HYD 339

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UNITED STATES
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HYDRAULIC MODEL STUDIES
OCHOCO DAM SPILLWAY
DESCHUTES PROJECT, OREGON

Hydraulic Laboratory Report No. Hyd-339

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

February 13, 1953

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Design and Construction Division
Engineering Laboratories Branch
Denver, Colorado
February 13, 1953

Laboratory Report No. Hyd-339
Hydraulic Laboratory Section
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Checked and
reviewed by: J. W. Ball

Subject: Hydraulic model studies--Ochoco Dam Spillway--Deschutes Project, Oregon

PURPOSE

Develop a spillway chute extension for Ochoco Dam which will turn the flow away from the hillside and allow the water to spring away from the downstream end of the chute to prevent undercutting the structure.

CONCLUSIONS

1. The recommended design of the 75-foot spillway chute extension with flow deflectors at the downstream end and a deflector block on the left chute wall at Station 1+98 (Figure 16) satisfactorily handles the design flood.

2. Flow is not uniformly distributed across the original spillway chute. When the discharge is less than 1,500 cfs this uneven distribution is not of major importance, but for larger discharges the flow tends to concentrate on the left side at the downstream end of the chute (Figure 7A).

3. A bucket at the downstream end of the chute causes a jump to form in the chute at small discharges (Figure 10A). The water downstream from the jump does not spring away from the end of the chute but drops off the end and causes undercutting close to the foundation.

4. A weir across the channel (Figure 7B) eliminates the necessity for repair work on the portion of the old structure upstream from the weir, but has the detrimental effects of decreasing the over-all coefficient of discharge and causing uneven flow distribution in the chute for all flows.

5. The velocity of the water at the downstream end of the chute is too great to be turned by a moderate superelevated section (Figure 8B).

6. Although the design with the chute extension turned 10 degrees to the right and two rows of flow deflectors, one at the turn and one at the downstream end of the chute, satisfactorily turned the water and absorbed much of the energy of the stream, the design was too complex (Figure 12).

7. The maximum discharge of 11,000 cfs requires a reservoir head 5-1/4 feet above the crest (discharge curve, Figure 5).

RECOMMENDATIONS

1. Construct a deflector block on the left wall at Station 1+98 with dimensions as shown in Figure 15B. This block produces a fairly uniform depth across the downstream end of the spillway chute for all discharges (Figure 8A).

2. Construct the 75-foot long spillway chute extension 50 feet 5 inches wide and on a 0.089 slope; continue the present side slopes; i.e., 1/2:1 for the left wall and 1:1 for the right wall; place six flow deflectors on the downstream end of the chute extension, and warp the downstream end of the left wall as shown in Figure 16.

INTRODUCTION

Ochoco Dam was completed in 1921 by the Ochoco Irrigation District as part of the irrigation plan for the arid land north of Bend, Oregon (Figure 1). The earth-filled dam (Figure 2) is approximately 125 feet high and 1,100 feet long. The spillway, left of the dam, has an uncontrolled, curved crest 275 feet long, and a spillway chute on a 0.089 slope extending 335 feet downstream from the axis of the dam. The outlet tunnel passes through the dam at elevation 3048, 83 feet below the spillway crest elevation.

Leakage through and around the dam was so severe that the reservoir seldom reached the crest elevation; the seepage water was collected in wooden troughs on the downstream face of the dam and channeled into the irrigation canal. The approaches to the crest have been overgrown with vegetation, and the concrete in the spillway and chute has been badly weathered. The hillside immediately downstream from the spillway chute has been eroded to a depth of 35 feet (Figure 3).

The Bureau has included Ochoco Dam in its plans for the Deschutes Project and appropriated funds for the rehabilitation of the spillway, outlet works, canal, and dam. This model study concerns only the repairs to be made to the spillway.

THE MODEL

Preliminary requirements called for extending the spillway chute 75 feet, and adding 8 to 10 inches to the thickness of the chute floor and 2 to 3 inches to the side slopes and crest. It was desirable to study the approach to the spillway crest and the action of the flow for approximately 350 feet downstream from the chute extension. These considerations required that the model include a prototype ground area of about 400 by 1,000 feet. The maximum design discharge was 11,000 cfs. The results of the analysis of the model size and discharge requirements indicated that a 1:36 scale model, which would occupy 12 by 30 feet of floor space and discharge 1.5 cfs, would be optimum. The model was built to this scale and included a gravel approach to the crest, a concrete crest and chute, scaled to the original but including the floor and wall repairs, a means for rapid and simple installation of various designs of the 75-foot spillway extension, and a gravel-filled tail box for scour study downstream from the chute (Figures 4A and B). Water supplied to the model by a laboratory pump was measured by a Venturi meter. A point gage was mounted in the head box to measure model reservoir elevation (Figure 4B).

THE INVESTIGATION*

Crest Capacity

The uncontrolled crest, representing the prototype after repairs (Figure 4B), was calibrated for flows up to the maximum design discharge of 11,000 cfs. The calibration curve is a plot of Q versus reservoir head above the crest (Figure 5).

Flow in the Channel

For discharges less than about 1,500 cfs the flow was fairly well distributed at the downstream end of the original spillway chute. At these discharges the water flowed over the crest, piled up on the left wall at about the same station as the downstream end of the crest, flowed back across the chute floor to the right wall about 75 feet downstream from the centerline of the dam, and then recrossed the chute diagonally toward the downstream end. A wave caused by the cross-channel flow for a discharge of 1,000 cfs is shown on Figure 6A; however, the depth of water at the downstream end of the chute for this discharge was uniform. Uneven distribution of flow at the higher discharges is

*All distances, discharges, and velocities are prototype unless otherwise stated. Stations are on the intersection of the left wall and the channel floor with Station 0+00 at the head of the channel.

shown on Figures 7A (8,000 cfs) and 6B (11,000 cfs). About one-half the flow was concentrated in the left one-quarter of the chute width at the downstream end when the discharge was greater than 5,000 cfs.

It was necessary to obtain uniform flow at the chute exit before the design of this portion of the spillway could be adequately tested. A pier was placed on the chute centerline about 20 feet upstream from the new construction (Figure 10A), but its position had to be changed for each discharge to give the desired distribution. Therefore, this pier could not be used for the prototype.

The source of the uneven flow was in the chute section adjacent to the crest. An attempt was made to obtain uniform flow by placing a pier, similar to the one shown in Figure 10B, in this area, but, as before, to get the desired results the position of the pier had to be changed for each discharge.

Sixty-four 3-foot cubes (baffle blocks) were mounted on the chute floor with the upstream blocks at the same station as the right end of the spillway crest. The blocks were in eight equal rows 3 feet apart. This arrangement produced satisfactory flow conditions at the spillway exit for flows up to about 4,000 cfs. For larger discharges the flow in the chute was very similar to that without the baffle blocks.

It was suggested that a weir be placed across the chute at about Station 0+75. Repair work would not have to be done to the portion of the old structure upstream from such a weir, and it was thought that the flow conditions might be improved. The weir was placed at different stations and at various angles to the chute centerline. Flow conditions for a flow of 3,000 cfs with the weir at right angles to the left wall at Station 0+74.16 are shown on Figure 7B. The design was unsatisfactory because it (1) produced a very poor flow condition in the chute for all discharges, and (2) reduced the effective length of the crest to such an extent that the reservoir had to be above the maximum allowable head to produce the design discharge of 11,000 cfs.

A deflector block was placed against the left wall across from the right or downstream end of the spillway crest to deflect a part of the stream and break up the concentrated flow. This design was remarkably effective. The best location of the deflector was determined to be at Station 1+98, and the best size and shape to be as shown on Figure 15B.

The distribution in the chute for discharges under 1,500 cfs was satisfactory without flow guides, and the deflector produced the desired flow distribution for greater discharges. Flows of less than 1,000 cfs did not reach the deflector block. The flow conditions at the deflector block for a Q of 11,000 cfs is shown on Figure 8A.

Spillway Chute Extensions

Superelevated chute extension. An attempt was made to turn the flow by superelevating the chute near the exit. The velocity of the stream was too great to permit the change in direction by a reasonable amount of superelevation. The flow conditions for 5,000 cfs for a combination of superelevation of the chute floor and a curved left wall is shown on Figure 8B. The direction of flow was not changed until it struck the wall, then it formed a concentrated jet at the wall. Since the high velocity-flow made superelevation impracticable, the tests were continued using flow deflectors at the end of the chute floor.

Flow deflectors. Four designs were submitted to the laboratory for the preliminary model tests on flow deflectors. Each design included a ski jump at the toe of the chute and deflectors to turn the stream (Figure 9). The right side or face of three of the flow deflector designs was spherical or superelevated (Types "A," "B," and "D," Figure 9). The model tests showed that the superelevated surface used did not change the direction of flow of the high-velocity stream; the water had a tendency to climb the curved or warped face, but did not change direction noticeably. The fourth design included six deflectors equally spaced across the chute outlet (Type "C," Figure 9). The right face of each deflector was vertical and curved to the right. The left wall of the chute was warped from 1/2:1 to vertical, and the vertical wall curved to the right. This latter design was chosen for the initial tests of flow deflectors.

Type "C" flow deflector.--The deflectors were formed of sheet metal and soldered to the 75-foot chute extension. The deflectors were 19-1/2 feet long and 10 feet high. The vertical right face of each curved to the right on a 32-foot radius. The ski jump started 19-1/2 feet upstream from the toe of the chute with a 30-foot vertical curve, $\Delta = 29°05'$. The floor of the chute continued on a slope of -0.445 from the end of the vertical curve to the end of the chute, terminating at an elevation 4.4 feet higher than the start of the vertical curve. This ski jump, designed to project the stream away from the toe of the chute, served adversely. The deflectors caused a hydraulic jump to form in the chute for discharges below 1,950 cfs, causing the stream to spill close enough to the toe of the chute to undermine it (Figure 10A). For discharges larger than 1,950 cfs, the pool in the "bucket" was swept out (Figure 10B).

Effect of varying the ski jump.--When the flow was such that the hydraulic jump did not form upstream from the Type "C" deflectors, the stream was turned by the vertical right faces of the deflectors in a satisfactory manner. The left faces of the deflectors had little effect on the flow. A new model chute extension was constructed with the floor continuing on the same slope as the original chute. The new deflectors had a vertical right face as before,

but a conical surface replaced the warped surface of the left face of the Type "C" deflectors. This design would be simpler to construct in the field. Fillets of clay were molded into the spaces between the deflectors and could be varied or removed as desired.

When the clay fillets were shaped to terminate at about the same elevation as the ski jump used with the Type "C" deflectors, the flow was similar to that with the Type "C" deflector. As the rise of the ski jump was decreased, the pool upstream from the deflectors swept out at smaller discharges, and when the clay was removed a jump did not form. Tests were made leaving one or more of the spaces between the deflectors free. This innovation was not successful. The flow conditions for a discharge of 1,350 cfs, the maximum "Q" at which a jump will form with the center opening clear and the clay fillets between the other deflectors extending about 3.25 feet above the chute floor, are shown on Figure 11A. Flow conditions, for a discharge of 5,400 cfs and with the deflectors and clay ski jump the same as in Figure 11A, are shown on Figure 11B. The stream is deflected to the right but spreads out very little in the direction of flow.

Two rows of flow deflectors.--It was thought the flow might be turned in two stages rather than attempting to make the complete turn at the downstream end of the chute extension. The chute extension floor was continued on the original slope ($S = 0.089$) and the side walls were turned 10 degrees to the right. Six deflectors were placed in the new construction extending 20 feet downstream from Station 5+52.9 and curved to the right on a radius of 92.4 feet, $\Delta = 12°30'$. The deflectors used in the previous test were placed on the downstream end of the chute extension (Figure 12A).

The stream was turned satisfactorily, and the two rows of deflectors absorbed much of the energy of the flow. However, the design was considered unsatisfactory for prototype construction because (1) the upstream deflectors, 1 foot thick, 9 feet high, and 20 feet long, would be too frail for concrete construction, (2) the water striking the upstream deflectors was deflected to the right and directed upward about 15 degrees; the jets from these deflectors impinged on or near the downstream deflectors for flows from 2,000 to 8,000 cfs (Figure 12B), and (3) the design with the six additional deflectors appeared too costly. For these reasons further tests on the design were not made even though the flow was turned satisfactorily.

RECOMMENDED DESIGN

The deflectors used with the clay fillet ski jump design operated satisfactorily when the clay was removed, allowing the chute floor to continue on the slope S = 0.089 to its downstream edge; however, the deflectors had been hastily shaped from wood and were not geometrically exact. Six deflectors of the recommended design were formed of sheet metal and were held to close tolerances, the shape being that shown in Figure 15A. Twenty-three piezometers were located in one of the deflectors in order to study the pressures at particular points.

The downstream end of the left wall extension was warped from the original side slope of 1/2:1 at Station 6+03.3 to vertical at Station 6+27.3, the downstream end of the new construction. The intersection of the floor and the warped surface was curved to the right on a radius of 51 feet, $\Delta = 28°05'$. The right wall continued on a side slope of 1:1. The chute floor continued on the original slope S = 0.089.

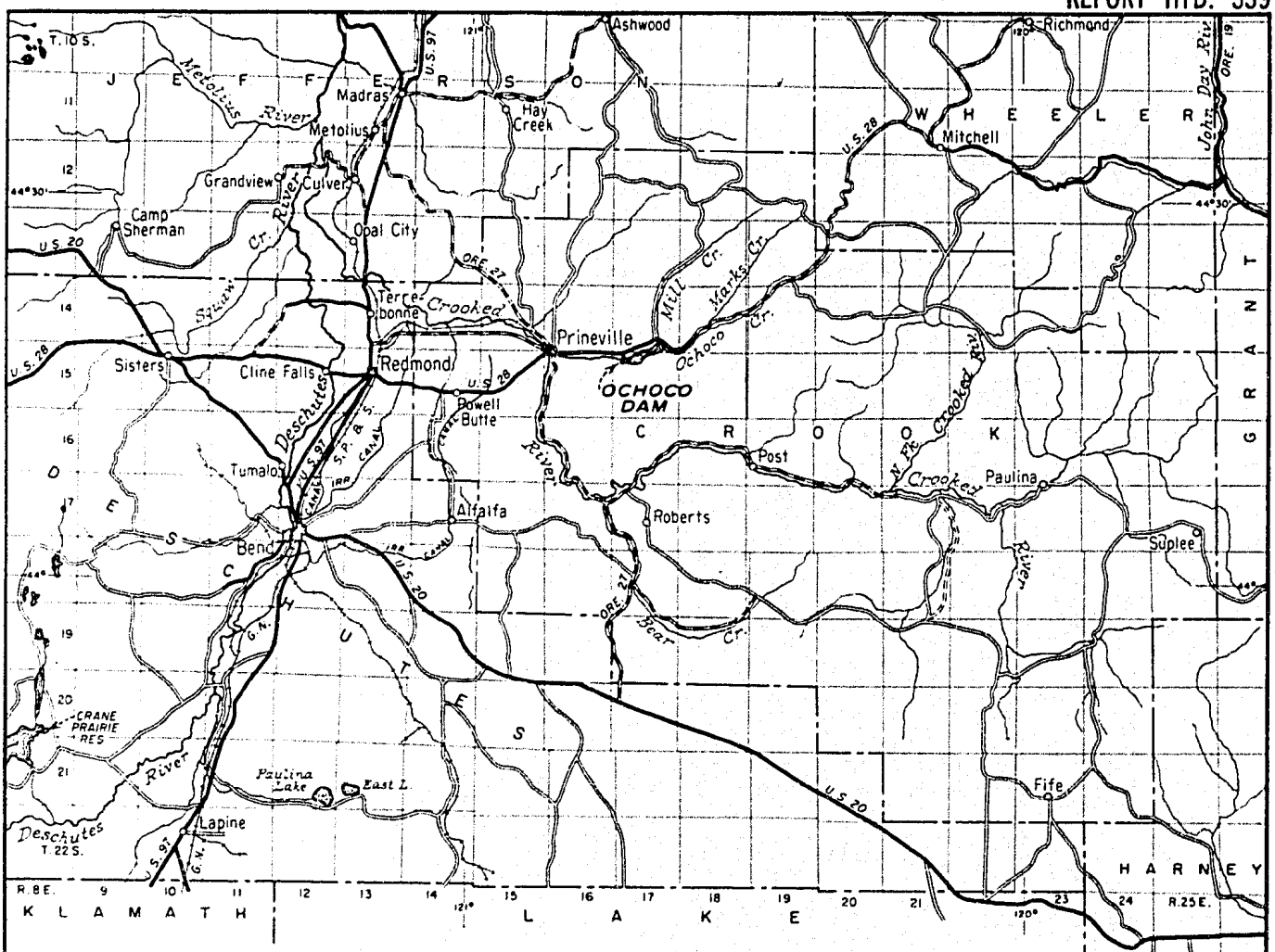
The deflector block on the left spillway wall opposite the downstream end of the crest was constructed of clay with the upstream face of sheet metal. Fifteen piezometers were placed in the upstream face to determine forces acting on the block, and the clay was shaped to determine optimum size requirements.

The recommended prototype dimensions of the flow deflectors and deflector block are given on Figure 15. The model in its final form is shown on Figure 13, and the location of these parts and the pressures on them are given on Figure 16. The recommended design deflector block and flow deflectors with a discharge of 11,000 cfs are shown on Figures 8A and 14A. Conditions at the flow deflectors for a discharge of 1,000 cfs are shown on Figure 14B.

Prototype Operation

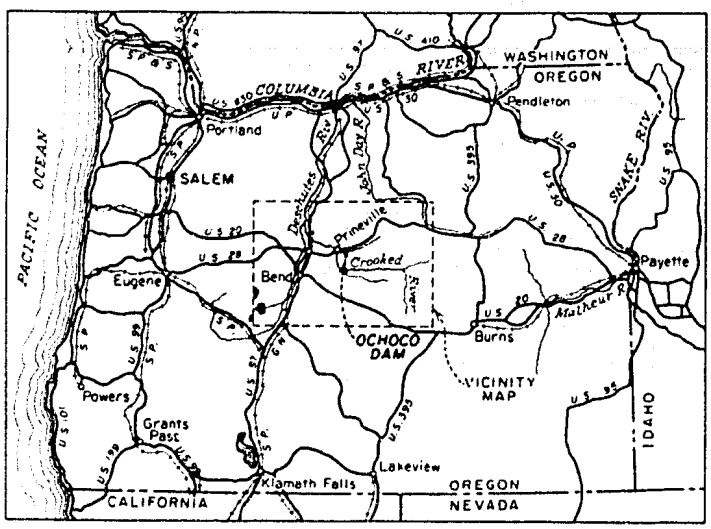
Figures 17, 18, and 19 show the prototype in operation with the design as recommended, and under a discharge of 750 cfs. For this small flow the stream does not impinge on the deflector block. Note the cross-channel wave in the model, Figure 6A, and the prototype, Figures 17B and 18A. The comparison between model and prototype action at the flow deflectors, as shown in Figures 14B and 19B, indicates that the prototype should operate as predicted throughout the full range of discharges up to a maximum flood of 11,000 cfs.

FIGURE 1
REPORT HYD. 339



VICINITY MAP

5 0 5 10 15 20 25
SCALE OF MILES



INDEX MAP

EXPLANATION
(Vicinity Map Only)

- OILED OR PAVED ROADS
- GRAVELLED ROADS
- IMPROVED ROADS

UNITED STATES
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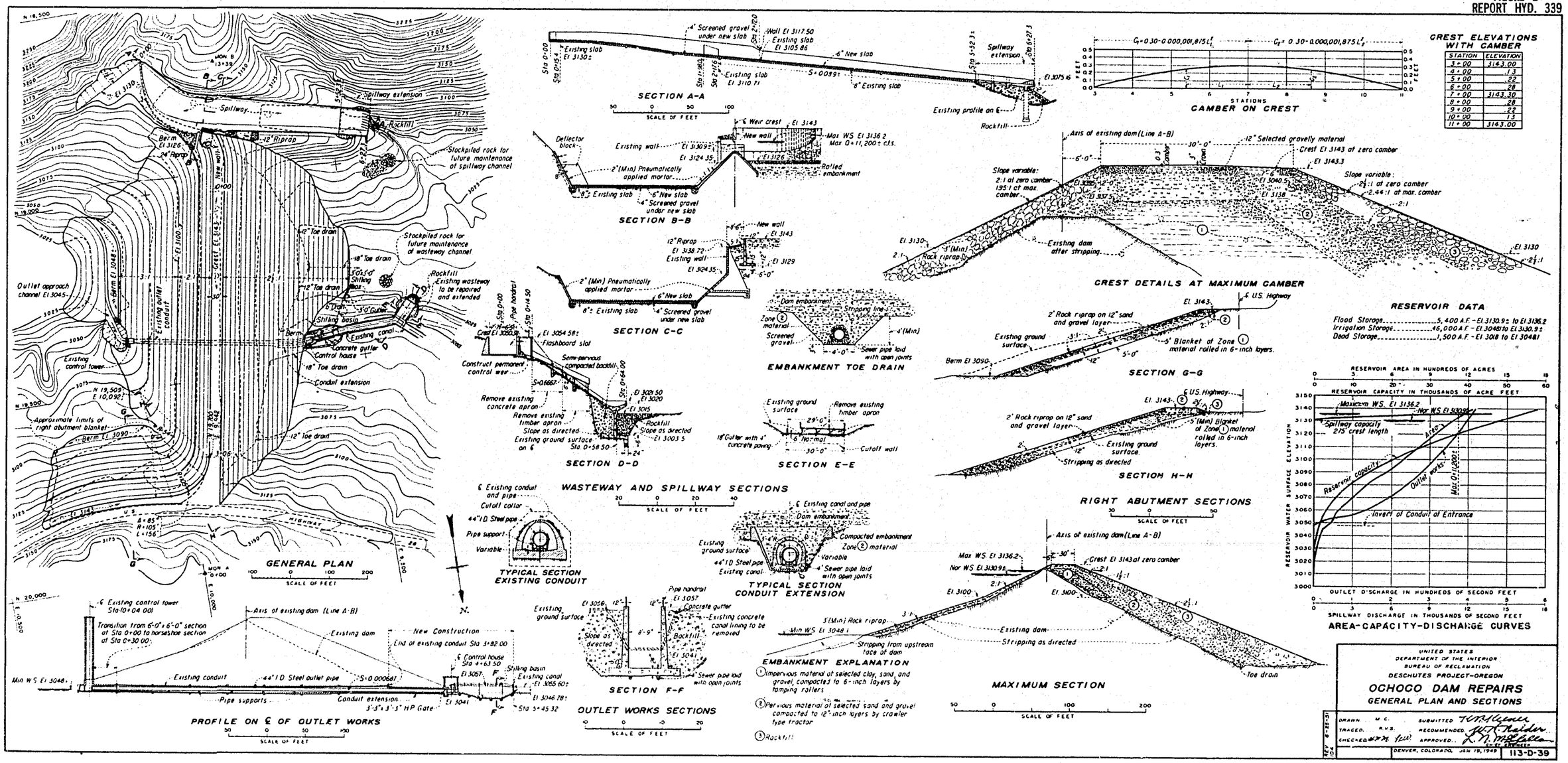
DESCHUTES PROJECT - OREGON

OCHOCO DAM REPAIRS
LOCATION MAP

DRAWN M.C. SUBMITTED [signature]
TRACED B.F.W. RECOMMENDED W.H. Nalder
CHECKED [signature] APPROVED L.N. McClellan
CHIEF ENGINEER

DENVER, COLORADO - JAN 19, 1949 | 113-D-34

FIGURE 2
REPORT HYD. 339



CREST ELEVATIONS WITH CAMBER

STATION	ELEVATION
3+00	3143.00
4+00	.13
5+00	.22
6+00	.28
7+00	3143.30
8+00	.28
9+00	.22
10+00	.13
11+00	3143.00

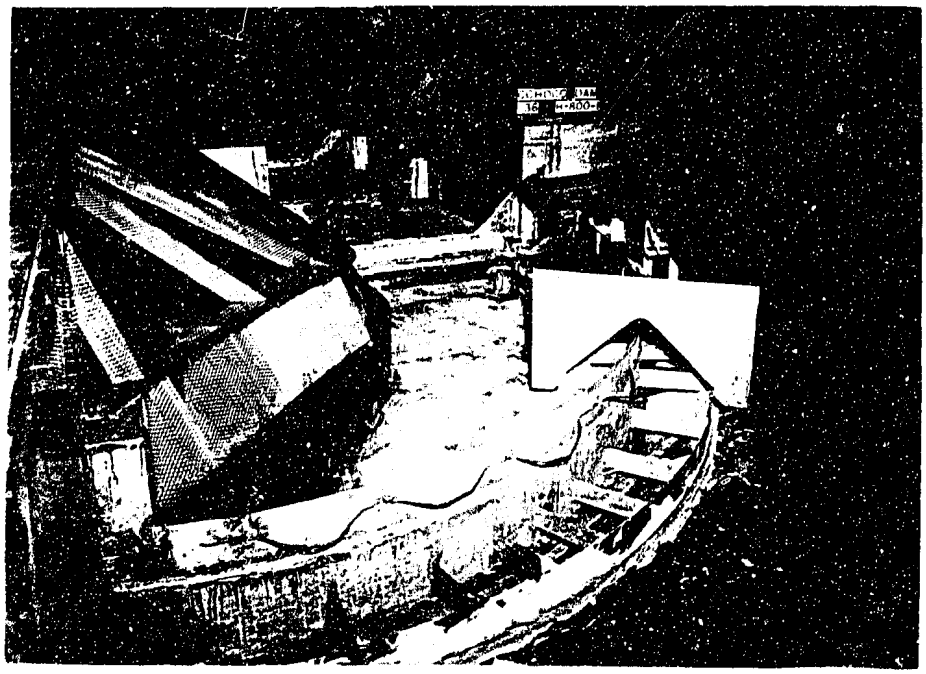
RESERVOIR DATA

Flood Storage.....5,400 A.F. - El 3130.9± to El 3136.2
Irrigation Storage.....46,000 A.F. - El 3048± to El 3130.9±
Dead Storage.....1,500 A.F. - El 3018 to El 3048±

A. Crest and chute

B. Looking upstream into the scoured area at end of the chute

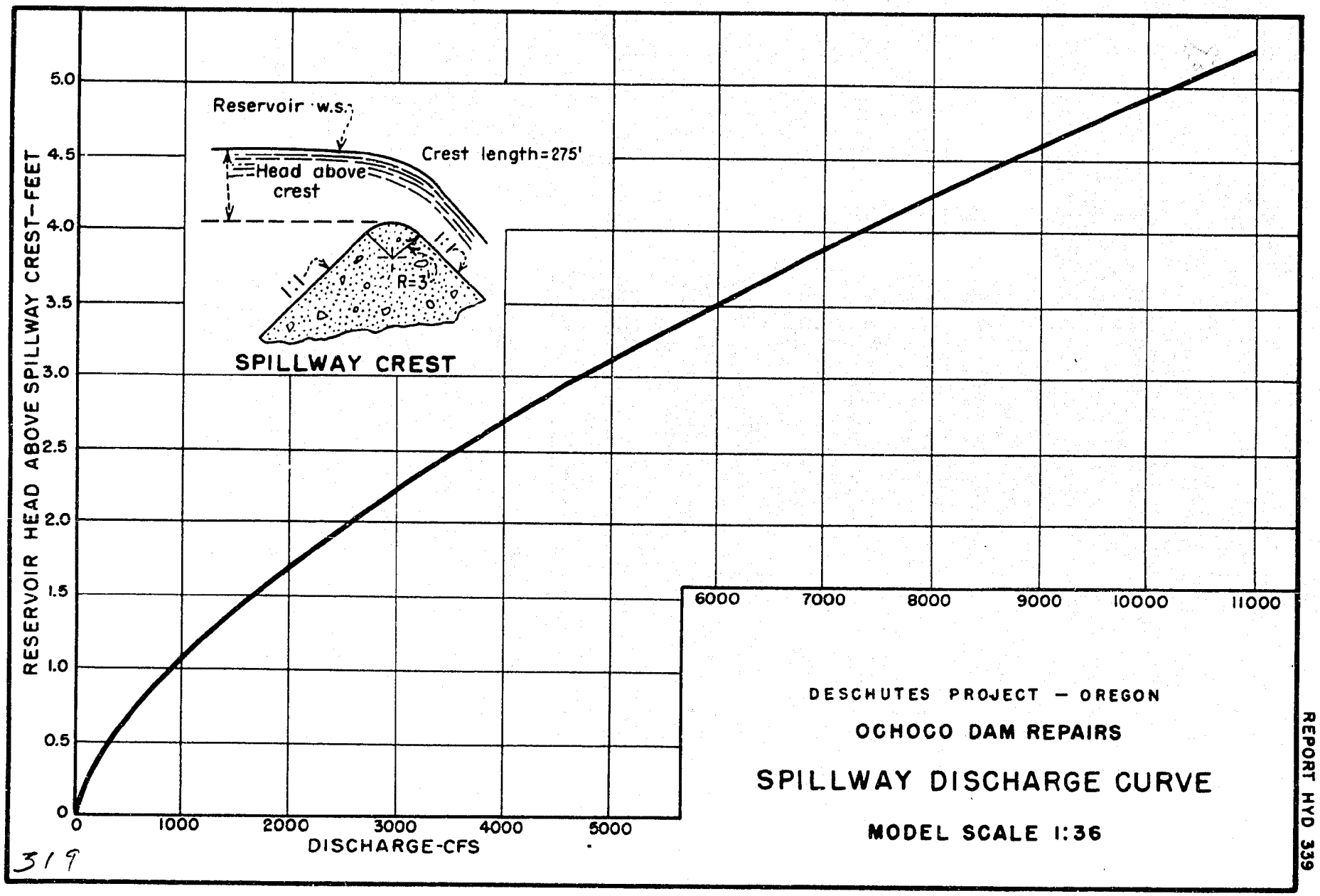
Deschutes Project
OCHOCO DAM REPAIRS
Prototype Before Repairs



A. Wire mesh foundation for upstream face of dam--
far right
Upper chute and crest templates--foreground
Spillway chute templates--left background

B. Completed model

Deschutes Project
OCHOCO DAM REPAIRS
Original Model Construction
Model Scale 1:36



DESCHUTES PROJECT — OREGON

OCHOCO DAM REPAIRS

SPILLWAY DISCHARGE CURVE

MODEL SCALE 1:36

FIGURE 5
REPORT HYD 339

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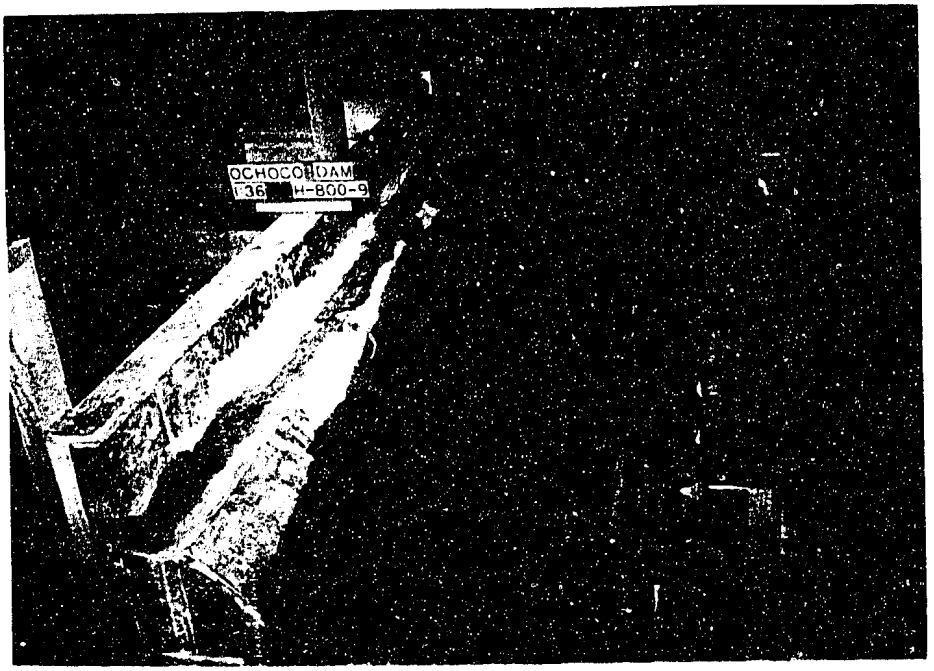
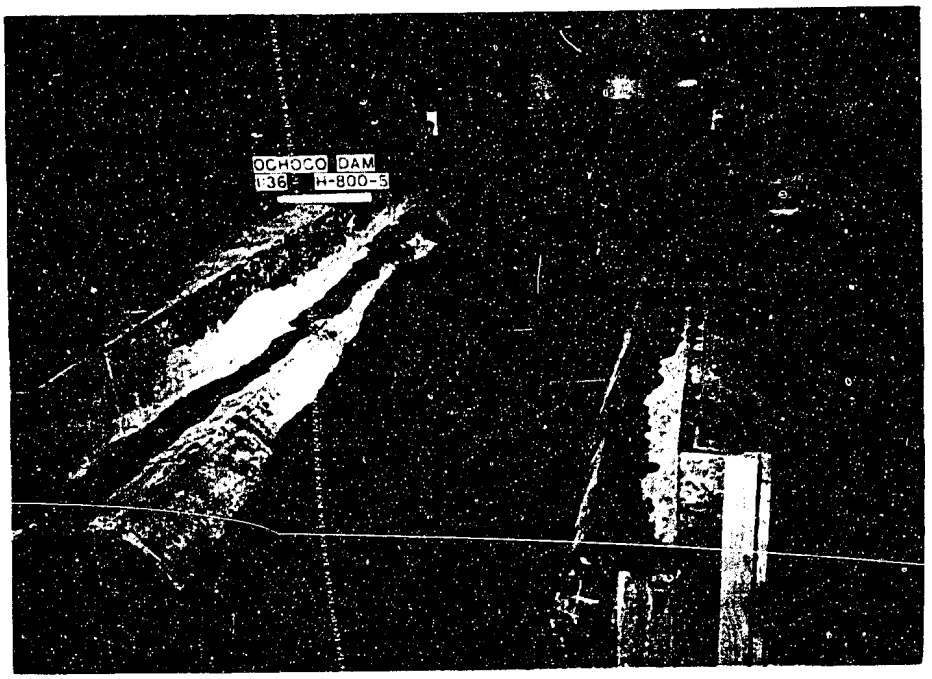


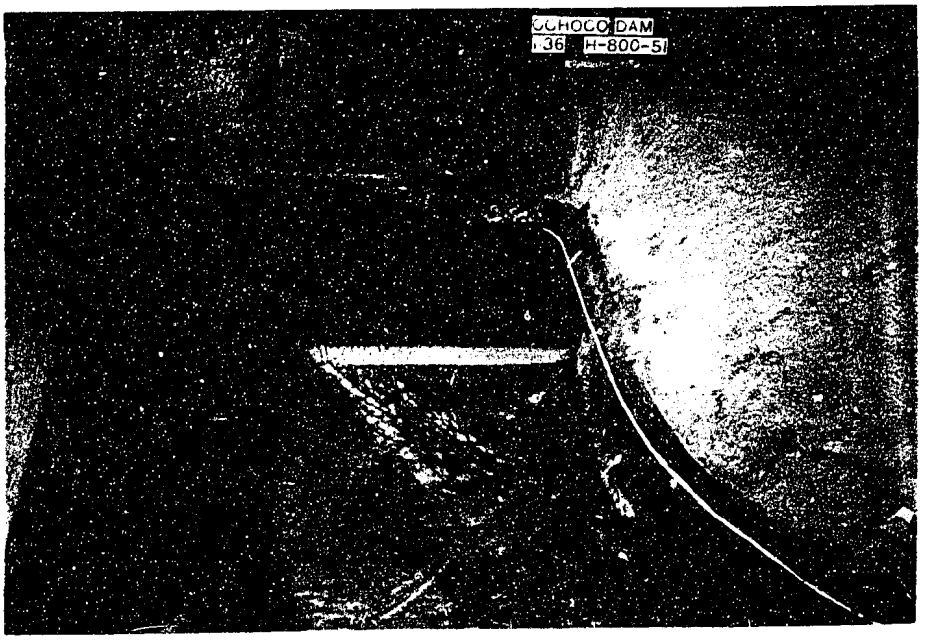
A. View upstream showing the crest and chute
Discharge--1,000 cfs



B. View upstream showing the crest and chute
Discharge--11,000 cfs

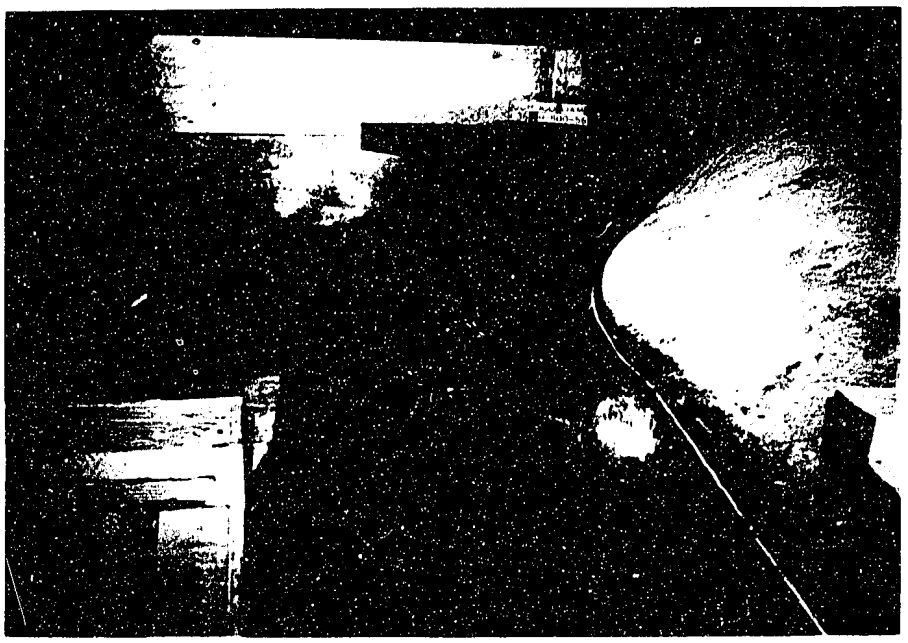
Deschutes Project
OCHOCO DAM REPAIRS
Flow Conditions in Original
Spillway and Chute
Model Scale 1:36

A. Straight chute end without deflectors or flow straighteners
Downstream end of the chute viewed from the right bank
Discharge--8,000 cfs

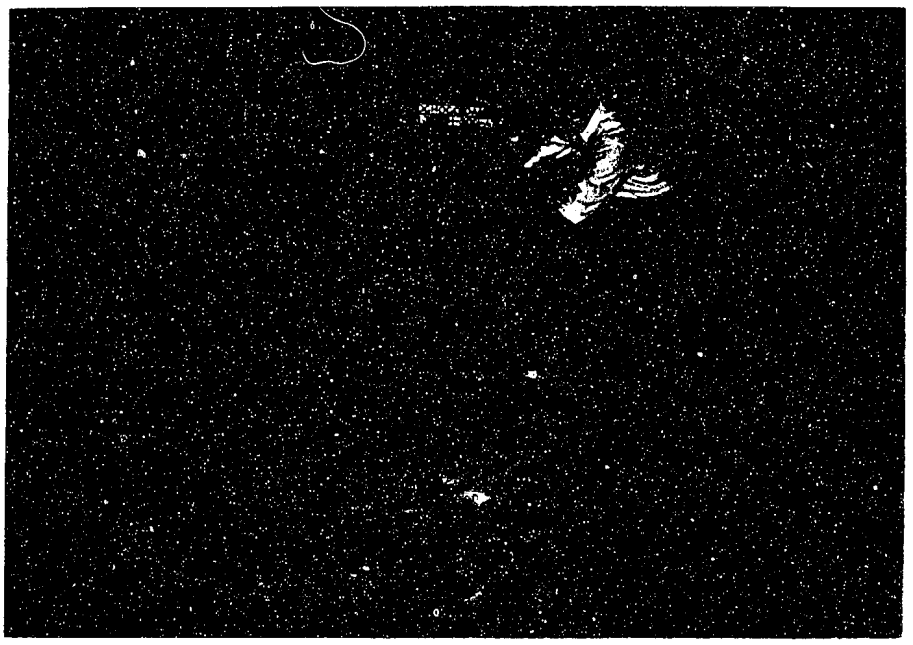


B. Cross weir at Station 0+74.16
View upstream toward the crest
Discharge--3,000 cfs

Deschutes Project
OCHOCO DAM REPAIRS
Model Scale 1:36

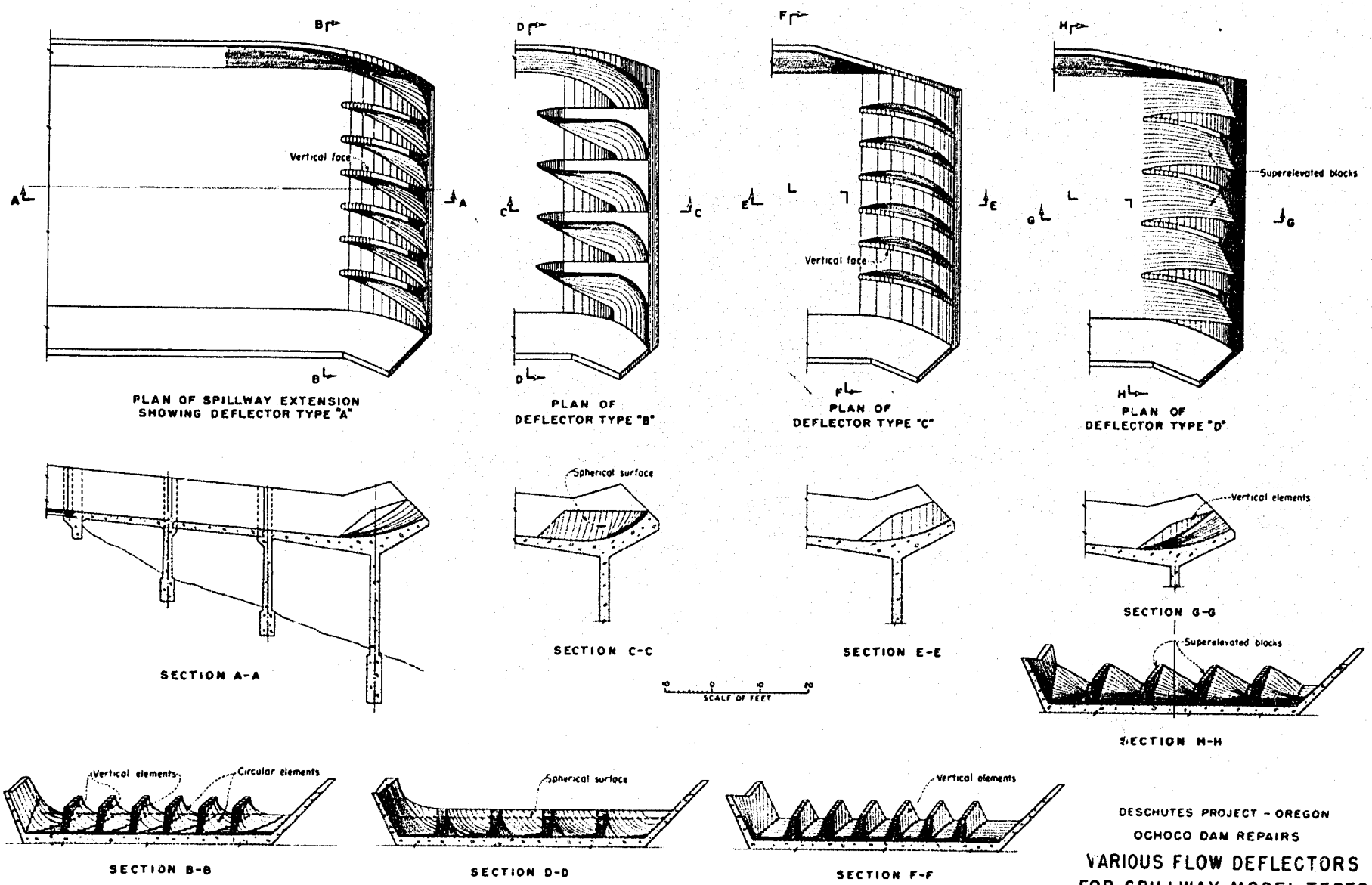


A. Recommended design deflector block at
Station 1+98.0
View upstream toward the crest
Discharge--11,000 cfs



B. Super-elevated chute end with curved left wall
View upstream at the downstream end of the chute
Discharge--5,000 cfs

Deschutes Project
OCHOCO DAM REPAIRS
Model Scale 1:36



DESCHUTES PROJECT - OREGON

OCHOCO DAM REPAIRS

VARIOUS FLOW DEFLECTORS FOR SPILLWAY MODEL TESTS

FIGURE 9
REPORT HYD 339

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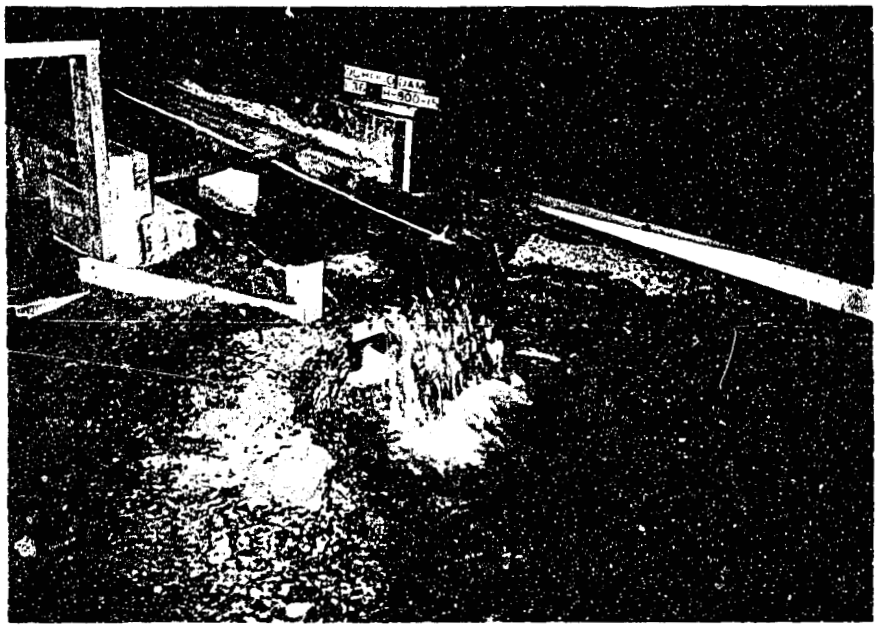
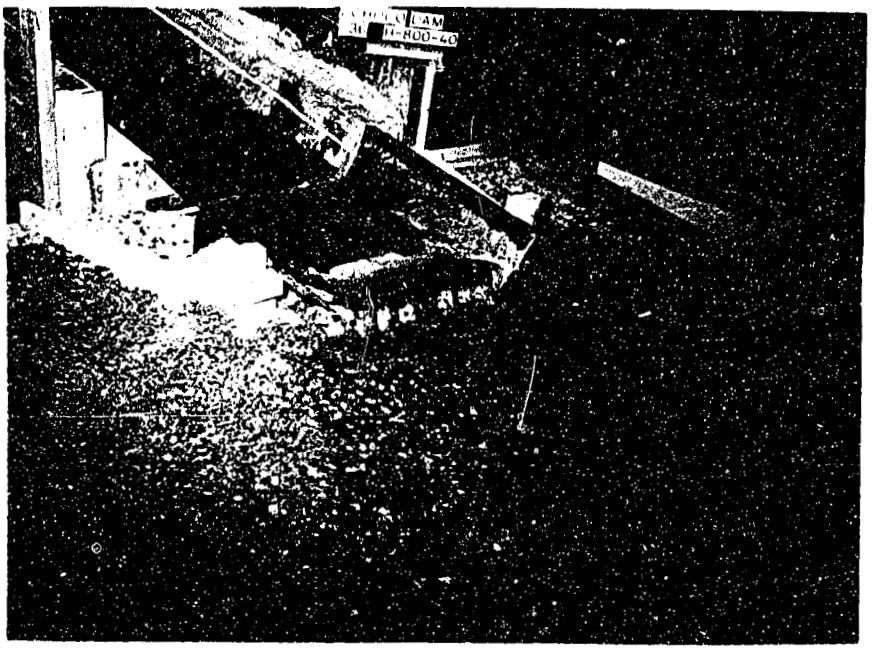


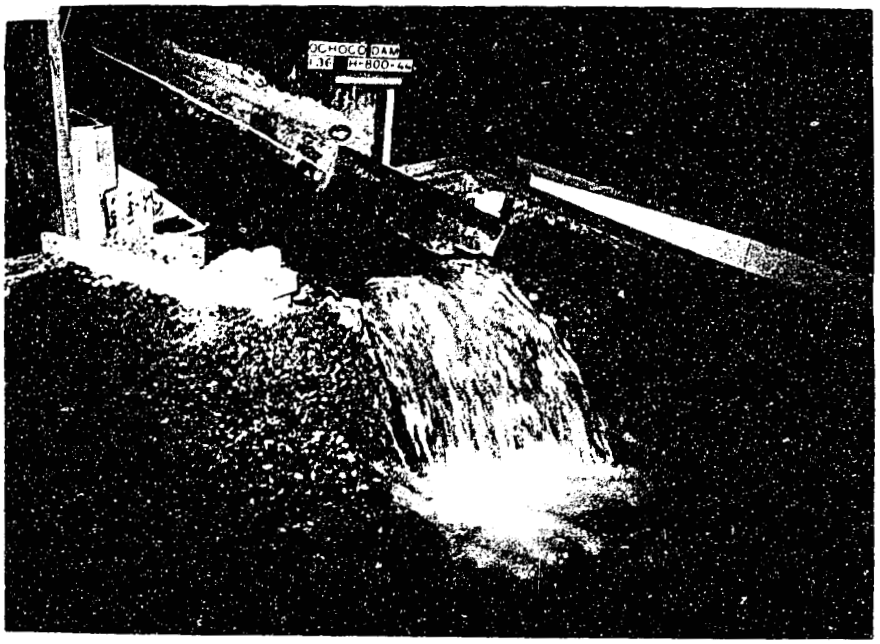
A. Downstream end of the chute with flow straightening vane viewed from the right bank
Discharge--1,900 cfs

B. Downstream end of the chute viewed from the left bank
Discharge--5,000 cfs

Deschutes Project
OCHOCO DAM REPAIRS
Flow Conditions With Type "C" Deflectors
Model Scale 1:36

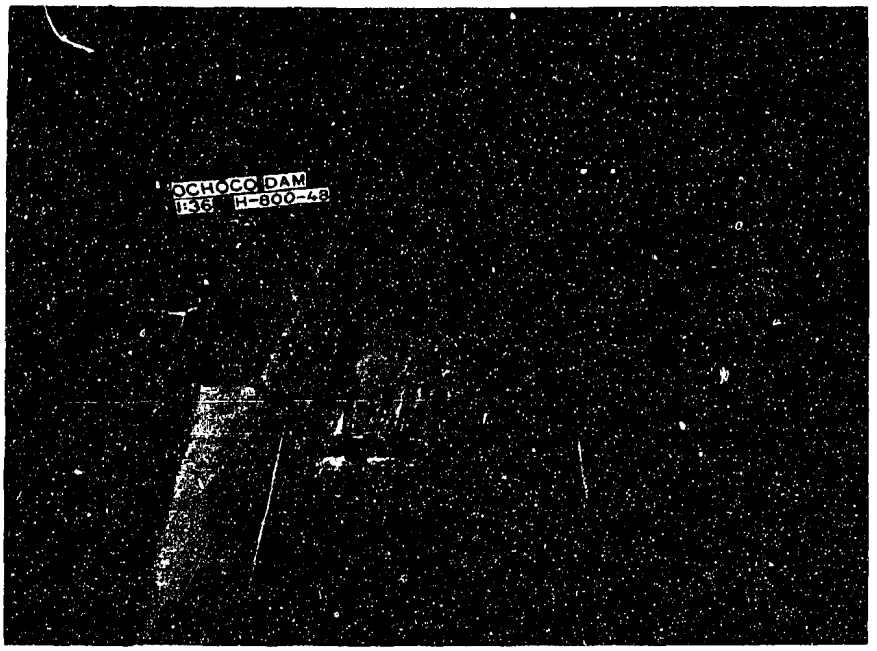


A. Downstream end of the chute viewed from the right bank
Discharge 1,350 cfs

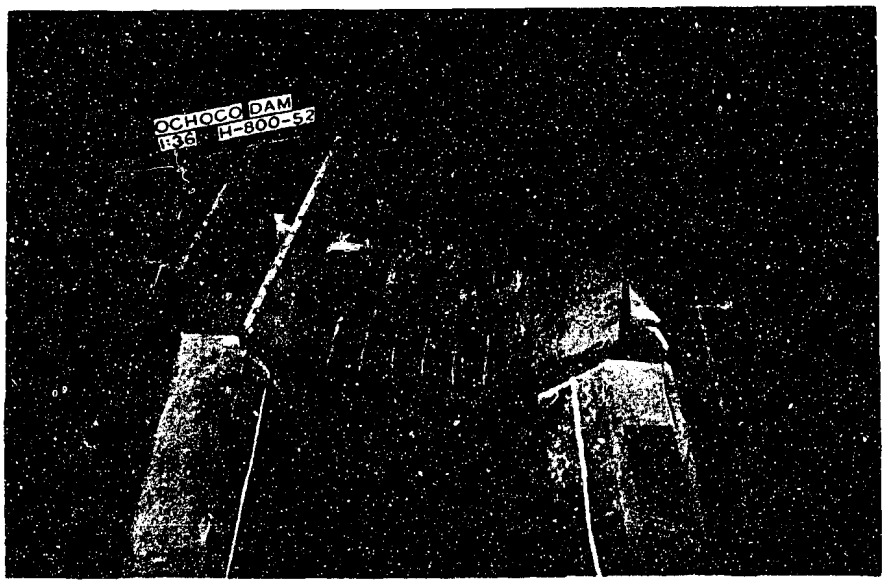


B. Downstream end of the chute viewed from the right bank
Discharge--5,400 cfs

Deschutes Project
OCHOCO DAM REPAIRS
Conditions with Flow Deflectors - Clay Fillet
Ski Jump - Center Opening Clear
Model Scale 1:36



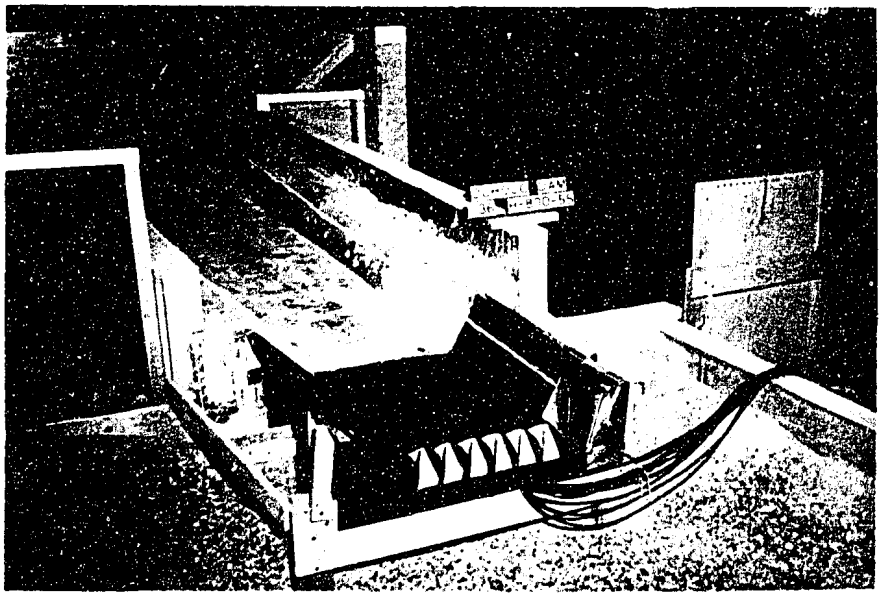
A. View downstream showing downstream end of the chute



B. View downstream showing downstream end of the chute
Discharge--5,000 cfs

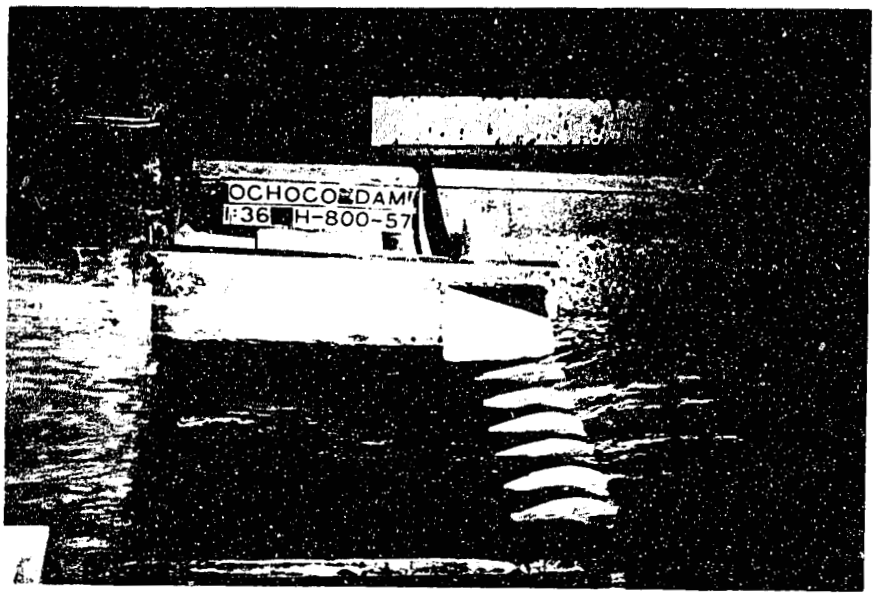
Deschutes Project
OCHOCO DAM REPAIRS
Conditions for Double Row of
Flow Deflectors - 10° Turn
Model Scale 1:36

A. Looking downstream

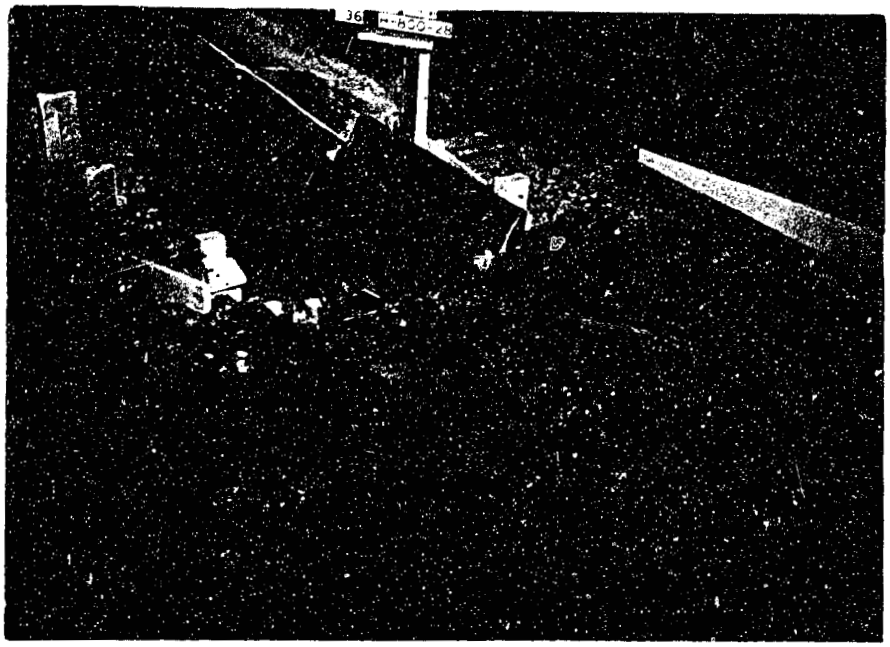


B. Looking upstream

Deschutes Project
OCHOCO DAM REPAIRS
Recommended Design Chute Extension
and Flow Deflectors
Model Scale 1:36

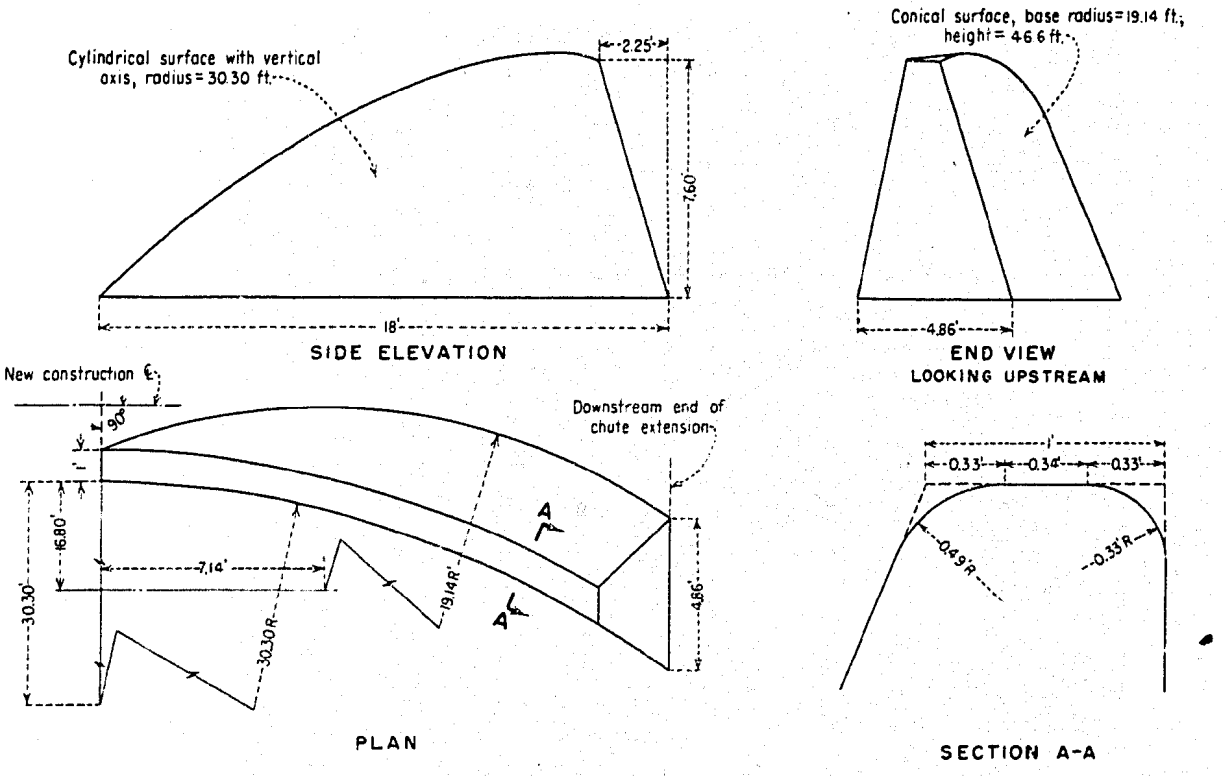


A. Downstream end of the chute viewed from the right bank
Discharge--11,000 cfs

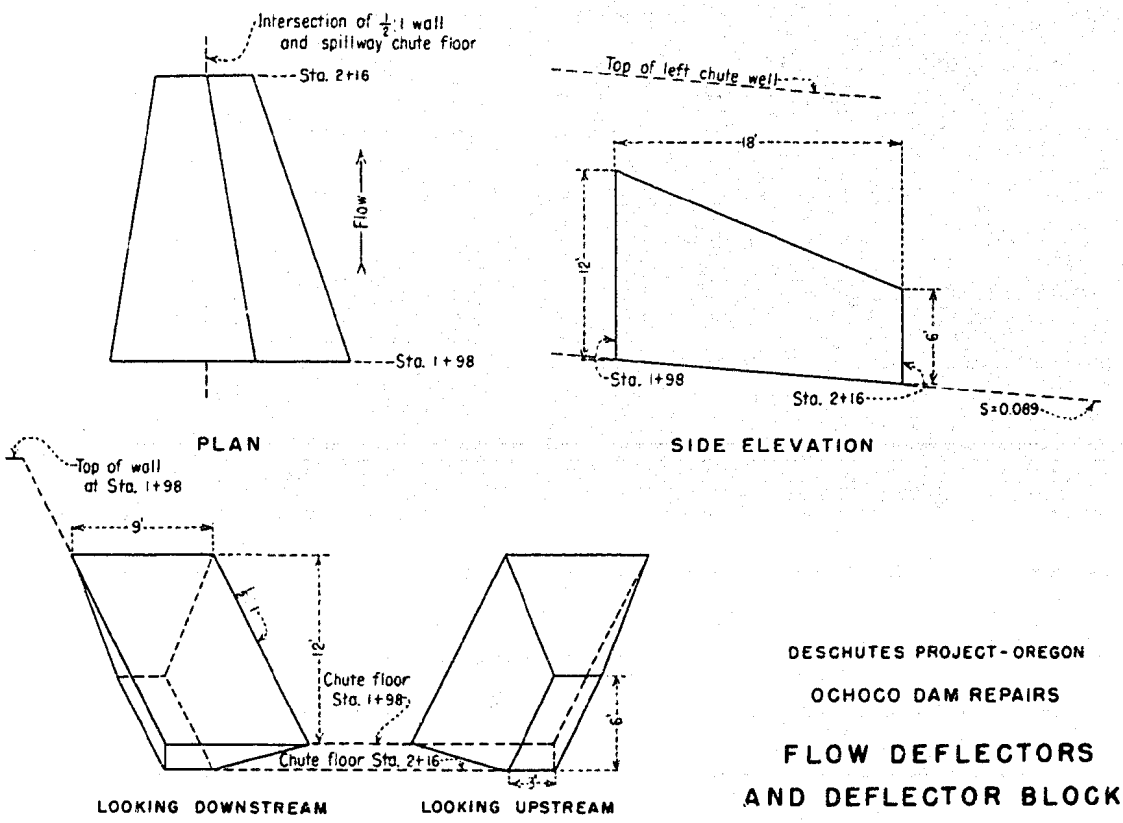


B. Downstream end of the chute
Discharge--1,000 cfs

Deschutes Project
OCHOCO DAM REPAIRS
Conditions for Recommended Design Chute Extension and Flow Deflectors
Model Scale 1:36



A. FLOW DEFLECTORS, 6 REQ'D



B. DEFLECTOR BLOCK, 1 REQ'D

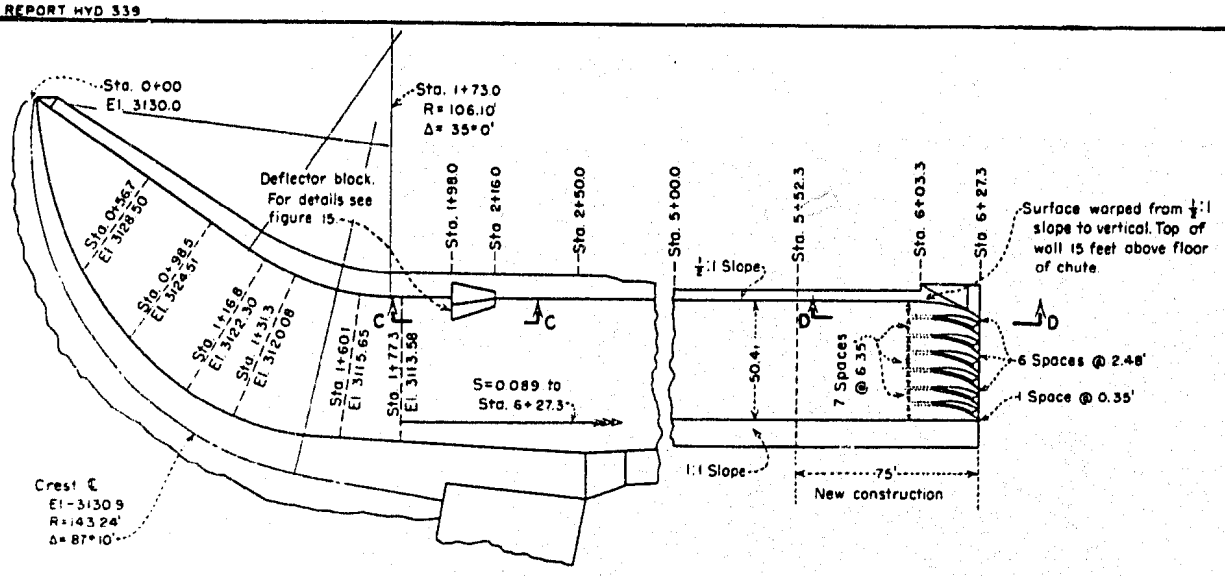
DESCHUTES PROJECT - OREGON

OCHOCO DAM REPAIRS

FLOW DEFLECTORS AND DEFLECTOR BLOCK

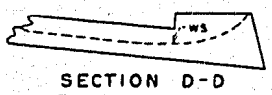
RECOMMENDED DESIGN

FIGURE 16
REPORT HYD 339

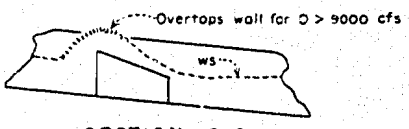


NOTE
For further spillway details see figure 2

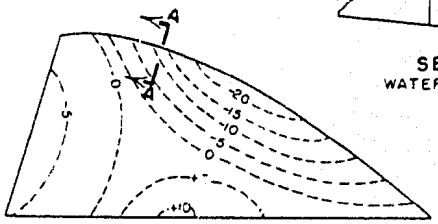
SPILLWAY PLAN



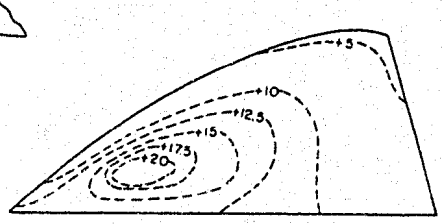
SECTION D-D
WATER SURFACE PROFILE



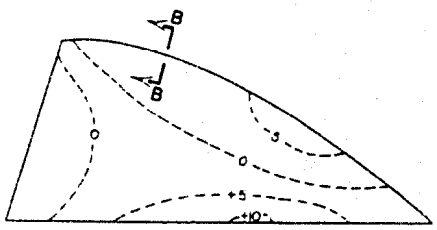
SECTION C-C
WATER SURFACE PROFILE



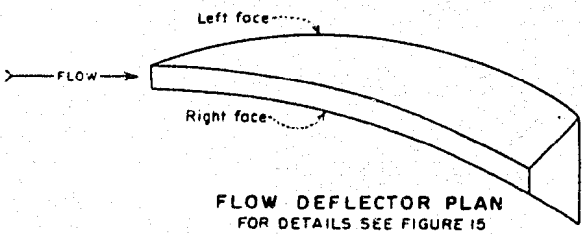
FLOW DEFLECTOR
PRESSURES-LEFT FACE
SHARP TOP EDGES



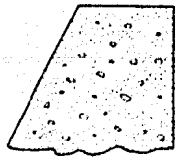
FLOW DEFLECTOR
PRESSURES-RIGHT FACE



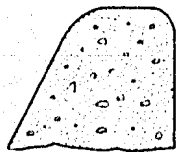
FLOW DEFLECTOR
PRESSURES-LEFT FACE
ROUNDED TOP EDGES
RECOMMENDED DESIGN



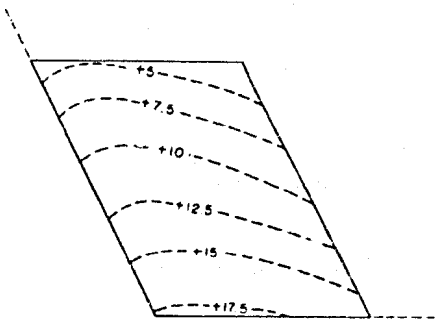
FLOW DEFLECTOR PLAN
FOR DETAILS SEE FIGURE 15



SECTION A-A



SECTION B-B



DEFLECTOR BLOCK
PRESSURES ON UPSTREAM FACE

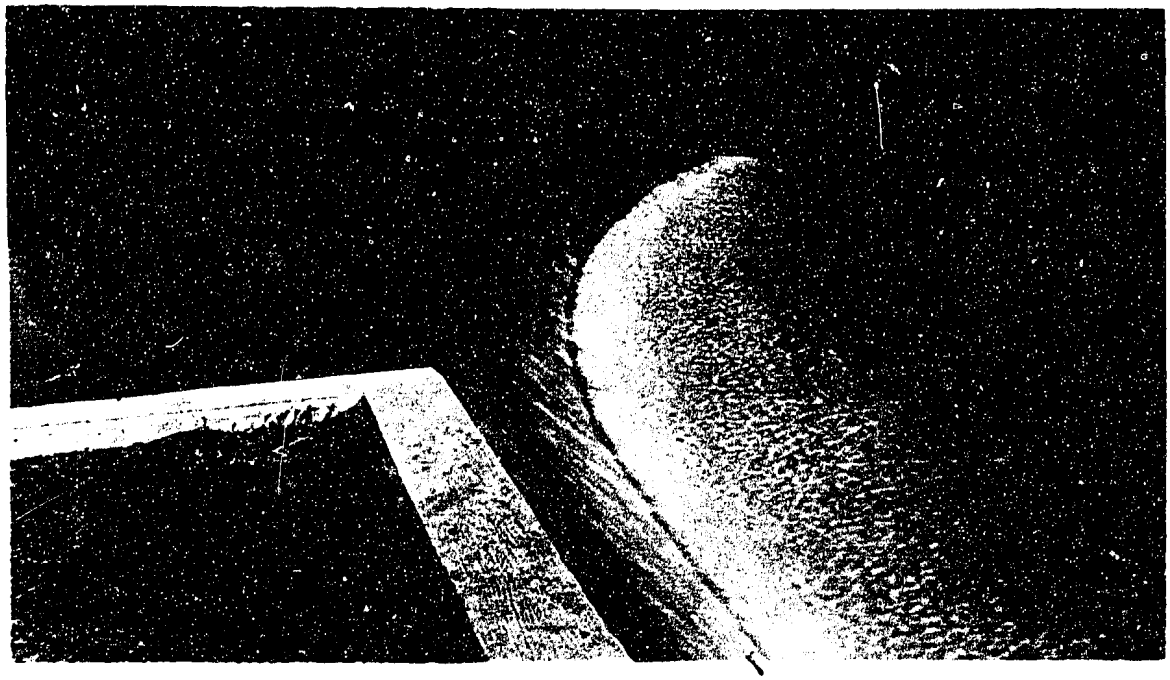
Note: Pressures in feet of water Q=11,000 cfs

DESCHUTES PROJECT-OREGON

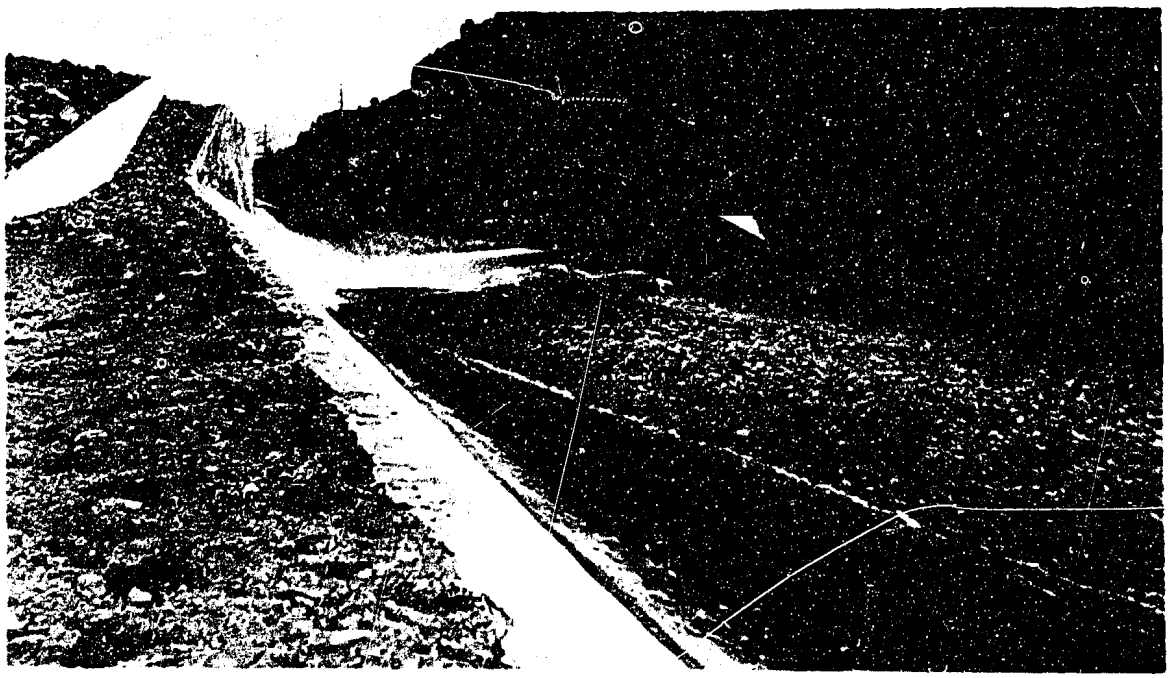
OCHOCO DAM REPAIRS

SPILLWAY PLAN
PRESSURES ON FLOW DEFLECTORS
AND DEFLECTOR BLOCK

MODEL SCALE 1:36



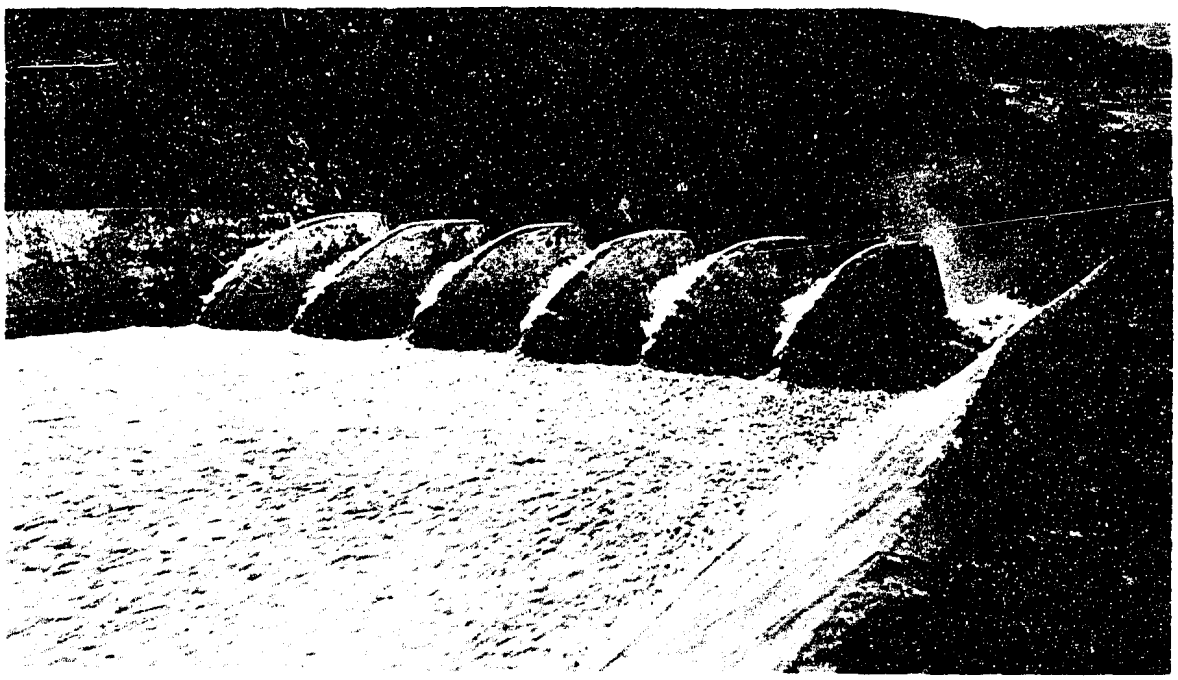
A. Looking upstream toward the crest



B. Looking upstream; flow deflector block at right, crest in background

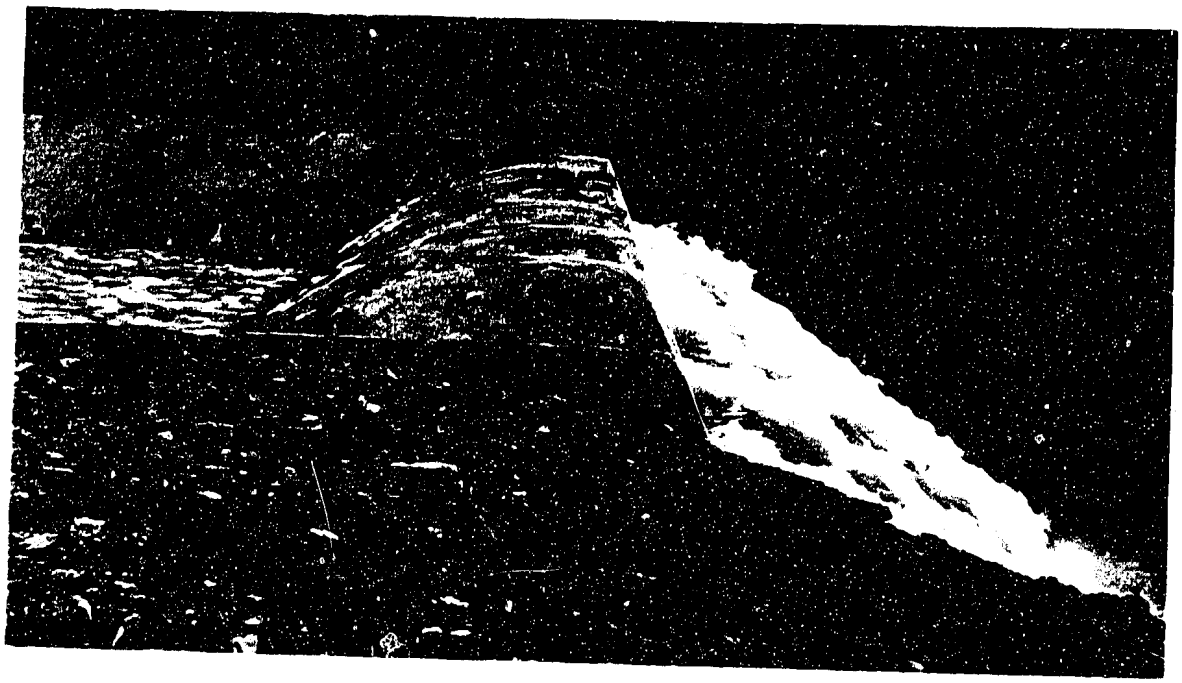
Deschutes Project
OCHOCO DAM REPAIRS
Prototype Spillway Crest and Channel
After Repairs
Discharge--750 cfs

A. Looking down the spillway chute

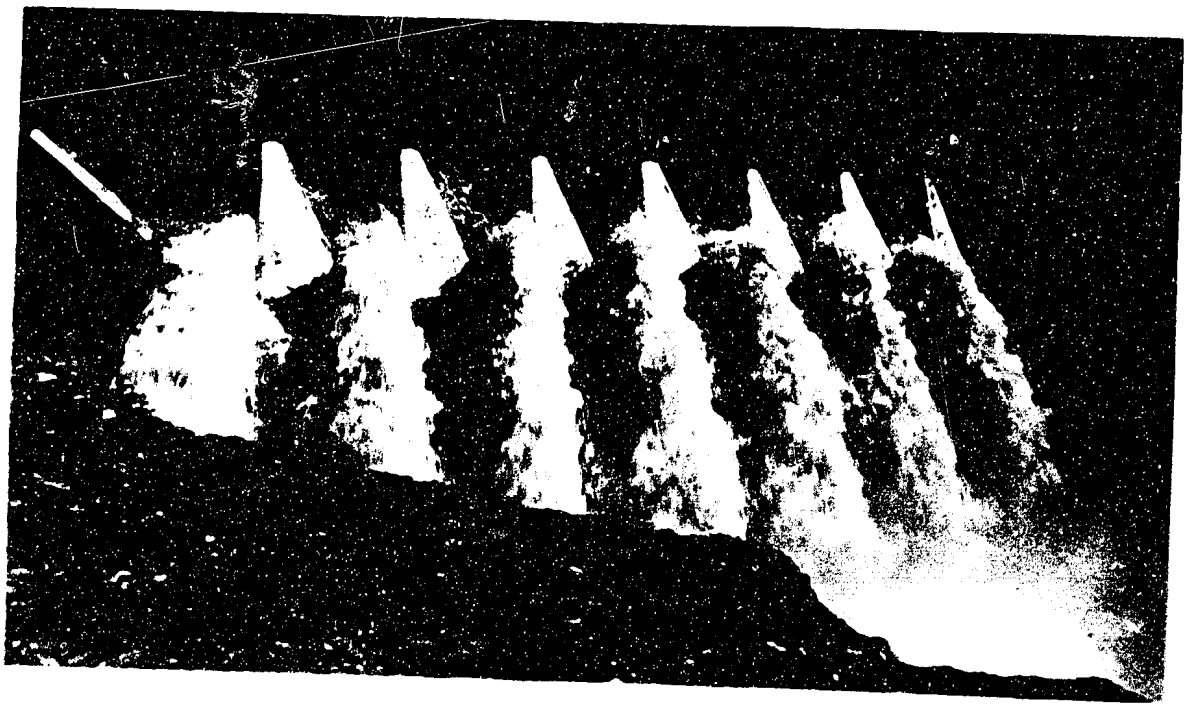


B. The flow deflectors from upstream

Deschutes Project
OCHOCO DAM REPAIRS
Prototype Spillway Chute Extension and
Flow Deflectors After Repairs
Discharge--750 cfs



A. Flow deflectors from the right side



B. Looking upstream at the flow deflectors

Deschutes Project
OCHOCO DAM REPAIRS
Flow Conditions at End of Prototype
Spillway Chute After Repairs
Discharge--750 cfs