HYD-197

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 197

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HYDRAULIC MODEL STUDIES OF THE SPILLWAY AND RIVER OUTLETS OF CANYON FERRY DAM - MISSOURI BASIN PROJECT - MONTANA

By

Fred Locher

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Denver, Colorado
March 18, 1946

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Branch of Design and Construction
Engineering and Geological Control
and Research Division
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Hydraulic Laboratory
Compiled by: Fred Locher

Reviewed by: J. N. Bradley

Subject: Hydraulic model studies of the spillway and river outlets of Canyon Ferry Dam - Missouri Basin Project - Montana.

General. Canyon Ferry Dam, which is located on the upper reach of the Missouri River, east of Helena, Montana, figure 1, is a part of the Missouri Basin Project. The structure will be a gravity dam approximately 175 feet high with an overfall spillway utilizing a combination sloped and horizontal apron stilling pool for the dissipation of energy. In addition to the spillway there will be four river outlets through the dam controlled by four jet-flow gates. These will also discharge into the spillway stilling pool and can be utilized to supplement the maximum spillway discharge as well as to regulate the river flow downstream during normal flows.

The discharge from Canyon Ferry Dam will flow directly into the upstream end of a reservoir created by Hauser Lake Dam. With a spillway discharging into a lake, it is not possible to obtain a satisfactory hydraulic jump with the conventional horizontal floor in the stilling pool, so the combination sloped apron and horizontal floor design was employed. It was expected that a suitable hydraulic jump would form on this apron with the tail water elevations peculiar to this installation. The stilling pool was intended to operate satisfactorily for discharges up to 100,000 second-feet with the tail water level constant at elevation 3650.00.

The spillway was designed for a maximum flood of 200,000 second-feet. The highest recorded flood was 33,500 second-feet and other maximum yearly flows have been as low as 5,000 second-feet, so it is doubtful if the maximum designed flood will ever occur, or should it occur, the maximum flow will be of short duration. Under these circumstances it seemed inadvisable to construct a stilling pool sufficiently large to function perfectly at the maximum flood. Instead, the pool was designed for satisfactory operation with flows of 100,000 second-feet or less with the tail water at elevation 3650. To provide for flows above 100,000 second-feet a 2:1 upward sloping sill was placed on the downstream end of the stilling pool floor to deflect the bottom flow upward and produce a bucket action to prevent excessive scour. It was not expected that the pool would sweep out under the latter condition but that a partial or imperfect jump would form combined with a boiling action immediately downstream similar to that from a bucket. At the time the original design was prepared information concerning tail water levels was lacking. Later when the model studies were in progress, information was received with which it was possible to estimate the tail water elevation for the complete range of discharges.

The model. The model of the original design was constructed on a 1:60 scale according to figure 2. The overflow section, river outlets, gates, and the curve at the toe of the dam were constructed of sheet metal. The 4:1 slope in the stilling pool and the outside pool walls were made from sheet rock. The horizontal portion of the pool, the pool sill, and the piers at the top of the dam were made of wood. The component parts of the model were placed inside of a, sheet metal lined, wooden box which comprised the head box and a representative part of Hauser Lake Dam reservoir. The spillway section was soldered to the sheet metal lining of the box and formed an effective bulkhead for sealing the model such that all water entering the model passed over the crest with none leaking past the sides or bottom.

Initial tests. The initial tests consisted of visual observations to determine the adequacy of the design shown on figure 2. These tests indicated that a satisfactory jump could be maintained in the stilling pool for spillway discharges up to 60,000 second-feet with the tail water level at elevation 3650. With flows in excess of 60,000 second-feet, there was a pronounced surface boil or bucket action which formed immediately downstream from the 2:1 upward sloped sill on the apron. This did not produce an excessive amount of scour in the river channel until the spillway discharge exceeded 100,000 second-feet. Flows above 100,000 second-feet, with the tail water at elevation 3650, caused the pool to sweep out. This resulted in a trajectory jet springing from the stilling pool and striking the river bed approximately 200 feet downstream, which if allowed to continue for a sufficient period of time would have produced deep scour at this point.

Figures 3 and 4 show the model arrangement and flow conditions for discharges of 25,000, 50,000, and 100,000 second-feet. At flows of 25,000 and 50,000 second-feet, a good hydraulic jump formed and there was little disturbance of the water surface downstream, figures 3B and 4A. At 100,000 second-feet the boiling action is apparent in figure 4B. This is partly obscured by the tail gate control rod, however, a close inspection will reveal a roller similar to that which occurs downstream from a trajectory bucket which is partly submerged.

Tests were not made on the outlets at this time, as shortly after the model was completed, it was decided to raise the conduits above the normal reservoir elevation of Hauser Lake to keep them dry and easily accessible for periodic inspection. Also, the intermediate training walls were not placed in the stilling pool because their only purpose was to stabilize the pool when the river outlets were operating, and since the outlets were not operated, the absence of the walls did not have any effect on the stilling pool performance.

It was necessary to use a considerable depth of concrete over the sound rock foundation to obtain the 4:1 slope at the toe of the dam, and since the performance of the pool was not as efficient as was anticipated, it was decided to change the slope of the apron to 6:1.

This served to save concrete as well as increase the efficiency of the pool without lengthening it. The change was accomplished by maintaining the horizontal portion of the pool in its original position and extending the 6:1 slope upstream towards the toe of the dam until it became tangent to the new location of the 50-foot radius curve, figure 5. Other changes and additions to the model involved raising the centerline of the outlets from elevation 3645.35 to 3653.50, increasing the conduit diameters from 75 to 84 inches, eliminating the outlet beavertails to allow the conduits to discharge horizontally, placing the gates on the crest, and adding the intermediate training walls in the stilling pools. The intermediate walls as installed at this time were of the same dimensions as shown on figure 2.

Tests leading to the recommended spillway design. Studies with the revised model indicated that discharging the river outlets horizontally, without the use of the beavertails to spread the flow, was satisfactory provided there was no flow over the spillway. When both the spillway and outlets were discharging simultaneously, a vacuum of sufficient magnitude formed under the jets in the model to cause them to be pushed down against the face of the dam. At certain discharges this condition became unstable. The jet from a river outlet would intermittently flow on the face of the dam for a short period of time, then suddenly break free and penetrate the spillway nappe. Flow would continue in this manner until the air beneath the jet was evacuated, after which time the outlet jet would be forced back to the face of the dam. Operation under these conditions will produce vibration and possibly cavitation, neither of which is desirable. The outlets and the spillway should not be operated simultaneously except in an emergency where the additional capacity of the river outlets is an absolute necessity. This should be resorted to only when the river discharge approaches 200,000 second-feet. The outlets could have been designed to function along with the spillway by providing aeration to the underside of the jets. This was considered unnecessary because sufficient flexibility of spillway operation was provided. This will be explained more fully later in the report.

Study of the spillway flow at the junction of the river outlets with the face of the dam revealed that the spillway flow was striking the invert of the outlets and that damage at this point might be expected. Piezometers placed immediately below the outlets, figure 5, indicated negative pressures of approximately 12 feet of water prototype. While this pressure was not sufficiently low to cause damage by cavitation, it was considered advisable to place deflectors upstream of the openings to divert the flow over the outlet inverts. The deflectors shown in figure 5, proved satisfactory in the model, however, a certain amount of aeration will be necessary. The model showed that a vent equivalent to a 30-inch pipe in the prototype was adequate. Special vents will not be necessary for this purpose in the prototype, since it was planned to use the jet-flow gates in the conduits. The air vents provided for these gates will be adequate to aerate the conduits when the spillway only is operating. These gates are not shown on figures 2 and 5. Figure 6A shows the model of the recommended design with deflectors over the pair of river outlets on the right, looking upstream. Deflectors were not placed over the left pair because their operation would have been similar and their installation would not have added anything to the study.

The results of tests to determine the adequacy of the stilling pool are shown on figure 7. The curve labeled, "satisfactory jump," represents the minimum water surface at which the conventional type of hydraulic jump will occur. The curve labeled, "pronounced bucket action from stilling pool sill," indicates the minimum tail water allowable for a particular discharge which will not cause excessive scour in the river. At the low stage of tail water, the pool did not sweep out but there was insufficient depth to destroy the bottom velocity which had ample force to produce a distinct boiling action immediately downstream from the pool sill. Figure 6B, 8 and 9A, show the flow conditions in the pool for prototype discharges of 25,000, 50,000, 100,000, and 200,000 second-feet with tail water elevations at 3650 for the first three discharges and at elevation 3670 for 200,000 second-feet. The scour resulting from a flow of 200,000 second-feet is shown on figure 9B. The maximum scour occurred at the downstream end of the pool training walls. This was the result of eddies caused by the flow leaving the pool. With sufficient tail water the depth of this scour was not serious, however, a flow of 200,000 second-feet will produce deep scour at the ends of the walls if the tail water is sufficiently low to allow the resulting bucket action from the stilling pool sill to continue for an extended period of time. At discharges below 100,000 second-feet a limited amount of movement of bed material occurred but deep scour was not present at any point.

Tests leading to the recommended outlet design. Studies to determine the effect of discharging the river outlets into the pool demonstrated the necessity of providing intermediate walls to stabilize the flow. Without the walls, the discharge from the jets caused two large vortices to form in the center of the pool which had sufficient energy to move bed material from the river into the stilling basin. Operation in this manner caused the deposited material to rotate slowly on the apron which, if allowed to continue for a period of time, might cause erosion of the concrete apron. As originally designed, the intermediate walls extended to the stilling pool sill, with the top of the walls at the water surface elevation of 3650. Tests with the model showed that the downstream 44 feet could be removed without impairing the action in the pool. The model with the river outlets discharging is shown on figure 10A.

The junction of the intermediate training walls with the face of the dam introduced a potential source of cavitation. The original design consisted of extending the horizontal surface of the top of the wall into the face of the dam making an intersection which abruptly changed the direction of flow. A piezometer placed as shown in figure 2 indicated unstable flow at the junction of the two surfaces. At times the flow would spring free of the intermediate wall allowing it to aerate. Other times the surface sealed and the pressure would reduce to that equivalent to the vapor pressure of water in the prototype.

Similar intermediate training walls were used at Marshall Ford Dam to stabilize the pool when the two large center outlets were operating. These walls had a 90 degree V splitter on the top as shown on figure 11C. The same arrangement was installed in the model and tested. This had a stabilizing effect on the spillway flow over the intermediate training walls but the pressures at the junction with the face of the dam were consistently at the vapor pressure of water, prototype, indicating cavitation and the resulting erosion. Other shapes of splitters were tested to find one which would have pressures in conformity with good design. The second was that shown in figure 11A. This was acceptable from a hydraulic viewpoint but it would have been an exceedingly difficult shape to form and construct. The third splitter, figure 11B, was simpler in that it did not curve up the face of the dam. It was of the same cross section as the previous splitter and was parallel to the top of the intermediate training wall. The negative pressures on this arrangement varied between four and six feet of water, prototype. These negative pressures were completely eliminated by increasing the radius of the splitter from five feet to six feet three inches as shown on figure 11D. The positive pressure on this design varied between two and four feet of water, prototype, with no negative pressures present at any discharge.

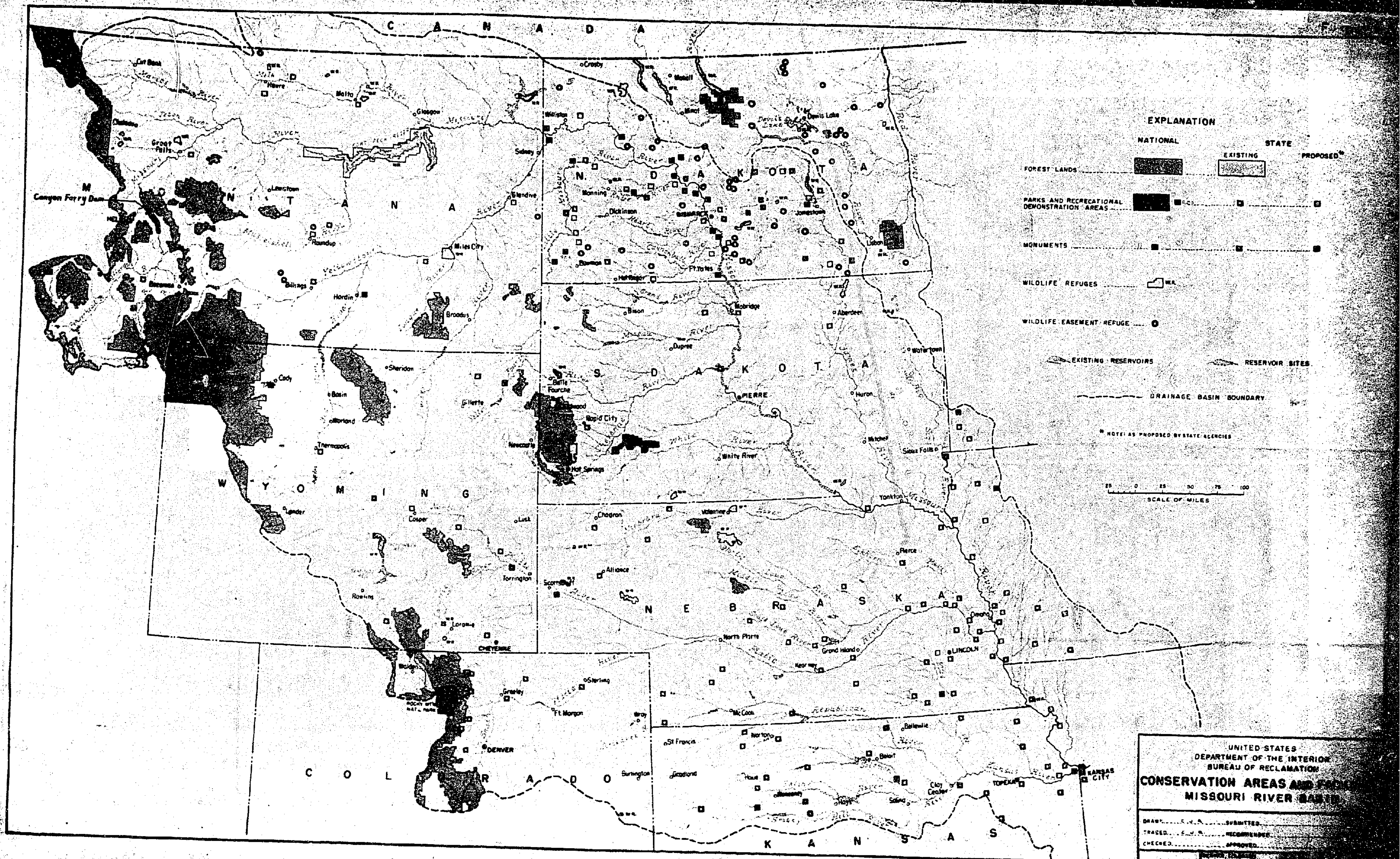
The splitter designs indicating acceptable pressure distributions, all had a sharp edge pointed into the flow. There was some objection to the sharp edge because, if formed in concrete, it might disintegrate rapidly in the high velocity jet. Provisions will be necessary to prevent damage to this part of the splitter. It appears that either armor plate for the edge or a slight rounding might provide a solution. In view of the difficulty of obtaining a sound as well as smooth surface at the junction of the armor plate with the concrete, it would seem advisable to round the sharp edge slightly. Investigation in the model indicated that the point formed by the junction of the two six-foot three-inch radii can be rounded by a two-inch radius curve as shown in figure 11D.

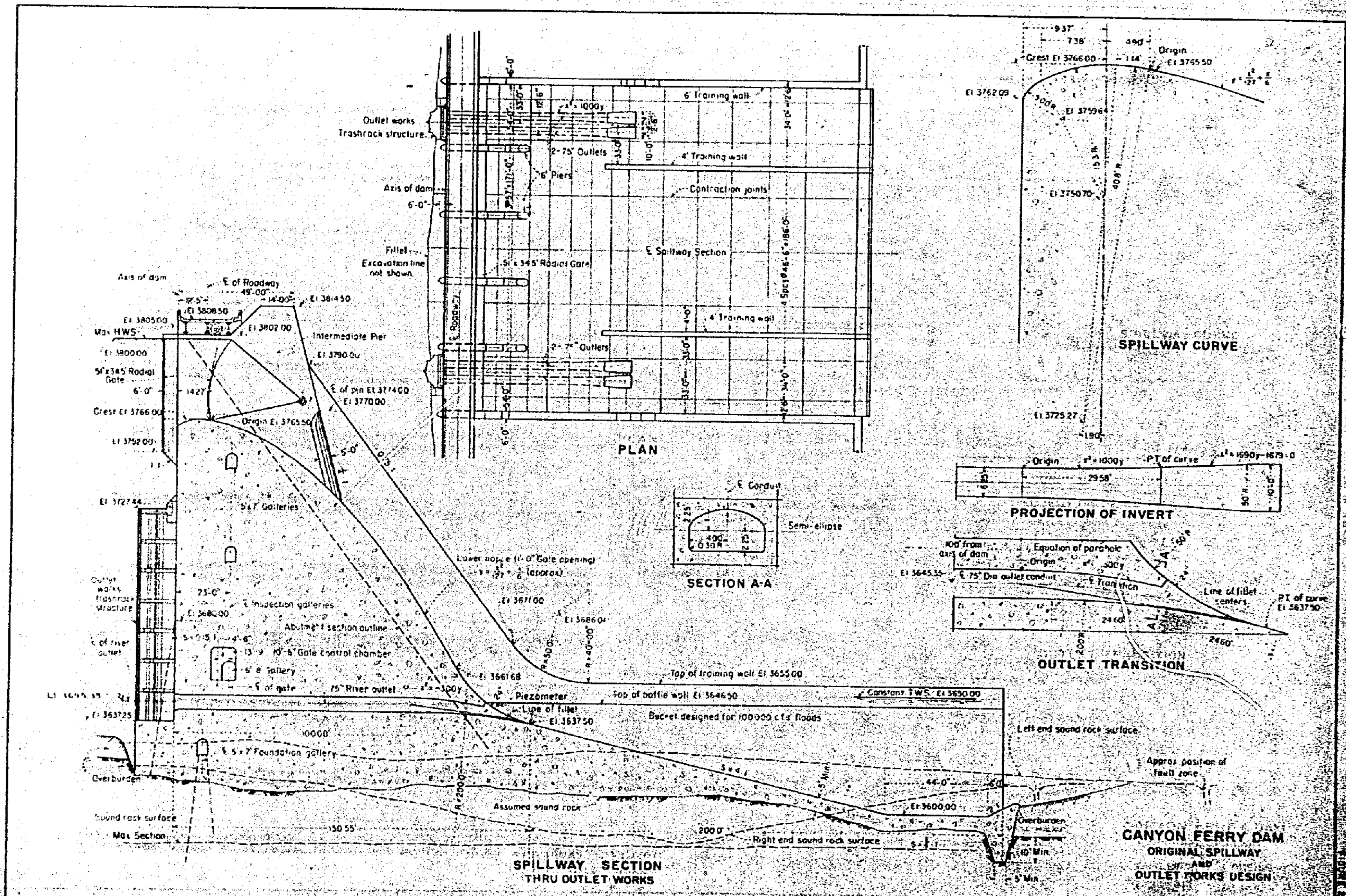
Operation of the Spillway and Outlets. The installation of intermediate training walls in the stilling pool greatly increased the flexibility of flow regulation at the dam. First, it will not be necessary to operate the spillway gates with uniform discharge through each gate nor will it be necessary to operate all of the gates at one time. The two end gates may be opened singly or in unision, or the discharge from one end gate may be different from the other. The only limiting factor is that the discharge from one gate should not exceed 15,000 second-feetwhen the tail water is at or above elevation 3650. At lower tail water levels the discharge should be reduced. The three center gates should not be operated unless the two end gates are also discharging similar quantities of water. Figure 10B shows the flow with the two end gates operating.

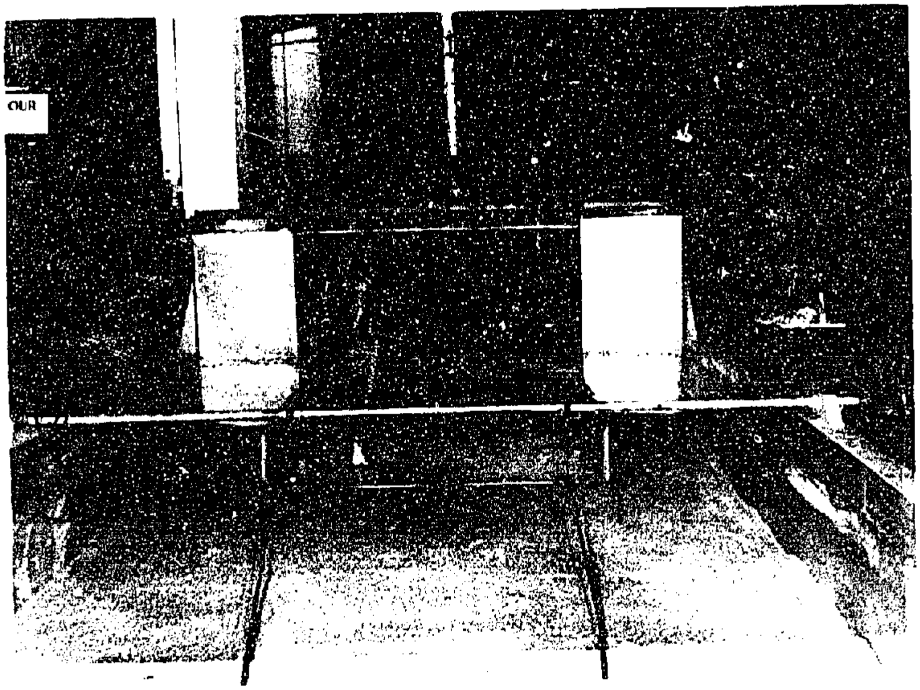
As stated previously the outlets should not be operated simultaneously with the spillway. The only exception to this is that the left end gate and the right river outlets, or the opposite combination, may be operated at the same time. In these instances there will not be flow over the operating outlets and satisfactory performance will be obtained.

<u>Spillway rating curves</u>. The relationship between the total head on the crest and discharge are shown on figure 12. This data was obtained from the model by closing the river outlets, completely opening the spilling gates, running a particular discharge over the spillway crest and recording the corresponding head. This was repeated for various discharges until the entire head-discharge curve was obtained.

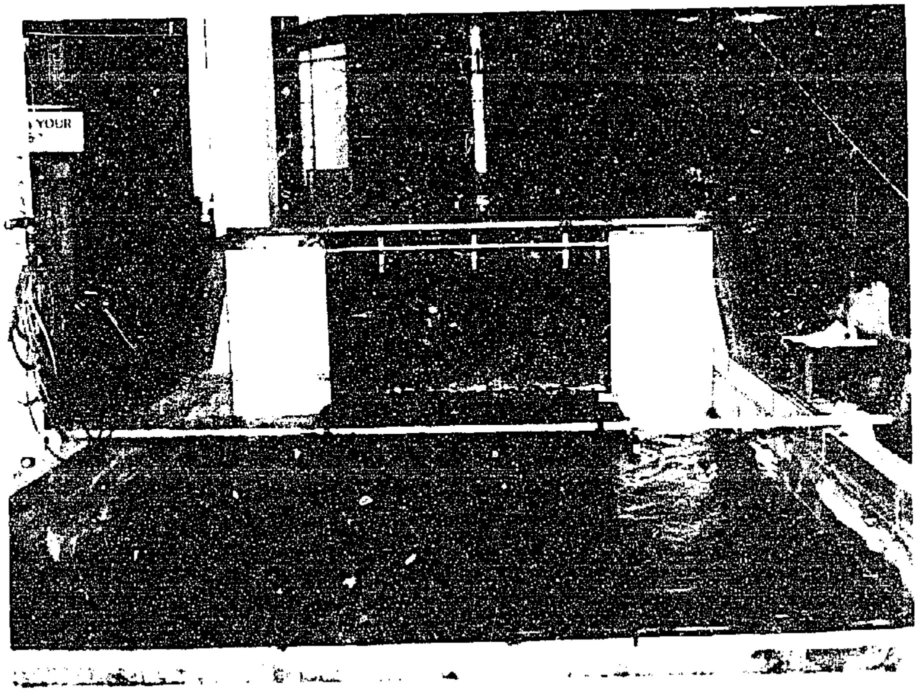
The coefficient curve shown on figure 12, was obtained from the spillway discharge data. It was computed from the formula $Q = CLH^{3/2}$, where Q was the total discharge, C the coefficient of discharge, L the net length of the crest (meaning width of piers excluded), and H the total head (including velocity head of approach) above the top of the spillway crest. The maximum value of the coefficient as determined from the model was 3.63.


CANADA
MONTANA
N. DAKOTA
S. DAKOTA
WYOMING
NEBRASKA
COLORADO
KANSAS
Canyon Ferry Dam
Cut Bank
Havre
Malta
Glasgow
Great Falls
Lewistown
Roundup
Billings
Hardin
Miles City
Broadus
Glendive
Sidney
Williston
Crosby
Minot
Devils Lake
Dickinson
Bismarck
Jamestown
Bowman
Lisbon
Ft. Yates
Bison
Mobridge
Aberdeen
Dupree
Watertown
Belle Fourche
Rapid City
Pierre
Huron
Newcastle
Hot Springs
White River
Mitchell
Sioux Falls
Yankton
Sheridan
Cody
Basin
Worland
Gillette
Thermopolis
Lander
Casper
Lusk
Torrington
Rawlins
Laramie
CHEYENNE
Walden
Greeley
Sterling
Ft. Morgan
Wray
DENVER
Burlington
Chadron
Valentine
Alliance
Scottsbluff
Pierce
Omaha
North Platte
Grand Island
LINCOLN
McCook
St. Francis
Norton
Belleville
Beloit
Goodland
Hays
Clay Center
Salina
TOPEKA
KANSAS CITY
EXPLANATION
NATIONAL
STATE
EXISTING
PROPOSED*
FOREST LANDS
PARKS AND RECRECATIONAL DEMONSTRATION AREAS
MONUMENTS
WILDLIFE REFUGES
W.R.
WILDLIFE EASEMENT REFUGE
EXISTING RESERVOIRS
RESERVOIR SITES
DRAINAGE BASIN BOUNDARY
* NOTE: AS PROPOSED BY STATE AGENCIES
25 0 25 50 75 100
SCALE OF MILES
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CONSERVATION AREAS
MISSOURI RIVER
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED


PLAN
SPILLWAY CURVE
PROJECTION OF INVERT
SECTION A-A
OUTLET TRANSITION
SPILLWAY SECTION
THRU OUTLET WORKS
Outlet works
Trashrack structure
Axis of dam
Contraction joints
6' Training wall
4' Training wall
2-75" Outlets
6' Piers
Intermediate Pier
Piezometer
Line of fillet
Semi-ellipse
Left end sound rock surface
Right end sound rock surface
Assumed sound rock
Approx. position of fault zone
Overburden
Sound rock surface
Max Section
Top of training wall El 3655.00
Top of baffle wall El 3646.50
Bucket designed for 100,000 c.f.s. floods
Constant TWS El 3650.00
5'x7' Foundation gallery
Abutment section outline
Line of fillet centers
CANYON FERRY DAM
ORIGINAL SPILLWAY
AND
OUTLET WORKS DESIGN

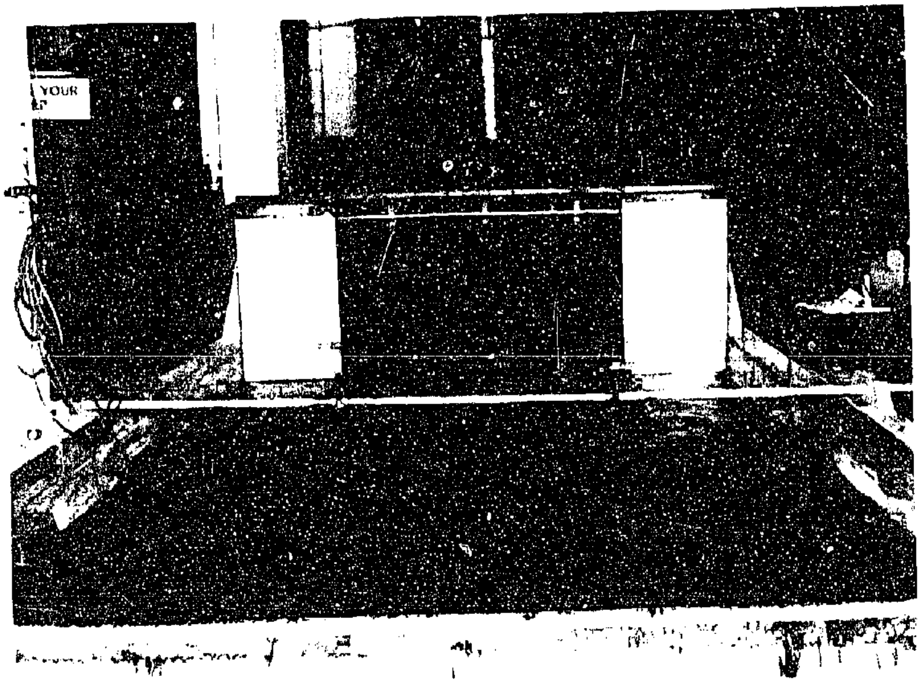


A - Model Arrangement



B - Discharge 25,000 C.F.S. - W.S. Elevation 3050.00

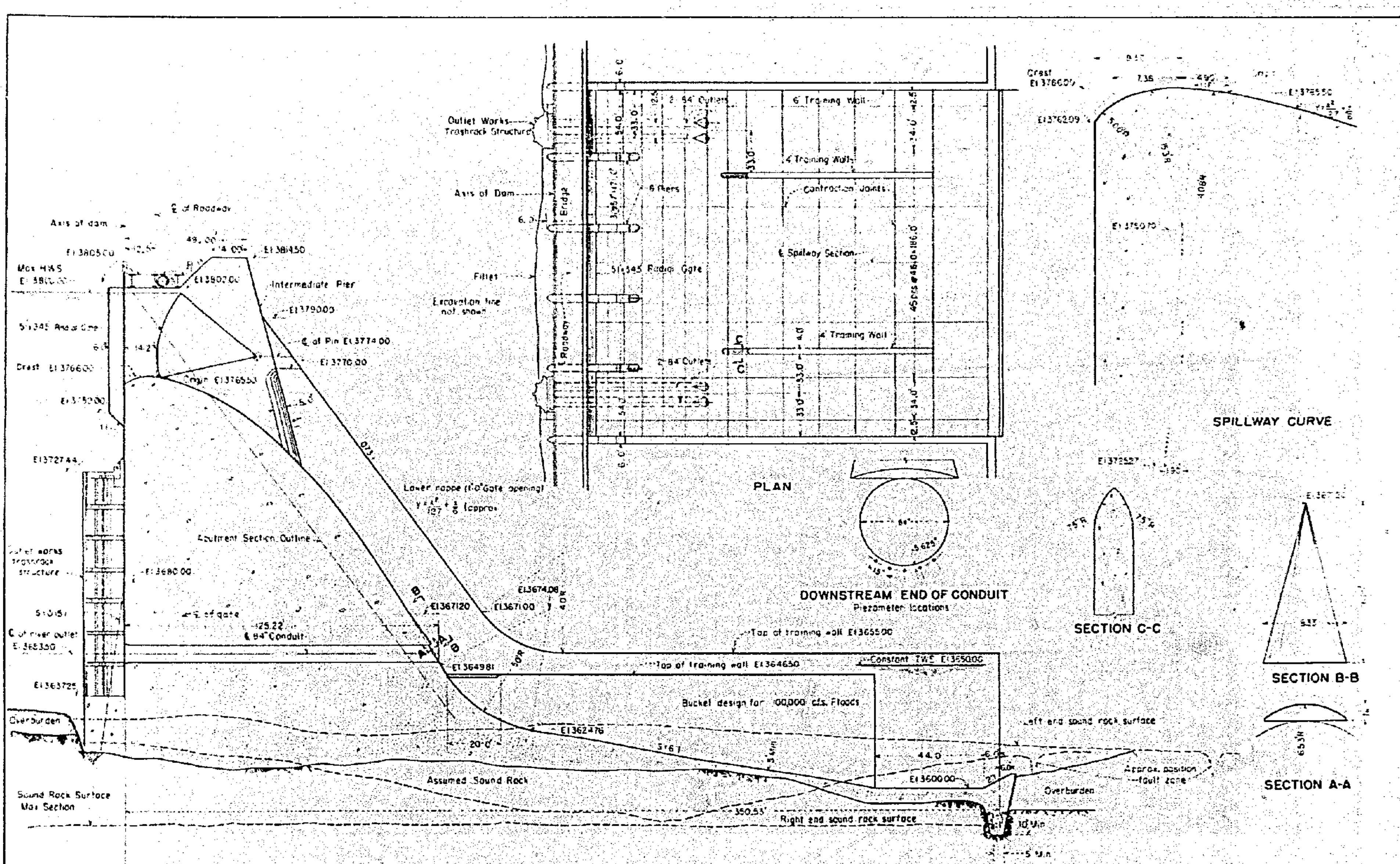
CANYON FERRY DAM - ORIGINAL DESIGN



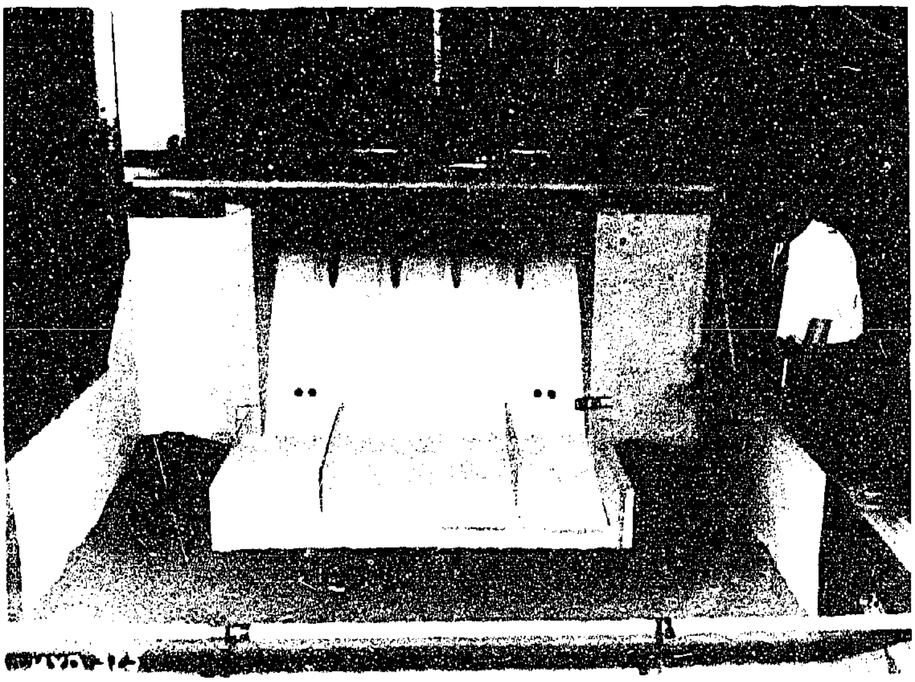
A - Discharge 50,000 S.F. - W.S. Elevation 3650.00

B - Discharge 1[illegible],00[illegible] S.F. - W.S. Elevation 3650.00

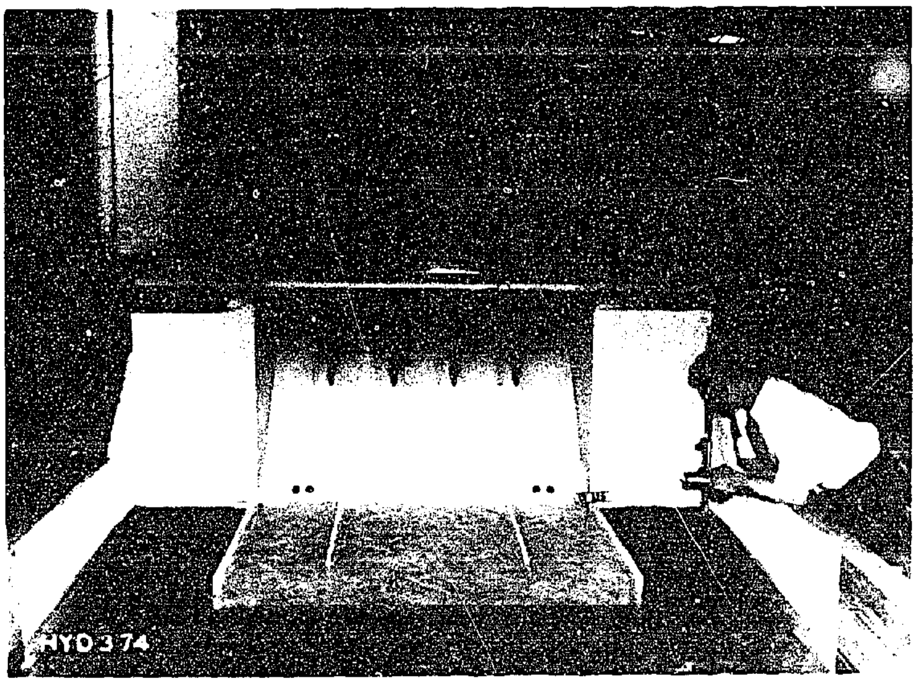
CANYON FERRY DAM - ORIGINAL DESIGN



CANYON FERRY DAM
RECOMMENDED DESIGN

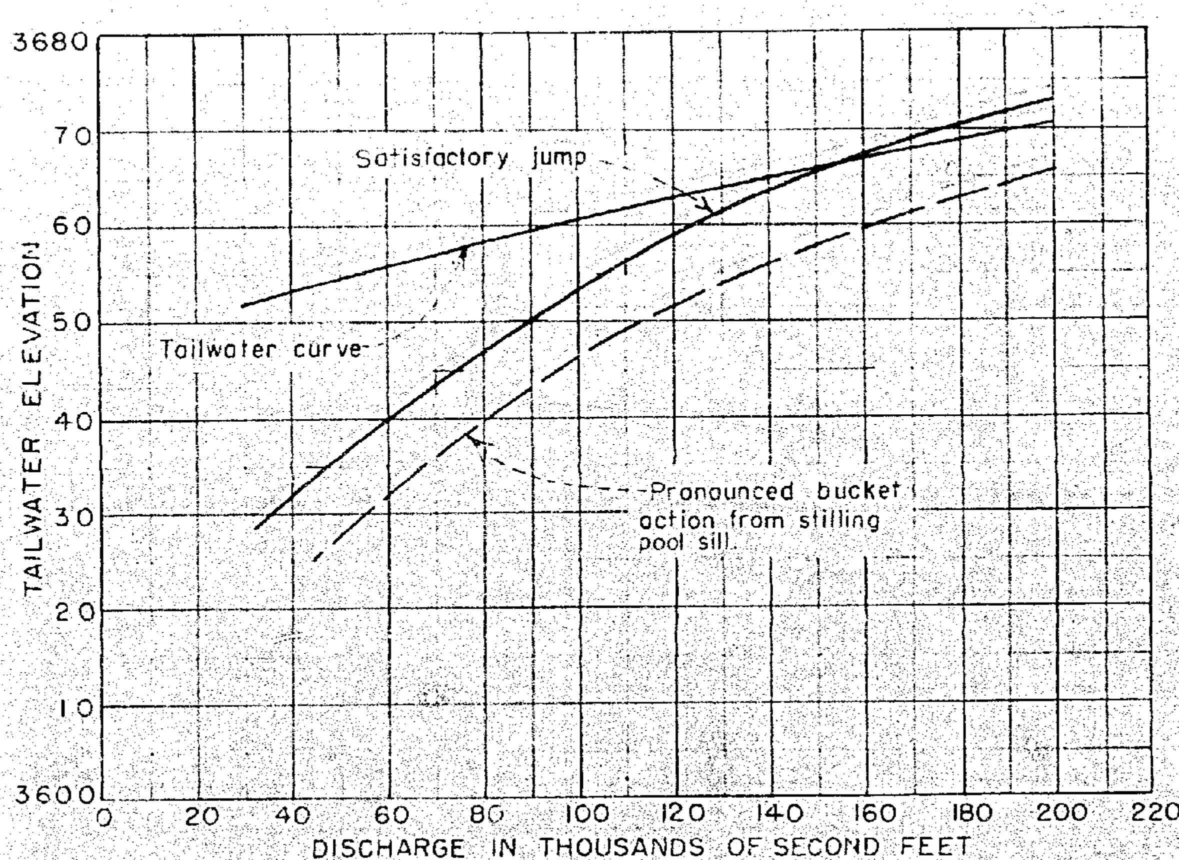


A - Model Arrangement



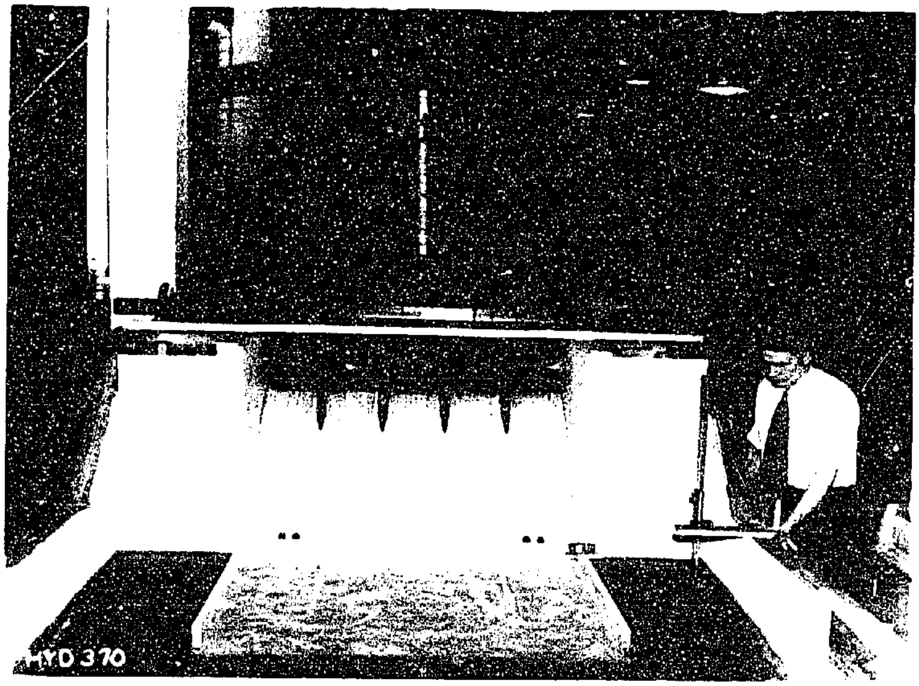
B - Discharge 25,000 S.F. - W.S. Elevation 3650.00

CANYON FERRY DAM - RECOMMENDED DESIGN

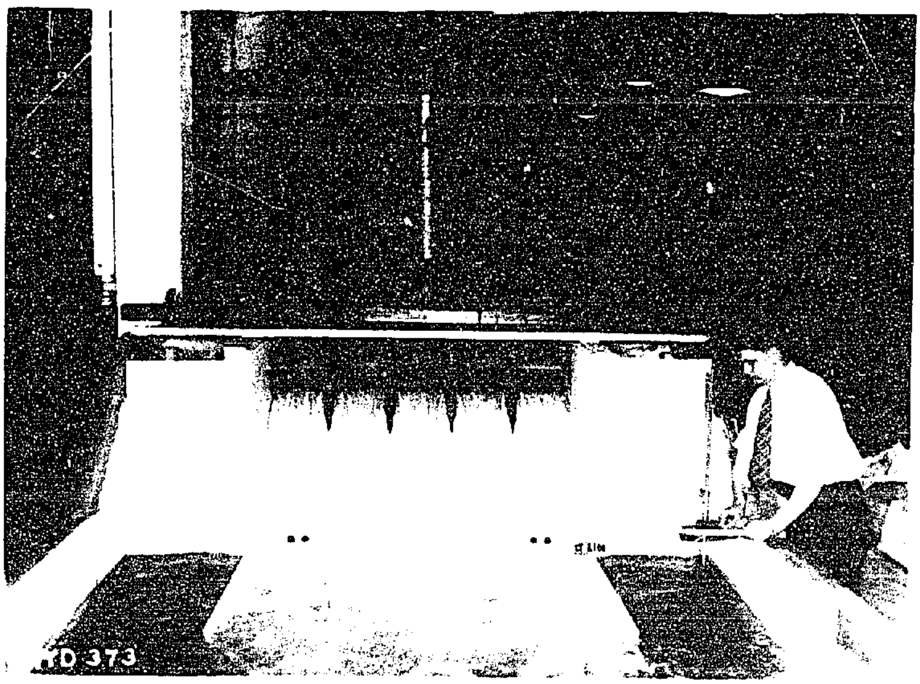


CANYON FERRY DAM
HYDRAULIC JUMP-TAILWATER CURVE
RIVER OUTLETS CLOSED
RECOMMENDED DESIGN

Figure 7

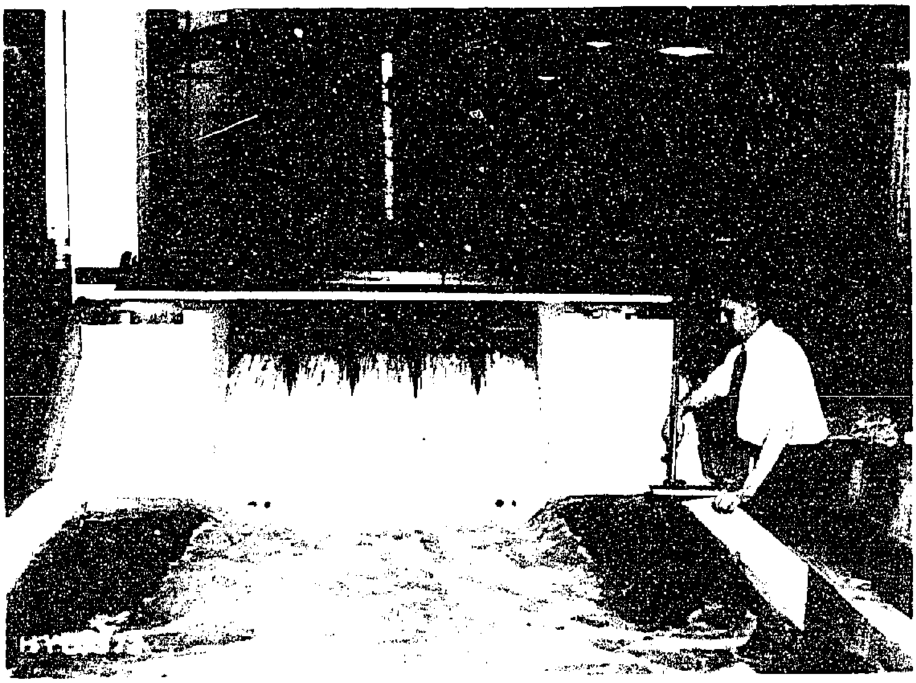


A - Discharge 50,000 S.F. - W.S. Elevation 3650.00

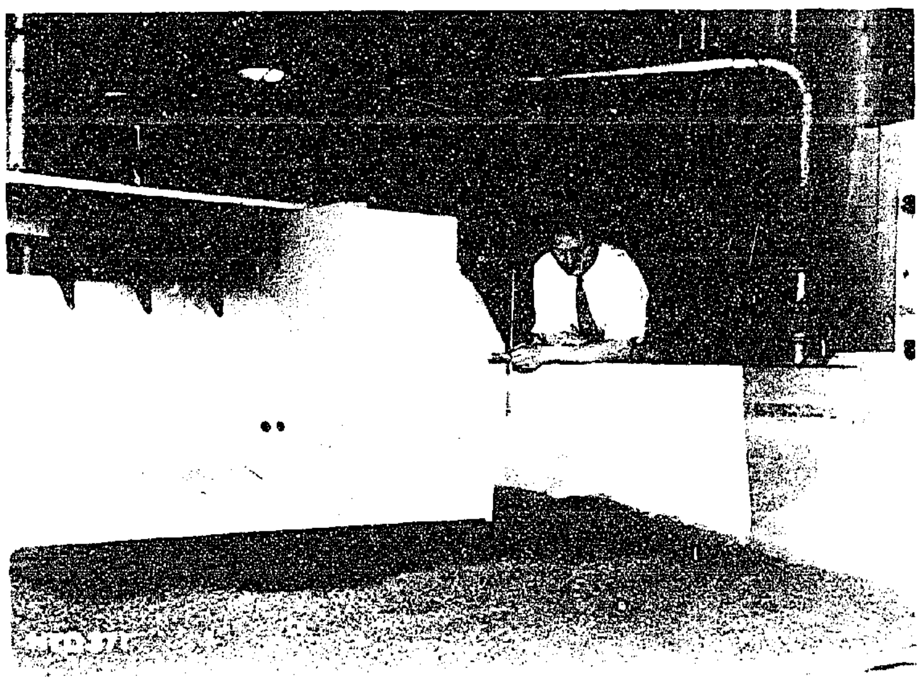


B - Discharge 100,000 S.F. - W.S. Elevation 3650.00

CANYON FERRY DAM - RECOMMENDED DESIGN

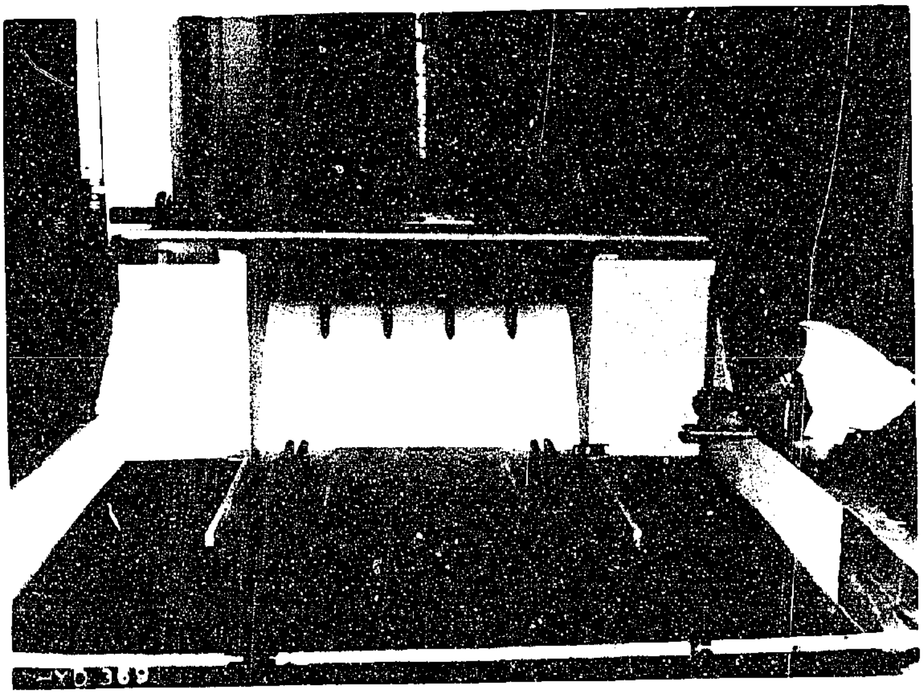


A - Discharge 200,000 S.F. - W.S. Elevation 3670.00

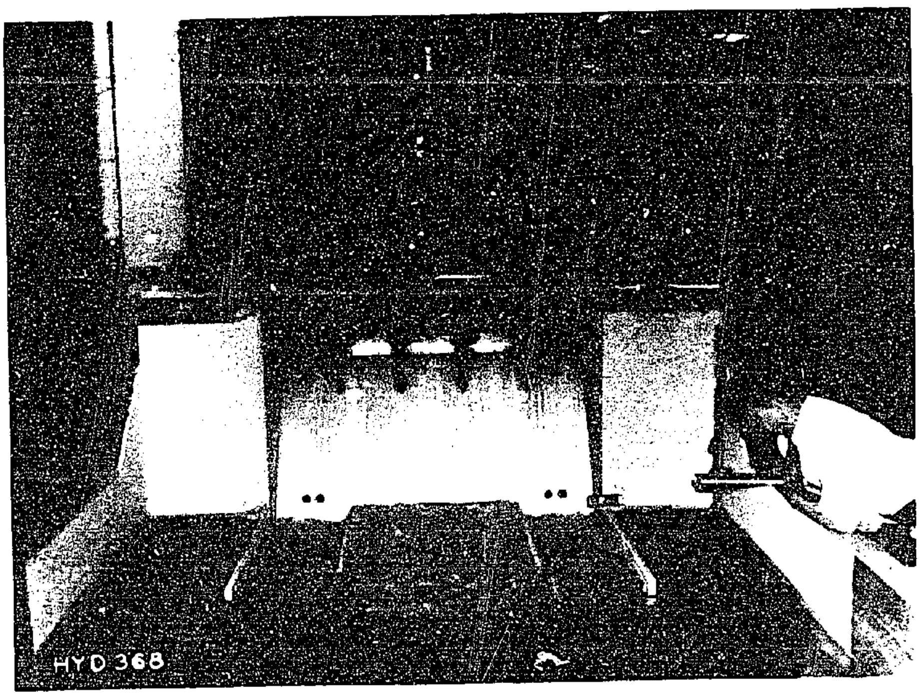


B - Scour after flow of 200,000 Second-feet

CANYON FERRY DAM - RECOMMENDED DESIGN



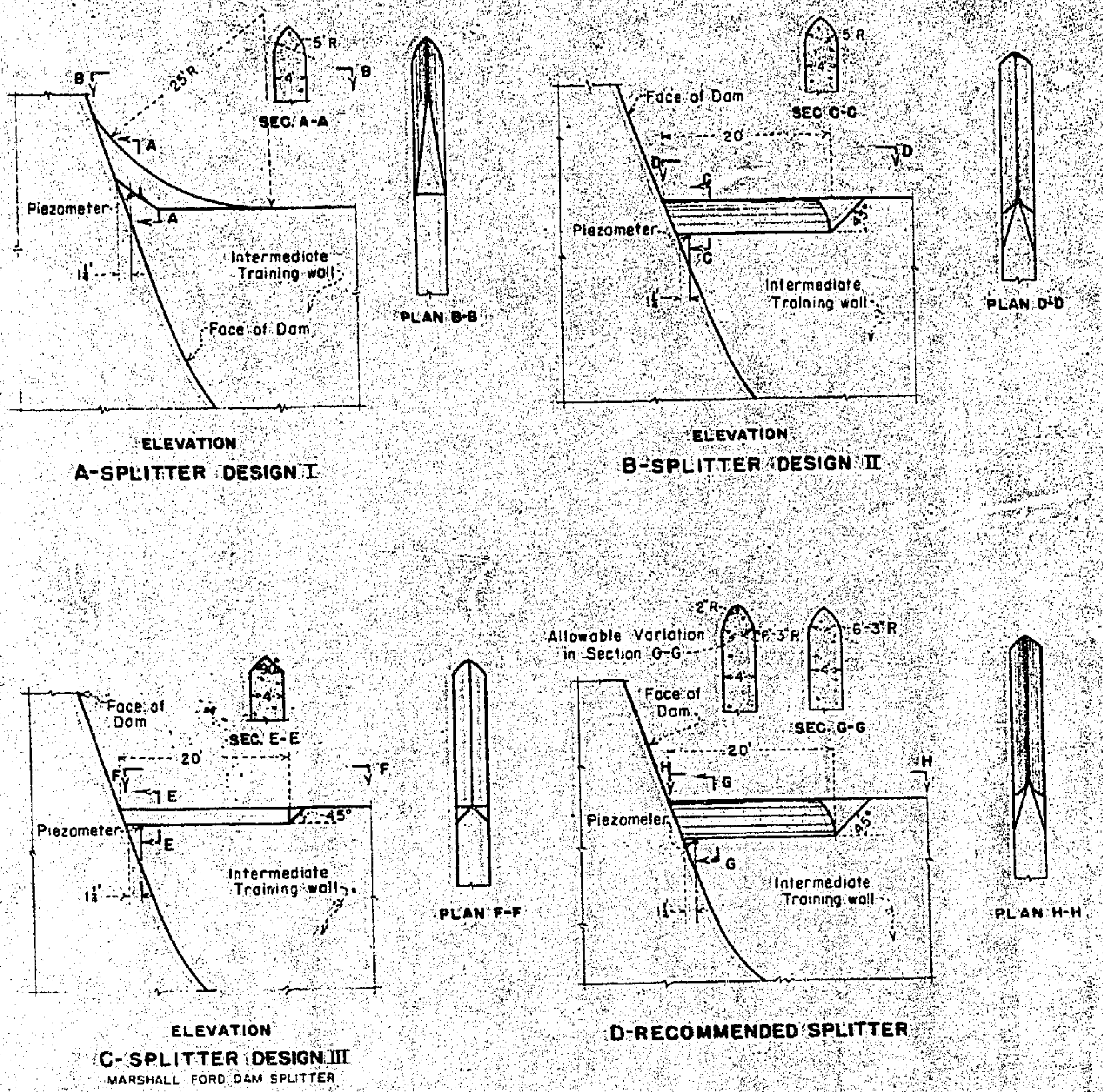
A - River Outlets discharging 10,000 Second-feet



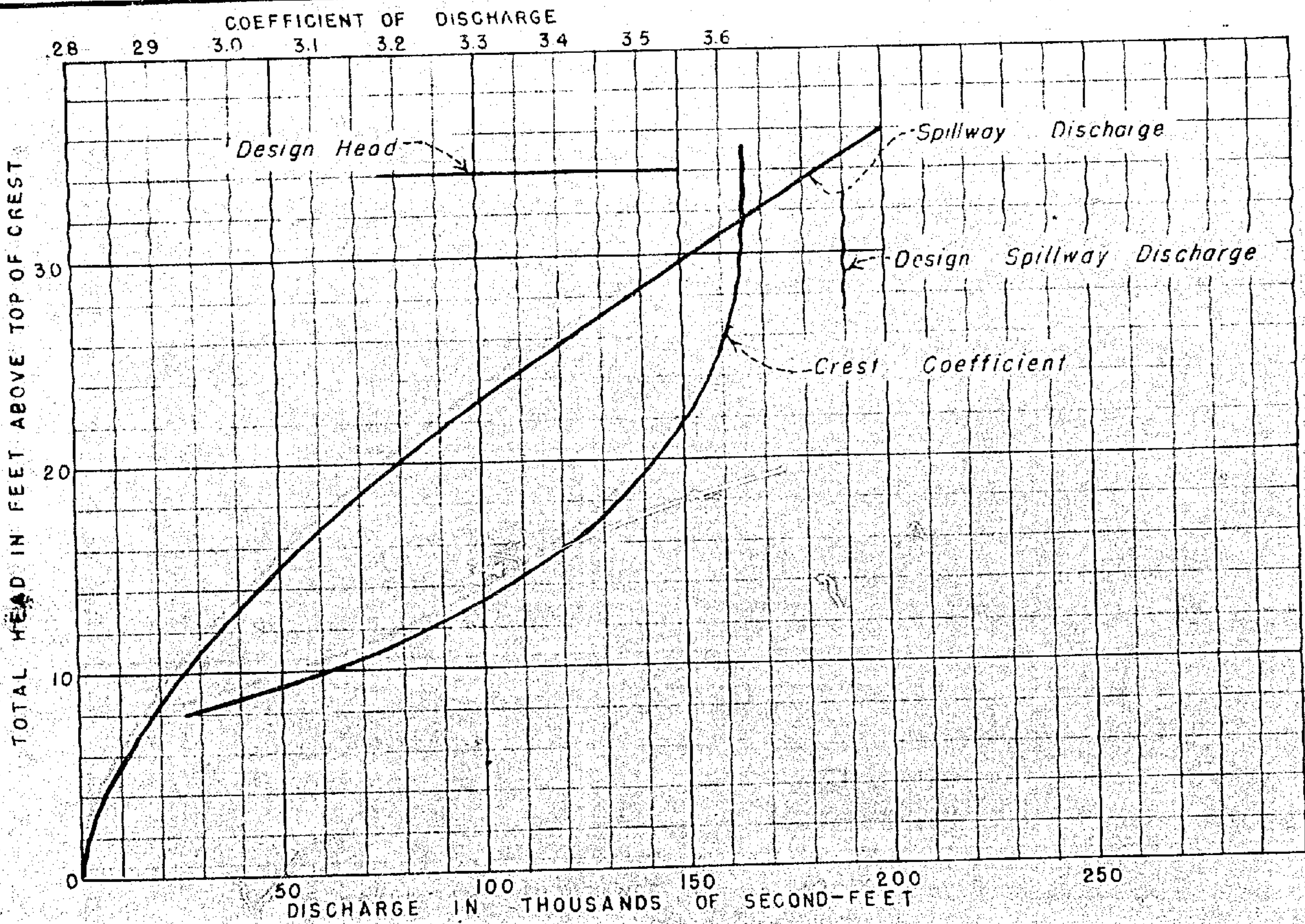
B - End Gates discharging [illegible],000 Second feet each

CANYON FERRY DAM -- RECOMMENDED DESIGN

FIGURE 11



CANYON FERRY DAM
INTERMEDIATE TRAINING WALL SPLITTERS



CANYON FERRY DAM
SPILLWAY RATING CURVE
RIVER OUTLETS CLOSED

FIGURE 12

20