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Gordon H. Flammer

C. Earl Israelsen

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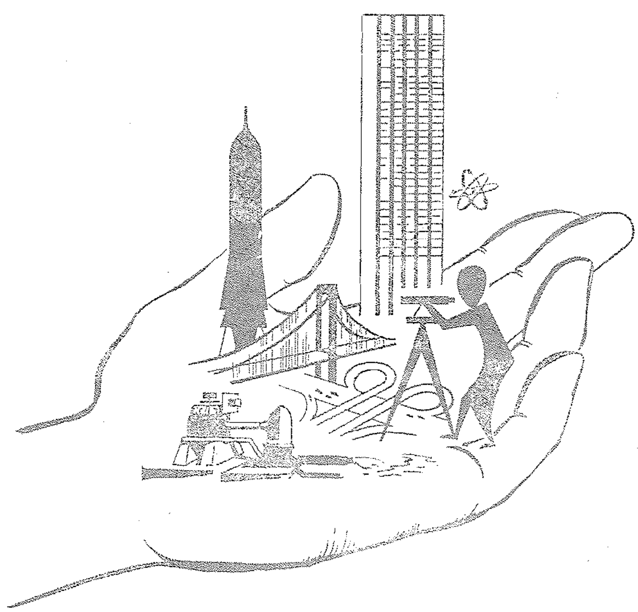

Performed for the
Utah Water and Power Board
Jay R. Bingham, Director

By the

Engineering Experiment Station
College of Engineering
Utah State University
Gordon H. Flammer, Project Leader
Report Prepared by C. Earl Israelsen

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MODEL ANALYSIS

OF SPILLWAY AND STILLING BASIN

OF PORCUPINE DAM

East of Avon, Utah

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Introduction

The Engineering Experiment Station at Utah State University was engaged by the Utah Water and Power Board to make a model analysis of the spillway and stilling basin of the Porcupine Dam. This dam will be located on the East Fork of Little Bear River, just east of Avon, Utah. It will be approximately 650 feet long and 160 feet high, composed of zoned earth fill with rock rip-rap facing. The spillway will have a reinforced concrete inlet section and the remainder of the chute and stilling basin will be excavated out of the rock and left unlined.

The design-flow and the elevation of the spillway crest were both determined by the Water and Power Board. The purpose of the model study was to design an economical spillway that would carry the design-flow with a minimum of head over the crest. Also, studies were made to determine whether or not there were danger of the toe of the dam being undermined by the swirling waters from the stilling basin.

Several radically different designs were tested as were a number of variations in each design. Only part of these are detailed in this report. Pictures of the final design are included.

Project's Personnel

Jay R. Bingham is director of the Utah Water and Power Board; and he, with his staff, is in charge of planning, issuing of contracts, and inspecting during construction of the Board's projects.

Dr. Vaughn E. Hansen is director of the Engineering Experiment Station and is in charge of all research done there. Dr. Gordon H. Flammer served as project leader for this particular study, and all tests were under his supervision. Model construction, modification and testing were carried out by C. Earl Israelsen, research engineer, and Joe Stapley, student assistant.

Acknowledgement is made to engineers of the Utah Water and Power Board and to those staff members of the Civil Engineering Department of Utah State University who supplied information and suggestions.

Theory and Computation

In order to have dynamic similarity between a model and its geometrically similar prototype, the ratio of all corresponding forces acting on the two must be the same. If the model obeys the Froude law, these requirements will be met.

$$\frac{V_p^2}{L_p g_p} = \frac{V_m^2}{L_m g_m} \quad \text{or} \quad \frac{V_p^2}{V_m^2} = \frac{L_p g_p}{L_m g_m} \quad \text{and let} \quad V_r = \frac{V_p}{V_m} \quad \text{etc.}$$

then $V_r^2 = L_r g_r$, but since $g_r = 1$, $V_r = (L_r)^{1/2}$

For this particular model a scale ratio of 1:50 was used. Thus

$$L_r = \frac{L_m}{L_p} = \frac{1}{50}$$

Since $V_r = (L_r)^{1/2}$, $V_m = \frac{V_p}{\sqrt{50}}$ $\qquad V_r = \frac{L_r}{T_r} = L_r^{1/2}$

so $T_r = L_r^{1/2}$, $T_m = \frac{T_p}{\sqrt{50}}$

$$Q_r = \frac{L_r^3}{T_r} = \frac{L_r^3}{L_r^{1/2}} = L_r^{5/2}$$

$$Q_m = \frac{Q_p}{17700}$$

The design discharge specified was 4500 cfs and this was later reduced to 4200 cfs. The model discharge for each of these two prototype discharges is:

$$Q_m = \frac{4500}{17700} = 0.254 \text{ cfs representing 4500 cfs}$$

$$Q_m = \frac{4200}{17700} = 0.237 \text{ cfs representing 4200 cfs}$$

Procedures

A 4 x 8 x 4 foot deep box lined with 3/4-inch marine plywood was built for the purpose of testing the first design. A baffle was constructed across one end to still the water entering the reservoir. The box was four feet deep in order that the irrigation outlet could be tested at the same time as the spillway, even though they were at different elevations. Water entered the model through a six-inch pipe. An elbow meter in the line was calibrated by means of a 12-inch flow meter in the supply main. This calibration was checked by means of a small volumetric tank into which the water flowed after it left the model.

Design No. 1

Description: The first model was built with approximately the same general location and alignment as the design furnished by the Bureau of Reclamation, and was done at a scale ratio of 1:50. The spillway was of the side-inlet type with a total crest length of 132 feet. The depth of the floor below the crest at the upper end of the inlet, Sta. 0+00, was four feet, and at Sta. 1+20 was 10 feet. A 100-foot vertical curve began at Sta. 1+90 and below this the chute slope was 0.4. The inlet and chute both had smooth, vertical walls and were 12 feet in width.

Flow Conditions: A test run was made using the design discharge of 4500 cfs, which at this scale-ratio was 0.254 cfs. At this discharge the spillway was submerged and the dam was overtopped. The first 100 feet of the inlet was totally ineffective because of submergence. These results indicated the need for a drastic change of design.

Materials were purchased with which to build a glory-hole spillway model, but before it was assembled, it was decided to further design and test a drop-inlet type because of the lower costs anticipated.

Design No. 2

Description: At this point in the testing program the engineers of the Utah Water and Power Board felt it advisable to design the spillway for the south end of the dam instead of the north as originally designed. Their decision made it possible to design a slightly shorter chute with a steeper grade.

Another plywood-lined box was constructed complete with a baffle and a six-inch valve-controlled water supply. This box was placed on an elevated platform and enclosed the upper end of the spillway chute, the spillway inlet and a portion of the reservoir and dam. A second box approximately 8 x 8 x 1-1/2 feet deep was constructed downstream from the first one and at a lower elevation. This contained the lower portion of the spillway chute, the stilling basin, and the toe of the dam. The spillway chute was built to connect the two boxes.

The problem was now two-fold. First, the elevation of the dam crest was given as 5390, the spillway crest elevation 5381, and the design discharge of 4500 cfs. (This was later reduced by Water and Power Board officials to 4200 cfs.) A spillway was desired that would handle this flow with a maximum of 3.6 feet of head. Second, a determination was to be made whether or not there were danger of the toe of the dam being undermined by swirling waters from the stilling basin. Also of interest was the determination of the maximum flow the spillway would carry before overtopping of the dam occurred.

A drop inlet was constructed into which water could flow from three sides. It was 50 feet long and 15 feet wide with vertical walls and a crest length of 115 feet. Downstream from the inlet was a 100-foot section that converged from 15 feet to 12 feet in width , and the 12-foot width was maintained on down the chute to the stilling basin. The walls and floor of the chute below the inlet were lined with 1/2-inch diameter stones to simulate rough rock excavation. On the prototype, this would represent average roughnesses of approximately two feet in height. The degree of smoothness that could be economically obtained in this type of rock excavation was not known, and the large roughnesses were used on the model to insure safety in the size designation. These roughnesses were screened stones that were adhered to the walls with Marsh Adhesive which is a pliable waterproof adhesive used in the building industry for applying wallboard.

Flow Conditions: At a discharge of 4500 cfs, the head over the spillway crest was approximately 5.8 feet. The flow pattern was good and the water depths in the chute were not excessive. Downstream the water backed up onto the toe of the dam; but the velocities here were negligible and no scouring occurred. The tendency of the flow was to continue beyond the stilling basin in the same direction as the spillway chute rather than to follow the channel back into the river. The stilling basin is not adequate to prevent all scouring beyond it, but scouring in this area is of no great concern. Bedrock is close to the surface and no property of any value is involved. The only critical scour area would be at the toe of the dam.

Design No. 3

Description: The 50-foot inlet was widened to 24 feet. The floor slope between Sta. 0+00 and 0+65 was 0.16. A 100-foot vertical curve connected this with a downstream slope of 0.50. The walls of the inlet and chute were vertical. The chute converged from 24 feet at Sta. 0+50 to 12 feet at Sta. 1+50. The floor was rough beyond Sta. 1+50, and the walls were rough beyond Sta. 0+50.

Flow Conditions: At a discharge of 4500 cfs, the head was 4.58 feet. The depth of flow in the chute at Sta. 0+00 was nine feet and at Sta. 0+50, 17 feet. There was no change in the design or operation of the stilling basin.

Design No. 4

Description: The inlet was lengthened to 65 feet giving a total crest length of 154 feet. Inlet walls and floor were smooth and the smooth floor extended to Sta. 1+15. Walls were of smooth rock excavation from Sta. 0+65 to Sta. 1+15, and both walls and floor beyond this station were lined with two-foot roughnesses. Slopes remained the same, i.e. 0.16 upstream and 0.50 downstream.

Flow Conditions: At a discharge of 4200 cfs, the head was 3.8 feet. The depth of flow on centerline at Sta. 0+75 was 12.5 feet, at Sta. 1+25 it was 16.7 feet, and at Sta. 3+00 it was 8.5 feet. At a discharge of 4500 cfs, the head was 4.1 feet.

Design No. 6

Description: Practical considerations indicated that 1:4 side slopes throughout would make construction safer and that the chute should be widened from 12 feet to 14 feet to allow adequate space for the operation of construction equipment. The model was modified to incorporate these changes, and the floor slopes were also changed. From Sta. 0+00 to Sta. 0+25 the slope was 0.32. Floor elevation at Sta. 0+00 was 5376. From Sta. 0+25 to Sta. 1+31 the slope was 0.0913, followed by a 100-foot vertical curve. Beyond Sta. 2+31, the slope was 0.482, to Sta. 4+79 which was the stilling basin floor at Elevation 5210.1. The roughnesses on the walls and floor remained the same as in the previous run.

Flow Conditions: A run on this model showed excellent flow conditions with no submergence of the wier crest. However, the head over the crest was still slightly higher than was desired, so the inlet was lengthened another 3.3 feet, making a total crest length of 162 feet. This brought the head down to 3.6 feet at 4200 cfs discharge and 4.0 feet at 4500 cfs. Flow conditions indicate that the approach channel should be excavated to a depth of three feet below the inlet crest.

The dam overtopped at nine feet of head and at a discharge of 11,050 cfs. The depths of flow at various points down the chute are given in the following table for maximum discharge of 11,050 cfs and for design-discharge of 4200 cfs.

Water Measured at Spillway Centerline

Station	"h" at 7000 cfs	"h" at 11,050 cfs
0+00	1.67	11.4
0+25	10.8	20.4
0+50	11.9	21.6
0+75	10.2	19.5
1+00	7.5	15.8
1+25	8.6	19.5
1+50	10.0	18.3
1+75	8.7	17.0
2+00	7.9	15.8
2+25	6.8	14.6
2+50	6.2	13.7
2+75	6.2	12.9
3+00	6.2	12.5
3+25	5.6	12.1
3+50	5.6	11.6
3+75	5.6	11.2
4+00	5.6	10.8
4+25	5.6	10.4
4+50	6.6	10.4
5+00	22.1	20.4

Summary

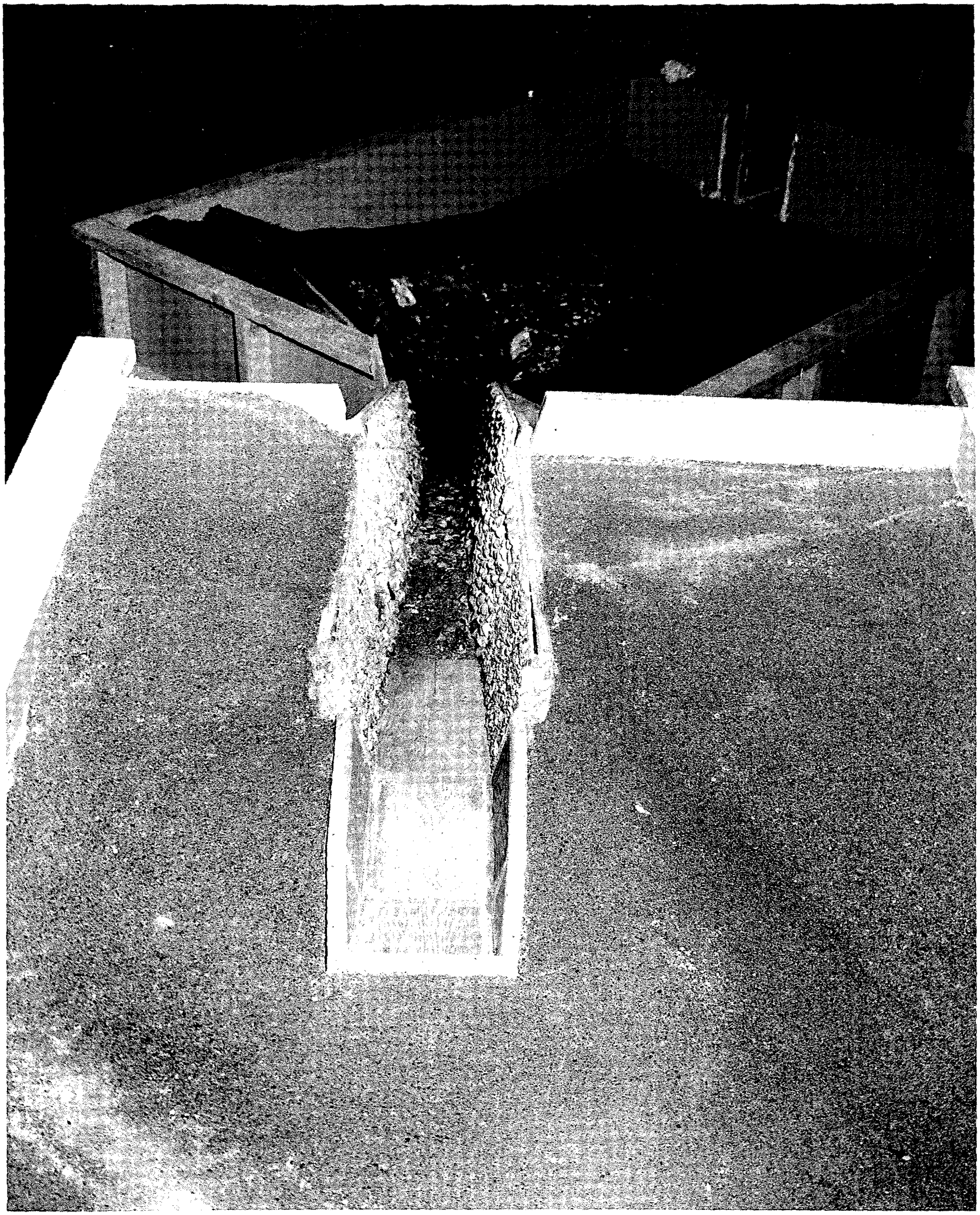
The final design of the spillway for Porcupine Dam is as shown in the Appendix. At a discharge of 4200 cfs, the head over the crest is 3.6 feet. At 4500 cfs it is 4.0 feet, and at nine feet the dam overtops at a discharge of 11,050 cfs.

Water inundated the toe of the dam, but velocities were negligible and no scour occurred. However, the stilling basin is not adequate to prevent scour in the area west of its outlet channel. Land in this area is of little value, and bedrock is close to the ground surface. It was deemed unnecessary to enlarge the stilling basin to prevent what little scour may occur here.

APPENDIX

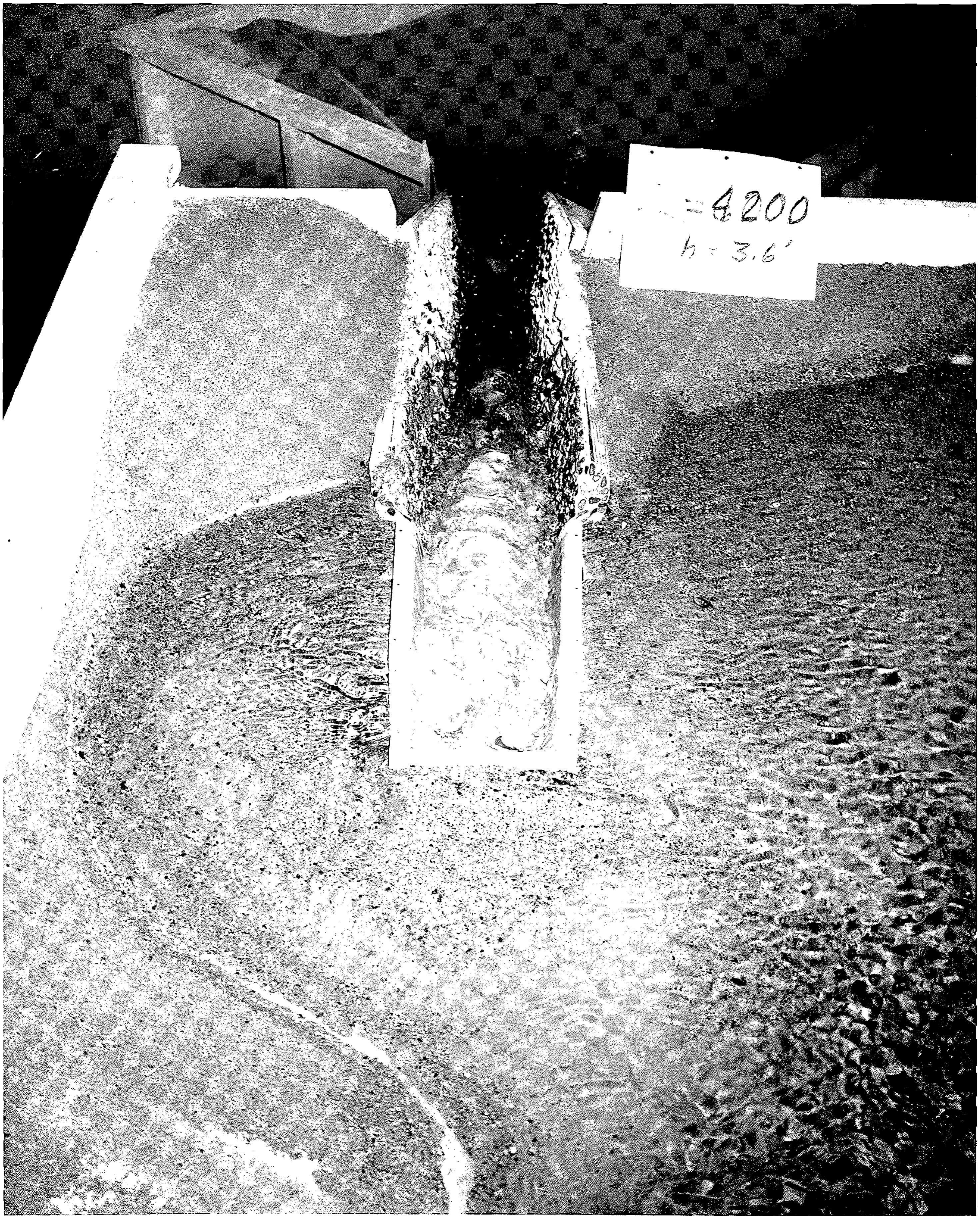
Picture No. 1

This shows an over-all view of the model from above the spillway inlet. Note the smooth walls and floor of the inlet which simulates concrete. The first 50 feet of the walls are of smooth rock excavation and the remainder of the walls and floor are extremely rough. The approach to the inlet is three feet below the spillway crest.



Picture No. 2

At the design discharge of 4200 cfs, the depth of head over the crest is 3.6 feet. Flow conditions down the chute are extremely favorable. Note the convergence in width of the chute from 24 feet to 14 feet below the inlet section. The crest acts as a wier along its entire length, with no submergence.


=4200
h = 3.6'

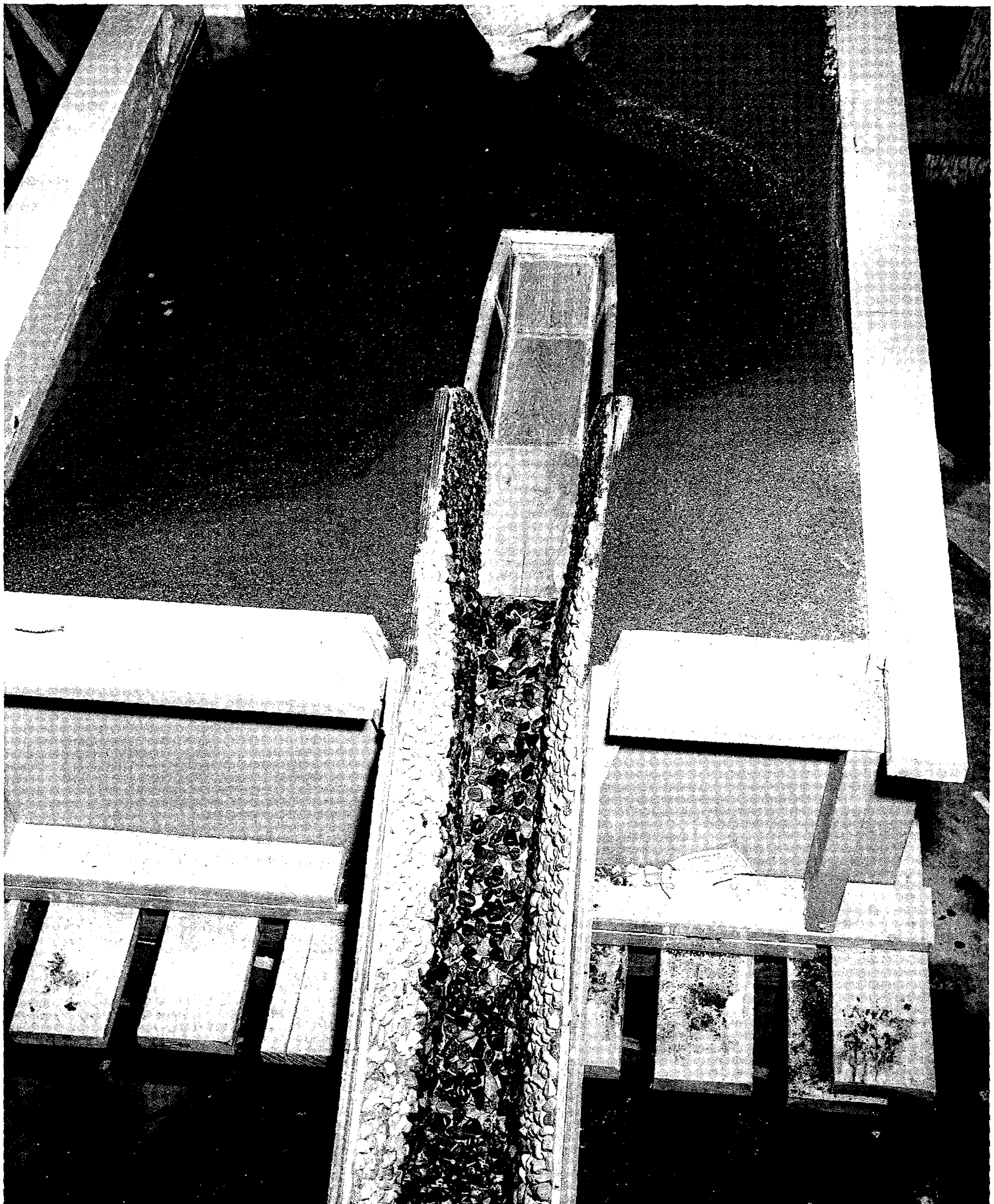
Picture No. 3

At 4500 cfs, flow conditions are still favorable and the head is only four feet. At 11,050 cfs the head is nine feet and the dam overtops. Water depths at 25-foot stations down the chute are given in table form in this report. The roughnesses were very effective in smoothing out the flow down the chute.


1 Q = 4500
Head = 4'

Picture No. 4

A view the same as Picture No. 3 but with no water running. The floor of the inlet is 24 feet wide and the side slopes are 1/4 to 1. The stones seen on the floor of the chute simulate two-foot average-height roughnesses on the prototype. The smaller roughnesses on the upstream side-walls would be approximately one foot high.



Picture No. 5

The tendency of the flow as it races down the chute is to continue on in the same direction after it leaves the stilling basin. The channel turns to the right at an angle of approximately 44 degrees. Some scour in this area is not considered serious because bedrock is close to the ground surface and the land has little value.


Q = 4200
h = 3.6'

Picture No. 6

The stilling basin is excavated out of bedrock and left unlined. The picture shows that there is water at the toe of the dam, but the velocities are negligible and no scour occurs.


Q = 4200
Q=1200

Picture No. 7

Water seen leaving the stilling basin still has considerable velocity. However, because bedrock is so close to the surface, no particular problem is expected with scour in this area.