UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 123

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HYDRAULIC MODEL STUDIES RELATING TO THE DESIGN OF THE DAVIS DAM - DAVIS DAM PROJECT, ARIZONIA - NEVADA

By

J. A. LINDSEY

- - -

Denver, Colorado

February 16, 1943

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: HYDRAULIC MODEL STUDIES RELATING TO THE DESIGN OF THE DAVIS DAM, DAVIS DAM PROJECT, ARIZONA-NEVADA

- - -

By J. A. Lindsey, Assistant Engineer

Under Direction of

J. E. Warnock, Engineer

and

R. F. Blanks, Senior Engineer

- - -

Denver, Colorado,
February 16, 1943.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
February 16, 1943

Laboratory Report No. 123
Hydraulic Laboratory
Compiled by: J. A. Lindsey
Reviewed by: J. E. Warnock

Subject: Hydraulic model studies relating to the design of the Davis Dam--Davis Dam Project, Arizona-Nevada.

INTRODUCTION

1. The Prototype

The Davis Dam will be constructed on the Colorado River approximately sixty-seven miles downstream from Boulder Dam and about twenty-nine miles west of Kingman, Arizona, (Figure 1). The dam will be an earth-and-rockfill structure 1,350 feet long, 138 feet high, and will have a reservoir capacity of 1,600,000 acre-feet of active storage, (Figure 2). An unlined curved channel will be cut through the hillside at the left abutment of the dam for the dual purpose of diverting the flow around the dam during the construction stage, and supplying the flow to the spillway and powerhouse in the ultimate development. The powerhouse will contain four or five generators to augment the Boulder power output. Discharge regulation will be provided by two outlets and by an overflow spillway to be constructed to the left of the powerhouse. The outlets will be located to the left and right of the overflow spillway section. Each outlet will have a rectangular bellmouth entrance with a 22-foot by 19-foot radial gate, regulating the discharge onto an ogee apron which has a 75-foot radius bucket on the downstream portion. The overflow spillway will consist of three bays separated by 10-foot thick streamlined piers which provide support for 50-foot by 50-foot spillway gates. When the gates are raised, the flow will pass over an ogee spillway having a 75-foot radius bucket for the downstream portion, which when extended forms the bucket for the outlets. This bucket serves to dissipate the energy of the jets from both spillway and outlets. It is anticipated that the riverbed will retrogress, after the structure is built, sufficiently to lower the tailwater elevation 15 feet to 20 feet, consequently, two tailwater elevations were used in the investigation, i.e., present and ultimate tailwater.

FIG. 1
DRAWING No.1

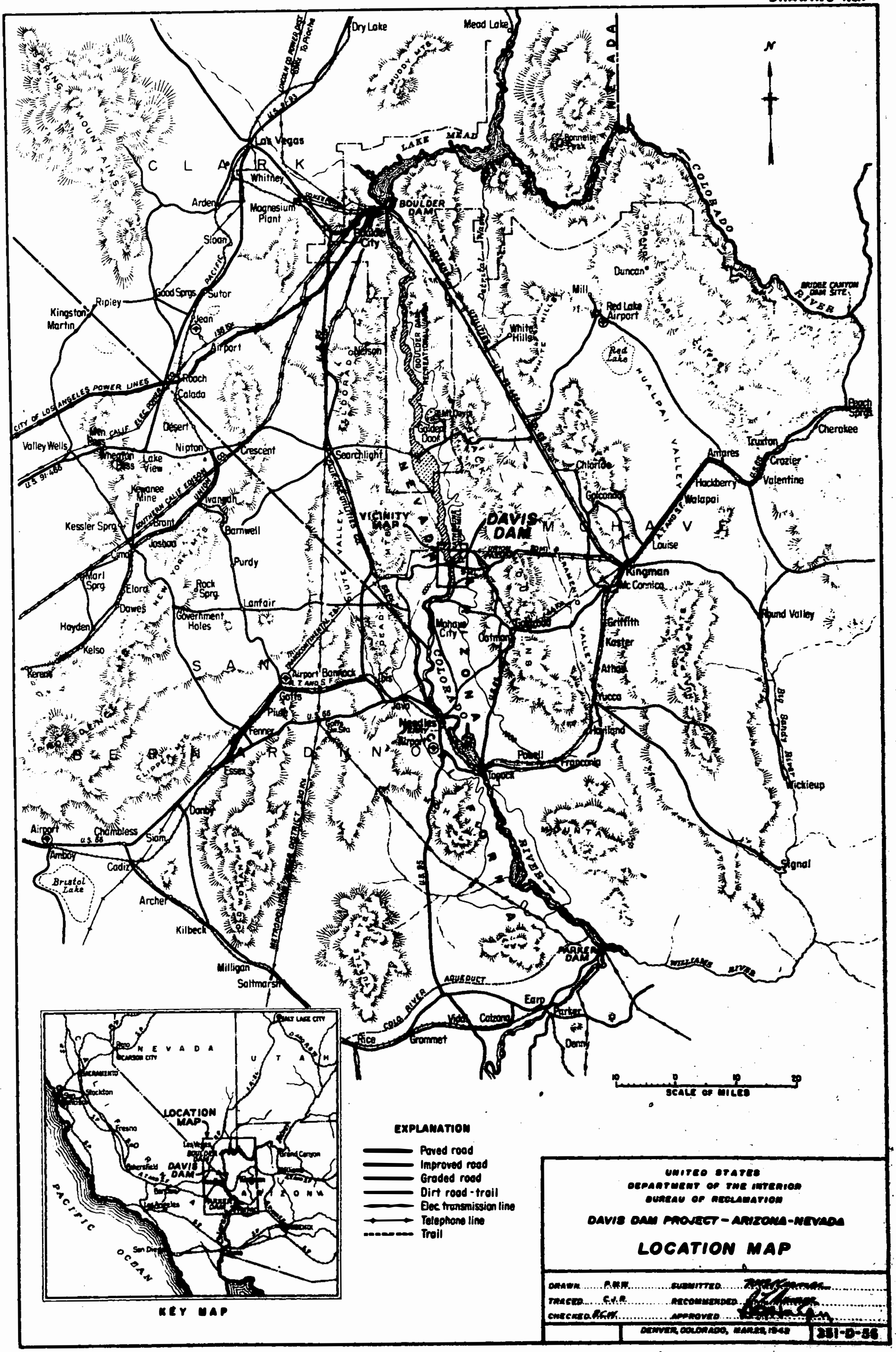


FIG. 2

DRAWING No.8

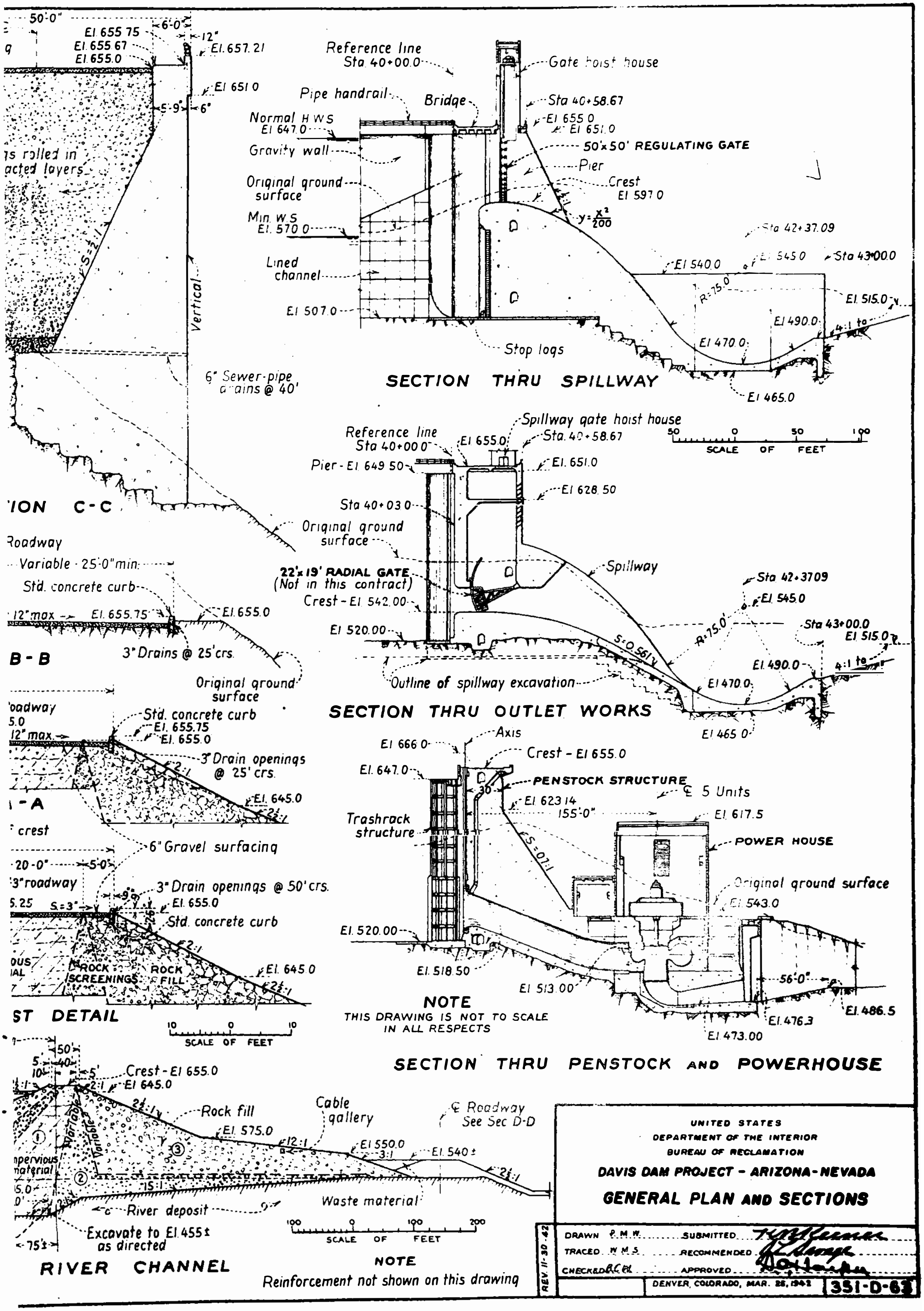
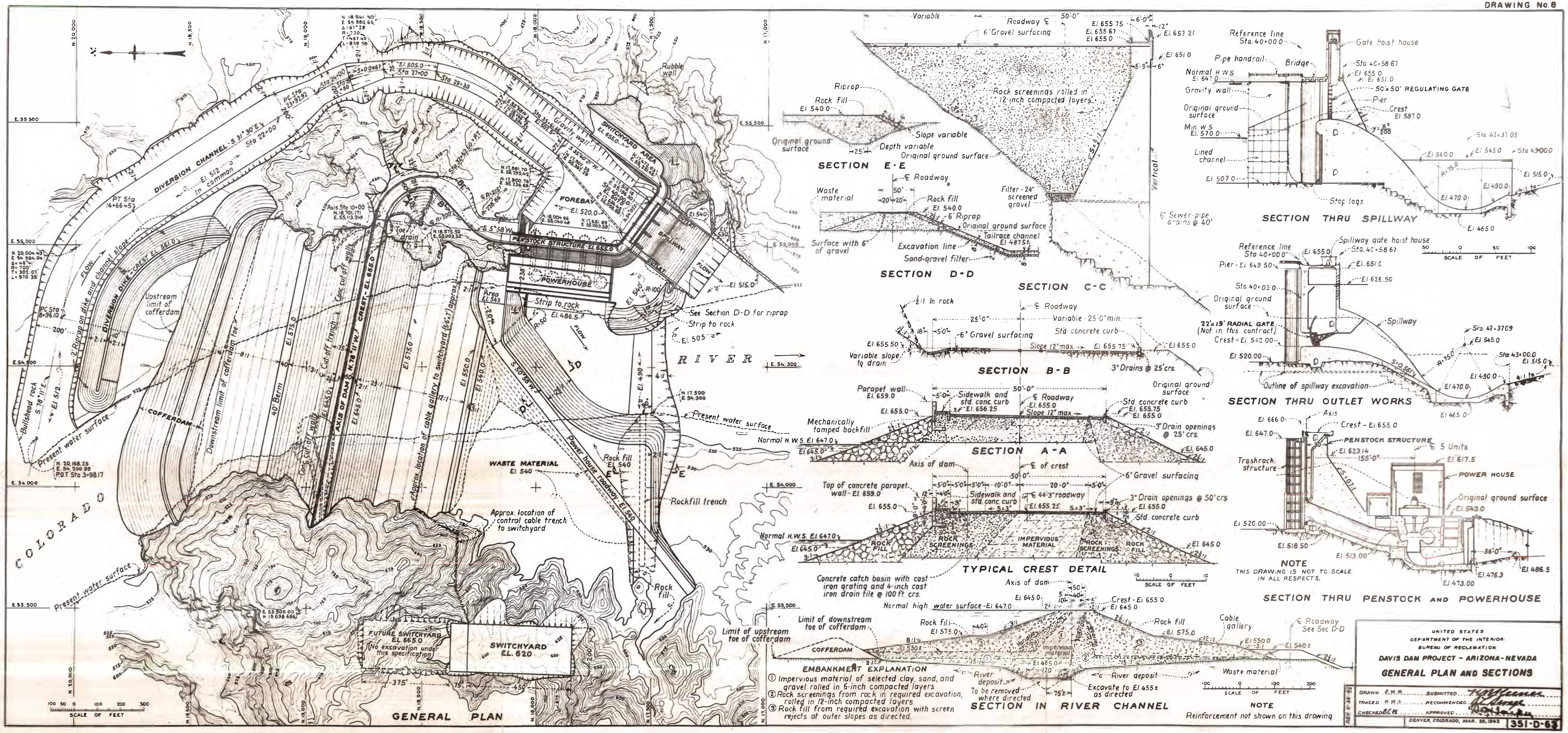


FIG. 2

DRAWING No. 6



2. Purpose of Model Studies

Four models of Davis Dam were constructed to accomplish the following objectives: (1) to determine the discharge calibrations; (2) to determine the most satisfactory designs for the various features of the project; (3) to correct inadequacies of the proposed designs; and (4) to determine the most satisfactory method of operating the spillway and outlet gates.

3. Summary of the Investigation

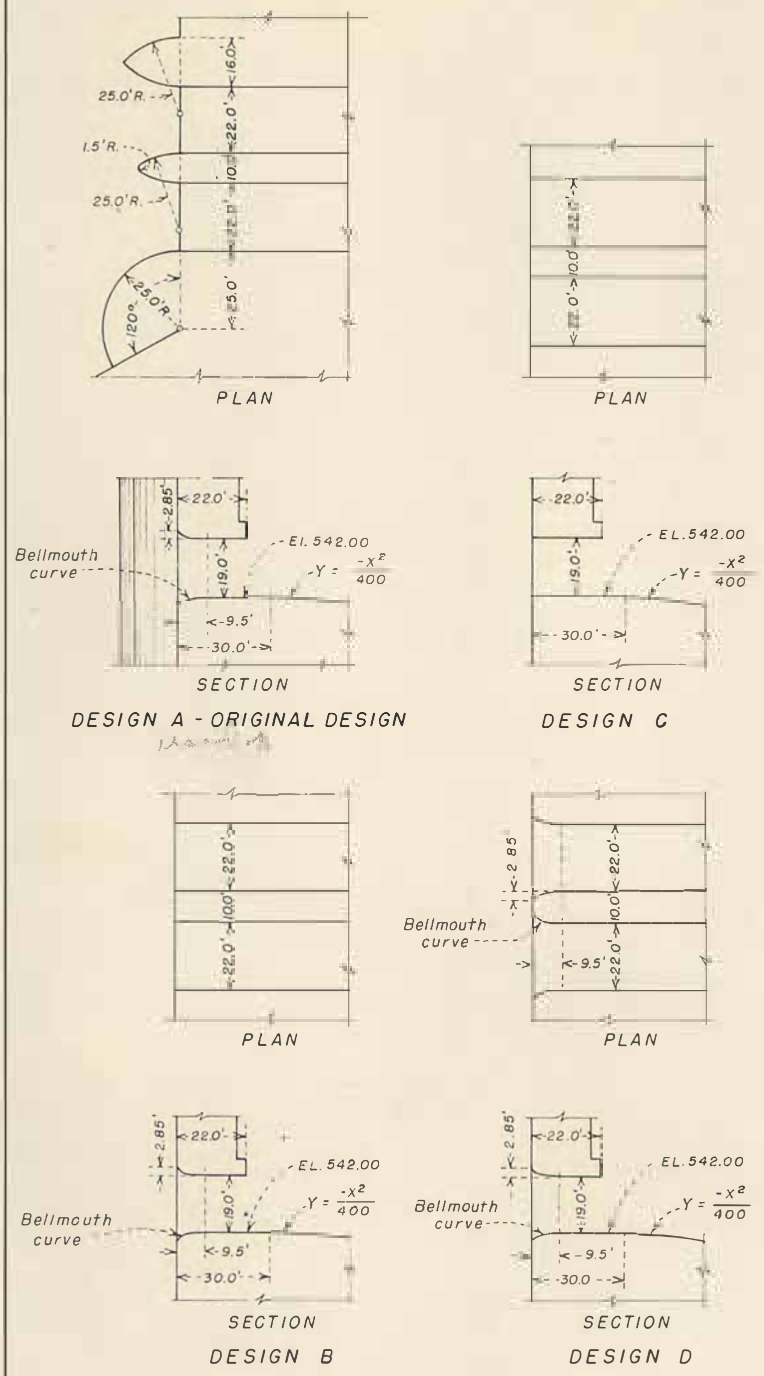
A 1 to 50 scale model of the outlets was first constructed to determine the discharge coefficients for several proposed entrance designs (Figure 3). The original design was selected as the proposed design, as it gave satisfactory discharge coefficients and would be most practical from the structurâl viewpoint. Tests were made of several preliminary designs (Figure 4), for the diversion control structures, but as the scour conditions were unsatisfactory, these tests were deferred until the conclusion of the ultimate design studies.

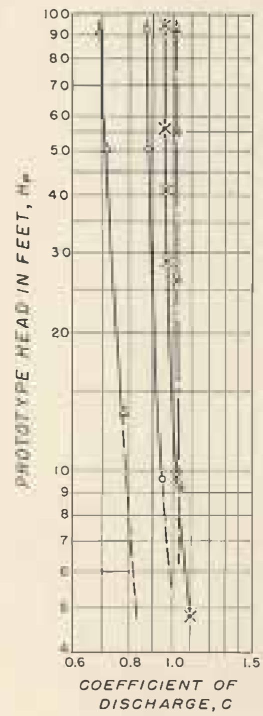
A study of the channel was made on the 1 to 100 scale model of the ultimate development to ascertain the extent of excavation required in the powerhouse forebay approach. Numerous tests were made to determine the most economical and satisfactory forebay excavation design (Figure 5). A wide variety of shapes were tested, varying from the long curved section in Design 1, to the sharp 300-degree turn-back in Design 4. The design in which the excavation made an angle of 60 degrees with the axis of the powerhouse, had the best flow conditions, and at the same time reduced the rock excavation estimates by approximating $250,000 from the original design. Satisfactory results were obtained for the 60-degree scheme for the forebay for either a 5-unit or 4-unit powerplant. Additional economy is possible if the right bank is curved as in Design 8, (Figure 5G). Studies of the powerhouse tailrace channel demonstrated that the retaining walls at the sides of the tailrace, contemplated in the original design, could be eliminated with the exception of a short training wall at the right of the powerhouse.

The recommended spillway bucket profile was evolved from studies on 1 to 100 and 1 to 48 scale models. Action of the high trajectory bucket, contemplated in the original design, was found to be satisfactory with the exception of the scour which occurred at the end of the lip for low discharges (Design 1, Figure 6). Aprons were tried below the lip which helped somewhat in reducing this scour (Designs 2 to 6, Figure 6). However, because of this scour condition and the spray caused by the trajectory of the jet, it was decided to change to a submerged bucket which will act as a roller bucket for low flows and higher tailwater, and as a trajectory bucket for higher flows and a reduced tailwater elevation. This bucket would be 40 feet lower than originally proposed and can have a radius of 75 feet rather than 100 feet, (Figure 6-F). The rock bench downstream from the bucket should not be excavated lower than elevation 515.00 as the rock shelf will help to maintain a hydraulic jump on the spillway bucket at higher discharges. The training walls between the outlets and overflow spillway can be eliminated with no ill effects to the flow conditions.

Architectural considerations indicated the desirability of placing one outlet on each side of the overflow spillway rather than both to the right, as originally planned. This rearrangement was very satisfactory as no reduction in the discharge coefficient of the left outlet was noted and the flow conditions on the bucket were improved.

Tests indicated that teeth and steps would help to dissipate the energy of the jet, but they were not employed on the final design due to the difficulty of repair and maintenance under water. The spillway





EXPLANATION

—×— Design A
—○— Design B
—△— Design C
-·—✳—· Design D

$$C = \frac{Q}{A\sqrt{2gh}}$$

where C = Coefficient of discharge
Q = Discharge in cubic feet per second
A = Area of opening in square feet.
g = Acceleration of gravity.
h = Head measured from top of opening to water surface.

Note: Dimensions are in prototype values.

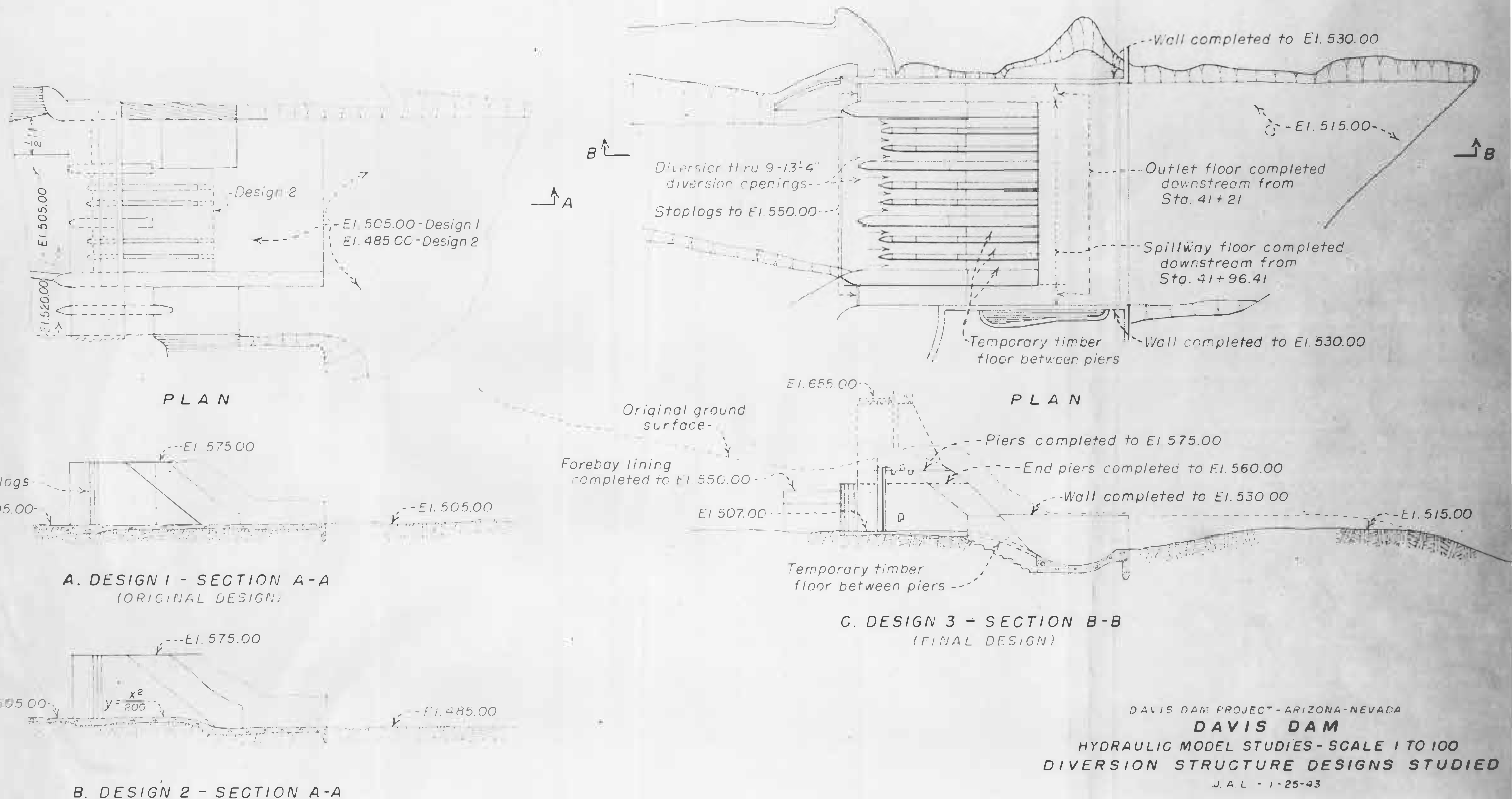
DAVIS DAM PROJECT - ARIZONA - NEVADA

DAVIS DAM

HYDRAULIC MODEL STUDIES - 1 TO 50 SCALE

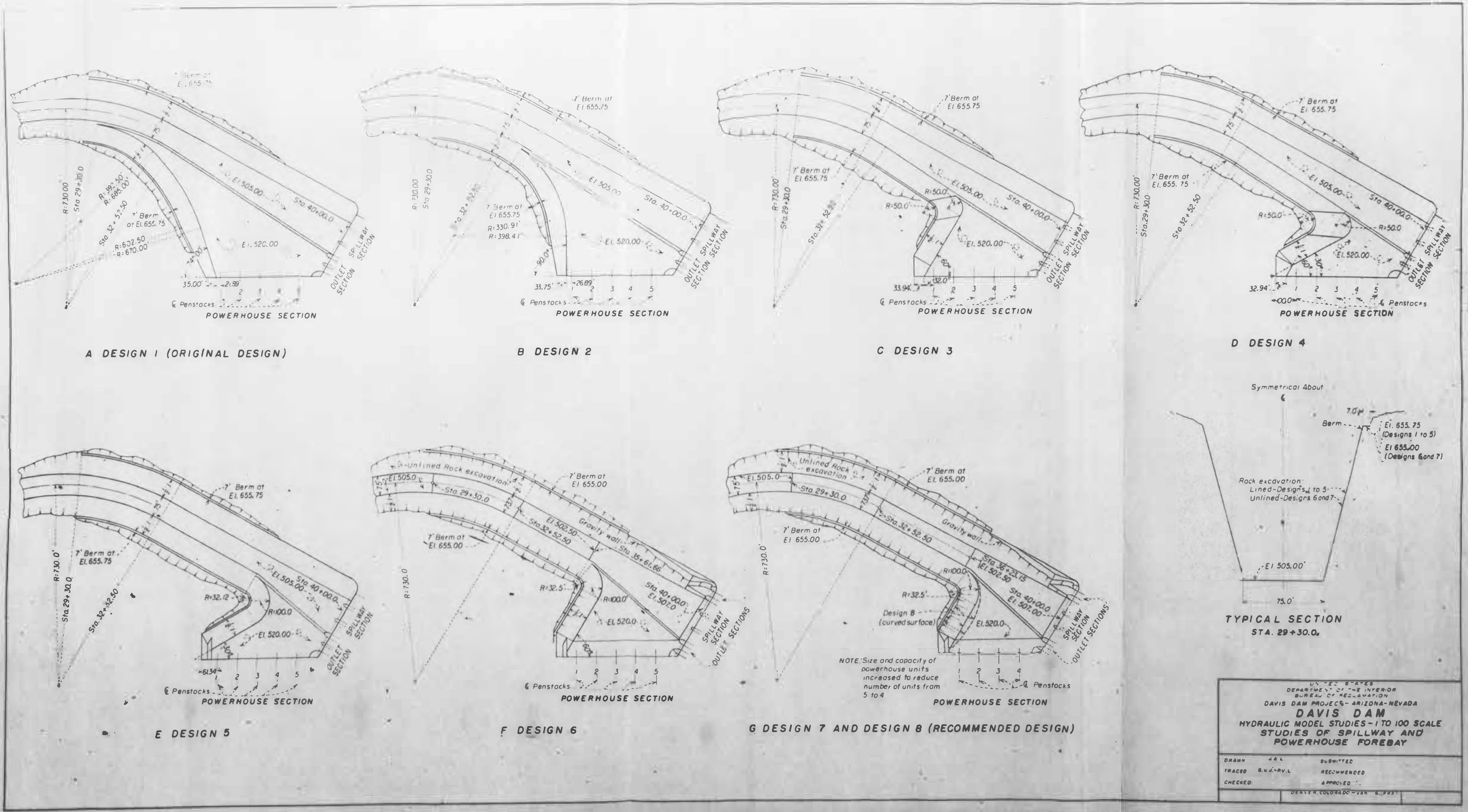
COEFFICIENTS OF OUTLET DESIGNS

J. A. L. - 11-19-42



DAVIS DAM PROJECT - ARIZONA - NEVADA
DAVIS DAM
HYDRAULIC MODEL STUDIES - SCALE 1 TO 100
DIVERSION STRUCTURE DESIGNS STUDIED
J.A.L. - 1-25-43

FIGURE 5


A DESIGN 1 (ORIGINAL DESIGN)
B DESIGN 2
C DESIGN 3
D DESIGN 4
E DESIGN 5
F DESIGN 6
G DESIGN 7 AND DESIGN 8 (RECOMMENDED DESIGN)
POWERHOUSE SECTION
OUTLET SECTION
SPILLWAY SECTION
℄ Penstocks
7' Berm at El. 655.75
7' Berm at El. 655.00
El. 505.00
El. 520.00
Sta 29+30.0
Sta 32+52.50
Sta 40+00.0
R=730.00
Unlined Rock excavation
Gravity wall
Design 8 (curved surface)
NOTE: Size and capacity of powerhouse units increased to reduce number of units from 5 to 4
TYPICAL SECTION
STA. 29+30.0
Symmetrical About ℄
Berm
El. 655.75 (Designs 1 to 5)
El 655.00 (Designs 6 and 7)
Rock excavation: Lined-Designs 1 to 5 Unlined-Designs 6 and 7
El 505.00'
75.0'
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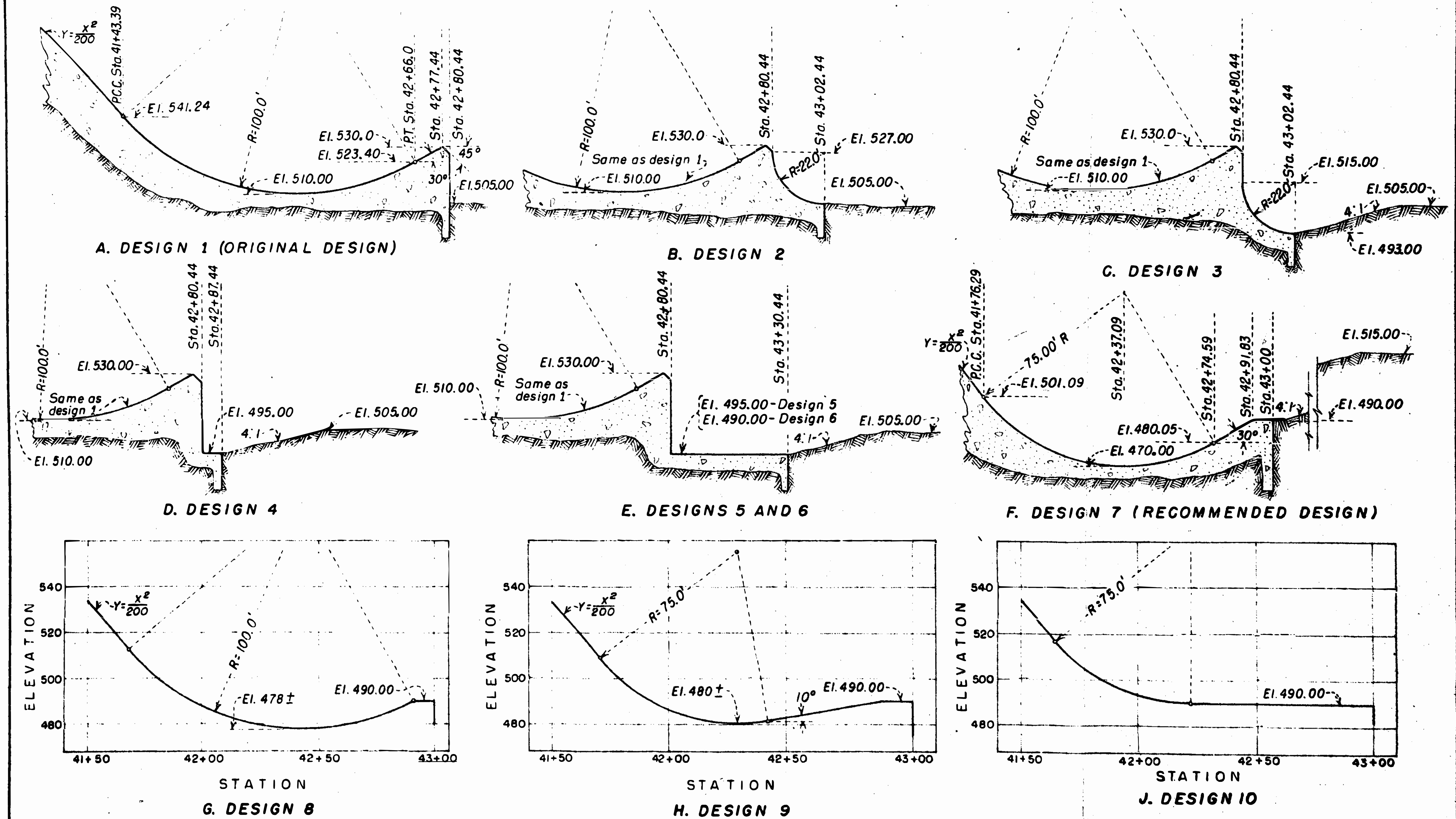
DAVIS DAM PROJECT-ARIZONA-NEVADA
DAVIS DAM
HYDRAULIC MODEL STUDIES-1 TO 100 SCALE
STUDIES OF SPILLWAY AND
POWERHOUSE FOREBAY
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO



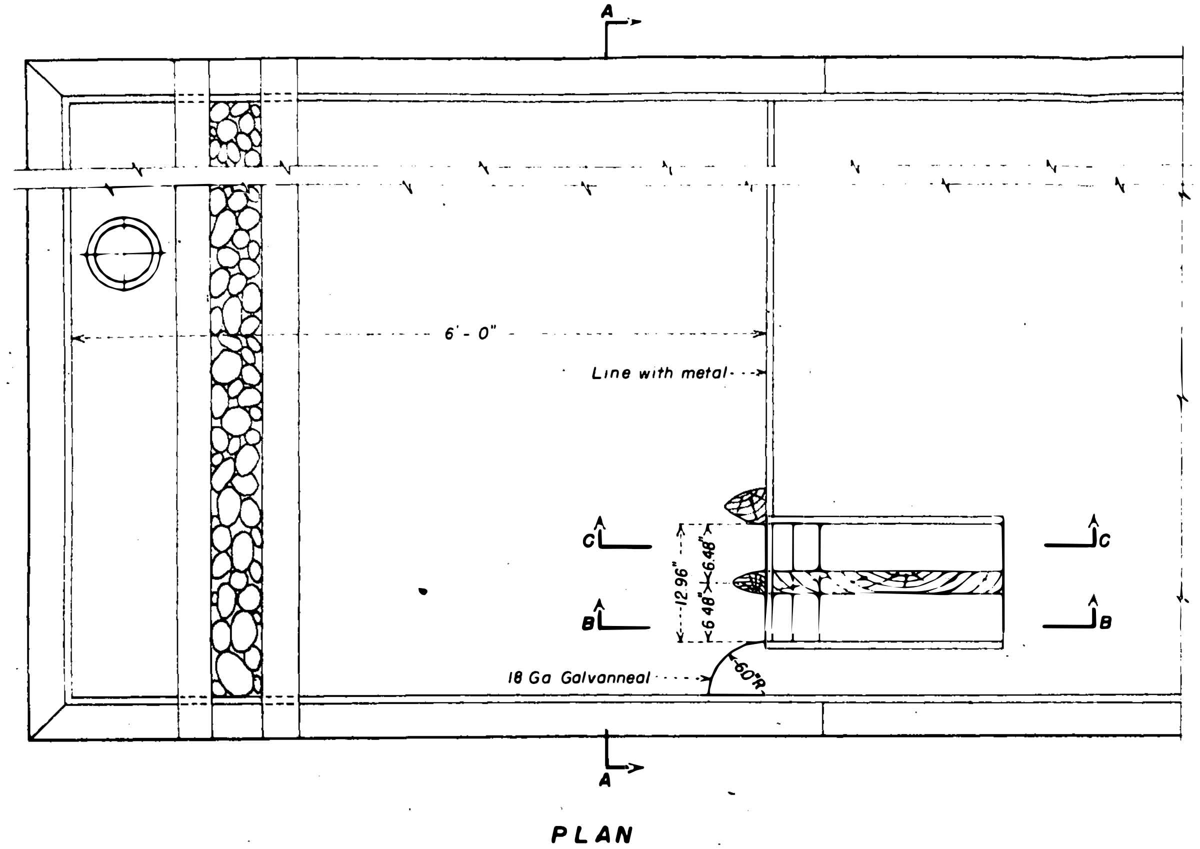
DAVIS DAM PROJECT-ARIZONA-NEVADA

DAVIS DAM

HYDRAULIC MODEL STUDIES-1 TO 100 AND 1 TO 48 SCALE

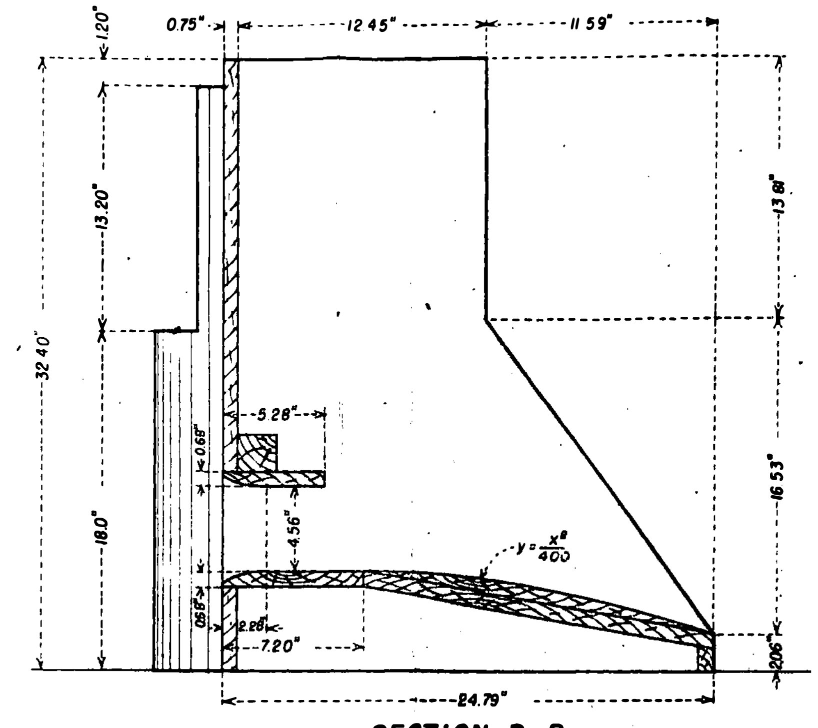
SPILLWAY BUCKET DESIGNS

FIGURE 7

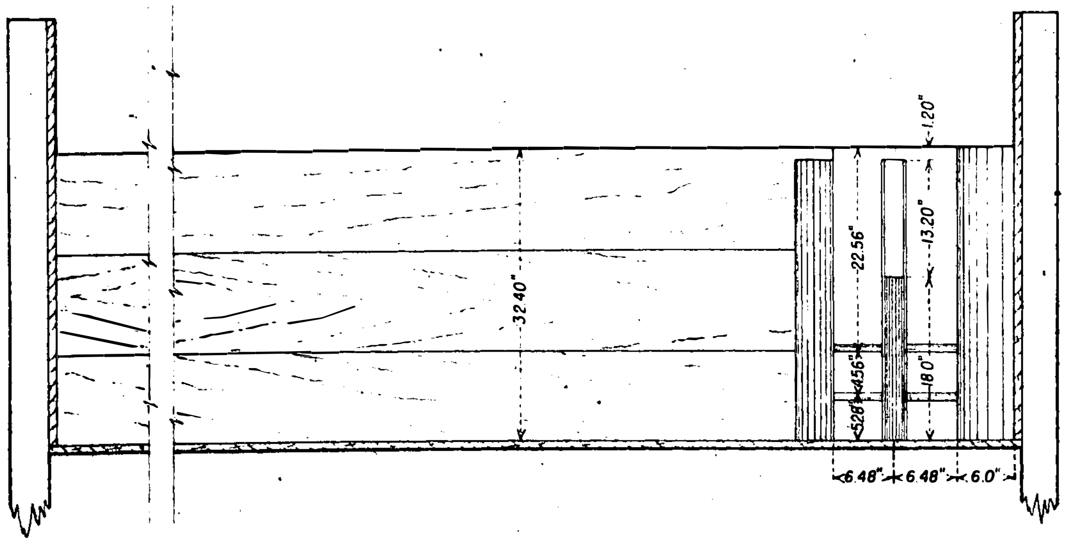


PLAN

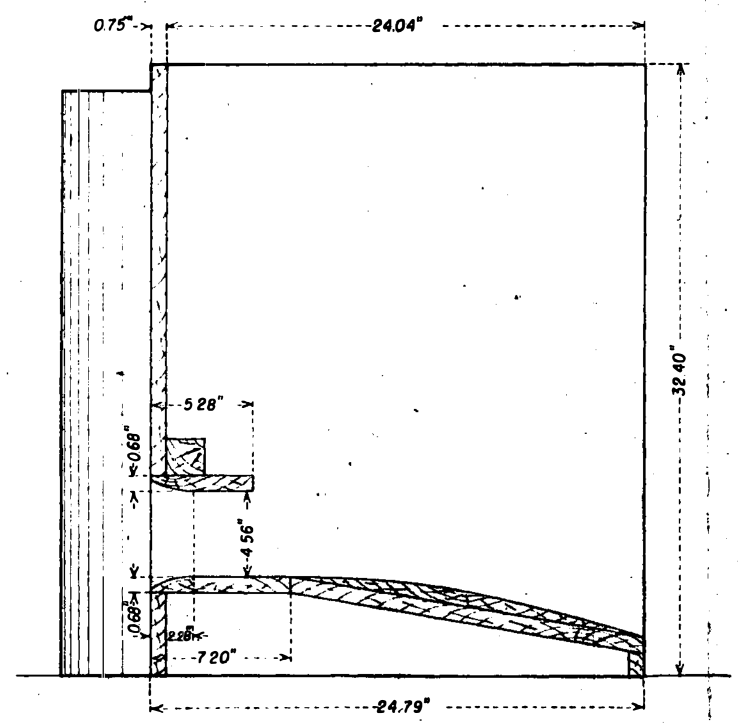
Notes:
Seal all joints with white lead
Use redwood.



SECTION B-B
ENLARGED



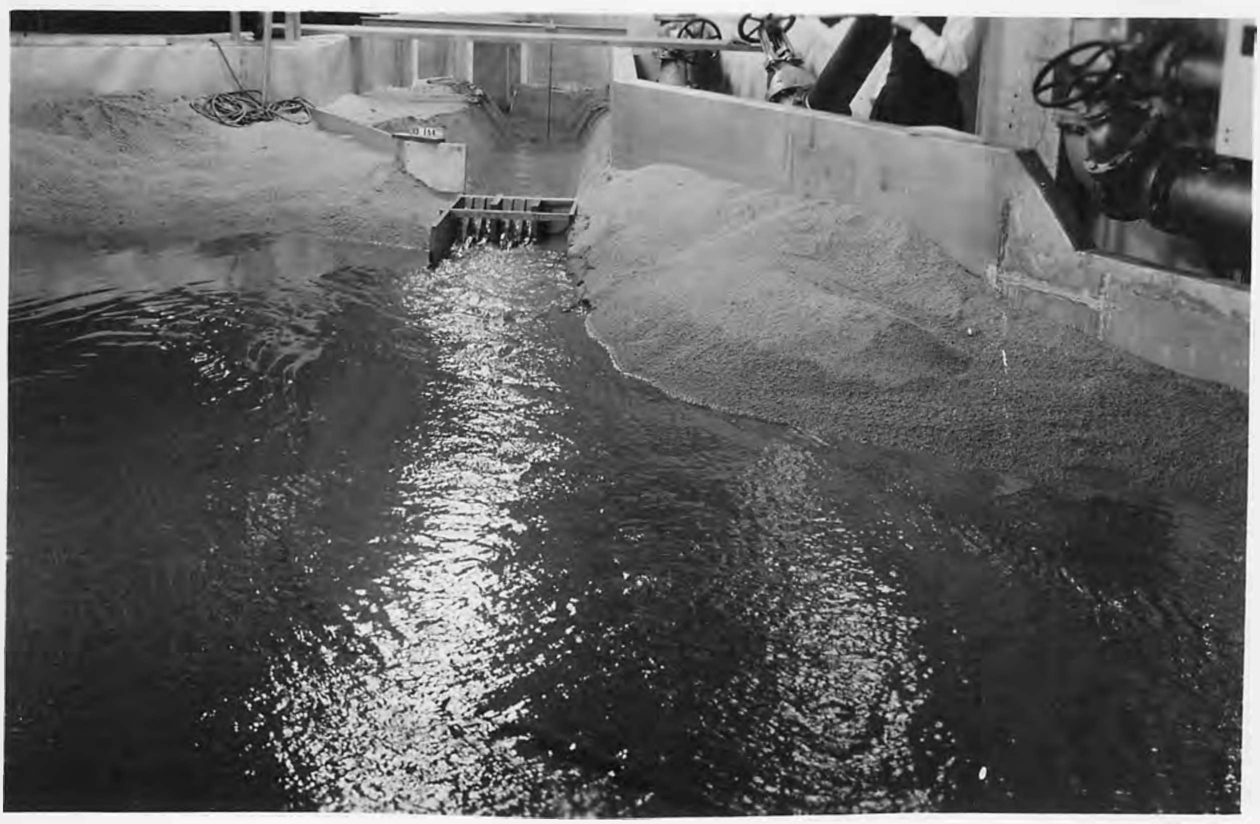
SECTION A-A



SECTION C-C
ENLARGED

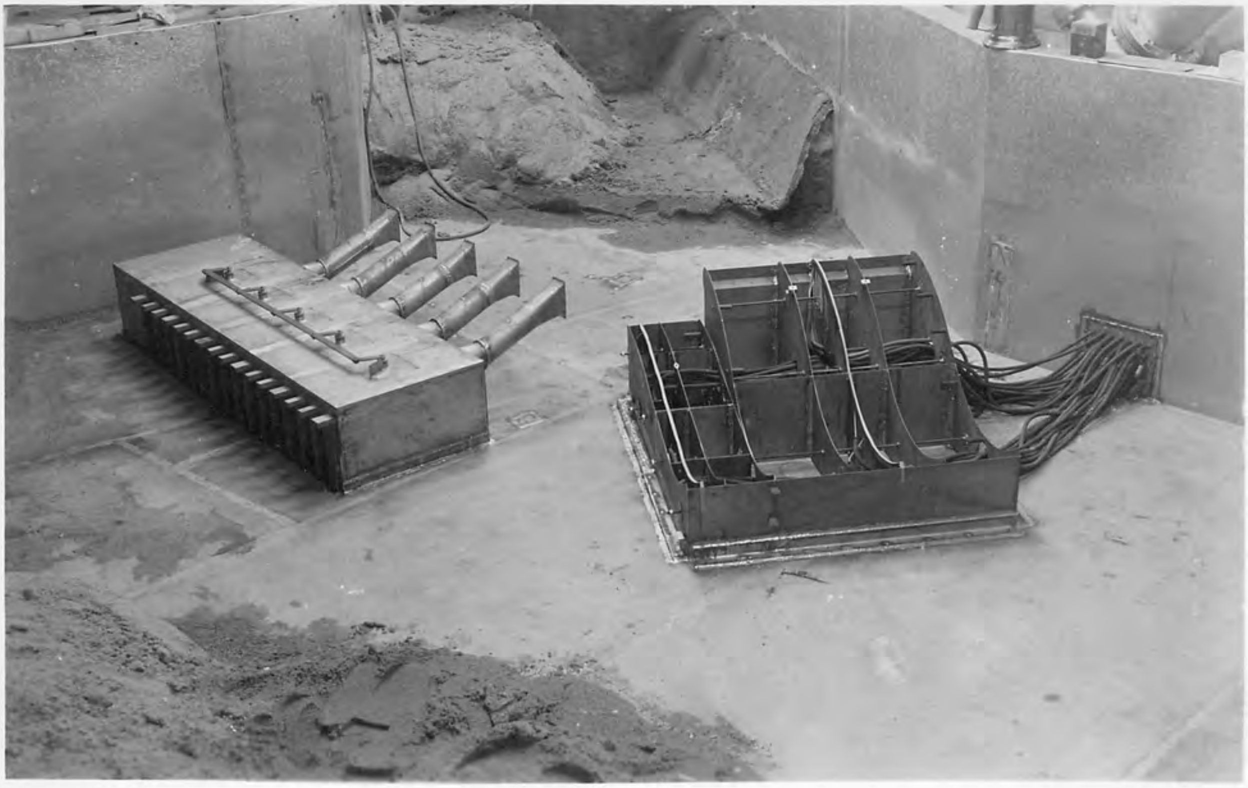
DAVIS DAM PROJECT - ARIZONA-NEVADA
DAVIS DAM
HYDRAULIC MODEL STUDIES - 1 TO 50 SCALE
DETAILS OF CALIBRATION MODEL

A. MODEL ARRANGEMENT.



B. FLOW CONDITIONS AT MAXIMUM DISCHARGE, 60,000 SECOND-FEET.

DAVIS DAM DIVERSION MODEL - ORIGINAL DESIGN - 1 TO 100 SCALE



A. CONSTRUCTION DETAILS OF POWERHOUSE AND SPILLWAY SECTIONS.

B. SCOUR OF RIVERBED AFTER 10 HOURS OF 250,000 SECOND-FEET DISCHARGE (POTOTYPE VALUES).

DAVIS DAM, ORIGINAL DESIGN, ULTIMATE STAGE MODEL - 1 TO 100 SCALE.

retaining walls should be made vertical to prevent the formation of undesirable eddies on the bucket, and the spillway gates should be operated with the center gate open one-half as much as the right and left gates to improve the flow conditions.

Still and motion pictures of the final design were taken for numerous operating conditions, and are on file in the hydraulic laboratory to be used in future model prototype comparison studies.

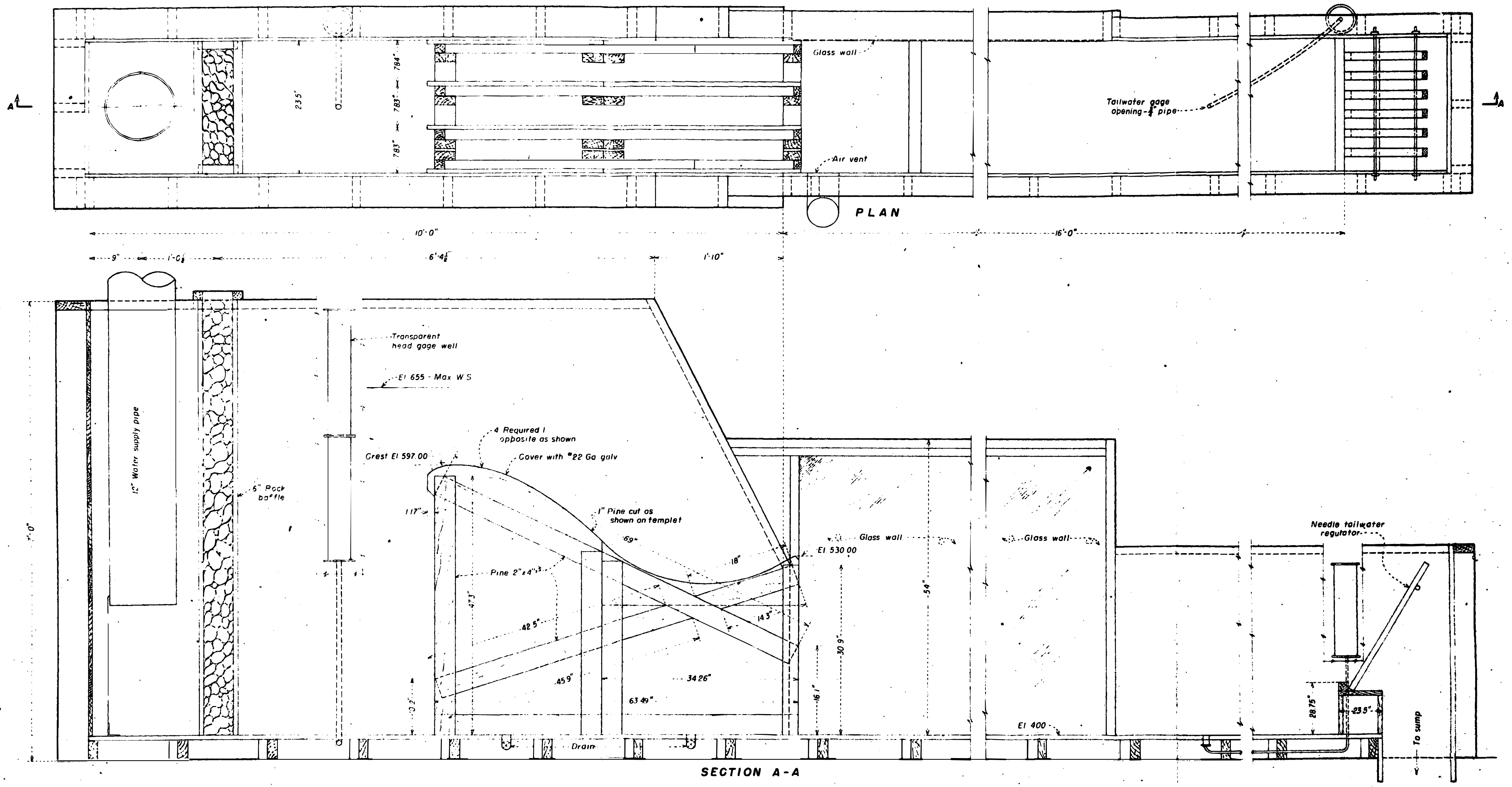
The final design of the diversion plan was tested on the model and found to be entirely satisfactory. (To reduce the velocities through the approach channel, stop-logs should be placed in the right bay after the powerhouse wall has been constructed.)

4. The Models

The first model on the Davis Dam Project was a 1 to 50 scale model of the outlet works, constructed to determine the discharge calibration and the relative efficiency of several different pier shapes of the recommended outlet design (Figure 7). The model was made of redwood and placed in a metal-lined box with no topography.

A model of the diversion plan was constructed to a scale of 1 to 100 to include the diversion channel and approximately 2,750 feet of the river downstream from the axis of the dam (Figure 8). The model was constructed of redwood and concrete with sand used to represent the topography downstream. After testing the preliminary diversion plan, the ultimate designs of the powerhouse and spillway were placed in the 1 to 100 scale model box and tested. The powerhouse was constructed of 12-gage and 20-gage galvanized iron with brass valves to regulate the discharge through the draft tubes (Figure 9). The spillway was constructed with redwood for the piers and gates, sheet metal radial gates, and a concrete spillway formed by using metal templates as guides.

To determine the relative scour of several proposed designs, a sectional profile model of a portion of the spillway was constructed



DAVIS DAM PROJECT - ARIZONA-NEVADA
DAVIS DAM
HYDRAULIC MODEL STUDIES - 1 TO 48 SCALE
SECTIONAL MODEL DETAILS

to a scale ratio of 1 to 48, and placed in a glass-paneled flume. The model was constructed by forming ribs of 2 inch by 4 inch and 1 inch pine boards into the spillway cross-sectional shape and covering with 24-gage galvanized iron (Figure 10). A sheet of 12-gage galvanized iron was used to provide the gate for regulating the forebay water surface elevation.

5. Calibration of Outlet Orifices

Calibration tests were made on the 1 to 50 scale model to determine the discharge coefficient for the submerged outlet portions of the spillway section and the effect of various entrance conditions on the coefficient. The coefficient used was the value of C in the equation, $C = \frac{Q}{A\sqrt{2gh}}$, where Q equals the prototype discharge in cubic feet a second. A equals the area of the prototype opening in square feet, g equals the value of the acceleration of gravity of 32.16 a second, and h equals the prototype head measured in feet from the top of the opening to the water surface upstream.

The original outlet design, (Design A, Figure 3), was in effect a rectangular semibellmouth with a flat curved surface at the top and bottom of the entrance while on the sides, curved piers extended beyond the opening (Figure 3). The bellmouth curve was designed from data previously obtained in the hydraulic laboratory.[1] In Design B, the curved pier noses were removed to make the opening a sharp 90-degree corner on the sides. In Design C, the bellmouth curves on the top and bottom of the entrance were replaced with sharp

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1 Hydraulic Model Studies for the Design of Sluice Entrances for Grand Coulee Dam, Hydraulic Machinery Laboratory Report No. HM-1, Denver, Colorado, September 15, 1939, (HYD-66).

90-degree corners, making the opening sharp on all four sides. Design D consisted of the original bellmouth curve on the top, bottom, and the sides of the entrance, making a rectangular bellmouth opening.

The original design, with the bellmouth curve on the top and the bottom, gave a coefficient which varied from 1.09 at a head of five feet to 0.95 at a head of 100 feet, prototype values. This coefficient was greater than 1.0 as the head was measured from the top of the opening rather than the center. In Design B, with the pier noses removed, the resulting contraction of the jet lowered the coefficient to 1.0 at a head of five feet, and 0.87 at a head of 100 feet. In Design C, the sharp corners of all four sides contracted the jet sufficiently to lower the coefficient to 0.84 at a head of five feet, and 0.68 at a head of 100 feet. The tests clearly showed that Designs B and C would be uneconomical as the size of the opening would have to be considerably increased with a consequent increase in the cost of the control mechanism. The effect of rounding all corners to form a rectangular bellmouth, (Design D) was tried. The coefficients for this design were very good, varying from 1.03 at a head of five feet to 1.02 at a head of 100 feet. Design A did not give as large a coefficient at the higher heads as Design D because of the suppression of the contraction of the jet by the piers which extended beyond the opening. The original design was used, rather than Design D, as the piers were required for structural reasons. The outlets were separated on the final design to place one on each side of the spillway. Consequently, the calibration curve for Design A may not be correct, although tests on the 1 to 100 model indicated that the coefficients would be very similar to those with the outlets together.

6. Preliminary Diversion Studies

The design of the temporary structure in the spillway section, which would discharge the river flow during the construction of the powerhouse, was studied on the 1 to 100 scale model to determine the

the flow conditions in the structure and the probable scouring action of the flow on the channel downstream (Figure 8). When the original model was tested, the flow conditions through the structure were fairly satisfactory at the lower discharges, but at the maximum design discharge of 60,000 second-feet prototype, the scour was extremely severe immediately downstream from the structure (Figure 11). As the rock at the damsite is of doubtful quality, this scour would undermine the structure and might conceivably result in its total destruction. The model was then revised by curving the downstream portion of the apron downward on a parabolic curve from elevation 505.00 to 485.00 to form a hydraulic jump which would dissipate the energy of the jet on the apron and not on the rock downstream. This revision decreased the scour somewhat but was not as effective as desired, for the tailwater elevation was too high with respect to the apron, thus submerging the jump and reducing its effectiveness. The study of the original diversion plan was discontinued as the ultimate design models were ready to install in the 1 to 100 scale model box. These early tests demonstrated that the temporary spillway would have to be provided with an effective energy dissipator or the structure could possibly be destroyed by the scouring and undermining action of the flow as it leaves the apron.

7. Forebay Channel Studies

When the preliminary studies were concluded, the structure representing the ultimate stage of the powerhouse and spillway were placed in the 1 to 100 scale model box (Figure 9). Studies were made to ascertain the adequacy of the forebay channel. The directions of the currents in the forebay were determined by adding a small stream of potassium permanganate solution to the water.

The initial tests on the original design demonstrated that when the flow was passing through the powerhouse only, the flow had a tendency to concentrate on the left side of the forebay channel and form a return current on the right side of the channel, leaving an area in the center with no apparent motion (Figure 5-A). At the higher discharges, with the spillway in operation, the flow conditions were good as the greater portion of the flow continued straight over the spillway while that portion which entered the penstocks turned at the point where the channel widened, thus preventing the formation of motionless areas or upstream currents in the forebay.

In Design 2, the right bank was extended perpendicular to the powerhouse (Figure 5-B). Flow conditions in this design were only slightly improved over those in the original design as the upstream currents and motionless area were still formed at the lower discharges.

In Design 3, the right bank was extended from the edge of the powerhouse parallel to the axis of the spillway (Figure 5-C). Some eddies were present when this design was tested, but they were not as large as on the preceding design and the excavation would be considerably less.

In Design 4, (Figure 5-D), the right bank was extended from the edge of the powerhouse at an angle of 30 degrees from the axis of the powerhouse. There were less eddies with this design than with any of the previous designs tested. This design was abandoned, however, as a vortice was intermittently formed in front of Penstock No. 1.

Two designs were proposed, Designs 5 and 6, similar to designs 4 and 3, respectively, differing in the curvature of the excavation (Figures 5-C, D, E, and F). A series of tests were made to determine the head discharge relationships through the spillway and powerhouse for Designs 2, 5, and 6 (Figures 5-B, E, and F, 12 and 13). Such a study was necessary, as any design which would entail greater head losses through the approach channel would lower the water surface elevation above the penstocks, reducing the power head. If this head loss were to amount to several feet, the saving in construction costs

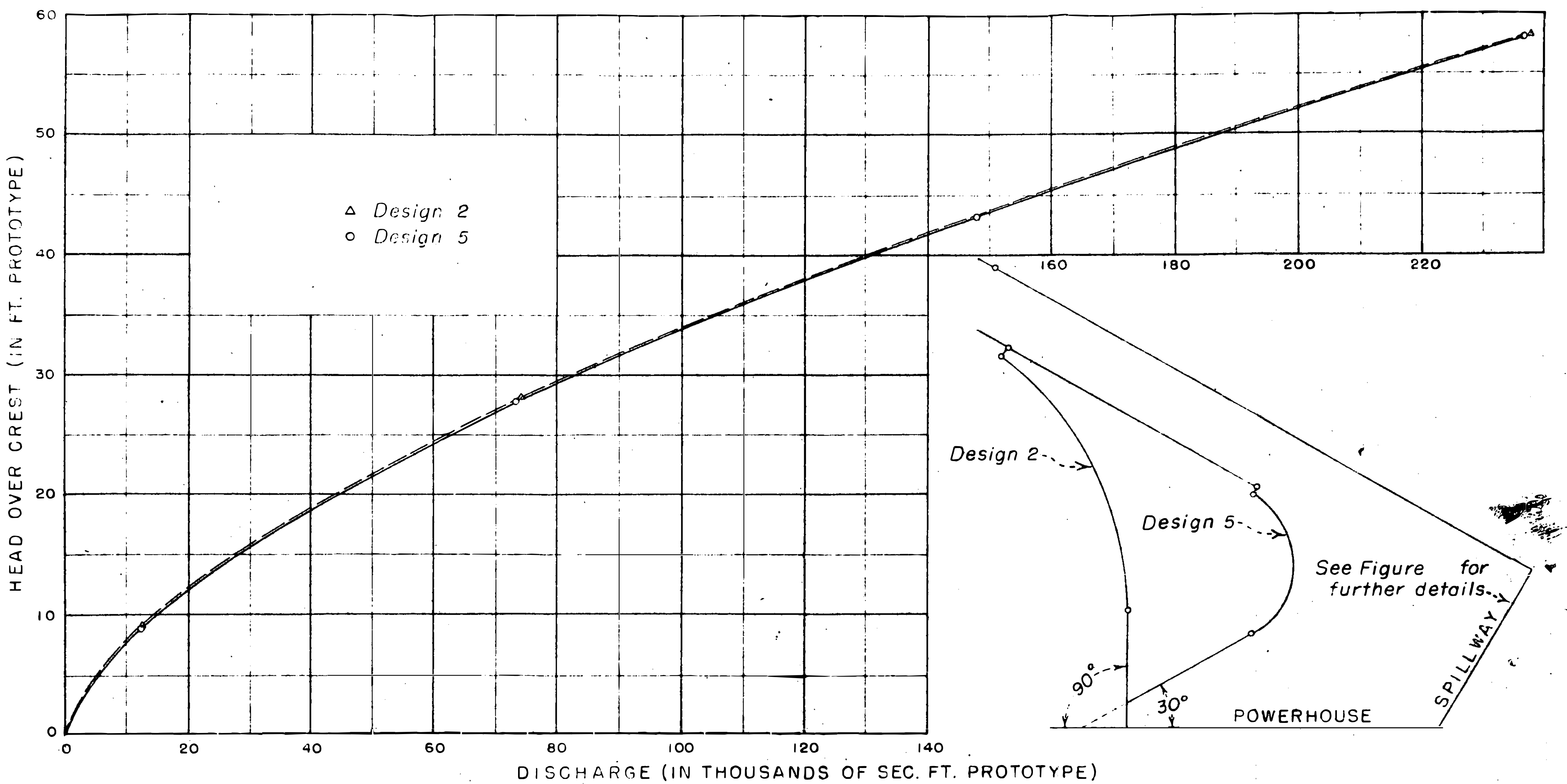
A. DESIGN 1 - ORIGINAL DESIGN.

B. DESIGN 2.

DAVIS DAM DIVERSION MODEL - DESIGNS 1 AND 2 - 1 TO 100 SCALE - SCOUR AFTER 100 MINUTES OF 60,000 SECOND-FEET DISCHARGE. (PROTOTYPE VALUES).

through reduction of the rock excavation would be more than offset by the loss in power revenue during the life of the structure. It was necessary to use exaggerated discharges through the powerhouse in these tests, for at normal prototype discharges, no differences could be detected between the various proposed designs. The shape of the forebay had very little effect on the regain of pressure head from velocity head, or on the amount of water which could be made to pass through the penstocks or spillway at a given reservoir elevation (Figures 12 and 13). It was concluded that eddies present in Designs 2 and 6, prevented the regain of velocity head, while in Design 5, it was caused by the friction loss through the circuitous approach. Design 6 appeared to have the most satisfactory flow conditions and was tentatively recommended. As an economy measure, the concrete lining was eliminated.

Design 7, similar to Design 6, was installed in the model and tested to ascertain flow conditions in the event the number of power units were decreased from 5 to 4 (Figure 5-G). Flow conditions were very satisfactory. However, a motionless area was present along the right wall near the powerhouse which indicated that the wall could be turned back with a curved surface, Design 8, rather than the plane surface used in Design 7 (Figure 5-G). As Design 8 would further reduce the required excavation and at the same time slightly improve the flow conditions, it is therefore recommended that this design be used on the prototype. It was noted that as the spillway discharge increased, the flow entering the penstocks moved farther downstream before turning back and entering the penstocks. It may be anticipated, therefore, that at a constant reservoir elevation, the head available at the turbines will drop somewhat when the spillway discharge increases, due to the increased head losses in the forebay.



DAVIS DAM PROJECT - ARIZONA - NEVADA

DAVIS DAM

HYDRAULIC MODEL STUDIES - 1 TO 100 SCALE

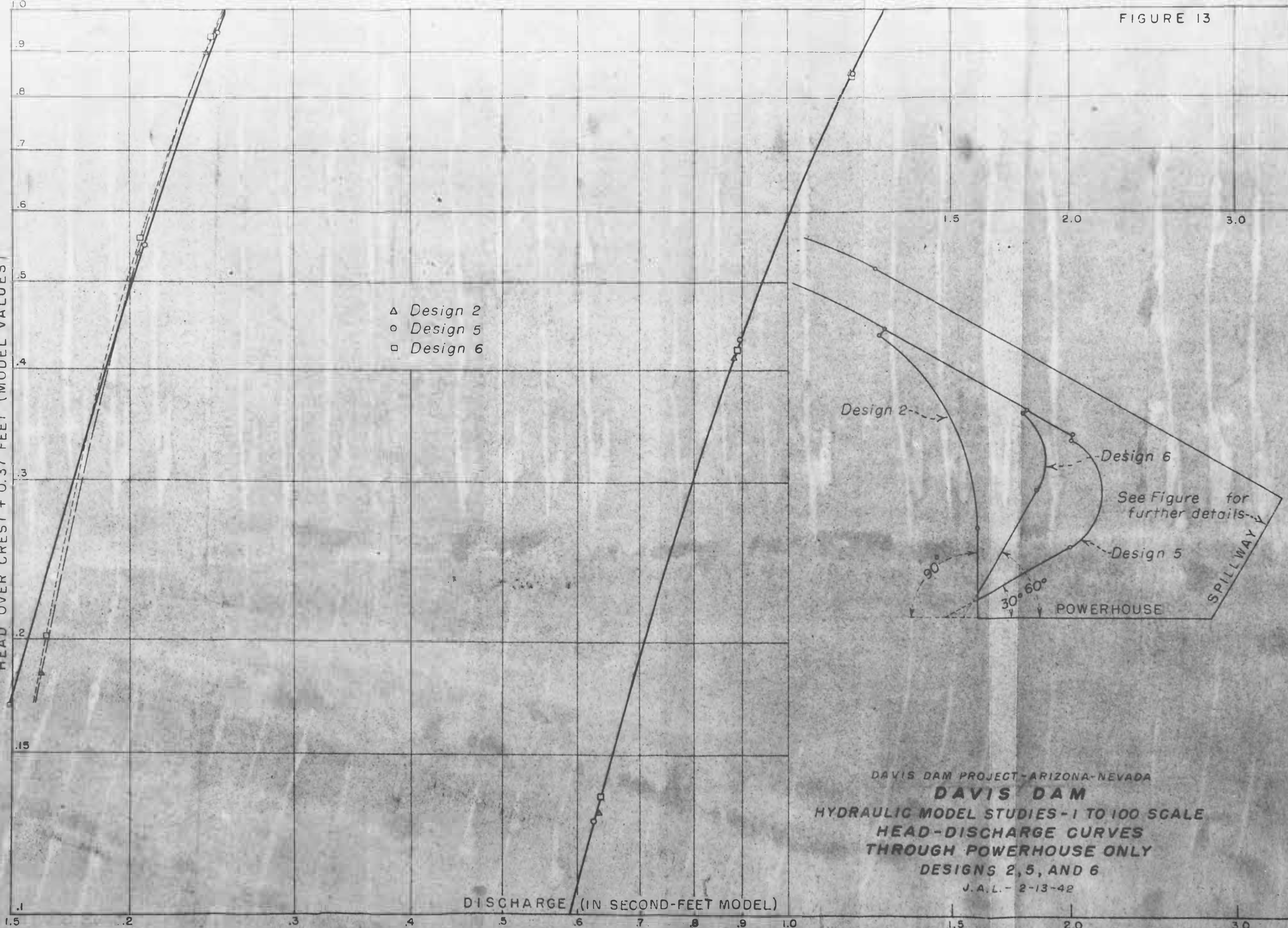
HEAD-DISCHARGE CURVES

FREE DISCHARGE OVER SPILLWAY

DESIGNS 2 AND 5

J.A.L. - 2-26-42

FIGURE 13



DAVIS DAM PROJECT-ARIZONA-NEVADA
DAVIS DAM
HYDRAULIC MODEL STUDIES - 1 TO 100 SCALE
HEAD-DISCHARGE CURVES
THROUGH POWERHOUSE ONLY
DESIGNS 2, 5, AND 6
J. A. L. - 2-13-42

8. Tailrace Wall Studies

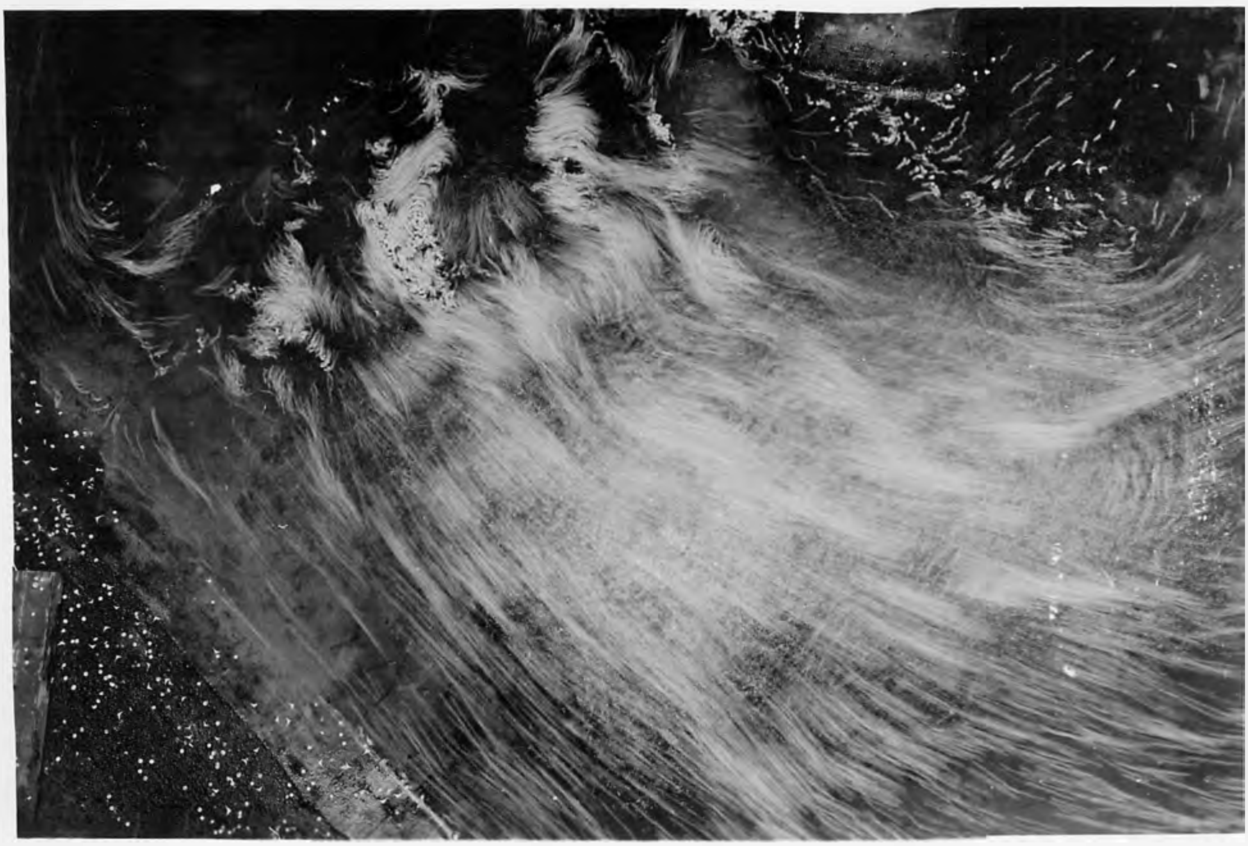
Several types of retaining walls and embankments on the sides of the powerhouse tailrace were tested to determine whether or not the type of design had any marked effect on the regain of static head from velocity head between the draft tube outlets and the river channel downstream. The riverbed was capped with a one-inch layer of concrete to maintain the same riverbed during the tests. Concrete and wooden blocks, formed to represent various designs for the embankments and retaining walls, were placed in the model during the course of the tests (Figures 14 and 15). A sheet metal gage well with a one-eigth-inch slot on the bottom was placed on the downstream face of the powerhouse to dampen the surges in the tailrace water surface elevation. Point gages, with neon glow tubes attached for greater accuracy, were used to measure the water surface in the well and at a point on the river channel approximately 1,000 feet (prototype) downstream from the toe of the spillway. The powerhouse gates were fully opened to give an exaggerated discharge of approximately 72,500 second-feet (prototype) to accentuate any slight differences between the various proposed designs. The original design provided for expensive retaining walls on both the right and left sides of the powerhouse tailrace (Figure 14-A). The tests showed that these walls were unnecessary as there was only 0.15-foot (prototype) of head regained more than that regained when no walls whatsoever were present (Figure 14-B). Visual studies indicated that a short training wall was necessary at the right side of the powerhouse to prevent the formation of undesirable eddies (Figure 15-B).

9. Spillway Studies on the 1 to 100 Scale Model

Observation of flow conditions on the 1 to 100 scale model of the original design indicated that undesirable scour would occur at the toe of the spillway at low discharges (Figure 16-A). It was also observed that the impact of the jet trajected from the spillway bucket would produce a large amount of spray and mist when it struck the water surface downstream (Figure 16-B). This would be troublesome to the outdoor electrical system as the evaporation of the river water would leave a deposit of salts which would cause extensive power leakage if allowed to accumulate. This led to the decision that the switchyard should not be located on the level area at elevation 540.00 between the powerhouse and the spillway, as a certain amount of mist will be formed regardless of the type of spillway used. A 1 to 48 scale sectional model of the spillway was constructed to determine flow characteristics and necessary alterations of the trajectory bucket design. An alternate scheme was then proposed employing the roller bucket design, which placed the bucket lip at elevation 490.00 (Figure 6-F). The 1 to 100 model was revised by lowering the bottom of the bucket to elevation 470.00, changing the radius to 75 feet and the lip to elevation 490.00 (Figure 6-F). The extent of the rock excavation required downstream from the spillway was determined by sweep out tests with the rock progressively at elevation 505.00, 510.00, and 515.00 (Figure 17). Flow conditions were most satisfactory when the rock was excavated to elevation 515.00 as the hydraulic jump remained on the bucket at considerably higher discharges than when more of the rock was excavated, and in addition the reduction in rock excavation will make some saving in cost.

Additional tests on the 1 to 48 scale model indicated that a bucket design which consisted of a 75-foot radius bucket and 10-degree upward sloping apron might give as good results as the design with the 75-foot radius bucket (Figures 6-H and 18). When this design was placed in the 1 to 100 scale model, at discharges of 10,000 to 15,000 second-feet, the eddy currents on the bucket were very severe and might scour the prototype bucket if pieces of rock should get in the flow and roll back and forth. In addition, the spillway jet swept off the apron at a discharge of 15,000 second-feet at ultimate tailwater elevation; and when the discharge was increased to 100,000 second-feet at ultimate tailwater elevation, the material downstream from the bucket was

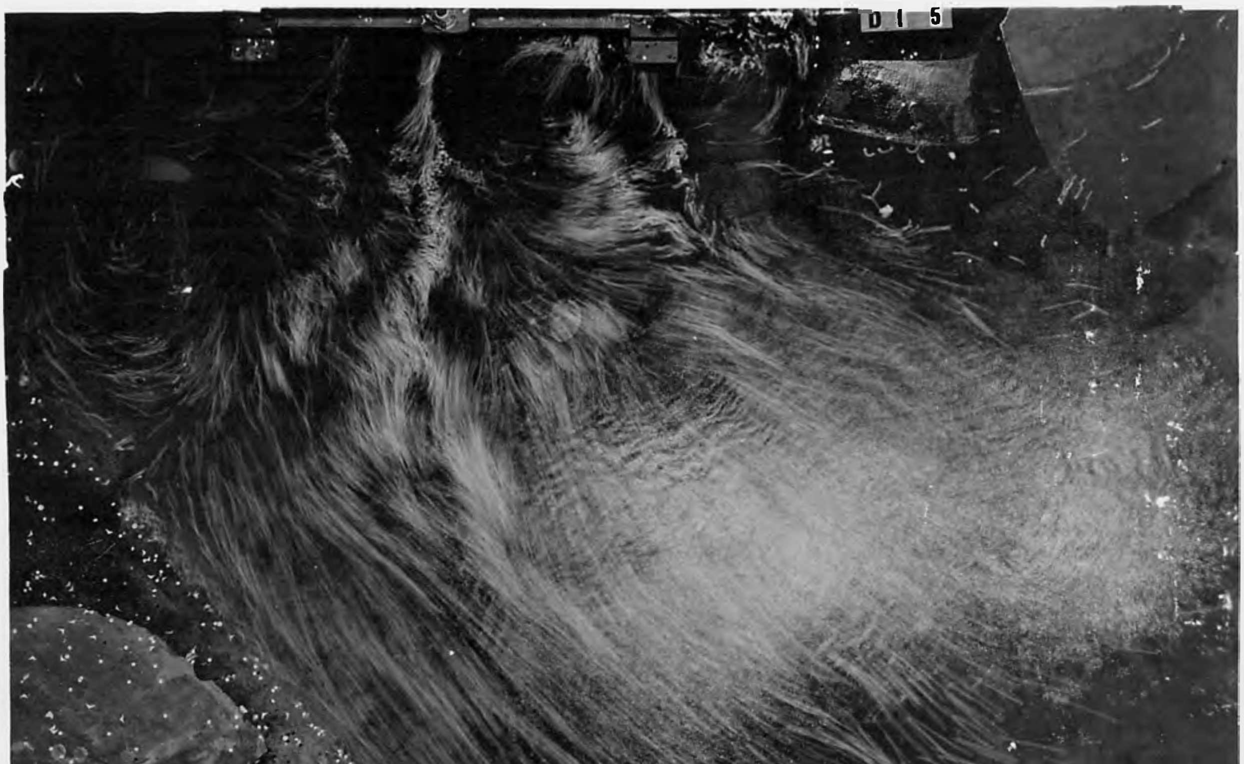
A. FLOW LINES WITH ORIGINAL DESIGN RETAINING WALLS.



B. FLOW LINES WITH NO WALLS TO RIGHT AND LEFT OF POWERHOUSE.

DAVIS DAM ULTIMATE STAGE MODEL - 1 TO 100 SCALE - EXAGGERATED POWERHOUSE DISCHARGE OF 72,500 SECOND-FEET - FOREBAY ELEVATION 647.00 - TAILWATER ELEVATION 527.00.

A. FLOW LINES WITH SHORT WALL ON LEFT AND RIGHT WALL EXTENDED TO EMBANKMENT



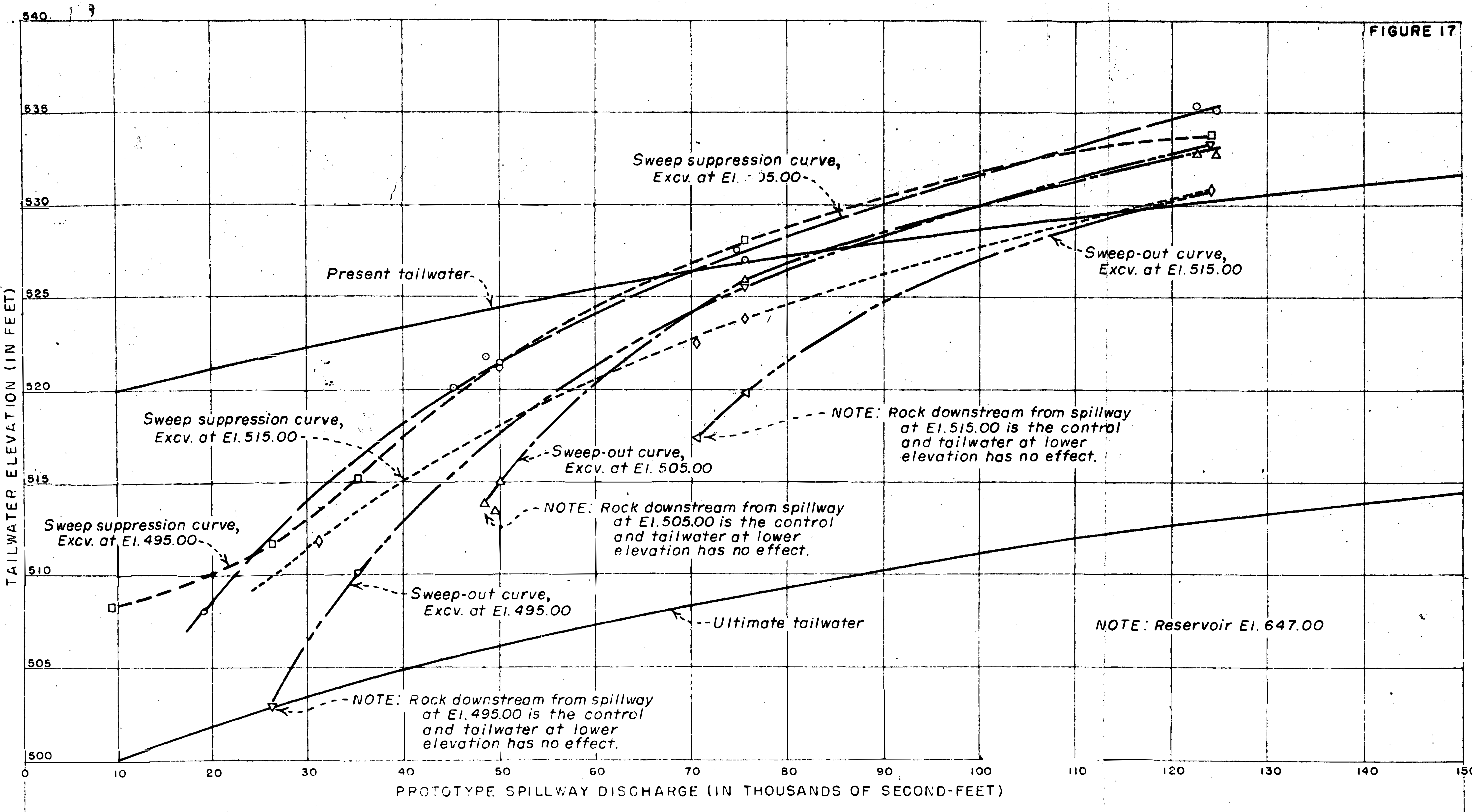
B. FLOW LINES FOR THE RECOMMENDED DESIGN - A SHORT WALL ON THE RIGHT AND RIP-RAP ON THE LEFT BANK.

DAVIS DAM ULTIMATE STAGE MODEL - 1 TO 100 SCALE - EXAGGERATED POWERHOUSE DISCHARGE OF 72,500 SECOND-FEET - FOREBAY ELEVATION 647.00 - TAILWATER ELEVATION 527.00.

A. FLOW CONDITIONS WITH POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 5,000 SECOND-FEET.

B. FLOW CONDITIONS WITH POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 75,000 SECOND-FEET.

DAVIS DAM ULTIMATE STAGE MODEL - 1 TO 100 SCALE - FOREBAY ELEVATION 647.00 - PRESENT TAILWATER ELEVATIONS.



DAVIS DAM PROJECT – ARIZONA-NEVADA

DAVIS DAM

HYDRAULIC MODEL STUDIES - 1 TO 100 SCALE

SPILLWAY BUCKET FLOW CHARACTERISTICS

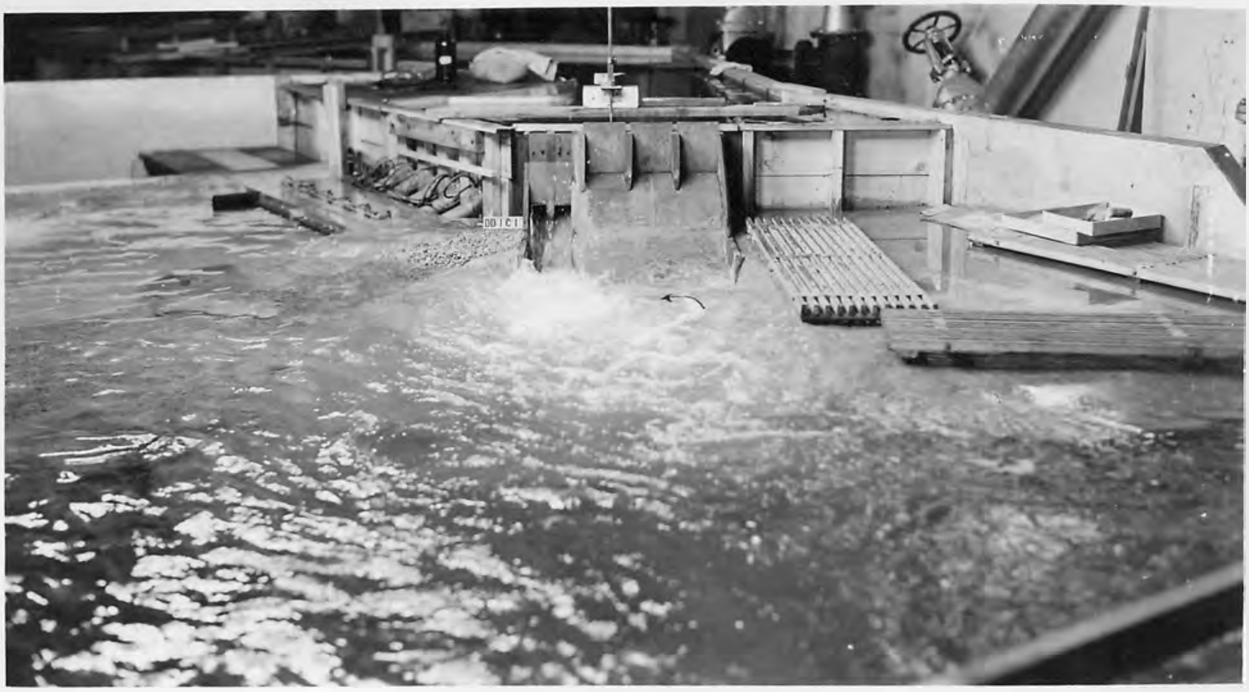
(DESIGN 7)

washed to a depth of 15 feet below the lip. As this would tend to undermine and endanger the structure, the 75-foot radius bucket design was replaced (Figure 6-F).

10. Spillway Profile Studies on the 1 to 48 Scale Model

Studies on the 1 to 48 model showed that it would not be economical to construct a sloping apron type of energy dissipator, as the apron would be extremely long, and the training walls excessively large to withstand the pressure differential, thus the study resolved itself into determining the type of bucket design which would give the most satisfactory results at the lowest cost. The original design gave results similar to those on the 1 to 100 scale model (Figures 6 and 19). Preliminary studies demonstrated that undesirable scour at the lower discharges could be prevented by lowering the bucket lip to elevation 493.00, but that it would have to be lowered to elevation 470.00 before the jump would remain on the apron for all probable discharges. A 22-foot radius deflector was placed on the downstream face of the original design bucket to minimize scour at the toe of the structure (Figure 6-B). The deflector failed to function correctly until it was lowered 12 feet, where it was fairly effective in preventing scour (Figure 6-C). Since it would be difficult to build this type of deflector, a design was tested which consisted of a 7-foot long horizontal shelf at elevation 495.00, with a 4 to 1 slope to elevation 505.00 (Figure 6-D). Some scour occurred with a discharge of 10,000 second-feet through the spillway at ultimate tailwater elevation. Therefore a horizontal shelf 50 feet long at elevation 495.00 was substituted (Figure 6-E). Considerable scour was still present when the design was tested at a discharge of 10,000 to 15,000 second-feet at ultimate tailwater elevations, as the velocity of the flow at the end of the shelf was greater than critical velocity. This condition was not present when the shelf was lowered to elevation 490.00, and tests indicated that such a design would effectively prevent the scour at low discharges (Figures 6-E and 19-C). Even at the ultimate tailwater elevations, there was a sufficient depth of water over the shelf so that most of the kinetic energy was dissipated by turbulent eddies before the flow left the shelf. The flow in this design would sweep off the bucket at a discharge of 20,400 second-feet and the sweep cessation point was 8,000 second-feet.

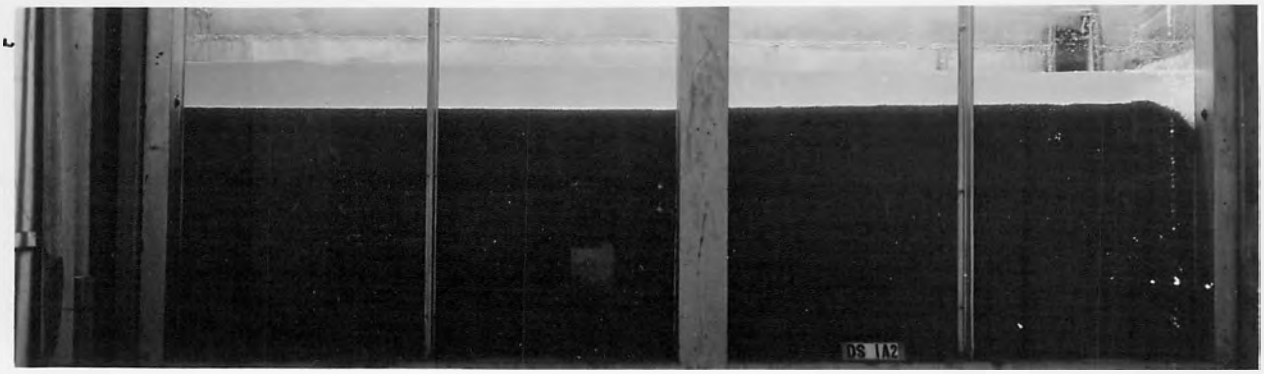
A revised bucket design, which consisted of a 75-foot radius bucket with the lowest portion at elevation 470.00 and the lip at elevation 490.00, was placed in the 1 to 48 scale model for testing (Figures 6-F and 20). At the same time, removable metal sections were built to fit on top of Design 7 to test other designs. The next revision had a 100-foot radius with the lip at elevation 490.00 (Figure 6-G). Another revision had a 75-foot radius curve connecting the parabolic surface with an apron downstream which sloped upward at 10 degrees to elevation 490.00 (Figure 6-H). The final revision tested had a 75-foot radius curve connecting the parabolic surface with a horizontal apron at elevation 490.00 (Figure 6-J). Each revision was tested to obtain sweep out curves and observe the relative scour and turbulence to determine the most suitable design. Design 7 gave the best results, as far as sweep out and scour were concerned, but Design 10 was the least turbulent when the sweeping jet was brought back on the apron. However, as the scour was very great at higher discharges with the horizontal bucket, Design 10 was abandoned. Design 8 with the 100-foot radius bucket, was not very satisfactory as the flow swept off the apron at comparatively low discharges, but Design 9 with the 10-degree upward sloping apron gave promise of being a satisfactory design and was tested on the 1 to 100



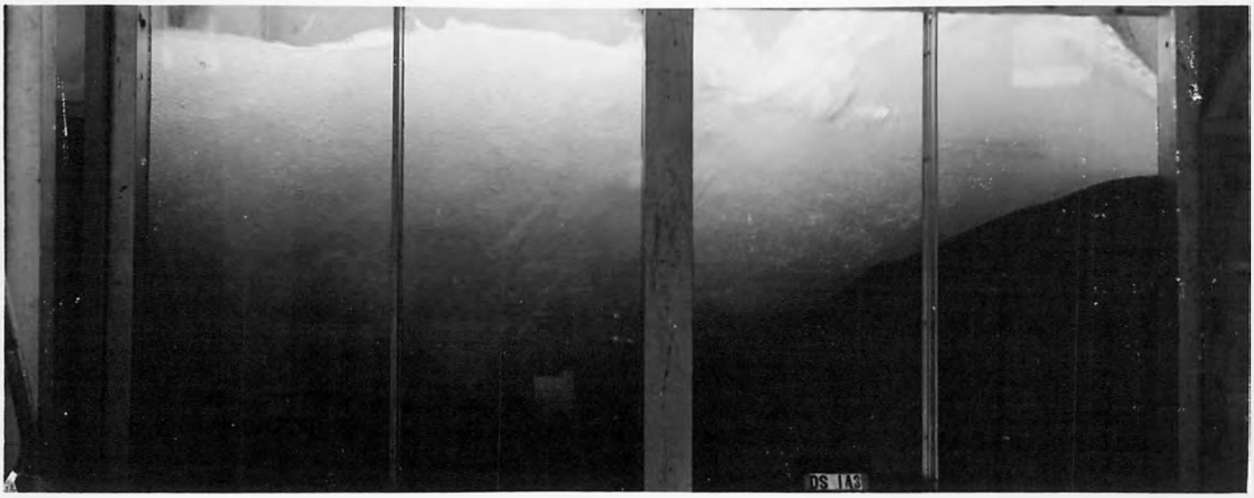
A. EDDY ON SPILLWAY BUCKET WHEN POWERHOUSE DISCHARGE IS 25,000 SECOND-FEET, OUTLET DISCHARGE IS 60,000 SECOND-FEET, NO SPILLWAY DISCHARGE.

B. EDDY ON OUTLET BUCKET WHEN POWERHOUSE DISCHARGE IS 25,000 SECOND-FEET, NO OUTLET DISCHARGE, SPILLWAY DISCHARGE 25,000 SECOND-FEET.

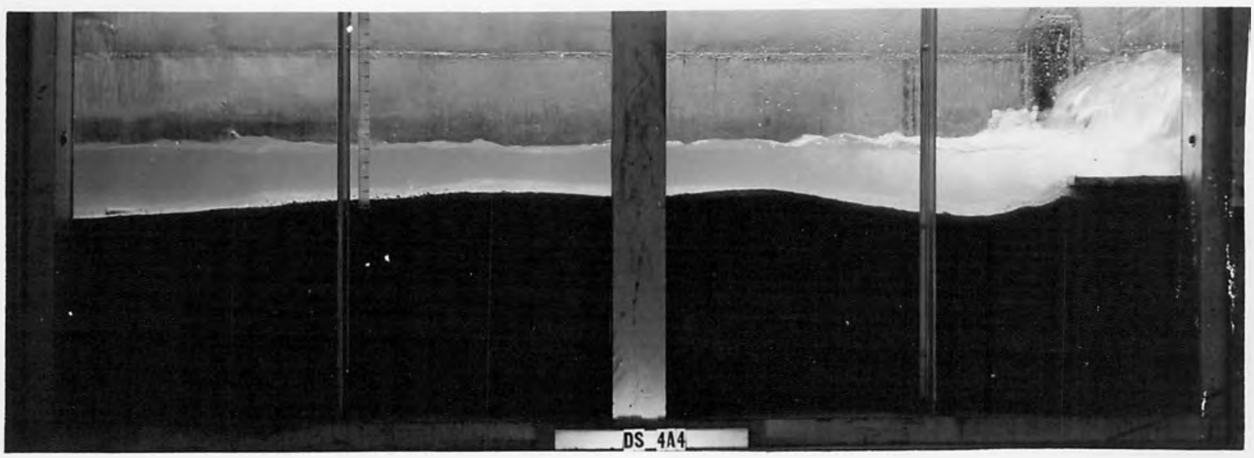
DAVIS DAM BUCKET DESIGN H - MODEL SCALE 1 TO 100 - FOREBAY ELEVATION 547.00 - PRESENT TAILWATER ELEVATIONS - EDDIES ON BUCKET WITH BOTH OUTLETS TO RIGHT OF SPILLWAY.



A. SCOUR WITH SPILLWAY DISCHARGE 5,000 SECOND-FEET, RESERVOIR ELEVATION 647.00, AND TAILWATER ELEVATION 520.00.



B. SCOUR WITH SPILLWAY DISCHARGE 240,000 SECOND-FEET, RESERVOIR ELEVATION 655.00 AND TAILWATER ELEVATION 535.00.



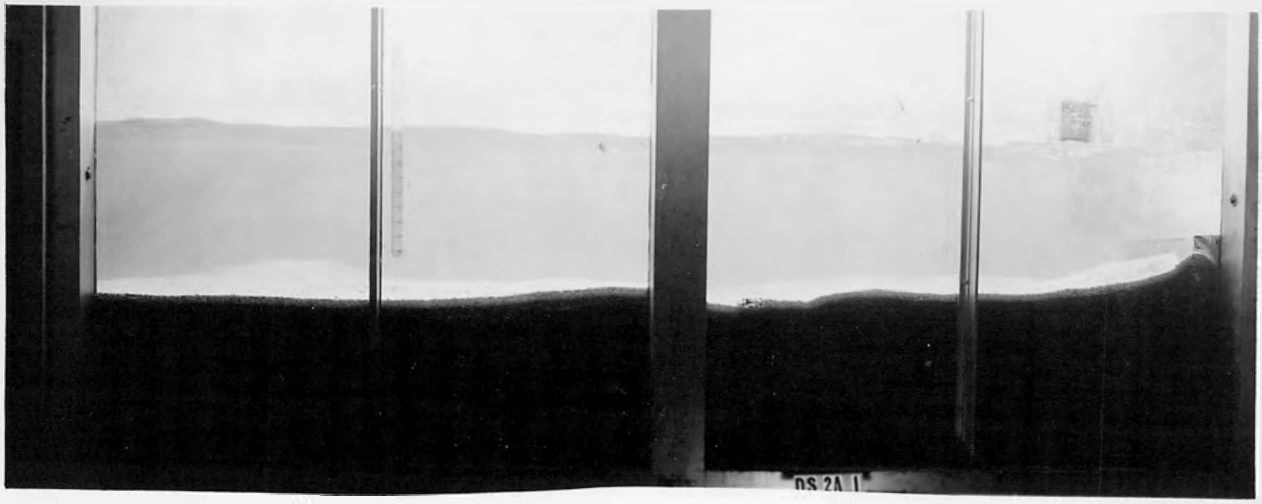
C. SHELF 50 FEET LONG AT ELEVATION 490.00 PREVENTS SCOUR WHEN SPILLWAY DISCHARGE IS 17,500 SECOND-FEET, RESERVOIR ELEVATION IS 647.00, AND TAILWATER ELEVATION IS 502.00.

DAVIS DAM SECTIONAL MODEL - ORIGINAL BUCKET DESIGN - 1 TO 48 SCALE.

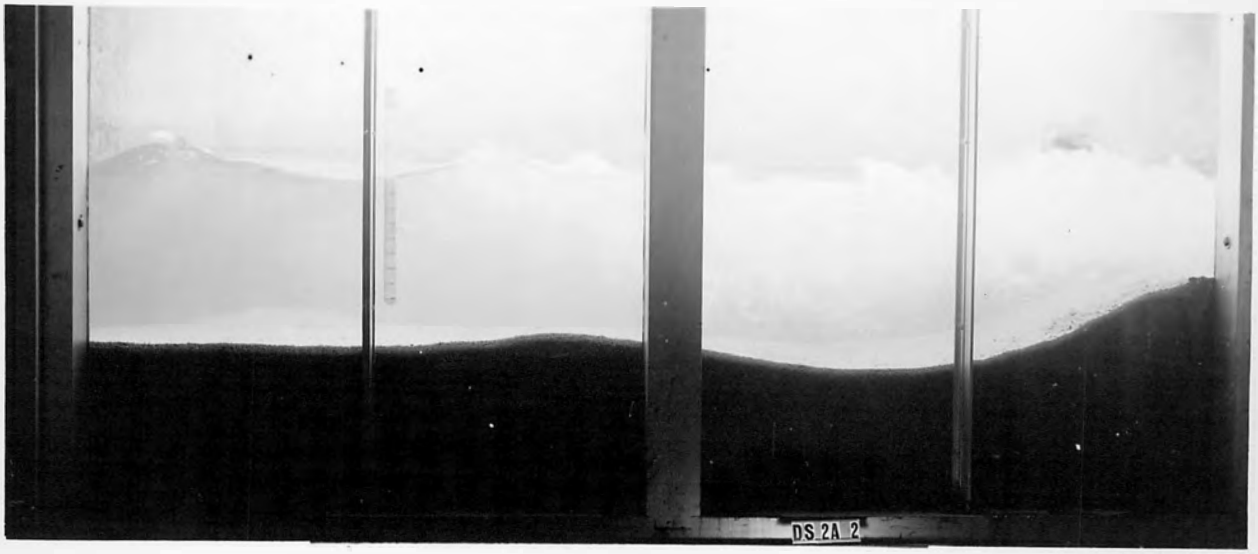
scale model along with Design 7. The 1 to 100 scale model tests demonstrated that Design 7 would give the most satisfactory results. It was therefore adopted as the recommended design (Figure 6-F). Pressure tests were also made on the spillway for the original and recommended designs (Figures 21 and 22).

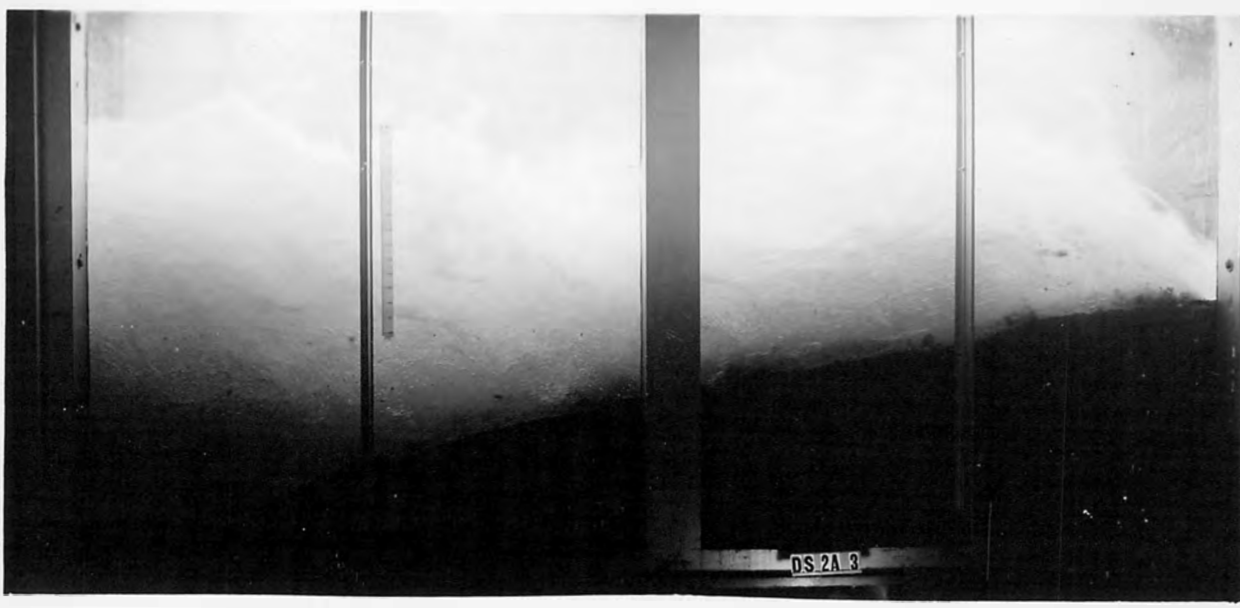
11. Study of Appurtenant Features

The behavior of the 1 to 100 model indicated that the training wall between the spillway and outlets could be lowered from elevation 550.00 to elevation 523.00, with little likelihood of being overtopped, especially at the ultimate tailwater elevations. Subsequent tests showed that a portion of, and even all of the intermediate training wall could be eliminated without producing undesirable flow conditions. If anything, when the intermediate training wall was removed entirely, the flow spread out over the entire bucket and consequently did not sweep off the bucket at as low discharges, and in addition, the saving in cost was considerable. When the pier next to the outlet section was streamlined similar to the other piers, very little more water fell into the outlet section than before, and as this improved the symmetry of the structure, it was decided to shape all piers the same. The appearance of the spillway structure was improved from the architectural standpoint, by placing one outlet on each side of the overflow spillway section, instead of both outlets to the right, as in the original design. The 1 to 100 scale model was changed accordingly, and tested to determine the effect of the change on the hydraulics of the structure. Calibration of the right and left outlets showed no appreciable difference in the discharge coefficient, due to the contraction by the piers on the right and left side of the outlets. Locating the outlet works symmetrically also, greatly reduced the eddies on the spillway bucket (Figures 18 and 23-A).



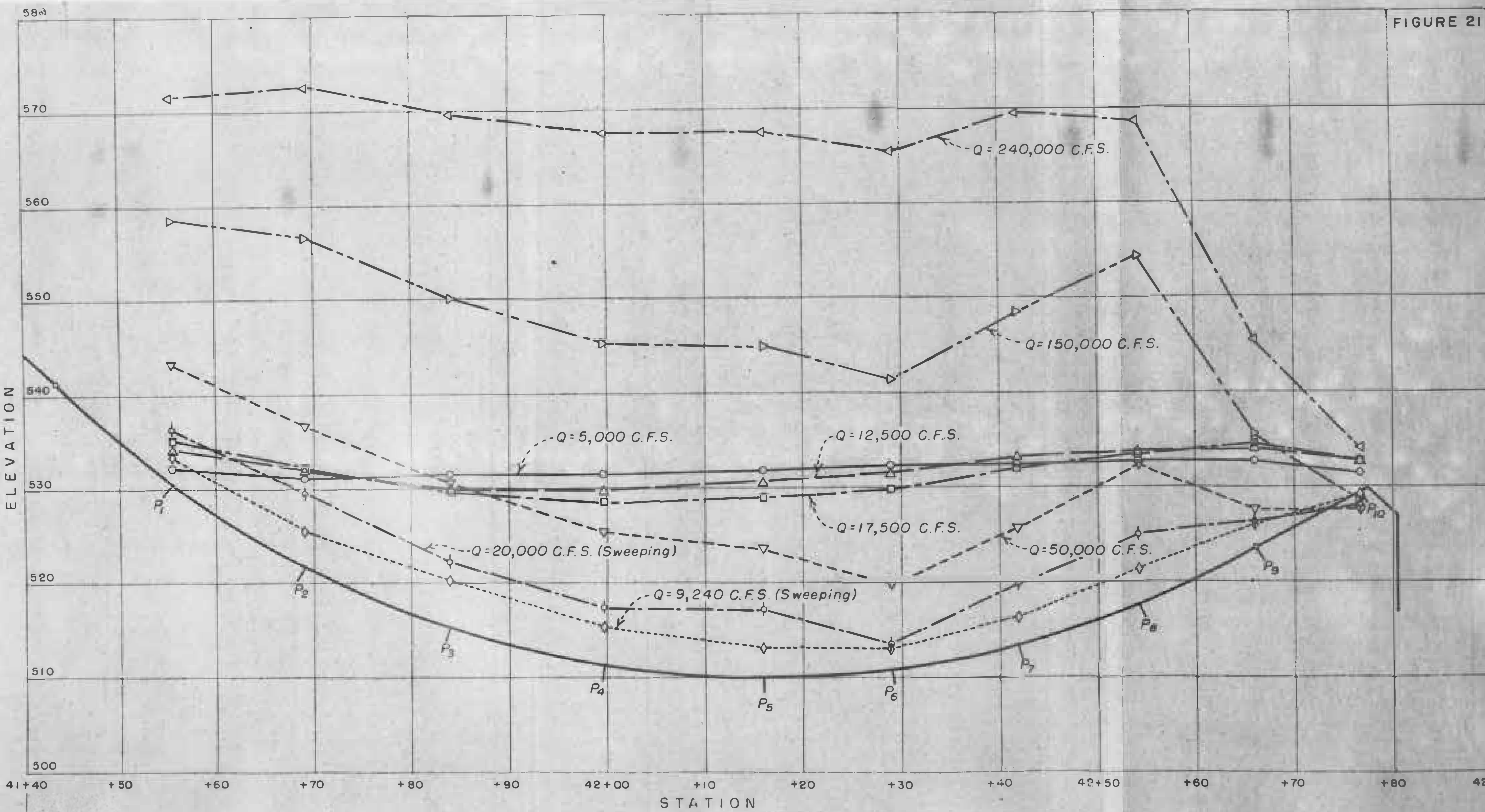
A. ABSENCE OF SCOUR WITH DISCHARGE OF 12,500 SECOND-FEET.



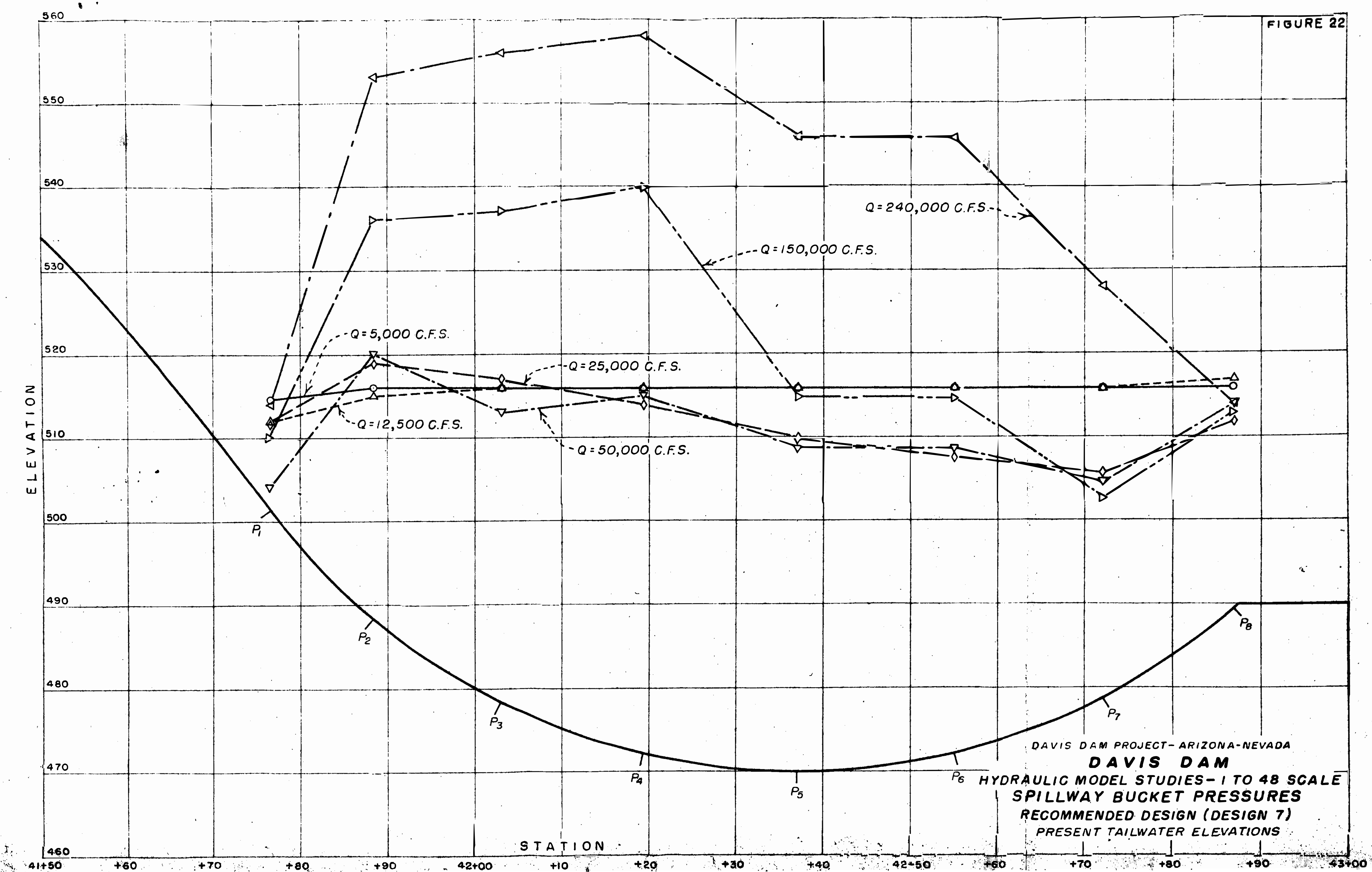


B. SCOUR WITH DISCHARGE OF 240,000 SECOND-FEET.

DAVIS DAM - MODEL SCALE 1:48 - RECOMMENDED DESIGN - NORMAL RESERVOIR ELEVATIONS - PRESENT TAILWATER ELEVATIONS.



DAVIS DAM PROJECT – ARIZONA – NEVADA
DAVIS DAM
HYDRAULIC MODEL STUDIES – 1 TO 48 SCALE
SPILLWAY BUCKET PRESSURES
ORIGINAL DESIGN (DESIGN 1)



DAVIS DAM PROJECT- ARIZONA-NEVADA

DAVIS DAM

HYDRAULIC MODEL STUDIES- 1 TO 48 SCALE

SPILLWAY BUCKET PRESSURES

RECOMMENDED DESIGN (DESIGN 7)

PRESENT TAILWATER ELEVATIONS

Studies were made on various types of steps and teeth to obtain a type which would prevent the jet from sweeping off the bucket. The most successful design consisted of a double row of steps on the bucket and spillway sections. Inasmuch as these steps would always be under water and the spillway in practically constant operation, it would be difficult to repair them if they should be damaged, consequently this design was abandoned in favor of the smooth bucket.

To minimize the use of reinforcing steel, if possible, it was proposed that the slope of the retaining walls at the sides of the spillway bucket be changed from vertical to a slope of one-half to one. When the one-half to one sloping walls were tested on the model, water flowed upstream adjacent to the walls and created severe eddies on the bucket which increased the tendency for the jet to sweep off the bucket (Figure 23). This back flow could not be prevented on this design as it was caused by the lower water surface elevations on the bucket, due to the velocity head, as compared with the higher water surface elevation in the river channel. For these reasons, it was recommended that the retaining walls be made vertical.

Gate operation tests showed that the left and right gates should be opened the same amount and the center gate should be opened one-half as much as the other two gates. It will be necessary to follow this operation pattern on the prototype to prevent the jet from sweeping off the bucket at low discharges (Figure 24-A).

12. Diversion Studies

At the conclusion of the ultimate design tests on the 1 to 100 scale model, the center section of the overflow spillway was removed, and the piers of the diversion plan installed (Figure 4-C). The final diversion plan consisted of three bays, separated by 10-foot thick piers, each of which is divided into three channels by two 5-foot thick piers. Any of the nine channels can be closed by placing stop logs in the slots provided at the upstream end of the piers.

The model was tested at discharges of 25,000, 40,000, and 60,000 second-feet, to obtain the velocities through the various sections of the diversion channel and stop-log section. A series of tests were made with: (1) all three bays open; (2) the right bay closed; (3) the center and right bay closed and finally (4) the left and right bays closed. The water surface elevations and energy gradients were plotted and compared with plots of the computed prototype water surface and energy gradients (Figure 25). Considering that the bottom of the model did not strictly conform to the prototype, the computed and measured values checked very well. These tests showed that when all three bays are open, the velocities would become greater than critical at discharges of more than 25,000 second-feet through the downstream end of the approach channel (station 32 + 52.50 to station 36 + 23.15). In addition, an undesirable whirling pier contraction effect was noted at the right pier. Therefore, it is recommended that stop-logs be placed in the right bay as soon as possible. It is feasible to close two bays after the earth dam has been contemplated to elevation 575.00 to enable the placing of mass concrete in the spillway section. The reservoir would then overtop the upstream cofferdam, but no damage should occur if the earth dam were completed to this elevation. Diversion through the outlets may begin as soon as they are completed.

CONCLUSIONS

13. Results of the Investigations

Several types of bellmouth entrances for the outlet spillways were tested on the 1 to 50 scale model, but as the original semi-bellmouth design gave satisfactory discharge coefficients, it was

A. FLOW CONDITIONS WITH VERTICAL RETAINING WALLS AT SIDES OF SPILLWAY BUCKET (RECOMMENDED DESIGN).

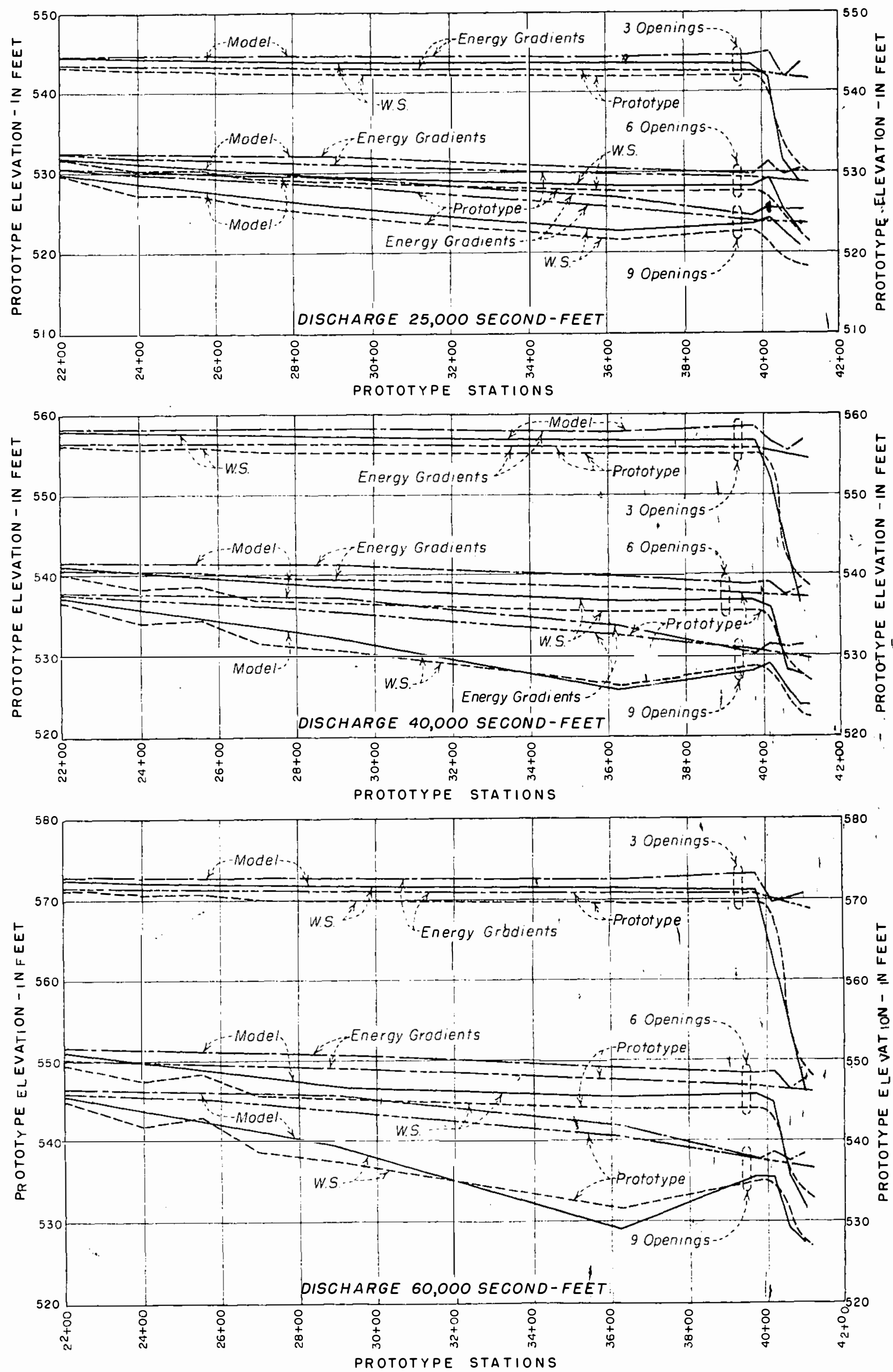
B. FLOW CONDITIONS WITH ½ TO 1 SLOPING RETAINING WALLS AT SIDES OF SPILLWAY BUCKET

DAVIS DAM - RECOMMENDED BUCKET DESIGN - MODEL SCALE 1 TO 100 - SPILLWAY DISCHARGE 75,000 SECOND-FEET - NO OUTLET DISCHARGE - TAILWATER ELEVATION 508.50 - CENTER SPILLWAY GATE OPEN ONE-HALF AS MUCH AS RIGHT AND LEFT GATE

A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 100,000 SECOND-FEET, PRESENT TAILWATER ELEVATION, OUTLET GATES CLOSED.

B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 100,000 SECOND-FEET, ULTIMATE TAILWATER ELEVATION, OUTLET GATES CLOSED.

DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL AT N.15,850, E.53,900 - RESERVOIR ELEVATION 647.00.



EXPLANATION

Model Energy Gradient
Prototype En. Gr.
Model W.S.
Prototype W.S.

DAVIS DAM PROJECT - ARIZONA-NEVADA

DAVIS DAM

HYDRAULIC MODEL STUDIES - 1 TO 100 SCALE

WATER-SURFACE AND ENERGY GRADIENTS

FINAL DESIGN DIVERSION PLAN

selected as the recommended design. The preliminary diversion design tested on the 1 to 100 scale model was inadequate, as the flow would scour the riverbed downstream, and probably endanger the structure. A revision was tested, but as it was still unsatisfactory, additional tests were made at the conclusion of the studies on the ultimate design.

The 1 to 100 scale model of the ultimate design was tested to determine the most practical and economical shape of the forebay approach channel. The shape was changed considerably from the original design without reducing the head available for power production. The recommended design effected a marked saving in excavation costs over those of the original design.

An investigation of several proposed designs for the retaining walls at the sides of the powerhouse tailrace was made to effect economies in the design. The type of retaining wall had little effect on the difference in water surface elevation at the penstock outlets and the river channel, thus it made little difference in power production what type of wall was used. The recommended design consisted of a short wall on the right side of the powerhouse to prevent the formation of undesirable eddies. This design will be much cheaper to build than the original proposed design.

Spillway profile studies were conducted on the 1 to 100 and 1 to 48 scale models to determine the most satisfactory shape for the downstream bucket. The design that was finally evolved consisted of a low bucket which served as a roller bucket at lower discharges and as a trajectory bucket at higher discharges. Cost limitations prevented the design of a sloping apron or of a true roller bucket. Therefore, it is felt that the recommended spillway design in the most practicable under the conditions imposed.

The studies produced further economies in the design by eliminating the intermediate training wall between the outlet and overflow spillways. The architectural appearance was improved, with no detrimental hydraulic conditions, by placing one outlet on each side of the overflow spillway, instead of both to the right as originally designed. Two rows of steps on the spillway would aid in dissipating the energy of the jet, but as it would be difficult to repair them, their construction was not recommended. The spillway retaining walls could not be built on a one-half to one back slope, instead of vertical, as strong eddies formed on the bucket would help to sweep off the jet. Tests showed that the spillway gates should be operated in such a manner that for all discharges the right and left gates should be open an equal amount, and the center gate one-half as much as the other two. The final design of the diversion plan was found to be practicable, and flow conditions were satisfactory.

14. Recommendations

On the basis of the model studies, it is recommended that:

a. The original design semibellmouth type of entrance be used on the outlets.

b. The diversion plan be changed by placing the ultimate design bucket at the end of the apron to serve as an energy dissipator.

c. The shape of the forebay be changed to reduce the excavation required (Figure 5).

d. The retaining wall on the left side of the tailrace be eliminated and only a short wall built on the right side.

e. The spillway bucket may be lowered to elevation 470.00 at the lowest point, with the lip elevation 490.00, and a 75-foot radius bucket (Figure 6-F), or a paved apron may be placed downstream from the high trajectory bucket (Figure 6-E).

f. The intermediate spillway training wall be eliminated.

g. The outlets be placed, one to the left, and one to the right of the overflow spillway; to make the structure more symmetrical.

h. No teeth or steps be placed on the bucket to aid in energy dissipation.

i. The spillway retaining walls be built vertical to prevent undesirable backflow and eddies on the bucket.

j. The rock bench downstream from the spillway be excavated only to elevation 515.00 to help keep the jet from sweeping off the spillway bucket.

k. The left and right spillway gates be opened an equal amount and the center gate one-half as much as the left and right gates.

l. The right bay of the diversion structure be blocked off after initial closure of the river.

J. A. Lindsey.

A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 100,000 SECOND-FEET
PRESENT TAILWATER ELEVATION, OUTLET GATES CLOSED.

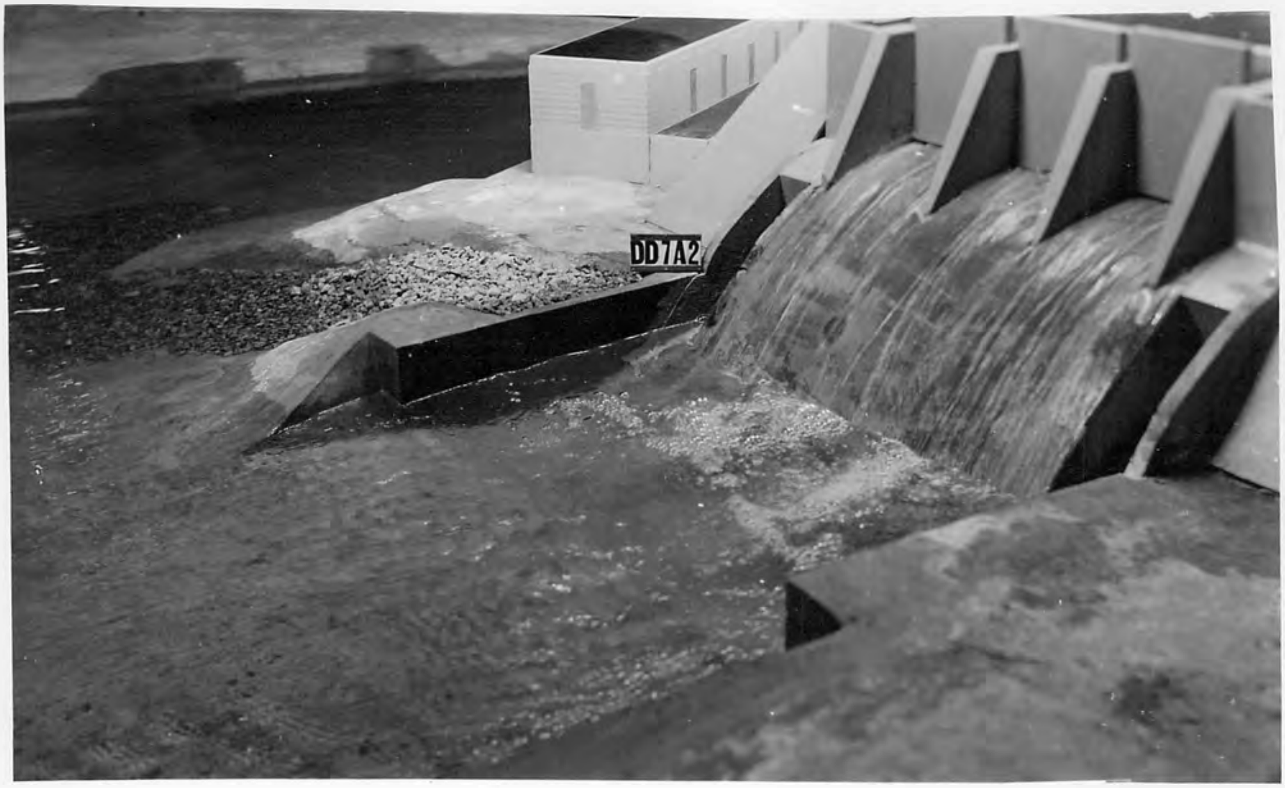
B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 100,000 SECOND-FEET,
ULTIMATE TAILWATER ELEVATION, OUTLET GATES CLOSED.

DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL
AT N.16,850,E.55,200 - RESERVOIR ELEVATION 647.00.

A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 50,000 SECOND-FEET, PRESENT TAILWATER ELEVATION, OUTLET GATES CLOSED.

B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 50,000 SECOND-FEET, ULTIMATE TAILWATER ELEVATION, OUTLET GATES CLOSED.

DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL AT N.16,850,E.55,200 - RESERVOIR ELEVATION 647.00.

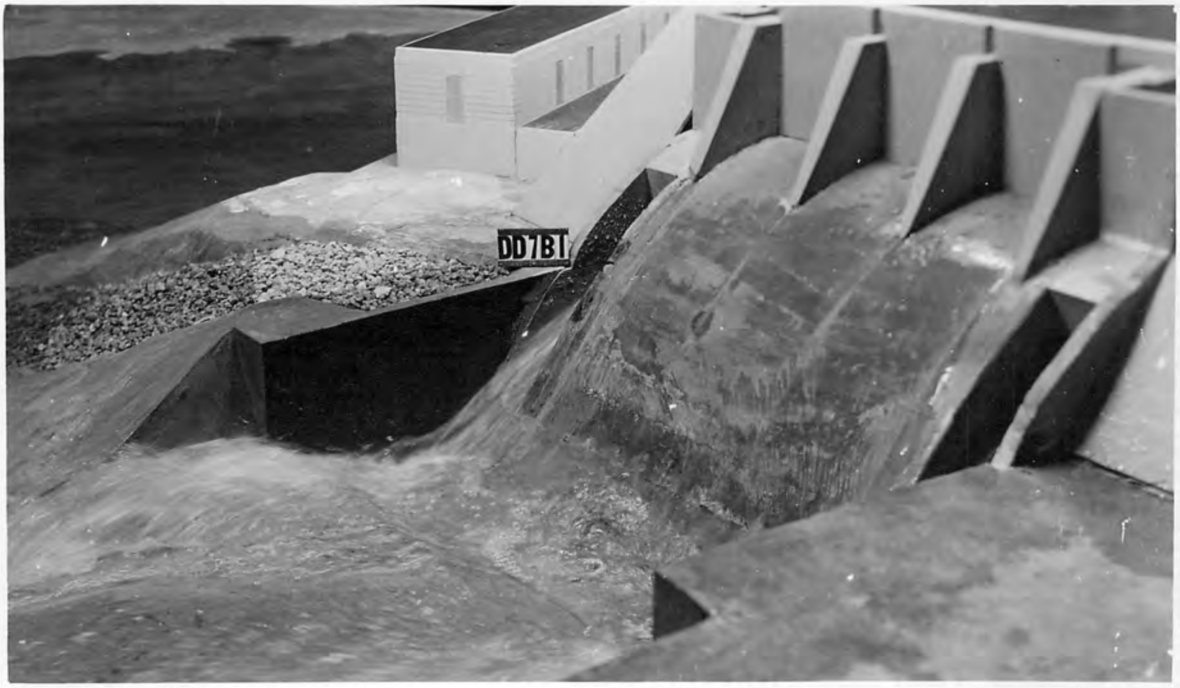


A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 10,000 SECOND-FEET
PRESENT TAILWATER ELEVATION, OUTLET GATES CLOSED.

B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 10,000 SECOND-FEET,
ULTIMATE TAILWATER ELEVATION, OUTLET GATES CLOSED.

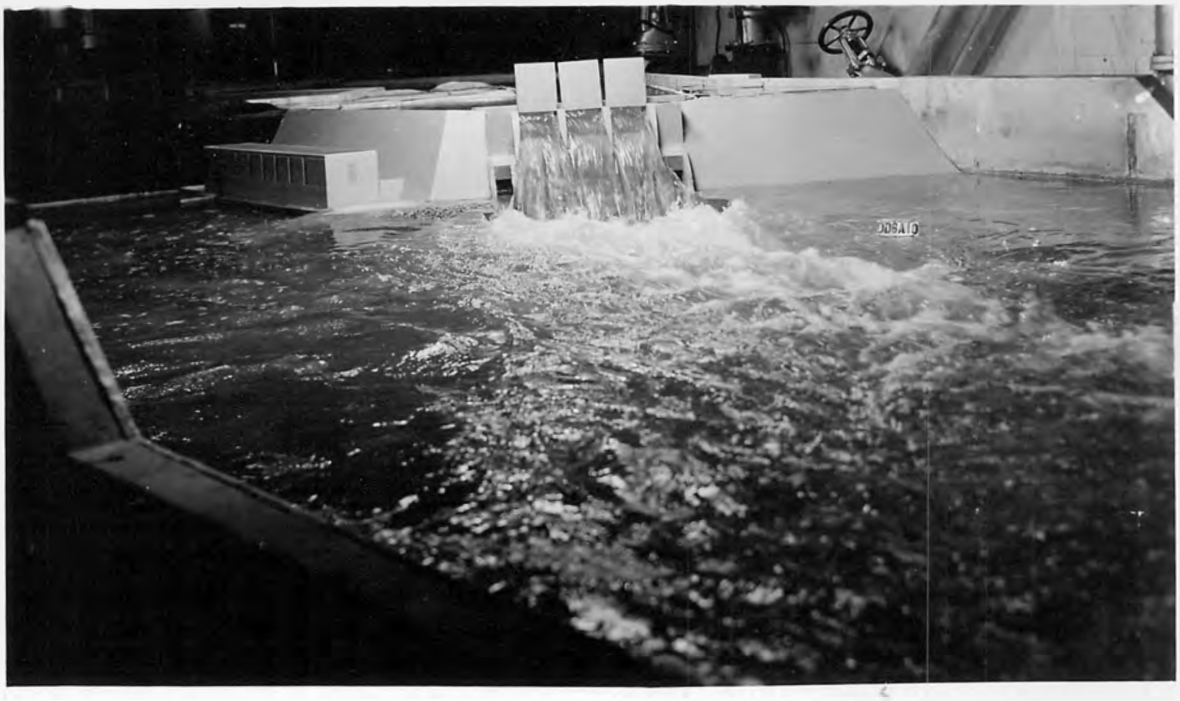
DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL
AT N.16,850,E.55,200 - RESERVIOR ELEVATION 647.00.

A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, OUTLET DISCHARGE 10,000 SECOND-FEET EACH, PRESENT TAILWATER ELEVATION, SPILLWAY GATES CLOSED.

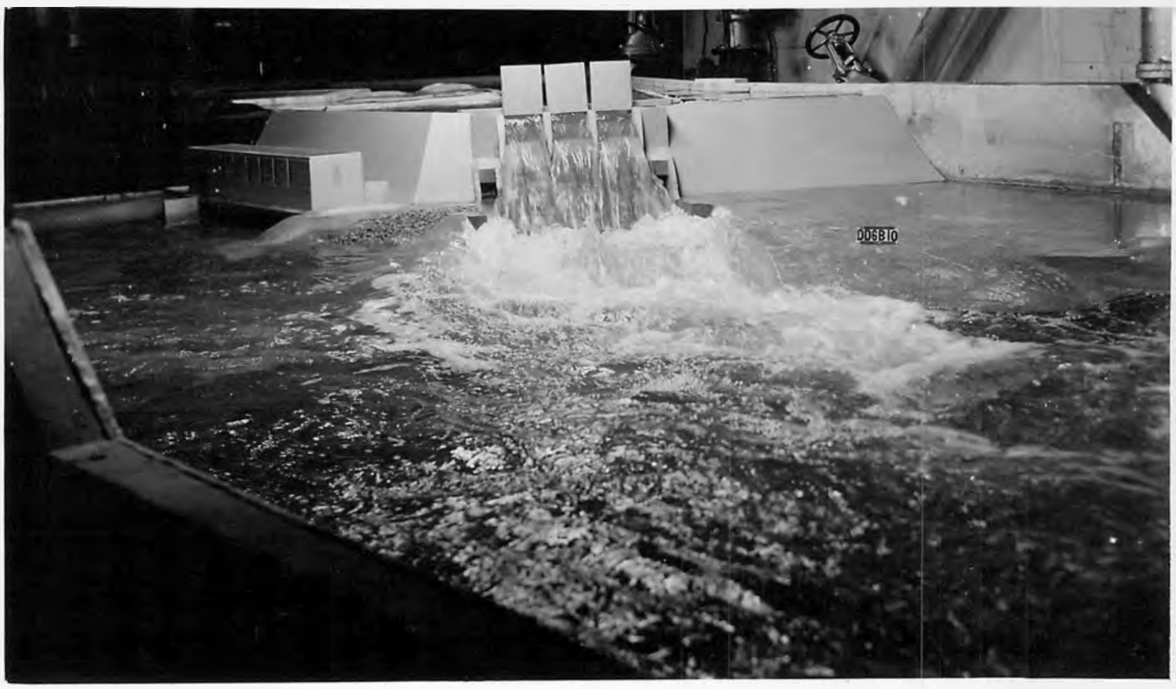


B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, OUTLET DISCHARGE 10,000 SECOND-FEET EACH, ULTIMATE TAILWATER ELEVATION, SPILLWAY GATES CLOSED.

DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL AT N.16,850,E.55,200 - RESERVOIR ELEVATION 647.00.

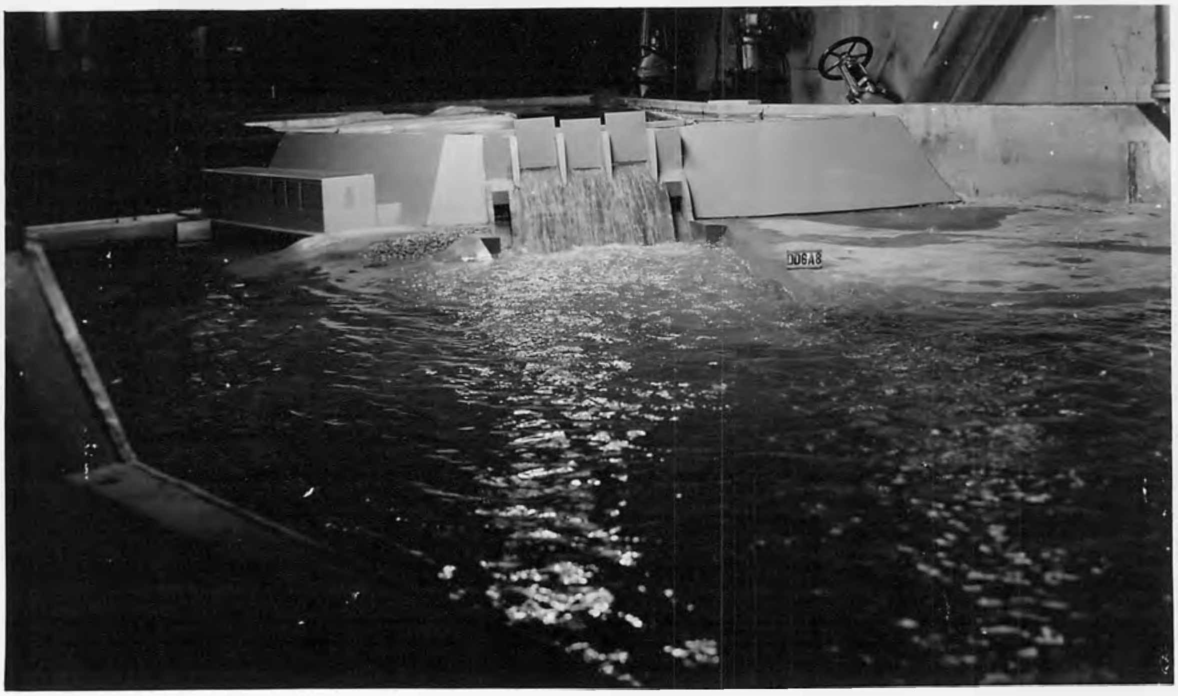


A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 240,000 SECOND-FEET, PRESENT TAILWATER ELEVATION, OUTLET GATES CLOSED.

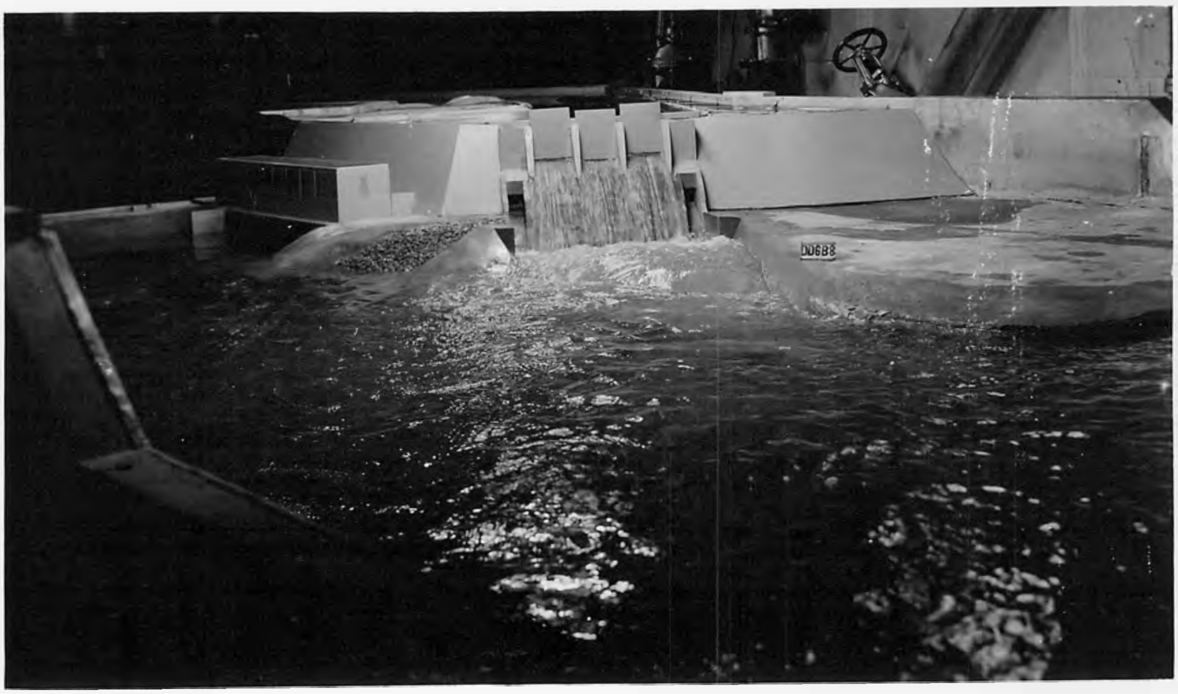


B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 240,000 SECOND-FEET ULTIMATE TAILWATER ELEVATION, OUTLET GATES CLOSED.

DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL AT N.15,850,E.53,900 - RESERVOIR ELEVATION 647.00.

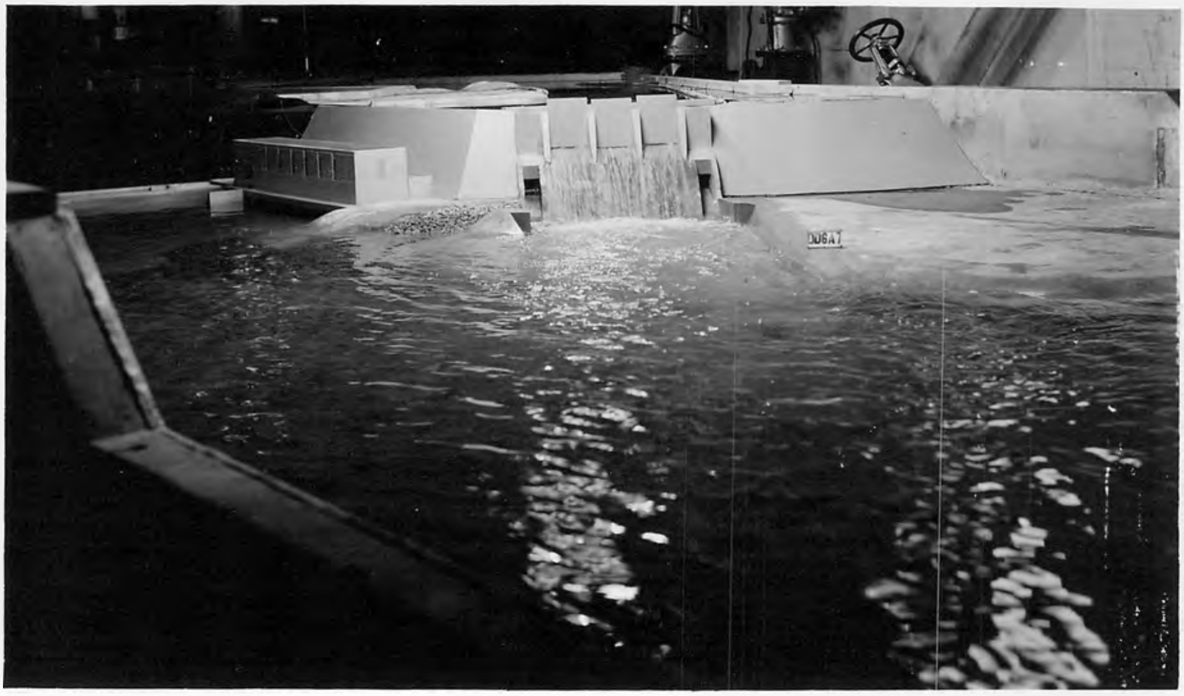


A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 50,000 SECOND-FEET, PRESENT TAILWATER ELEVATION, OUTLET GATES CLOSED.

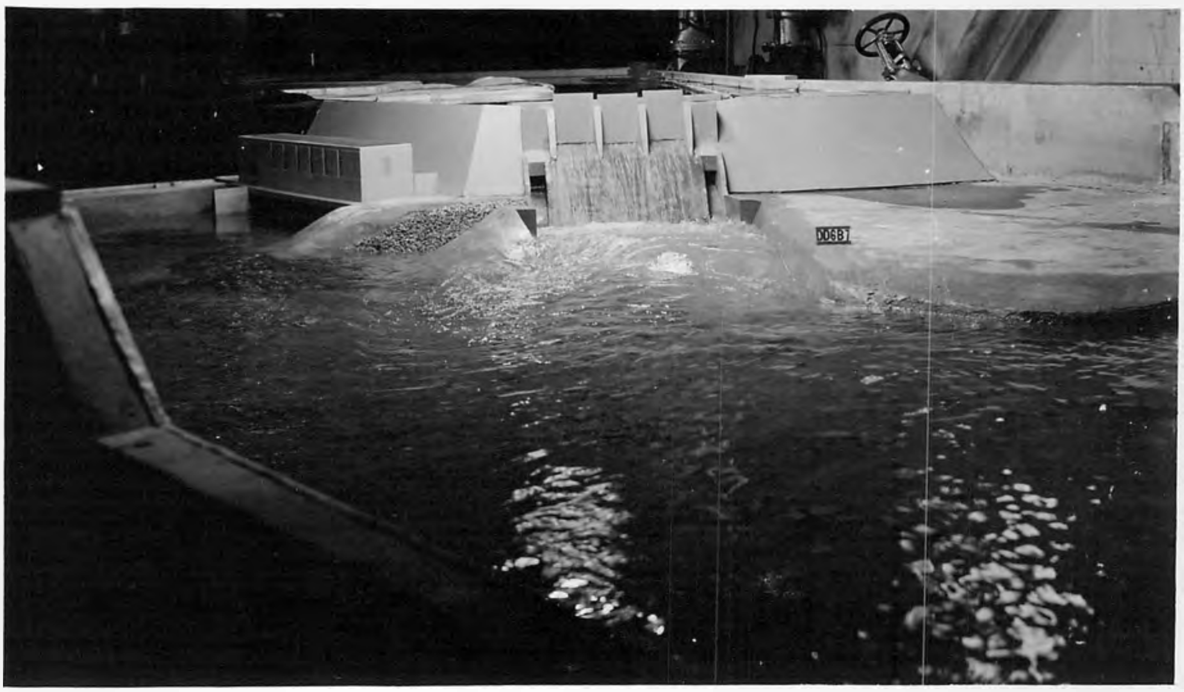


B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 50,000 SECOND-FEET, ULTIMATE TAILWATER ELEVATION, OUTLET GATES CLOSED.

DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL AT N.15,850, E.53,900 - RESERVOIR ELEVATION 647.00.

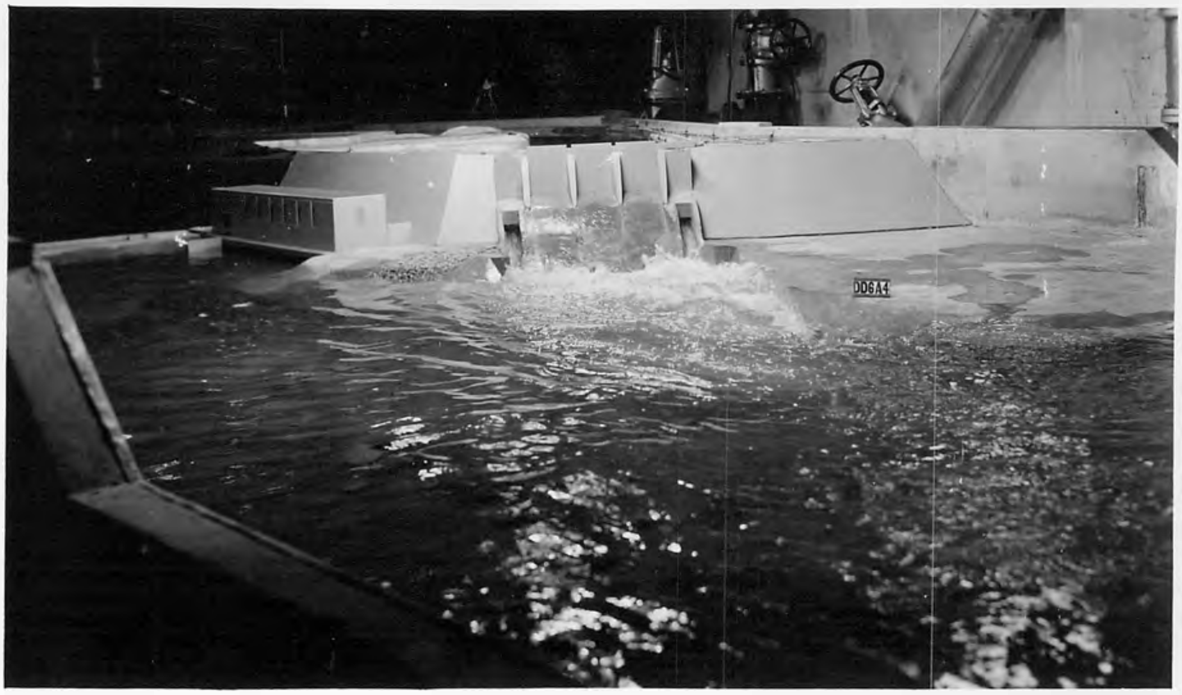


A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 25,000 SECOND-FEET, PRESENT TAILWATER ELEVATION, OUTLET GATES CLOSED.

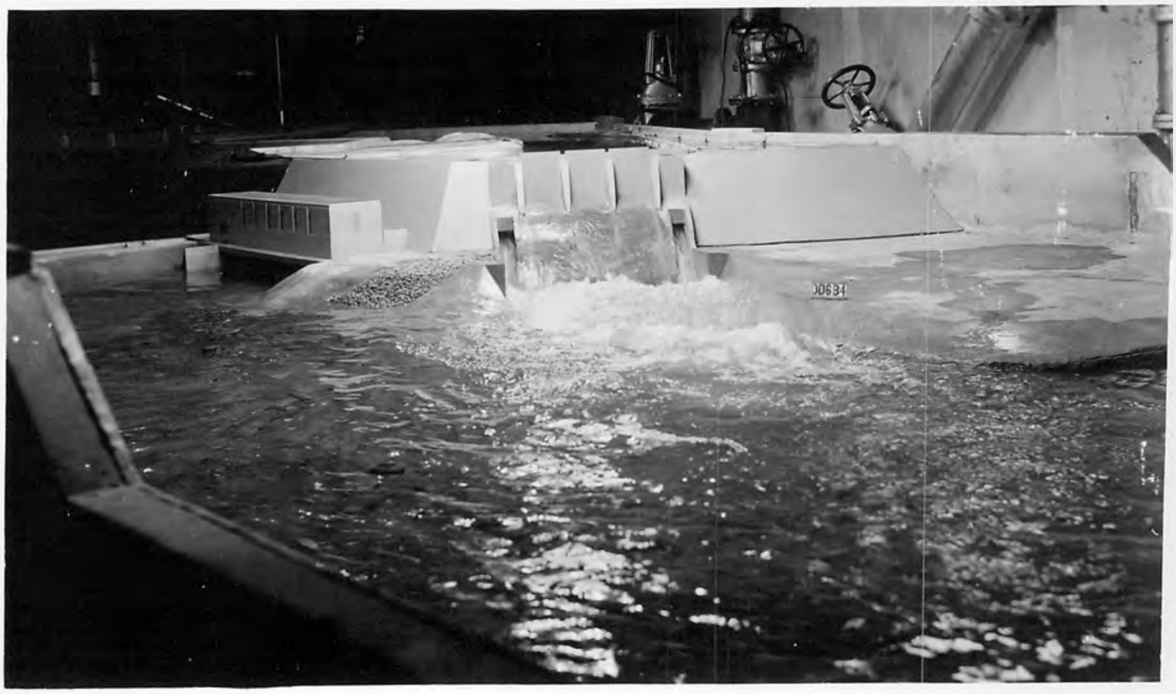


B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 25,000 SECOND-FEET, ULTIMATE TAILWATER ELEVATION, OUTLET GATES CLOSED.

DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL AT N.15,850, E.53,900 - RESERVOIR ELEVATION 647.00.



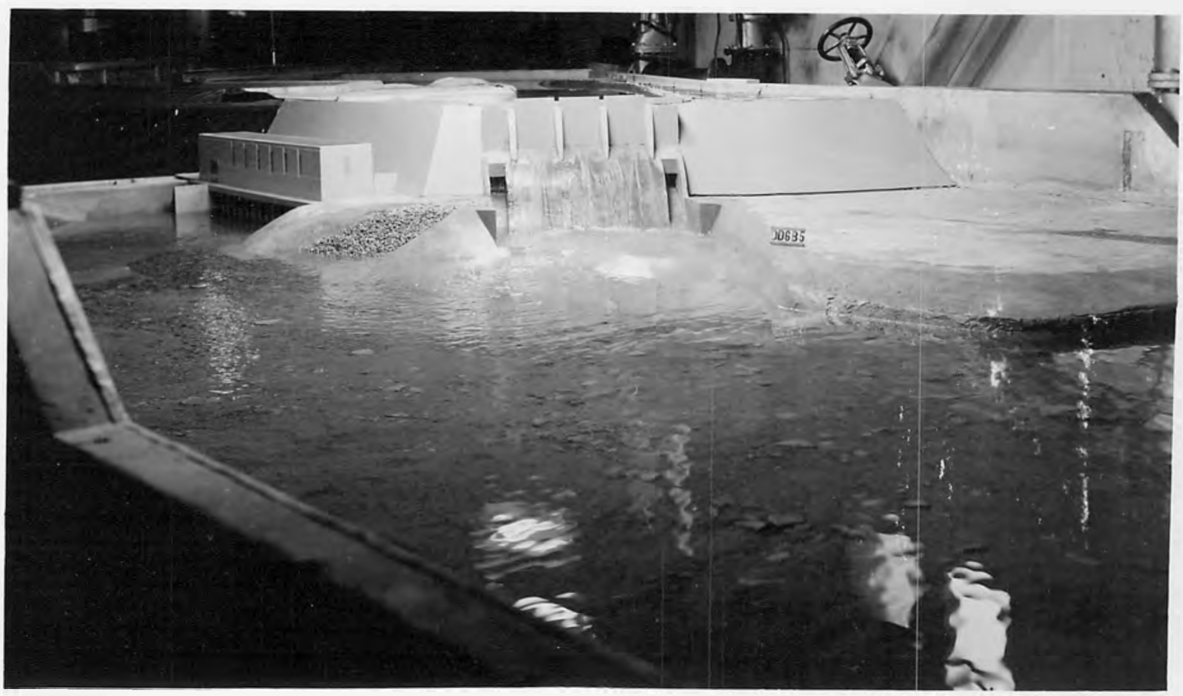
A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, OUTLET DISCHARGE 30,000 SECOND-FEET EACH, PRESENT TAILWATER ELEVATION, SPILLWAY GATES CLOSED.



B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, OUTLET DISCHARGE 30,000 SECOND-FEET EACH, ULTIMATE TAILWATER ELEVATION, SPILLWAY GATES CLOSED.

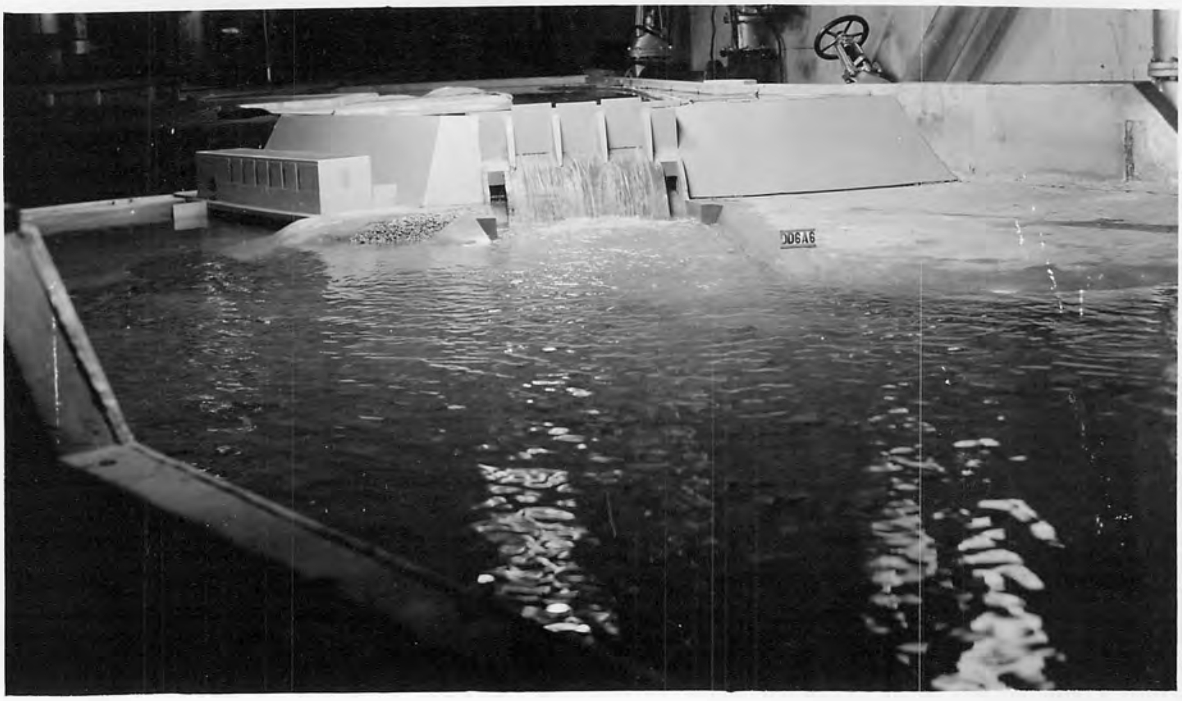
DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL AT N.15,850,E.53,900 - RESERVOIR ELEVATION 647.00.

A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 5,000 SECOND-FEET, PRESENT TAILWATER ELEVATION, OUTLET GATES CLOSED.

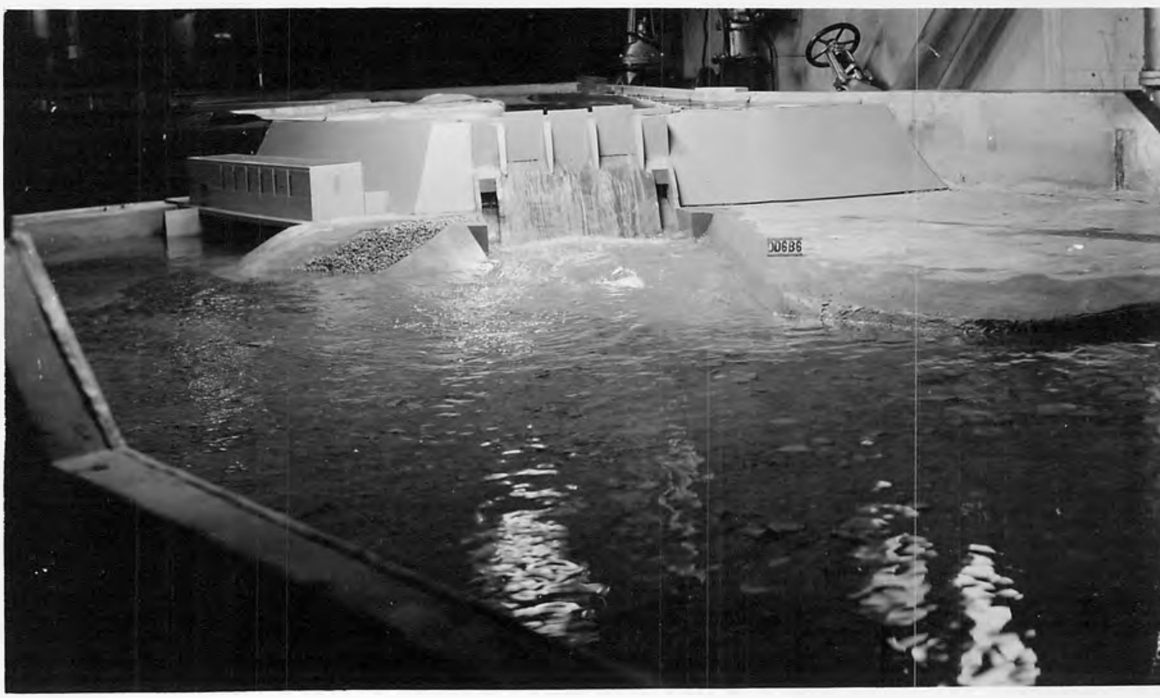


B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 5,000 SECOND-FEET, ULTIMATE TAILWATER ELEVATION, OUTLET GATES CLOSED.

DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL AT N.15,850,E.53,900 - RESERVOIR ELEVATION 647.00.

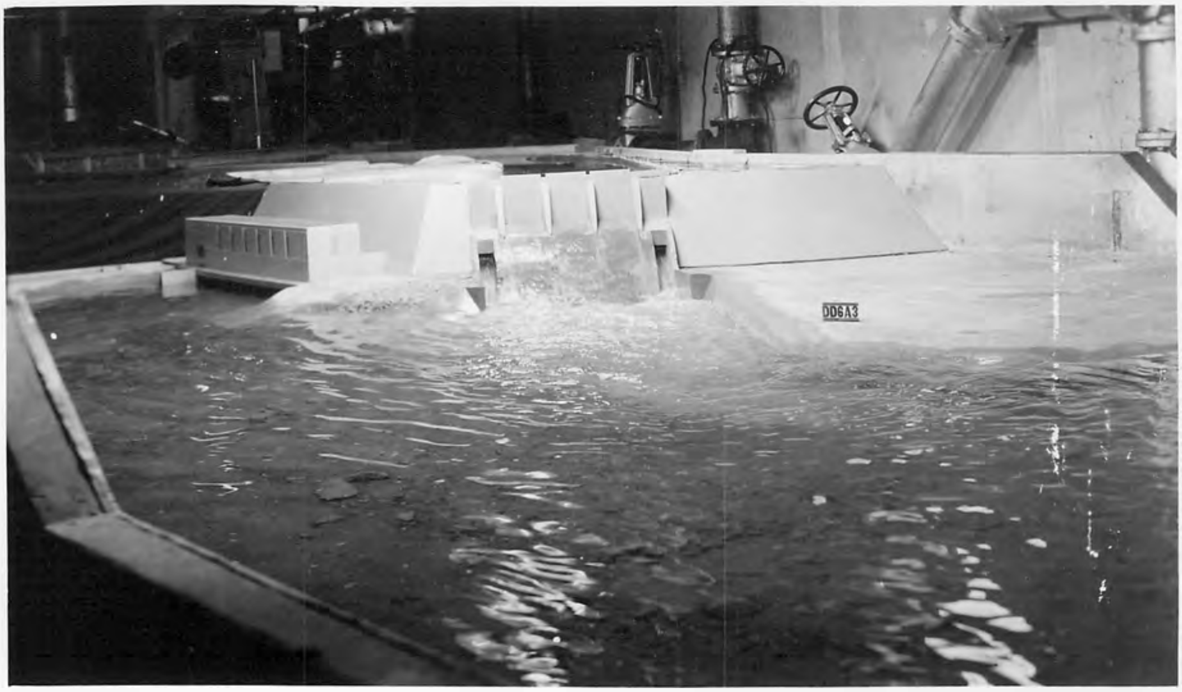


A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 15,000 SECOND-FEET, PRESENT TAILWATER ELEVATION, OUTLET GATES CLOSED.

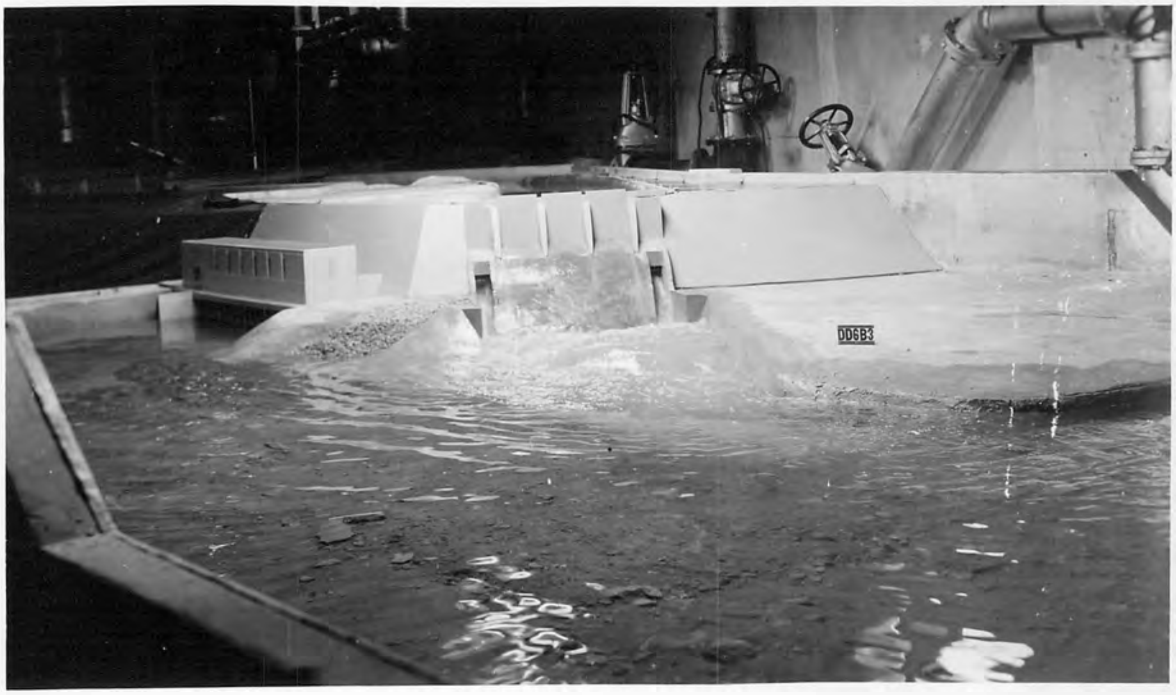


B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, SPILLWAY DISCHARGE 15,000 SECOND-FEET, ULTIMATE TAILWATER ELEVATION, OUTLET GATES CLOSED.

DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL AT N.15,850,E.53,900 - RESERVOIR ELEVATION 647.00.



A. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, OUTLET DISCHARGE 10,000 SECOND-FEET EACH, PRESENT TAILWATER ELEVATION, SPILLWAY GATES CLOSED.



B. POWERHOUSE DISCHARGE 25,000 SECOND-FEET, OUTLET DISCHARGE 10,000 SECOND-FEET EACH, ULTIMATE TAILWATER ELEVATION, SPILLWAY GATES CLOSED.

DAVIS DAM RECOMMENDED DESIGN - MODEL SCALE 1 TO 100 - VIEWS FROM HILL AT N.15,850, E.53,900 - RESERVOIR ELEVATION 647.00.