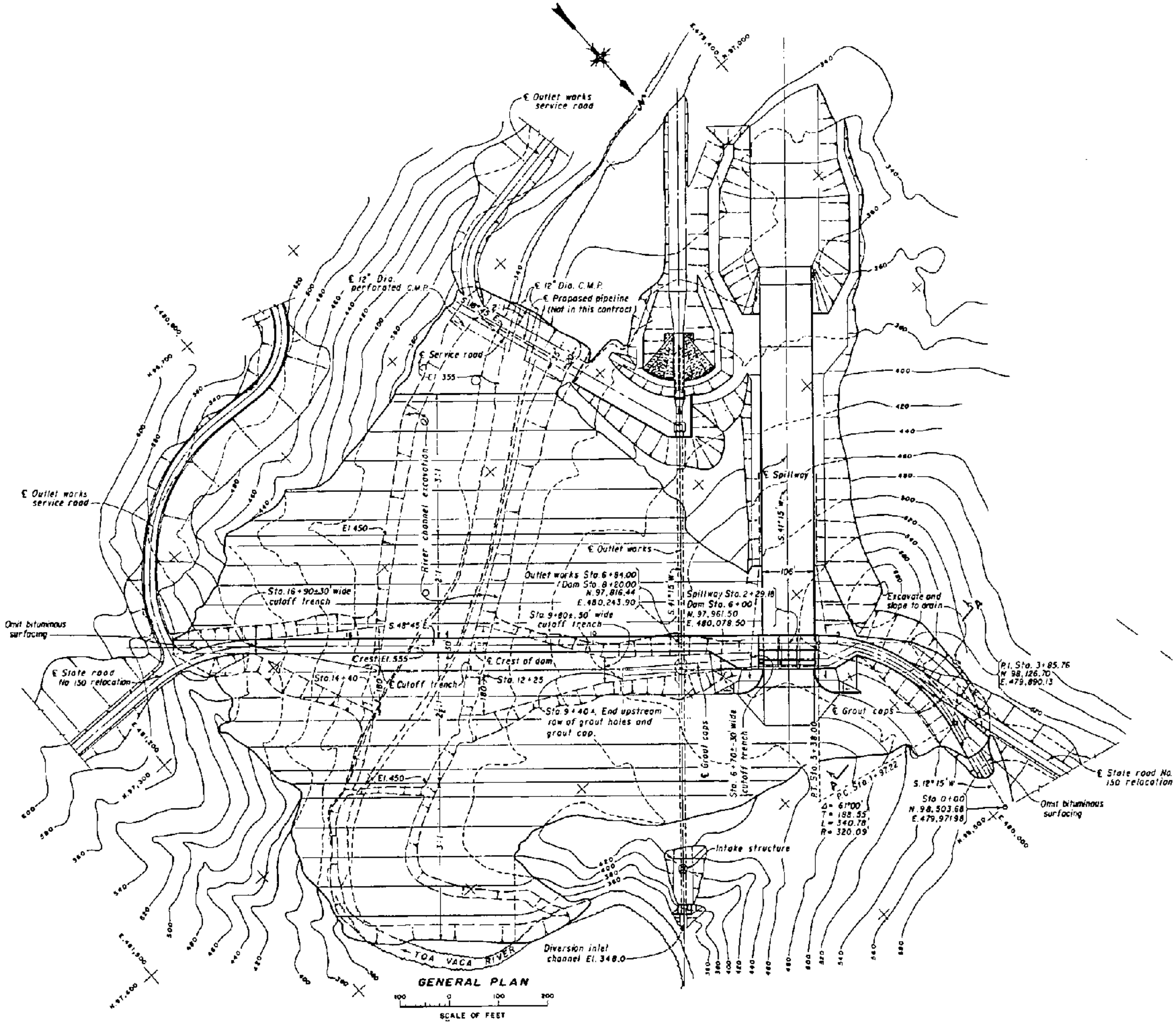


Figure 1. Toa Vaca Dam—general plan and sections.

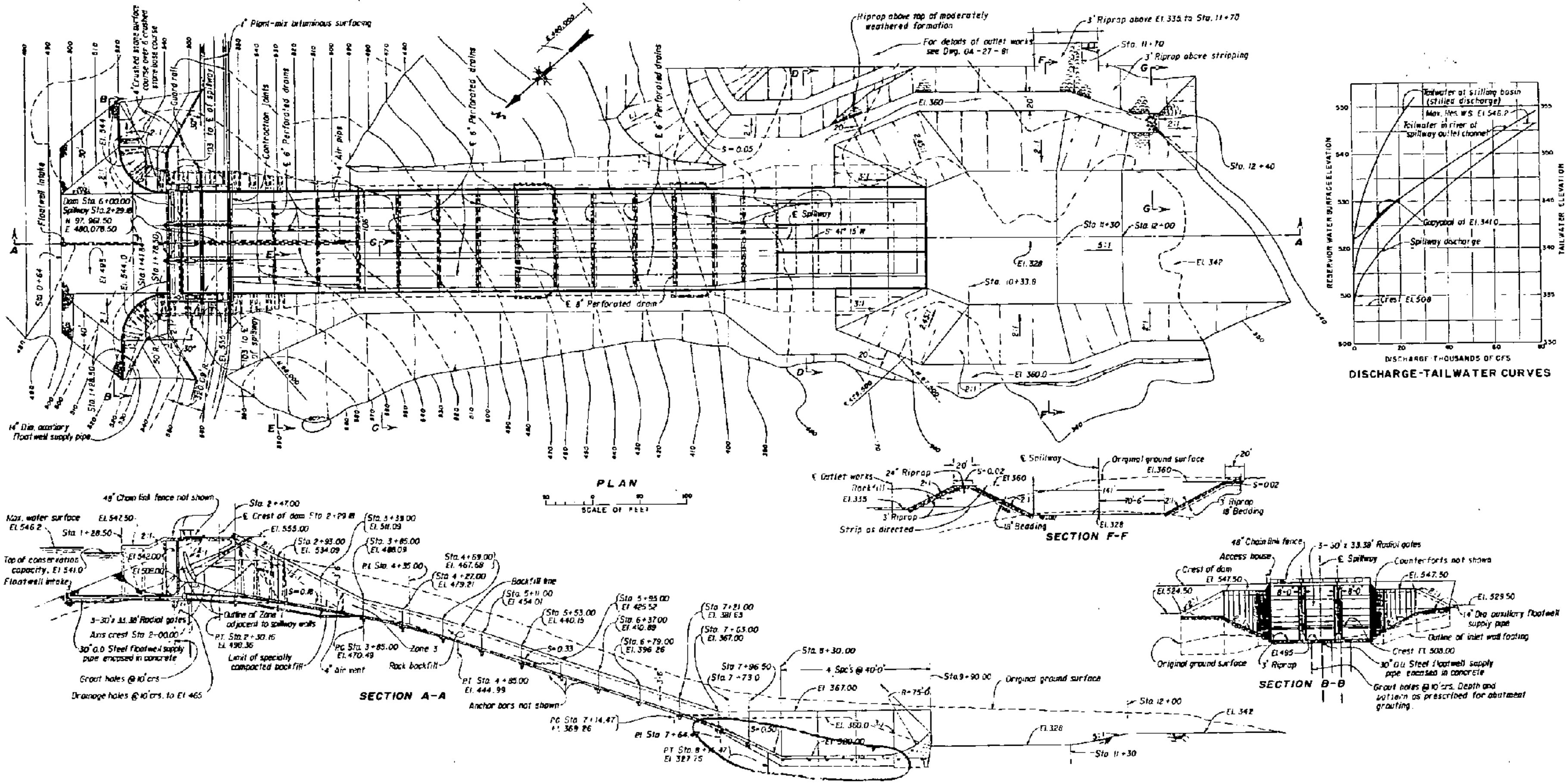
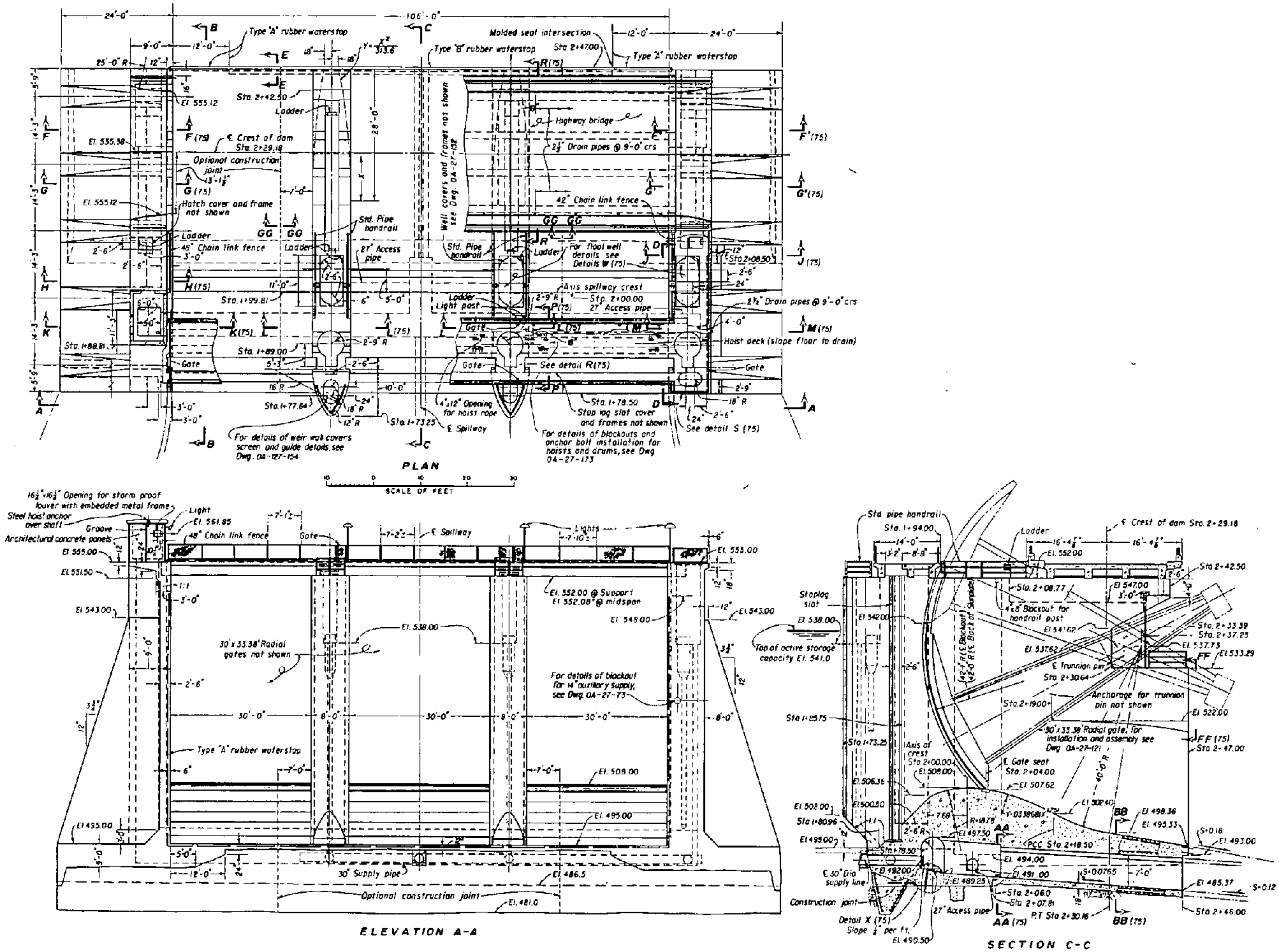


Figure 2.

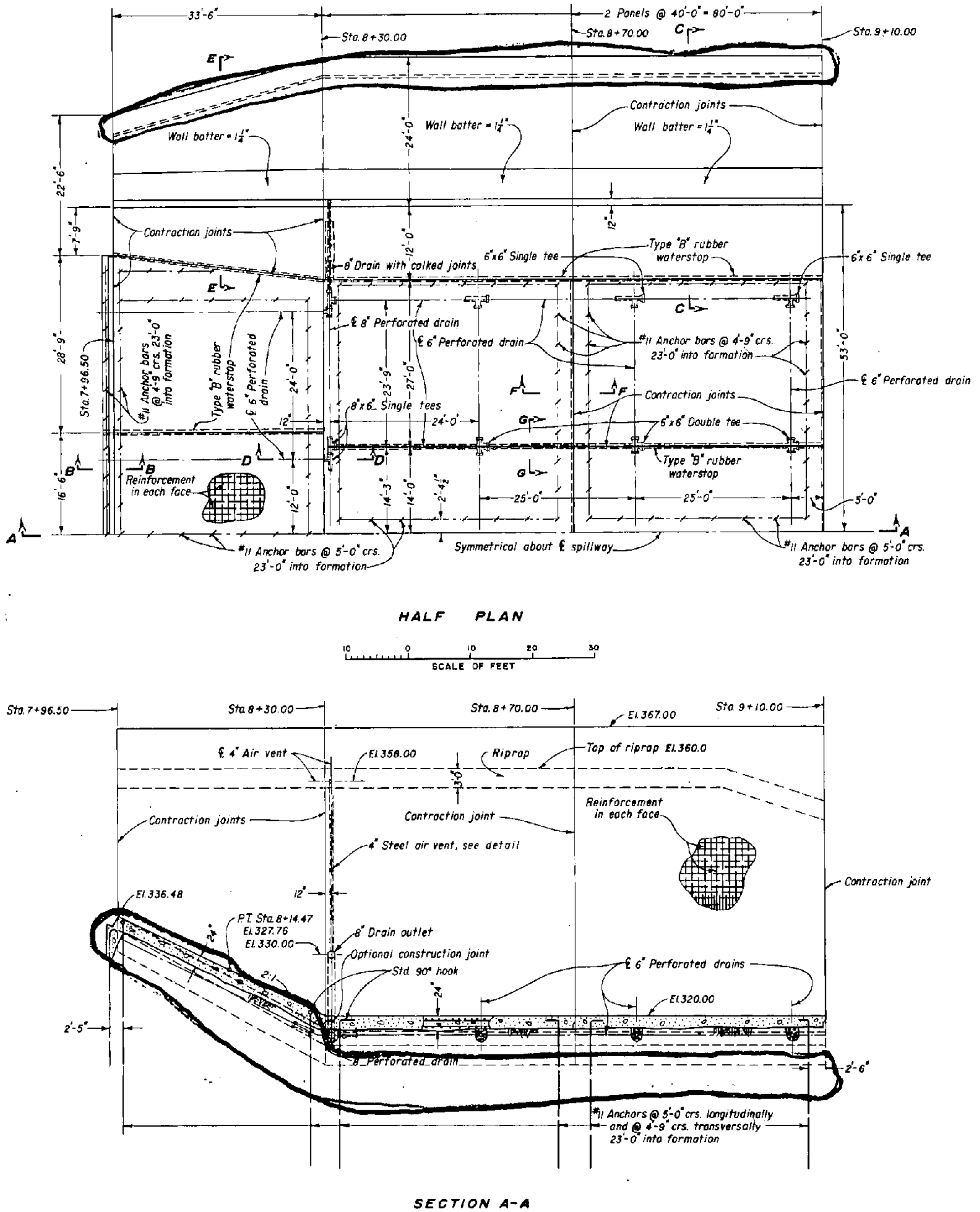
Toa Vaca Dam spillway—plan and sections.



Toa Vaca Dam spillway—gate structure.

Figure 3.

Figure 4.



Toa Vaca Dam spillway—stilling basin—Station 7+96.50 to **Station 9+10.00.**

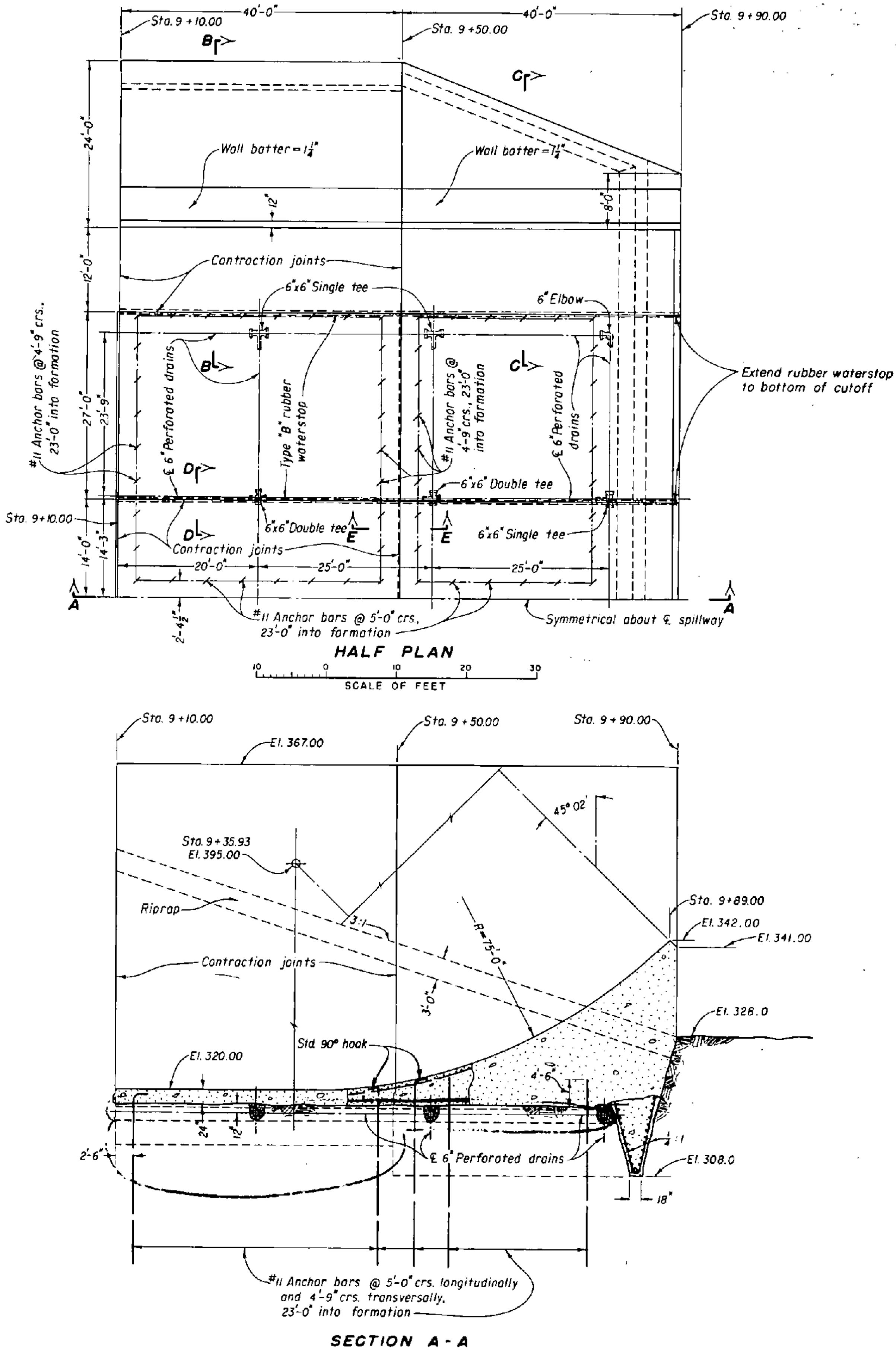
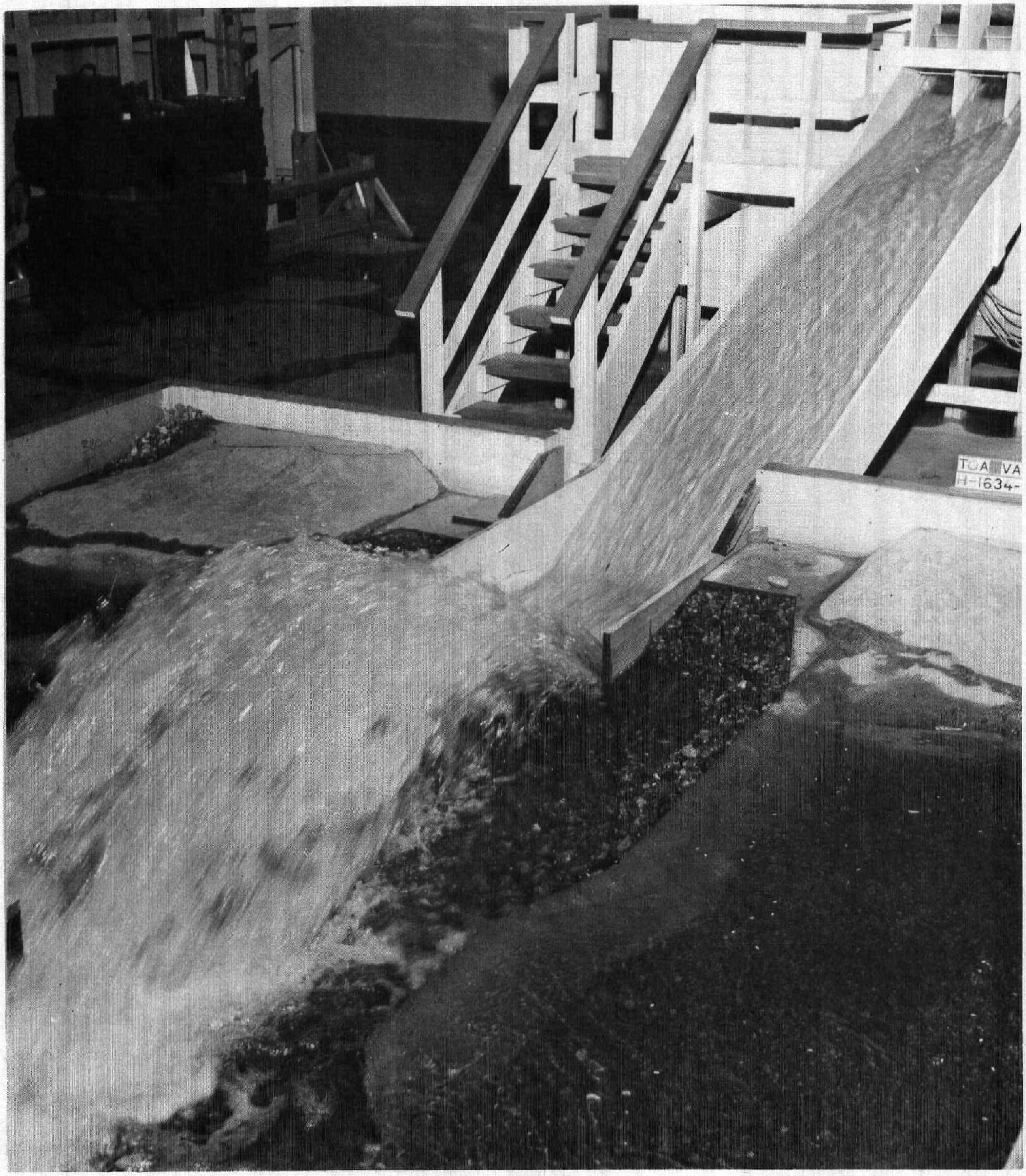


Figure 5. Toa Vaca Dam spillway—stilling basin—Station 9+10.00 to Station 9+90.00.

Figure 6

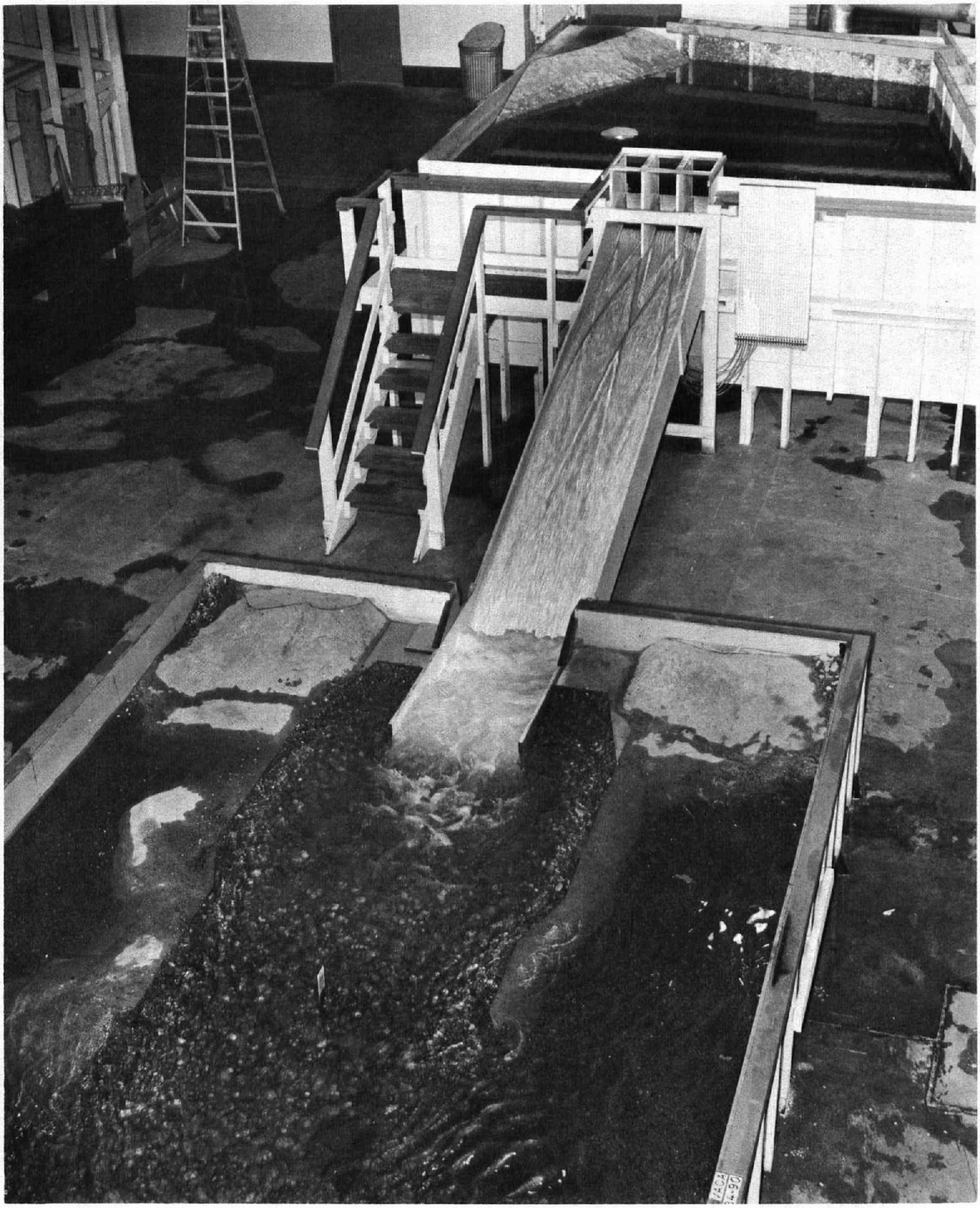


77,000 cfs (2,180 cms). Photo POA27-D-67606

Toa Vaca Dam Spillway
Recommended Chute and Flip-Bucket in Operation

1:48 Scale Model

Figure 7

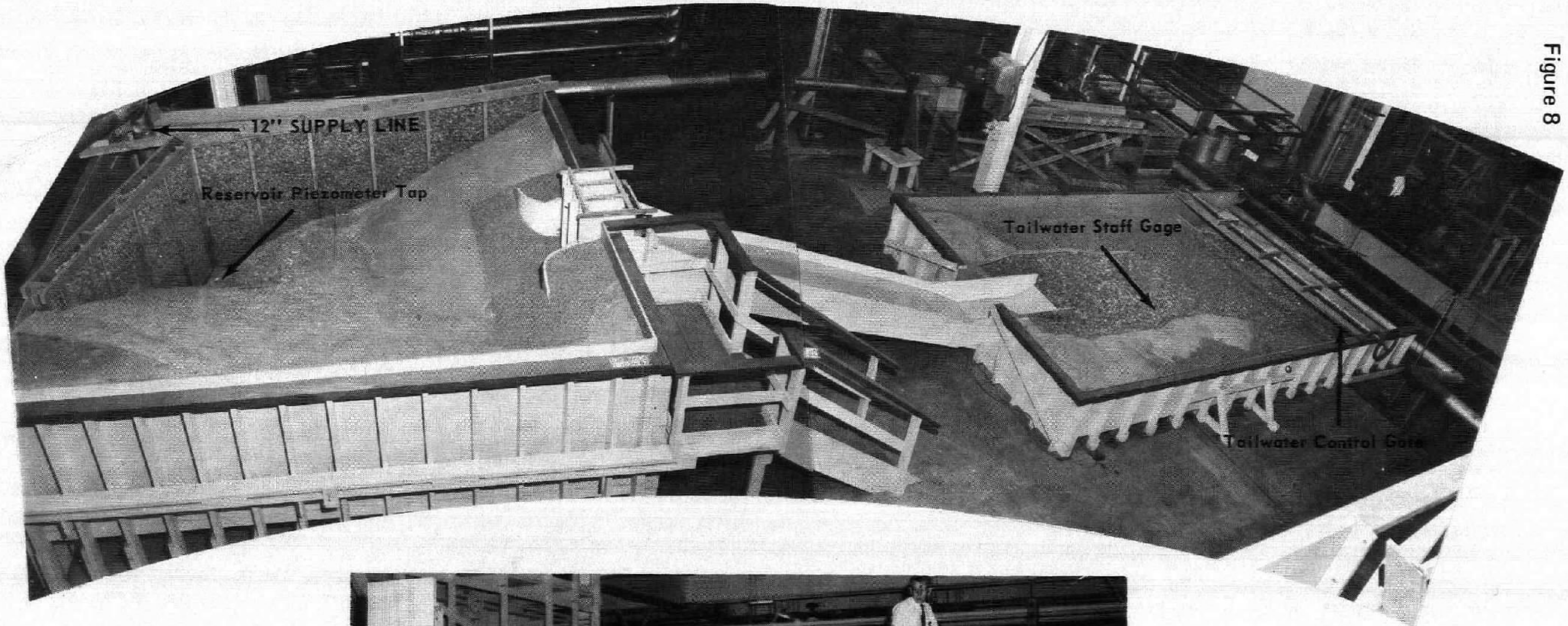


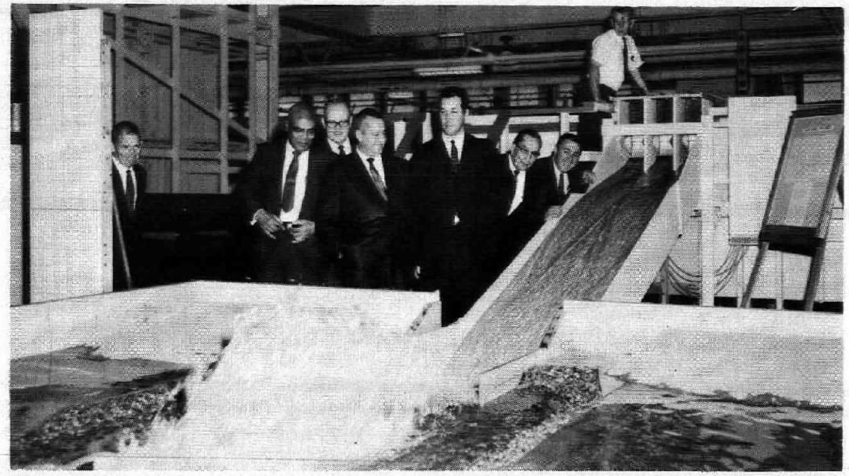
26,400 cfs (747.57 cms). Photo POA27-D-67599

Toa Vaca Dam Spillway
Recommended Chute and Basin in Operation

1:48 Scale Model

Figure 8



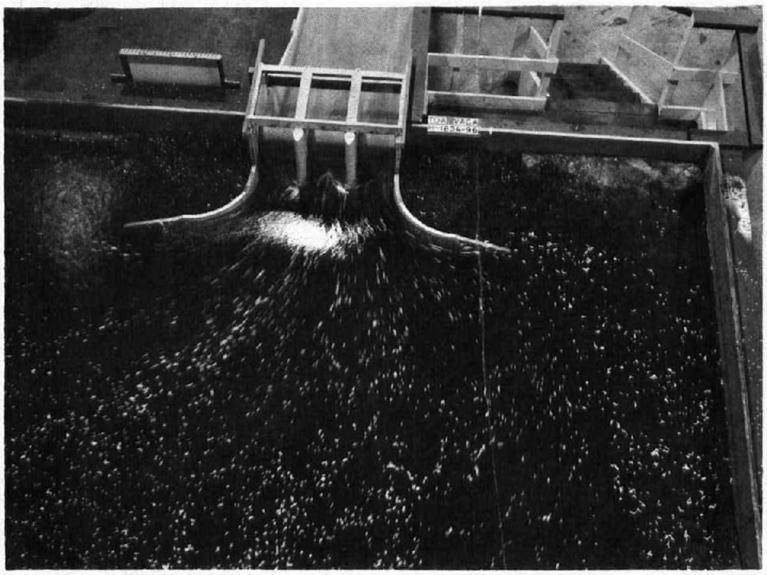


Recommended design discharging approximately 30,000 cfs (849.51 cms) observed by (from left to right): Austin, Abadia, Arthur, Colon, Bochnowich, Marquez, Hilf, and Beichley.

Toa Vaca Dam Spillway

1:48 Scale Model

Q = 26,400 cfs (747.57 cms). Reservoir elevation 546.6 feet (166.42 m). Photo POA27-D-67597

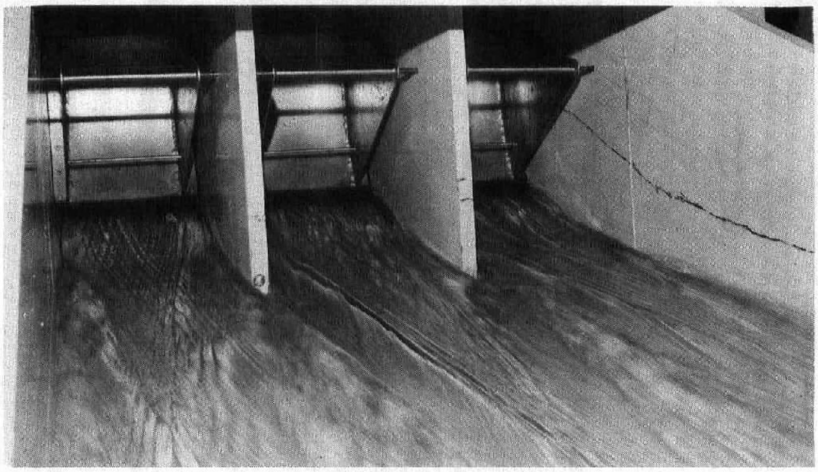


Q = 78,000 cfs (2,208.73 cms). Reservoir elevation 546.6 feet (166.42 m). Photo POA27-D-67610

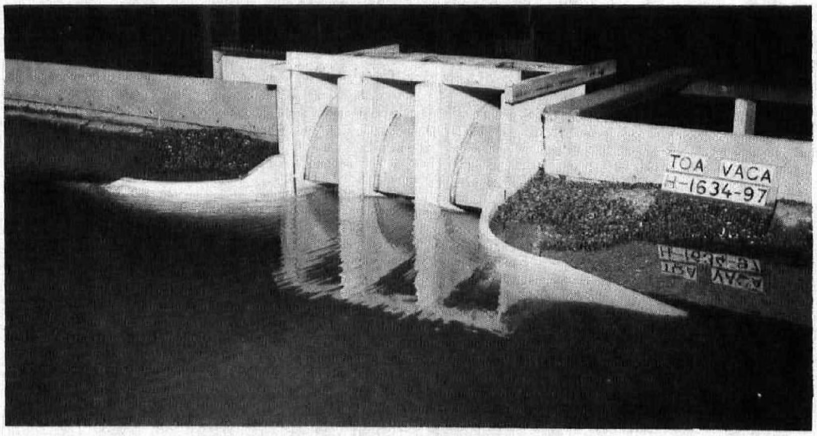
Toa Vaca Dam Spillway
Flow in Spillway Approach Area

1:48 Scale Model

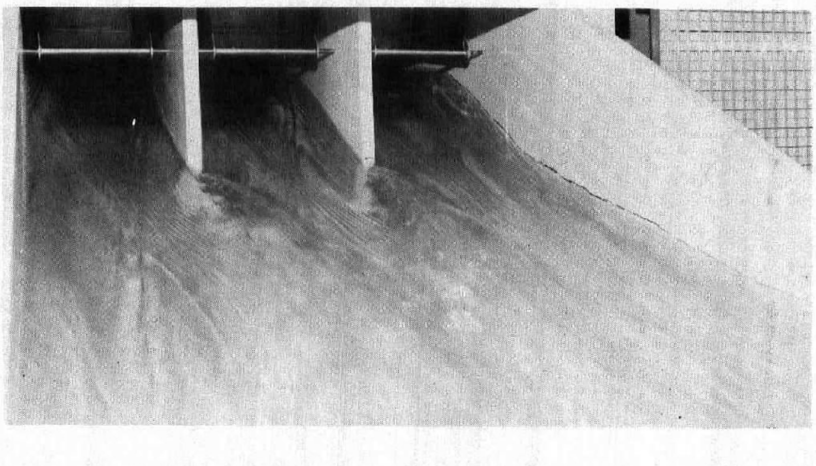
Figure 10



Reservoir elevation 546.6 feet (166.42 m). Q = 26,400 cfs (747.57 cms).
Photo POA27-D-67598



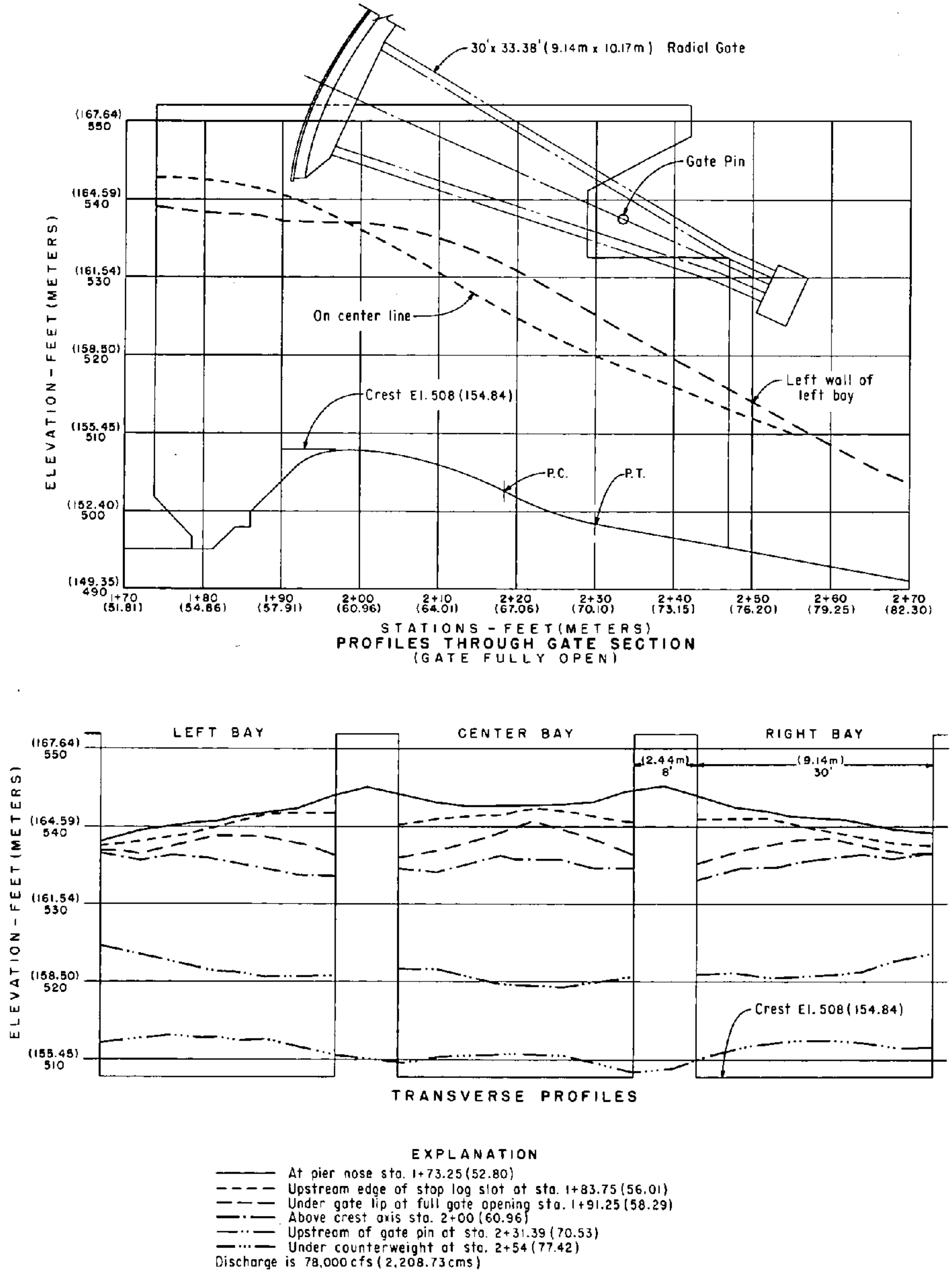
Reservoir elevation 546.6 feet (166.42 m). Q = 78,000 cfs (2,208.73 cms).
Photo POA27-D-67601



Reservoir elevation 546.6 feet (166.42 m). Q = 78,000 cfs (2,208.73 cms).
Photo POA27-D-67602

Toa Vaca Dam Spillway
Flow-through Gate Section

1:48 Scale Model

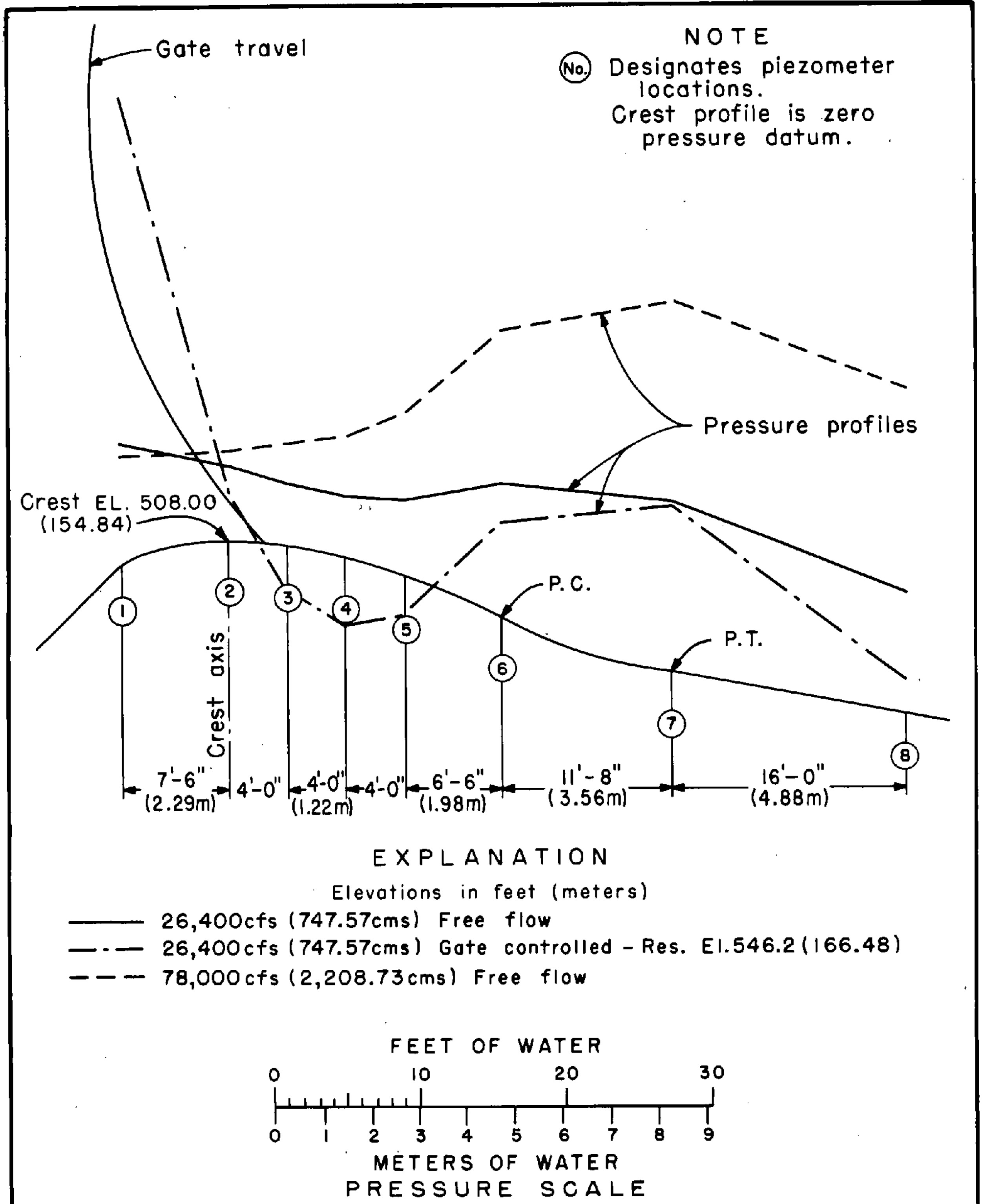


Toa Vaca Dam Spillway
Water-surface Profiles in Gate Section

1:48 Scale Model

742

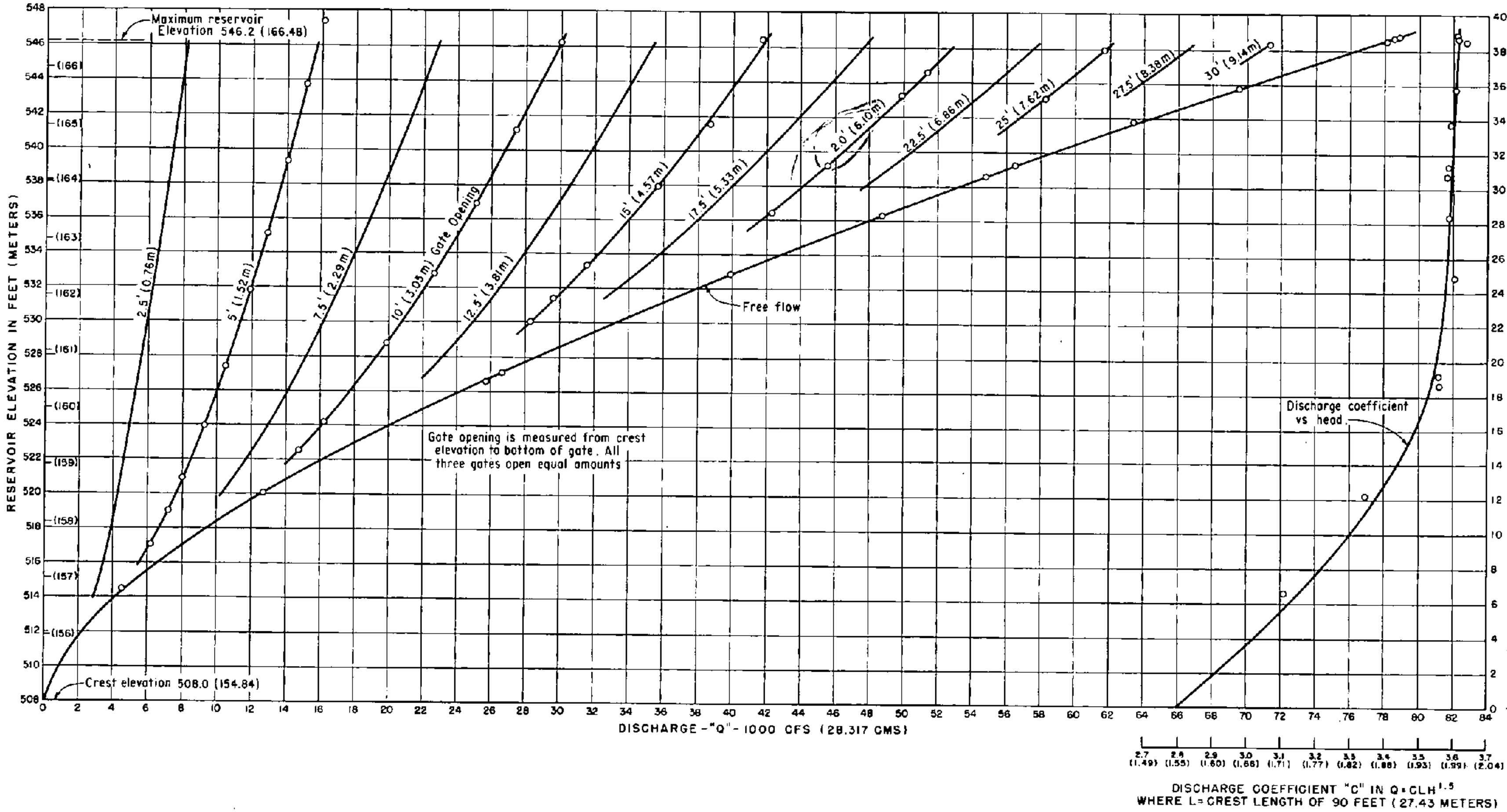
Figure 12



Toa Vaca Dam Spillway
Crest Pressures

1:48 Scale Model

742

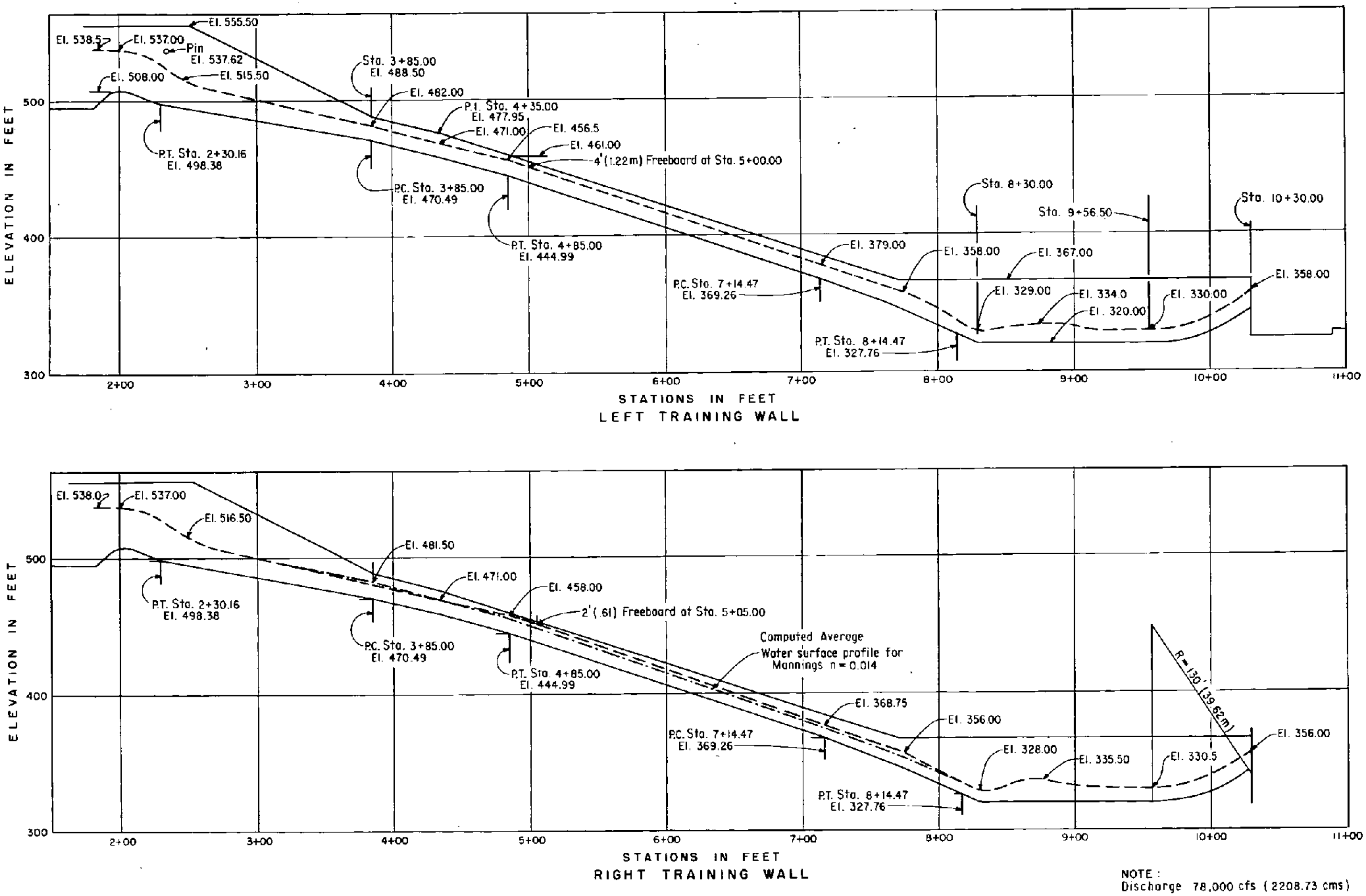


Toa Vaca Dam Spillway
Discharge Calibration

1:48 Scale Model

Note : Units are in English (Metric)

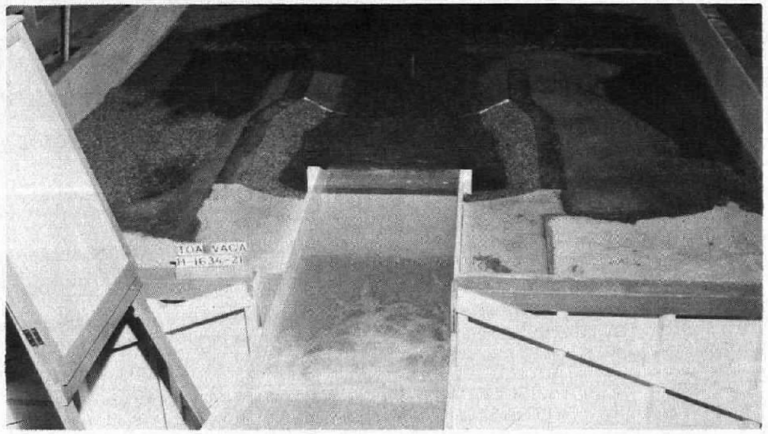
Figure 13



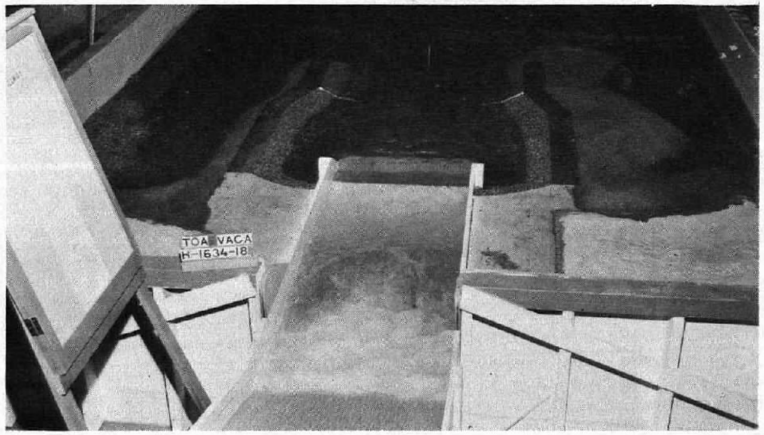
FEET 0 100 200
METERS 0 10 20 30 40 50 60
SCALE

NOTE:
Discharge 78,000 cfs (2208.73 cms)

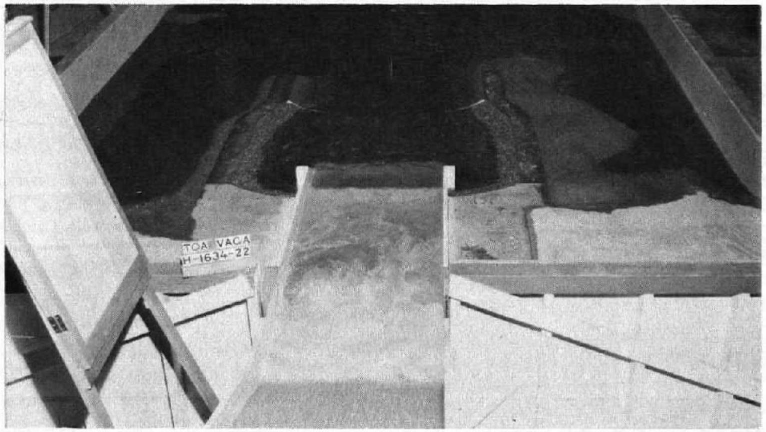
Toa Vaca Dam Spillway
Water-surface Profiles in Chute and Preliminary Flip Bucket
1:48 Scale Model



5,000 cfs (141.58 cms). Tailwater elevation 345.9 feet (105.43 m).
Photo POA27-D-67579



10,000 cfs (283.17 cms). Tailwater elevation 348.9 feet (106.34 m).
Photo POA27-D-67578



15,000 cfs (424.75 cms). Tailwater elevation 351.4 feet (107.11 m).
Photo POA27-D-67580

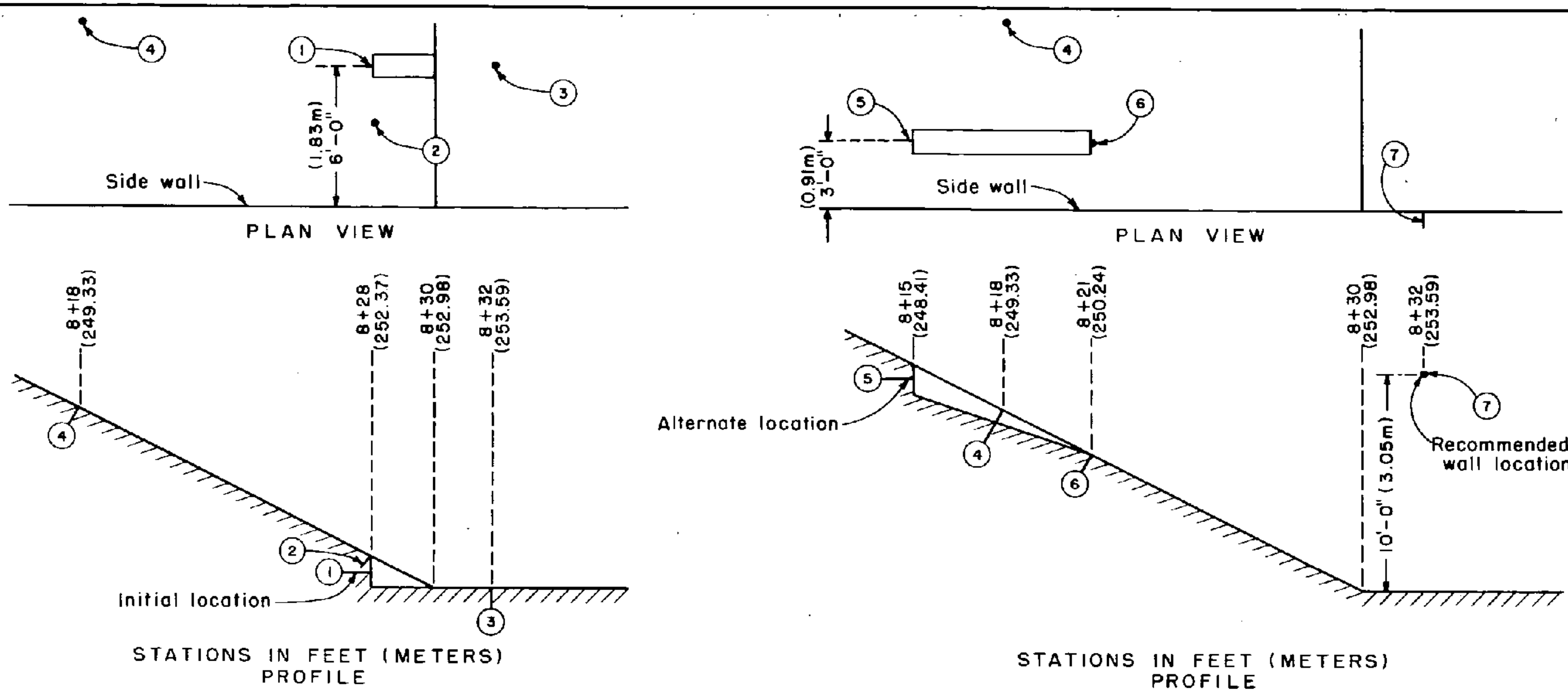
20,000 cfs (566.34 cms). Tailwater elevation 353.5 feet (107.75 m).
Photo POA27-D-67581

Note: Reservoir elevation 546.2 feet (166.48 m) with all three gates opened equally.

Toa Vaca Dam Spillway
Preliminary Basin in Operation

1:48 Scale Model

Figure 15



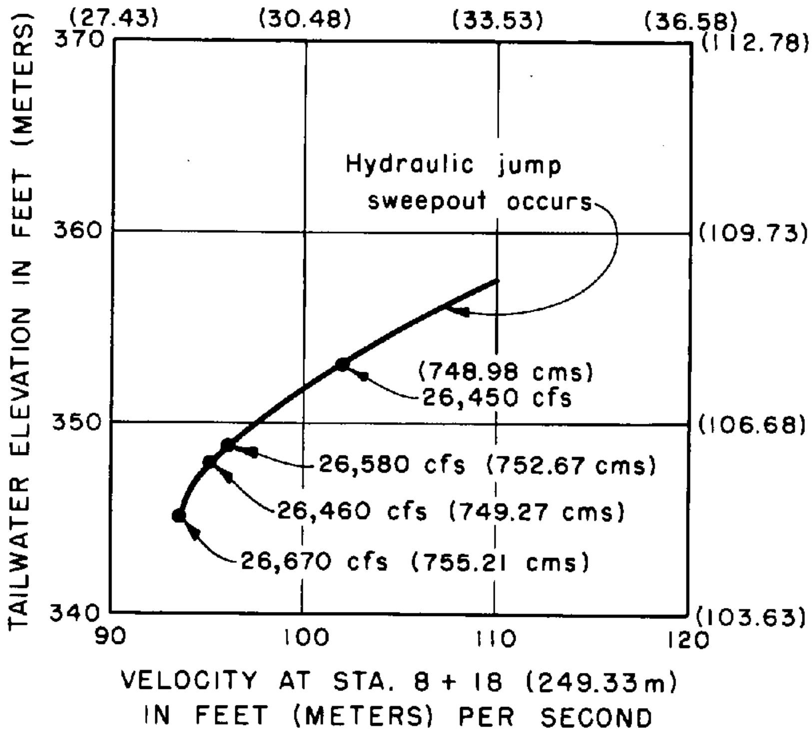
FLOW CONDITION	DISCHARGE IN CFS (CMS)	HYDRAULIC JUMP IN OR OUT	PIEZOMETER PRESSURES IN FEET (METERS) OF WATER						
			1	2	3	4	5	6	7
MAX. RESERVOIR El.	(747.57) 26,400	IN					(1.62) 5.3	(1.37) 4.5	(2.50) 8.2
MAX. RESERVOIR El.	(747.57) 26,400	OUT	(9.36) 30.7	(10.30) 33.8	(16.40) 53.8	(4.27) 14.0	(1.55) −5.1	(3.57) −11.7	—
FREE FLOW	(1415.85) 50,000	OUT				(1.77) 5.8	(0.67) −2.2	(0.53) −1.73	—
FREE FLOW	(2,208.73) 78,000	OUT	(13.71) 45.0	(20.79) 68.2	(27.49) 90.2	(5.33) 17.5	(1.83) 6.0	(5.18) 17.0	—

NOTE

(No) Designates piezometer location.
Pressures positive unless shown negative.
Proposed drain locations are at piezometers 1, 5 and 7.

Toa Vaca Dam Spillway
Pressures at Proposed Drain Outlet

1:48 Scale Model



EXPLANATION

• Data Points

Mannings "n" of 0.014 in the chute produces a velocity of 97.7 feet (29.78 m) per second at Sta. 8 + 18 (249.33 m).

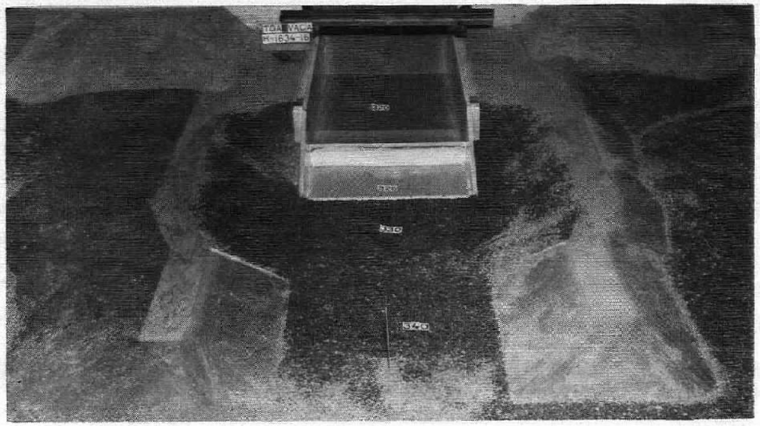
Mannings "n" of 0.008 in the chute produces a velocity of 109 feet (33.22 m) per second in the chute.

Toa Vaca Dam Spillway
Tailwater Versus Velocity for
Hydraulic Jump Sweepout in the
Preliminary Basin

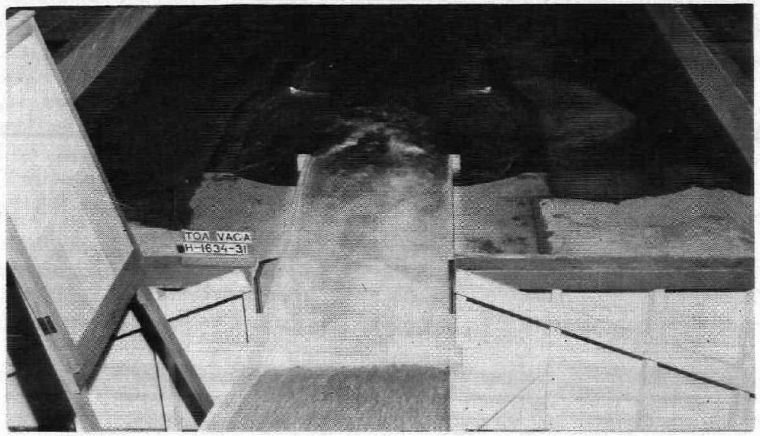
1:48 Scale Model

742

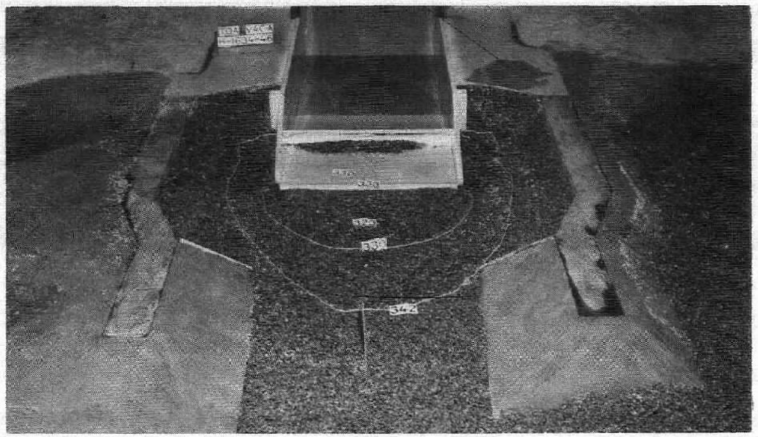
Figure 18



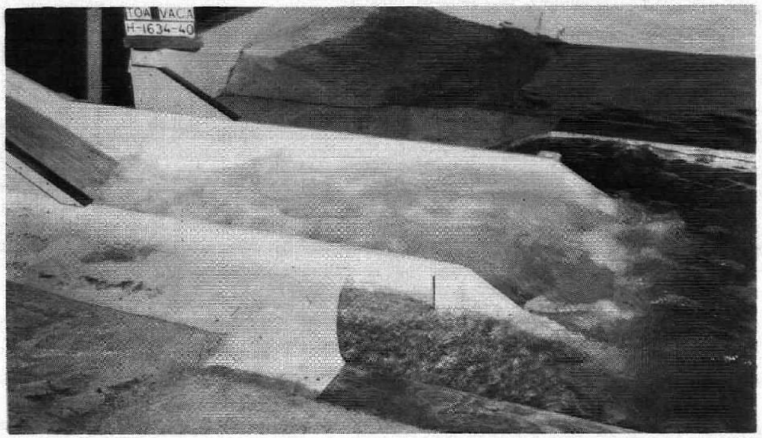
Preliminary basin and channel. Channel bed elevations are in feet. Photo POA27-D-67577



26,400 cfs (747.57 cms). Tailwater elevation 355.8 feet (108.45 m). Photo POA27-D-67582



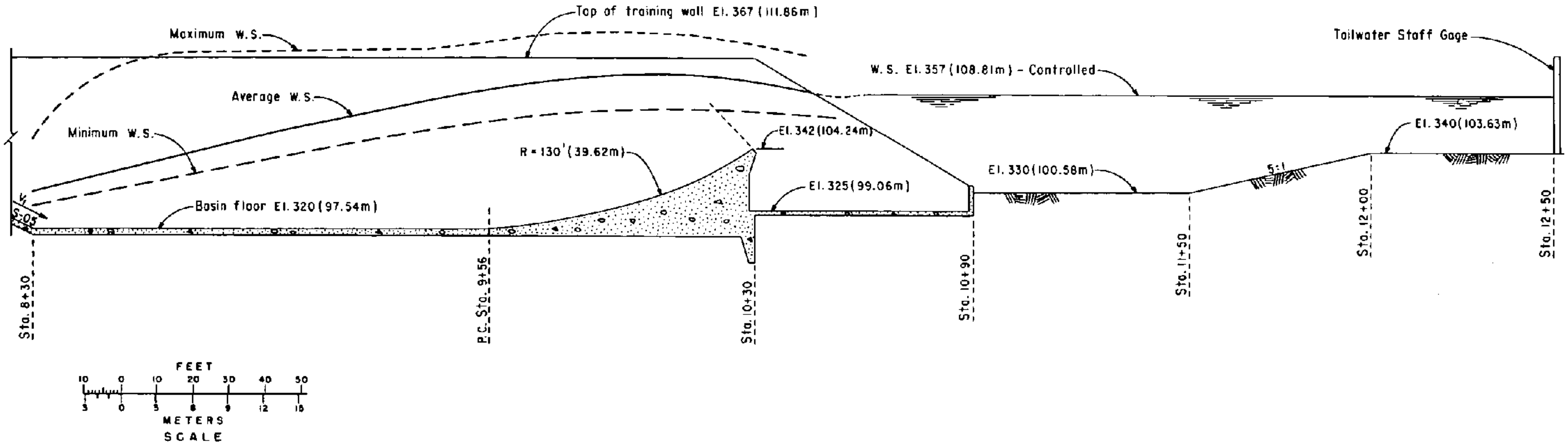
Erosion after 1-hour operation of the model at 26,400 cfs (747.57 cms). Photo POA27-D-67584



30,000 cfs (849.51 cms). Tailwater elevation 357.0 feet (108.81 m). Photo POA27-D-67583

Toa Vaca Dam Spillway
Preliminary Basin
Operation and Channel Erosion

1:48 Scale Model



EXPLANATION

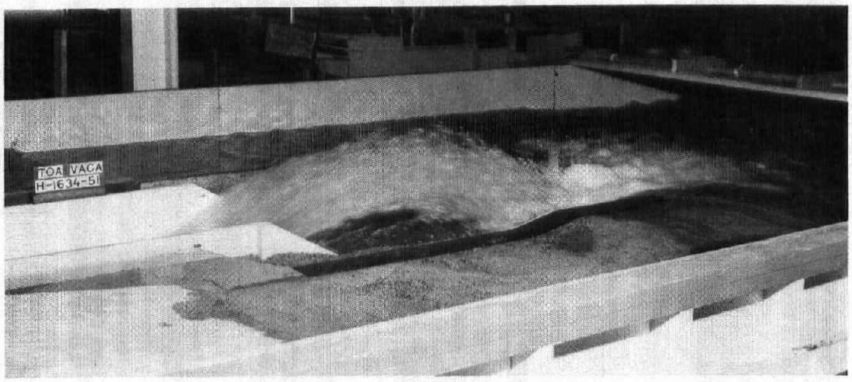
Maximum Water Surface is at the top of wave peaks
Minimum Water Surface is the bottom of the minimum trough elevations
Basin Width 106 feet (32.31m)
Discharge = 30,000 cfs (849.51 cms)
V_1 = 97.7 ft. (29.78m) per second to represent a Mannings "n" of 0.014

Toa Vaca Dam Spillway
Water-surface Profiles through Preliminary Basin and Channel

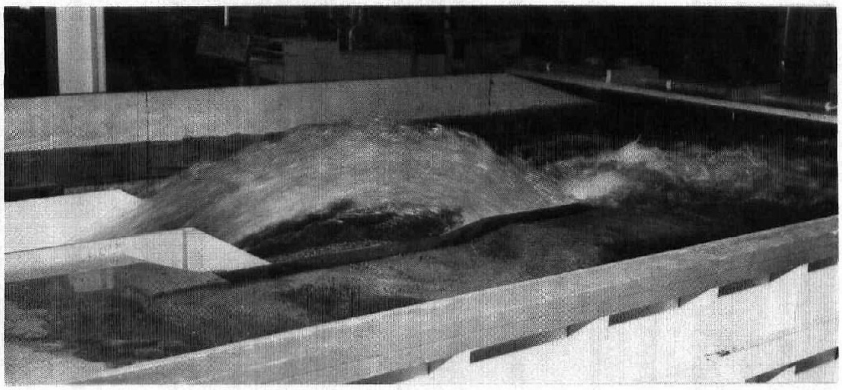
1:48 Scale Model

Figure 19

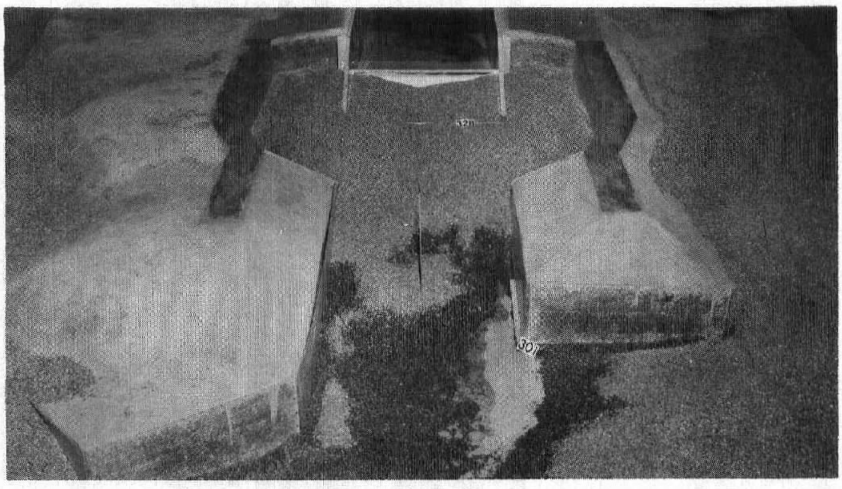
Figure 20



50,000 cfs (1,415.85 cms). Tailwater elevation 349 feet (106.38 m). Photo POA17-D-67585



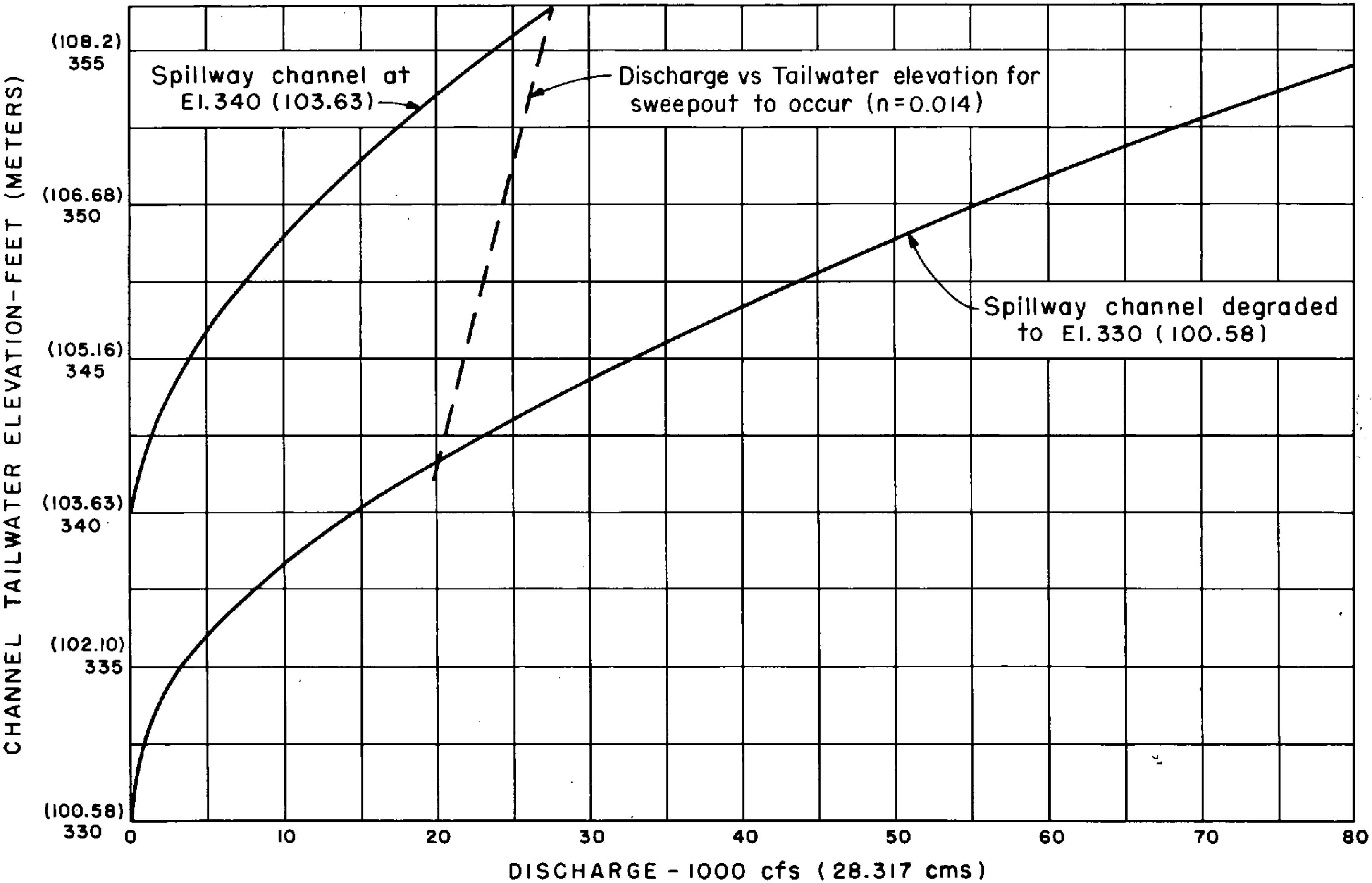
78,000 cfs (2,208.73 cms). Tailwater elevation 354 feet (107.90 m). Photo POA27-D-67586



Erosion after prolonged operation at the above flows. Photo POA27-D-67587

Toa Vaca Dam Spillway
Preliminary Flip Bucket
Operation and Channel Erosion

1:48 Scale Model



Toa Vaca Dam Spillway
Tailwater Elevation for Hydraulic Jump Sweepout

Figure 21

Figure 22

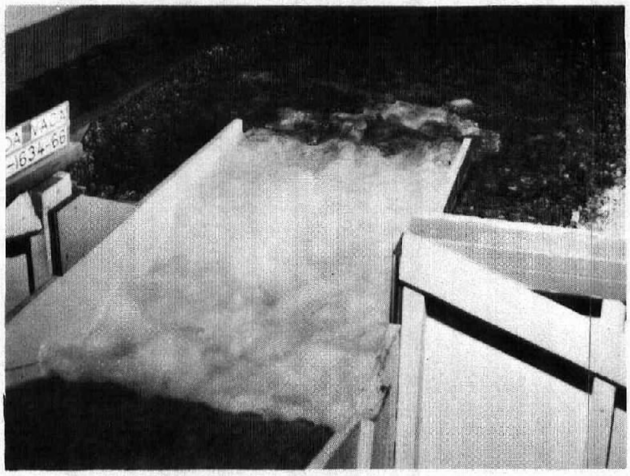


Photo POA27-D-67591

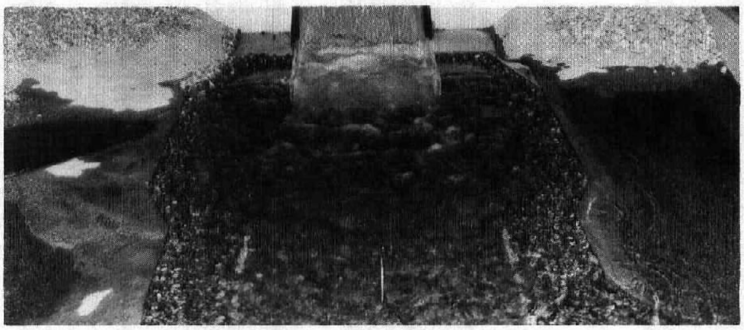


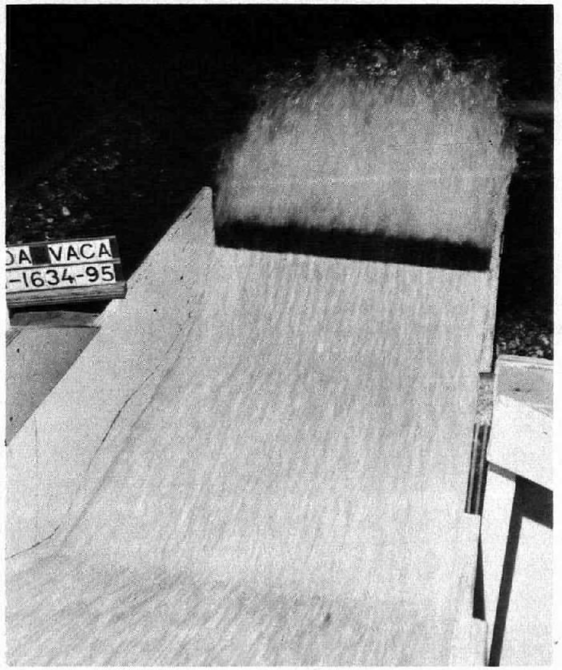
Photo POA27-D-67589

26,400 cfs (747.57 cms). Photo POA27-D-67590

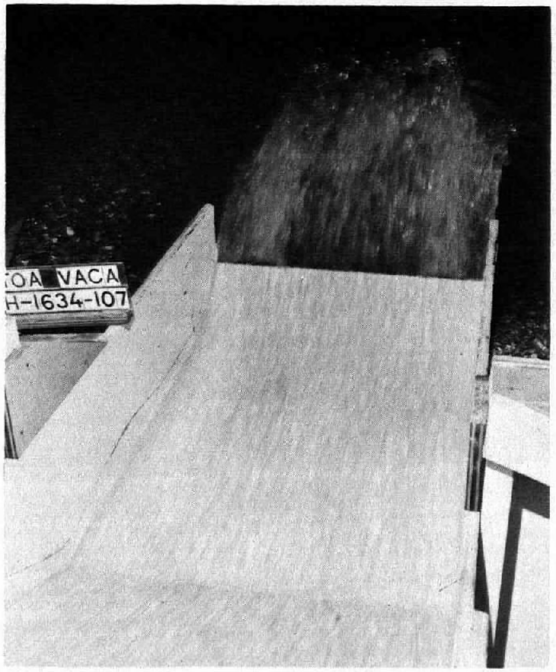
Reservoir elevation 546.2 feet (166.48 m).
Tailwater elevation 355.9 feet (108.48 m).

Toa Vaca Dam Spillway
Design Flow in Recommended Basin

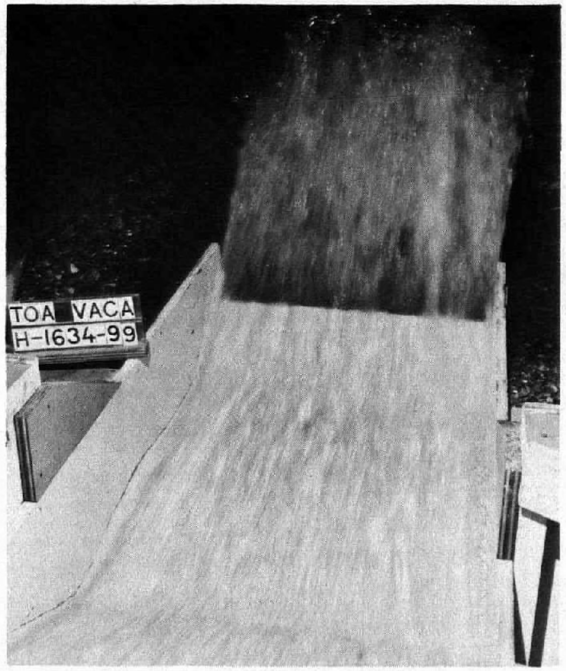
1:48 Scale Model



27,800 cfs (787.21 cms). Tailwater elevation 356.3 feet (108.60 m). Photo POA27-D-67600



26,400 cfs (747.57 cms). Tailwater elevation 346.3 feet (105.55 m). Photo POA27-D-67608



78,000 cfs (2,208.73 cms). Tailwater elevation 354.2 feet. Photo POA27-D-67603

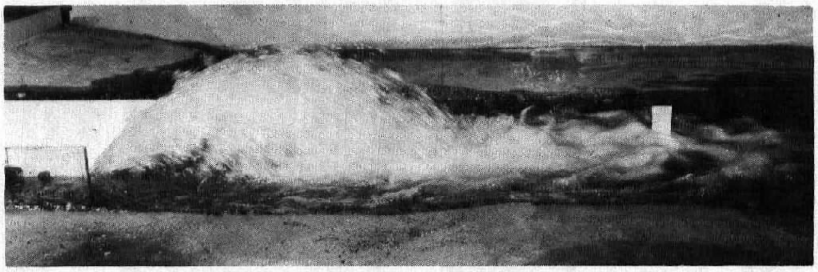
Note: Reservoir at elevation 546.2 feet (166.48 m).

Toa Vaca Dam Spillway
Recommended Flip Bucket in Operation

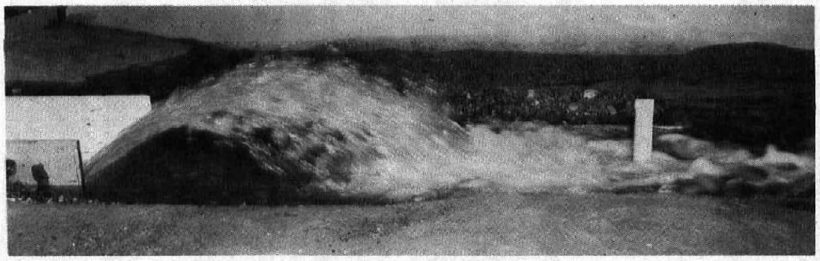
1:48 Scale Model

Figure 23

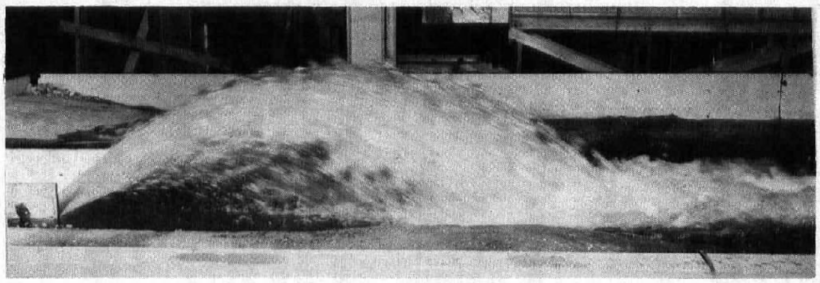
Figure 24



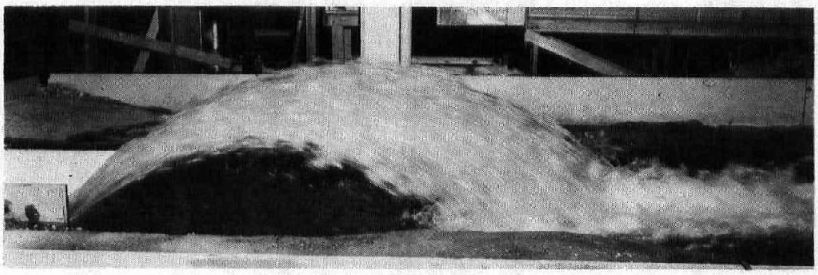
26,400 cfs (747.57 m). Tailwater elevation 355.9 feet (108.48 m) (before channel degradation). Photo POA27-D-67609



26,400 cfs (747.57 m). Tailwater elevation 343.3 feet (104.64 m) (after channel degradation). Photo POA27-D-67607



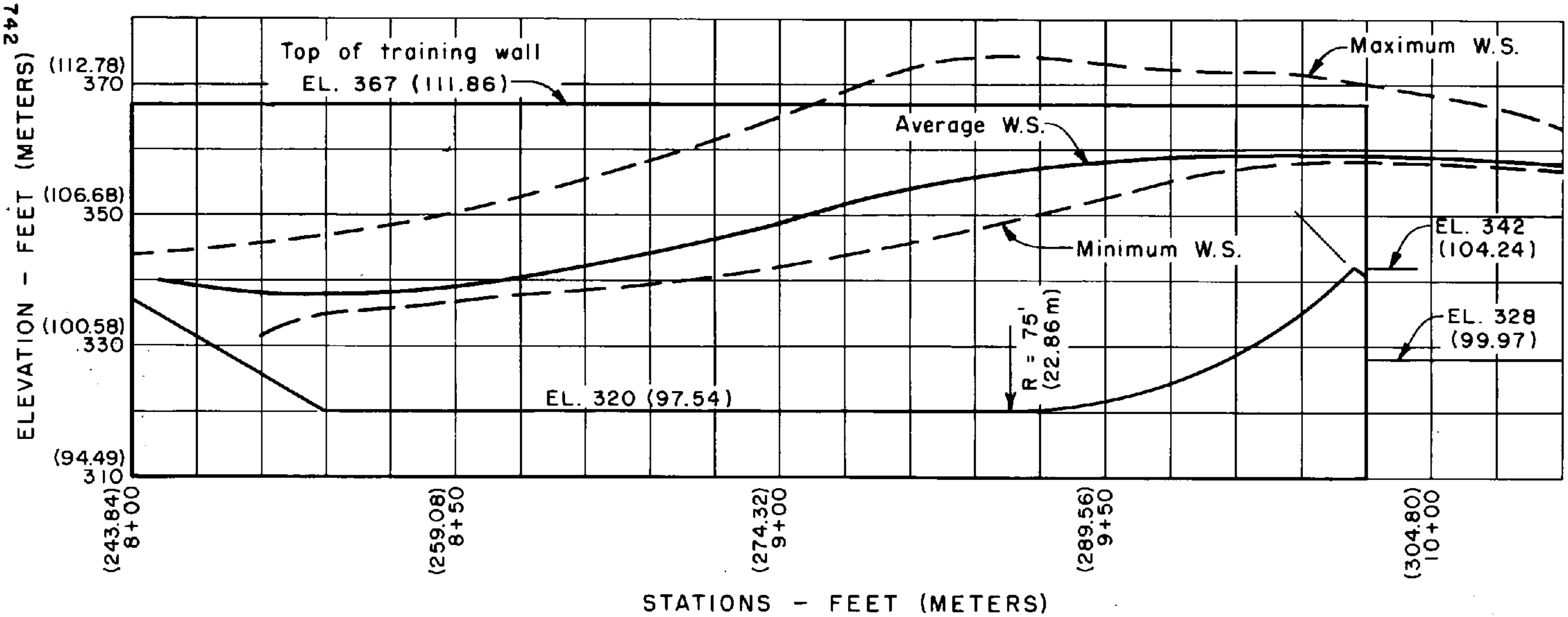
78,000 cfs (2,208.73 cms). Tailwater elevation 354.2 feet (107.96 m) (tailwater under jet is momentarily at bucket lip elevation). Photo POA27-D-67605



78,000 cfs (2,208.73 cms). Tailwater elevation 354.2 feet (107.96 m) (tailwater under jet is swept away from bucket lip). Photo POA27-D-67604

Toa Vaca Dam Spillway
Recommended Flip Bucket in Operation

1:48 Scale Model



NOTE

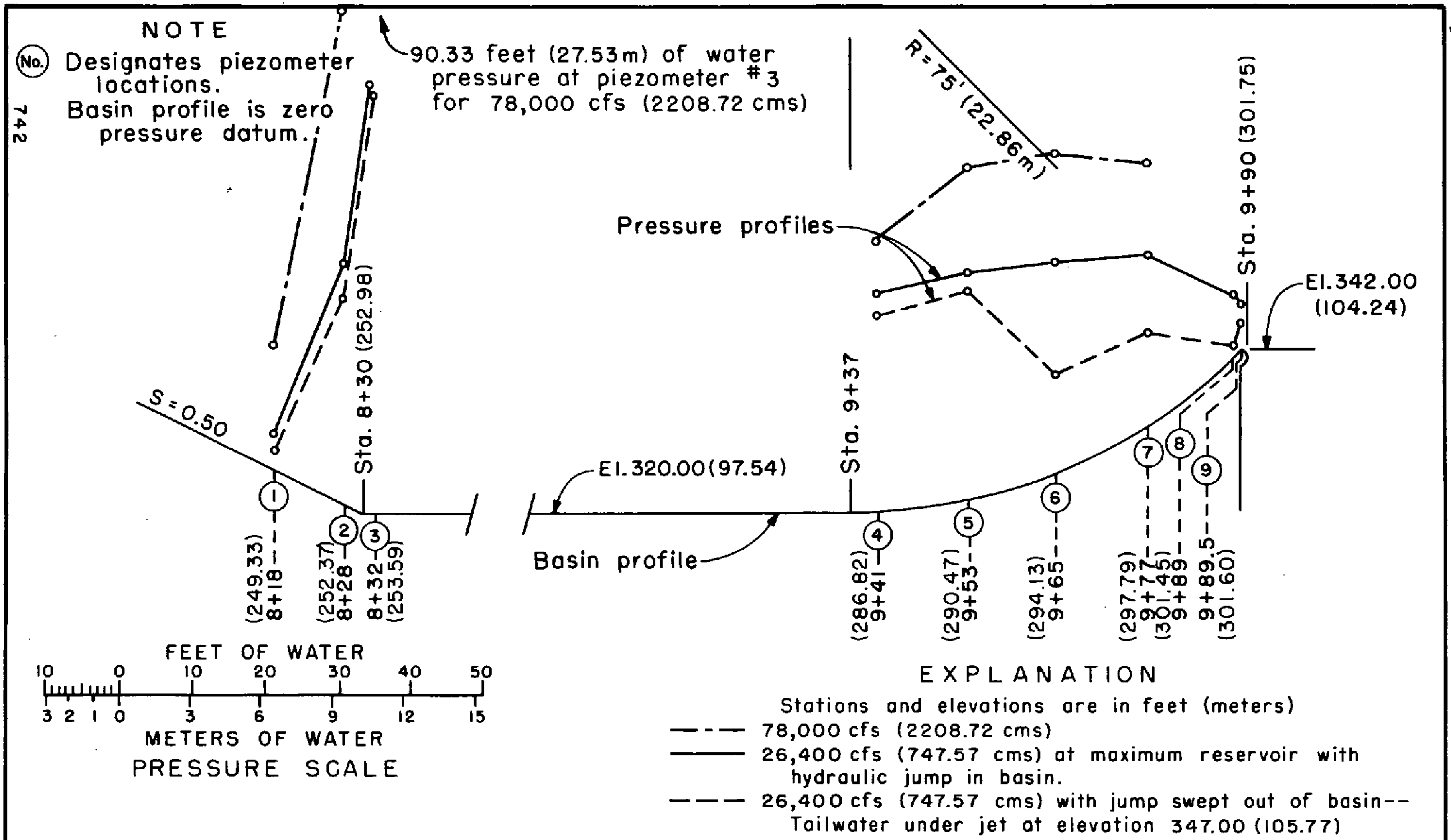
The profiles were measured along the left training wall for 26,400 cfs (747.57 cms). The water surface surges between the minimum and maximum levels. Splashes in the upstream portion of the basin exceed the maximum level. The tailwater was regulated to elevation 356.00 (108.51) at sta. 12 + 74 (388.32) where the waves were approximately 3 feet (0.92m) high. The entrance velocity was regulated for a spillway chute roughness coefficient of n = 0.014.

Toa Vaca Dam Spillway
Water-surface Profiles in the Recommended Basin

1:48 Scale Model

Figure 25

742

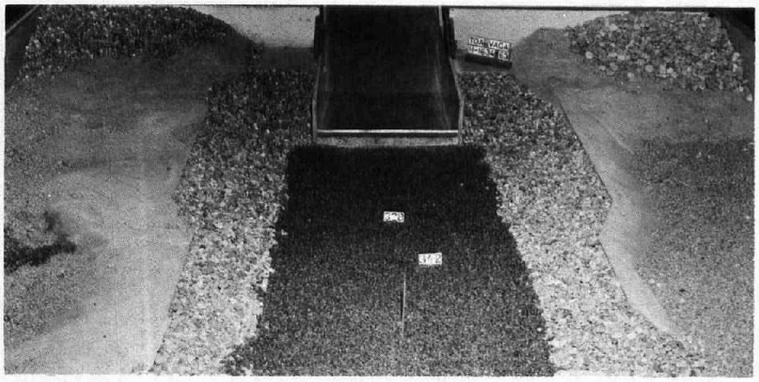


Toa Vaca Dam Spillway
Pressures in the
Recommended Basin

1:48 Scale Model

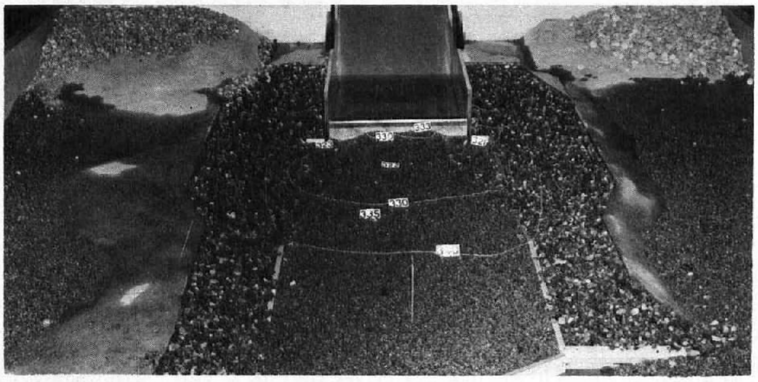
Figure 26

Figure 27



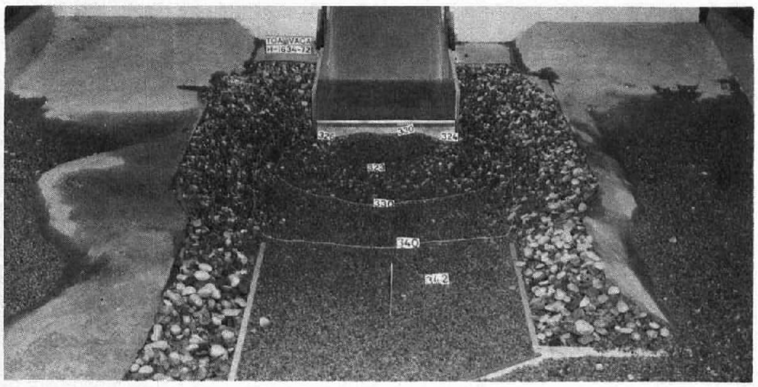
A

Erodible pea gravel bed with 3/4- to 1-1/2-inch (1.90- to 3.81-cm) stones for riprap banks. Photo POA27-D-67588



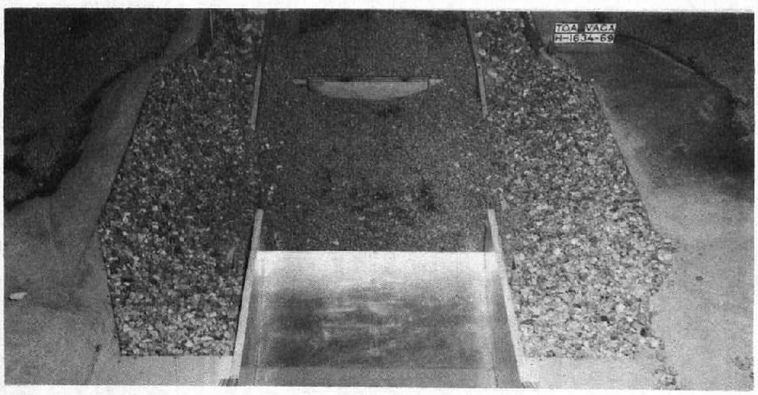
B

Erosion after 1 hour at 26,400 cfs (747.57 cms). Reservoir elevation 546.2 feet (166.48 m). Photo POA27-D-67592



C

Erosion after 1 hour at 26,400 cfs (747.57 cms). Reservoir elevation 546.2 feet (166.48 m). Bed elevation 328 feet (99.97 m) had been riprapped prior to test. Photo POA27-D-67594



D

Erosion after sweepout at 26,400 cfs (747.57 cms). Reservoir elevation 546.2 feet (166.48 m). Photo POA27-D-67593

Toa Vaca Dam Spillway
Erosion in the Recommended Channel

1:48 Scale Model

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

ABSTRACT

A 1:48 scale model was used to develop the hydraulic design of the spillway at Toa Vaca Dam, Puerto Rico. The spillway consists of an approach channel, a gate structure with three 30- by 33.38-ft (9.14- by 10.17-m) radial gates, a sloping chute, a combination stilling basin and flip bucket, and a discharge channel. The spillway is designed for a maximum discharge of approximately 77,000 cfs (2,180 cms). Energy is dissipated by hydraulic jump for low discharges and by flip-out for high discharges. The model included the entire spillway with approach and discharge channels, reservoir topography extending approximately 600 ft (182.88 m) upstream from the dam, and river channel topography extending approximately 600 ft (182.88 m) downstream from the stilling basin. Model studies included investigation of approach flow conditions, distribution of flow through the gates, water surface profiles, discharge coefficients, pressures on the crest, pressures in the stilling basin, flow characteristics in the combination stilling basin-flip bucket, and erosion in the discharge channel. Details of the testing and recommended modifications prompted by the testing are described.

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DESCRIPTORS–/ *stilling basins/ *flip buckets/ erosion/ spillway gates/ hydraulic structures/ *hydraulic models/ discharges/ performance/ radial gates/ spillway crests/ open channels/ *chutes/ subsurface drains/ water surface profiles/ *model tests/ channels/ pressure/ calibrations/ Puerto Rico/ piers/ test procedures/ *spillways/ hydraulic design/ operations
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