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HYDRAULIC MODEL STUDIES OF MODIFICATION TO KLANG GATES DAM, MALAYSIA

March 1983

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16. ABSTRACT

A 1:36-scale hydraulic model was used to study a proposed modification to Klang Gates Dam, Malaysia. To raise the reservoir elevation 3.05 m (10 ft), four 5029- by 2743-mm (16.5- by 9-ft) radial gates were to be added to the double-curvature spillway. Spillway pressures were measured for a flush sillplate and for a raised sillplate to accommodate the gates to the curvatures of the spillway. Discharge calibration curves were determined for various gate openings. Velocities were measured in the downstream channel to study possible scour potential and recommended excavations for minimizing scour damage. All possible single- and double-gate operations were investigated in terms of backflow around the corners of the spillway retaining walls and over the downstream stilling basin lip that could transport rocks into the basin.

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Denver, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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K. Gibson performed most of the work concerning gate calibrations, spillway pressures, and downstream velocities, while R. A. Dodge conducted the investigations related to single- and double-gate operations. The cooperation and suggestions of J. Legas of the Dams Branch, Division of Design, were helpful in developing recommendations of this report. B. Prokop accomplished the difficult editing required to blend two memorandum reports by different authors into one combined report. E. J. Carlson, Head, Hydraulic Research Section, made a final technical review. Final editing and preparation of the manuscript for printing were accomplished by R. Mohrbacher, Technical Publications Branch.

The research covered by this report was funded by the Malaysian Government.

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PURPOSE AND APPLICATION

These model studies were made to help Bureau of Reclamation designers formulate and verify design concepts for modifying Klang Gates Dam, Malaysia. The studies were mainly directed toward assessing the effects of adding four radial gates to a double-curvature spillway.

The results and experience of these studies were used by designers to finalize their design for the modification. Besides being applicable to this modification, the experience gained may be of help in designing other gated spillways.

INTRODUCTION

The proposed modification would raise the reservoir elevation 3.05 m (10 ft) by adding four 5029- by 2743-mm (16.5- by 9-ft) radial gates to the spillway. These studies were initially requested to verify the hydraulic design of the radial gates, double-curvature spillway, and stilling basin. Early in the studies, it became apparent that the immediate downstream river channel and appurtenant structures were threatened by scour, flood, and wave action during discharges that were well within the design capacities of the existing system as well as with the modification. Thus, it was decided to include an investigation of the channel immediately downstream from the dam. Later, the designers requested determination of the optimum single- and double-gate operation combinations from the four gates, their discharge ranges, and, if possible, further calibration of the gates for a 152-mm (6-in) opening. These studies were summarized and submitted to the Concrete Dams Section in preliminary form so the Malaysian project team could be informed of the results.

CONCLUSIONS

1. Hydraulic performance of the proposed spillway modification was satisfactory. At the design reservoir elevation of 97.8 m (321 ft) and with the gates fully opened, the release was 376.6 m^3/s (13 300 ft^3/s). This was greater than the original design maximum discharge of 334.1 m^3/s (11 800 ft^3/s).

2. The immediate downstream river channel handled discharges less than 53.8 m^3/s (1900 ft^3/s) without forseeable problems; but at higher discharges, damage to the gabions and control house by scour, flood, or wave action appeared possible. This potential river channel damage is associated not only with the proposed modification, but could occur with the existing spillway for discharges exceeding 53.8 m^3/s (1900 ft^3/s).

3. The extent of possible scour and wave damage was not determined from the model. However, channelization is advisable if the spillway is operated at discharges greater than 53.8 m^3/s (1900 ft^3/s).

4. An extrapolated calibration for a 152-mm (6-in) gate opening is shown in table 1. It is recommended that this extrapolation and the calibration given on figure 9 be checked in the field and, if necessary, modified by using downstream gaging.

5. Because the Mechanical Branch indicated that the gates can be operated at openings as small as 25 mm (1 in) and the gates cannot be accurately model-calibrated for small gate openings at the scale of 1:36, it is recommended that , if needed, calibration curves for gate openings smaller than 152 mm (6 in) be determined in the field by gaging the stream.

6. Four-gate operation is recommended for as low a discharge as is compatible with accuracy requirements and/or confidence in the calibrations developed from the downstream gaging.

7. If undesirable gate vibrations are noted or it is otherwise necessary or preferable to use double-gate operations, gates 1 and 4 should be used to provide discharges between 17.0 and 28.3 m^3/s (600 and 1000 ft^3/s). For single-gate operation, gate 1 is recommended for discharges less than 17.0 m^3/s (600 ft^3/s).

THE MODEL

The model, constructed to a scale of 1:36, included 43.9 m (144 ft) of reservoir approach to the spillway, part of the concrete arch dam, the spillway, and the stilling basin (fig. 1). The spillway and slotted bucket energy dissipator were milled from high-density polyurethane plastic and sanded to the desired profile.

Model topography was determined from 1.5-m (5-ft) interval contour maps supplied to the Bureau by the Malaysian Government. Scaled contours were cut from wood, placed in the model, and covered with metal lath. The lath was then covered with approximately 19 mm (0.75 in) of cement-sand mortar. Three removable portions of topography were utilized to study possible channelization of the downstream river channel (fig. 2). Rock gabions, constructed in the prototype after flooding of the control house had occurred, and the water supply control house were scaled from the contour maps and recent photographs. The model riverbed represented 0.2- to 1.8-m (9-in to 6-ft) boulders.

To use an existing model tail box, a 152-mm (6-in) strip was left out of the downstream channel topography. This strip was parallel to the dam, in a straight portion of the channel, and immediately upstream of the turn in the rock gabions (fig. 2). Decreased friction losses caused by foreshortening the model at this location were negligible and had an insignificant effect on water surface elevation compared with form losses caused by the channel topography.

The four 5029- by 2743-mm (16.5- by 9-ft) top seal radial gates were made of sheet metal. To compensate for the double curvature of the spillway crest, either the gate sillplate could be raised to match the straight gate lip and seal or the gate lip and seal could be curved downward to meet and seal with a flush sillplate. Both of these cases were model tested. A detail of the raised sillplate is shown on figure 7.

MEASUREMENTS AND MODEL OPERATION

Water was supplied to the model through the permanent laboratory system and was measured by venturi meters for the larger flows and with a small orifice meter for the small flows. For tests with single- and double-gate operation, the small flows were passed through the spillway with the gates fully open. Thus, the small flows were set by main laboratory valves rather than with the model spillway gates. Doing this saved the time that would be required to adjust small flows through the very small gate openings of the model. It was assumed that the resulting flow in the model stilling basin and exit channel area would act like gate-controlled flow in the prototype spillway, and qualitative determinations of optimum gate position on the crest and gate could be made rapidly in the model. A flap-type tailgate was used to adjust the tailwater elevation and to collect eroded gravel.

Pressures on the spillway surface were measured using a pressure transducer connected consecutively to 17 piezometers installed along the centerline of the gated right spillway bay. The transducer output voltage was measured by a digital voltmeter calibrated to display pressure in feet of water.

Tailwater elevations relative to painted contour lines were observed and recorded at locations along both banks of the downstream channel for various discharges. With this information, cross-sectional area of the flow could be determined and, knowing the discharge, average velocities in the channel could be calculated.

To further save time and to partially quantify the model results for selection of best gate operation with one or two gates, the contraction differential head caused by backflow around the downstream corners of the stilling basin retaining walls was measured (figs. 1 and 19). This was done rather than making time-consuming, detailed velocity measurements in the complicated stilling basin flows.

TEST PROGRAM AND INVESTIGATIONS

A study of the hydraulic performance of the proposed spillway modification was advisable because the existing spillway was not designed originally for the addition of radial gates. Pressure data measured by piezometers on the model spillway were plotted to determine spillway pressure profiles at various reservoir heads and gate openings. Pressures were recorded for the raised sillplate (fig. 7) and, for an alternative design, a flush sillplate requiring a curved bottom gate seal.

Discharge measurements at various reservoir heads and gate openings were recorded and plotted to obtain discharge curves for field operations. Although the Mechanical Branch indicated that the prototype gate can be used with gate openings down to 25 mm (1 in), the model was considered inadequate for determining the discharge capacity of gate openings smaller than 305 mm (1 ft) because of possible scale effects discussed later in this report. Therefore, an extrapolation from the measured capacity curves was made to obtain an approximate discharge relationship for a 152-mm (6-in) gate opening.

The study of the downstream river channel involved observing stilling basin effectiveness, recording tailwater elevations, and recognizing possible scour problems.

The portion of the downstream channel that was modeled had three flow control points: (a), (b), and (c) on figure 2. The first constriction was the right canyon wall beginning at the end of the stilling basin and extending about 23 m (75 ft) downstream. This protrusion into the channel constricted the flow leaving the stilling basin. The second constriction was formed by the narrowing of the channel about 30.5 m (100 ft) downstream. Bounded on the left by the rock gabions and on the right by the high riverbank, this constriction, hereafter referred to as the nob, controlled the spillway tailwater depth for flows up to approximately 170 m^3/s (6000 ft^3/s). The third constriction occurred at the end of the rock gabions where an outcrop formed the left bank and a vertical cliff formed the right bank. This constriction was called the rock. Three removable topography sections, one at each of the above control points, were removed in various combinations to study their effect on tailwater elevations and flow conditions. Figures 2 through 5 show views of the model with and without the removable topography sections.

The contraction differential heads caused by backflow around the retaining wall corners (fig. 19) were obtained for various discharges and gate combinations, and are considered the measure of the strength of the backflow. Backflow on the right side could be more critical if rock spalls off the steep bank and is carried by backflow into the stilling basin. The left side is protected by rock gabions and is less likely to carry large rock. The differential heads were measured for all possible combinations of one- and two-gate operation. (See table 3.)

RESULTS

Pressures on Spillway

The minimum pressures on the spillway during both gated and free-flow discharge occurred near the fourth piezometer downstream. (See figs. 6 and 7.) Figure 6 shows that for design discharge at maximum reservoir elevation of 97.8 m (321 ft), the minimum pressure head decreased to -1.2 m (-4 ft) of water as the gate opening increased to 2.7 m (9 ft). Figure 7 shows that with the gates fully open the minimum pressure decreased to -1.7 m (-5.5 ft) of water as the reservoir elevation increased to 99.4 m (326 ft). The raised sillplate had very little effect on the spillway pressures (fig. 8). The lowest pressure for the design reservoir elevation of 97.8 m (321 ft), both with and without the raised sillplate, was -1.2 m (-4 ft) of water with gates fully open. The pressures measured on the spillway were damped or averaged but are not considered low enough to cause cavitation for the velocities expected on the spillway. No periodic pressure fluctuations were noted that could be attributed to flow tending to separate from the spillway surface. Small pressure variations of ±4 percent were noted in the measurements obtained with the transducer system.

Spillway Capacity and Gate Calibration

To determine the spillway capacity, heads and discharges were measured for gate openings of 0.3, 0.6, 0.9, 1.5, and 2.1 m (1, 2, 3, 5, and 7 ft) and fully open. A maximum discharge of 376.6 m^3/s (13 300 ft^3/s) occurred at maximum reservoir elevation 97.8 m (321 ft) with gates fully open, as shown by the capacity curves on figure 9. Model calibrations should be verified by stream gaging when possible. The lack of repeatability of trial calibrations with 152-mm (6-in) gate openings indicated that the reservoir head/discharge data were sensitive to the precision of setting the gate openings. A cross plot of the previous calibration data was made to extrapolate a calibration for the 152-mm (6-in) gate openings. The trial calibrations indicated considerably lower discharges than the extrapolated calibration. Because of the scale effects in the trial calibrations, the extrapolated calibration (see table 1) was considered more reliable; however, it definitely should be verified by stream gaging or metering downstream of the dam. The extrapolation indicates that at reservoir elevation 97.8 m (321 ft), four gates with 152-mm (6-in) openings would deliver about 31.1 m^3/s (1100 ft^3/s), and one gate could be used to control flow down to about 7.8 m^3/s (275 ft^3/s).

Stilling Basin and Downstream Channel

In general, the stilling basin, originally designed for 334.1 m^3/s (11 800 ft^3/s), operated well at all discharges. Downstream river channel data were obtained while the model was operated at discharges of 53.8, 87.8, 124.6, 164.2, and 376.6 m^3/s (1900, 3100, 4400, 5800, and 13 300 ft^3/s). A tabulation of tailwater elevations and calculated velocities at several locations for these discharges is given in table 2. The existing channel was satisfactory for discharges up to 53.8 m^3/s (1900 ft^3/s) with all topography features in place (fig. 10). However, for greater discharges, scour started.

When the discharge reached 124.6 m^3/s (4400 ft^3/s) with all topography in place, gravel representing riverbed material up to 0.9 m (3 ft) in diameter was being moved in the model (fig. 11). Scouring was most prominent immediately downstream of both the nob and the rock. Average velocities along the gabions between the nob and rock were about 6.1 m/s (20 ft/s), and water was beginning to splash over the stilling basin walls. After removing the nob section, the tailwater elevation in the stilling basin was lowered approximately 0.3 m (1 ft) and the overtopping stopped (fig. 12). However, this channelization increased the downstream velocities.

There were several inferior flow conditions at the discharge of 164.2 m^3/s (5800 ft^3/s). With all topography features in place, water was flowing over the retaining walls, over the highest part of the backfill behind the rock gabions, and also over the section of gabions protecting the control house (fig. 13). Removing both the nob and rock sections alleviated the conditions mentioned above. Water now splashed only over the retaining walls, and no water reached the control house from either behind the gabions or over the gabions (fig. 14). However, downstream velocities were considered high, being 6.1 to 7.6 m/s (20 to 25 ft/s). Removing the canyon section in addition to the nob and rock did not lower the tailwater elevation (fig. 15).

At a discharge of 376.6 m^3/s (13 300 ft^3/s) with all topography features in place, water flowed approximately 1.2 m (4 ft) over the retaining walls, 0.6 m (2 ft) over the highest section of the gabions, and 1.8 m (6 ft) along the side of the control house (fig. 16). Wave action was very rough throughout the channel, and velocities averaged greater than 6.1 m/s (20 ft/s). Removal of the nob and rock lowered tailwater elevations approximately 0.3 m (1 ft) (fig. 17). Removing the canyon section in addition to the rock and nob proved detrimental by creating a very strong back eddy at the right side of the stilling basin (fig. 18).

Values of the backflow contraction differential heads are listed in table 3 in terms of prototype meters (feet) of head for both the right and left sides of the stilling basin. The data for discharges 31.1, 42.5, and 56.6 m^3/s (1100, 1500, and 2000 ft^3/s) and for all possible combinations of any two gates out of the four, indicate that using gates 1 and 4 together (gate numbering as shown in fig. 19) resulted in the smallest backflow corner currents. Most other combinations resulted in significantly higher currents on either the right or left side of the stilling basin.

All two-gate operations caused back currents; operation of the two outer gates together at 56.6 m^3/s (1100 ft^3/s) resulted in zero backflow at the retaining wall corners on their respective sides, but bottom back current was detected over the center of the stilling basin lip. This current was not measured because of cost and time constraints. However, the middle back current strength would be about equal to the average of the left and right corner differential heads measured with flow from gates 3 and 4, or about 0.27 m (0.88 ft) at 31.1 m^3/s (1100 ft^3/s). Center bottom backflow was also observed (using a string probe) with four-gate operation. For given discharges, center and corner backflow velocities appeared to be about the same magnitude.

Values of backflow contraction differential heads are listed in table 3 for single-gate operation for all gates at discharges of 8.5, 17.0, 22.7, and 31.1 m^3/s (300, 600, 800, and 1100 ft^3/s). Selection of any gate for single operation affects the choice of the second gate for double-gate operation, because the designers prefer to sequence from single- to double-gate operation using a common gate for simplicity of controller design and for smoothness of gate operation. Consideration of gates other than 1 and 4 for double-gate operation would have to be justified in terms of considerable reduction of the back currents for some other gate for single operation at the expense of increased back currents for double operation. The back currents caused by flow through gate 1 were not significantly greater than for gate 3, especially in view of the precision of the water surface measurements possible with the model. The use of gate 4, however, was not recommended because of the significantly higher back current on the left side of the stilling basin. Despite the possibility of large rock falling off the right bank, gate 1 was selected for single operation, with gate 4 sequenced into operation for double operation.

Table 1. — *Extrapolated discharge for 152-mm (6-in) gate opening*

Reservoir water elevation		Discharge for four gates	
m	ft	m^3/s	ft^3/s
92.7	304	16.7	590
93.0	305	18.7	660
93.6	307	20.7	730
94.5	310	23.8	840
96.3	316	26.9	950
97.8	321	31.1	1100

Table 2. — *Tailwater elevations and calculated velocities for various flow rates*

Q		Topo	Elevations: L.W. and Grd.		Elevations: House		Velocities: No. 1		Velocities: No. 2		Velocities: No. 3		Comments
m^3/s	ft^3/s		m	ft	m	ft	m/s	ft/s	m/s	ft/s	m/s	ft/s	
53.8	1 900	EX	69.2	227	65.2	214	3.0	10	4.3	14	4.6	15	
87.8	3 100	EX	69.5	228	67.4	221	3.7	12	5.8	19	6.4	21	
124.6	4 400	EX	70.1	230	68.3	224	3.7	12	6.7	22	6.1	20	Splashing over retaining walls
124.6	4 400	N	69.8	229	68.0	223			7.6	25	6.7	22	Splashing nearly stopped
164.2	5 800	EX	70.4	231	68.9	226			5.8	19	4.6	15	Flowing over retaining walls. Water on house from behind and over gabion
164.2	5 800	R&N	70.1	230	68.0	223			7.6	25	6.1	20	Water no longer on house
164.2	5 800	R,N&B	70.1	230	68.0	223							
376.6	13 300	EX	71.6	235	70,7	232							
376.6	13 300	R&N	71.3	234	70.4	231							Removal of rock section not much help
376.6	13 300	R,N&B	71.3	234	70.4	231							Strong back eddy at basin. Not recommended; therefore, velocities not measured.

Q — Discharge.
Topo — Model topography.
EX — Existing topography.
N — Nob topography section removed.
R — Rock section at end of gabions removed.
B — Canyon section at stilling basin removed.
L.W. — Left wall of stilling basin.
Grd. — Backfill behind gabions.
House — Average along river side of house or gabion at middle of house.

Locations of calculated average velocities

No. 1 — Just upstream of nob.
No. 2 — Just downstream of turn.
No. 3 — Just upstream of rock.

Table 3. — *Backflow contraction differential heads around the downstream corners of the stilling basin retaining walls*

Discharge		Gates opened	Right side differential head		Left side differential head	
m³/s	ft³/s		m	ft	m	ft
31.1	1100	1, 2	0.43	1.42	0	0
		2, 3	0.36	1.18	0	0
		3, 4	0	0	0.54	1.77
		1, 4	0	0	0	0
		2, 4	0	0	0.18	0.59
		1, 3	0.29	0.94	0	0
42.5	1500	1, 2	0.50	1.65	0.07	0.24
		2, 3	0.40	1.30	0	0
		3, 4	0	0	0.68	2.24
		1, 4	0.14	0.47	0.11	0.35
		2, 4	0.14	0.47	0.32	1.06
		1, 3	0.14	0.47	0	0
57	2000	1, 2	0.72	2.36	0.18	0.59
		2, 3	0.54	1.77	0	0
		3, 4	0.43	1.42	1.01	3.31
		1, 4	0.29	0.94	0.22	0.71
		2, 4	0	0	0.36	1.18
		1, 3	0.25	0.83	0.25	0.83
8.5	300	1	0	0	0	0
		2	0	0	0	0
		3	0	0	0.07	0.24
		4	0	0	0.36	1.18
17	600	1	0.29	0.94	0	0
		2	0.32	1.06	0.22	0.71
		3	0.18	0.59	0.11	0.35
		4	0	0	0.54	1.77
22.7	800	1	0.25	0.83	0	0
		2	0.32	1.06	0.14	0.47
		3	0.07	0.24	0.14	0.47
		4	0	0	0.47	1.54
31.1	1100	1	0.43	1.42	0	0
		2	0.36	1.18	0	0
		3	0.36	1.18	0.07	0.24
		4	0	0	0.68	2.24

Figure 1. — Upstream view of 1:36 model, showing gated spillway. P801-D-80167

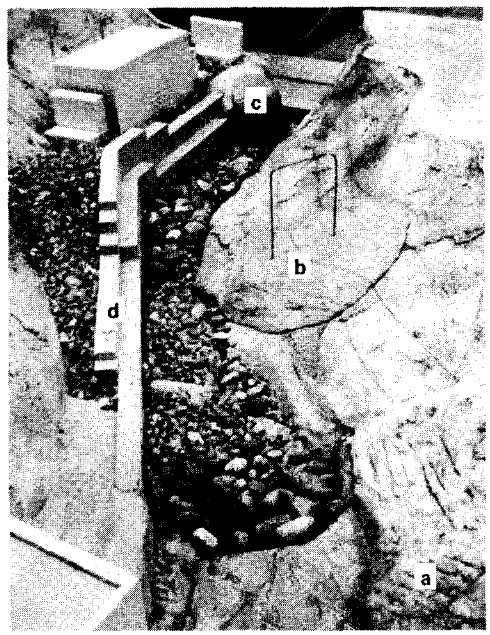

Figure 2. — Downstream channel with gabions and removable topography. P801-D-80168

(a) canyon
(b) nob
(c) rock
(d) gabions

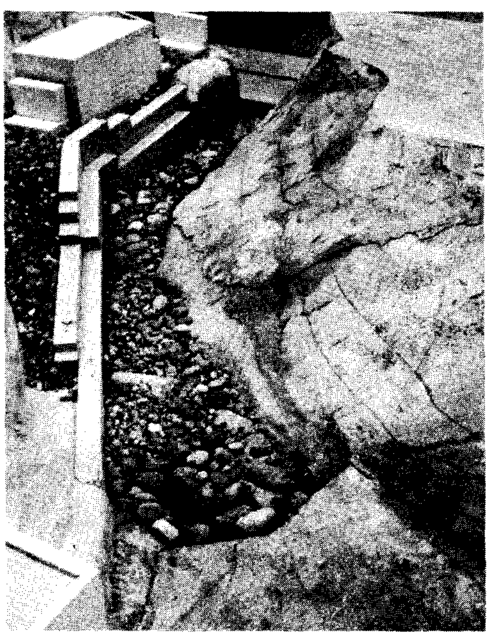

Figure 3. — Downstream view without removable topography in place. P801-D-80169

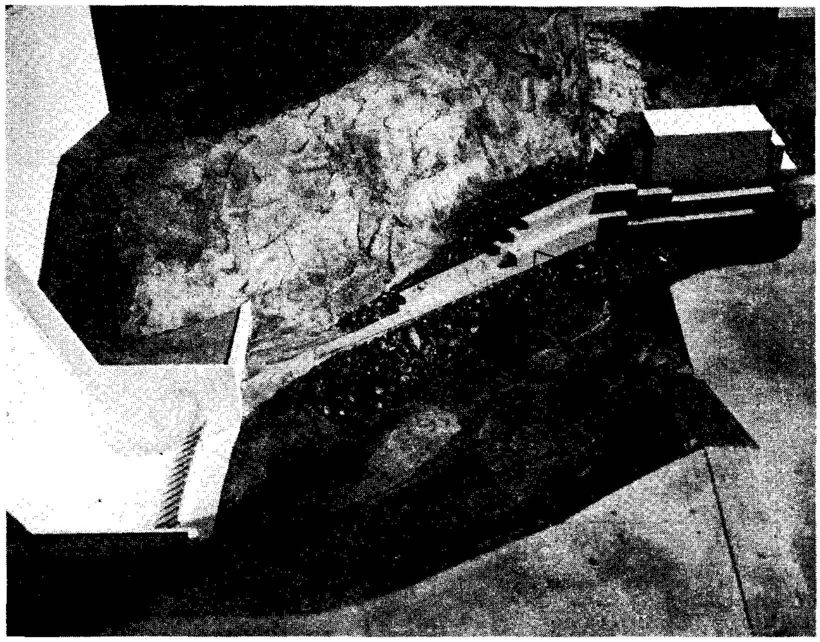

Figure 4. — View from right bank with removable topography in place. P801-D-80170

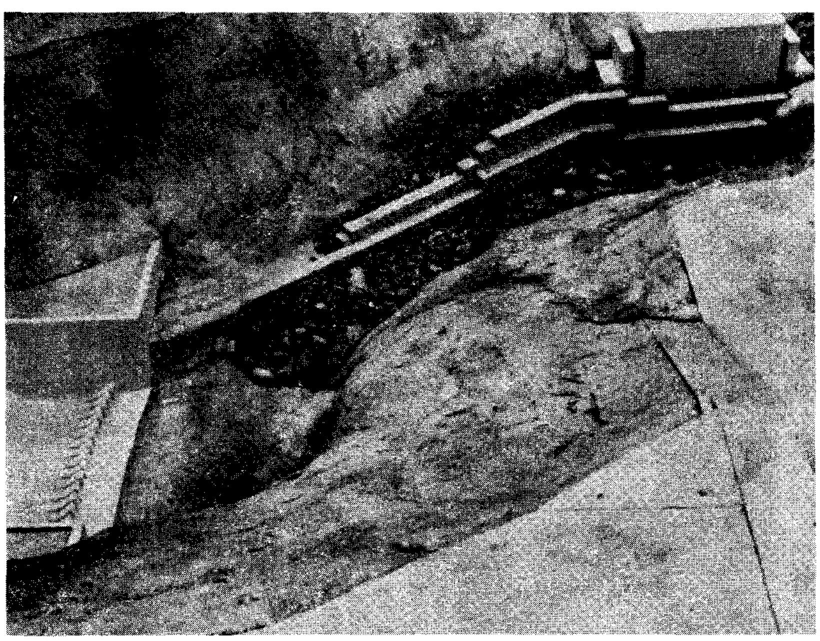

Figure 5. — View from right bank without removable topography, or as shown in specifications drawing. P801-D-80171

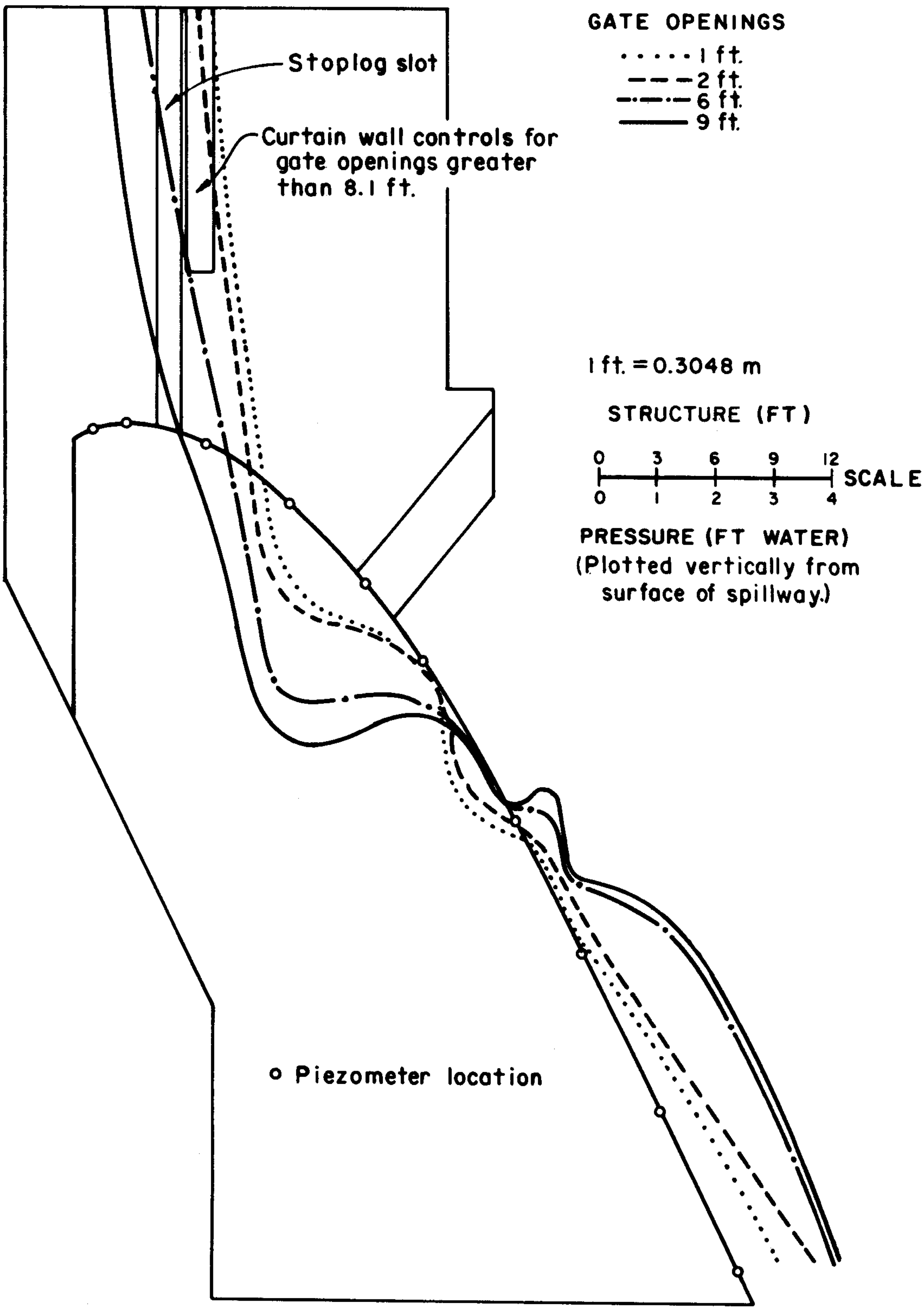

Figure 6. — Pressure profiles for various gate openings with flush sillplates and reservoir elevation at 97.8 m (321 ft).

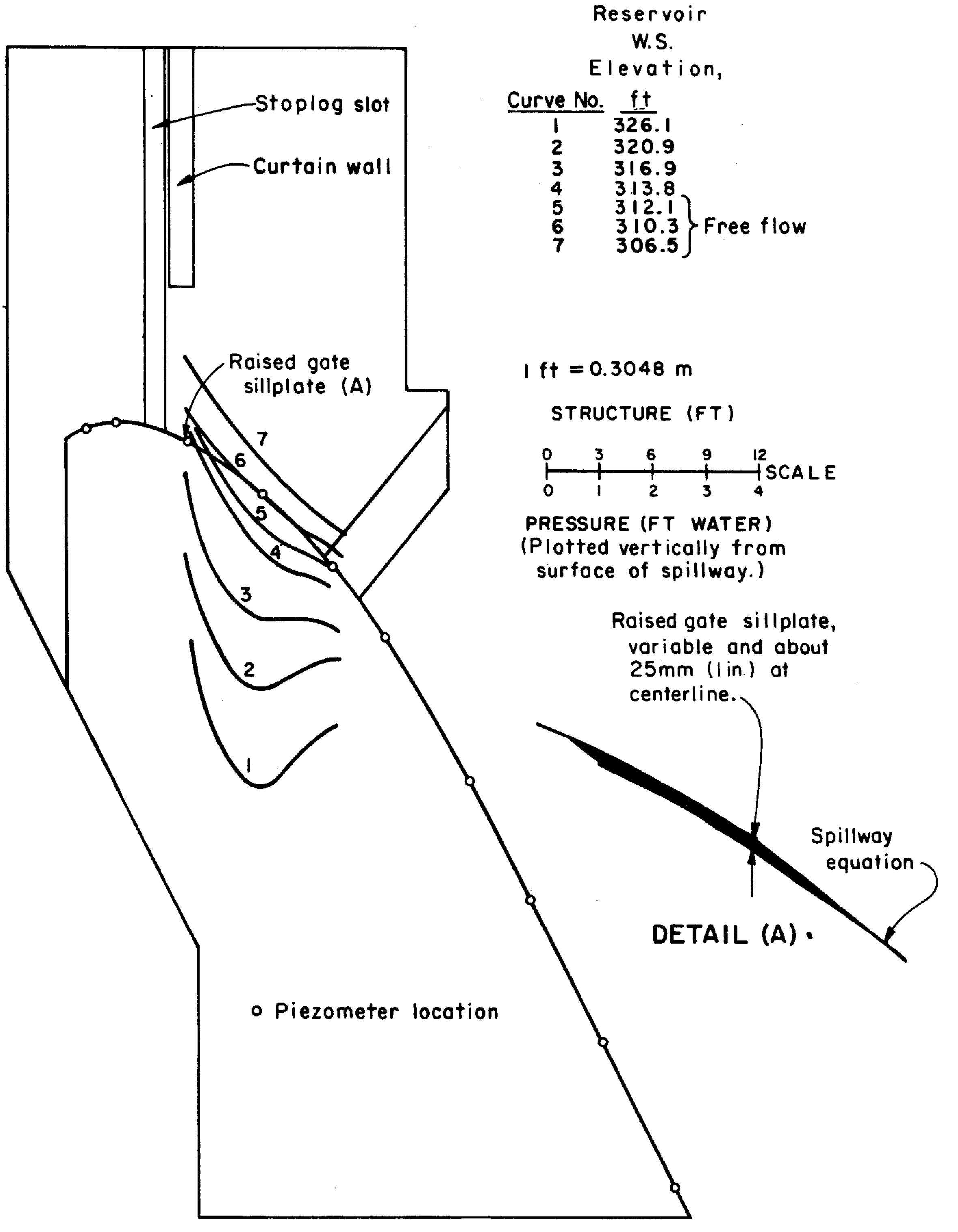

Figure 7. — Pressure profiles for various heads with raised sillplates and gates fully opened.

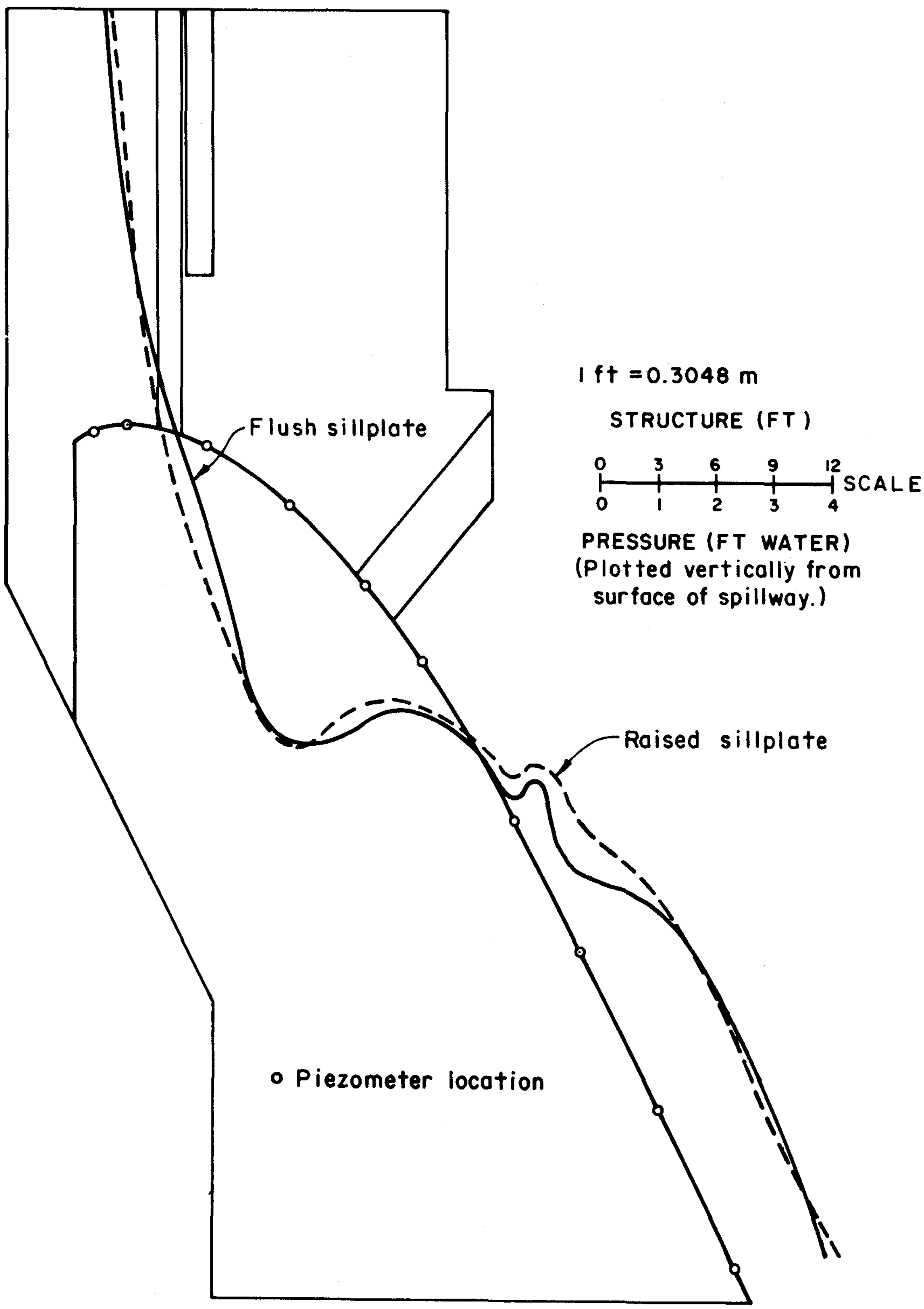

Figure 8. — Pressure profiles for flush and raised sillplates. Gates fully opened and reservoir elevation at 97.8 m (321 ft).

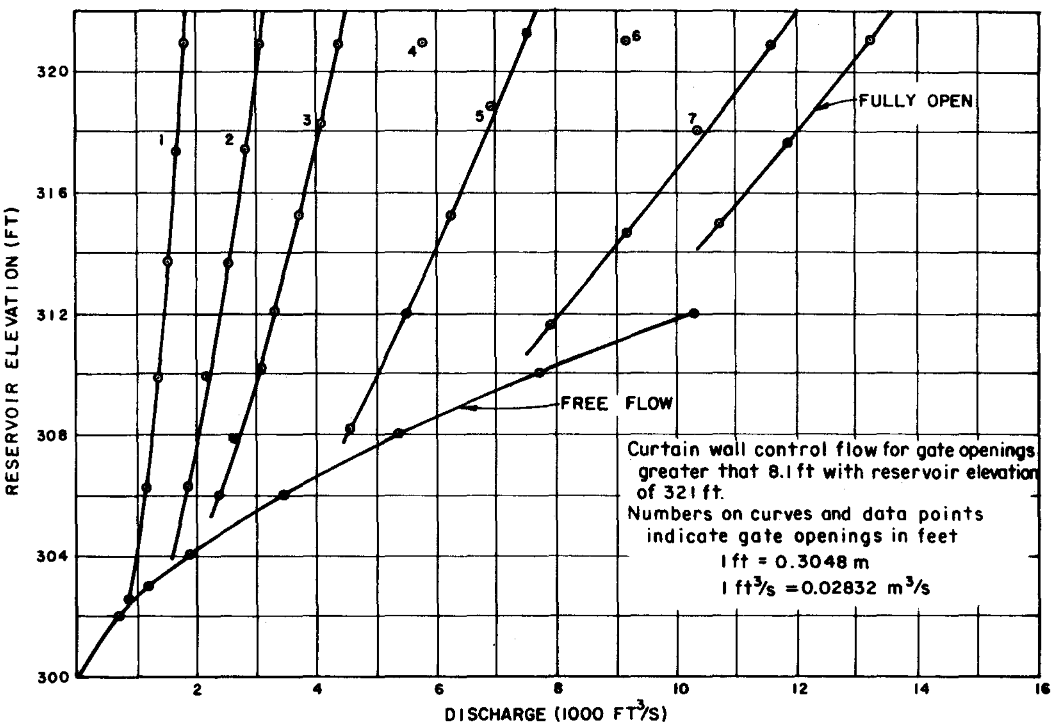

Figure 9. — Calibration for four equally opened gates.

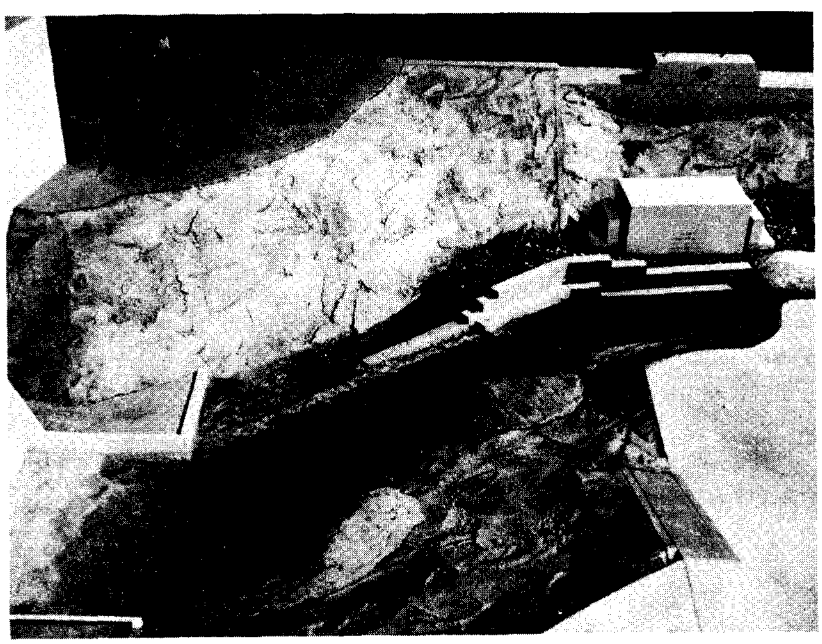

Figure 10. — Channel flow of 53.8 m³/s (1900 ft³/s) with all topography features in place. P801-D-80172

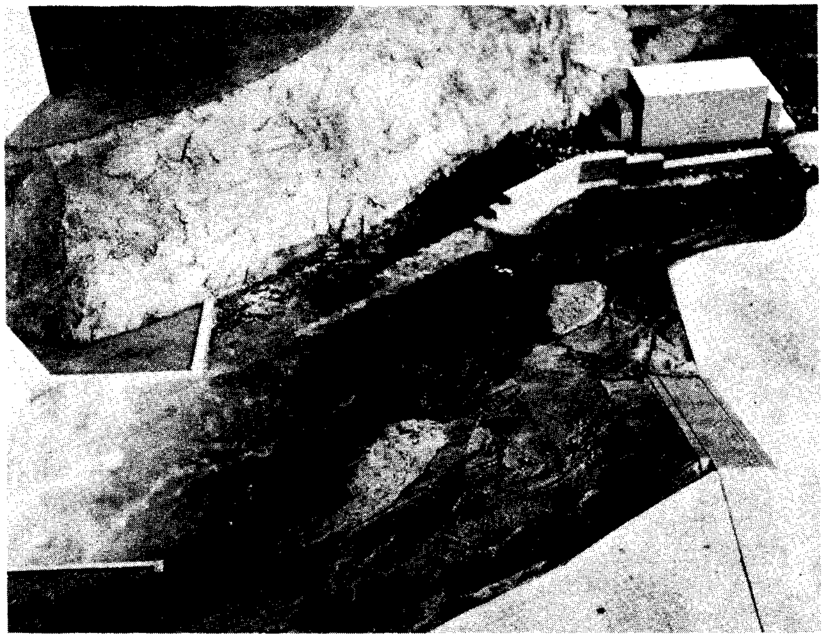

Figure 11. — Channel flow of 124.6 m³/s (4400 ft³/s) with all topography features in place. P801-D-80173

Figure 12. — Channel flow of 124.6 m³/s (4400 ft³/s) with nob removed. P801-D-80174

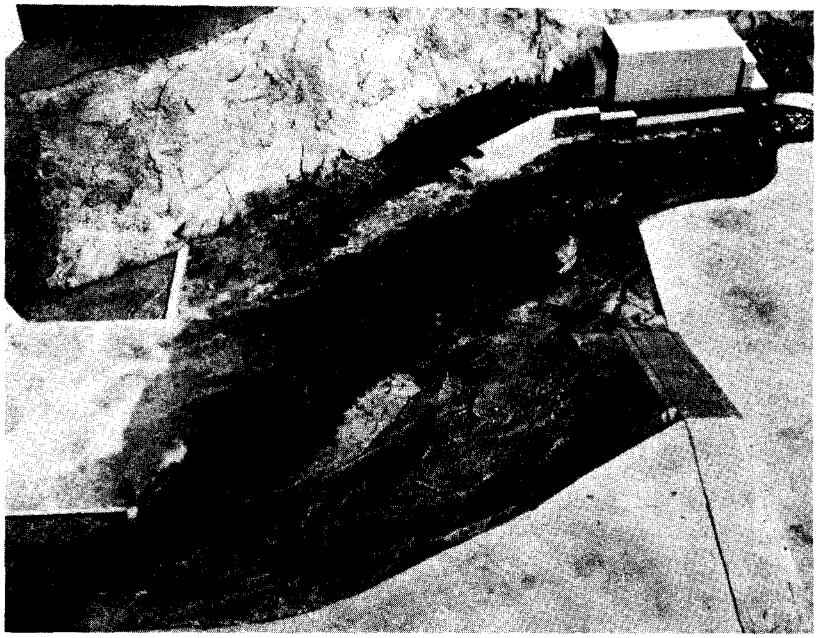

Figure 13. — Channel flow of 164.2 m^3/s (5800 ft^3/s) with all topography features in place. P801-D-80175

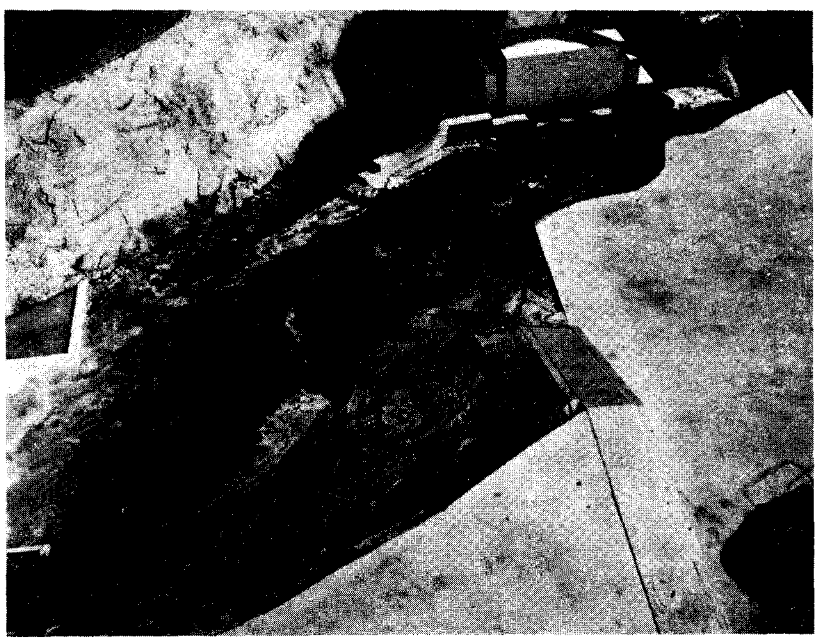

Figure 14. — Channel flow of 164.2 m^3/s (5800 ft^3/s) with nob and rock removed. P801-D-80176

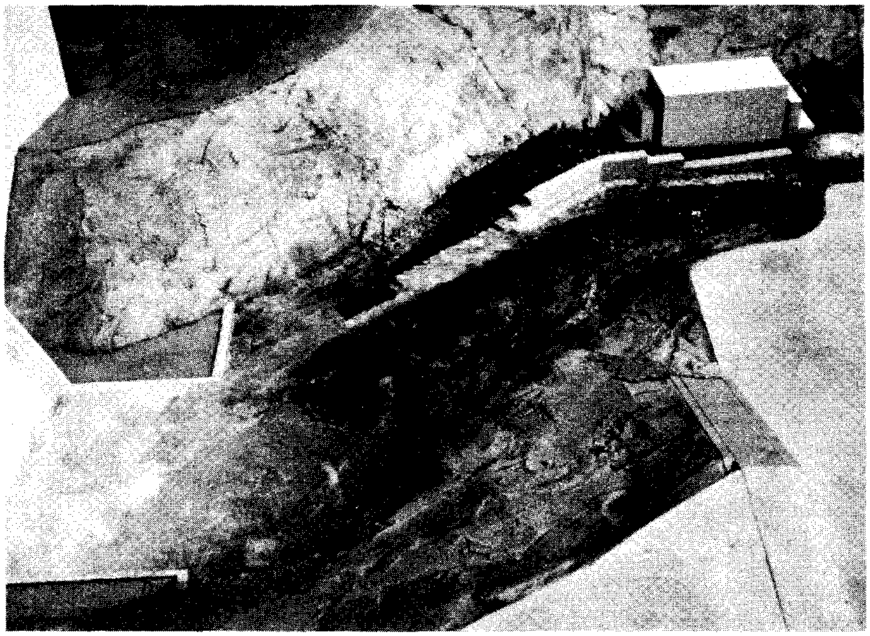

Figure 15. — Channel flow of 164.2 m^3/s (5800 ft^3/s) with canyon wall, nob, and rock removed. P801-D-80177

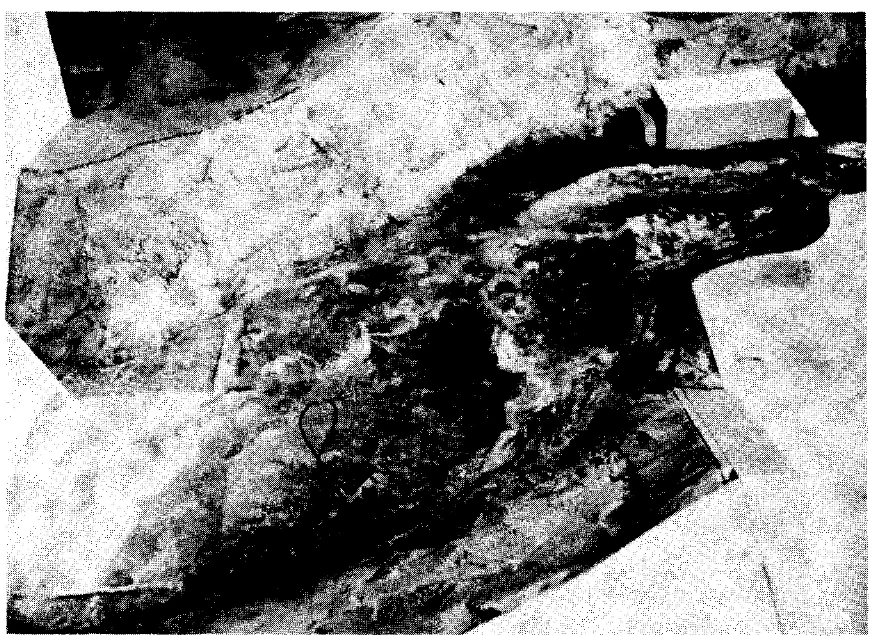

Figure 16. — Channel flow of 376.6 m^3/s (13 300 ft^3/s) with all topography features in place. P801-D-80178

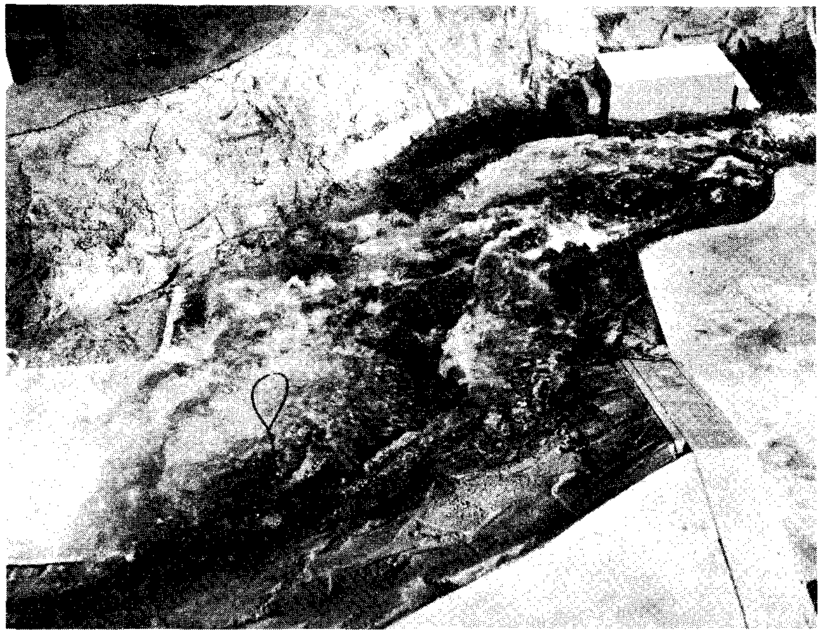

Figure 17. — Channel flow of 376.6 m^3/s (13 300 ft^3/s) with nob and rock removed. P801-D-80179

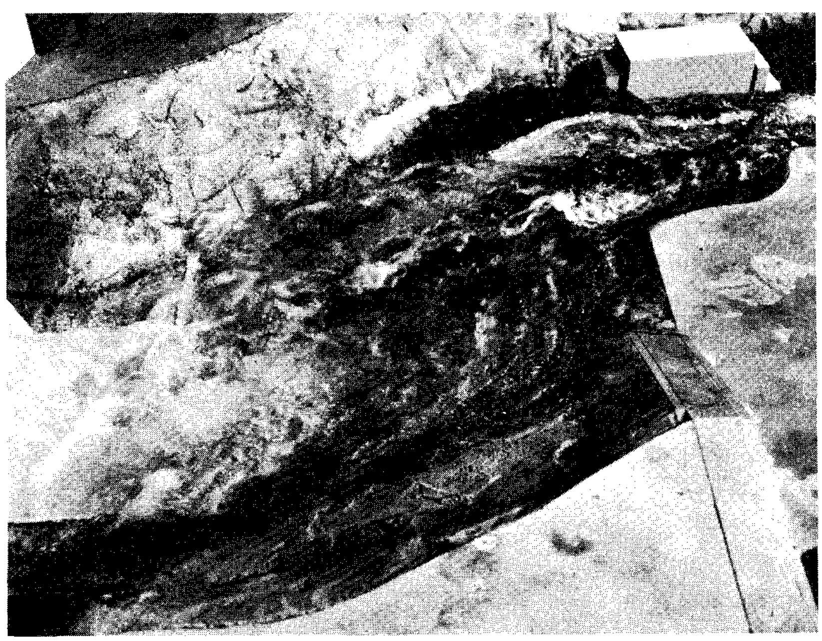

Figure 18. — Channel flow of 376.6 m^3/s (13 300 ft^3/s) with canyon wall, nob, and rock removed. P801-D-80180

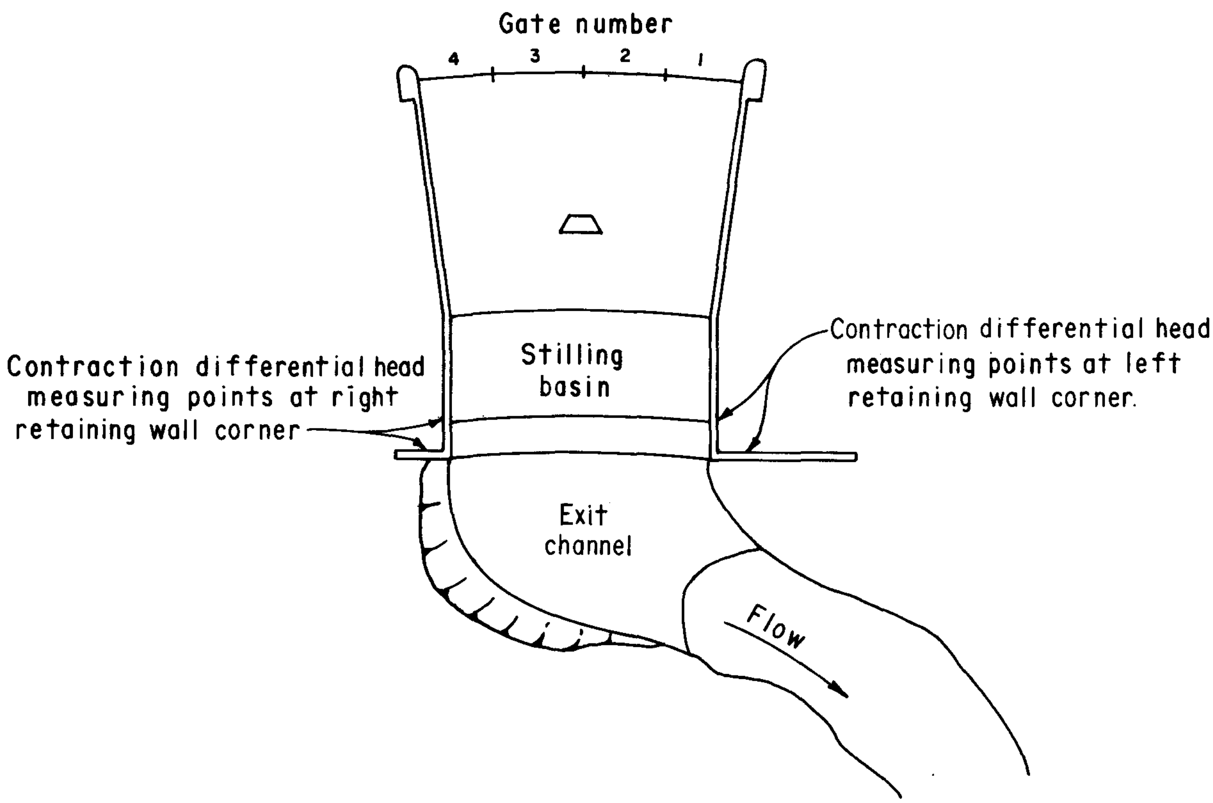

Figure 19. — Plan showing gate numbering and retaining wall corners.

GPO 839-760

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.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.