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UNITED STATES
DEPARTMENT OF THE INTERIOR
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HYDRAULIC LABORATORY REPORT NO. 178

HYDRAULIC MODEL STUDY OF CONDITIONS IN RIVER CHANNEL BELOW BRIDGE CANYON DAM DURING OPERATION OF THE SPILLWAYS AND OUTLET WORKS - BRIDGE CANYON PROJECT--

By

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Denver, Colorado
July 21, 1945

UNITED STATES -
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
July 21, 1945

Laboratory Report No. 178
Hydraulic Laboratory
Compiled by: J. N. Bradley

Reviewed by: J. E. Warnock

Subject: Hydraulic model study of conditions in river channel below Bridge Canyon Dam during operation of the spillways and outlet works - Bridge Canyon Project.

1. Introduction. Bridge Canyon Dam, which will be located on the Colorado River 118 river miles upstream from Boulder Dam, is scheduled as a postwar project. It is part of the general plan for the development of the Colorado River Basin and will serve the multiple purpose of power supply, silt control and supply of irrigation water for the State of Arizona. The dam proper will be of the arch-gravity type, similar to Boulder Dam, but it will be slightly higher and located in a narrower canyon. A plan and section of the original design is included as figures 1 and 2, respectively. The design is novel in that the powerhouse will be located within the dam.

Previous to the model work on Bridge Canyon Dam, a model of the river channel below Boulder Dam was studied (Hydraulic Laboratory Report No. 143) to determine necessary modifications to the spillway and outlet tunnels on that structure. As the spillway design is similar and the spillway capacity identical for the two dams, the Boulder Dam model was revised to represent the river at

FIG. 1

LEFT SPILLWAY

℄ 50' DIA. DIVERSION TUNNEL

℄ 50' DIA. DIVERSION AND SPILLWAY TUNNEL

UPPER COFFERDAM

LOWER COFFERDAM

COLORADO

RIVER

℄ 20' DIA. DIVERSION TUNNEL

℄ 50' DIA. DIVERSION TUNNEL

℄ 50' DIA. DIVERSION AND SPILLWAY TUNNEL

RIGHT SPILLWAY

REFERENCE DRAWING

PRELIMINARY ESTIMATES

PRELIMINARY ESTIMATE DRAWING

BRIDGE CANYON PROJECT, INVESTIGATIONS, ARIZONA

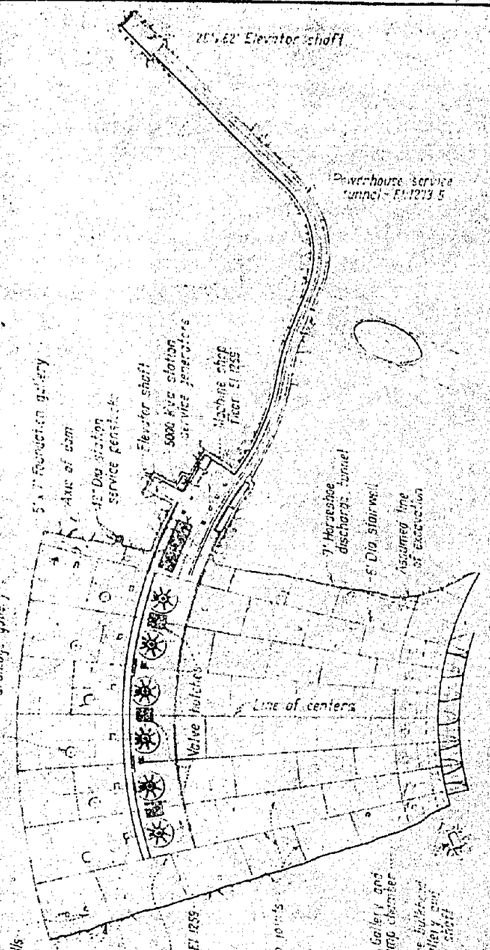
BRIDGE CANYON DAM

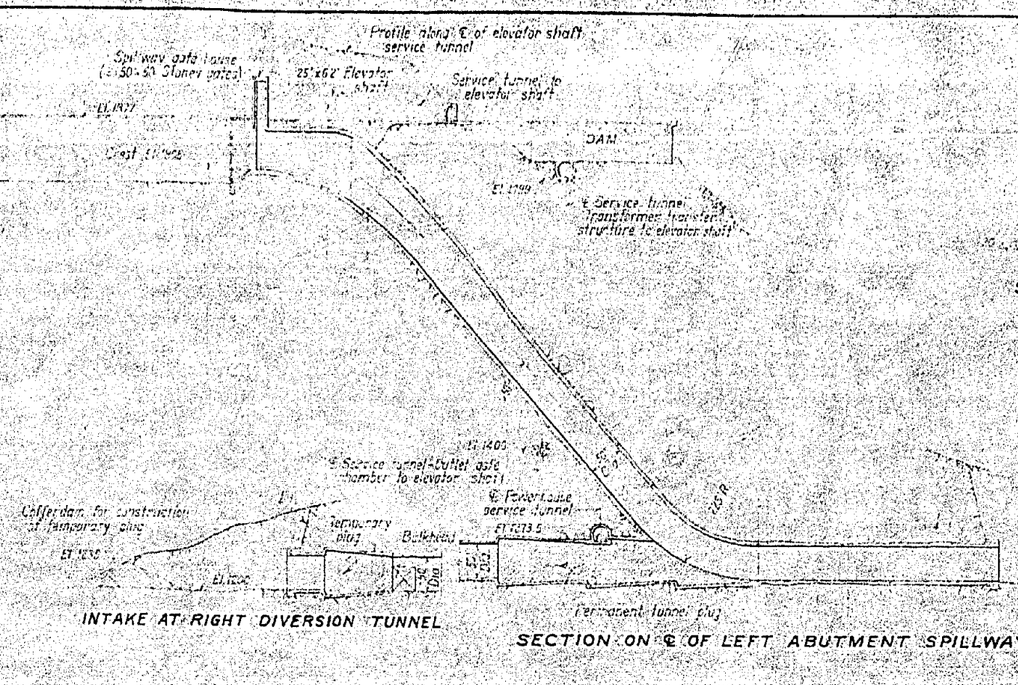
LOWER GNEISS SITE

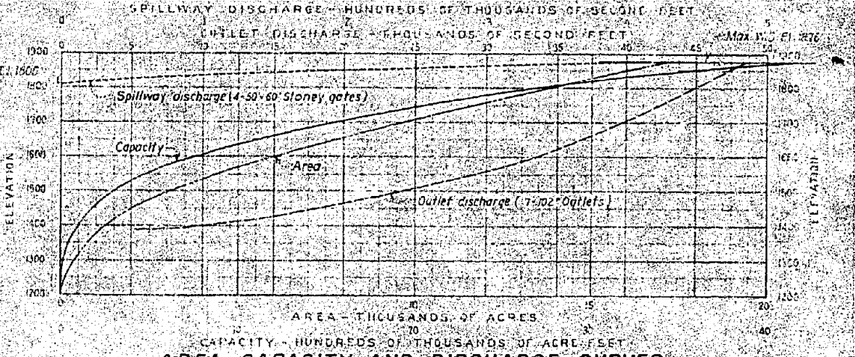
GENERAL PLAN

359-D-134

FIG. 9





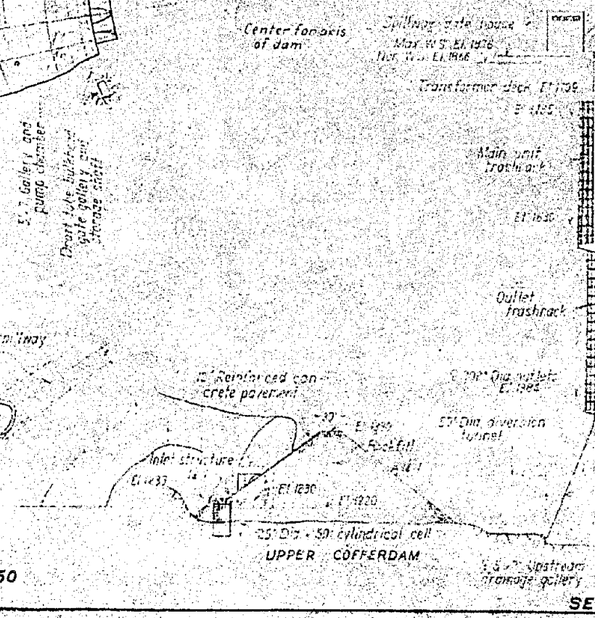


AREA, CAPACITY AND DISCHARGE CURVES

REFERENCE DRAWING

GENERAL PLAN 359-D-134

PRELIMINARY ESTIMATE DRAWING



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

BRIDGE CANYON PROJECT INVESTIGATIONS - ARIZONA

BRIDGE CANYON DAM
LOWER GNEISS SITE
GENERAL SECTIONS

DRAWN	K.O.	SUBMITTED	
TRACED	H.P.N.	RECOMMENDED	
CHECKED		APPROVED	

DENVER, COLORADO FEB 21 1936

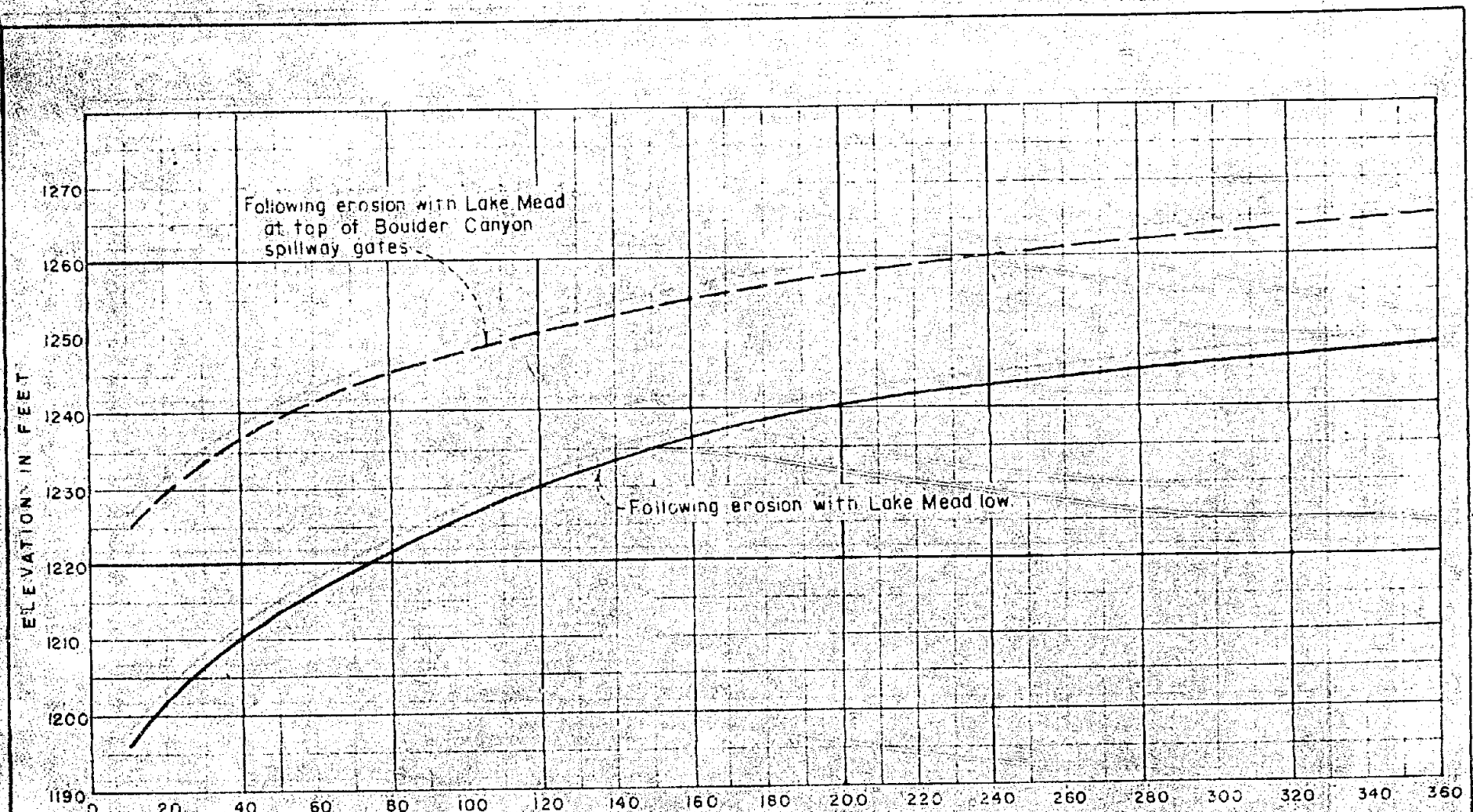
359-D-135

Bridge Canyon Dam. This report deals with tests performed on the latter for which flow conditions in the river were observed during operation of the spillways and outlet works.

2. The problem. At this stage of the design the spillways proper, as indicated on figures 1 and 2, are subject to change based on future model and structural studies. The discharge conditions at the river however will of necessity be similar to those at Boulder Dam. As difficulty has been experienced with undermining of the downstream portal structures of the spillways and outlet tunnels at Boulder Dam, the flow conditions which will occur at the Bridge Canyon Dam, were investigated by a model study for the purpose of preventing a similar occurrence if possible.

The original design, figures 1 and 2, provided trapezoidal unpaved channels for conveyance of the spillway flow from the downstream tunnel portals to the river. These channels will serve as a portion of the diversion plan during construction of the dam and there is no objection to their use for this purpose. From experience gained at Boulder Dam where velocities of approximately 150 feet per second were involved under similar circumstances, these unpaved channels do not appear practical for conducting the high-velocity spillway flow to the river, regardless of the fact that it is generally understood that the rock is of excellent character. It then became a case of whether trapezoidal channels be paved heavily for their entire length or a less costly method be devised to accomplish the same end. This constitutes the basis of the model study.

3. Tailwater conditions. As the Bridge Canyon Dam will be located at the headwaters of Lake Mead, the tailwater elevation



BRIDGE CANYON PROJECT

LOWER GNIESS DAM SITE

APPROXIMATE FUTURE TAILWATER ELEVATIONS

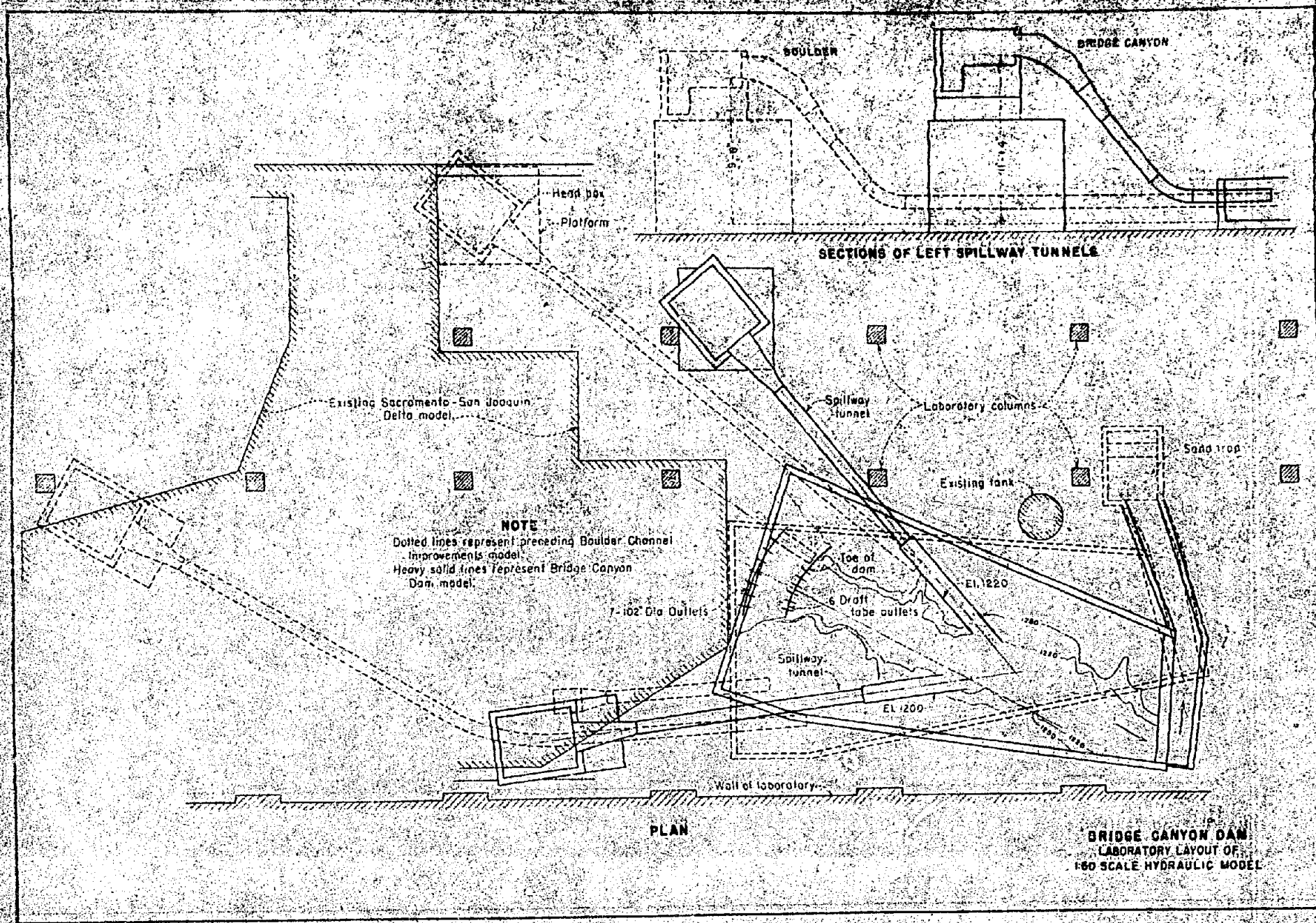
2-27-43

FIGURE 33

below the dam will be controlled to a great extent by the level of the lake. This is evident from figure 3 which shows the estimated tailwater elevations below Bridge Canyon Dam for the two extreme levels of Lake Mead. The curves are also presumably corrected to allow for erosion which will occur upon release of water from the dam, in the stretch of river between the foot of Bridge Canyon Dam and Lake Mead. The level of Lake Mead can vary up to a maximum elevation of 1232. The tailwater at Bridge Canyon Dam will vary between the two curves shown on figure 3 for any discharge condition. This means that the spillways at Bridge Canyon Dam will be required to operate satisfactorily over a wide range of tailwater elevations. Because of the uncertainty of the curves, the model was tested over a greater range of tailwater conditions than the curves include.

4. The original spillway design. The layout of the Bridge Canyon Dam model, which was on a 1:60 scale, is shown on figure 4. It included the complete spillways, the seven outlet conduits, the powerplant tailrace and a 2,000-foot reach of the river. Because of the preliminary nature of the study, the flow conditions in the river produced by the spillways, outlet works and power plant were of chief interest. The actual details of the spillways and outlet design are subject to future change based on model studies of these features.

From figure 1 it was possible to foresee that the discharge from both spillways will impinge on the opposite canyon walls for any appreciable flow. The extent or seriousness of this impingement



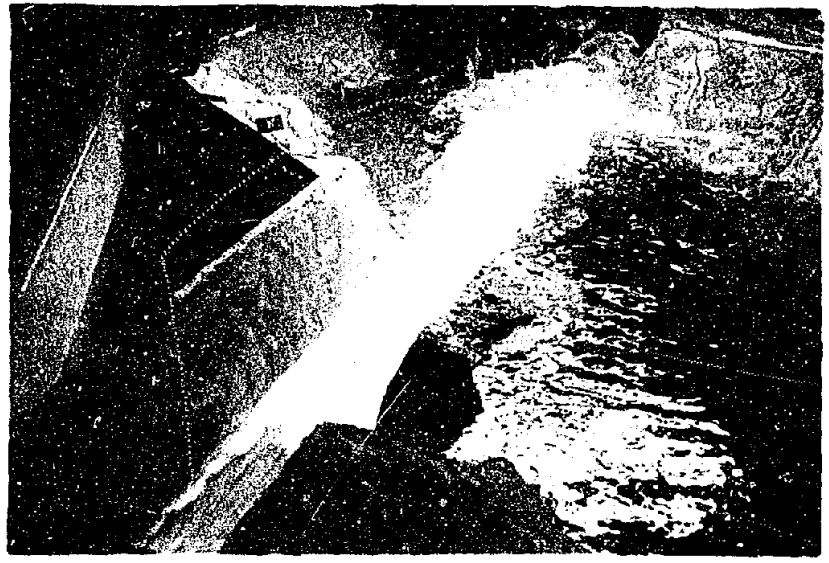
BRIDGE CANYON DAM
LABORATORY LAYOUT OF
1-60 SCALE HYDRAULIC MODEL

FIGURE 4

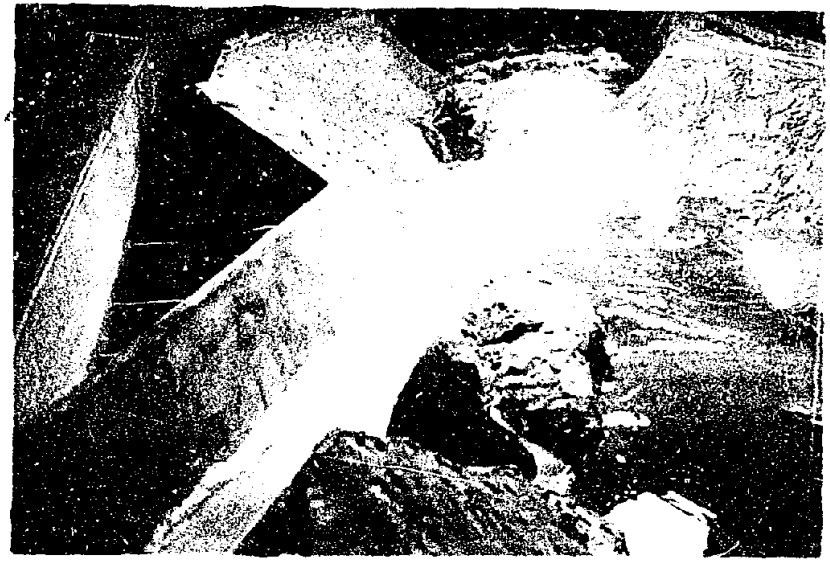
is best illustrated by the model. The photographs on figures 5, 6, and 7, were taken looking downstream for representative spillway flows with the model constructed according to the original design (figures 1 and 2). Figure 5A and B show the left spillway discharging at 50,000 second-feet for the two extreme tailwater conditions, respectively. Photographs C and D on the same figure show the left spillway discharging at 150,000 second-feet for high and low tailwater levels. In both cases the photographs show that the jet from the left spillway impinged on the right canyon wall.

At Boulder Dam, where similar conditions exist, impingement produced rapid undermining of the canyon walls. This was later accompanied by spalling of the walls above the undermined portions. Rock falling into the river from this source produced bars in the stream which raised the level of the water surface at the powerhouse tailrace, thus reducing the power head on the turbines. If undermining is allowed to persist, intermittent dredging of the river channel will become necessary. It is therefore desired to reduce deposition of rock in the river channel below Bridge Canyon Dam to a minimum.

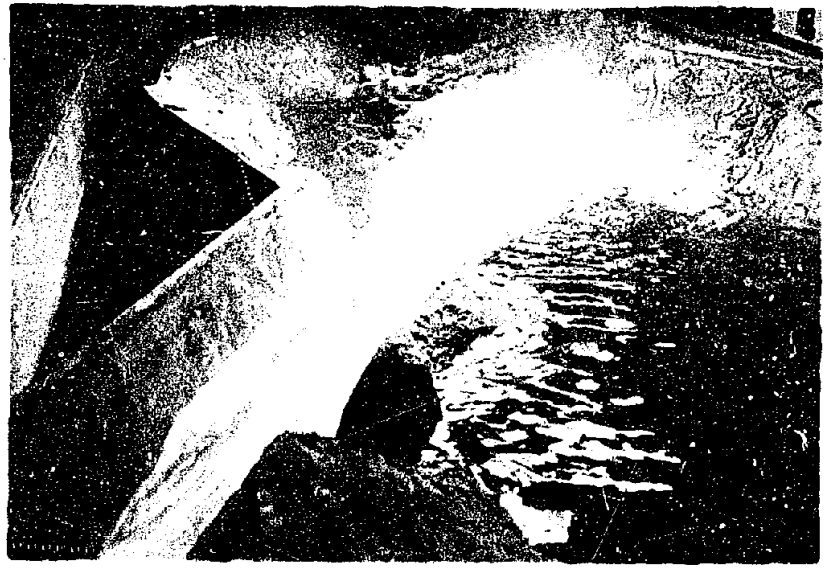
Figure 6 shows the right spillway operating at discharges of 50,000 and 150,000 second-feet for the extreme tailwater elevations. The jet from this spillway likewise climbed the canyon wall on the opposite side of the river. The left wall, at the point of impingement, is not as steep as the one on the opposite side of the river, and a greater distance exists between the portal of the right tunnel and the point of impingement, thus the condition is not as serious.



A. Discharge 50,000 second-feet
Tailwater elevation 1242



B. Discharge 50,000 second-feet
Tailwater elevation 1216

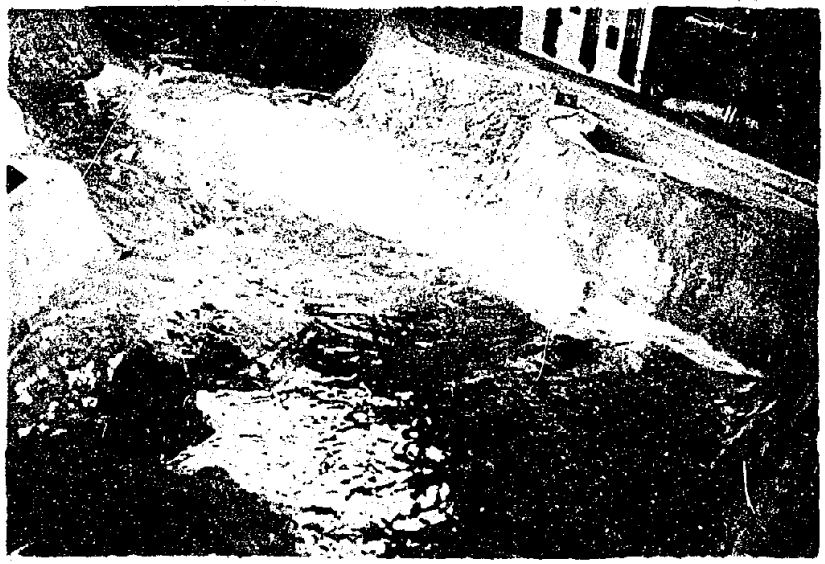


C. Discharge 150,000 second-feet
Tailwater elevation 1254

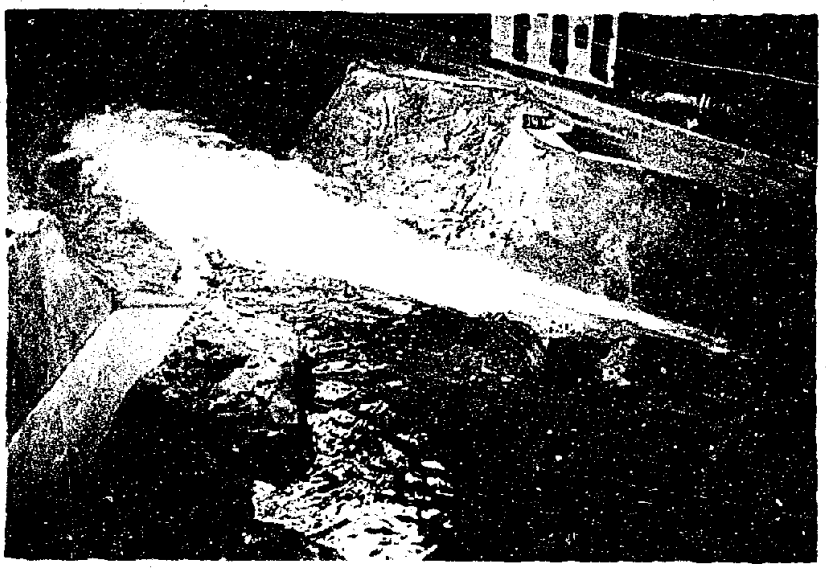
D. Discharge 150,000 second-feet
Tailwater elevation 1236

ORIGINAL DESIGN-LEFT SPILLWAY IN OPERATION

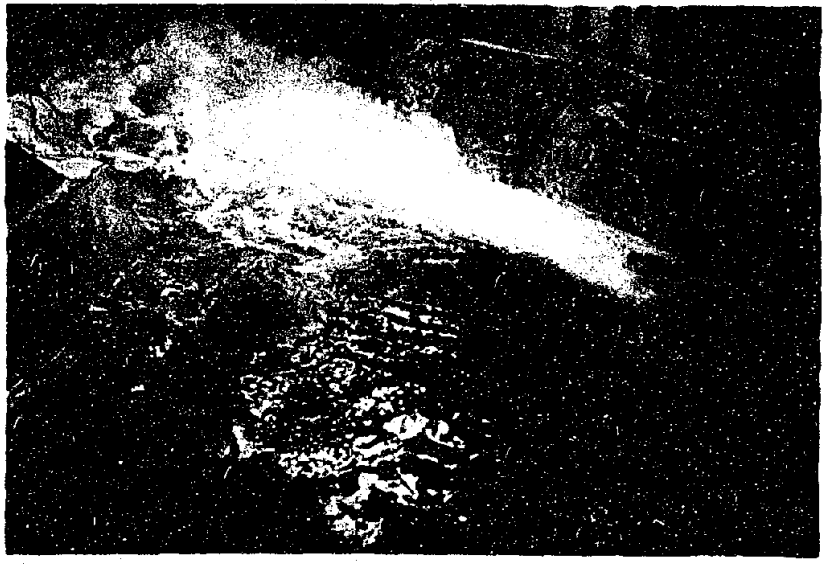
FIGURE 5



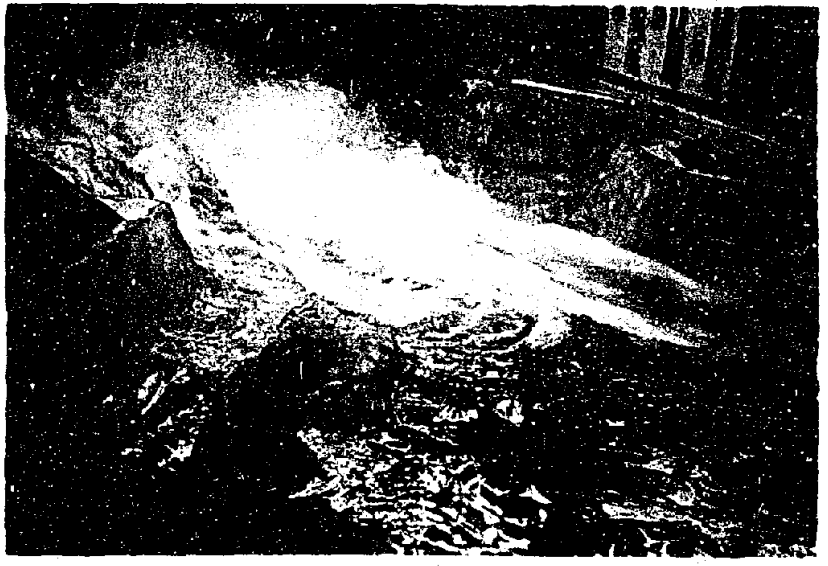
A. Discharge 50,000 second-feet
Tailwater elevation 1242



B. Discharge 50,000 second-feet
Tailwater elevation 1216



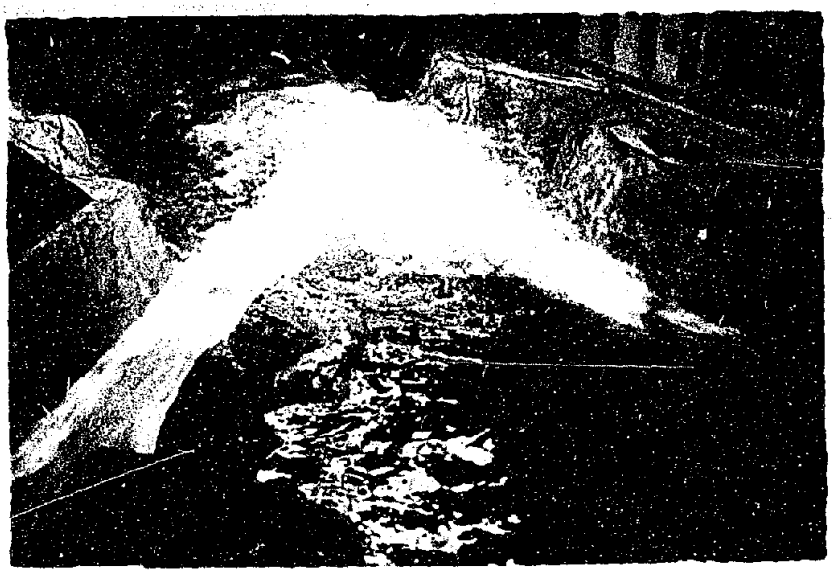
C. Discharge 150,000 second-feet
Tailwater elevation 1254



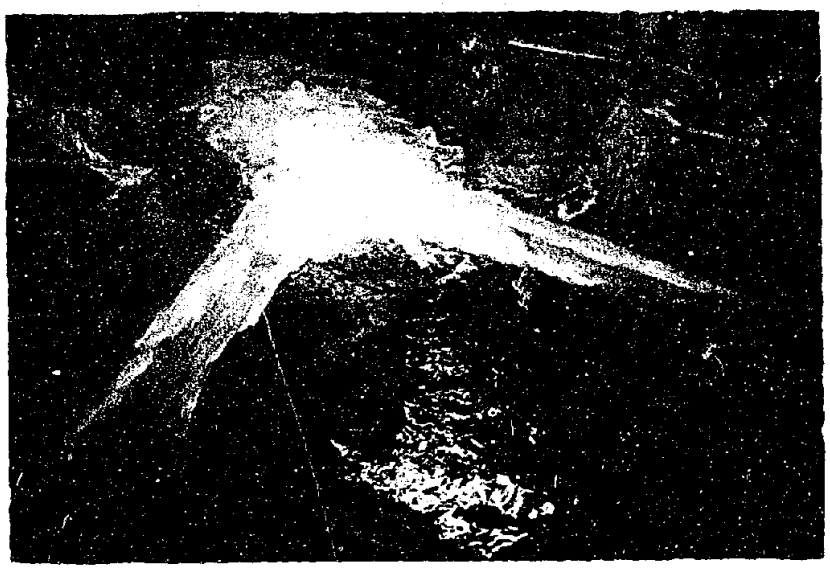
D. Discharge 150,000 second-feet
Tailwater elevation 1236

ORIGINAL DESIGN-RIGHT SPILLWAY IN OPERATION

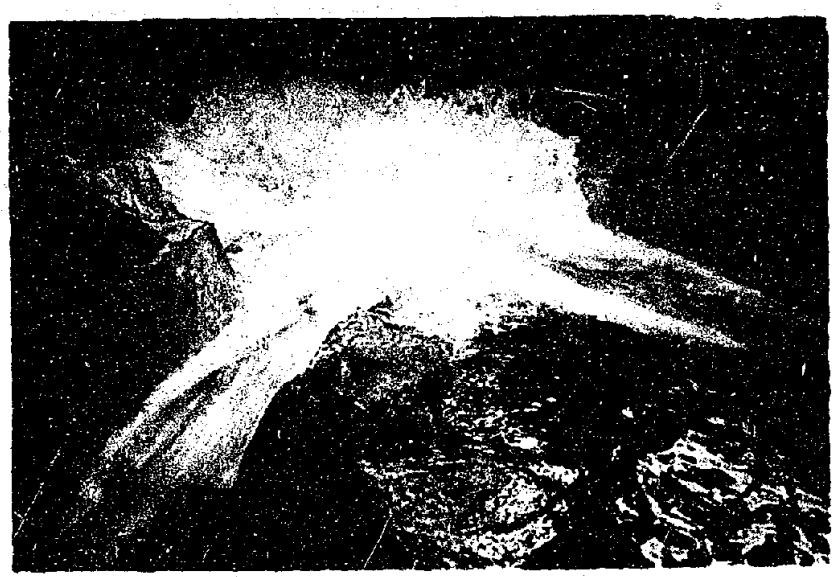
FIGURE 6



A. Discharge 50,000 second-feet per spillway
Tailwater elevation 1249



B. Discharge 50,000 second-feet per spillway
Tailwater elevation 1228



C. Discharge 150,000 second-feet per spillway
Tailwater elevation 1263

D. Discharge 150,000 second-feet per spillway
Tailwater elvation 1246

ORIGINAL DESIGN-BOTH SPILLWAYS IN OPERATION

FIGURE 7

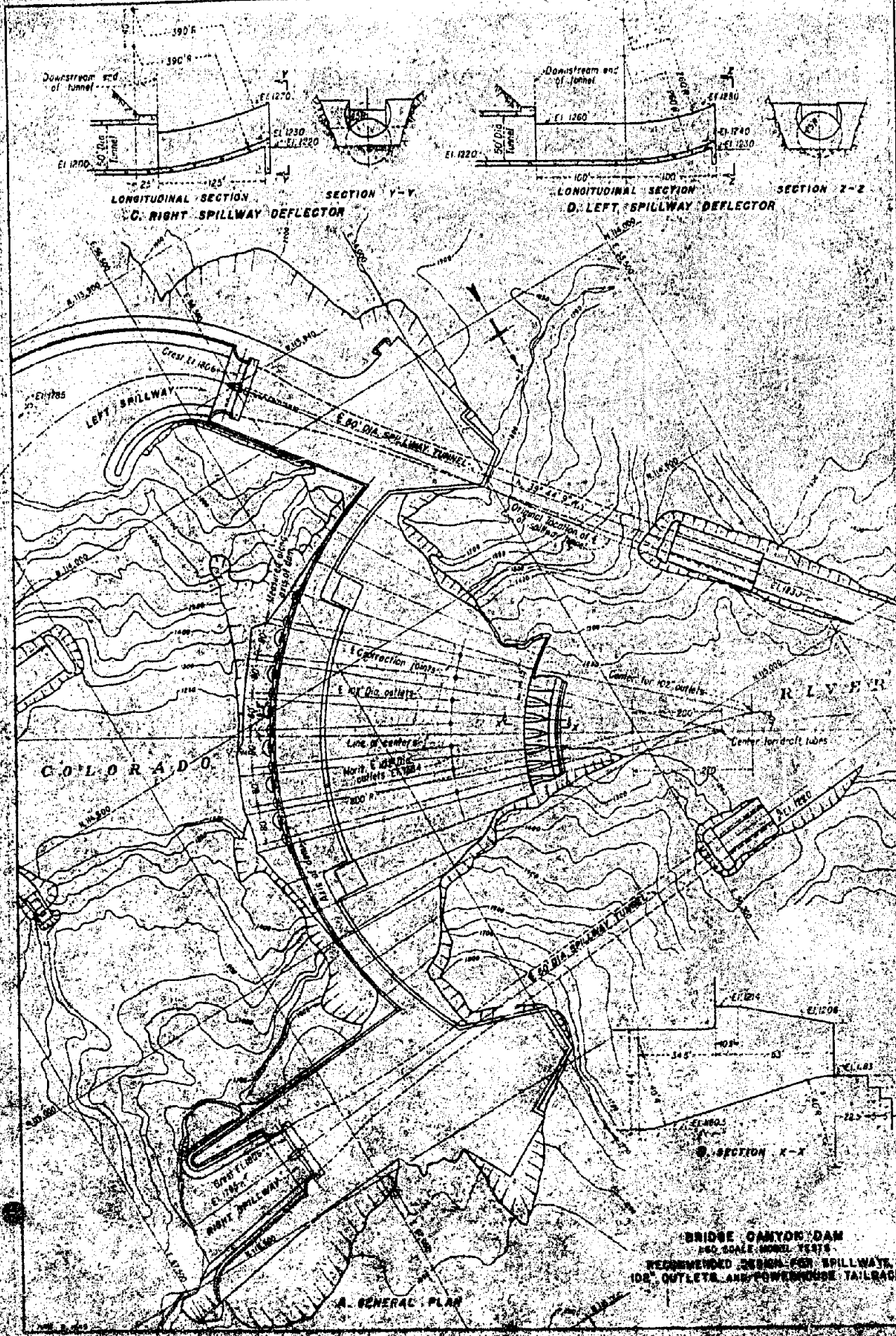
The tunnel on the right side of the river is located 20 feet lower than the one on the left side, therefore a difference in the flow conditions on the two sides can be expected.

The photographs on figure 7 show both spillways, as originally designed, operating simultaneously with equal discharges of 50,000 and 150,000 second-feet for the extreme tailwater conditions. Impingement of the jet on the right canyon wall continued to predominate for dual spillway operation, while impingement on the left wall was relieved to a considerable extent.

5. Revisions to spillway tunnels. The greatest objection to the original design was the impingement of the jet on the right canyon wall. This condition was remedied early by swinging the center line of the left spillway approximately 2.5 degrees, in a counterclockwise direction, about the point described by the intersection of E 56,380 and N 113,840. The relocated spillway is shown in relation to the original alignment on figure 8.

Impingement of the jet from the right spillway on the left bank was not as intense as in the above case and would involve a large expenditure for a correspondingly small amount of improvement. For this reason the alignment of the right spillway was not changed.

The next step was concentrated on avoiding the use of the unpaved trapezoidal channels for the high-velocity spillway flow. As stated previously, these channels are necessary for diversion and will operate satisfactorily under those conditions. The first inclination was the use of a deflector scheme similar to that which proved so effective on the modification of the Boulder Dam tunnels.



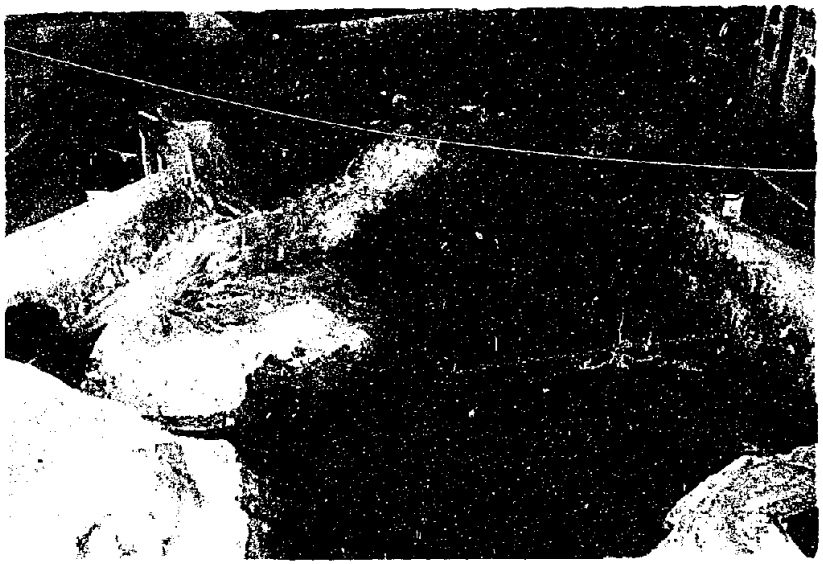
BRIDGE CANYON DAM
1:60 SCALE MODEL TESTS
RECOMMENDED DESIGN FOR SPILLWAYS, 102" OUTLETS AND POWERHOUSE TAILRACE

The first deflector tried was of the same shape and dimensions as that recommended for the spillways at Boulder Dam (figure 15, HYD-143). The overall length of the original Bridge Canyon deflectors was 100 feet and they were installed in the trapezoidal channels immediately downstream from the tunnel portals. Difficulty was experienced in that the jet trajectory from the left spillway did not clear the trapezoidal channel and the lip of the deflector on the right spillway was of insufficient height to operate properly over the complete tailwater range. As the invert of the right tunnel is located at elevation 1,200 while the invert of the left tunnel is at elevation 1,220, the latter difficulty could be expected.

After considerable experimenting, deflectors with the proper length and rise were developed to produce the desired results. These are shown in detail on figure 8C and D. The cross section of the deflectors was changed to a circular shape throughout. An extension of 100 feet was recommended for the left tunnel in addition to a deflector 100 feet in length, with 20 feet of rise, located downstream from the extension. With this arrangement the trajectory of the jet sprung free of the trapezoidal channel for discharges in excess of 20,000 second-feet. It was necessary to make the deflector on the right spillway 150 feet long with 30 feet of rise to operate properly with the increased tailwater depth on this side. Of the 150 feet of length, the first 25 feet of the deflector were incorporated in the tunnel proper while the remaining 125 feet were located downstream from the tunnel portal.

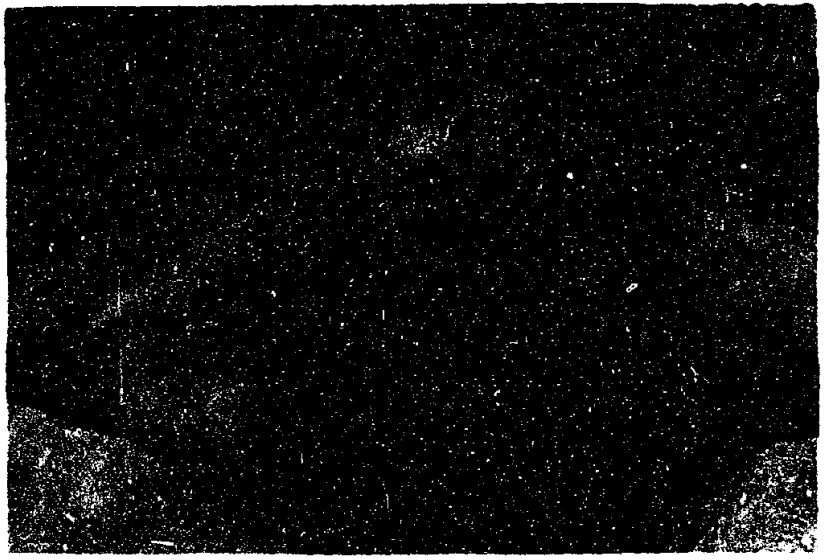
The circular cross section of the deflectors reduced the spreading of the jets, which was desirable, and should also affect a saving in the cost of construction.

Photographs of the spillways in operation with the deflectors as recommended (figure 8) are shown on figures 9 to 13, inclusive. Figures 9 through 10B show the left spillway operating at the two extreme tailwater levels for 25,000, 100,000 and 150,000 second-feet. As the river bends to the right downstream rotation of the left spillway alignment resulted in the jet discharging directly down the river with a minimum of interference on the canyon wall on the opposite side. Photographs on figures 10C and D and figure 11 show the right spillway discharging under the same conditions. Impingement on the opposite bank remained severe, however, it was found that this can be controlled partially by operating the two spillways together as shown in the photographs on figure 12 and figure 13A and B. In this case, both spillways are shown operating at 25,000 100,000 and 150,000 second-feet each for the two extreme tailwater elevations. For equal discharges from the two spillways up to 100,000 second-feet each, the jets combined and the resultant flow was directly down the river. For higher discharges, as can be observed from figure 13A and B, the jet from the right spillway partially penetrated through the jet from the left spillway resulting in some water climbing the left canyon wall. This condition can be controlled to some extent by reducing the discharge through the right spillway or increasing the discharge from the left spillway. The total capacity of the spillways is 200,000 second-feet each. For

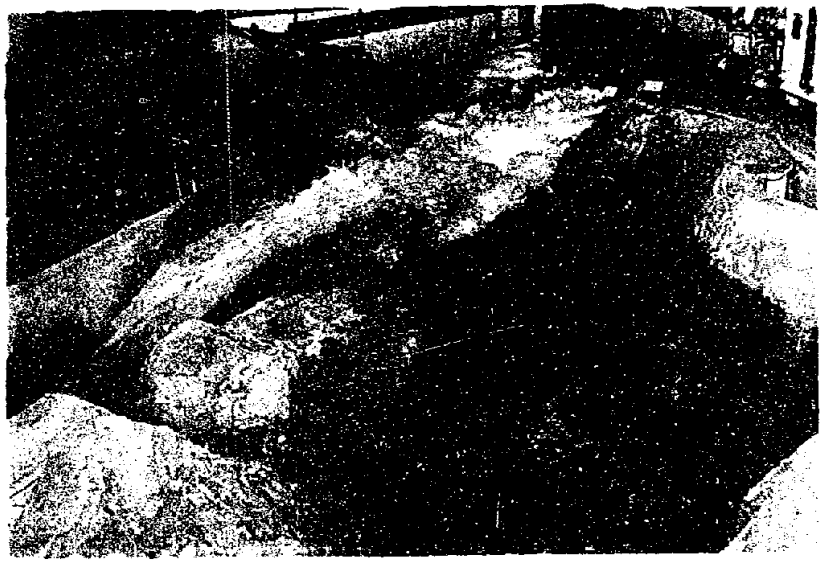


A. Discharge 25,000 second-feet
Tailwater elevation 1235

B. Discharge 25,000 second-feet
Tailwater elevation 1208



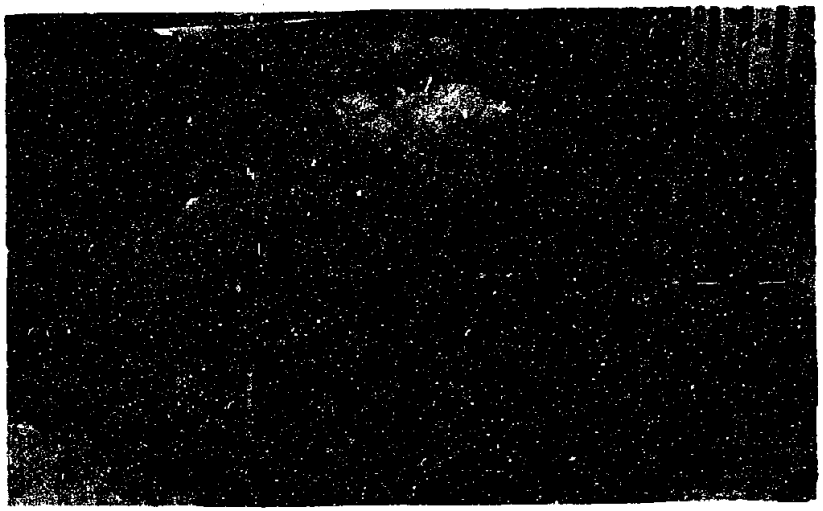
C. Discharge 100,000 second-feet
Tailwater elevation 1249



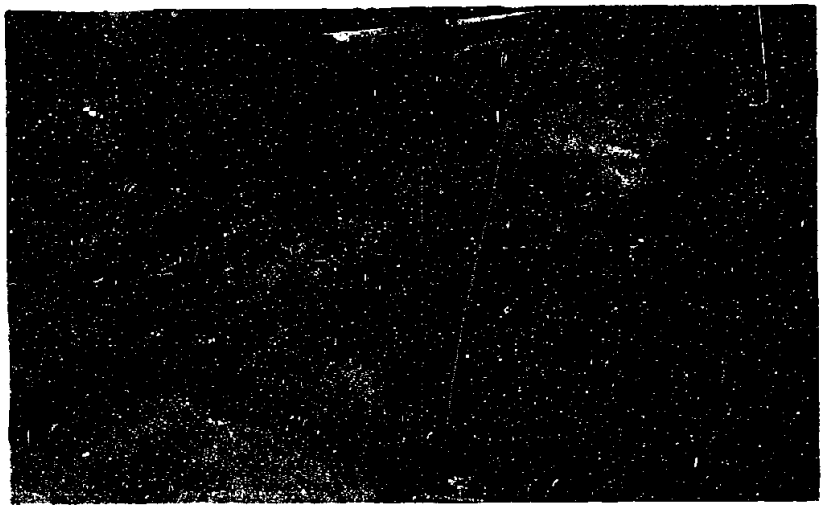
D. Discharge 100,000 second-feet
Tailwater elevation 1228

RECOMMENDED DESIGN-LEFT SPILLWAY IN OPERATION

PLATE 5



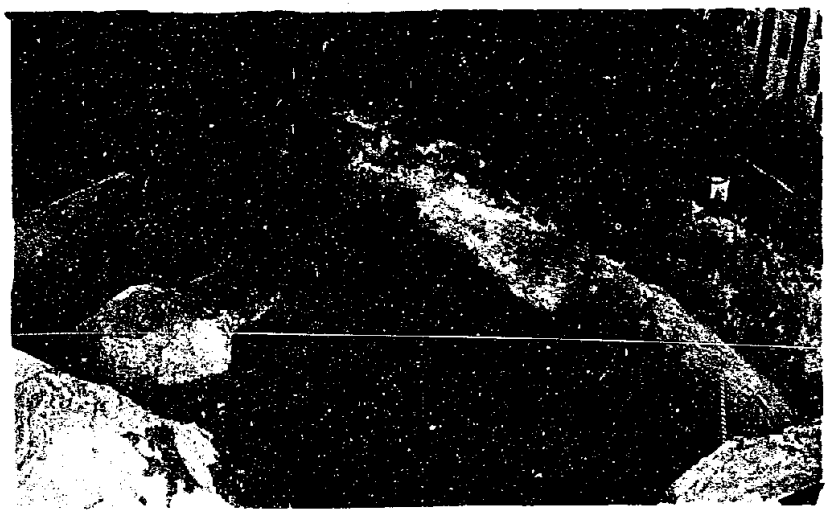
A. Discharge 150,000 second-feet
Tailwater elevation 1254



B. Discharge 150,000 second-feet
Tailwater elevation 1236

LEFT SPILLWAY IN OPERATION

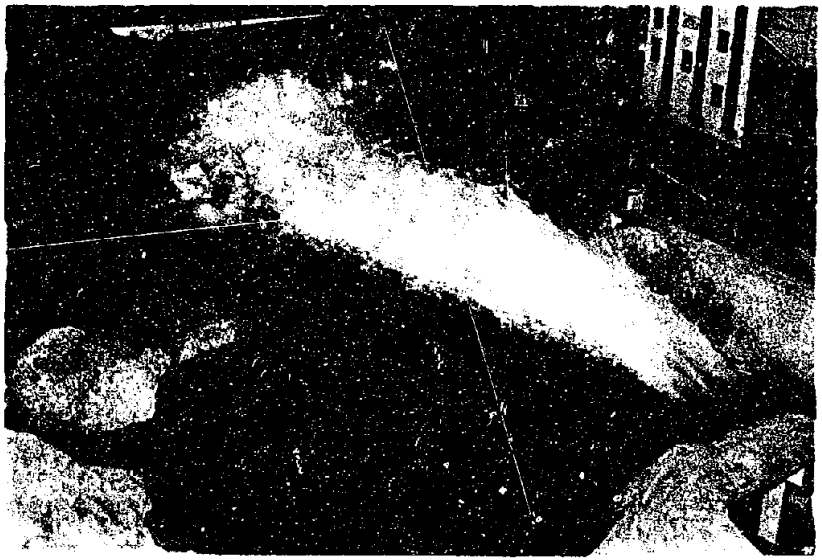
C. Discharge 25,000 second-feet
Tailwater elevation 1235



D. Discharge 25,000 second-feet
Tailwater elevation 1208

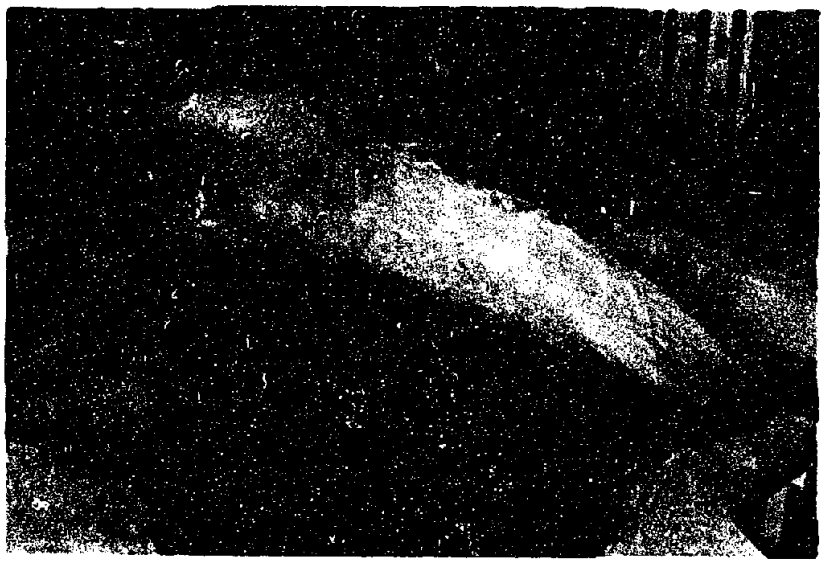
RIGHT SPILLWAY IN OPERATION

RECOMMENDED DESIGN

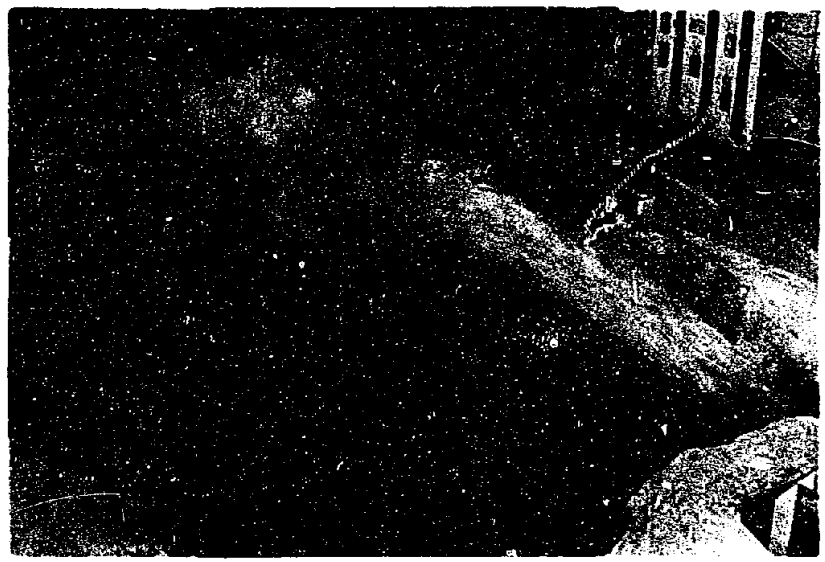


A. Discharge 100,000 second-feet
Tailwater elevation 1249

B. Discharge 100,000 second-feet
Tailwater elevation 1228



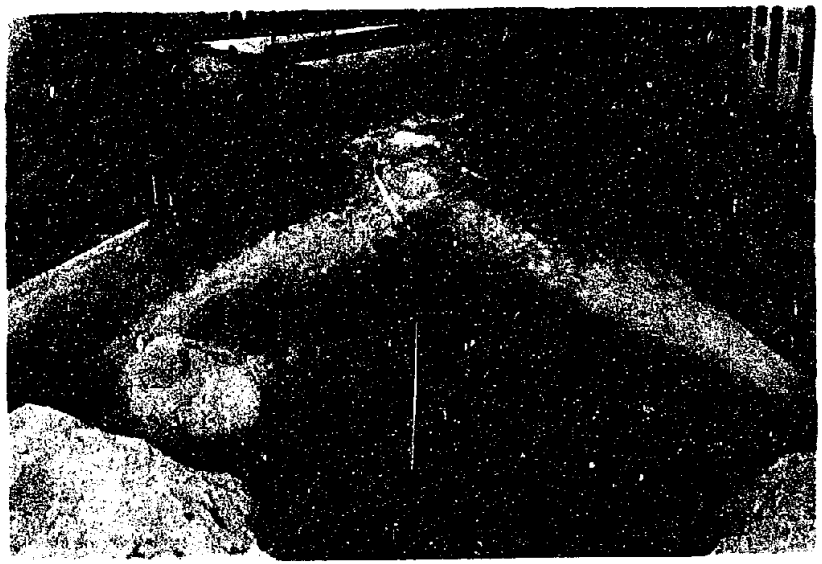
C. Discharge 150,000 second-feet
Tailwater elevation 1254



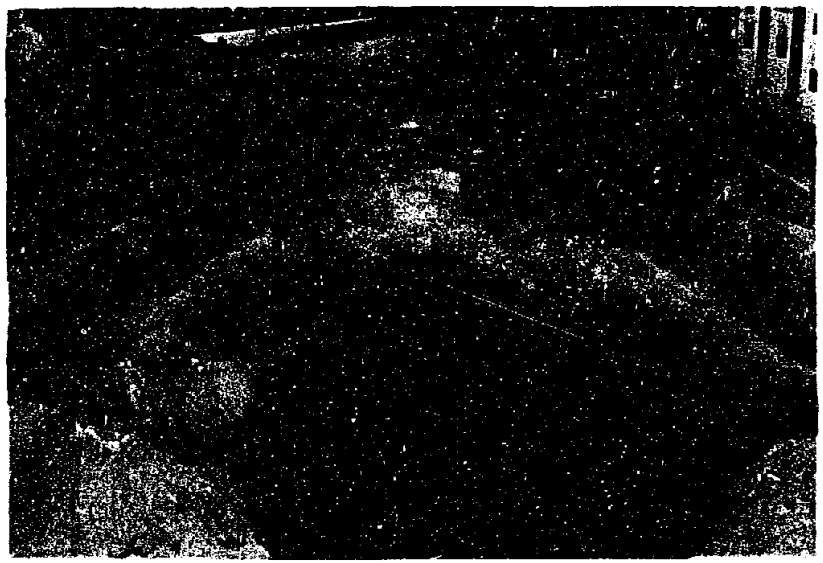
D. Discharge 150,000 second-feet
Tailwater elevation 1236

RECOMMENDED DESIGN-RIGHT SPILLWAY IN OPERATION

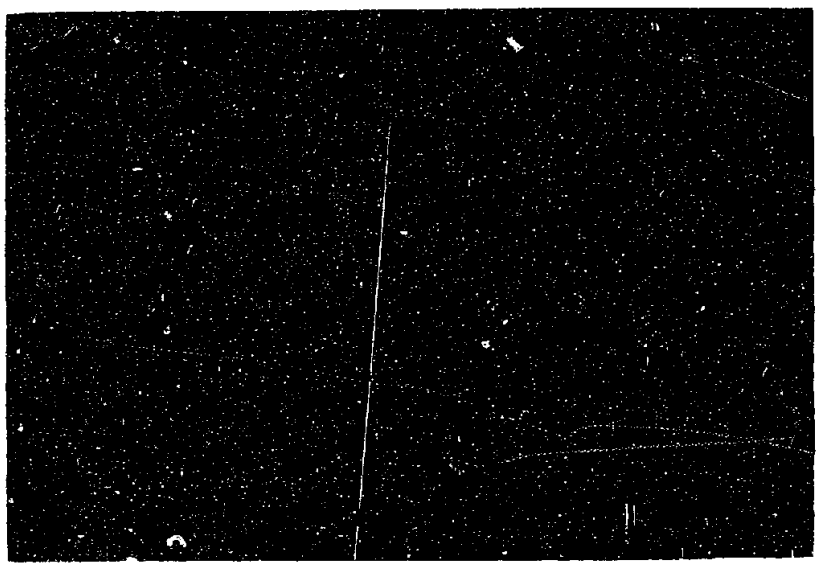
FIGURE 11



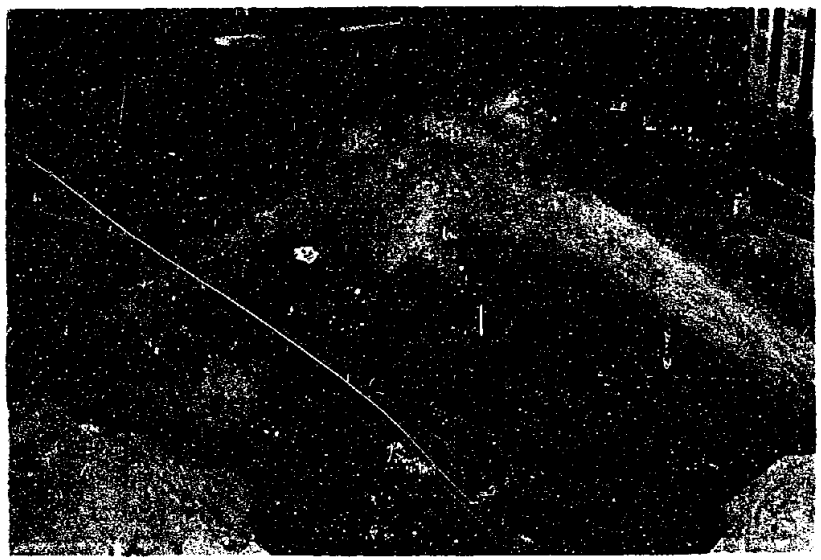
A. Discharge 25,000 second-feet per spillway
Tailwater elevation 1242



B. Discharge 25,000 second-feet per sp
Tailwater elevation 1216



C. Discharge 100,000 second-feet per spillway
Tailwater elevation 1258



D. Discharge 100,000 second-feet per spillway
Tailwater elevation 1241

RECOMMENDED DESIGN-BOTH SPILLWAYS IN OPERATION

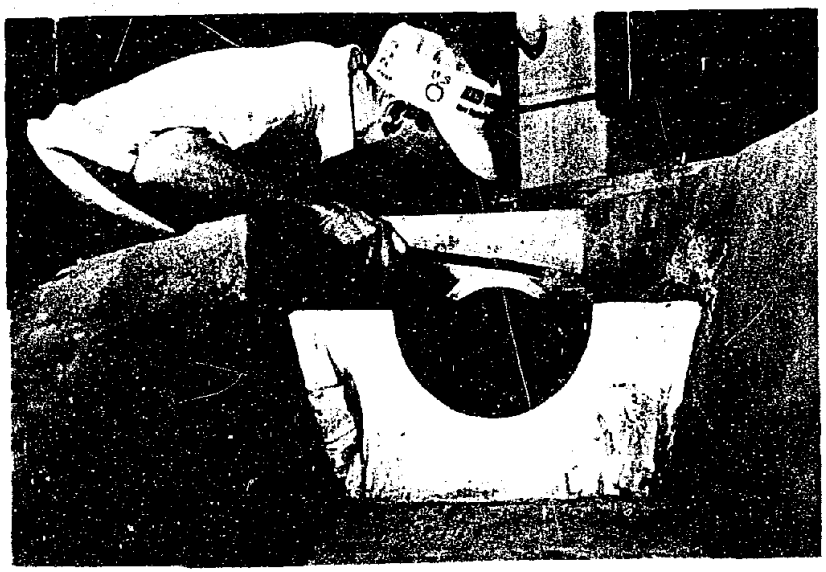
FIGURE 12

A. Discharge 150,000 second-feet per spillway
Tailwater elevation 1263

B. Discharge 150,000 second-feet per spillway
Tailwater elevation 1246

BOTH SPILLWAYS OPERATING

C. Deflector at end of right spillway



D. Deflector at end of left spillway

DEFLECTORS TO BE ADDED AFTER DIVERSON HAS BEEN COMPLETED

RECOMMENDED DESIGN

FIGURE 13

the deflector design as recommended, the left spillway will sweep out at 8,000 second-feet and the right spillway at 13,000 second-feet.

As the cross section of the river in the vicinity of the dam is much too small to efficiently dissipate the tremendous amount of energy involved, and as the rock at the dam site is considered excellent gneiss, the most feasible solution to the spillway problem is to release the combined flow as directly downstream as possible, allowing the dissipation of energy to occur over a long stretch of the river. This can be accomplished by proper manipulation of the spillway gates.

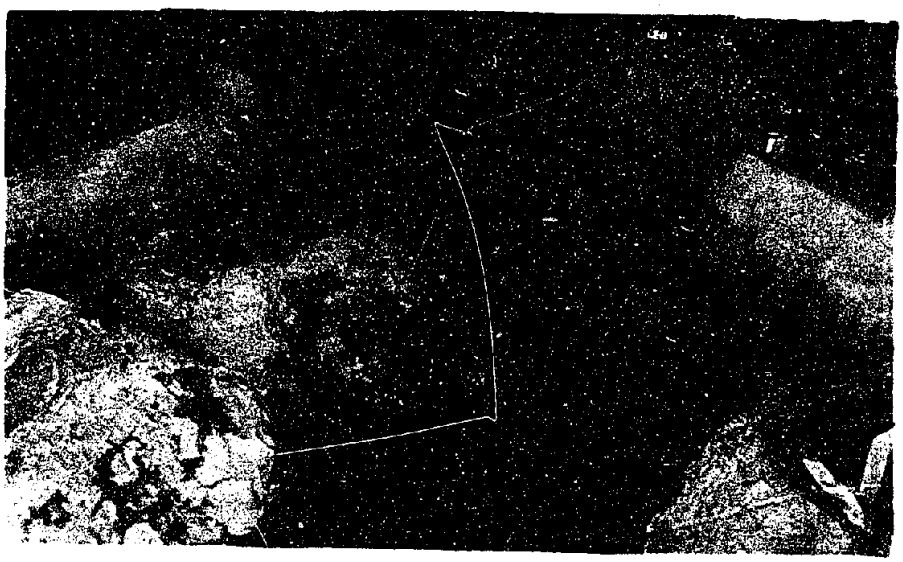
Some indication of the action of the jets on the river bed can be observed from the photographs on figure 14. Photograph A shows the preparation of the sand bed before the tests were performed, and photograph B indicates the scour after a discharge of 150,000 second-feet for the original design. Photograph C indicates the position of the scour to be expected from the recommended design. The scouring occurred farther downstream in the latter case, which is advantageous. Photographs of the two model spillway deflectors are shown in figure 13C and D.

6. The original outlet design. The outlet design will consist of seven 102-inch conduits extending through the dam at elevation 1384 as shown on figures 1 and 2. The flow through each conduit will be controlled by two circular high-pressure slide gates of the ring-follower type which will operate either fully open or entirely closed. In addition to providing for

FIGURE 14

A. View of river bed previous to testing

B. View showing scour in river channel after flow of 150,000 second-feet (Original design)



C. View showing scour in river channel after flow of 150,000 second-feet (Recommended design)

PATTERN OF SCOUR IN RIVER CHANNEL

release of water downstream, the outlets will also serve the dual purpose of sluiceways. The Bridge Canyon Reservoir is not large and is expected to fill rapidly with silt. This means that a method must be provided to remove the silt from the reservoir in the vicinity of the intakes to the penstocks leading to the powerhouse. The seven outlets as shown in figures 1 and 2 are expected to perform this function.

The alignment of the outlet conduits as originally designed was such that the jets did not center in the river downstream but impinged on the right canyon wall as shown in figure 15. Photographs A and B show two views of the outlets discharging under maximum head. Photographs C and D are similar views of the outlets discharging at the minimum allowable head on the power penstocks which still will be considerable, approximating 270 feet. Photographs B and D on figure 15 show the outer jet impinging on the right canyon wall for operation at both maximum and minimum heads. As a secondary effect, a flow of water and river bed material occurred in an upstream direction along the left bank of the river causing vortices to form in the tailrace below the jets and resulting in the deposition of river bed material in the draft tubes of the turbines. This condition prevailed for all tailwater levels and is clearly defined by the white water in photograph D. The jets produced an ejector action which reduced the level of the water in the tailrace to a value less than that downstream from the outlet disturbance. This difference in water level caused the flow in an upstream direction, along the left bank. It was felt that both disadvantages

A. Outlets operating at maximum head-
Reservoir elevation 1876

B. View from above showing outlets operating at
maximum head

C. Outlets operating at minimum head-
Reservoir elevation 1655

D. View from above showing outlets operating at
minimum head

ORIGINAL DESIGN-OUTLETS IN OPERATION

FIGURE 15

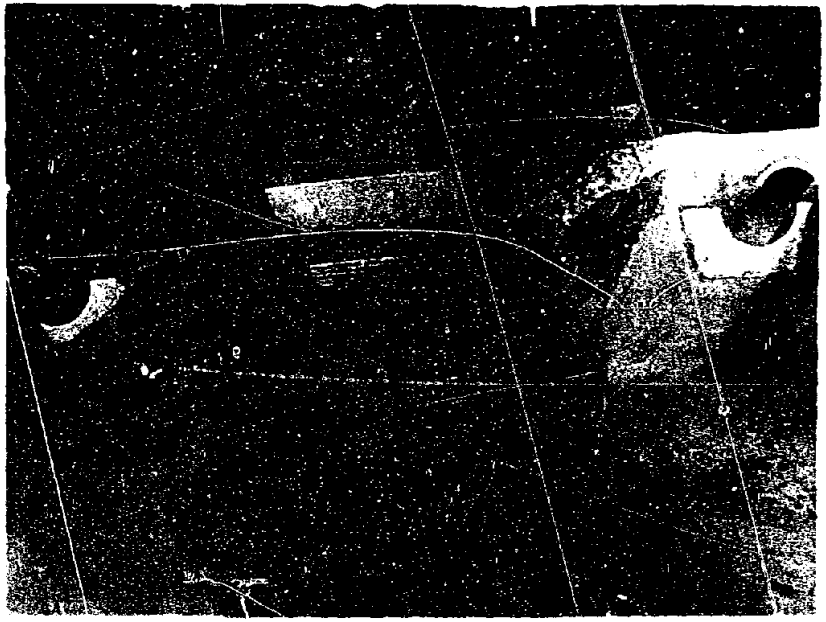
could be alleviated by centering the jets in the river.

7. The recommended outlet design. After a few trials, the outlet conduits were shifted to the positions shown on figure 8, which is the recommended alignment. As the original conduits were close to construction joints, it was necessary to move each conduit into the adjacent block to the left and shift the intakes on the upstream face of the dam a corresponding amount (compare figures 1 and 8). Figure 16A is a general view of the model showing the outlets, as revised, discharging at the maximum head, and figure 16C is a view looking down on the revised outlets discharging at the minimum head. The winding nature of the river made it impossible to center the jets in the river for both maximum and minimum heads. A compromise was therefore made between the two and the results were quite satisfactory. It can be observed from figure 16C that little back flow existed for the revised design when the outlets were discharging at the minimum head. This was also true for all operating heads.

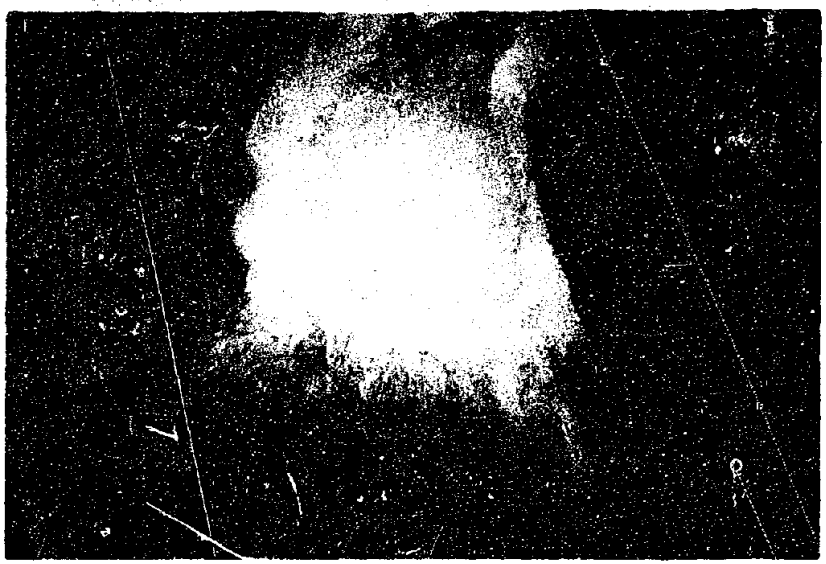
Operation of both the outlet works and spillways will create a tremendous amount of spray. For this reason it is recommended that all exposed switching and transmission equipment be located completely out of the canyon.

8. Draft tube barrier. As the outlets at times will discharge a great amount of silt and heavier materials into the river, some of which will work upstream and enter the turbine draft tubes, a means was deemed advisable to reduce deposition in the draft tubes to a minimum. Model tests indicated that the

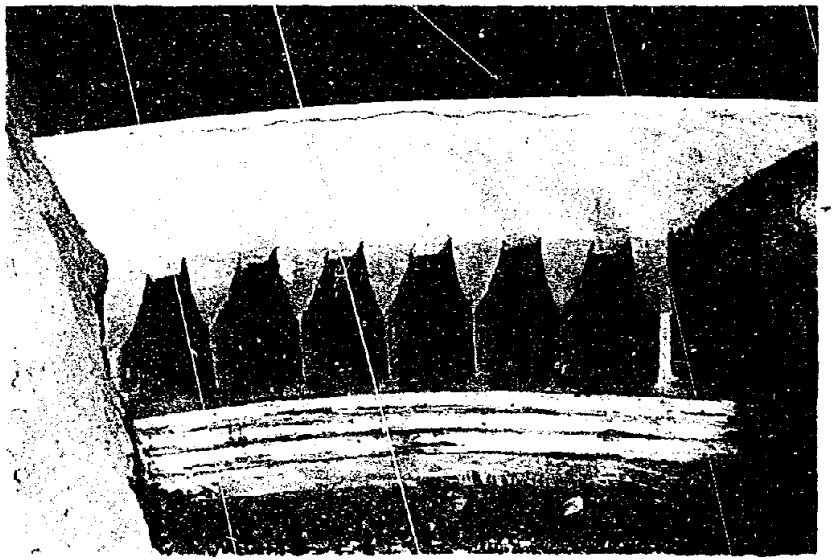
A. Outlets operating at maximum head-
Reservoir elevation 1876



B. View of model showing recommended design



C. Outlets operating at minimum head-
Reservoir elevation 1655



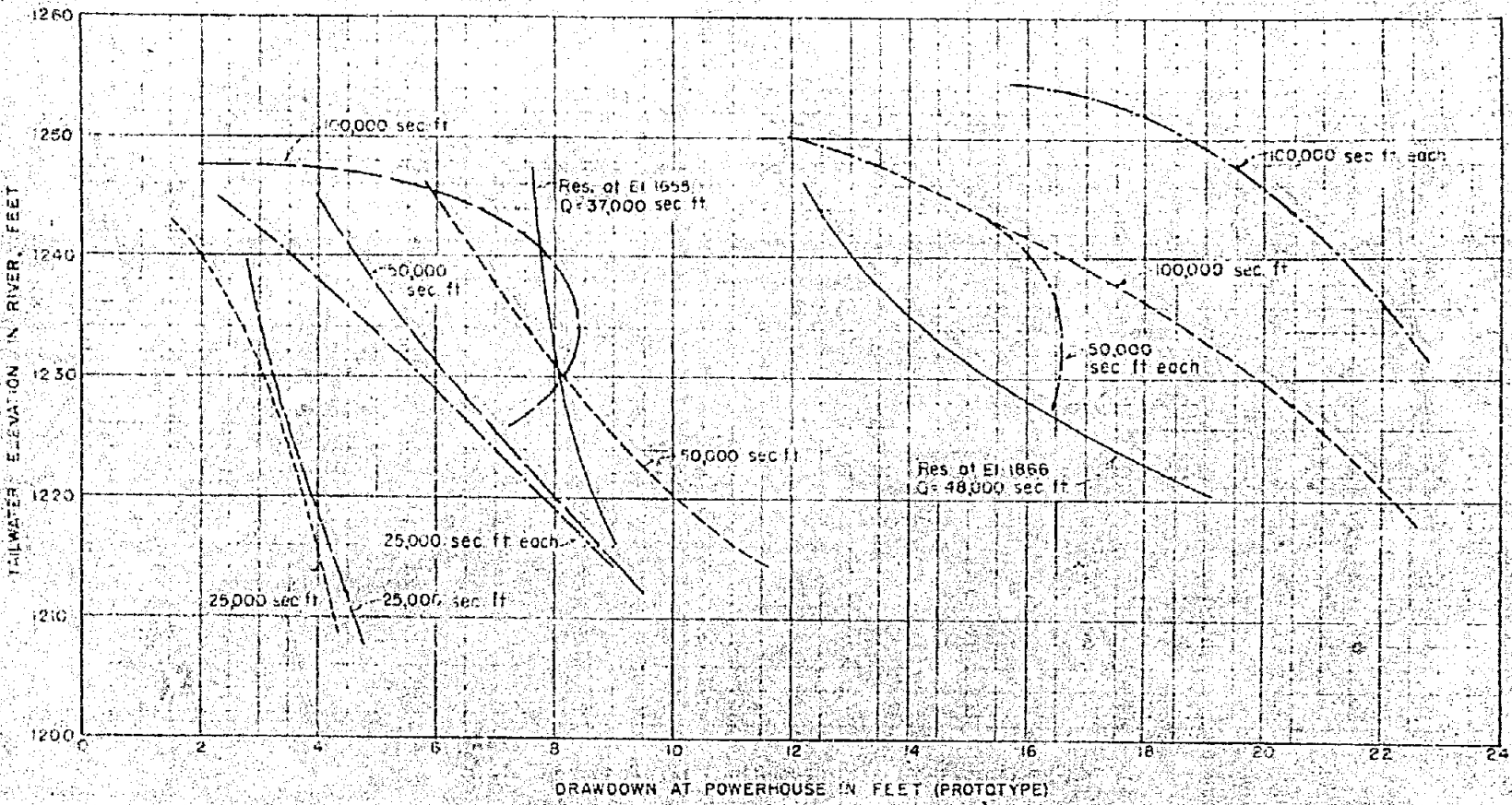
D. Close up view of draft tube barrier

RECOMMENDED DESIGN

FIGURE 16

best results will be obtained by incorporating a small dam in the downstream portion of the draft tubes as shown on figure 8B. With this arrangement, no material was deposited in the draft tubes of the model, while a considerable amount of material was transported into the tubes in the original design, figure 2. Regardless of design, there is no doubt that material will be trapped in the prototype draft tubes, which will eventually require removal by mechanical means. Stop-log slots will be provided so that the draft tubes can be isolated and unwatered individually for inspection purposes, and the removal of deposited material. Figure 16D shows a photograph of the draft tube barrier as recommended, and photograph B on the same figure is an upstream view of the complete model in which the designs, as recommended in the preceding pages have been incorporated.

9. Drawdown of tailwater at powerhouse produced by operation of spillways and outlet works. With certain combinations of operation of the spillways or outlet works, an ejector action occurred in the river which resulted in lower corresponding water surface levels at the powerhouse than at points downstream. The extent of this drawdown effect is shown on figure 17 for a few flow combinations. In all cases shown on figure 17, the discharge from the powerhouse was 10,000 second-feet. A decrease in flow from the powerhouse would cause the drawdown to increase. The river elevation was measured at a point 2,000 feet downstream from the axis of the dam and a second measurement was obtained in the powerhouse tailrace. The difference



EXPLANATION

- Left Spillway
- Right Spillway
- Both Spillways
- Outlets

NOTES

For all conditions shown, the powerhouse discharge was 10,000 second feet. Tailwater elevation of river measured 2000 feet downstream from axis of dam.

BRIDGE CANYON DAM

CURVES SHOWING DRAWDOWN OF TAILRACE PRODUCED BY VARIOUS COMBINATIONS OF FLOW FROM SPILLWAYS AND OUTLETS

FIGURE 17

in elevation indicated by the two gages constitutes the horizontal scale on figure 17. Each curve represents a constant flow condition over a wide range of tailwater depths. The most pronounced drawdown, a maximum of 22 feet, occurred with both spillways operating at 100,000 second-feet each. Approximately the same drawdown occurred with the left spillway operating at 100,000 second-feet. The next largest drawdown of approximately 19 feet was produced by the outlets operating alone at the maximum head. Some drawdown occurred for practically any flow condition as would be expected.

10. Conclusions. It is recognized that the above tests constitute only preliminary studies on a large dam. As the building of Bridge Canyon Dam materializes, more detailed model studies will undoubtedly follow. With this in mind the preceding studies were limited principally to alignment of the spillways and outlet works and flow conditions in the river.